MOIST-SOIL MANAGED WETLANDS AND THEIR ASSOCIATED VEGETATIVE, AQUATIC INVERTEBRATE, AND WATERFOWL COMMUNITIES IN EAST-CENTRAL TEXAS

By

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Presented to the Faculty of the Graduate School of

Stephen F. Austin State University

In Partial Fulfillment

Of the Requirements

For the Degree of

Doctor of Philosophy

STEPHEN F. AUSTIN STATE UNIVERSITY

AUGUST 2012

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SUMMARY AND MANAGEMENT IMPLICATIONS

Wetland and waterfowl managers are constantly looking for ways to improve waterfowl use and maximize production of their managed wetlands. One way to maximize production and use is through the practice of moist-soil management. Whether such moist-soil managed wetland are passively or intensively managed with water control structures (i.e., pumps, flash board risers or screw gates), the overall objective is to maximize food production for wetland dependent species by manipulating hydroperiods and hydrology within the wetland. By doing so, wetland seed bank dynamics and potential, seed production of desired moist-soil plant species, decomposition of wetland vegetation, and aquatic invertebrate community can be specifically managed, all of which will influence migrating and wintering waterfowl body condition, food habits, and feather molt intensity.

To understand wetland plant community composition and dynamics a vegetative baseline should be created through metrics such as seed bank expression experiments. Seed bank expression allows for determining wetland potential under various management scenarios (i.e., treatments) such as drawdown and inundation. Drawdown is the process of removing water from the wetland while inundation is the process of adding or flooding the managed wetland. Controlled and properly timed water manipulation (i.e., moist-soil management) is used to mimic natural wet-dry cycles in natural seasonal wetlands, where moist-soil seed producing annual plants meet environmental queues and begin to germinate. While moist, these plants grow and mature through most of the growing season, after which water is returned prior to fall migrating and wintering waterfowl arrive. Timing of water addition and removal, as well as inundation duration drives plant germination, growth, and production. Timing and duration of inundation is critical for several reasons, as (1) desirable moist-soil plant species that produce high quality and quantities of food respond best to slow early-mid growing seasons drawdowns, (2) annual drawdowns produce greater stem densities and seeds, and (3) greater stem densities slow water movement within a managed wetland, which can aid in nutrient capture and sediment removal, aiding to the water purification processes wetlands naturally perform.

As managers gain the ability to control water removal, addition, and inundation duration, they can then begin to focus upon maximizing seed and invertebrate production, key elements to moist-soil management practices for waterfowl. To estimate seed production and duck use days (DUDs), several different seed yield models have been developed to estimate production for a number of desirable moist-soil plant species. These models are useful, as they aid in estimating seed production and provide several techniques to estimate production. The two methods typically used are the phytomorphological and dot grid methods, each of which can precisely estimate seed production of common moist-soil plant species. However, regional models should be developed, as most desirable moist-soil plants exhibit high phytomorphological variation among important features, even within sites. Development of regional models will allow managers to identify relevant features for moist-soil plant species of interest to focus management efforts while accurately estimating seed production.

Once techniques for maximizing and estimating seed production are validated and used, understanding and controlling the mechanisms by which hydroperiod controls litter decomposition and dynamics under field conditions is also crucial. Eventually moist-soil plants will senesce and fall to the wetland basin to being the decomposition process. Wetland plants go through three stages of decomposition while inundated: leaching (0-45 days), decomposer (46-120 days), and (121-220 days). Management of decomposition rates through proper management techniques (i.e., drawdown and inundation) are required so litter does not negatively affect germination rates of desired moist-soil plant species during drawdown periods nor inhibit aquatic invertebrate colonization or production.

A key element in the decomposition process is that moist-soil plant materials will decompose nearly complete in 220 days (approximately 7 months). For wetlands managed using moist-soil techniques, this inundation duration synchronizes extremely well with when water should be added (late August/September) and when it should be removed (March – April). This temporal window also allows for development of invertebrate communities on decomposing plant matter. Invertebrates are key elements for wintering waterfowl nutritive demands during late winter and early spring, and this temporal decomposition window will coincide with peak aquatic invertebrate production. Upon addition of water to moist-soil wetlands a flush of aquatic invertebrates will emerge to assist in the decomposition of plant materials as well as become available to wetland dependent species for consumption, increasing the production of the wetland. If drawdowns are managed to promote germination and seed production, and subsequent inundation is maintained for the duration of the decomposition processes, abundance and quality food sources (i.e., seeds and aquatic invertebrates) will be available to migrating and wintering waterfowl.

Management of such wetlands is focused specifically upon food production for wintering waterfowl, where waterfowl using moist-soil managed wetlands should avoid food shortages and avoid delays in molt progression, while simultaneously maintaining body condition. Moreover, waterfowl wintering in moist soil-managed wetlands in more southerly latitudes should avoid extended periods of severe winter weather which may alleviate (1) commonly observed mid-winter declines in body condition, (2) pressures to extend or delay molt, and (3) potential food shortages. Evaluating body condition, food habits, and feather molt intensity allows managers to gain perspective of the regional landscape quality and overall species population health.

A common management mistake is either maintaining water on moist-soil managed wetlands during the growing season or extending inundation duration beyond the aforementioned temporal window during fall and winter. Either will negatively impact germination, seed production, decomposition, and desirable aquatic invertebrate community development. Desirable moist-soil plant species miss environmental queues to germinate which results in a change in the overall plant community, which may take one or more subsequent growing seasons to restore to desirable conditions. Moreover, seed production and aquatic invertebrate abundance will decline over time, which will eventually alter moist-soil managed wetlands from productive waterfowl-food producing managed wetland to waterfowl loafing sites. As inundation duration extends, decomposition processes change and slow, plant communities changes from hydric annual seed producing plants to perennial aquatic or less desirable emergent plant communities, and desirable soft bodied aquatic invertebrates mature and depart and the invertebrate community. In all, wetland suitability for waterfowl will decline as marked declines in DUDs will be observed. A key element is to maintain inundation for 7 months to maximize production and then flush the system and prepare it for subsequent years.

Richland Creek Wildlife Management Area has the unique ability to control for many of these factors once the entire tract of moist-soil wetlands is online and functional. These wetlands can be managed as a complex, where each individual moist-soil managed wetland can have its own prescription and individual water control. Having individual prescriptions will provide suitable and quality habitat simultaneously throughout the annual cycle for waterfowl, shorebirds, and waterbirds. Moreover, as these wetlands are managed to provide moist-soil habitat for wetland dependent wildlife as well as provide quality water via recycling, inundation or drawdown conditions can be provided all year long while meeting management objectives. Regionally, this complex of moist-soil managed wetlands will provide important waterfowl and waterbird habitats throughout the annual cycle every year, while the regional importance of the area will be magnified in years of moderate to extreme drought.

ABSTRACT

Moist-soil management in the southeastern U.S. is used to stimulate growth of waterfowl food (i.e., aquatic invertebrates and seeds, however, little experimental work has been published on the effectiveness of moist-soil management in the south-central United States where the growing seasons are longer, climate warmer, and plant assemblages more complex. During April 2004 – May 2008 I, (1) investigated moist-soil managed wetland seed bank dynamics, (2) calculated seed yield, (3) estimated plant decomposition rates, (4) measured and calculated aquatic invertebrate diversity, richness, abundance, and biomass, (5) estimated body condition, food item occurrence, and feather molt chronology for blue-winged teal (*Anas discors*), green-winged teal (*A. crecca*), and Northern shoveler (*A. clypeata*), (8) calculated Duck-Use Days, and (9) quantified seasonal vegetative community structure and development on Richland Creek Wildlife Management Area.

Each plant that germinated in seed bank expression experiments (under flooded or moist conditions) was identified and categorized as desirable or non-desirable. A total of 6,802 seedlings of 27 species from 14 families were recorded, which resulted in similar species diversity indices between moist and flooded treatments, which had relatively high species similarity (32.7%). Stem densities varied between treatments and desirable and non-desirable moist-soil plants (X^2 = 2271.5, P < 0.001) and subsequent analysis found that there was an interaction (Wilks' λ = 0.96: P < 0.001) between treatment and plant

status (desirable / non-desirable) with densities of desirable species nearly double that of non-desirable seedling in moist treatments and the converse under flooded treatments. Seed yield models were created for four common moist-soil plant species: barnyardgrass (*Echinochloa crusgalli*), wild millet (*Echinochloa walteri*), jungle rice (*E. colona*), and cultivated rice (*Oryza sativa*), found in regional locations in Texas by regressing dry seed mass per plant (dependent variable [γ])against external phytomorphological features (i.e., total inflorescence height, number of inflorescence present, inflorescences volume, etc.) or number of dots obscured to predict species specific seed production. Regression models and contained all or a combination of the phytomorphological features: plant height, total number of inflorescence, inflorescence volume, inflorescence height, and average inflorescence mass for normal linear and point of origion models. Inflorescence diameter and inflorescence volume were positively correlated ($r = 0.86$, $P < 0.001$) for all species and models. Both simple linear and point of origin regression analyses were successful in developing valid seed yield production models for all 4 focal species, where models explained 52-98% of the variation in seed biomass, depending upon species and variable inclusion.

Mean decay coefficient rates for three common moist-soil plant species ranged from 0.72-0.80 within 30 days of initial deployment to 0.36 after 300 days of initial deployment. Over time all three moist-soil plant species lost nearly 100% of initial mass during the 11 month deployment period.

A total of 12,240 individual specimens were captured representing forty-seven species of aquatic invertebrates identified to the lowest taxon possible. Biomass was highest in 2004(71.15 g) and continually declined in 2005 (29.28 g) and 2006 (15.75 g). Analysis examining total numbers of individual invertebrates and total biomass of invertebrates among and between months, years, cells, and groups found no significant differences. However, differences were found examining total mass of invertebrates by month*year, month*cell, and year*cell. Overall diversity indices for the specimens identified was 0.806/5.17 and 3.33 for the Simpson's and Shannon-Wiener diversity indices.

Three duck species were scientifically and hunter harvested between 15 September 2004 – 15 March 2005, 15 September 2005 – 15 March 2006, and 15 September 2006 – 15 March 2007 to estimate body condition, food item occurrence, and feather molt intensity. In general, adult and juvenile males tended to be heavier and longer then their female counter parts, while adult and juvenile females had higher mean fat scores than their male counterparts. Analysis examining differences in overall body condition indices found significant differences and differed depending on species and age and sex as well as along a temporal scale ($P < 0.05$). A total of 34 food items were identified and ranged from seeds, invertebrates, grit, and shot. Common species found were nodding smartweed (*Polygonum lapthifolium*) and Panicum (*Panicum* sp.). Significant differences ($P < 0.05$) were found for percent occurrence mass between species and year, age-sex cohorts, age*year, and year*sex. Two hundred and two individuals had a total of 28,672 individual feathers erupting/molting overall among three dabbling duck species. Among age-sex cohorts adult females had the highest overall molt score (10.08). Overall molt score between months was highest during January (12.35) and lowest in October (2.54). Analysis found significant differences ($P < 0.05$) overall with significant interactions found between species and body condition indices 2.

This research generated important landscape as well as moist-soil managed wetland cell information that will be beneficial to on the ground management practices. Maximizing how moist-soil wetland management takes place on the Richland Creek Wildlife Management Area and surrounding region will benefit migrating and wintering waterfowl as well as many other wetland dependent species. Future research is needed to evaluate how to best manage the completed moist-soil wetland project as a whole management unit.

ACKNOWLEDGMENTS

Funding for this project was provided by the Texas Parks and Wildlife Department and the Arthur Temple College of Forestry and Agriculture at Stephen F. Austin State University. I am extremely grateful to both organizations for their support of this project. I would also like to thank the Tarrant Regional Water District for their support in the form of at will data and willingness to give me a lift on hot summer days back to my field vehicle.

I genuinely thank my major advisor, Dr. Warren C. Conway, for all his support and insight during my time here. I appreciate the support and willingness of Drs. Christopher Comer, Hans Williams, D. Brent Burt, and Daniel Scognamillo for their advice while serving on my graduate committee.

I thank Rhu Henderson, Curtis Green, Shay Tyler, John Varnell, Chris Bartley, Andy McCrady, Dustin Holowell, Paul Tidwell, Angela Magiamelli, Shaun Crook, Helen Marx, Dandy Byers, Harley Skidmore, Raynie Skidmore, Brad Hunt, Chris Davis, Brant Frazier, David Sundet, Matt Triby, Billy Hardy, Ryan Bass, and Jason Speights for their invaluable laboratory and field assistance.

I thank the entire staff at Richland Creek Wildlife Management Area for their support in the field and laughs during my time on the area. I could not have made it through those long hot days out in the field without them. Jeffrey Gunnels, Corey Mason, Eric Woolverton, Edwin Bowan, Gary Rhodes, Matt Symmank, and Kevin Kraai.

I thank my parents, Dan and Linda Collins Jr., for their undivided love, support, and encouragement throughout my lifetime. I would not by where I am today without them. I thank my brother and sister, Michael and Kimberly Collins, for their support, laughs, and good times. I thank my in-laws Van and Julie Spear for their love, support, and visits so I could be out in the field. I thank the entire Collins family (i.e., too many to name, damn big Irish families) for their love and support during my graduate days and also thank my brother and sister in-law Trip and Meg as well as their respective families for their support during my dissertation work.

Special thanks are in order for my wife Julia, for all of her support, love, and understanding. She is the only one I know who would put up with me through thick and thin. We have come a long way and I look forward to our next adventure together. My son, Daniel, and daughter, Evelyn, have brought a love and joy to me that is unspeakable. One day they will understand how much they mean to me.

This dissertation is dedicated to those of my family who are not able to be here with me today: Daniel Patrick Collins Sr., Marie Collins, Emily DeRose, Gerald DeRose, and Babe Spear.

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CHAPTER I

MOIST-SOIL MANAGEMENT AND ITS APPLICATIONS ON RICHLAND CREEK WILDLIFE MANAGEMENT AREA

INTRODUCTION

Wetlands are ecologically important ecosystems, and their value for fish and wildlife populations are well known. Wetlands support extensive food webs, abundant biodiversity, and play a major role in providing unique habitats for a wide variety of flora and fauna (Mitsch and Gosselink 1993). They can be highly productive, exhibit fast rates of succession, and maintain high biological biomass (Lugo 1995). As a result, wetlands cannot be characterized simply, exhibiting large variance in many structural and functional parameters, as well as hydrology, which all combine to limit the usefulness of generalized management solutions to common wetland management problems (Euliss et al. 2004). These variances make it necessary to relate management recommendations to specific types of wetland ecosystems (Lugo 1995).

The National Wetlands Inventory conducted in the mid-1980's reported that between 1780 and 1980, approximately 53 % of wetlands were lost in the lower 48 states, and Texas alone had a 52 % decline (Mitsch and Gosselink 1993). During this time, total wetland area decreased from 89.5 million ha to 42.2 million ha, which has significantly increased the importance of those remaining wetlands for wetland dependent flora and fauna (Taft et al. 2002). In 1977, wetlands received federal protection, from the passage of amendments to the Clean Water Act. Specifically, Section 404 of the Clean Water Act authorized the Army Corps of Engineers to issue permits for dredging and filling practices affecting wetlands. This permitting has allowed the creation of thousands of hectares of wetlands in the U.S. to mitigate for wetland losses (Fernandez and Karp

1998), with the goal of maintaining and improving wetland chemical, physical, and biological integrity (Brinson and Rheinhardt 1996, Mitsch and Wilson 1996).

Constructed wetlands are human made, engineered areas, specifically designed for water treatment by (1) establishing optimal physical, chemical, and biological conditions that mimic those occurring in natural wetlands (Jin et al. 2002) and (2) acting as sinks for nutrients in high concentrations (Mitsch et al. 1995). The simplicity of constructed treatment wetland design, compared with technology-based wastewater treatment systems, result in lower operation and maintenance requirements (Jin et al. 2002). The elevated ability of these wetlands to store and clean water has important ecological, environmental, and economical implications (Luo et al. 1997). To improve water quality within constructed treatment wetlands, they must remove suspended solids and nutrients, which are facilitated by shallow water, waters with low velocity that allow suspended solid settlement, high vegetative productivity, presence of both aerobic and anaerobic sediments, and the accumulation of litter, and eventually, peat (Mitsch and Gosselink 1993).

Often, constructed wetlands are managed using moist-soil management techniques (Rundle and Fredrickson 1981) and are normally impounded by levees with control structures to manipulate hydrology. In moist-soil situations, wetlands are generally drained during spring or summer to promote growth and seed production of annual seed producing hydrophytes, and then flooded during autumn (Rundle and Fredrickson 1981, Lane and Jensen 1999) and winter to promote invertebrate production and use by wintering waterfowl (Gray et al. 1999, Anderson and Smith 1999, Anderson and Smith 2000). Moist-soil managed wetlands provide rich sources of seeds, tubers, and aquatic invertebrates for migrating and wintering waterfowl, shorebirds and other wetland dependent wildlife (Fredrickson and Taylor 1982, Hakous and Smith 1993, Baldassarre and Bolen 1994, Duffy and LaBar 1994, Gray et al. 1999, Anderson and Smith 2000). Moist-soil management techniques provide a mechanism for enhancement of established wetlands, restoration of former wetlands, and creation of new wetland habitats (Lane and Jensen 1999), as well as to contribute stabilization of global levels of Nitrogen, atmospheric Sulfur, Carbon Dioxide, and methane (Keiper et al. 2002). As such, monitoring moist-soil managed wetlands is essential to determine whether such created ecosystems truly serve similar functions as natural wetlands.

Overall objectives of moist-soil management should be to (1) maximize production of desirable vegetation, (2) control growth of undesirable vegetation, and (3) provide required habitats for a diversity of wetland dependent wildlife species (Lane and Jensen 1999). Moist-soil management techniques were initially developed and extensively tested in the upper Midwest and Mississippi Alluvial Valley, and during the last 20 years, such practices have received considerable attention in other regions (Lane and Jense 1999). Moist-soil management is used to some extent throughout the Southeast to stimulate growth of waterfowl food plants, but little experimental work has been published on the effectiveness of moist-soil management in the south-central United States where the growing season is longer, the climate warmer, and plant assemblages more complex (Polasek et al. 1995).

JUSTIFICATION

The rate at which wetlands are being lost on a global scale is unknown (Mitch and Gosselink 1993) although the conterminous United States alone have lost > 50% of existing wetlands prior to European settlement (Dahl and Johnson 1991). The importance of wetlands to provide wildlife habitat, water quality, groundwater recharge, and flood prevention have prompted efforts to restore and construct new wetlands (Mitsch and Wilson 1996, Kellogg and Bridgham 2002, DeBerry and Perry 2004). Because of these efforts, the way success is measured and achieved, has become a focus of wetland scientists and managers because of the money, time, and energy spent on creating replacement wetlands (Mitsch and Wilson 1996). Successful wetland creation or construction may mean the establishment of a biologically viable and sustainable wetland ecosystem, but may also be defined based upon functional replacement, and is often relative; gauged against local or regional natural reference wetlands (Mitsch and Wilson 1996). However, all of these viewpoints have flaws, as beneficially sustainable and viable wetlands may not be functionally replacing natural wetlands, which may be poor references to evaluate success of constructed or created wetlands. Unfortunately, published research has been unable to develop satisfactory methods of assessing and quantifying the ability of created wetlands to replace natural wetlands (Confer and Niering 1992, Mitsch and Wilson 1996).

The overall goal of this research is to evaluate how recently created moist-soil managed wetlands provide suitable wetland wildlife habitat via investigating aquatic invertebrate production, temporal vegetation change, decomposition rates of common moist-soil plant species, seed production, seed bank dynamics, as well as waterfowl body condition, food habits, and feather molt chronology. This research will provide both public and private landowners important strategies for improving conservation and management plans for managed wetlands regionally, but will also have important and valuable implications throughout, where moist-soil management practices are used to manage wetlands.

OBJECTIVES

As moist-soil management in different geographic regions becomes increasingly relevant, criteria need to be developed to successfully manage and monitor these systems. The overall goals of this research project are to evaluate the effects of moist-soil management practices on moist-soil wetlands of varying ages in east central Texas, at the Richland Creek Wildlife Management Area. The specific objectives of this research are to: (1) investigate moist-soil managed wetland seed bank dynamics and potential in field and germination trials, (2) calculate seed production of important waterfowl food species found in moist-soil managed wetlands, (3) calculate decomposition rates of abundant moist-soil plant species, (4) measure and calculate aquatic and benthic invertebrate diversity, richness, abundance, and biomass, in response(s) to moist-soil management practices and related water quality parameters (i.e., water depth, temperature, pH, dissolved oxygen, and salinity) and substrate type, in moist-soil managed wetlands, (5) investigate body condition indices of 3 dabbling duck species, (6) food habits of 3 dabbling duck species, (7) feather molt chronology of 3 dabbling duck species, (8) quantify seasonal vegetative community structure and development within moist-soil managed wetlands and (9) calculate Duck Use Days of moist-soil managed wetland.

STUDY AREA

This research occurred on the Richland Creek Wildlife Management Area's (RCWMA) North unit moist-soil managed wetlands 1-4 (Figure 1.1). The RCWMA (31º 13' N, 96º 11' W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The RCWMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were functioning. Construction of moist-soil managed wetland units 5-6 began in the summer of 2006 and have been functioning since November of 2009.

Local climate is considered subtropical with mild winters and warm humid summers, with an average daily summer temperature of 34º C and winter temperature of 5º C, a growing season of 246 days, and average rainfall of 101.6 cm a year (NRCS

2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, mollisols soils. Topography is level and elevation ranges from flat to gentle rolling (NRCS 2002).

Vegetation within the South unit (Figure 1.4) is characterized by vast bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. The typical water management strategy on the north unit consists of slow drawdown (i.e., removal of water) starting late March to early April and lasting until mid August. Inundation (i.e., flooding) begins in late August and last throughout the fall and winter months until the preceding drawdown occurrence. These management actions produced common species such as barnyard grass (*Echinochloa crusgalli*), erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet (*Echinochloa walterii*), and water primrose (*Ludwigia peploides*) (Chapter IX).

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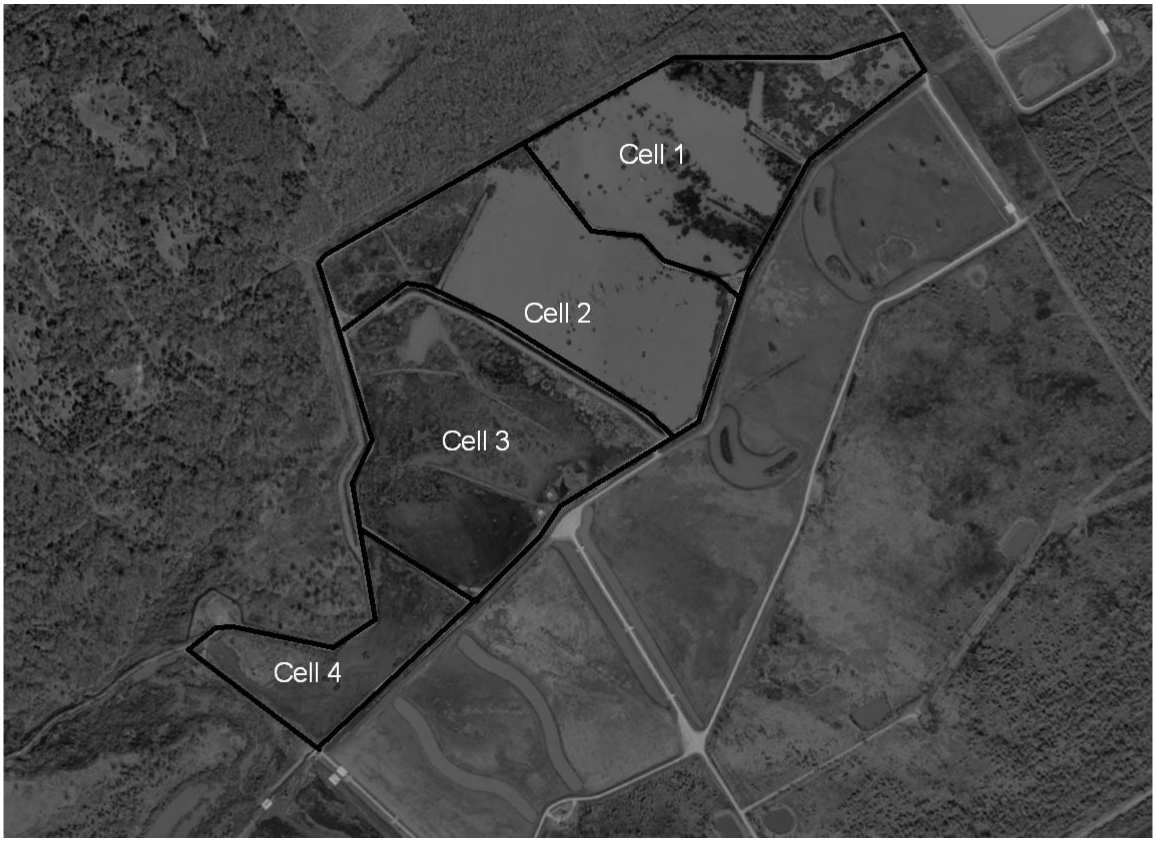

Figure 1.1. Moist-soil managed wetland unit 1-4 located on Richland Creek Wildlife Management Area in east-central Texas.

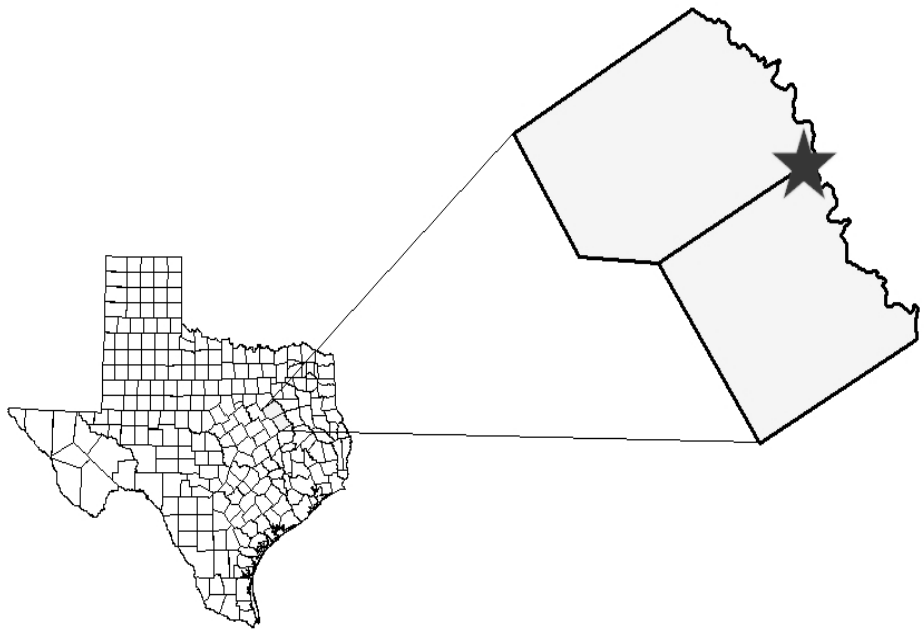

Figure 1.2. Location of Richland Creek Wildlife Management within Freestone and Navarro counties, east-central Texas.

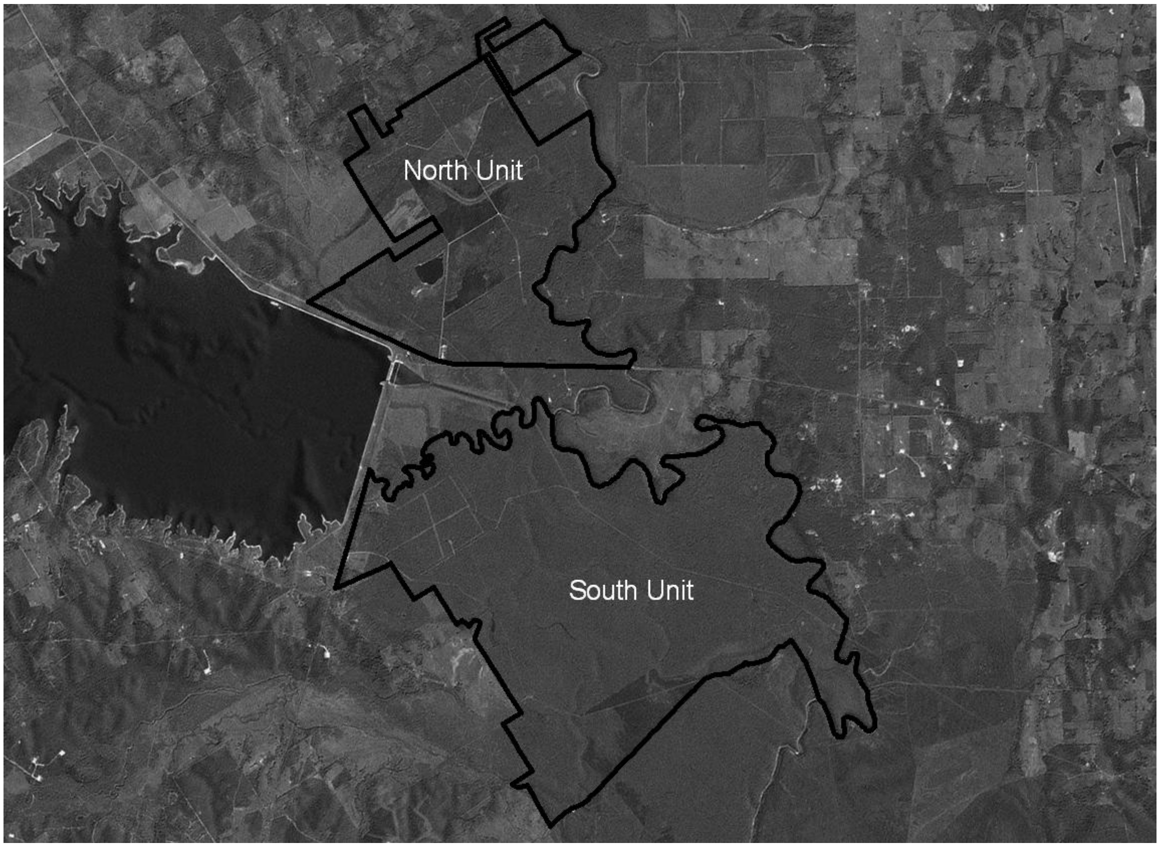

Figure 1.3. Location of the North and South units in Richland Creek Wildlife Management Area, in east-central Texas.

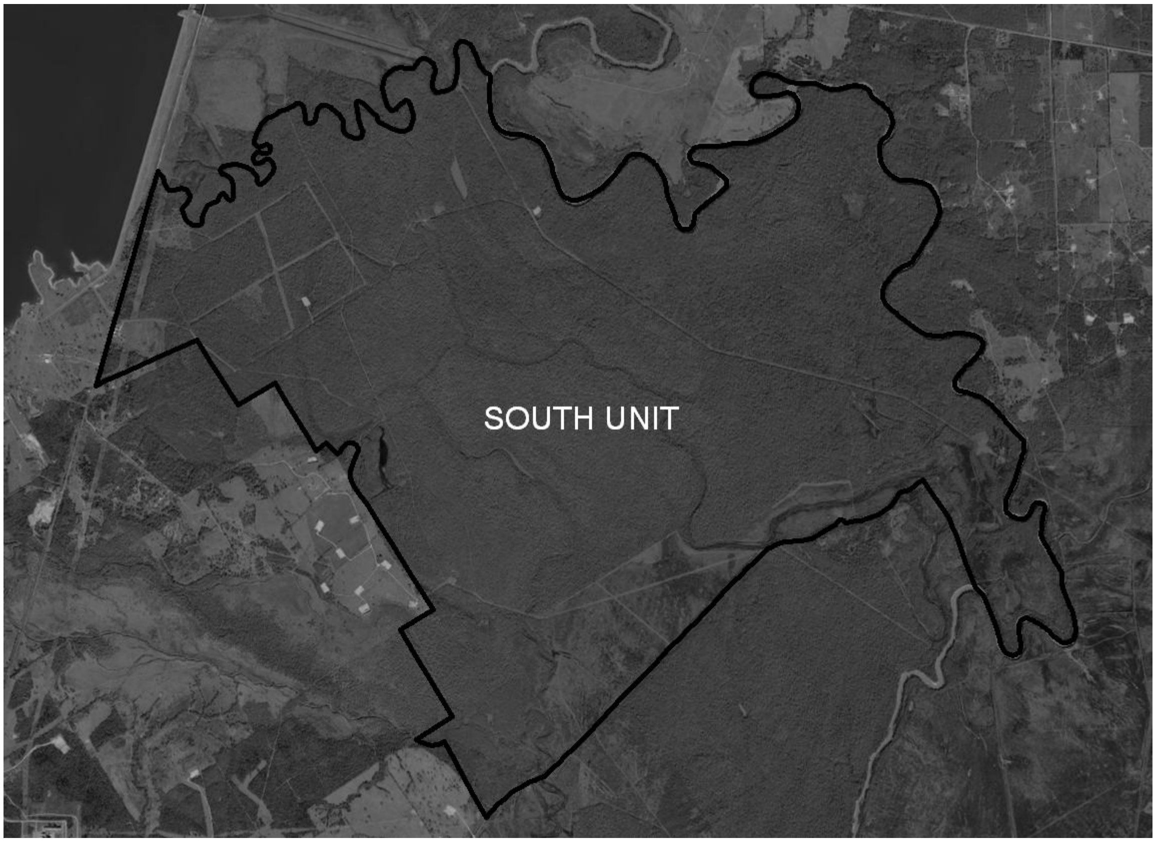

Figure 1.4. South Unit of Richland Creek Wildlife Management Area located in east-central Texas.

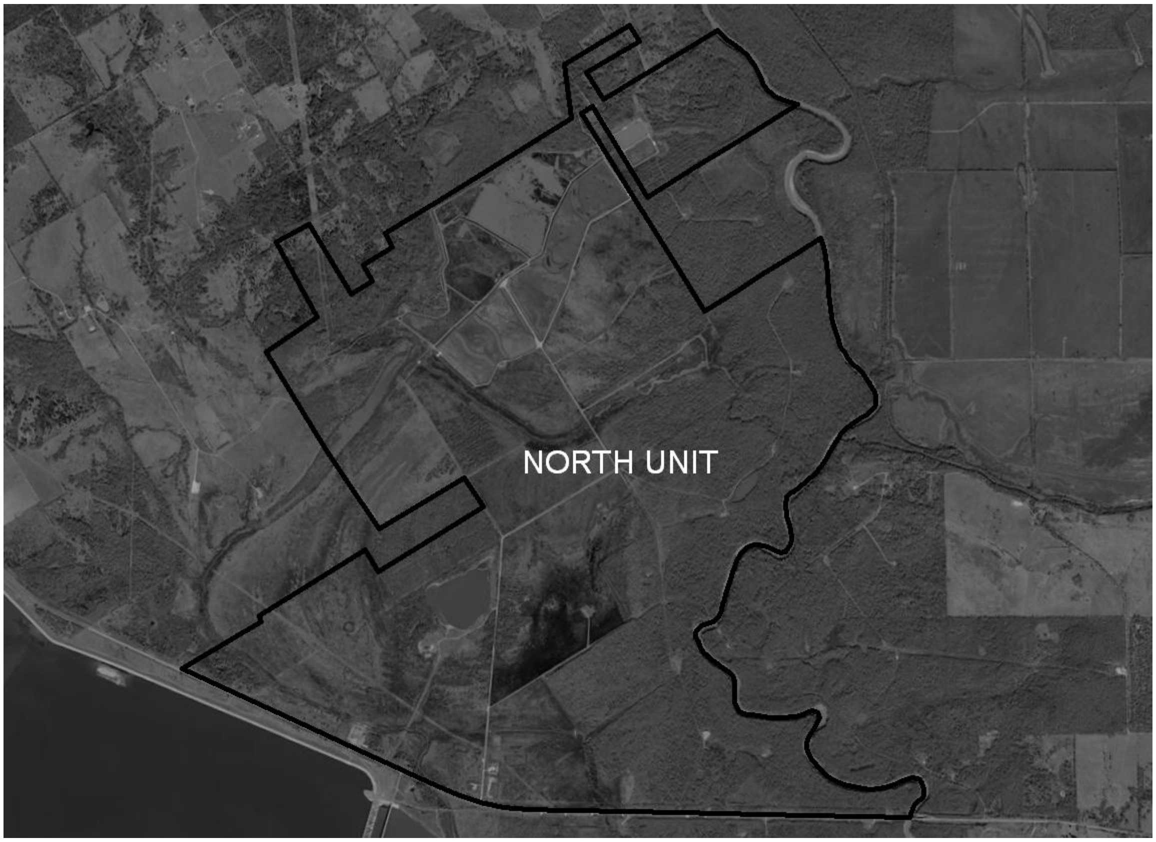

Figure 1.5. North Unit of Richland Creek Wildlife Management Area located in east-central Texas.

CHAPTER II

SEED BANK POTENTIAL OF NEWLY CREATED MOIST-SOIL MANAGED WETLANDS ON RICHLAND CREEK WILDLIFE MANAGEMENT AREA, TEXAS

INTRODUCTION

Moist-soil managed wetlands are typically shallow water areas impounded by levees, allowing for flooding (i.e., water addition) during fall and winter, and drawdown (i.e., water removal) in spring and summer (Fredrickson and Taylor 1982, Lane and Jensen 1999). Water level manipulations typically drive nutrient cycling by influencing decomposition rates and timing of plants and other materials, both of which combine to direct plant community structure and succession (Gerritsen and Greening 1989). Plant species recruitment typically occurs during drawdown periods, when the moist-soil managed wetland is free of standing water, but the substratum remains moist (Lane and Jensen 1999). During drawdown persistent seeds within the seed bank will germinate in response to favorable conditions such as varying temperature, light, and oxygen regimes (Leck 2003). Such short duration drawdowns promote germination and growth of annual wetland plants that produce high quality seeds, tubers, and structure for aquatic invertebrates, waterfowl, shorebirds, and other waterbirds (Lane and Jensen 1999). Conversely, extended periods of flooding tend to promote lower quality seed producing perennial aquatic and emergent wetland plants (Howard and Medelssohn 1995), but important foraging habitat, substrate, and cover for migrating and wintering waterfowl and other wetland dependent species (Fredrickson and Taylor 1982). By manipulating water levels within moist-soil managed wetlands, managers can target specific plant community development, and seed germination, growth and subsequent seed production and promote desirable moist-soil plants (van der Valk and Davis 1978).

Many regions (i.e., Central Valley of California, Lower Mississippi, and Texas High Plains and Coast) have established habitat management objectives for migrating and wintering waterfowl, generally targeted towards North American Waterfowl Management Plan goals (Lane and Jensen 1999). Specifically, management of moist-soil wetlands and seasonal wetlands is focused upon moist-soil plant and seed production to provide quality foraging habitat for migrating and wintering waterfowl (Checkett et al. 2002). Generally, the overarching objectives of moist-soil management are to increase wetland productivity and waterfowl use, where moist-soil management techniques maximize production of naturally occurring wetland plants (Strader and Stinson 2005). Moist-soil management promotes the production of naturally occurring desirable wetland vegetation by emulating and manipulating natural wetland functions (e.g., hydrology and successional stage) (Lane and Jensen 1999). Hydrology is a dominant factor controlling development of spatial variation in wetland plant communities and is responsible for horizontal zonation of adult plants, seeds, and seedlings in both natural and moist-soil managed wetlands (Baldwin et al. 2001). Manipulations in hydrology will influence plant species composition during patterns of emergence from the seed bank (Casanova and Brock 2000, Johnson et al. 2000, Baldwin et al. 2001). For example, van der Valk and Davis (1978) established relationships between periodic drawdown, emergence from the seed bank, vegetative growth, and inundation in prairie pothole wetlands which share hydrology regimes much like moist-soil managed wetlands for waterfowl habitat management used throughout the southern U.S. (Strader and Stinson 2005). Annual plants are important components of both types of wetlands, and their presence is due to favorable drawdown and soil exposure conditions for seed germination and seedling growth (Leck and Simpson 1993). Conversely, flooding can reduce seed germination and severely reduce seedling survival (Galinato and van der Valk 1986, Baldwin et al. 1996). Consequently, hydrology variation (i.e., water manipulation) is important in controlling temporal variation in plant species composition of moist-soil managed wetlands (Baldwin 2001) and to maximize habitat availability and utilization, depth and timing of flooding and/or drawdown should be well planned (Lane and Jensen 1999).

To maintain, promote, or change moist-soil plant populations, production, and floristic diversity, aspects such as species distribution, reproductive strategy, seed bank composition and viability should be known and quantified for a given managed wetland (Leck and Graveline 1979). As such, examining seed bank potential can help managers (1) maintain a persistent and desirable plant community and (2) understand temporal seed bank dynamics, particularly as related to providing quality habitat to migrating and wintering waterfowl (Fredrickson and Taylor 1982). Such research on wetland seed banks is significant to plant population ecology, as well as many applied fields, such as conservation, restoration, and success of managed wetland communities (Araki and Washitani 2000).

When moist-soil managed wetlands are specifically created to provide wintering waterfowl habitat, seed bank dynamics can ultimately influence success and failure of any management objectives, even under proper water manipulation strategies. Successful seed bank exploitation requires a basic understanding of the composition of the already existing seed bank (van der Valk et al. 1992) in order for these management practices and objectives to be a reality. Specifically, temporal changes in seed bank size, species composition, and persistence will provide insight into the importance of the seed bank to the overall management objectives (Leck 2003). Indeed, in newly created wetlands, existing seed banks may greatly influence initial plant species composition, where undesirable plant communities may be enhanced or promoted depending upon hydrology and/or basin manipulations (Galinato and van der Valk 1986, Baldwin et al. 1996, Leck 2003).

Commonly recognized as a primary limiting physical factor that varies along elevation gradients in many wetland habitats, water depth has been demonstrated to have negative impacts on moist-soil plant species survival, at both long and short temporal scales (Howard and Mendelssohn 1995). Emergent herbaceous moist-soil species have a varying response to flooding or submergence, which is generally regarded as inhibitory to plant growth (Howard and Mendelssohn 1995, Flynn et al. 1999, Casanova and Brock 2000). Flooding and/or submergence typically promotes the growth of undesirable wetland plant species (Fredrickson and Taylor 1982, Lane and Jensen 1999). In such conditions, subsequent management efforts may be hindered, particularly if undesirable plants are not controlled or effectively removed from the seed bank (i.e., interrupt desirable seed production). The primary objective of this portion of the research was to quantify seed bank expression of newly created moist-soil managed wetlands at the Richland Creek Wildlife Management Area (RCWMA) in east-central Texas. Specifically, the effects of experimentally simulated inundation and drawdown conditions on seed bank expression were examined over time for moist-soil managed wetlands at the Richland Creek Wildlife Management Area.

METHODS

Study Area

This research was conducted on the Richland Creek Wildlife Management Area's (RCWMA) North Unit moist-soil managed wetlands 1-4 (Figure 1.1) and older unmanaged moist-soil wetlands named the triangle, gut, and DU marsh (Figure 2.1). The RCWMA (31º13'N, 96º11'W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The RCWMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were fully functional. Construction of moist-soil managed wetland units 5-6 began in the summer 2006 and these cells have been functioning since November 2009.

Local climate is considered subtropical with mild winters and warm humid summers, an average daily summer temperature of 34º C and winter temperature of 5º C, a growing season of 246 days, and average rainfall of 101.6 cm per year (NRCS 2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, and mollisol soils (NRCS 2002).

Vegetation within the South Unit (Figure 1.4) is characterized by extensive bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North Unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. The typical water management strategy consists of slow drawdown (i.e., removal of water) starting late March - early April and lasting until mid August. Inundation (i.e., flooding) begins in late August and lasts throughout fall and winter until drawdown the following spring. These management actions produced common species such as barnyardgrass, erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet, and water primrose (*Ludwigia peploides*) (Appendix A).

Seed bank sample collection

Seed bank samples were collected from four created moist-soil managed wetland unit(s) 1 (n = 17), unit 2 (n = 21), unit 3 (n=25), and unit 4 (n = 12) as well as from three older managed moist-soil wetlands named the triangle field (n = 15), gut (n = 15), and DU marsh (n = 15) respectively, on RCWMA a week prior to, or during, initial drawdown during late March 2005 (Figure 2.1). The number of samples collected in the newly established wetlands was determined by the number of established permanent plots (see Appendix A). While the three older moist-soil managed wetlands did not have established plots the number of samples collected was consistent among these three managed wetlands. Transects within the four created moist-soil managed wetland cells were systematically located lengthwise running in the approximate east-west cardinal direction within each wetland. One transect was in the approximate middle, and the second two transects were located 50 m from the wetland edge. Once transects were established, permanent plots were determined using the middle transect. Facing west on the middle transect in each moist-soil management wetland every 50 m within the individual moist-soil managed wetlands, a 2-digit number was removed from a random number generator. The number determined how many paces were walked in the approximate cardinal direction (i.e., north or south) off the middle transect (ex. 42 = 42 paces). If the number was odd, the plot was placed to the south the appropriate number of paces, and if the number was even, the plot was placed to the north of the transect the appropriate number of paces. Once at the established plot location seed bank sample collection occurred in the approximate southeastern corner of all plots. Seed bank samples were collected to a depth of 10 cm using a 5.5 cm diameter soil corer, resulting in 950 cm^3 samples, following Kadlec and Smith (1984) and Haukos and Smith (2001). Once removed, all samples were placed into labeled plastic bags and then on dry ice, and stored in a walk-in refrigerator (4° C). Samples remained in chilled for < 3 weeks before they were taken out for deployment in seed bank expression experiments.

Seed bank expression experiments

Individual seed bank samples were homogenized, divided in half, and each half placed into an individual 4 x 10 x 20 cm plastic dish each lined with 2 cm of sterilized potting soil. Each dish was labeled using a wooden tongue depressor with the moist-soil managed wetland identification, plot identification, and treatment exposure written for complete identification. Each half of each seed bank sample was randomly assigned into a simulated drawdown or flooding treatment (van der Valk and Davis 1978, Kadlec and Smith 1984). Samples, in dishes, were then randomly arranged on four germination tables in the greenhouse at Stephen F. Austin State University (SFASU). To maintain similar environmental conditions on both sample halves (i.e., drawdown and flooding) samples were placed on the same table, but randomly throughout, so as no two half-samples next to one another. Dishes exposed to simulated drawdown treatments monitored daily, and watered as needed with distilled water to maintain moist-soil conditions without standing water (Kadlec and Smith 1984, van der Valk and Davis 1978). Dishes exposed to the simulated flooding treatments were also monitored daily, and watered as needed to maintain 4 cm of standing water within each dish (Kadlec and

Smith 1984, Haukos and Smith 2001). Dishes were monitored from 25 April – 31 October 2005, corresponding with the growing season in Navarro and Freestone counties (NRCS 2002).

Soil seed bank assessment followed the seedling emergence technique (Smith and Kadlec 1983, Pederson and Smith 1988, Haukos and Smith 2001), where as seeds germinated seedlings were identified and counted once monthly. Seedling emergence was calculated as the cumulative number (*n*) of identified desirable and nondesirable (see below) seedlings during each month, and then each group total (i.e., desirable, nondesirable) was divided by the overall total number of seedlings counted. Once identified, seedlings were carefully removed to prevent soil disturbance. Unidentified seedlings were transplanted to individual containers and grown until identified. Nomenclature followed Correll and Johnston (1979) and seedlings were verified by voucher specimens at the SFASU Herbarium.

Seedling classification

Seedlings were classified as desirable or non-desirable, respectively, based upon their known value for waterfowl, following Frederickson and Taylor (1982). Desirable plants were defined as those that provide energy or some other nutritive requirement to migrating and wintering waterfowl (Fredrickson and Taylor 1982, Strader and Stinson 2005). Non-desirable species were defined as those that provide neither high quantity nor high quality seed, tend to dominate later successional stages, (Fredrickson and Taylor 1982, Strader and Stinson 2005). Non-desirable species may provide aquatic invertebrate substrate(s), or perform some other wetland functions (Fredrickson and Taylor 1982).

They may not necessarily be undesirable wetland plants, but are not considered desirable as direct food or food producers for wintering waterfowl (see Fredrickson and Taylor 1982).

After classification as desirable or undesirable, seedlings were assigned to plant groups and plant standardized groups commonly used by the Natural Resource Conservation Service (NRCS) within the National Plant Database (i.e., annual introduced grass, perennial native forb, annual native grass, etc.) (USDA 2011). The following group assignments were used to indicate a combination of growth habit (grass, forb, shrub, vine, or grass-like), life cycle (annual or perennial), and source (native or exotic): annual native grass (ang), annual introduced grass (aig), perennial introduced forb (pif), annual native forb (anf), annual perennial native (apn), perennial native (pn), perennial native grass-like (pnef), perennial native forb (pnf), annual perennial native subshrub (nsh), annual native forb (anf), and annual native vine (anv) (USDA 2011). When both annual and perennial are indicated for one species, this indicates that the individual plant species can have growth durations as either annual or perennial. The following standardized plant groups were created using a combination of growth habit and life cycle: annual grass (ag), perennial forb (pf), annual forb (af), perennial grass (pg), perennial shrub (ps), and annual vine (av). This standardization was used to group both native and exotic plants together, as some introduced plant species are beneficial to waterfowl management, such as barnyardgrass (*Echinochloa crusgalli*) (Fredrickson and Taylor 1982, Stutzenbaker 1999).

Data analyses

Each dish was considered an experimental unit (Smith and Kadlec 1983). A suite of diversity indices (i.e., Niche overlap, Simpson's diversity index, Shannon-Wiener diversity index, Species Evenness) were calculated for both treatments (i.e., moist or inundated), moist-soil managed wetlands (i.e., specific managed wetland from which seed bank samples were removed), treatment*moist-soil managed wetlands, treatment over time (i.e., 30-day periods). Percent similarity (i.e., niche overlap) was calculated using the relative abundance of all species summed to 100%. This index is calculated by:

$$P = \Sigma_i \text{ minimum } (p_{1i}, p_{2i})$$

Where P = percentage similarity between sample 1 and 2

p_{1i} = percentage of species i in community sample 1

p_{2i} = percentage of species i in community sample 2

This index ranges from 0 (no similarity) to 100 (complete similarity) allowing for comparison between units of interest (i.e., treatments, managed wetland, etc.) (Krebs 1999).

Chi-squared analysis was used to examine differences in stem density (i.e., number of stems/dish) among (1) desirable and non-desirable moist-soil plants between simulated treatments, (2) desirable and non-desirable moist-soil plants over time (i.e., 30-day increments), (3) treatments among plant groups, (4) treatments among plant standardized groups, (5) moist-soil managed wetland cells among simulated treatments, (6) simulated treatments among managed and unmanaged moist-soil wetlands, (7) managed/unmanaged moist-soil wetlands among desirable/undesirable plant species, (8) managed/unmanaged moist-soil wetlands between time periods, and (9) managed/unmanaged moist-soil wetlands between desirable/undesirable plant species and time period. A repeated measure, three-way multivariate analysis of variance (MANOVA) was also used to examine differences in stem density between desirable and undesirable plant species, among time periods and simulated treatments; between simulated treatments and species groups, species standardized groups; moist-soil managed wetlands, and managed to unmanaged moist-soil wetlands between treatments as well as time period x desirable/undesirable plant species, desirable/undesirable plant species, and time periods. If differences ($P < 0.05$) occurred in MANOVA subsequent univariate analysis of variance (ANOVA) was used, followed by least square mean separation if differences ($P < 0.05$) occurred in ANOVA.

RESULTS

A total of 6,802 seedlings representing 27 species were identified. Seedlings represented 14 families, 13 plant groups, and 6 standardized plant groups (Table 2.1). Of the 27 species identified, only one (*Cyperus pseudovegetus*) was not recorded during field transects (see Appendix A). A total of 11 desirable (n = 5127 individuals) and 16 undesirable species (n = 1675 individuals) were identified (Table 2.2). Approximately 75% of all individual seedlings were desirable, regardless of experimental moist-soil treatment (i.e., moist or flooded; Table 2.2). Within the experimental drawdown treatments, most germination occurred within the first 60 days, while germination within flooded treatments were more evenly distributed among the four 30-day time periods (Figure 2.2). More than 80% of desirable plant species germinated within the first 60 days of experimental drawdown conditions (Figure 2.3). The first two 30-day time periods were dominated by at > 50% desirable moist-soil plant species germination, whereas the final two 30-day time periods were dominated by > 50% undesirable moist-soil plant species (Figure 2.4).

Overall, Simpson's and Shannon-Wiener species diversity indices were similar between experimental moist and flooded treatments, which ranged from 2.01 to 5.14 for moist treatment and 1.18 to 4.38 for flooded treatment (Table 2.3). Over the course of four time periods (0-30, 31-60, 61-90, 91-120 days) both diversity indices ranged between 1.18 to 5.14 respectively (Table 2.3). There was relatively high species similarity (32.7%) for those germinating in both experimental moist and flooded treatments. Niche overlap estimates were comparable to the similarity estimates, as 39%

of species identified in moist treatments were also found in flooded treatments, and 42% of species identified in flooded treatments were found in moist treatments. Plant species evenness was skewed towards two desirable moist-soil plant species (Table 2.4). Red-rooted flatnut sedge (*Cyperus erythrorhizos*) accounted for 36 % of all individual seedlings and 48% of all desirable plant seedlings (Table 2.4). Similarly, toothcup (*Ammannia coccinea*) accounted for 24% of all individual seedlings and 31% of all desirable plant seedlings (Table 2.4). Although erect burhead (*Echinodorus rostratus*) and water primrose (*Ludwigia peploides*) only accounted for 8% of all individual seedlings, they accounted for 34% and 33% of all undesirable seedlings, respectively (Table 2.4).

A total of 2342 and 1114 desirable seedlings germinated from seed bank samples collected in the newer moist-soil managed wetlands (units 1-4) exposed to simulated moist and flooded treatments, respectively, and 305 and 643 undesirable seedlings were identified from the same wetlands exposed to simulated moist and flooded treatments, respectively (Table 2.5). In the three older managed moist-soil wetland units (i.e., triangle, gut, and DU marsh) a total of 780 and 890 desirable seedlings germinated from seed bank samples exposed to simulated moist and flooded treatments, respectively (Table 2.6), while a total of 304 and 424 undesirable seedlings germinated from seed bank samples exposed to simulated moist and flooded treatments, respectively (Table 2.6). Red-rooted flatnut sedge and nodding smartweed were the species with the greatest numbers of desirable seedlings that germinated under simulated moist and toothcup had the greatest number of desirable seedlings germintate under simulated flooded treatment conditions (Table 2.7). Water primrose, frog fruit (*Phyla lancelota*), and waterhemp (*Amaranthus tuberculata*) were the species with the greatest numbers of non-desirable seedlings to germinate under simulated moist treatment conditions, while erect burhead (*Echinodorus rostratus*), water primrose, and duck potatoe (*Sagittaria lancifolia*) were the species with the greatest number of non-desirable seedlings to germinate under flooded treatment conditions (Table 2.8).

Stem densities varied between treatments and desirable and non-desirable moist-soil plants (X^2 = 2271.5, $P < 0.001$), where desirable plant species had greater stem densities than non-desirable plant species in both simulated moist and flooded treatment (Table 2.9). Stem densities also varied between desirable and non-desirable moist-soil plants across time periods (X^2 = 544.6, $P < 0.001$), where desirable plant species had greater densities than non-desirable plant species for the first 3 time periods (Table 2.10). Similarly, stem densities varied between treatments and moist-soil plant groups (X^2 = 1876.5, P = <0.001) (Table 2.11), where stem densities were typically greater in the simulated moist treatment. Stem densities also varied between treatments and moist-soil plant standardized groups (X^2 = 1378.6, $P < 0.001$), where annual grasses reached the greatest densities in the moist treatment (Table 2.12). Stem densities also varied (X^2 = 731.9, $P < 0.001$) among individual moist-soil managed wetlands, where both desirable and non-desirable stem densities were greater in the simulated moist treatment (Table 2.13), and stem densities varied between simulated treatments and among managed and unmanaged moist-soil wetland cells (X^2 = 342.7, $P < 0.001$), where greatest densities occurred in managed wetlands, regardless of treatment (Table 2.14). Desirable seedlings reached greater densities in both managed and unmanaged moist-soil wetlands (X^2 = 278.5, P < 0.001) (Table 2.15). Stem densities for all seedlings were greatest from seed bank samples collected from managed wetlands during all four 30-day temporal periods (X^2 = 137.4, P < 0.001) (Table 2.16). Finally, seedling stem densities were greatest for both desirable and undesirable species in managed wetlands during all four 30-day temporal periods (X^2 = 1136.60, P < 0.001) and (X^2 = 251.58, P < 0.001) (Table 2.17).

Stem density for all species combined did not vary between desirable and non-desirable species (Wilks' λ = 0.99, P = 0.228); however, there was an interaction (Wilks' λ = 0.96; P < 0.001) between treatment and plant status (desirable/non-desirable). Densities of desirable seedlings were nearly double those of undesirable seedlings in moist treatments, while the converse was true for the flooded treatment. I also observed significant stem density differences within each treatment, where moist-soil produced higher desirable stem densities and flooded produced higher non-desirable stem densities (Table 2.18).

Stem density varied between plant status and time period (Wilks' λ = 0.98, P < 0.001), where subsequent ANOVAs (F = 7.24, P < 0.001) demonstrated that germination was similar between desirable and non-desirable species during the first 30 days (Table 2.19). However, irrespective of simulated treatment, stem densities of desirable seedlings was greatest during the second 30-day period, while undesirable seedling stem densities were greatest during the last two 30-day periods (Table 2.19). Interactions also occurred between simulated treatments and time period (Wilks' λ = 0.99; P = 0.036). Subsequent ANOVAs demonstrated that seedling densities varied among time periods (F = 2.86, P =

0.036). Seedling germination was greatest during the first 2 time periods for the moist treatment and germination was greatest through the first 3 time periods for the flooded treatment (Table 2.20).

Stem density varied between treatments and among plant groups (Wilks' λ = 0.972, df = 9, $P < 0.001$) and interactions were found where treatment had an effect on the moist-soil plant group density (Table 2.21). Densities of stems by plant group under moist-soil conditions produced nearly double that of flooded conditions. Stem density varied between treatment and standardized plant groups (Wilks' λ = 0.9782, df = 5, $P < 0.001$) (Table 2.22). Subsequent univariate analysis found an effect on standardized moist-soil plant group density by treatments ($F = 4.20$, $P < 0.001$), where density of standardized plant groups under moist-soil conditions produced more annual grass than under flooded conditions, while the converse was true for annual forbs (Table 2.22). Stem density varied between treatment and moist-soil managed wetlands (Wilks' λ = 0.9751, df = 6, $P < 0.001$) and interactions were found where treatment had an effect on stem density within each moist-soil managed wetland (Table 2.23). Treatment influenced moist-soil wetland unit stem densities ($F = 5.66$, $P < 0.001$), where stem density during drawdown conditions were similar among moist-soil managed wetlands 1 and 3, 4 and triangle, and 2 and DU marsh, respectively. Flooded treatment produced stem densities similar in moist-soil wetland 2 and triangle, moist-soil managed wetland 3 and 4, and Gut and DU Marsh. Moist-soil managed wetlands 1 and 3 had greater stem densities within the moist treatment and moist-soil managed wetlands 3 and 4 had greater stem densities within the flooded treatment (Table 2.23).

Stem densities varied between treatment and managed and unmanaged moist-soil wetlands (Wilks' λ = 0.9914, df = 1, P < 0.0007) (Table 2.24), where stem densities varied between managed and unmanaged wetlands (F = 11.63, P < 0.007). Stem density in managed moist-soil wetlands under drawdown were more similar to unmanaged flooded moist-soil managed wetlands, while moist-soil managed wetland under flooded conditions were similar to unmanaged moist-soil wetlands under drawdown conditions (Table 2.24). Stem density varied between time periods and managed/unmanaged moist-soil wetland (Wilks' λ = 0.9970, df = 3, P < 0.2711) (Table 2.25), where stem density differences in desirable and undesirable species, varied among time periods (Table 2.25). Desirable species had the greatest stem densities in the first two time periods while the first three time periods produced the greatest stem densities for undesirable species (Table 2.25).

DISCUSSION

Drawdown and flooded treatments had ≈ 32% of their species in common, slightly higher than van der Valk and Davis (1978), who reported that drawdown and flooded treatments had only approximately 25% species similarity. As little as 2 cm of standing water may significantly influence seed germination (van der Valk and Davis 1978), where all available seeds contained within the seed bank may not germinate under either treatment condition (van der Valk and Davis 1978). However, the moist treatment had more seedlings germinate throughout the entire study, similar to Smith and Kadlec (1983) who found that more species germinated in moist than submerged treatments and suggested there is greater potential for species composition change under moist field conditions. Several factors may influence species composition change under moist field conditions. Seeds may respond to favorable varying temperatures, light, oxygen regimes as well as in soil, lack of canopy, and drawdown conditions that provide suitable germination conditions to be exploited (Leck 2003). Baldwin et al. (2001) also found that twice as many species and five times greater individual seedlings emerged from drawdown conditions than under flood conditions. Therefore moist-soil conditions (i.e., drawdown) should be created as early as mid-March in order to produce the necessary annual emergent desirable species for continual renewal of the seed bank.

Fredrickson and Taylor (1982) suggested that early season slow drawdowns will produce a more desirable, dense, and diverse vegetative community that results in greater seed production. This greater seed production allow for desirable plant species expansion as well as provide essential food resources for migrating and wintering waterfowl. Thus, it is the current goal of many wetland wildlife managers (Fredrickson and Taylor 1982, Lane and Jensen 1999, Strader and Stinson 2005). Therefore utilizing moist-soil techniques will maximize production of naturally occurring wetland vegetation. By emulating and manipulating natural wetland functions (e.g., hydrology and successional stage) via precise control of hydrology and manipulation of plant succession, wildlife managers can achieve desired plant communities and provide habitat requirements for a variety of wildlife species throughout their annual cycles (Lane and Jensen 1999). In the playas of Texas, Haukos and Smith (1993) suggested moist-soil conditions should be created as early as possible in April to allow for desirable plant species germination, such as smartweeds and annual grasses, and reported that plants germinating early in April had greater overall seed production.

As there was a rapid response from early and continuous germinators in the moist treatment, drawdowns should promote establishment of desirable wetland plant species such as pink smartweed (*Polygonum pensylvanicum*), nodding smartweed (*Polygonum lapathifolium*), curly dock (*Rumex crispus*), and barnyard grass (Haukos and Smith 2001). Early and continuous germinators are species that germinate rapidly after exposure to drawdown conditions and then proceed with low germination rates (i.e., early) during the remainder of the growing season or produce seedlings at the same rate (i.e., continuous) throughout the growing season under drawdown conditions (Haukos and Smith 2001). It has been documented that species such as barnyard grass and smartweeds can produce 1,350 kg/ha (Fredrickson and Taylor 1982, Laubhan and Fredrickson 1992, Gray et al. 1999, Sherfy and Kirkpatrick 1999, Bowyer et al. 2005).

Many early and continuous germinators are considered desirable to waterfowl managers due to their ability to provide food for wintering and migrating waterfowl (Fredrickson and taylor 1982).

Over 50% of desirable species had germinated within the first 30 days of exposure and > 80 % within the first 60 days. This mirrors studies in playas, where germination was initiated within the first 30 days of exposure to treatments, and after 90 days of exposure 63% and 77% of seedlings germinated in moist and flooded conditions, respectively (Pederson 1983, Haukos and Smith 1997, Haukos and Smith 2001). Similarly, Welling et al. (1988) found that nearly all seed bank germination occurred in the first two months of exposure to drawdown treatments in the Prairie Pothole Region. In order to successfully exploit Richland Creek Wildlife Management Area's soil seed banks, estimates of seed bank species composition is needed to direct management activities. As desirable species will typically germinate within 60 days of drawdown conditions, it should be relatively straightforward to direct plant species composition in managed wetlands via strategic drawdown and flooding treatments. Also, managers should keep in mind that non-desirable species germinated under flooded conditions. For example, in this study, >50% of non-desirable species germinated in the last two 30-day time periods. Managers should be conscious of water depth, as Baldwin et al. (2001) reported that < 4 cm of standing water reduced total seedlings by 50%, emphasizing the importance of shallow water levels early in the growing season for the establishment of those desirable annual species.

Although 27 of 57 known species germinated (see Appendix A), not all species growing on the site will be represented in its seed bank (van der Valk et al. 1992). Seed bank experiments not only reflect last year's vegetation, but also, to a limited extent, the immediate past vegetation (Leck and Simpson 1987). Compositional changes will increase in diversity due to differences in germination environment, effects of management practices such as turning the seed bank over (i.e., disking) and establishment of new species and maturation of managed moist-soil wetlands. If germination of a certain species assemblage is desired, knowledge of seed bank composition and expression studies, will help determine species presence such that specific treatments can be applied to promote germination of those desired species (Smith and Kadlec 1983).

Moist-soil wetlands on RCWMA are relatively new, so many annual seed producing moist-soil plant species were present both in field vegetative transect data (see Appendix A) and seed bank data. Generally, the most prolific seed producers and desirable plants for waterfowl are these annuals that dominate early successional seral stages (i.e., new wetlands) (Strader and Stinson 2005). Therefore, proper germination conditions were met for many of the species both in the greenhouse and in the actual moist-soil managed wetlands. Desirable species (i.e., annual moist-soil plants that produce large amounts of seed), were present in greater densities under moist conditions and within the first 60 days of exposure to moist conditions. Also managed moist-soil wetlands had greater moist-soil plant densities under moist conditions than unmanaged moist-soil wetlands. Moist-soil managed wetlands 1-4 had greater mean seedling germination than the 3 remaining moist-soil managed wetlands (Triangle, Gut, and DU marsh), water control capacity is much reduced on the latter 3 moist-soil managed wetlands. This should be encouraging to wetland managers because it shows that managers can produce annual moist-soil plant species through water manipulations (i.e., frequent drawdown and flooding conditions).

Baldwin et al. (2001) documented negative impacts on vegetation due to greater water depths in both field and greenhouse conditions. Inhibitory effects of flooding on vegetative growth and seedling recruitment have been widely documented (Galinato and van der Valk 1986, McKee and Mendelssohn 1989, Baldwin et al 2001). As moist-soil managed wetlands 1-4 age, greenhouse seed bank expression experiments and field scale transect data should look similar in species composition, as dominant species will be more persistent under consistent water management. However, if management practices are inconsistent or objectives vary annually, seed bank and field scale composition may diverge. For example, wild millet is known to occur within the moist-soil managed wetlands, but did not occur in the seed bank expression experiments, perhaps because proper germination conditions were not met. Toothcup was also the dominant species in both seed bank expression experiments and vegetation transects during 2004 (see Appendix A), but its relative density and dominance dropped to extremely low and irrelevant quantities in 2005 and 2006 (see Appendix A). Reduction in this species may be attributed to longer inundation periods and greater water depths during the 2005 growing season. For example, Smith and Kadlec (1983) found that germination conditions were not met for *Tamarix pentandra*, *Potamogeton crispus*, and *P. pectinatus* in seed bank trials, although they were known to occur in the field. They postulated that few seeds were present in their samples, perhaps due to to poor seed recruitment and germination. van der Valk and Davis (1978) also reported this same phenomenon for seeds of both *Sparganium* and *Scirpus fluviatilis,* where discrepancies were observed between field and seed bank samples.

Within many greenhouse experiments, some species might not germinate due to competition, allelopathy, poor germination conditions, and small sample size. Keddy (1999 and 2000) suggested that prediction of the presence and abundance of a particular species would require foresight regarding how these various variables (i.e., hydrology, competition, allelopathy, and disturbance) would act on germination and other life history traits of the plant species available. One possible way to corroborate seed bank and field transect data would be to use growth chambers in which the environment can be controlled and allow a longer growing period to express the seed bank to its full potential.

In this study, the greatest differences occurred between managed and unmanaged moist-soil wetlands. When the 4 created moist-soil managed wetlands were constructed, the top layer of soil was used to create levees, which may have exposed seeds that were deposited long ago. This construction technique may have allowed the expression of vegetative characteristics that the wetlands exhibited in the recent past. Vegetation data from August 2004 detected red-rooted flatnut sedge as a dominant species found in all 4 moist-soil wetlands, and the seed bank data also reflects this (see Appendix A). However, it was not detected again on field scale transects during the next two years, which indicates that germination conditions were only met in 2004 germination for red-rooted flatnut sedge.

The succesional model proposed by van der Valk (1981) for freshwater wetlands dependent on periodic changes in hydrology (i.e., water level) can be applied to all 7 moist-soil wetlands found on Richland Creek Wildlife Management Area. van der Valk (1981) postulated that wetland floristic composition normally results from (1) destruction of all or some of the existing vegetation by pathogens, herbivores, or man, (2) changes in the physical or chemical habitat conditions (i.e., change in water or nutrient levels) that favor the growth of some species over others, (3) interactions among plants (i.e., competition, allelopathy), or (4) the invasion and establishment of new species. Within the moist-soil wetlands located on RCWMA, destruction of existing vegetation and physical conditions occurred through drawdown and inundation allowing for annual seedlings to germinate and begin the process of establishment. Specifically, the change in water levels should allow for nutrient cycling, plant senescence, and subsequent decomposition of the plant litter, allowing new seedlings to germinate during the growing season when drawdown occurs (van der Valk and Davis 1978,van der Valk 1981, van der Valk et al. 1992).

Fredrickson and Taylor (1982) developed a list of plant species and their desirability for the lower Mississippi River Valley that has been used on a national scale. While this list of plants is very good starting point, development of region specific list(s) of desirable / undesirable plant species (see Chapter III) should be pursued. For example, erect burhead (*Echinodorus rostratus*) occurred regularly in blue-winged teal (*Anas discors*) and green-winged teal (*A. crecca*) collected on RCWMA (see Chapter VI), but it is currently listed as an undesirable plant species. Although it occurred in approximately

7.2 % of all samples collected, it was equal to or greater than some of the most desirable plant species such as nodding smartweed (7.1 %), barnyard grass (1.7 %), and wild millet (0.5 %) (see Chapter VI, Appendix A). When comparing relative density of erect burhead to other desirable moist-soil plant species such as barnyard grass and wild millet, it typically had similar relative density values to desirable moist-soil plant species (see Appendix A). This might be an indication that erect burhead is selected as a desirable food source for waterfowl and a re-evaluation/development of regional specific desirable moist-soil plant species guidelines is needed.

Management Implications

Manipulating the water regime within moist-soil managed wetlands should be common practice and will benefit many wildlife species. The seed bank along with other variables such as invertebrate eggs represents a substantial component of wetland diversity (Brock et al. 2003). Using the techniques of drawdown and flooding will allow managers to select how they want to influence their wetland plant communities based on their seed bank components and the seed bank's response to the presence or absence of water during the germination period. Continuous flooding may cause certain species to miss cues to germinate and could possibly lead to a loss in viability and biodiversity within this type of wetland ecosystem.

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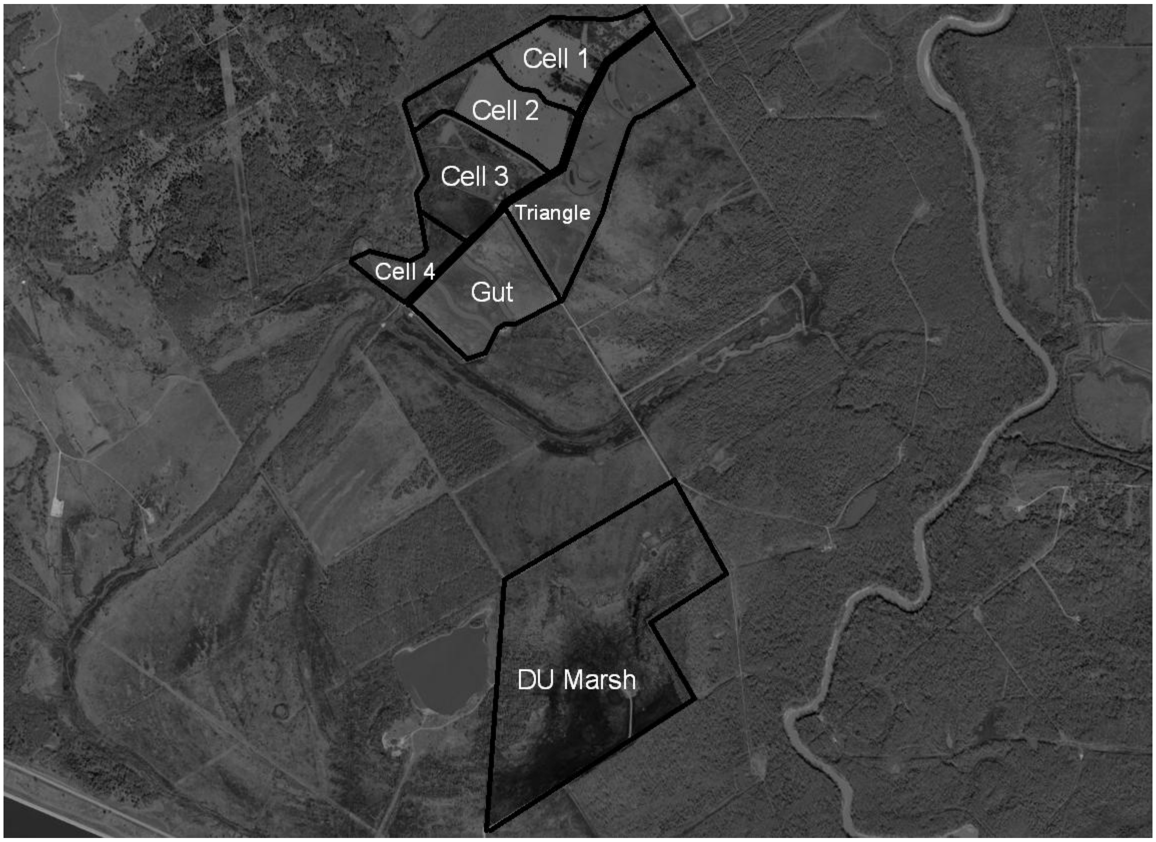

Figure 2.1. Locations of wetlands used to collect seed bank samples on Richland Creek Wildlife Management Area, in east-central Texas 2005.

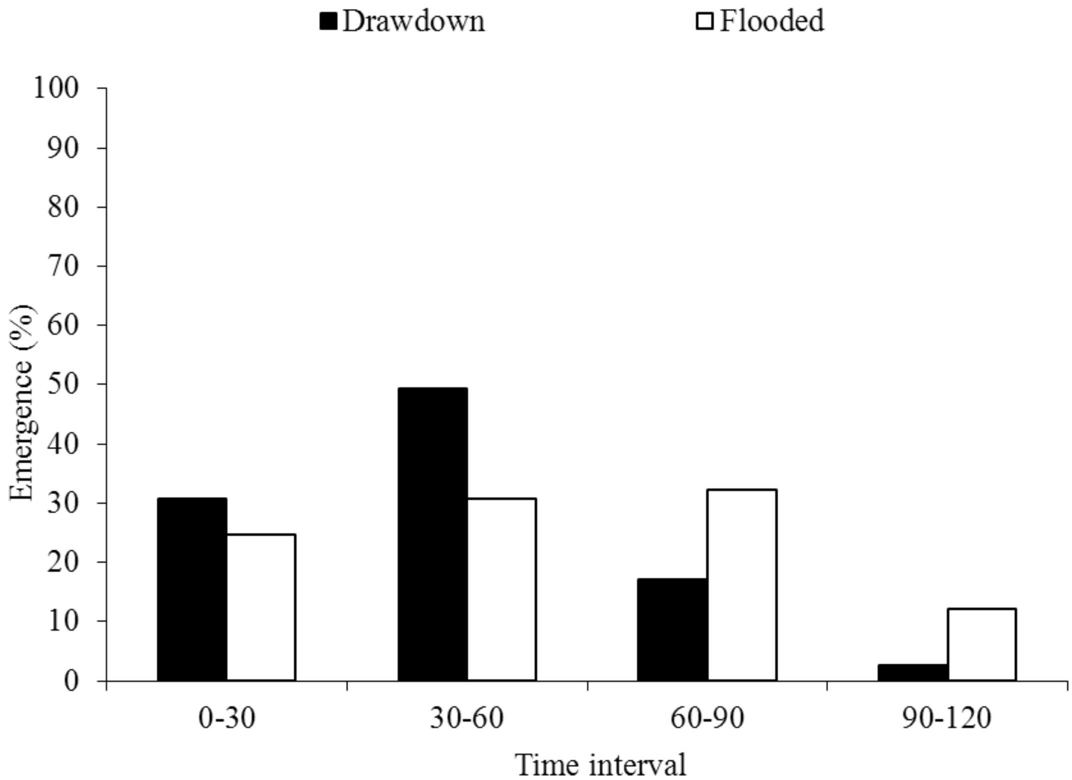

Figure 2.2. Total seedling emergence (%) of seed bank samples exposed to drawdown and flooded treatments during four 30-day periods from Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

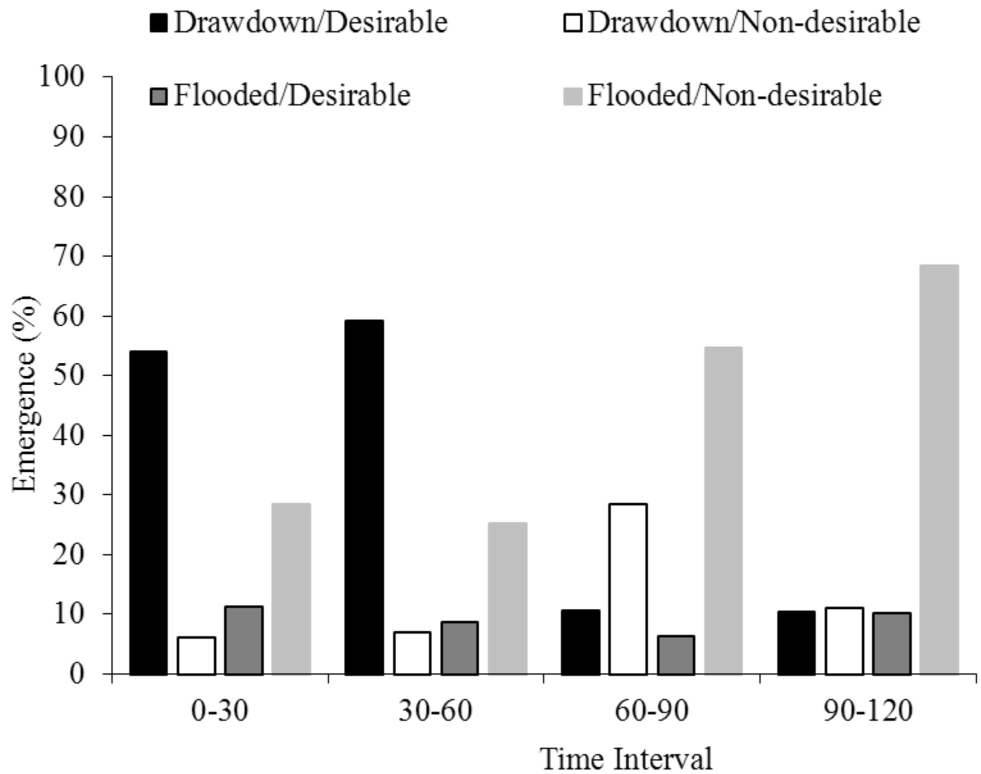

Figure 2.3. Seedling (desirable/non-desirable) emergence (%) from seed bank samples exposed to drawdown and flooded treatments during four 30-day periods from Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

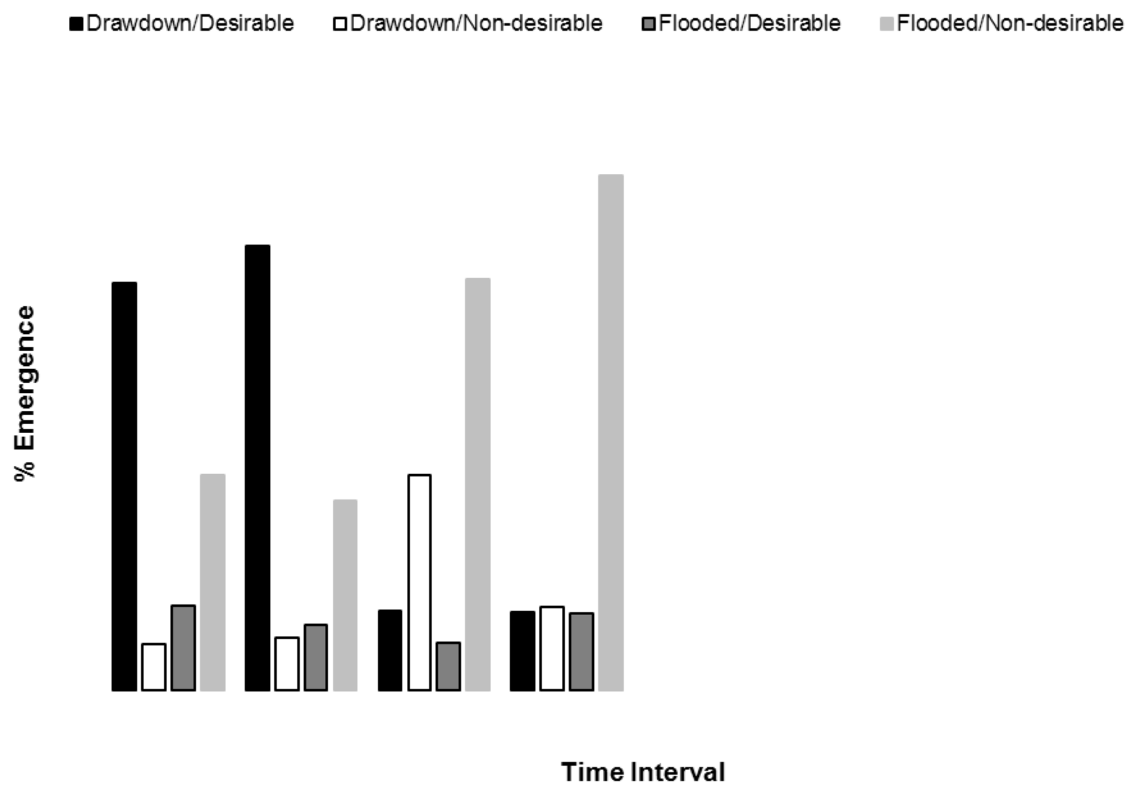

Figure 2.4. Percent seedling emergence during four individual 30-day periods exposed to drawdown and flooded treatments from samples taken from Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

Table 2.1. Family, scientific name, group, and standardized group of seedlings recorded in simulated moist-soil treatments (i.e., moist or flooded) during seed bank expression experiments from samples collected at Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

Family	Scientific Name	Group	Standardized Group
Alismataceae	*Echinodorus rostratus*	perennial native emergent forb	perennial forb
	Sagittaria platuphylla	perennial native emergent forb	perennial forb
	Sagittaria lancifolia	perennial native emergent forb	perennial forb
Amaranthaceae	*Amaranthus tuberculata*	annual native forb	annual forb
Asteraceae	*Mikania scandens*	annual native vine	annual vine
	Aster spp.	perennial native forb	perennial forb
	Eclipta prostrate	annual native forb	annual forb
	Xanthium strumarium	annual native forb	annual forb
Ceratophyllaceae	*Ceratophyllum demersum*	perennial native forb	perennial forb
Chenopodiaceae	*Chenopodium album*	annual native forb	annual forb

Table 2.1. (continued). Family, scientific name, group, and standardized group of seedlings recorded in simulated moist-soil treatments (i.e., moist or flooded) during seed bank expression experiments from samples collected at Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

Family	Scientific Name	Group	Standardized Group
Cyperaceae	*Cyperus erythrorhizos*	annual perennial native	annual grass
	Cyperus pseudovegetus	perennial native	perennial grass
	Eleocharis quadrangulata	perennial native grass-like	perennial grass
Fabaceae	*Desmanthus illinoensis*	perennial native forb	perennial forb
	Sesbania macrocarpa	annual perennial native subshrub	perennial shurb
Lythraceae	*Ammannia coccinea*	annual native forb	annual forb
Marsileaceae	*Marsilea vetita*	perennial native forb/herb	perennial forb
Onagraceae	*Ludwigia peploides*	perennial native forb	perennial forb
Poaceae	*Leptochloa fascicularis*	annual native grass	annual grass
	Eragrostis hypnoides	annual native grass	annual grass

Table 2.1. (continued). Family, scientific name, group, and standardized group of seedlings recorded in simulated moist-soil treatments (i.e., moist or flooded) during seed bank expression experiments from samples collected at Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

Family	Scientific Name	Group	Standardized Group
Poaceae	*Panicum virgatum*	annual native grass	annual grass
	Echinochloa crusgalli	annual introduced grass	annual grass
Polygonaceae	*Rumex crispus*	perennial introduced forb	perennial forb
	Poylgonum lapathifolium	annual native forb	annual forb
	Polygonum hydroperoides	annual native forb	annual forb
Potamogetonaceae	*Potamogeton* spp.	perennial native forb	perennial forb
Sapindaceae	*Cadiospermum halicacabum*	annual native vine	annual vine
Verbenaceae	*Phyla lancelota*	perennial native forb	perennial forb

Table 2.2. Family, scientific name, occurrence, and moist-soil plant classification (i.e., desirable or non-desirable)[1] of seedlings recorded in simulated moist-soil treatment (i.e., moist or flooded) through seed bank germination experiments from seed bank samples collected from the Richland Creek Wildlife Management Area, Freestone County, Texas, 2005.

Family	Scientific Name	Moist	Flooded	Desirable[1]	Non-desirable[1]
Alismataceae	*Echinodorus rostratus*	X	X		X
	Sagittaria platuphylla	X	X		X
	Sagittaria lancifolia		X		X
Amaranthaceae	*Amaranthus tuberculatus*	X	X		X
Asteraceae	*Mikania scandens*	X			X
	Aster spp.	X	X		X
	Eclipta prostrate	X	X		X
	Xanthium strumarium	X	X		X
Chenopodiaceae	*Chenopodium album*	X	X		X

[1]Classification follows Fredrickson and Taylor (1982).

Table 2.2. (continued). Family, scientific name, occurrence, and moist-soil plant classification (i.e., desirable or non-desirable)[1] of seedlings recorded in simulated moist-soil treatment (i.e., moist or flooded) through seed bank germination experiments from seed bank samples collected from the Richland Creek Wildlife Management Area, Freestone County, Texas, 2005.

Family	Scientific Name	Moist	Flooded	Desirable[1]	Non-desirable[1]
Cyperaceae	*Cyperus erthrorhizos*	X	X	X	
	Cyperus pseudovegetus	X	X	X	
	Eleocharis quadrangulata	X	X	X	
Fabaceae	*Desmanthus illinoensis*	X			X
	Sesbania macrocarpa	X	X		X
Lythraceae	*Ammannia coccinea*	X	X	X	
Marsileaceae	*Marsilea vetita*		X		X
Onagraceae	*Ludwigia peploides*	X	X		X
Poaceae	*Leptochloa fascicularis*	X		X	

[1]Classification follows Fredrickson and Taylor (1982).

Table 2.2. (continued). Family, scientific name, occurrence, and moist-soil plant classification (i.e., desirable or non-desirable)[1] of seedlings recorded in simulated moist-soil treatment (i.e., moist or flooded) through seed bank germination experiments from seed bank samples collected from the Richland Creek Wildlife Management Area, Freestone County, Texas, 2005.

Family	Scientific Name	Moist	Flooded	Desirable[1]	Non-desirable[1]
Poaceae	*Eragrostis hypnoides*	X	X	X	
	Panicum virgatum	X	X	X	
	Echinochloa crusgalli	X	X	X	
Polygonaceae	*Rumex crispus*	X	X	X	
	Polygonum lapathifolium	X	X	X	
	Polygonum hydropiperoides	X		X	
Potamogetonaceae	*Potamogeton spp.*		X		X
Sapindaceae	*Cardiospermum halicacabum*	X			X
Verbenaceae	*Phyla lancelota*	X	X		X

[1]Classification follows Fredrickson and Taylor (1982).

Table 2.3. Plant species diversity indices from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) during four 30 day temporal windows from the Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

Diversity Index	Treatment	Overall	0-30 days	31-60 days	61-90 days	91-120 days
Simpson's	Moist	3.26	2.69	2.47	4.67	5.14
Simpson's	Flooded	3.57	3.45	4.38	1.49	2.07
Shannon-Wiener	Moist	2.57	2.16	2.01	2.55	2.83
Shannon-Wiener	Flooded	2.33	1.99	2.50	1.18	1.65

Table 2.4. Scientific name, total number of seedlings (*n*), overall evenness estimate (*P*), and evenness estimates (*P*) of desirable or undesirable species identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

Species	Total (*n*)	Overall Evenness (*P*)	Desirable Evenness (*P*)	Undesirable Evenness (*P*)
Cyperus erythrorhizos	2446	0.359	0.477	--
Ammannia coccinea	1613	0.237	0.314	--
Poylgonum lapathifolium	595	0.087	0.116	--
Echinodorus rostratus	578	0.084	--	0.344
Ludwigia peploides	555	0.081	--	0.330
Eragrostis hypnoides	181	0.026	0.035	--
Phyla lancelota	145	0.021	--	0.086
Saggitaria platuphylla	120	0.017	--	0.071
Polygonum hydroperoided	104	0.015	0.020	--
Echinochloa crusgalli	71	0.010	0.013	--
Chenopodium album	57	0.008	--	0.033
Desmanthus illinoensis	47	0.006	--	0.028
Marsilea vetita	45	0.006	--	0.025
Amaranthus tuberculata	43	0.006	--	0.019
Rumex crispus	42	0.006	0.008	--

Table 2.4 Continued. Scientific name, total number of seedlings (*n*), overall evenness estimate (*P*), and evenness estimates (*P*) of desirable or undesirable species identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from Richland Creek Wildlife Management Area, Freestone County, Texas 2005.

Species	Total (*n*)	Overall Evenness (*P*)	Desirable Evenness (*P*)	Undesirable Evenness (*P*)
Panicum virgatum	38	0.005	0.007	--
Aster spp.	32	0.004	--	0.019
Xanthium strumarium	18	0.002	--	0.010
Cyperus pseudovegetus	14	0.002	0.002	--
Leptochloa fasicularis	14	0.002	0.002	--
Potamogeton spp	11	0.001	--	0.007
Eleocharis quadrangulata	7	0.001	0.001	--
Eclipta prostrate	3	0.001	--	0.006
Cadiospermum halicacabum	2	0.001	--	0.001
Sesbania macrocarpa	2	0.001	--	0.001
Saggitaria lancifolia	1	0.001	--	0.001
Total	6802	1.00	1.00	1.00

Table 2.5 Means ($\bar{x}$), standard errors (SE), and number of desirable and non-desirable moist-soil plant species seedlings identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from four newly created moist-soil managed wetlands at Richland Creek Wildlife Management area, Freestone county, Texas 2005.

	Moist Treatment						Flooded					
	Desirable			Non-desirable			Desirable			Non-desirable		
Wetland	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
1	745	9.68	18.29	164	2.98	4.09	73	2.15	1.88	140	7.00	8.61
2	511	6.01	7.79	126	2.10	1.49	51	1.59	1.29	31	1.72	1.02
3	904	10.39	14.46	579	7.62	12.25	90	2.05	3.21	275	8.33	9.47
4	182	4.55	5.82	245	8.75	12.49	91	2.28	2.20	197	5.63	8.83
Total	2342	7.66	4.79	1114	5.36	4.79	305	2.02	0.56	643	5.67	2.98

Table 2.6. Means ($\bar{x}$), standard errors (SE), and number of desirable and non-desirable moist-soil plant species seedlings identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from three older moist-soil managed wetlands at Richland Creek Wildlife Management area, Freestone county, Texas 2005.

	Moist Treatment						Flooded					
	Desirable			Non-desirable			Desirable			Non-desirable		
Wetland	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Triangle	313	4.17	5.25	103	2.64	2.80	113	3.23	3.53	57	2.04	1.82
Gut	267	4.77	6.14	312	5.29	5.20	111	3.36	4.13	225	5.23	7.70
DU	200	2.25	1.76	475	7.31	9.19	80	2.35	2.71	142	4.90	6.07
Total	780	3.73	1.75	890	5.08	2.31	304	2.98	0.50	424	4.05	2.25

Table 2.7. Means ($\bar{x}$), standard error (SE), and numbers of desirable moist-soil plant seedlings identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from Richland Creek Wildlife Management area, Freestone County, Texas 2005.

		Moist Treatment			Flooded Treatment			Total		
Family	Species	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Cyperaceae	*Cyperus pseudovegetus*	13	1.08	0.08	1	1.00	--	14	1.08	0.07
	Cyperus erythrorhizos	1949	7.92	0.31	497	3.50	0.25	2446	6.30	0.24
	Eleocharis quadrangulata	7	1.17	0.15	--	--	--	7	1.17	0.15
Lythraceae	*Ammannia coccinea*	217	4.43	0.47	1396	7.59	0.27	1613	6.92	0.24
Poaceae	*Echinochloa crusgalli*	64	2.78	0.33	7	1.75	0.19	71	2.63	0.29
	Leptochloa fascicularis	5	1.25	0.22	9	1.29	0.16	14	1.27	0.12
	Panicum virgatum	35	3.18	0.66	3	1.50	0.41	38	2.92	0.59
	Eragrostis hypnoides	178	3.42	0.37	3	1.50	0.41	181	3.35	0.36
Polgonaceae	*Poylgonum lapathifolium*	533	6.42	0.32	62	2.07	0.30	595	5.27	0.28
	Rumex crispus	40	5.71	1.29	2	1.00	0.00	42	4.67	1.13
	Polygonum hydroperoided	81	5.06	0.75	23	3.29	0.75	104	4.52	0.58
Total		3122	6.13	0.19	2005	5.23	0.18	5127	5.75	0.14

Table 2.8. Means ($\bar{x}$), standard error (SE), and numbers of non-desirable moist-soil plant seedlings identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from Richland Creek Wildlife Management area, Freestone County, Texas 2005..

		Moist Treatment			Flooded Treatment			Total		
Family	Species	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Alismataceae	*Saggitaria lancifolia*	1	1.00	--	119	3.05	0.52	120	3.00	0.51
	Echinodorus rostratus	--	--	--	578	6.02	0.32	578	6.02	0.32
Amaranthaceae	*Amaranthus tuberculata*	56	1.81	0.26	1	1.00	--	57	1.78	0.26
Asteraceae	*Aster* spp.	31	2.21	0.27	1	1.00	--	32	2.13	0.26
	Mikania scandens	17	2.13	0.44	1	1.00	--	18	2.00	0.41
	Xanthium strumarium	15	2.50	0.83	3	1.00	0.00	18	2.00	0.62
	Eclipta prostrate	2	1.00	0.00	1	1.00	0.00	3	1.00	0.00
Chenopodiaceae	*Chenopodium album*	42	2.10	0.33	1	1.00	0.00	43	2.05	0.32
Fabaceae	*Desmanthus illinoensis*	47	1.62	0.18	--	--	--	47	1.62	0.18
	Sesbania macrocarpa	1	1.00	0.00	1	1.00	--	2	1.00	0.00
Marsileaceae	*Marsilea vetita*	--	--	--	45	15.00	1.18	45	15.00	1.18
Onagraceae	*Ludwigia peploides*	256	2.78	0.22	299	6.50	0.51	555	4.02	0.26
Potamogetonaceae	*Potamogeton* spp.	--	--	--	11	1.38	0.16	11	1.38	0.16
Sapindaceae	*Cadiospermum halicacabum*	2	1.00	0.00	--	--	--	2	1.00	0.00
Verbenaceae	*Phyla lancelota*	139	3.02	0.30	6	1.20	0.18	145	2.84	0.28
Total		609	2.42	0.12	1066	5.20	0.23	1675	3.67	0.14

Table 2.9. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of desirable and non-desirable seedlings identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from Richland Creek Wildlife Management Area, Texas 2005.

	Treatment								
	Moist			Flooded			Total		
	n	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Desirable	3122a[1]	6.1	0.19	2005a	5.2	0.18	5127	5.7	0.14
Non-Desirable	609b	2.4	0.12	1066b	5.2	0.23	1675	3.7	0.14
Total	3731	4.9	0.15	3071	5.2	0.14	6802	5.0	0.10

[1] Means followed by the same letter within the same column are not different ($P > 0.05$).

Table 2.10. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of desirable and non-desirable seedlings identified from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) during four (30 day) temporal periods, from Richland Creek Wildlife Management Area, Texas 2005.

	Time Period														
	0-30			30-60			60-90			90-120			Total		
Species	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Desirable	1245a	5.90	0.20	2231a	7.40	0.30	1281a	5.20	0.20	370a	2.80	0.20	5127	5.70	0.10
Non-Desirable	661b	6.50	0.30	559b	3.50	0.20	345b	2.50	0.20	110a	1.90	0.30	1675	3.70	0.10
Total	1906	6.10	0.20	2790	6.00	0.20	1626	4.20	0.20	480	2.50	0.20	6802	5.00	0.10

[1] Means followed by the same letter within the same column are not different ($P > 0.05$).

Table 2.11. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of seedlings classified into groups (NRCS 2011) from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from Richland Creek Wildlife Management Area, Texas 2005.

	Treatment								
	Moist			Flooded			Total		
Group	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Annual introduced grass	64	2.8	0.33	7	1.8	0.19	71	2.6	0.29
Annual native forb	946	4.6	0.21	1487	6.6	0.25	2433	5.6	0.17
Annual native grass	218	3.3	0.31	15	1.4	0.13	233	3.0	0.28
Annual native vine	19	1.9	0.38	1	1.0	--	20	1.8	0.36
Annual perennial native	1949	7.9	0.31	497	3.5	0.25	2446	6.3	0.24
Annual native subshrub	1	1.0	--	1	1.0	--	2	1.0	0.00
Perennial introduced forb	40	5.7	1.29	2	1.0	0.00	42	4.7	1.13
Perennial native	13	1.1	0.08	1	1.0	--	14	1.1	0.07
Perennial native emergent forb	257	2.8	0.22	997	5.5	0.24	1254	4.6	0.19
Perennial native grass-like	7	1.2	0.15	--	--	--	7	1.2	0.15
Perennial native forb/herb	--	--	--	45	15.0	1.18	45	15.0	1.18
Perennial native forb	217	2.4	0.19	18	1.3	0.11	235	2.3	0.17
Total	3731	4.9	0.15	3071	5.2	0.14	6802	5.0	0.10

Table 2.12. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of seedlings classified into standardized groups (NRCS 2011) from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from Richland Creek Wildlife Management Area, Texas 2005.

	Treatment								
	Moist			Flooded			Total		
Standardized Group	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Annual forb	946	4.6	0.21	1487	6.6	0.25	2433	5.6	0.17
Annual grass	2231	6.6	0.26	519	3.3	0.23	2750	5.6	0.20
Annual vine	19	1.9	0.38	1	1.0	--	20	1.8	0.36
Perennial forb	514	2.7	0.15	1017	5.1	0.23	1531	4.0	0.15
Perennial grass	20	1.1	0.07	1	1.0	--	21	1.1	0.07
Perennial native forb/herb	--	--	--	45	15.0	1.18	45	15.0	1.18
Perennial shrub	1	1.0	--	1	1.0	--	2	1.0	0.00
Total	3731	4.9	0.15	3071	5.2	0.14	6802	5.0	0.10

Table 2.13. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of desirable and non-desirable moist-soil seedlings from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from individual moist-soil managed wetlands at Richland Creek Wildlife Management Area, Texas 2005.

	Moist						Flooded					
	Desirable			Non-desirable			Desirable			Non-desirable		
Wetland	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
1	745	9.68	18.29	164	2.98	4.09	73	2.15	1.88	140	7.00	8.61
2	511	6.01	7.79	126	2.10	1.49	51	1.59	1.29	31	1.72	1.02
3	904	10.39	14.46	579	7.62	12.25	90	2.05	3.21	275	8.33	9.47
4	182	4.55	5.82	245	8.75	12.49	91	2.28	2.20	197	5.63	8.83
Triangle	313	4.17	5.25	103	2.64	2.80	113	3.23	3.53	57	2.04	1.82
Gut	267	4.77	6.14	312	5.29	5.20	111	3.36	4.13	225	5.23	7.70
DU	200	2.25	1.76	475	7.31	9.19	80	2.35	2.71	142	4.90	6.07
Total	3122	5.97	4.50	2004	5.24	3.88	609	2.43	0.79	1067	4.98	2.78

Table 2.14. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of seedlings from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from managed and non-managed moist-soil managed wetlands at Richland Creek Wildlife Management Area, Texas 2005.

	Treatment								
	Moist			Flooded			Total		
Moist-soil wetland type	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Managed	2647	6.0	0.22	1757	5.4	0.21	4404	5.8	0.16
Unmanaged	1084	3.4	0.13	1314	5.0	0.18	2398	4.1	0.11
Total	3731	4.9	0.15	3071	5.2	0.14	6802	5.0	0.10

Table 2.15. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of desirable and non-desirable seedlings from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from managed and non-managed moist-soil managed wetlands at Richland Creek Wildlife Management Area, Texas 2005.

	Wetland Type								
Species	Managed			Unmanaged			Total		
	n	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Desirable	3456	6.8	0.20	1671	4.4	0.14	5127	5.7	0.14
Non-desirable	948	3.7	0.20	727	3.6	0.19	1675	3.7	0.14
Total	4404	5.8	0.16	2398	4.1	0.11	6802	5.0	0.10

Table 2.16. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), numbers, and standard errors (SE) of seedlings from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from managed and non-managed moist-soil managed wetlands during four (30 day) temporal periods from Richland Creek Wildlife Management Area, Texas 2005.

	Wetland Type								
Time Period	Managed			Unmanaged			Total		
	n	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
0-30	1227	6.9	0.27	679	5.1	0.26	1906	6.1	0.20
30-60	1977	7.2	0.30	813	4.3	0.19	2790	6.0	0.20
60-90	949	4.4	0.27	677	4.0	0.21	1626	4.2	0.18
90-120	251	2.6	0.22	229	2.4	0.22	480	2.5	0.15
Total	4404	5.8	0.16	2398	4.1	0.11	6802	5.0	0.10

Table 2.17. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), overall number of seedlings to germinate (n), and standard errors (SE) of desirable and non-desirable seedlings from seed bank samples exposed to simulated moist-soil treatment (i.e., moist or flooded) from managed and unmanaged moist-soil managed wetlands during four (30 day) temporal periods from Richland Creek Wildlife Management Area, Texas 2005.

	Time Period														
	0-30			30-60			60-90			90-120			Total		
Managed moist-soil wetlands	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
Desirable	841	7.1	0.3	1602	9.3	0.4	814	5.7	0.3	199	2.7	0.2	3456	6.8	0.2
Non-Desirable	386	6.4	0.5	375	3.7	0.3	135	1.9	0.2	52	2.3	0.7	948	3.7	0.2
Total	1227	6.9	0.3	1977	7.2	0.3	949	4.4	0.3	251	2.6	0.2	4404	5.8	0.2
Unmanaged moist-soil wetlands															
Desirable	404	4.4	0.3	629	4.9	0.2	467	4.5	0.3	171	2.9	0.3	1671	4.4	0.1
Non-Desirable	275	6.7	0.5	184	3.1	0.3	210	3.2	0.3	58	1.7	0.2	727	3.6	0.2
Total	679	5.1	0.3	813	4.3	0.2	677	4.0	0.2	229	2.4	0.2	2398	4.1	0.1

Table 2.18. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), standard error (SE), F, and P values resulting from analysis of variance for desirable and nondesirable seedling germination among and between two treatment conditions from seed bank samples taken on Richland Creek Wildlife Management Area, east-central Texas 2005.

	Moist		Flooded			
Plant status	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
Desirable	6.32	0.21	3.06	0.20	20.47	0.001
Non-desirable	2.74	0.14	6.33	0.18	30.33	0.001
	F	*P*	*F*	*P*		
	19.56	0.001	32.27	0.001		

Table 2.19. Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), standard error (SE), *F*, and *P* values resulting from analysis of variance for desirable and nondesirable seedling germination among and between four time periods from seed bank samples collected from Richland Creek Wildlife Management Area, east-central Texas 2005.

	Desirable		Non-desirable			
Time Period	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
0-30	5.93	0.58	6.54	0.88	0.36	0.549
31-60	7.15	0.79	4.54	0.48	10.67	0.001
61-90	2.25	0.22	5.16	0.52	9.74	0.002
91-120	1.60	0.17	2.93	0.34	1.04	0.309
	F	*P*	*F*	*P*		
	13.76	0.001	3.74	0.010		

Table 2.20 Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), standard error (SE), F, and P values resulting from analysis of variance for germintationof seedlings among and between two treatments over four time periods from seed bank samples taken on Richland Creek Wildlife Management Area, east-central Texas 2005.

	Moist		Flooded			
Time period	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
0-30	5.61	0.57	7.13	0.90	2.23	0.135
31-60	6.40	0.72	5.44	0.58	1.37	0.242
61-90	3.11	0.31	5.51	0.69	7.55	0.006
91-120	1.61	0.19	2.95	0.35	1.05	0.306
	F	*P*	*F*	*P*		
	4.93	0.002	9.63	0.001		

Table 2.21 Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), standard error (SE), F, and P values resulting from analysis of variance for moist-soil plant group seedling germination among and between two treatment conditions from seed bank samples taken on Richland Creek Wildlife Management Area, east-central Texas 2005.

	Moist		Flooded			
Moist-soil plant group	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
annual introduced grass	2.8	0.33	1.8	0.19	0.05	0.822
annual native forb	4.6	0.21	6.6	0.25	5.94	0.015
annual native grass	3.3	0.31	1.4	0.13	0.47	0.492
annual native vine	1.9	0.38	1.0	--	0.01	0.919
annual perennial native	7.9	0.31	3.5	0.25	24.62	0.001
annual native subshrub	1.0	--	1.0	--	0.00	1.000
perennial introduced forb	5.7	1.29	1.0	0.00	0.48	0.487
perennial native	1.1	0.08	1.0	--	0.00	0.992
perennial native emergent forb	2.8	0.22	5.5	0.24	6.34	0.012
perennial native grass-like	1.2	0.15	--	--	--	--
perennial native forb/herb	--	--	15.0	1.18	--	--
perennial native forb	2.4	0.19	1.3	0.11	0.22	0.636
	F	*P*	*F*	*P*		
	5.43	0.001	2.29	0.011		

Table 2.22 Mean ($\bar{x}$)stem densities (i.e., seedlings per experimental dish), standard error (SE), F, and P values resulting from analysis of variance for standardized moist-soil plant group seedling germination among and between two treatment conditions from seed bank samples taken on Richland Creek Wildlife Management Area, east-central Texas 2005.

	Moist		Flooded			
Standardized moist-soil plant group	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
annual forb	4.6	0.21	6.6	0.25	5.86	0.016
annual grass	6.6	0.26	3.3	0.23	16.41	0.001
annual vine	1.9	0.38	1.0	--	0.01	0.920
perennial forb	2.7	0.15	5.1	0.23	7.79	0.005
perennial grass	1.1	0.07	1.0	--	0.00	0.990
perennial native forb/herb	--	--	15.0	1.18	--	--
perennial shrub	1.0	--	1.0	--	0.00	1.000
	F	*P*	*F*	*P*		
	6.56	0.001	5.99	0.001		

Table 2.23 Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), standard error (SE), F, and P values resulting from analysis of variance for moist-soil managed wetland seedling germination among and between two treatment conditions from seed bank samples taken on Richland Creek Wildlife Management Area, east-central Texas 2005.

	Moist		Flooded			
Wetland	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
1	7.37	0.55	4.05	0.23	6.91	0.009
2	4.80	0.29	2.01	0.16	5.12	0.024
3	7.59	0.40	7.83	0.27	0.05	0.821
4	3.41	0.27	7.02	0.33	6.43	0.011
Triangle	3.87	0.23	2.39	0.19	1.29	0.257
Gut	4.25	0.28	5.26	0.23	0.69	0.406
DU	2.28	0.12	6.56	0.26	13.75	0.001
	F	*P*	*F*	*P*		
	8.18	0.001	2.48	0.015		

Table 2.24 Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), standard error (SE), F, and P values resulting from analysis of variance for managed and unmanaged moist-soil wetland seedling germination among and between two treatment conditions from seed bank samples taken on Richland Creek Wildlife Management Area, east-central Texas 2005.

	Managed		Unmanaged			
Moist-soil wetland type	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
Moist	6.03	0.22	3.37	0.13	17.88	0.001
Flooded	5.41	0.21	5.00	0.18	0.33	0.565
	F	*P*	*F*	*P*		
	0.99	0.321	5.22	0.022		

Table 2.25 Mean ($\bar{x}$) stem densities (i.e., seedlings per experimental dish), standard error (SE), F, and P values resulting from analysis of variance for desirable and nondesirable seedling germination among and between four time periods in managed and unmanaged moist-soil wetland from seed bank samples taken on Richland Creek Wildlife Management Area, east-central Texas 2005.

	Managed				Unmanaged					
	Desirable		Non-desirable		Desirable		Non-desirable			
Time Period	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
0-30	7.07	0.33	6.43	0.48	4.44	0.31	6.71	0.48	4.23	0.006
30-60	9.31	0.42	4.45	0.32	4.06	0.24	4.68	0.30	6.75	0.001
60-90	2.47	0.19	5.56	0.37	1.86	0.23	4.72	0.25	2.83	0.037
90-120	1.62	0.17	3.18	0.31	1.56	0.24	2.71	0.27	0.38	0.771
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*		
	13.20	0.001	5.57	0.001	1.09	0.366	3.22	0.002		

CHAPTER III

SEED YIELD PREDICTON MODELS OF FOUR COMMON MOIST-SOIL PLANT SPECIES IN NORTH-CENTRAL AND COASTAL TEXAS

INTRODUCTION

Waterfowl are affected by availability, quantity, and quality of wintering and migration habitat (Heitmeyer and Fredrickson 1981, Kaminski and Gluesin 1987, Raveling and Heitmeyer 1989, Haukos and Smith 1993), which includes not only physical space and suitable structure, but also food production during these energetically stressful periods of the annual cycle (Fredrickson and Taylor 1982, Haukos and Smith 1993, Anderson and Smith 1998, Taylor and Smith 2005). Moist-soil managed wetland habitats are considered to be effective at providing high quality wintering and migrating waterfowl foraging habitat (Low and Bellrose 1944, Fredrickson and Taylor 1982, Reinecke et al. 1989, Haukos and Smith 1993, Lane and Jensen 1999, Kaminski et al. 2003, Bowyer et al. 2005, Strader and Stinson 2005), even when other suitable non-managed habitats are available (Kaminski and Prince 1981, Fredrickson and Taylor 1982, Anderson and Smith 1999). Moist-soil management techniques typically encourage germination and growth of native, annual-seed producing plant species that provide essential nutritive value (i.e., carbohydrates, amino acids, and proteins; Loesch and Kaminski 1989, Bowyer et al. 2005) to waterfowl during winter and migration.

Some species, particularly dabbling ducks such as green-winged (*Anas crecca*) and blue-winged teal (*A. discors*), often congregate on moist-soil managed wetlands because of the high quality abundant natural foods produced through moist-soil management practices (Fredrickson and Taylor 1982, Moser et al. 1990, Haukos and Smith 1993, Anderson and Smith 1999, Strader and Stinson 2005). Moist-soil managed wetlands can be primary foraging habitats and have the potential to elevate waterfowl carrying capacity during winter, even in spatially limited habitats (Anderson and Smith 1999, Taylor and Smith 2005, Kross 2006). Moreover, when native moist-soil plant seeds are available during winter, ducks can avoid energy consuming feeding flights and concentrate feeding activities in such managed wetlands (Fredrickson and Taylor 1982, Baldassarre and Bolen 1984, Haukos and Smith 1993). By concentrating food production on managed wetlands, wintering waterfowl may remain in better body condition, elevate overwinter survival, pair earlier, arrive to breeding habitats earlier, and achieve greater reproductive success (Heitmeyer and Fredrickson 1981, Delnicki and Reinecke 1986, Hepp 1986, Haukos and Smith 1993) due to reduced energetic costs associated with foraging flights and the ability to spend more time in one place partaking in daily activities (Haukos and Smith 1993).

The overarching goal of waterfowl managers using moist-soil management techniques is to maximize production of naturally occurring moist-soil plant species so as to maximize and optimize use of these habitats by wetland dependent wildlife (Fredrickson and Taylor 1982, Moser et al. 1990, Lane and Jensen 1999, Strader and Stinson 2005, Taylor and Smith 2005). Specifically, moist-soil managed wetlands provide both migrating and wintering waterfowl foraging opportunities through production of moist-soil plant products (i.e., seeds and tubers) and aquatic invertebrates (Fredrickson and Taylor 1982, Haukos and Smith 1993, Anderson and Smtih 1999, Gray et al. 1999*a*, Lane and Jensen 1999, Strader and Stinson 2005, Taylor and Smith 2005). By means of manipulating managed wetland seed bank structure (i.e., disking, mowing, and inundation) and hydrology (via regulated drawdown and inundation) managers can influence moist-soil plant production by creating germination conditions suitable for desirable moist-soil wetland plants (Fredrickson and Taylor 1982, Reinecke et al. 1989, Lane and Jensen 1999, Strader and Stinson 2005, Taylor and Smith 2005). Such management practices should lead to improving proximate factors affecting waterfowl use of such wetland habitats (Haukos and Smith 1993, Gordon et al. 1998, Sherfy and Kirkpatrick 1999). Consequently, maximizing annual moist-soil plant seed production is typically a high management priority, whereby obtaining accurate estimates of seed production (i.e., seed yield) is desirable for waterfowl habitat evaluation (Laubhan and Fredrickson 1992, Gray et al. 1999*b*, Sherfy and Kirkpatrick 1999, Naylor et al. 2005). Typically, seed yield is estimated directly as the product of plant density and average seed mass per plant measured in quadrats extrapolated over the entire area of interest (Haukos and Smith 1993, Anderson and Smith 1998, Anderson and Smith 1999, Smith et al. 2004, Anderson 2007). However, these direct estimation techniques can be time consuming, require specialized equipment, and are often costly (Laubhan and Fredrickson 1992, Gray et al. 1999*b*, Sherfy and Kirkpatrick 1999, Anderson 2007). Consequently, indirect methods have been developed (i.e., phytomorphological and dot grid methods) to predict seed yield of desirable moist-soil plant species using regression modeling approaches (Laubhan and Fredrickson 1992, Gray et al. 1999 *b,c*, Sherfy and Kirkpatrick 1999, Anderson 2007). Such techniques also require field measurements of stem density, but typically require fewer samples and less field time to collect suitable samples to develop predictive regression models (Laubhan and Fredrickson 1992, Gray et al. 1999 *b,c*, Sherfy and Kirkpatrick 1999, Anderson 2007). These more modern indirect seed yield modeling techniques have been developed to improve model precision and accuracy, using easily obtained, parsimonious combinations of field-generated data. Laubhan and Fredrickson (1992) pioneered the conceptual framework for seed prediction modeling, where external morphological features (i.e., total plant height (TH), inflorescence height (SHH), inflorescence diameter (DI), inflorescence volume (IV), and total number of inflorescence (TSH)) are used to develop regression models predicting total seed biomass on a per unit area. Gray et al. (1999*c*) advanced the conceptual approach to this model building effort by developing the dot grid method. Rather than measuring linear morphological features of focal plant species, Gray et al. (1999*c*) collected individual plant inflorescences, placed them onto a "dot grid", and the number of dots partially or completely obscured by seeds or seed parts (see Figure 3.1) (Gray et al. 1999*b*,*c*).

Estimates of moist-soil seed production are useful to Joint Venture partners of the North American Waterfowl Management Plan (NAWMP; Canadian Wildlife Service and U.S. Fish and Wildlife Service 1986) for calculating annually variable duck-use-days (Reinecke et al. 1989, Naylor et al. 2005) and track temporal changes in wetland food abundance. Such data allow managers to better plan for habitat and foraging needs of wintering waterfowl (Naylor et al. 2005) and promote regionally suitable and important moist-soil species. However, these multiple regression models may produce biased predictions outside of the region of development and some variables are frequently subject to multicollinearity (Gray et al. 1999c). As such, several studies have emphasized the need for development of regionally-specific seed yield models, as relevant phytomorphological features may not be universal for predicting seed yield, as plant morphology and seed production may vary spatiotemporally (Reinecke et al. 1989, Mushet et al. 1992, Gray et al. 1999c).

Beyond regionality, empirical evidence indicates that local or regional-specific management practices can strongly influence germination and growth of important moist-soil plant species, whereby seed production can be highly variable within and among wetlands subjected to similar management techniques (Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Gray et al. 1999b, Anderson 2007). Regardless of region, moist-soil species such as barnyardgrass (*Echinochloa crusgalli*), wild millet (*Echinochloa walteri*), various sedges (*Cyperus* sp.), jungle rice (*E. colona*), and even cultivated rice (*Oryza sativa*) are highly productive annuals that provide abundant seeds that are desirable and nutritious for wintering waterfowl (Fredrickson and Taylor 1982, Laubhan and Fredrickson 1992, Elphick and Oring 1998, Silberhorn 1999, Fleskes et al. 2005, Anderson 2007). All are frequently common in moist-soil managed wetlands and highly desirable in wetland managed throughout the southeastern U.S., including Texas (Tiner 1993, Haukos and Smith 1997, Stutzenbaker 1999). In response to this information gap regarding regionally-specific estimates of seed production, this research was designed to (1) estimate and (2) compare seed production estimates developed using phytomorphological and dot grid methods on barnyardgrass, wild millet, jungle rice, and cultivated rice produced in moist-soil managed wetlands within two geographic areas in Texas.

STUDY AREA

This research was conducted on the Richland Creek Wildlife Management Area's (RCWMA) North Unit moist-soil managed wetlands 1-4 (Figure 1.1). The RCWMA (31º13'N, 96º11'W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The RCWMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were fully functional. Construction of moist-soil managed wetland units 5-6 began in the summer 2006 and have been functioning since November 2009.

Local climate is considered subtropical with mild winters and warm humid summers, with an average daily summer temperature of 34º C and winter temperature of 5º C, a growing season of 246 days, and average rainfall of 101.6 cm a year (NRCS

2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, and mollisol soils (NRCS 2002).

Vegetation within the South Unit (Figure 1.4) is characterized by vast bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North Unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. The typical water management strategy consists of slow drawdown (i.e., removal of water) starting late March - early April and lasting until mid August. Inundation (i.e., flooding) begins in late August and lasts throughout fall and winter, until drawdown the following spring. These management actions produced common species such as barnyardgrass, erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet, and water primrose (*Ludwigia peploides*) (Appendix A).

Big Woods and the Trinity and Pettigrew Ranch sites are located within a 25 km radius of RCWMA and also occur within the Trinity River Basin. Local climate is similar to that experienced at RCWMA. Soils on the area are predominately of the Trinity Kaufman clay which is very deep, moderately well drained, very slowly permeable soil (NRCS 2002). Land use historically was dominated by both rowcrop agriculture and livestock grazing. Both sites contain natural and constructed moist-soil managed wetlands under state (Texas Wetland Program) and federal (Wetland Reserve Program, etc.) programs used for private land wetland creation and enhancement. Management practices on these sites mirror RCWMA, in terms of drawdown and inundation regimes. Vegetation communities found in managed wetlands are dominated by pink smartweed (*Polygonum pennsylvanicum*), Walter's millet, numerous *Carex* spp., and duck potato (*Sagittaria* spp.). Unmanaged wetlands are dominated by rushes (*Juncus* spp.), sedges (*Cyperus* spp.), green ash, black willow, cattail (*Typha domingensis*), and giant cutgrass (*Zizaniopsis miliacea*) (Collins, unpublished data).

The Nature Conservancy of Texas' Mad Island Marsh Preserve occurs on the upper Texas coast in Matagorda County, Texas (28°6'N, 95°8'W) southeast of Collegeport, Texas on the eastern portion of West Matagorda Bay. The region is broad and nearly level, ranging in elevation from 20-75 m (Smeins et al.1992). Local climate consists of long hot summers with average daily temperature of 33 º C and generally warm winters with average daily temperature of 16 º C, a growing season of 295 days, and annual rainfall of 120.9 cm (NRCS 1991). Regional soils consist of dense clay subsoils and are waterlogged during winter, but may exhibit droughty characteristics during dry conditions (Smeins et al. 1992). The study area contains the east arm of Mad Island Lake and its associated freshwater and brackish marshes, surrounded by typical coastal prairie dominated uplands dominated by little bluestem (*Schizachyrium scoparium*) and brownseed paspalum (*Paspalum plicatulum*) and shrubland habitats such as the mesquite-huisache series (*Proposis glandulosa-Acacia smallii*) and the sugarberry-elm series (*Celtis laevigata/C. reticulata-Ulmus* spp.) (Conway et al. 2002, Mangham and Williams 2007).

METHODS

Phytomorphological Method

Samples for all four focal species (barnyardgrass, wild millet, jungle rice, and cultivated rice) collected to construct models using the phytomorphological technique (Laubhan and Fredrickson 1992) were obtained by randomly placing a 0.0625-m^2 quadrat in monotypic stands of focal species at each study site in August and September 2004 and 2005. Samples (barnyardgrass and wild millet) were collected from RCWMA in both years, while barnyardgrass and wild millet samples were collected from Big Woods and the Trinity and Pettigrew Ranch sites in 2005 only, and both jungle rice and cultivated rice were collected from Mad Island Marsh Preserve in 2005 only. A minimum number of 15 samples of each species were collected in each moist-soil managed wetland. The following morphological features were measured on the "average" plant within each quadrat: plant height (TH) (cm), inflorescence height (SHH) (cm), inflorescence diameter (DI) (cm), total number of inflorescences present (TSH) (*n*) (Table 3.1) (Laubhan and Fredrickson 1992, Gray et al. 1999 *b*, Sherfy and Kirkpatrick 1999). Inflorescence volume (IV) (cm^3) was calculated using the following equation $IV = \frac{\pi (DI/2)^2 SHH}{3}$ following Laubhan and Fredrickson (1992).

After field data were collected, each inflorescence within each quadrat was clipped, removed, placed into a brown paper bag, and air dried for at least two weeks at room temperature (20°C) to constant mass (g). Once dry, all seeds were threshed and measured to the nearest 0.1g (i.e., initial wet seed mass), oven dried at 50ºC for > 24 hrs, and then remeasured to a constant 0.1g (i.e., final dry seed mass). Dry seed mass was the difference between initial wet seed mass (g) and final dry seed mass (g). Other measures included in model construction were mean seed mass on each inflorescence per sample quadrat (SSHD), average mass per inflorescence (SSHD), and standardized group value (GV1). The standardixed group value (GV1) was the median number number of inflorescences present within quadrats (i.e., 2-3 inflorescences present = 2.5). Mean seed mass per inflorescence per sample frame (SSHD) was calculated by dividing total grams of seed mass by total number of inflorescences (i.e., 14 (g)/quadrat with 14 inflorescence present = 1(g)/inflorescence).

Dot Grid Method

Samples used for simple linear regression model construction using the dot grid technique (Gray et al. 1999*c*) were collected by randomly clipping inflorescences of focal moist-soil plant species (i.e., barnyardgrass, wild millet, jungle rice, and cultivated rice) at the same time as data were collected for phytomorphological method. Because the dot grid method is not a quadrat technique, samples were taken from the representative stand used during data collection for the phytomorphological method, but not within the quadrat itself. Once clipped, inflorescences were immediately placed into a plant press, where care was taken to separate inflorescence pedicels to avoid seed overlap. Samples were pressed at room temperature (20°C) for $\geq$ 7 days. Once dry, each inflorescence was overlaid on a dot grid (9 dots/cm^2) (Figure 3.1) and the number of dots partially or completely obscured by seeds or seed parts was counted. Once all dots obscured were summed, inflorescences were removed, all seeds were threshed, and they were measured to the nearest 0.1 g, oven dried at 50ºC for 24 hrs, and then remeasured to the nearest 0.1g after drying.

Data Analyses

Univariate analysis of variance (ANOVA) was used to examine differences in plant phytomorphology (e.g., total height, inflorescence height, total number of inflorescence, etc.), among sites (i.e., Richland Creek Wildlife Management Area, Big Woods, Trinity and Petigrew Ranch, and Mad Island Marsh Preserve) and between years (i.e., 2004 and 2005) for all four focal species, as permissible given year/study site restrictions. To develop species-specific models for the phytomorphological and dot grid methods, simple and multiple linear regression was used employing both the no-intercept (i.e., point of origin) and intercept option, following prior research (Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Gray et al. 1999*b,c*, Anderson 2007). Dry seed mass per plant (dependent variable (γ)) was regressed against external phytomorphology (i.e., total inflorescence height, number of inflorescences present, inflorescences volume, etc.) or number of dots obscured to predict species specific seed production. During model development, the RCWMA, Big Woods, and Trinity and Petigrew Ranch were combined as the Middle Trinity River Valley sites.

Use of the no-intercept method (i.e., point of origin) for phytomorphological model development followed Laubhan and Frederickson (1992), which forces the regression line through the origin, and allows a value of 0 for all single independent variables. This approach was used to be consistent with previous work and to provide comparisons among model structures. Use of the normal intercept option for seed yield model development using the dot grid method followed Gray et al. (1999c). Assumptions of residual, normality, and homoscedasticity were tested using the Shapiro-Wilk test and residuals were plotted against predicted values of seed mass (Myers 1990, Bowerman and O'Connell 1993). If assumptions were violated ($P < 0.05$), then outlying residuals were removed until they followed a normal distribution (Gray et al. 1999c). Eigenvalue and condition indices were used to check for collinearity if $\geq$ 2 independent variables were present in selected models (Gray et al. 1999*b*). If collinearity was present, a single independent variable was removed (Gray et al. 1999*b*). Final model selection was based upon the best combination of the following criteria: greatest adjusted coefficient of determination (R^2_{adj}), greatest predicted R^2, lowest residual mean square (S^2) and Mallow's C_p statistic (Gray et al. 1999*b*). Finally, following Anderson (2007), Akaike Information Criterion (AIC) with corrections for small sample size (AIC_c) was used to select the best model from a set of plausible models for each species using the smallest AIC_c value (Burnham and Anderson 2002).

Seed production extrapolations

To estimate seed production (i.e., kg of moist-soil plant seeds per ha), a conversion factor of g per 0.0625 m^2 x 64.74 was used to estimate kg/ha (ex. 6 g x 64.74 = 388.44 kg/ha) (Laubhan 1992). This estimate can then be extrapolated to individual moist-soil units to estimate potential seed production.

RESULTS

Phytomorphology

Initial univariate analysis of variance examining differences in barnyardgrass phytomorphology showed variation among sites in 3 characters, total height (cm) (F = 13.76, $P < 0.001$), total number of inflorescence (n) (F = 209.30, $P < 0.001$), and total seed mass (g) (F = 55.42, $P < 0.001$) (Table 3.2). Barnyardgrass plants were taller at Mad Island Marsh Preserve, but had greatest seed mass and number of inflorescences at the Trinity and Petigrew Ranch site (Table 3.2). Barnyardgrass phytomorphology varied among sites and between years for all characters such as total height (cm) (F = 8.50, $P <$ 0.001) and inflorescence height (cm) (F = 7.04, $P < 0.001$) (Table 3.3), where inflorescence volume and total seed mass were greater in 2004 at RCWMA. The Trinity and Petigrew Ranch site had the shortest plants, but the greatest number of inflorescences and total seed mass in 2005 (Table 3.3). Similarly, phytomorphology for wild millet collected at RCWMA varied between years, where inflorescence volume and total seed mass was greater in 2004, but average seed mass per inflorescence was greater in 2005 (Table 3.4). No analyses were performed to examine phytomorphology variability in either jungle rice and cultivated rice as both were collected from Mad Island Marsh Preserve in 2005 only (Table 3.5).

Seed yield models: phytomorphological method

Overall, residuals were normally distributed ($P > 0.05$). Regression models were constructed for all 4 focal species containing all or a combination of plant height, total number of inflorescences, inflorescence volume, inflorescence height, and average inflorescence mass for both normal linear regression models and point of origin models. Inflorescence diameter and inflorescence volume were positively correlated (r = 0.86, $P < 0.001$) for all species and models. Therefore, inflorescence volume replaced inflorescence diameter in all models. Mallow's C_p statistic was always approximately equal to the number of parameters in models for both model structure sets. Collinearity diagnostics were within acceptable limits for all regression analyses, signifying no serious linear dependencies for analyses performed using either normal linear regression or point of origin regression (Tables 3.6 – 3.15). Both simple linear and point of origin regression analyses were successful in developing valid seed yield production models for all 4 focal species, where models explained 52-98% of the variation in seed biomass, depending upon species and variable inclusion (Table 3.16).

Barnyardgrass

For the collective Middle Trinity River Valley sites total number of inflorescences alone explained 28% of the variation in barnyardgrass seed biomass ($F = 64.41$; 1,167 df; $P < 0.001$; $R^2 = 0.28$) using normal linear regression. The final normal linear regression model combined total number of inflorescences, average inflorescence mass, and plant height ($F = 60.41$; 3,167 df; $P < 0.001$; $R^2 = 0.52$) to explain 52% of the variation in barnyardgrass biomass (Figure 3.2, Table 3.16, 3.17). Using point of origin regression, total number of inflorescences alone explained 82% of the variation in barnyardgrass seed biomass ($F = 791.81$; 1,167 df; $P < 0.001$; $R^2 = 0.82$). The final point of origin regression model combined total number of inflorescences, plant height, and average inflorescence mass ($F = 292.01$; 3,167 df; $P < 0.001$; $R^2 = 0.90$) (Table 3.16) to explain

90% of the variation of barnyardgrass seed biomass on collective Middle Trinity River Valley sites (Figure 3.3, Table 3.18). To verify these models using AIC, a total of 31 candidate models, each model was built using both normal linear regression and point of origin regression for barnyardgrass seed yield, where both approaches produced identical plausible additive models ($AIC_w = 0.69$) of plant height, total number of inflorescences, and average inflorescence mass (Table 3.19, Table 3.20).

For barnyardgrass from the Mad Island Marsh Preserve site, total number of inflorescences alone explained 74% of the variation in barnyardgrass seed biomass (F = 86.77; 1,28 df; $P < 0.001$; $R^2 = 0.74$) using normal linear regression. The final normal linear regression model combined total number of inflorescences and average inflorescence mass (F = 128.27; 2,28 df; $P < 0.001$; $R^2 = 0.93$) (Figure 3.4, Table 3.21) to explain 93% (Table 3.16) of the variation in barnyardgrass seed biomass. Using point of origin regression, total number of inflorescences alone explained 89% of the variation in barnyardgrass seed biomass (F = 271.83; 1,28 df; $P < 0.001$; $R^2 = 0.89$). The final point of origin regression model combined total number of inflorescences, plant height, and average inflorescence mass (F = 557.6; 2,28 df; $P < 0.001$; $R^2 = 0.98$) to explain 98% (Table 3.16) of the variation of barnyardgrass seed biomass at the Mad Island Marsh Preserve (Figure 3.5, Table 3.22). To verify these models using AIC, a total of 31 candidate models, each model was built using both normal linear regression and point of origin regression for barnyardgrass seed yield at the Mad Island Marsh Preserve. Both approaches produced identical plausible additive models. For models developed using simple linear regression, the additive model of total number of inflorescences and average inflorescence mass was the best ($AIC_w = 0.49$) (Table 3.23), and the additive model of plant height, total number of inflorescences and average inflorescence mass was the best ($AIC_w = 0.82$) for point of origin regression (Table 3.24).

Wild millet

For wild millet at the collective Middle Trinity River sites, total number of inflorescences alone explained 47% of the variation in wild millet seed biomass (F = 65.02; 1, 75 df; $P < 0.001$; $R^2 = 0.47$) using normal linear regression. The final normal linear regression model combined total number of inflorescences, plant height, and inflorescence volume (F = 31.19; 3, 75 df; $P < 0.001$; $R^2 = 0.56$) (Figure 3.6, Table 3.25) to explain 56% (Table 3.16) of the variation in wild millet seed biomass. Using point of origin regression, total number of inflorescences alone explained 86% of the variation in wild millet seed biomass (F = 489.43; 1, 75 df; $P < 0.001$; $R^2 = 0.86$). The final point of origin model combined total number of inflorescences and inflorescence volume (F = 258.30; 2, 75 df; $P < 0.001$; $R^2 = 0.87$) to explain 87% (Table 3.16) of the variation in wild millet seed biomass at the collective Middle Trinity River sites (Figure 3.7, Table 3.26). To verify these models using AIC, a total of 31 candidate models, each, were built using both normal linear regression and point of origin regression for wild millet seed biomass on the collective Middle Trinity River sites. For models developed using simple linear regression, an additive model of total number of inflorescences and inflorescence volume was best ($AIC_w = 0.58$) (Table 3.27). For models developed using point of origin, an additive model of the total number of inflorescences and inflorescence volume was best ($AIC_w = 0.57$) (Table 3.28).

Jungle rice

At the Mad Island Marsh Preserve, the total number of inflorescences alone explained 27% of the variation in jungle rice seed biomass (F = 8.68; 1, 24 df; P < 0.001; R^2 = 0.27) using normal linear regression. The final normal linear regression model combined total number of inflorescences, average inflorescence mass, inflorescence volume, and plant height (F = 61.39; 1, 24 df; P < 0.001; R^2 = 0.92) (Figure 3.8, Table 3.29) to explain 92% (Table 3.16) of the variation in jungle rice seed biomass. Using point of origin regression, the total number of inflorescences alone explained 85% of the variation in jungle rice seed biomass (F = 136.50; 1, 24 df; P < 0.001; R^2 = 0.85). The final point of origin model combined total number of inflorescences, plant height, and average inflorescence mass (F = 209.04; 1, 24 df; P < 0.001; R^2 = 0.96) (Figure 3.9, Table 3.30) to explain 96% (Table 3.16) of the variation in jungle rice seed biomass at the Mad Island Marsh Preserve. To verify these models using AIC, a total of 31 candidate models, each, were built using both normal linear regression and point of origin regression for jungle rice seed biomass at the Mad Island Marsh Preserve. For models developed using simple linear regression, an additive model of the total number of inflorescences and average inflorescence mass was best (AIC_w = 0.54) (Table 3.31). For models developed using point of origin, an additive model of plant height, total number of inflorescences, and average inflorescence mass was best (AIC_w = 0.54) (Table 3.32).

Cultivated rice

At the Mad Island Marsh Preserve, total number of inflorescences alone explained 29% of the variation in cultivated rice seed biomass (F = 13.44; 1, 33 df; P < 0.001; R^2 = 0.29) using normal linear regression. The final normal linear regression model combined total number of inflorescences and average inflorescence mass (F = 291.20, 1, 33 df; P < 0.001; R^2 = 0.94) (Figure 3.10, Table 3.33) to explain 94% (Table 3.16) of the variation in cultivated rice seed biomass at the Mad Island Marsh Preserve. Using point of origin regression, the total number of inflorescences alone explained 90% of the variation in cultivated rice seed biomass (F = 315.35; 1, 33 df; P < 0.001; R^2 = 0.90). The final point of origin model combined total number of inflorescences, plant height, inflorescence height and average inflorescence mass (F = 514.88; 1, 33 df; P < 0.001; R^2 = 0.98) (Figure 3.11, Table 3.34) to explain 98% (Table 3.16) of the variation in cultivated rice a the Mad Island Marsh Preserve. To verify these models using AIC, a total of 31 candidate models, each, were built using both normal linear regression and point of origin regression for cultivated rice seed biomass at the Mad Island Marsh Preserve. For models developed using simple linear regression, an additive model of the total number of inflorescence and average inflorescence mass was best (AIC_w = 0.72) (Table 3.35). For models developed using point of origin, an additive model of plant height, inflorescence height, total number of inflorescences, and average inflorescence mass was best (AIC_w = 0.56) (Table 3.36).

Seed yield models: dot grid method

Barnyardgrass

For the collective Middle Trinity River sites, the number of dots partially or completely obscured by barnyardgrass seeds or seed parts explained 47% of the variation in barnyardgrass seed biomass (F = 120.15; 1,134 df; P < 0.001; R^2 = 0.47) (Figure 3.12, Table 3.37), using simple linear regression. Using point of origin regression, the number of dots partially or completely obscured by barnyardgrass seeds or seed parts explained 93% of the variation in barnyardgrass seed biomass (F = 1791.33; 1, 134 df; P < 0.001; R^2 = 0.93) (Figure 3.13, Table 3.37). For barnyardgrass collected at the Mad Island Marsh Preserve, the number of dots partially or completely obscured by barnyardgrass seeds or seed parts explained 18% of the variation in barnyardgrass seed biomass (F = 6.48; 1, 30 df; P < 0.016; R^2 = 0.18) (Figure 3.14, Table 3.37) using simple linear regression. Using point of origin regression, the number of dots partially or completely obscured by barnyardgrass seeds or seed parts explained 85% of the of the variation in barnyardgrass seed biomass (F = 174.54; 1, 30 df; P < 0.001; R^2 = 0.85) (Figure 3.15, Table 3.37).

Wild millet

For the collective Middle Trinity River sites, the number of dots partially or completely obscured by wild millet seeds or seed parts, explained 74% of the variation in wild millet seed biomass (F = 110.47; 1, 39 df; P < 0.001; R^2 = 0.74) (Figure 3.16, Table 3.37) using simple linear regression. Using point of origin regression, the number of dots partially or completely obscured by wild millet seeds or seed parts explained 97% of the variation in wild millet seed biomass (*F* = 1382.14; 1, 39 df; *P* < 0.001; R^2 = 0.97) (Figure 3.17, Table 3.37).

Jungle rice

For jungle rice samples collected at the Mad Island Marsh Preserve, the number of dots partially or completely obscured by jungle rice seeds or seed parts explained only 1% of the variation in jungle rice seed biomass (*F* = 0.30; 1, 20 df; *P* = 0.588; R^2 = 0.01) (Figure 3.18, Table 3.37) using simple linear regression. However, point of origin regression performed much better, where the number of dots partially or completely obscured by jungle rice seeds or seed parts dots explained 90% of the of the variation in jungle rice seed biomass (*F* = 181.22; 1, 20 df; *P* < 0.001; R^2 = 0.90) (Figure 3.19, Table 3.37).

Cultivated rice

For cultivated rice samples collected at the Mad Island Marsh Preserve, the number of dots partially or completely obscured by cultivated rice seeds or seed parts explained 13% of the variation in cultivated rice seed biomass (*F* = 3.14, 1, 21 df; *P* < 0.091; R^2 = 0.13) (Figure 3.20, Table 3.37) using simple linear regression. However, point of origin regression performed considerably better, where number of dots partially or completely obscured by cultivated rice seeds or seed parts dots explained 95% of the of the variation in cultivated rice seed biomass (*F* = 470.94, 1, 21 df; *P* < 0.001; R^2 = 0.95) (Figure 3.21, Table 3.37).

Seed production extrapolations

Barnyardgrass

For the collective Middle Trinity River sites barnyardgrass production for both years combined was 4.34 g/inflorescence, which when extrapolated, was estimated to be 281 kg/ha (Table 3.38). Production within each year was variable, where in 2004, barnyardgrass seed production was estimated to be 320 kg/ha ($\bar{x}$ = 4.95 g/inflorescence), and in 2005, barnyardgrass seed production was estimated to be 241 kg/ha ($\bar{x}$ = 3.73 g/inflorescence) (Table 3.39). During 2005 at the Mad Island Marsh Preserve, barnyardgrass production was less than the Middle Trinity River sites; an estimated 202 kg/ha ($\bar{x}$ = 3.13 g/inflorescence) (Table 3.39).

Wild millet

For both years combined at RCWMA, wild millet production was 6.64 g/inflorescence, which when extrapolated, was estimated to be producing 430 kg/ha (Table 3.38). Production within each year was variable, where in 2004, wild millet seed production was estimated be to 502 kg/ha ($\bar{x}$ = 7.76 g/inflorescence), but in 2005, wild millet seed production was estimated to be 267 kg/ha ($\bar{x}$ = 4.13 g/inflorescence) (Table 3.39).

Jungle rice and cultivated rice

At the Mad Island Marsh Preserve, jungle rice production was 4.69 g/inflorescence, which when extrapolated was estimated to be 304 kg/ha of jungle rice seed (Table 3.38). Cultivated rice production was tremendous, where an estimated 3,677 kg/ha ($\bar{x}$ = 56.8 g/inflorescence) was produced at the Mad Island Marsh Preserve in 2005 (Table 3.38).

DISCUSSION

Seed yield prediction models developed during this study were consistent with other research (Gray et al. 1999bc, Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Anderson 2007), where both the phytomorphological and dot grid techniques satisfactorily explained much of the variation in seed biomass of focal plant species. The primary exception was for cultivated rice seed yield models developed using the phytomorphological technique in which normal linear regression models performed quite poorly, and point of origin models performed nearly perfectly. Such dramatic inconsistency between model approaches was the exception during this study, although point of origin regression models tended to perform better for all focal species. This approach forces regression lines through a zero intercept, preventing intercept estimation during model development. Such techniques focus upon measured variables, and prevent entry of unknown sources of variation as permitted by intercept estimation in normal linear regression. Although variance explanation tended to be variable depending upon regression technique used, there was general concordance in variable inclusion, regardless of where normal linear regression point of origin model was used. As such, either regression model development procedure should work in most instances, particularly when attempting to identify relevant phytomorphological features for most focal moist-soil species of interest.

Laubhan and Fredrickson (1992) found plant height and volume explained 88% of barnyardgrass seed mass, slightly more parsimonious than the three variable (i.e., total height, inflorescence height, and average mass per inflorescence) model for the Middle

Trinity River sites. However, model success was better with point of origin models, where 90% of the variation was explained by these three variables. The Mad Island Marsh Preserve model for barnyardgrass performed better, and was also a two variable model that included inflorescence height and average mass per inflorescence and explained 93% of the variation using linear regression. Gray et al. (1999b), using multiple linear regression analyses on phytomorphology found that plant height, volume, and pedicel number explained 95% of model variation for barnyardgrass. Although these studies produced slightly different models than the current study, they are perhaps more similar than first glance would indicate as inflorescence volume is correlated with other inflorescence measures. However, such variability among models and in phytomorphology as a whole (see Table 3.2) for this focal species highlights the previous call for regional and site specific predictive seed yield model development (see Laubhan and Frederickson 1992, Gray et al. 1999b).

Anderson (2007) examined wild millet seed production using predetermined variables, without a stepwise approach for model development. This approach regressed plant height, volume, pedicel numbers, and impoundments and found that these variables explained 77% of wild millet seed biomass, while another model showed plant height, inflorescence volume, and pedicel number explained 76% of seed biomass variation. Both models accounted for less seed biomass variance than the best point of origin models developed in this study for both barnyardgrass and wild millet. Moreover, pedicel number was never an included variable in any model for any focal species in this study.

Gray et al. (2009) examined moist-soil seed heads utilized desktop and portable scanners using estimated seed-head area to estimate production. They found that their models explained significant variation 87-98% in seed production. Specifically for barnyard grass and wild millet 97% and 98% of the variation was explained using the scanners to estimate production. Nonetheless, it seems that processing time was not much greater than taking phytomorphological measurements in the field. They estimated that processing time average of 15 – 45 seconds across species. However, wild millet was nearly 2 minutes/plant for the portable scanner. Our field collection took on average a minute per plot. This consisted of taking morphological measurements, clipping seed heads, and moving onto the next plot.

Inconsistency in variable inclusion (see Laubhan and Fredrickson 1992, Gray et al. 1999b, Anderson 2007) among studies provides evidence of regional variability in plant phytomorphology, perhaps due to variable hydrological or management regimes, genetic variation, soil conditions, or growing season duration. Seed production apparently varies widely within and among species and even localized variation within impoundments (i.e., moist-soil wetlands, units, etc.) might provide local sources of variation (Gray et al. 1999bc, Laubhan and Fredrickson 1992, Sherfy and Kirkpatrick 1999, Anderson 2007). Accounting for both local and regional variation within species may be difficult to capture without intensive sampling throughout a given study area and region (see Laubhan and Fredrickson 1992, Gray et al. 1999, Naylor et al. 2002). However, if samples are collected from representative stands of focal species, regardless of moist-soil management strategies, seed yield models should reflect local and/or regional conditions and water management approaches.

Beyond models developed using the phytomorphological technique, the Gray et al. (1999c) dot grid technique also performed well for the focal species in this study. Gray et al. (1999c) reported seed biomass variance explanation of 91-96% for five moist-soil species, where the number of barnyardgrass seeds or seed parts obscuring dots explained 95% of seed biomass variance. Anderson (2007) also evaluated the dot grid approach, and reported an 85% barnyardgrass seed biomass variance explanation. In this study, the dot grid models developed for barnyardgrass performed similarly - 86% variance explanation in seed biomass using point of origin, but only 47% of seed biomass variance using normal linear regression, less than half of the model explanation for barnyardgrass in Gray et al. (1999c). In the current study, considerably fewer samples were used than Gray et al. (1999c), which may account for some of the poorer observed performance. However, it remains unclear as to the impact of local and regional variation in phytomorphology has on development of seed prediction models using this dot grid method.

Previous research has documented tremendous variation in moist-soil seed production, depending upon species, geographic location, local climatic conditions, and local hydrology and hydrologic management regimes (Moser et al. 1990, Brock et al. 1994, Naylor et al. 2002, Bowyer et al. 2005, Reinecke and Hartke 2005). For example, in the California Central Valley, Naylor (2002) reported that seed biomass ranged from 200-586 kg/ha for barnyardgrass, swamp timothy (*Cripsis schenoides*), smartweed

(*Polygonum* spp.), sprangletop, spikerush (*Eleocharis* spp.), and bulrush (*Scirpus* spp.). Similarly, seed biomass estimates in Mississippi ranged from 331-1048 kg/ha ($\bar{x}$ = 603 kg/ha; Reinecke and Hartke 2005), while Bowyer et al. (2005) estimated seed production on Chautauqua NWR, Illinois to range between 329-1231 kg/ha, speculating that variation in seed biomass production was influenced by drawdown timing and duration. Haukos and Smith (1993) estimated using 5 species commonly managed for in playas averaged 590 kg/ha during their research and stated that this was a conservative estimate due to the exclusion of invertebrates and other plant seeds available. In the current study, barnyardgrass and wild millet production on the collective Middle Trinity River sites ranged from 241-320 and 267-520 kg/ha, respectively, while barnyardgrass and jungle rice were estimated to be 202 and 304 kg/ha respectively, at the Mad Island Marsh Preserve. Individually, each of these focal species produced considerably less seed than in other regions. However collectively, 500-800 kg/ha of focal species seed production was estimated to be produced, much more comparable to other studies (Naylor et al. 2002, Bowyer et al. 2005, Reinecke and Hartke 2005). Futhermore these could be considered conservative estimates, as not all species present were included in these production estimates. Kross et al. (2008*a*) reported that different methods and spatial scales of sampling, plant composition, and environments confound any comparisons with previous work especially if estimates were site-specific and only obtained by harvesting seeds from plant inflorescences (Low and Bellrose 1944, Haukos and Smith 1993, Bowyer et al. 2005). The reasoning was that harvesting inflorescence only represents food available to waterfowl if seeds mature simultaneously within species. Sampling is one time to account for different species phonologies, and seeds survive between sampling and waterfowl use (Reinecke and Hartke 2005). Kross et al. (2008 *a*) surveyed on a large scale and found units ranged from 71 kg/ha to 2,332 kg/ha which would indicate if regional estimates are needed, sampling across the region needs to occur to precisely estimate a mean seed production model to better help inform management practices. For example, Stafford et al. (2011) collected samples throughout Illinois Department of Natural Resource sites and in general exceeded the typical value used for conservation planning by the associated Joint Ventures (JV's). They suggested that despite annual and site-specific variation in production their estimates be incorporated in regional conservation plans but should only be applied to the southern portion of the JV, indicating geographic variability is prevalent and needs to be addressed on a large scale.

Beyond geographic variability in seed production, previous work has implicated wetland age as a factor influencing seed biomass production (Craft et al. 1999). Young moist-soil managed wetlands having more open nutrient cycles, increasing biomass accumulation during the early to middle stages instead of later stages in ecosystem development. Craft et al. (1999) reported that once early stage wetland plants (i.e., annual seed producing wetland plants) become established, biomass accumulation peaks (usually 1-3 year) during the first decade. For example, seed production estimates for the focal species at RCWMA, although comparable to other studies, may be less than potential production as this work was conducted after the first full year of moist-soil management was being executed on these newly constructed wetlands. Although most moist-soil plant communities are typically early seral stages dominated by annual grasses and sedges (van der Valk 1981) that result in high seed production (Reid et al. 1989) during early successional stages (Fredrickson and Taylor 1982), moist-soil managed wetlands often reach peak annual plant species production at age 4 and then decline in production of moist-soil annuals and switch to perennial species (Fredrickson and Taylor 1982, Reid et al. 1989). At RCWMA, moist-soil managed wetlands were not fully functional until late 2003, whereby seed production had not reached maximum capacity during the temporal window in which seed biomass data were collected (2004 and 2005) in year 2 and 3. Given previous research findings and knowing the production of the moist-soil managed wetlands at years 2 and 3, RCWMA managers will be better able to make informed management decisions on when drawdown should occur to set the plant community back to an early successional stage.

Beyond (or in conjunction with) age, local inundation/drawdown regimes will drive seed production (see Bowyer et al. 2005), particularly given the focal species response(s) to this type of hydrological management. For example, there was considerable variation in biomass estimates between 2004 and 2005 at RCWMA, where in 2004, wild millet was estimated to produce 520 kg/ha, but in 2005, production dropped to 267 kg/ha. Barnyard grass on Middle Trinity River sites also showed similar decreased production between years going from 320kg/ha to 241kg/ha, jungle rice and commercial rice only had one year of data so comparison between years was not possible. If wetland age was the driving factor in seed production, as related to wetland maturation, then seed production should have increased for both wild millet and barnyard grass between 2004 and 2005. However, during 2005, surface water was present throughout the growing season, in contrast to 2004, when moist-soil managed wetlands were subjected to traditional spring drawdown. Clearly, interannual variation in seed production is related to a complex combination of managed wetland age, drawdown technique, timing, and completeness.

Fredrickson and Taylor (1982) suggest that a slow, mid-season drawdown should promote greatest seed production in moist-soil managed wetlands. Although some plant species respond well to shallow flooding (2-5 cm) after attaining 10-15 cm, complete submergence for longer than 2-3 days can negatively impact growth and seed production of valuable waterfowl seeds such as millets, barnyardgasses, and smartweeds (van der Valk and Davis 1978, Fredrickson and Taylor 1982, Haukos 1991, Haukos and Smith 1993). As such, continual inundation throughout the growing season (as observed in 2005), will stunt and greatly reduce seed production in managed wetlands. If the proper drawdown had occurred in 2005, seed production should have been equal to or greater than the 2004 growing season due to (a) a real expansion of these species within moist-soil managed wetlands and (b) an additional year of age of the moist-soil managed wetlands.

Welling et al. (1998) found that during the first year of drawdown, emergent species were present along the height gradient; implying densities of seedlings were greatest near any shoreline that was present. Subsequent dispersal was determined by water currents and accumulation of these seeds occurred as water was drawdown. If water is not taken off a moist-soil wetland, potential impacts to seedling dispersal and growth are evident due to the influence surface water presence. Especially if water depth is too great for germination of desired moist-soil plant species as well as continual presence of water will influence how, what, and when species will germinate. Future efforts should focus upon drawdown experimentation so as to directly evaluate impacts upon seed production in moist-soil managed wetlands.

Cultivated rice planted on Mad Island Marsh Preserve was the Presidio variety, a cross between Jefferson and Maybelle varieties, that is known to have ratoon crop potential superior to most other varieties (McClung and Turner 2004). For example, the Presidio variety will produce an average of 3470 kg/ac first cut and then half as much as a ratoon cut (1369 kg/ac)(McClung 2003). Because this is a relatively new variety, variation in production, both in first and ratoon cuts, needs to be examined further, particularly if landowners want to manage wintering waterfowl habitats on these production fields. According to current industry standards, the cultivated rice production models grossly overestimated biomass, which might explain why our normal regression and point of origin models differed widely. An issue with any model validation is sample size, which should be improved to limit model variation and improve yield prediction strength.

Waste grains are typically readily available to wetland dependent species, but maximum field production should not be used as a gauge of available waste grains. For example, Stafford et al. (2005, 2006) sampled fields in the Mississippi Alluvial Valley (MAV) and reported waste rice availability averaged 471 kg/ha, where Manley (2004) reported that rice throughout the U.S. ranged between 344-491 kg/ha available after harvest. However, some suggest both quality and quantity diminish rapidly after harvest, really leaving very little available for wintering and migrating waterfowl (Miller and Wylie 1996, Manley 2004), as harvest timing will vary locally and regionally. Along this line of logic, Greer et al. (2009) contrasted these studies and suggested that a maximum of 52 kg/ha of rice was really available to waterfowl. They suggested that the Lower Mississippi Valley Joint Venture (LMVJV) reduce their estimated carrying capacity models accordingly. Waste grain was not estimated in this study, but future work, particularly with these new varieties, should lead future researchers to investigate how much waste grain is available to wintering waterfowl.

Jungle rice is one of 20 species of barnyardgrass in the *Echinochloa* genus, but there is little information on its production or value as waterfowl forage (Forsyth 1965, Wongsriphuek et al. 2008.). In its native India, jungle rice is a common weed of direct seeded rice fields and competes directly with cultivated rice (Dubey 2004). However, this was not observed in this study, where jungle rice was primarily found along the fringes of cultivated rice fields and never attained particularly great dominance nor abundance in any sampled field. Although seed production per plant (9,000-42,372 seeds per plant) can be tremendous, it varies due to growing conditions (Dubey 2004). However, such seed production on a per-plant basis would result in seed production estimates much greater than observed at the Mad Island Marsh Preserve.

Harmon et al. (1960) estimated 39 kg/ha of moist-soil plant seeds present in Louisiana rice fields after fall harvest and Reinecke et al. (1989) reported 12-37 kg/ha of moist-soil plant seeds in Arkansas rice fields. While these numbers are lower than what the jungle rice production models indicate, they could be useful to use since the models predict yield and not what is available. Reinecke et al. (1989) considered 450kg/ha a reasonable estimate for many moist-soil plant species and if this is the case jungle rice would fall well with these bounds. However, the variability in seed production due to environmental conditions could be a reason for its production on the Mad Island Marsh Preserve. The fact that the samples were not taken randomly rather from identified monotypic stands within a field could create a bias high. Jungle rice production is likely influenced by the agricultural practices of the region as well as the hot dry summer typically experienced in coastal Texas. Further investigation is needed as rice production on the Texas coast continues to decline, fields are left fallow, and this species possibly establishes itself as one of the dominant species in fallow fields. Currently, Farm Bill programs such as the Conservation and Wetland Reserve Programs offered through the Natural Resource Conservation Service can provide private landowners with cost-share opportunities that result in restored or managed wetlands that can produce greater waterbird diversity as well as production (Ratti et al. 2001, Kaminski et al. 2006., Kross et al. 2008*b*).

Management Implications

Laubhan (1992) suggested that for estimating seed production the phytomorphological technique accounts for the variation resulting from different environmental conditions and management practices as well as differences in the amount of seed produced by various plant species. This allows resource managers to make quick and reliable estimates of seed production. Although on-site information must be collected, the amount of field time required is minimal (i.e., about 1 min per sample); sampling normally is accomplished on an area within a few days. Estimates of seed production derived with this technique are used, in combination with other available information, to determine the potential number of waterfowl use-days available and to evaluate the effects of various management strategies on a particular site (Laubhan 1992). Gray et al. (1999*b*) postulated that the dot grid method is an easy and efficient technique to estimate seed yield of moist-soil plants, because the phytomorphological method could be tedious, and the use of multiple regression models unnecessarily complicated. These types of models can be less accurate and precise in such yield estimates. However, they suggested that researchers in different regional locations develop models to properly choose and utilize model selection to best fit their needs.

While the accuracy and precision of the dot grid method are adequate at predicting seed production, the phytomorphological method developed by Laubhan and Fredrickson (1992) is more than suitable because of its relative data collection ease. This technique also produces accurate and precise regression models to accurately estimate temporal and spatial changes in seed production. This will permit waterfowl managers to independently estimate seed production in individual moist-soil managed wetlands and evaluate the impacts of management practices on seed production of individual plant species temporally and spatially. During the course of this study other techniques have been published (Naylor et al. 2002, Gray et al. 2009), emphasizing to waterfowl managers the need to explore all techniques available.

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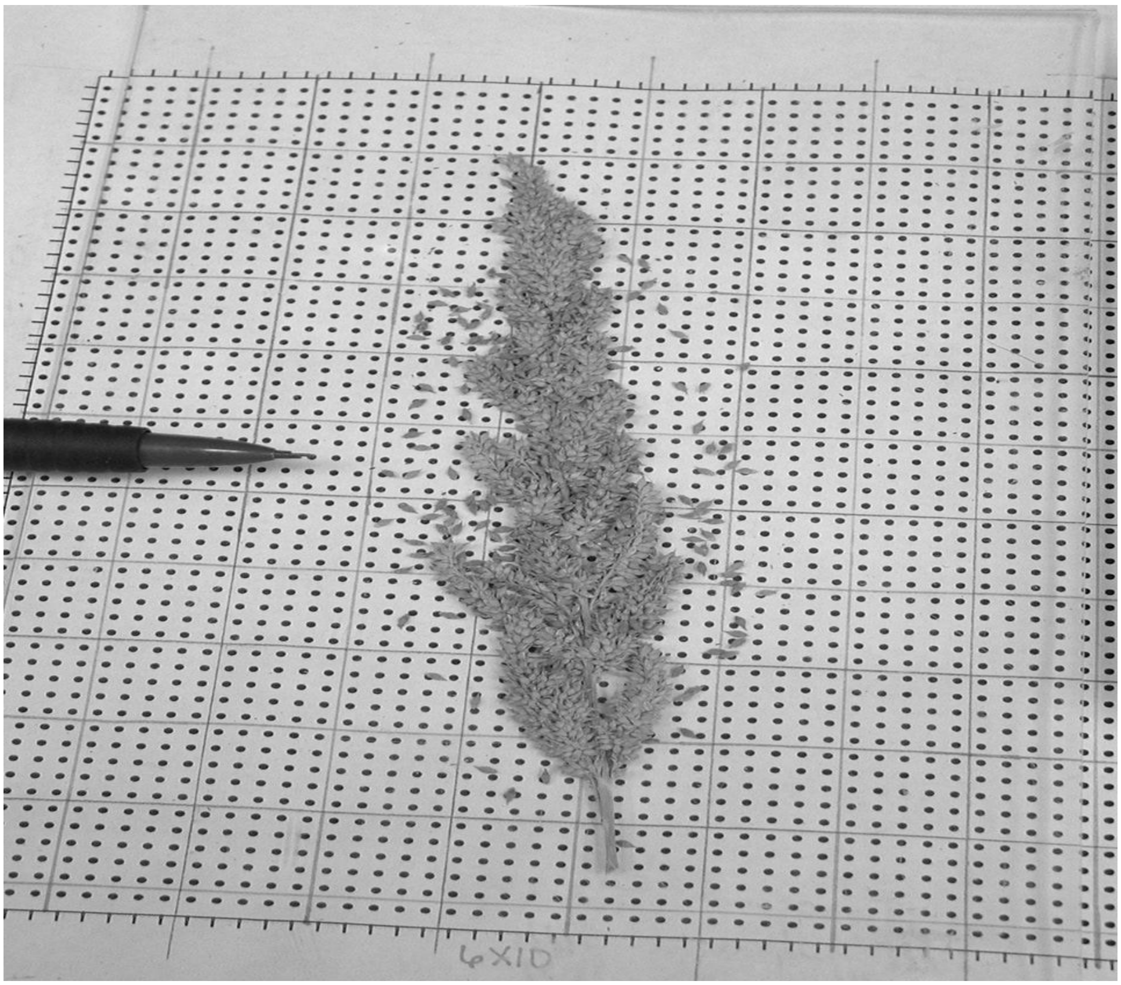

Figure 3.1. Example dot grid (9 dots/cm²) used to develop regression equations to estimate moist-soil plant biomass on the Middle Trinity River sites and Mad Island Nature Preserve located in east-central and coastal Texas 2004 and 2005.

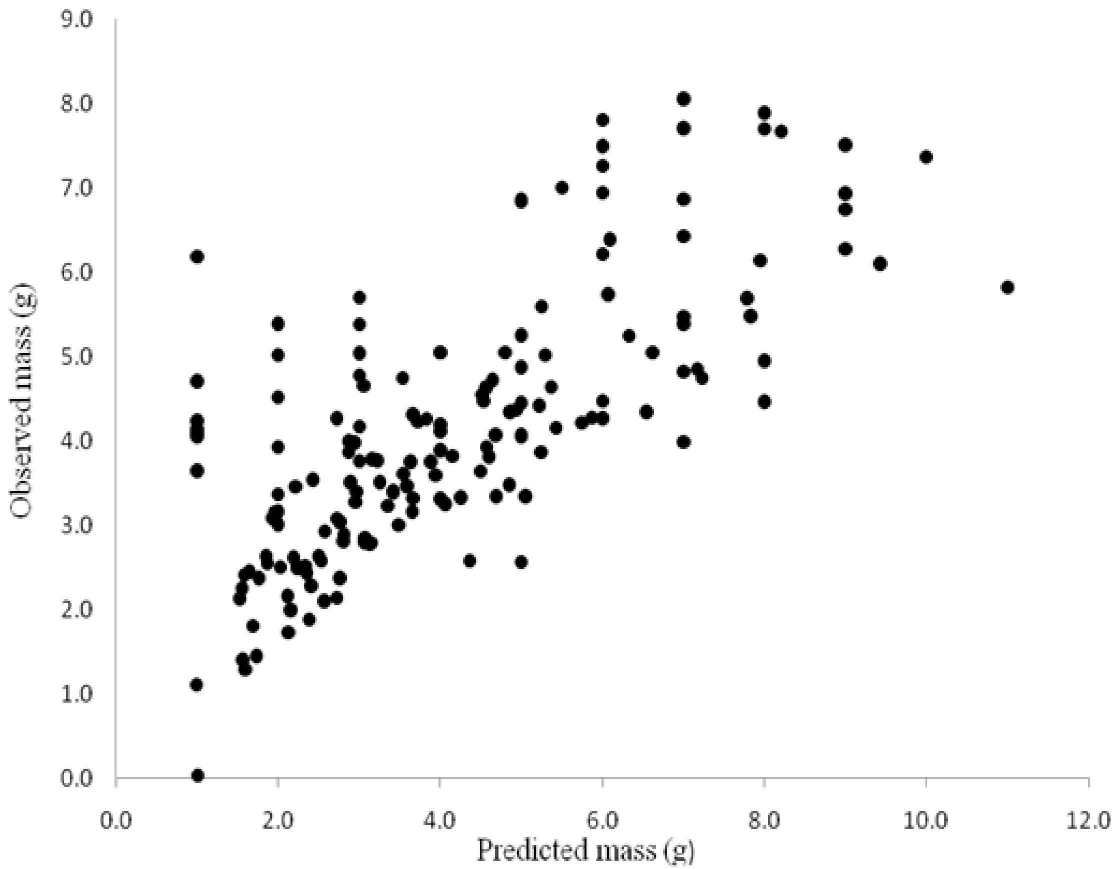

Figure 3.2. Scatterplot of observed and predicted barnyardgrass seedbiomass resulting from stepwise multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from barnyardgrass plants collected at Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Pettigrew Ranch (Freestone County, Texas) August 2004 and 2005.

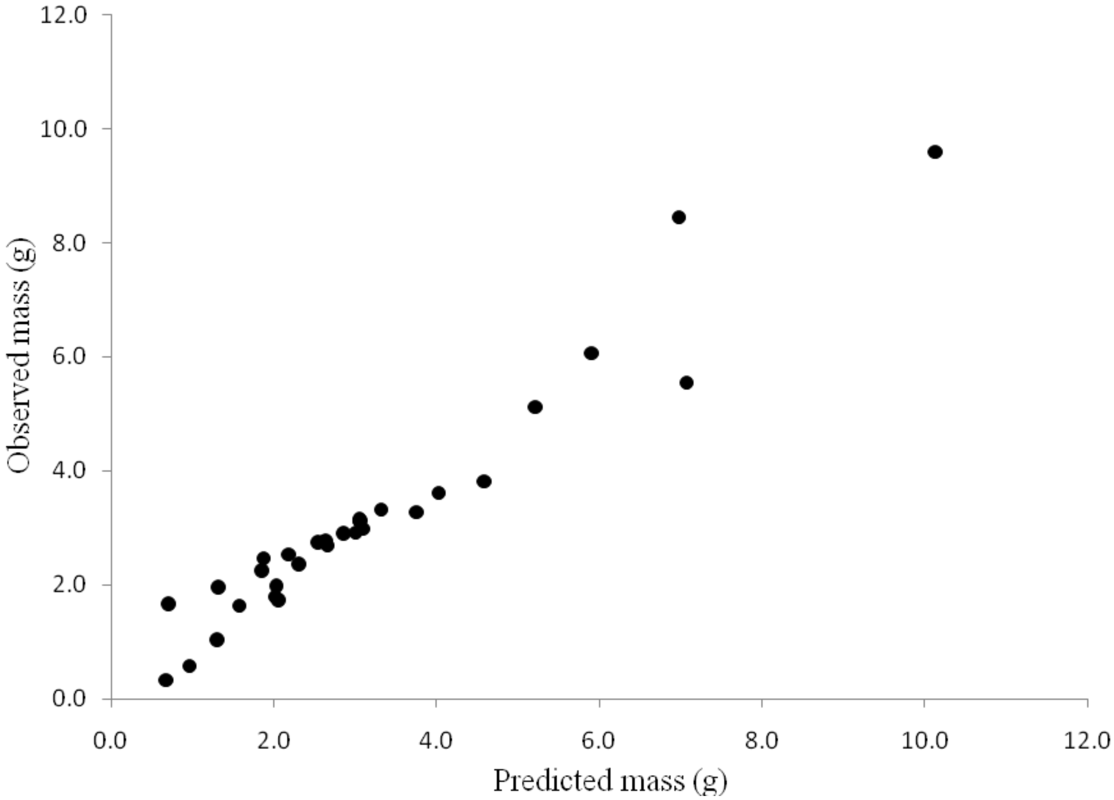

Figure 3.3. Scatterplot of observed and predicted barnyardgrass seedbiomass resulting from stepwise multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from barnyardgrass plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

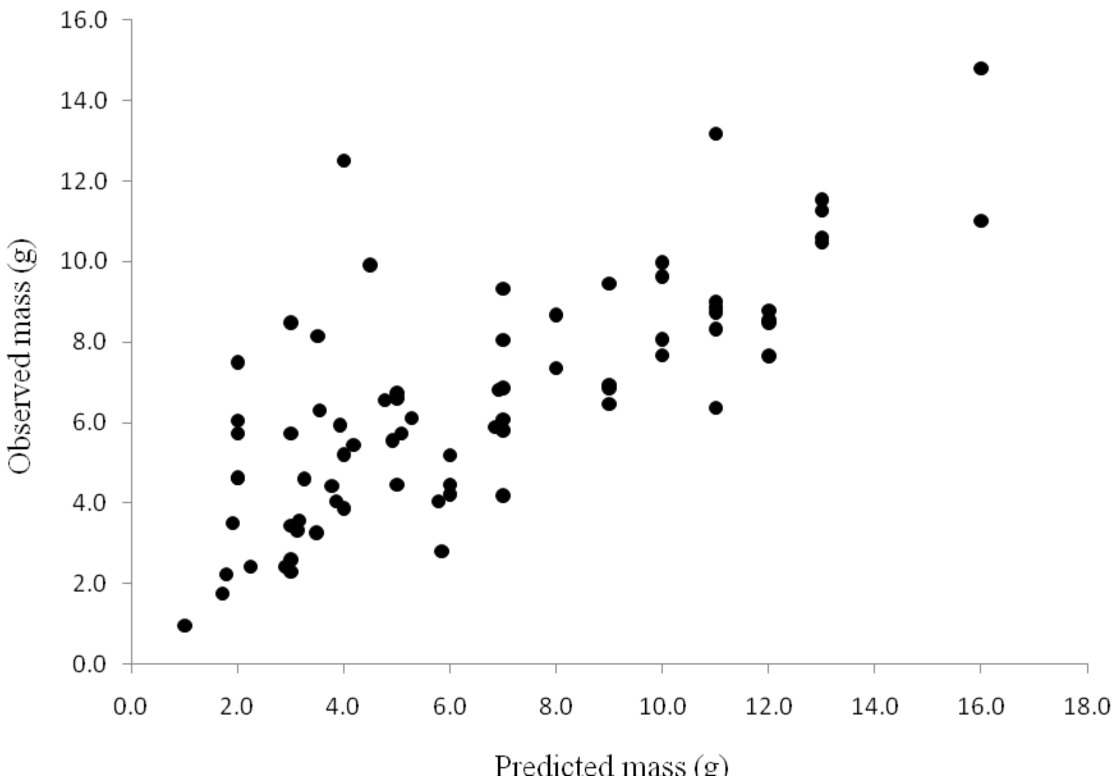

Figure 3.4. Scatterplot of observed and predicted wild millet seedbiomass resulting from stepwise multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from wild millet plants collected at Richland Creek Wildlife Management Area (Freestone County, Texas) August 2004 and 2005.

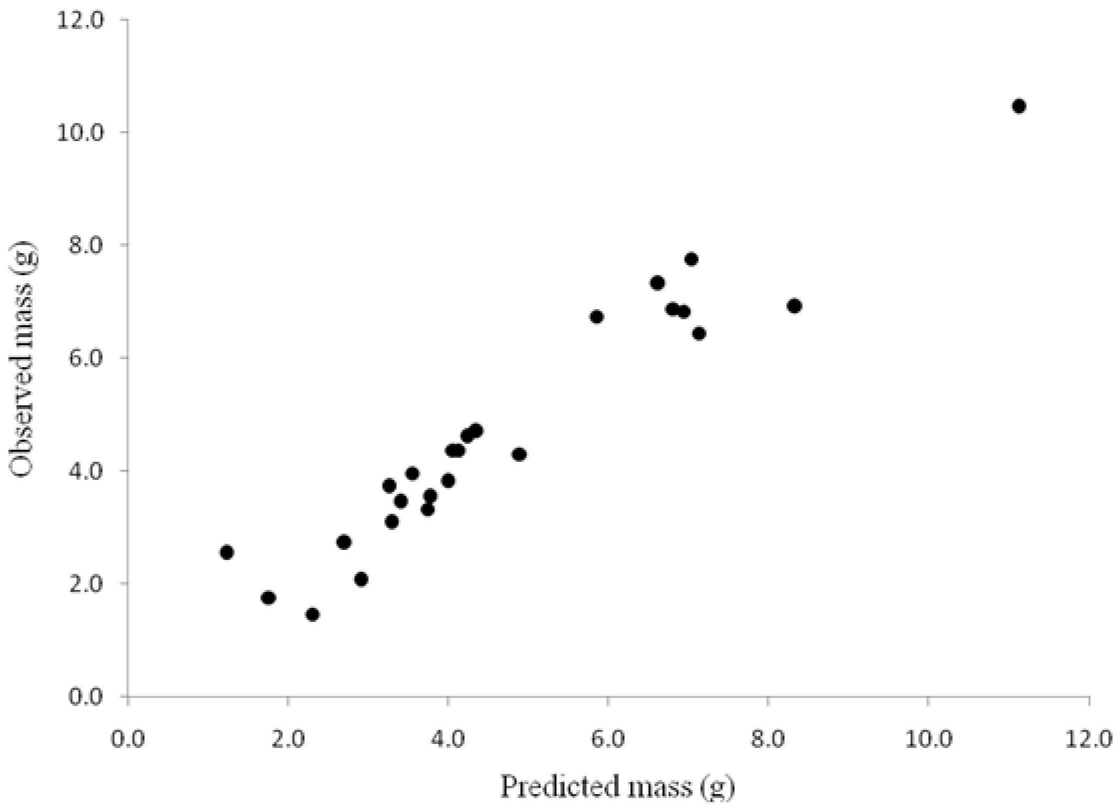

Figure 3.5. Scatterplot of observed and predicted jungle rice seedbiomass resulting from stepwise multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from jungle rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

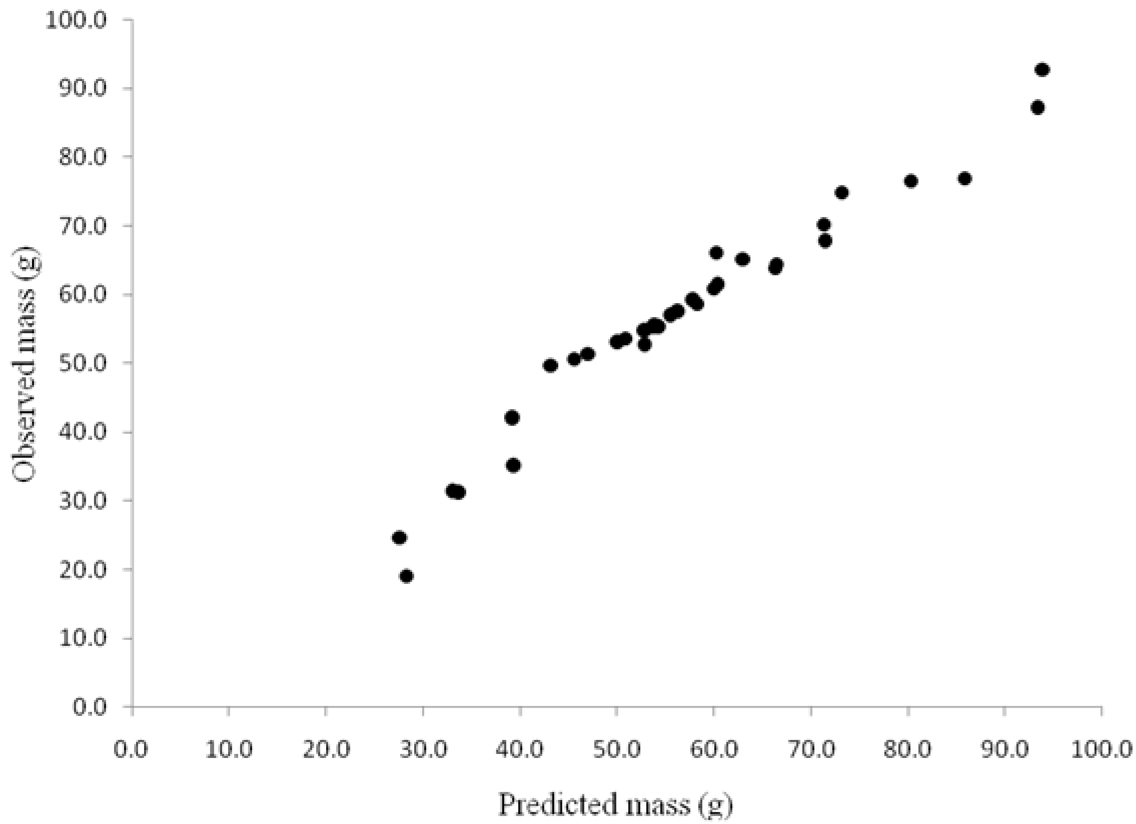

Figure 3.6. Scatterplot of observed and predicted cultivated rice seed biomass resulting from stepwise multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from cultivated rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

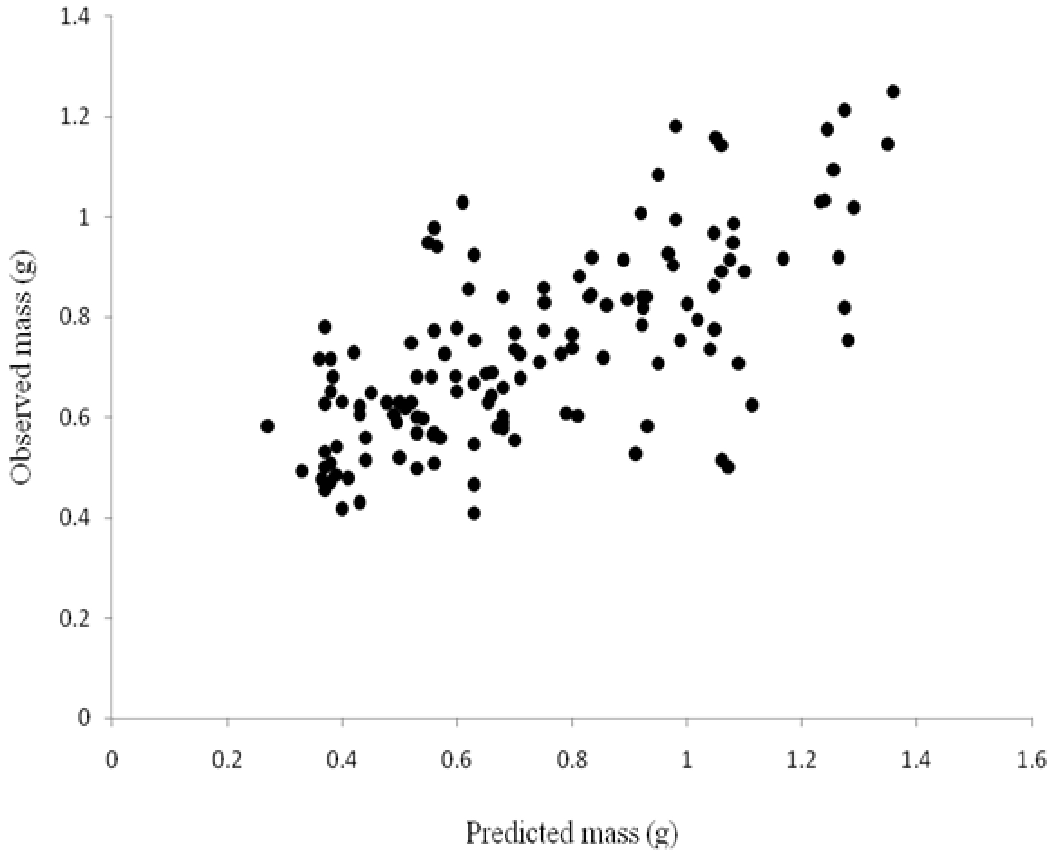

Figure 3.7. Scatterplot of observed and predicted barnyardgrass seedbiomass resulting from simple linear regression analyses using dot grid metrics and seed biomass calculations from barnyardgrass plants collected at Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Pettigrew Ranch (Freestone County, Texas) August 2004 and 2005.

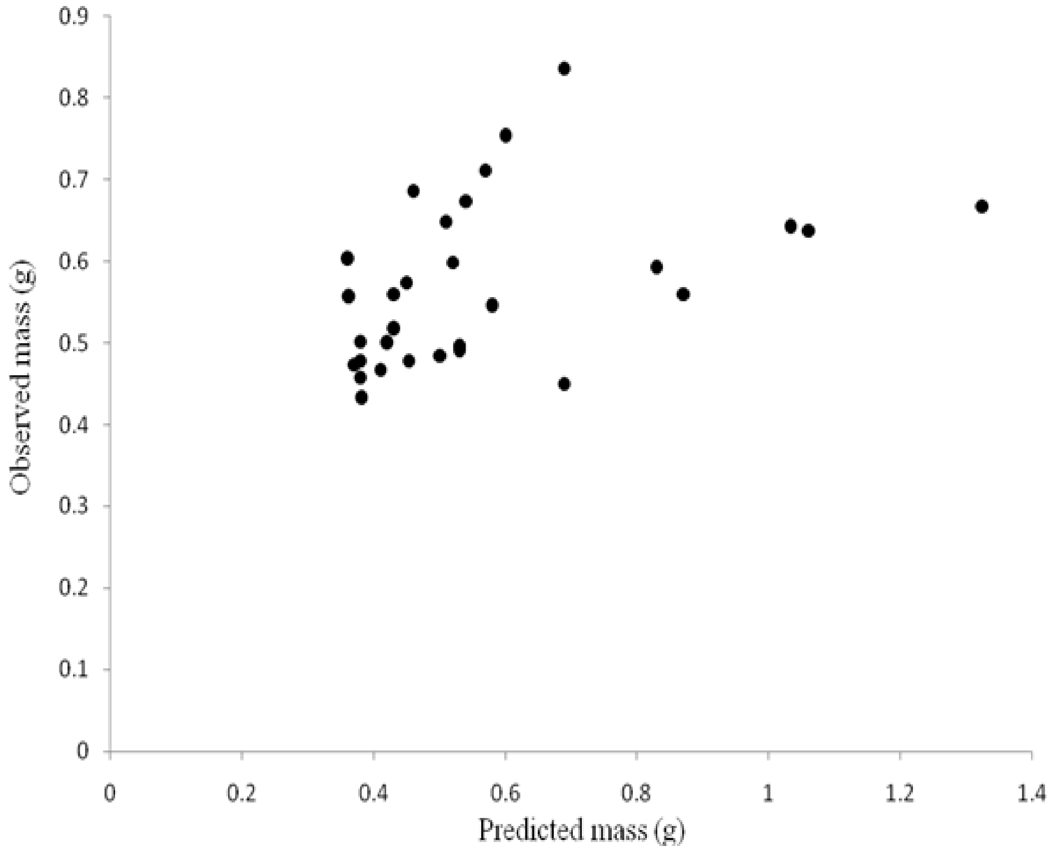

Figure 3.8. Scatterplot of observed and predicted barnyardgrass seed biomass resulting from stepwise multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from barnyardgrass plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

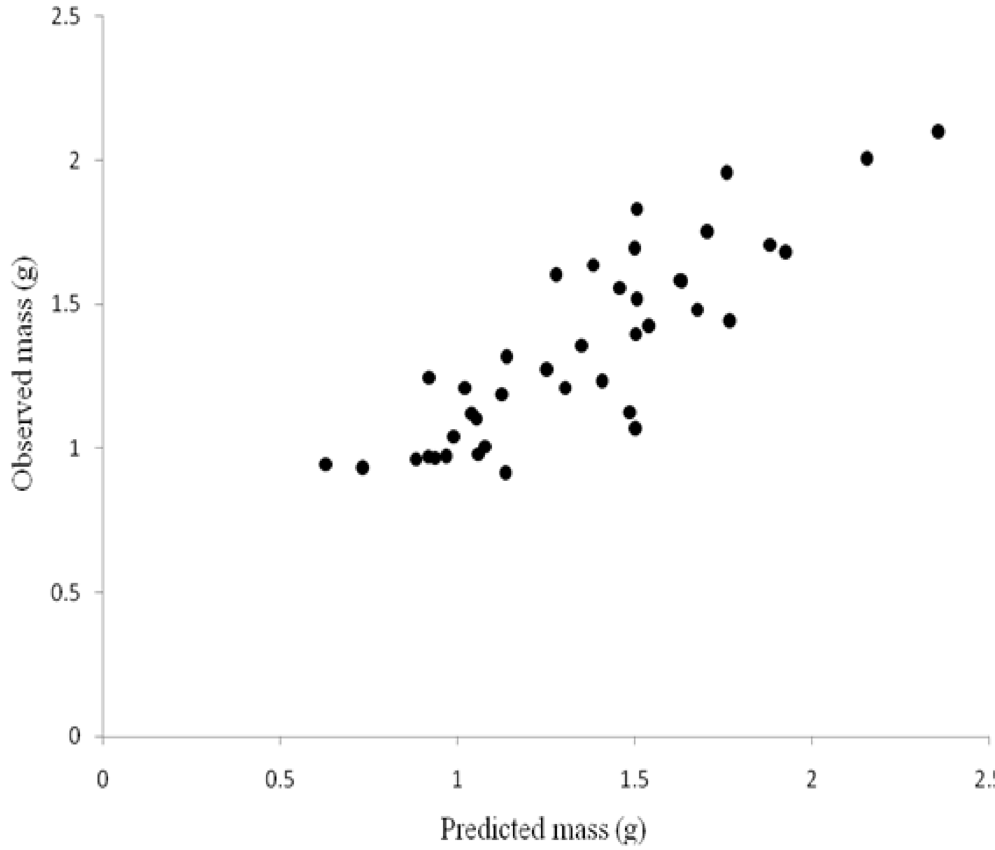

Figure 3.9. Scatterplot of observed and predicted wild millet seed biomass resulting from stepwise multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from wild millet plants collected at Richland Creek Wildlife Management Area (Freestone County, Texas) August 2004 and 2005.

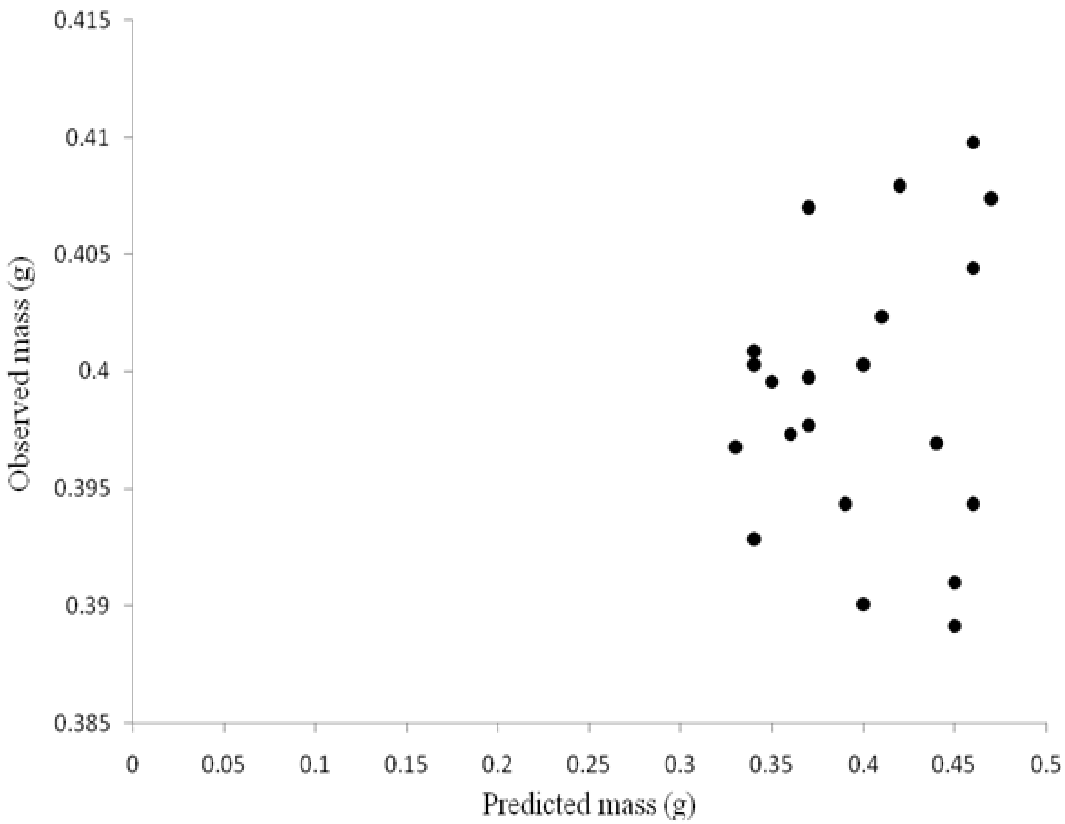

Figure 3.10. Scatterplot of observed and predicted jungle rice seedbiomass resulting from stepwise multiple linear regression analyses using dot grid metrics and seed biomass calculations from jungle rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

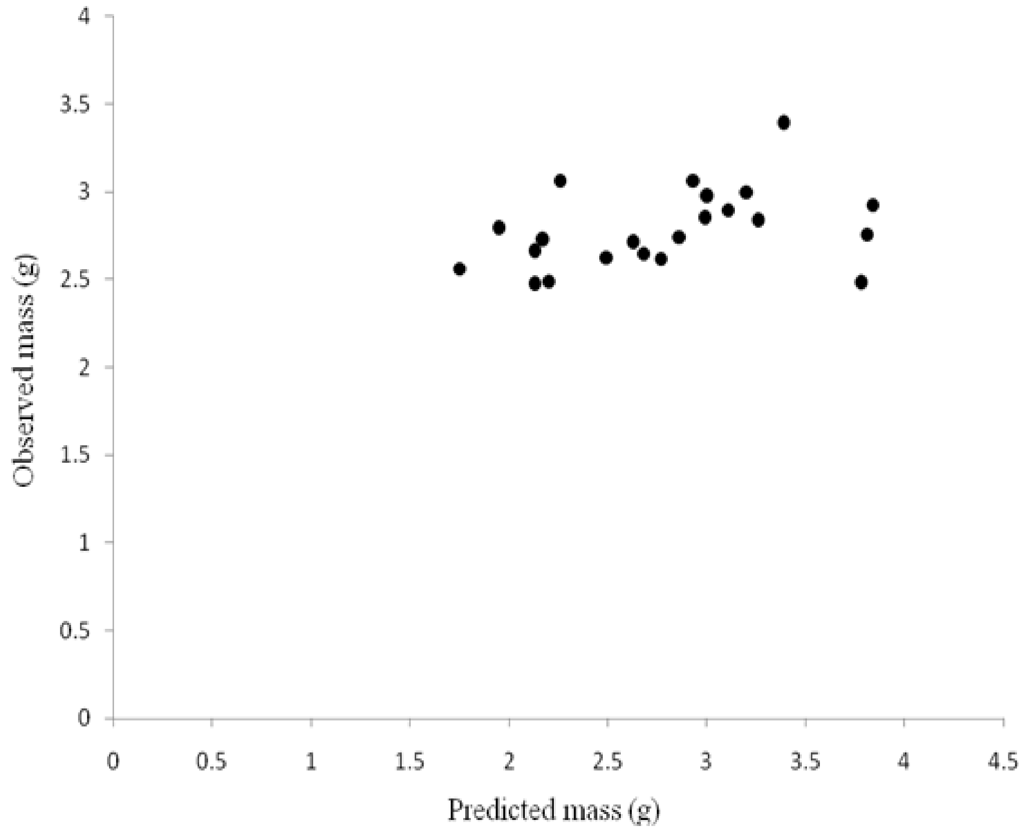

Figure 3.11. Scatterplot of observed and predicted cultivated rice seed biomass resulting from stepwise multiple linear regression analyses using dot grid metrics and seed biomass calculations from cultivated rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

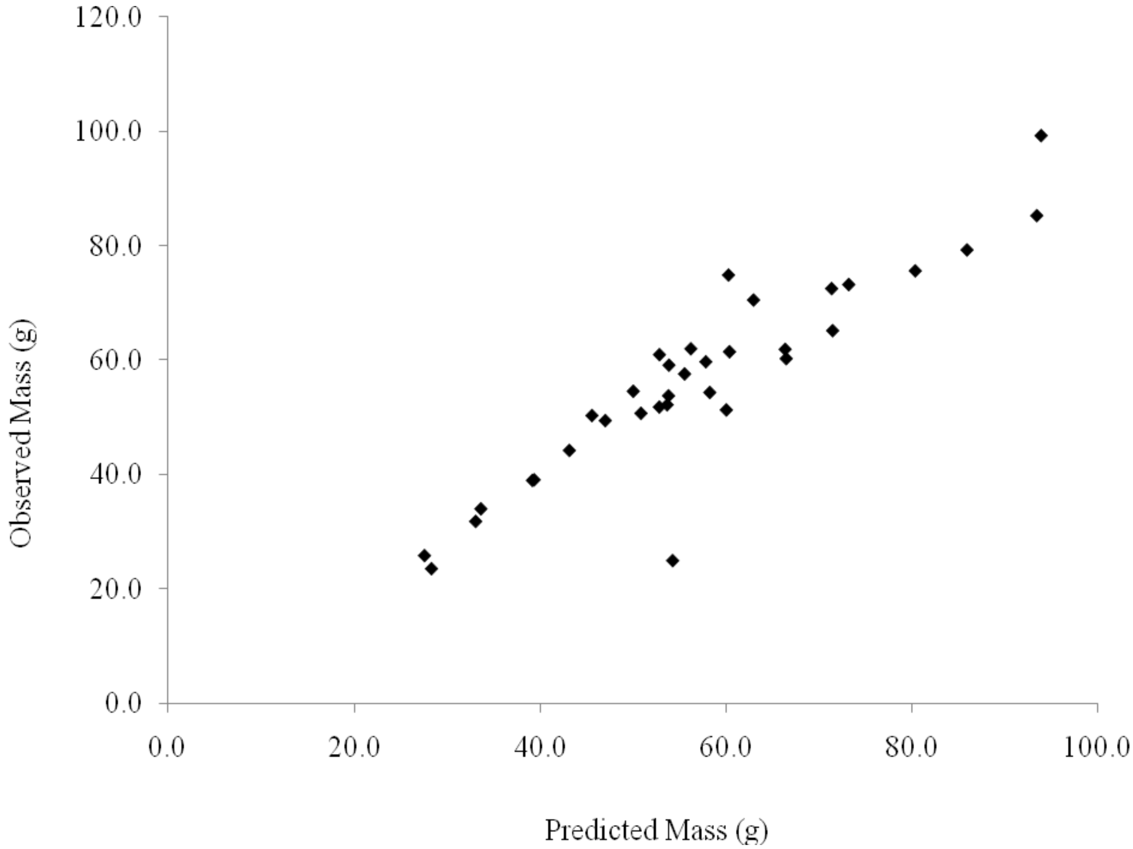

Figure 3.12. Scatterplot of observed and predicted cultivated rice seed biomass resulting from point of origin linear regression analyses using dot grid metrics and seed biomass calculations from cultivated rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

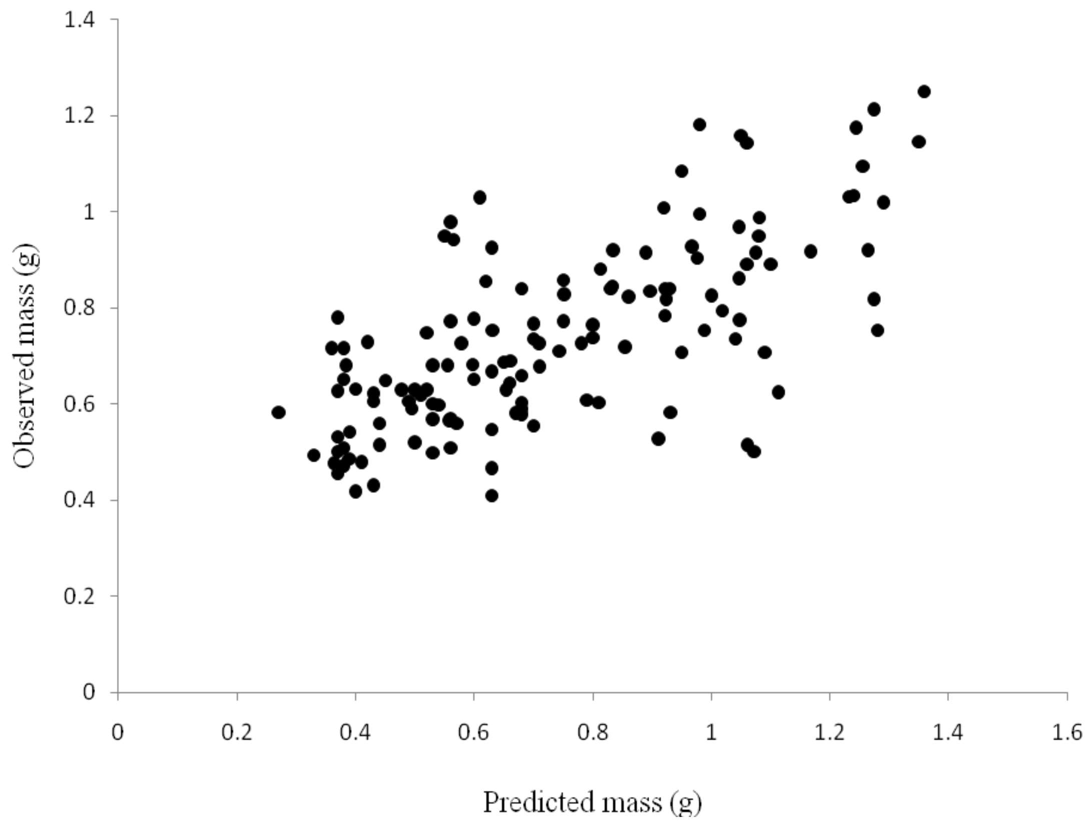

Figure 3.13. Scatterplot of observed and predicted barnyardgrass seedbiomass resulting from simple linear regression analyses using dot grid metrics and seed biomass calculations from barnyardgrass plants collected at Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Pettigrew Ranch (Freestone County, Texas) August 2004 and 2005.

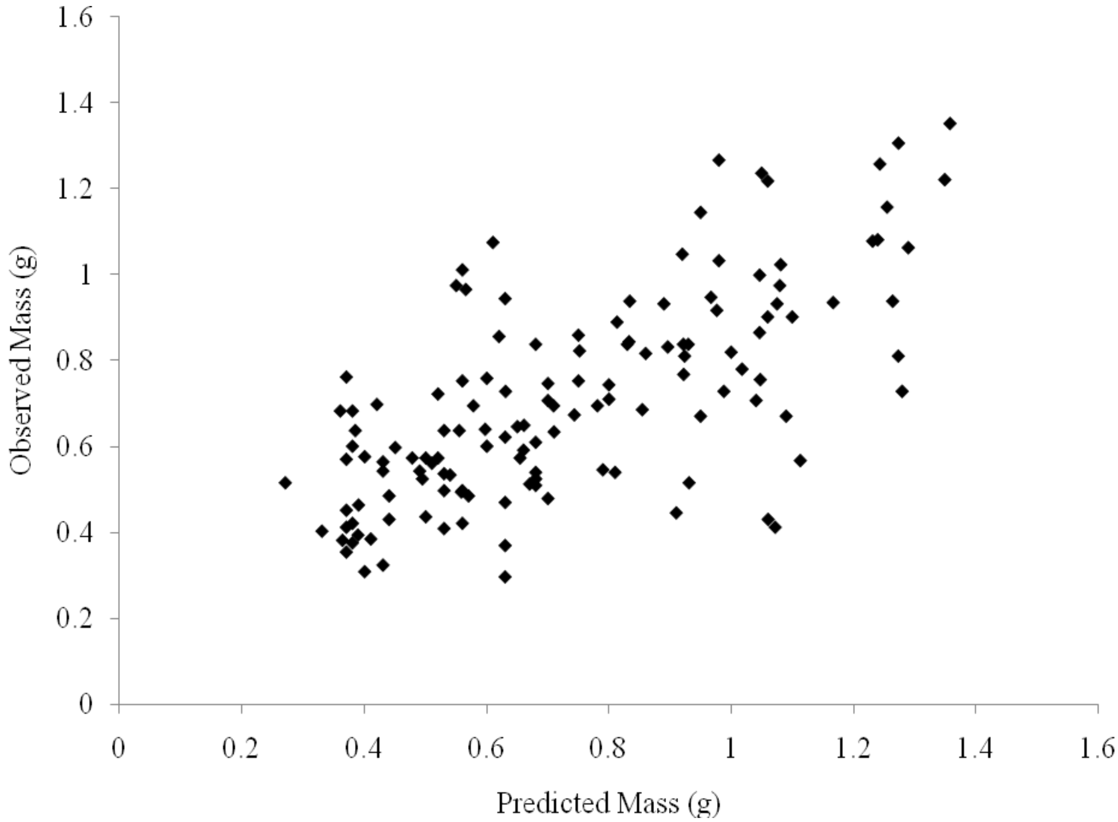

Figure 3.14. Scatterplot of observed and predicted barnyardgrass seed biomass resulting from point of origin regression analyses using dot grid metrics and seed biomass calculations from barnyardgrass plants collected Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Pettigrew Ranch (Freestone County, Texas) August 2004 and 2005.

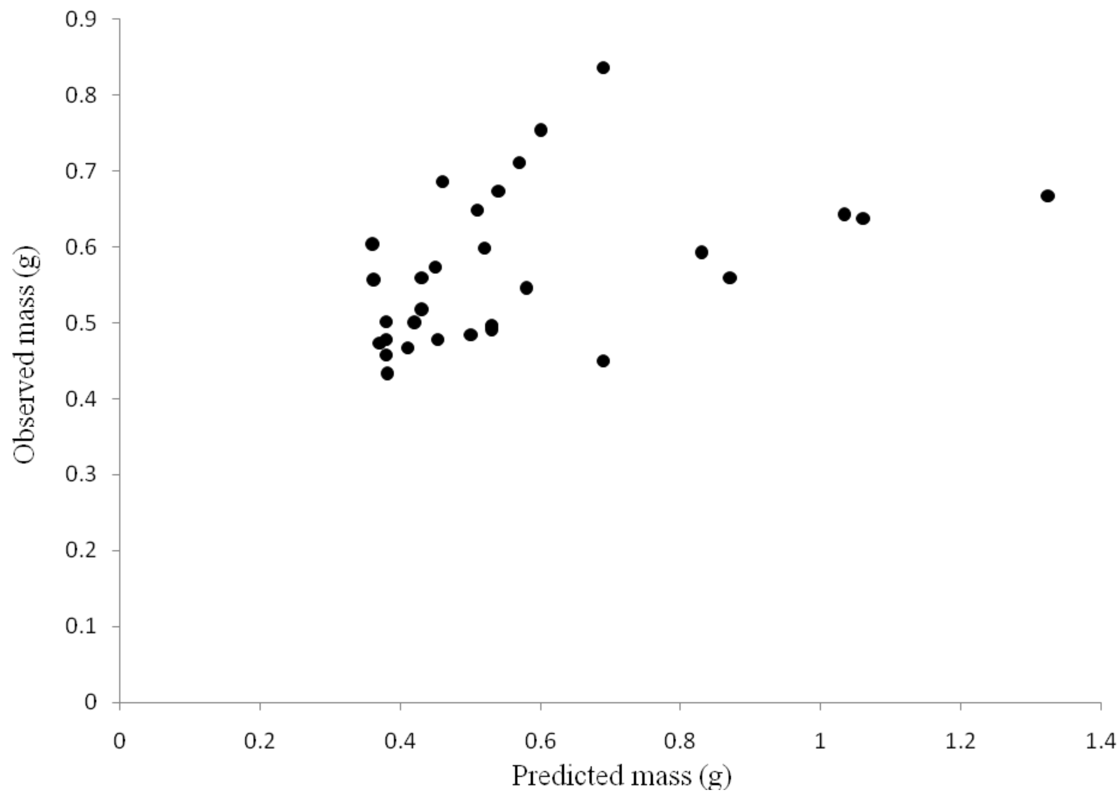

Figure 3.15. Scatterplot of observed and predicted barnyardgrass seed biomass resulting from normal multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from barnyardgrass plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

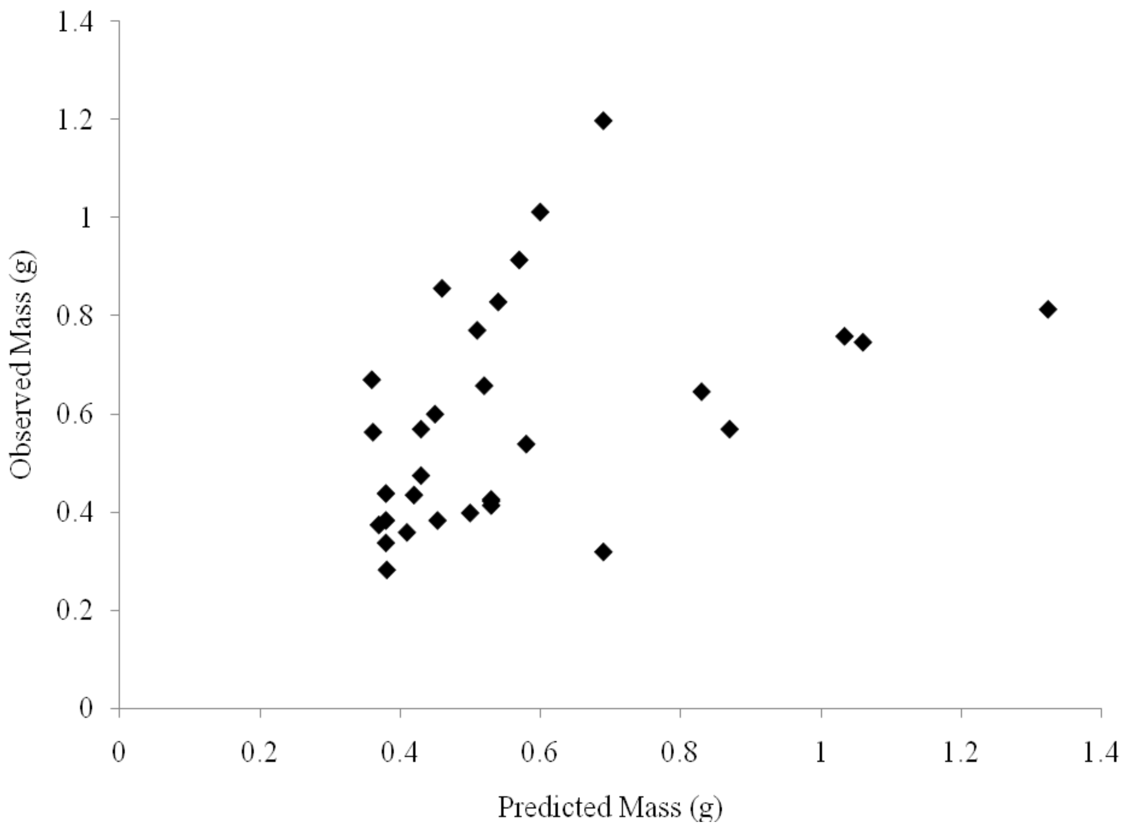

Figure 3.16. Scatterplot of observed and predicted barnyardgrass seed biomass resulting from point of origin regression analyses using dot grid metrics and seed biomass calculations from barnyardgrass plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

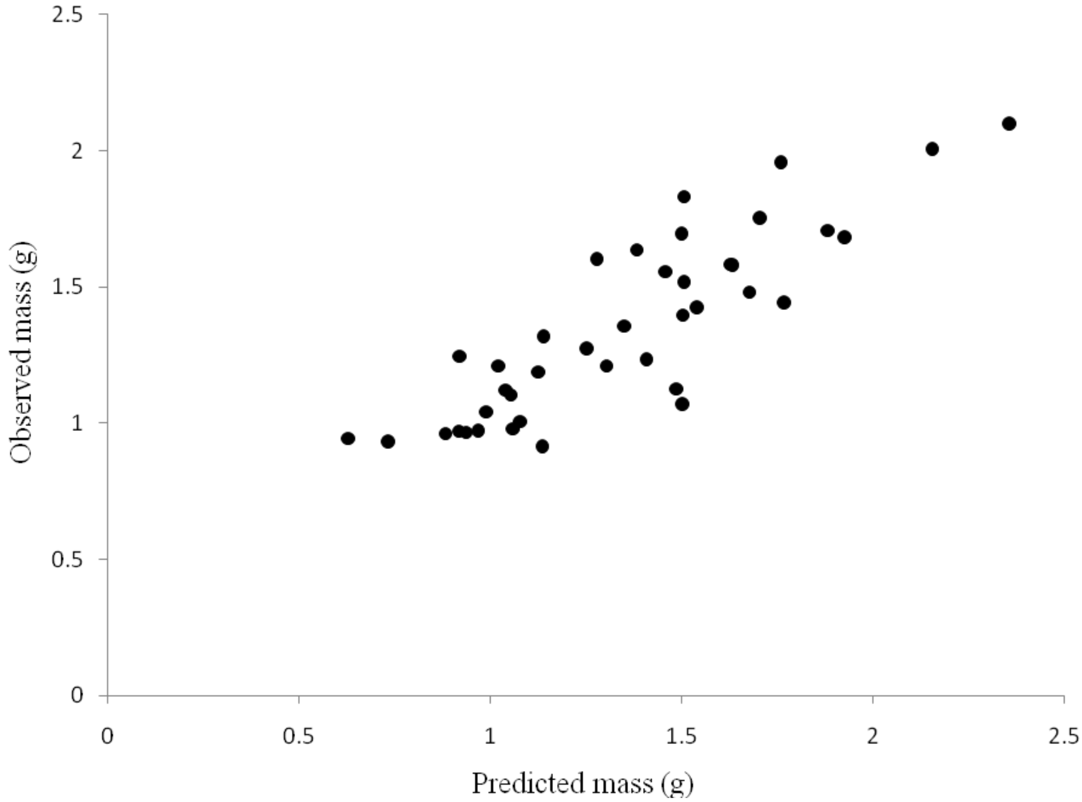

Figure 3.17. Scatterplot of observed and predicted wild millet seed biomass resulting from normal multiple linear regression analyses using phytomorphological metrics and seed biomass calculations from wild millet plants collected at Richland Creek Wildlife Management Area (Freestone County, Texas) August 2004 and 2005.

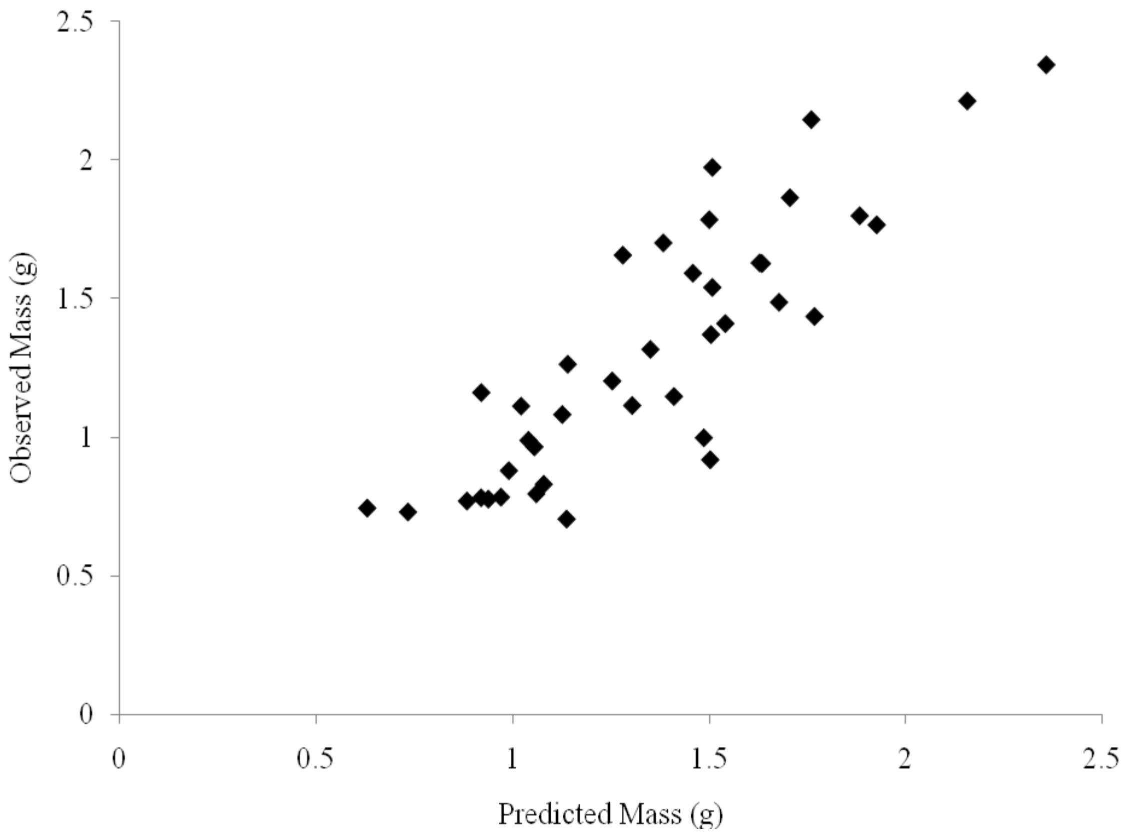

Figure 3.18. Scatterplot of observed and predicted wild millet seed biomass resulting from point of origin regression analyses using phytomorphological metrics and seed biomass calculations from wild millet plants collected at Richland Creek Wildlife Management Area (Freestone County, Texas) August 2004 and 2005.

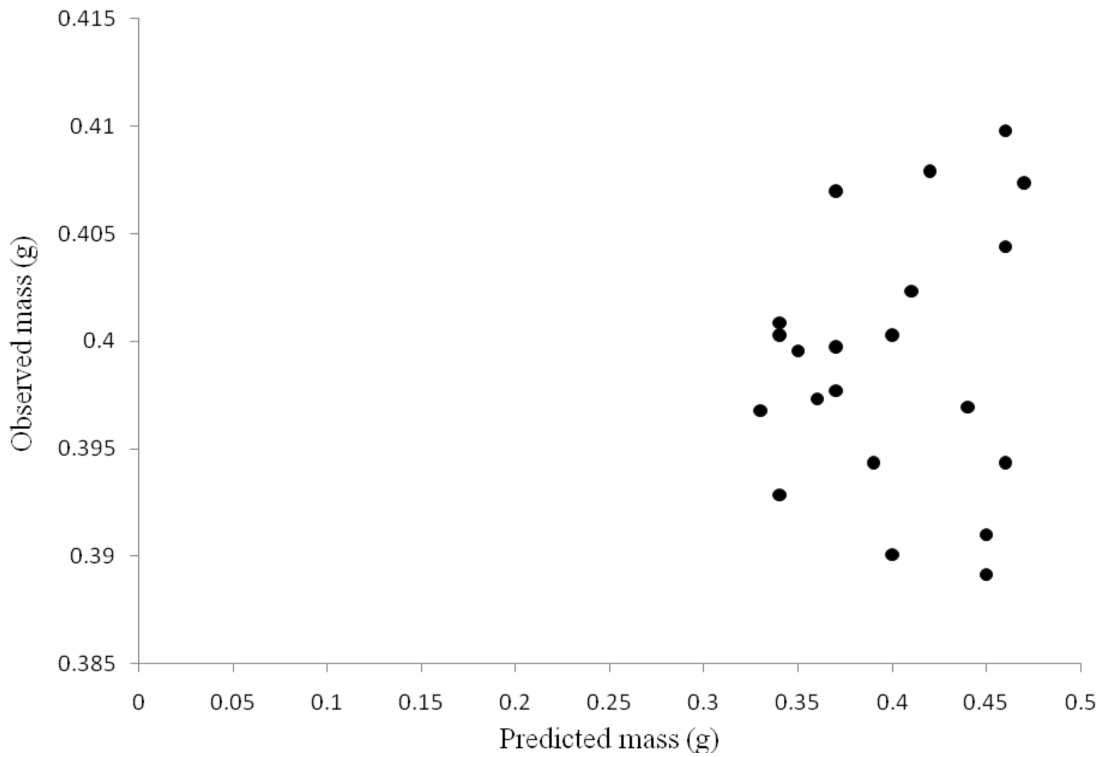

Figure 3.19. Scatterplot of observed and predicted jungle rice seedbiomass resulting from normal multiple linear regression analyses using dot grid metrics and seed biomass calculations from jungle rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

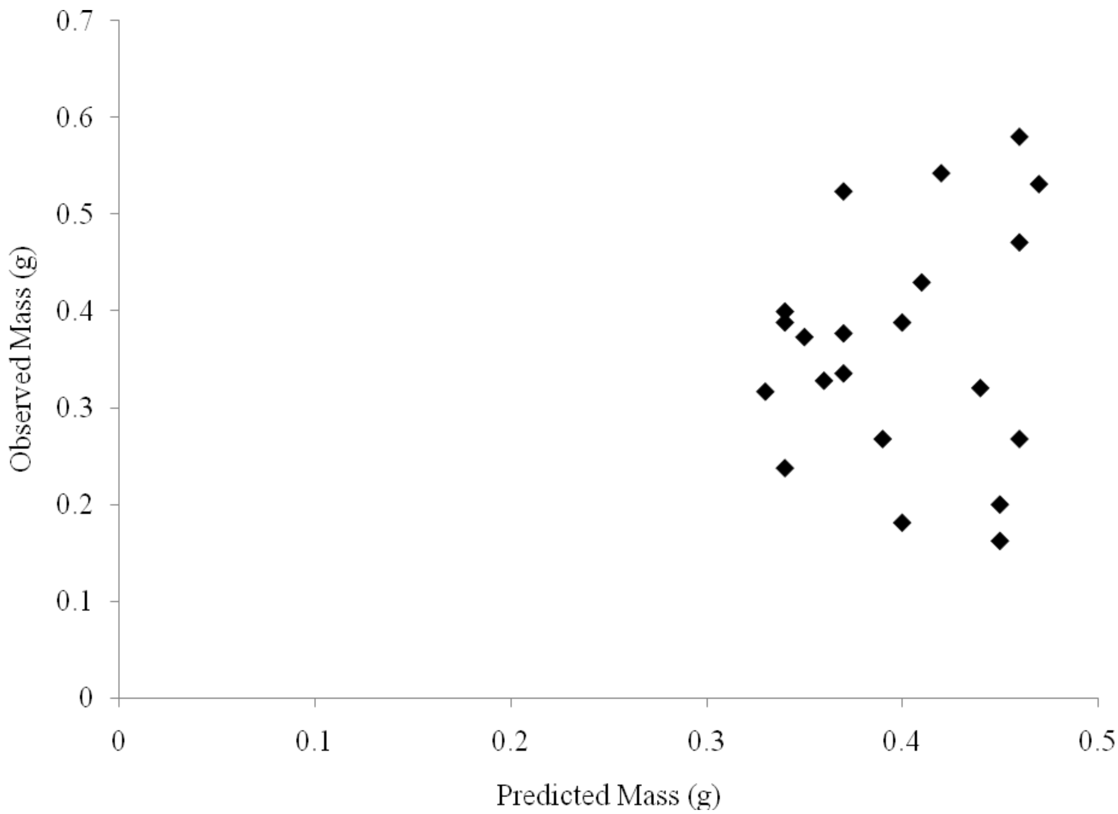

Figure 3.20. Scatterplot of observed and predicted jungle rice seedbiomass resulting from point of origin regression analyses using dot grid metrics and seed biomass calculations from jungle rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

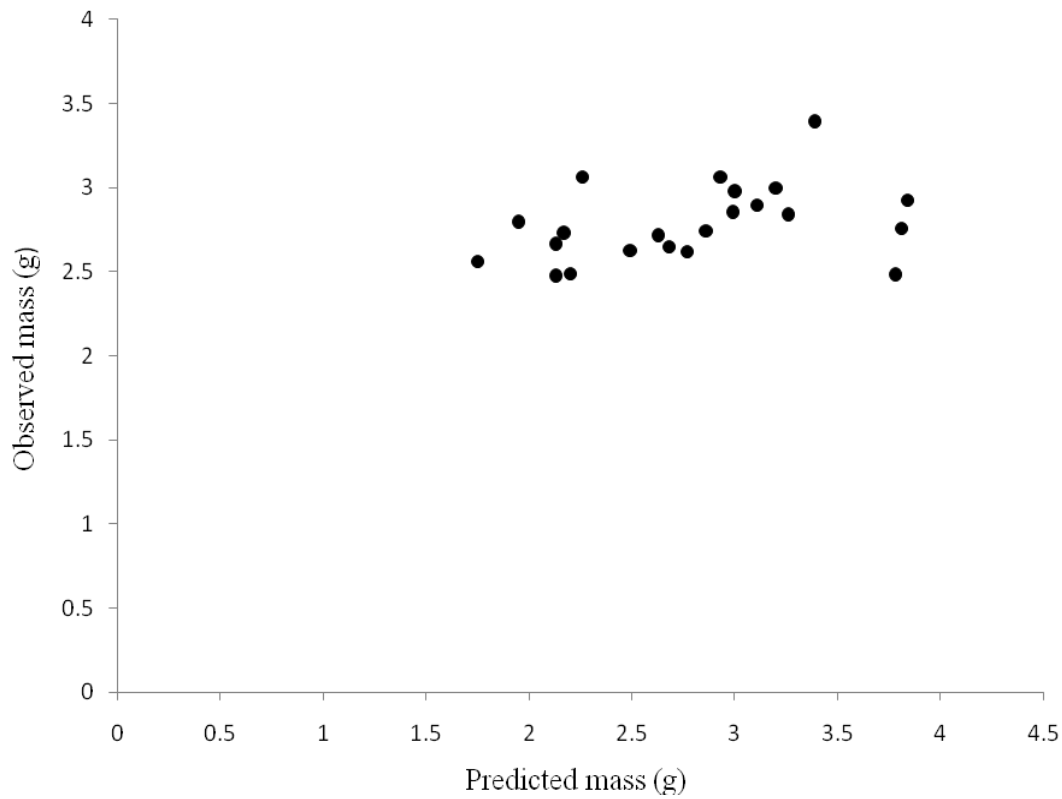

Figure 3.21. Scatterplot of observed and predicted cultivated rice seed biomass resulting from normal multiple linear regression analyses using dot grid metrics and seed biomass calculations from cultivated rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

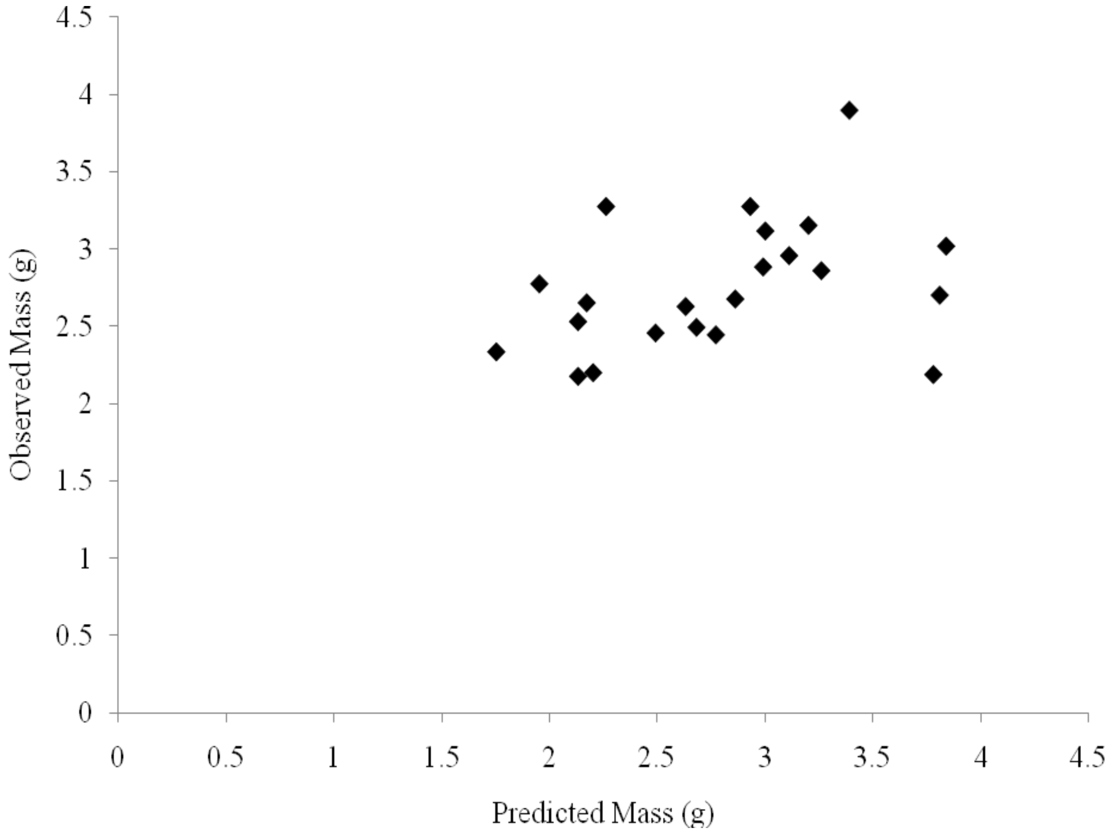

Figure 3.22. Scatterplot of observed and predicted cultivated rice seed biomass resulting from point of origin regression analyses using dot grid metrics and seed biomass calculations from cultivated rice plants collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

Table 3.1. Definitions of phytomorpological variables used to build regression models on moist-soil plant species collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), Trinity and Petigrew Ranch (Freestone County, Texas), and Mad Island Nature Preserve (Matagorda County, Texas) August 2004 and 2005.

Variable	Description
Plant Height (TH): plant height from ground level to the tip of the selected "average" plant within the sample frame	
Inflorescence Height (SHH): height of inflorescence (i.e., seed head), measurements taken from the base of the seed head to the tip of the selected "average" plant within the sample frame.	
Inflorescence Diameter (DI): measurement of inflorescence base using calipers to determine diameter	
Total # of inflorescence present (TSH): total number of inflorescence present within the 0.0625 m^2 sample frame	
Inflorescence volume (IV): measurement calculated: $IV = \pi \frac{(DI/2)^2 SHH}{3}$ to determine volume of the seed head measured	
Average inflorescence mass (SSHH): mean grams per inflorescence present within a sample frame	

Table 3.2 Mean, Standard Errors (SE), and *F* and *P* values resulting from univariate analyses of variance among phytomorphological characters of barnyardgrass collected from Big Woods (BW) (Freestone County), Trinity and Petigrew Ranch (TPR) (Freestone County), Richland Creek Wildlife Management Area (RC) (Freestone County), and Mad Island Nature Preserve (Matagorda County), Texas 2004-2005.

	BW (n = 50)		TPR (n = 17)		RC (n = 101)		Mad Island (n = 32)			
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
Total height (cm)	113.55	4.41	80.24	2.01	119.79	2.01	147.88	3.17	13.76	0.001
Inflorescence height (cm)	14.41	0.44	12.56	0.68	17.98	1.20	13.75	0.49	0.56	0.456
Total number inflorescence (n)	9.22	0.50	15.94	0.65	9.73	0.63	6.56	0.76	209.30	0.001
Inflorescence volume (cm^3)	32.28	2.02	12.83	1.16	65.36	3.07	12.64	1.27	3.82	0.052
Average mass per inflorescence (g/n)	2.95	0.29	3.36	0.28	1.46	0.31	2.12	0.22	27.18	0.052
Total seed mass (g)	3.70	0.26	5.08	0.42	4.22	0.26	3.13	0.36	55.42	0.001

Table 3.3. Mean, Standard Errors (SE), and F and P values resulting from univariate analyses of variance among phytomorphological characters of 4 moist-soil plant species collected from Big Woods (BW)(Freestone County), Trinity and Petigrew Ranch (TPR)(Freestone County), Mad Island Nature Preserve (Matagorda County), and Richland Creek Wildlife Management Area (Freestone County), Texas 2004-2005

	2004				2005									
	RC (n = 60)				RC (n = 41)		BW (n = 50)		TPR (n = 17)		Mad Island (n = 32)			
	x	SE	*F*	*P*	x	SE	x	SE	x	SE	x	SE	*F*	*P*
Total height (cm)	121.95	15.81	0.34	0.560	118.12	22.94	113.76	30.59	80.24	8.30	147.88	17.92	8.50	0.004
Inflorescence height (cm)	16.47	3.81	0.24	0.627	20.17	16.89	14.32	3.10	12.56	2.80	13.75	2.75	7.04	0.008
Total number inflorescence (n)	10.87	4.88	222.03	0.001	8.07	3.04	9.22	3.57	15.94	4.60	6.56	5.38	615.65	0.001
Inflorescence volume (cm³)	74.86	22.35	0.41	0.524	47.91	31.02	32.16	14.04	12.83	4.79	12.64	7.16	16.77	0.001
Average mass per inflorescence (g/n)	0.49	0.28	109.43	0.001	2.87	1.40	2.95	1.61	3.36	1.16	2.12	0.88	306.55	0.001
Total seed mass (g)	4.95	2.64	64.33	0.001	3.21	1.36	3.70	1.79	5.08	1.73	3.13	2.05	150.63	0.001

Table 3.4. Mean, Standard Errors (SE), and F and *P* values resulting from univariate analyses of variance among phytomorphological characters of jungle rice and cultivated rice collected from Mad Island Nature Preserve (Matagorda County), and Wild Millet collected from Richland Creek Wildlife Management Area (RC) (Freestone County), Texas 2004-2005.

	Jungle Rice Mad Island (*n* =25)				Cultivated Rice Mad Island (*n* = 34)				Wild Millet RC (*n* = 76)			
	$\bar{x}$	SE	*F*	*P*	$\bar{x}$	SE	*F*	*P*	$\bar{x}$	SE	*F*	*P*
Total height (cm)	124.96	3.21	3.67	0.07	75.31	2.81	0.52	0.48	155.74	2.92	6.75	0.01
Inflorescence height (cm)	10.57	0.33	1.80	0.20	10.16	0.88	0.21	0.65	26.41	0.75	0.02	0.88
Total number inflorescence (n)	19.04	1.55	138.88	0.00	28.06	1.87	475.87	0.00	8.39	0.40	63.48	0.00
Inflorescence volume (cm^3)	12.36	1.09	6.20	0.02	10.22	0.85	0.40	0.53	99.82	5.15	4.20	0.04
Average mass per inflorescence (g/n)	4.40	1.76	131.69	0.00	0.51	0.17	344.62	0.00	1.12	0.62	0.01	0.91
Total seed mass (g)	4.69	0.40	51.43	0.00	56.82	2.92	109.16	0.00	6.57	0.44	18.21	0.00

Table 3.5. Mean, Standard Errors (SE), and *F* and *P* values resulting from univariate analyses of variance among phytomorphological characters of wild millet collected from Richland Creek Wildlife Management Area (Freestone County), Texas 2004-2005.

	Year							
	2004 RC (n = 51)				2005 RC (n = 25)			
	$\bar{x}$	SE	*F*	*P*	$\bar{x}$	SE	*F*	*P*
Total height (cm)	151.52	23.44	0.10	0.755	164.36	27.75	1.97	0.177
Inflorescence height (cm)	25.14	4.90	0.06	0.816	29.00	8.54	0.30	0.591
Total number inflorescence (n)	9.24	3.43	275.85	0.001	6.68	2.98	294.10	0.001
Inflorescence volume (cm^3)	123.09	31.84	0.68	0.413	52.34	26.40	1.40	0.251
Average mass per inflorescence (g/n)	0.84	0.33	242.35	0.000	1.70	0.68	213.34	0.001
Total seed mass (g)	7.76	4.02	131.28	0.001	4.13	1.55	70.44	0.001

Table 3.6. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within barnyardgrass samples collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Petigrew Ranch (Freestone County, Texas) used in normal linear regression analysis.

			Proportion of Variation			
Stepwise Selection	Eigenvalue	Condition Index	Intercept	Plant Height	Total number Inflorescence	Mean Inflorescence Mass
1	3.50	1.00	0.002	0.003	0.011	0.019
2	0.34	3.19	0.003	0.017	0.013	0.721
3	0.14	4.97	0.009	0.060	0.779	0.030
4	0.01	15.85	0.986	0.921	0.196	0.230

Table 3.7. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within barnyardgrass samples collected on Mad Island Nature Preserve (Matagorda County, Texas) and used in point of origin regression analysis.

			Proportion of Variation				
Stepwise Selection	Eigenvalue	Condition Index	Plant Height	Inflorescence Height	Total number Inflorescence	Inflorescence Volume	Mean Inflorescence Mass
1	4.06	1.00	0.006	0.007	0.011	0.006	0.012
2	0.58	2.65	0.001	0.014	0.016	0.586	0.322
3	0.20	4.48	0.005	0.150	0.636	0.003	0.236
4	0.09	6.69	0.419	0.601	0.317	0.077	0.659
5	0.06	8.05	0.569	0.227	0.020	0.856	0.364

Table 3.8. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within barnyardgrass samples collected on Mad Island Nature Preserve (Matagorda County, Texas) and used normal linear regression analysis.

			Proportion of Variation		
Stepwise Selection	Eigenvalue	Condition Index	Intercept	Total Number Inflorescence	Mean Inflorescence Mass
1	2.68	1.00	0.018	0.038	0.015
2	0.25	3.30	0.135	0.903	0.043
3	0.07	6.12	0.846	0.057	0.941

Table 3.9. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within barnyardgrass samples collected on Mad Island Nature Preserve (Matagorda County, Texas) and used in point of origin regression analysis.

			Proportion of Variation				
Stepwise Selection	Eigenvalue	Condition Index	Plant Height	Inflorescence height	Total number Inflorescence	Inflorescence Volume	Mean Inflorescence Mass
1	4.63	1.00	0.001	0.001	0.011	0.006	0.006
2	0.35	3.53	0.006	0.006	0.509	0.038	0.014
3	0.22	4.48	0.004	0.001	0.110	0.304	0.215
4	0.06	8.70	0.079	0.041	0.355	0.567	0.765
5	0.01	19.72	0.910	0.950	0.017	0.084	0.000

Table 3.10. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within jungle rice samples collected on Mad Island Nature Preserve (Matagorda County, Texas) and used in stepwise regression analysis.

			Proportion of Variation			
Stepwise Selection	Eigenvalue	Condition Index	Intercept	Plant height	Total Number Inflorescence	Inflorescence Volume
1	3.76	1.00	0.0013	0.0017	0.0088	0.0100
2	0.12348	5.52	0.0118	0.0276	0.0460	0.9466
3	0.10892	5.87	0.0159	0.0456	0.8816	0.0097
4	0.01146	18.10	0.9710	0.9251	0.0636	0.0337

Table 3.11. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within jungle samples collected on Mad Island Nature Preserve (Matagorda County, Texas) and used in point of origin regression analysis.

			Proportion of Variation				
Stepwise Selection	Eigenvalue	Condition Index	Plant Height	Inflorescence height	Total Number Inflorescence	Inflorescence Volume	Mean Inflorescence Mass
1	4.64	1.00	0.0001	0.0001	0.0033	0.0052	0.0039
2	0.24	4.35	0.0001	0.0001	0.0362	0.2981	0.1198
3	0.06	8.52	0.0026	0.0009	0.7970	0.0035	0.3753
4	0.05	9.35	0.0140	0.0166	0.0053	0.6468	0.4176
5	0.00	53.15	0.9832	0.9824	0.1582	0.0464	0.0835

Table 3.12. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within wild millet samples collected on Richland Creek Wildlife Management Area (Freestone County, Texas) used in stepwise regression analysis.

			Proportion of Variation			
Stepwise Selection	Eigenvalue	Condition Index	Intercept	Plant Height	Total number Inflorescence	Inflorescence Volume
1	4.63	1.00	0.001	0.001	0.002	0.005
2	0.24	4.36	0.000	0.001	0.040	0.321
3	0.07	8.01	0.039	0.012	0.815	0.057
4	0.05	9.80	0.058	0.052	0.075	0.539
5	0.01	23.88	0.902	0.935	0.066	0.077

Table 3.13. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within wild millet samples collected on Richland Creek Wildlife Management Area (Freestone County, Texas) used in point of origin regression analysis.

			Proportion of Variation				
Stepwise Selection	Eigenvalue	Condition Index	Plant Height	Inflorescence Height	Total Number Inflorescence	Inflorescence Volume	Mean Inflorescence Mass
1	4.49	1.00	0.002	0.002	0.006	0.006	0.008
2	0.30	3.88	0.000	0.000	0.014	0.154	0.402
3	0.12	6.02	0.024	0.053	0.819	0.031	0.006
4	0.07	8.12	0.092	0.079	0.113	0.796	0.584
5	0.02	14.76	0.882	0.866	0.047	0.014	0.000

Table 3.14. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within cultivated rice samples collected on Mad Island Nature Preserve (Matagorda County, Texas) and used in normal linear regression analysis.

			Proportion of Variation		
Stepwise Selection	Eigenvalue	Condition Index	Intercept	Total Number Inflorescence	Mean Inflorescence Mass
1	2.90	1.00	0.010	0.009	0.007
2	0.07	6.59	0.793	0.436	0.016
3	0.04	8.87	0.196	0.555	0.978

Table 3.15. Eigenvalue and condition index values used for multicollinearity diagnostic analyses to determine if phytomoporphological variables were highly correlated within cultivated rice samples collected on Mad Island Nature Preserve (Matagorda County, Texas) and used in stepwise regression analysis.

			Proportion of Variation				
Stepwise Selection	Eigenvalue	Condition Index	Plant height	Inflorescence Height	Total Number Inflorescence	Inflorescence Volume	Mean Inflorescence Mass
1	4.61	1.00	0.0069	0.0014	0.0032	0.0013	0.0026
2	0.23	4.49	0.2771	0.0403	0.0150	0.0311	0.0116
3	0.11	6.47	0.6513	0.0086	0.2397	0.0096	0.0756
4	0.04	10.82	0.0405	0.0065	0.6864	0.0183	0.8484
5	0.02	17.11	0.0241	0.9432	0.0558	0.9397	0.0619

Table 3.16. Regression equations for estimating seed biomass (g) of 4 moist-soil plants using phytomorphological measurements collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), Trinity and Petigrew Ranch (Freestone County, Texas) and Mad Island Nature Preserve (Matagorda County, Texas) August 2004 and 2005.

Species	*n*	Equation	*F*	R^2	*P*
Barnyard Grass[1]	168	Y = -0.04763 + 0.01895(TH) + 0.29830(TSH) + -0.48020(SSHH) [a]	60.41	0.52	< 0.001
		Y = 0.01630(TH) + 0.29501(TSH) + -0.43259(SSHH) [b]	292.01	0.90	< 0.001
Barnyard Grass[2]	32	Y = 2.85323 + 0.40295(TSH) + -1.11388(SSHH) [a]	128.27	0.93	< 0.001
		Y = 0.01785(TH) + 0.41626(TSH) + -1.05019(SSHH) [b]	557.6	0.98	< 0.001
Wild Millet[1]	76	Y = -7.01527 + 0.03745(TH) + 0.71714(TSH) + 0.05204(IV) [a]	31.19	0.56	< 0.001
		Y = 0.00682(TH) + 0.40688(TSH) + -0.91945(SSHD) [b]	263.17	0.97	< 0.001
Jungle Rice[2]	25	Y = 5.29511 + 0.29448(TSH) + -0.01576(TH) +0.18691(IV) +-1.13804(SSHH) [a]	102.0	0.92	< 0.001
		Y = 0.02787(TH) + 0.28309(TSH) + -0.96071(SSHH) [b]	125.63	0.96	< 0.001
Rice[2]	34	Y = 57.46140 + 1.86339(TSH) + -104.51608(SSHH) [a]	687.45	0.94	< 0.001
		Y = 0.48262(TH) + 1.98994(TSH) +0.63947(SHH)+ -89.16090(SSHH) [b]	400.14	0.98	< 0.001

[1] Middle trinity River Valley Collection Sites
[2] Mad Island Nature Preserve Collection Site
[a] Normal Linear Regression
[b] Intercept through the point of origin regression

Table 3.17. Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for barnyardgrass seed biomass prediction model developed from stepwise multiple linear regression analyses using phytomorphological and seed biomass calculations from barnyardgrass collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Petigrew Ranch (Freestone County, Texas) August 2004 and 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Intercept	-0.0476	0.78	-0.06	0.951	-1.5959	1.5006
Total Height (cm)	0.01895	0	3.63	0.001	0.0087	0.0293
Total # Inflorescence (n)	0.2983	0.03	11.38	0.001	0.2466	0.3500
Average Inflorescence Mass (g)	-0.4802	0.08	-6.29	0.001	-0.6309	-0.3295

Table 3.18. Variables, parameter estimates and Standard Errors (SE), t values, P values, and 95 % Confidence Intervals (CI) for barnyardgrass seed biomass prediction model developed from point of origin multiple linear regression analyses using phytomorphological and seed biomass calculations from barnyardgrass collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Petigrew Ranch (Freestone County, Texas) 2004 and 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Total Height (cm)	0.0187	0.00	9.21	0.001	0.0147	0.0227
Total # Inflorescence (*n*)	0.2975	0.02	13.26	0.001	0.2532	0.3418
Average Inflorescence Weight (g/*n*)	-0.4825	0.07	-7.33	0.001	-0.6126	-0.3525

Table 3.19. Simple linear regression models for phytomorphological variables predicting seed yield biomass of barnyardgrass on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Petigrew Ranch (Freestone County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_c$	AIC $_w$
plant height + total number of inflorescence + average inflorescence mass	4	149.14	0.6911
plant height + total number of inflorescence + volume + average inflorescence mass	5	151.90	0.1744
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	153.23	0.0896
plant height + inflorescence height + total number of inflorescence + volume +average inflorescence mass	6	155.64	0.0268
total number of inflorescence + average inflorescence mass	3	158.04	0.0081
total number of inflorescence + volume + average inflorescence mass	4	158.34	0.0070
inflorescence height + total number of inflorescence + average inflorescence mass	4	160.72	0.0021
inflorescence height + total number of inflorescence + volume +average inflorescence mass	5	162.46	0.0009
plant height + inflorescence height + total number of inflorescence + volume	5	170.95	0.0000
plant height + total number of inflorescence + volume	4	171.91	0.0000

Table 3.20. Point of origin regression models for phytomorphological variables predicting seed yield biomass of barnyardgrass on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Petigrew Ranch (Freestone County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_c$	AIC $_w$
plant height + total number of inflorescence + average inflorescence mass	4	147.15	0.6911
plant height + total number of inflorescence + volume + average inflorescene mass	5	150.01	0.1700
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	151.23	0.0895
plant height + inflorescence height + total number of inflorescence + volume +average inflorescence mass	6	153.80	0.0248
total number of inflorescence + volume + average inflorescence mass	4	170.77	0.0000
inflorescence height + total number of inflorescence + volume+ average inflorescence mass	5	174.85	0.0000
plant height + inflorescence height + total number of inflorescence + volume	5	178.91	0.0000
plant height + total number of inflorescence + volume	4	181.25	0.0000
total number of inflorescence + volume	3	183.27	0.0000
inflorescence height + total number of inflorescence + volume	4	184.88	0.0000

Table 3.21. Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for barnyardgrass seed biomass prediction model developed from stepwise multiple linear regression analyses using phytomorphological and seed biomass calculations from barnyardgrass collected at Mad Island Nature Preserve (Matagorda County, Texas) August 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Intercept	2.8532	0.25	11.33	0.001	2.3370	3.3680
Inflorescence per sample (n)	0.4028	0.02	20.49	0.001	0.3627	0.4431
Average weight per Inflorescence (g)	-1.1138	0.12	-9.31	0.001	-1.3586	-0.8691

Table 3.22. Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for barnyardgrass seed biomass prediction model developed from point of origin linear regression analyses using phytomorphological and seed biomass calculations from barnyardgrass collected Mad Island Nature Preserve 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Total Height (cm)	0.01646	0.00	10.66	0.001	0.0133	0.0196
Total # Inflorescence (*n*)	0.41559	0.02	20.22	0.001	0.3736	0.4576
Average Inflorescence Weight (g/*n*)	-0.9636	0.12	-8.34	0.001	-1.1999	-0.7273

Table 3.23. Simple linear regression models for phytomorphological variables predicting seed yield biomass of barnyardgrass on Mad Island Nature Preserve (Matagorda County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_c$	AIC $_w$
total number of inflorescence + average inflorescence mass	3	-30.02	0.4878
plant height + total number of inflorescence + average inflorescene mass	4	-28.86	0.2731
total number of inflorescence + volume + average inflorescence mass	4	-27.13	0.1149
inflorescence height + total number of inflorescence + volume +average inflorescence mass	5	-25.66	0.0553
inflorescence height + total number of inflorescence + average inflorescence mass	4	-25.41	0.0487
plant height + total number of inflorescence + volume + average inflorescence mass	5	-22.50	0.0114
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	-21.61	0.0073
plant height + inflorescence height + total number of inflorescence + volume + average inflorescence mass	6	-18.55	0.0016
plant height + total number of inflorescence + volume	4	11.79	0.0000
plant height + inflorescence height + total number of inflorescence + volume	5	15.19	0.0000

Table 3.24. Point of origin regression models for phytomorphological variables predicting seed yield biomass of barnyardgrass on Mad Island Nature Preserve (Matagorda County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_{c}$	AIC $_{w}$
plant height + total number of inflorescence + average inflorescence mass	4	-24.29	0.8185
plant height + total number of inflorescence + volume + average infloresciene mass	5	-19.90	0.0544
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	-19.63	0.0474
plant height + inflorescence height + total number of inflorescence + volume +average inflorescence mass	6	-15.46	0.0059
inflorescence height + total number of inflorescence + average inflorescence mass	4	-10.07	0.0004
inflorescence height + total number of inflorescence + volume + average inflorescence mass	5	-5.58	0.0000
total number of inflorescence + volume + average inflorescence mass	4	6.30	0.0000
total number of inflorescence + volume	3	7.15	0.0000
plant height + total number of inflorescence + volume	4	10.57	0.0000
plant height + inflorescence height + total number of inflorescence + volume	5	13.69	0.0000

Table 3.25. Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for wild millet seed biomass prediction model developed from stepwise multiple linear regression analyses using phytomorphological and seed biomass calculations from wild millet collected on 3 Middle Trinity River sites August 2004 and 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Intercept	-7.01527	2.12	3.32	0.001	-11.2321	-2.7984
Total Height (cm)	0.03745	0.01	3.21	0.002	0.0142	0.0607
Total # Inflorescence (n)	0.71714	0.09	8.15	0.001	0.5418	0.8925
Inflorescence Volume (cm)	0.05204	0.02	2.55	0.013	0.0113	0.0928

Table 3.26. Variables, parameter estimates and Standard Errors (SE), t values, P values, and 95 % Confidence Intervals (CI) for wild millet seed biomass prediction model developed from no intercept multiple linear regression analyses using phytomorphological and seed biomass calculations from wild millet collected at Middle Trinity River Sites 2004 and 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Total # Inflorescence (*n*)	0.6408	0.07	8.76	0.001	0.4952	0.7865
Inflorescence Volume (cm)	0.0385	0.02	2.12	0.038	0.0023	0.0748

Table 3.27. Simple linear regression models for phytomorphological variables predicting seed yield biomass of wild millet on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Petigrew Ranch (Freestone County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_c$	AIC $_w$
plant height + total number of inflorescence + volume	4	155.58	0.5757
plant height + total number of inflorescence	3	157.57	0.1800
plant height + inflorescence height + total number of inflorescence + volume	5	159.85	0.0679
plant height + total number of inflorescence + volume +average inflorescence mass	5	159.87	0.0675
plant height + total number of inflorescence + average inflorescence mass	4	160.59	0.0469
plant height + inflorescence height + total number of inflorescence	4	161.65	0.0277
inflorescence height + total number of inflorescence + volume	4	162.61	0.0171
plant height + inflorescence height + total number of inflorescence + volume + average inflorescence mass	6	164.20	0.0077
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	164.27	0.0075
inflorescence height + total number of inflorescence + volume + average number of inflorescence	5	166.83	0.0021

Table 3.28. Point of origin regression models for phytomorphological variables predicting seed yield biomass of wild millet on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), and the Trinity and Petigrew Ranch (Freestone County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_c$	AIC $_w$
total number of inflorescence + volume	3	160.38	0.5707
plant height + total number of inflorescence + average inflorescence mass	4	164.20	0.0856
total number of inflorescence + volume + average inflorescence mass	4	164.28	0.0821
plant height + total number of inflorescence + volume	4	164.38	0.0779
inflorescence height + total number of inflorescence + volume	4	164.50	0.0734
inflorescence height + total number of inflorescence + average inflorescence mass	4	164.63	0.0689
plant height + total number of inflorescence + volume + average inflorescence mass	5	167.33	0.0178
inflorescence height + total number of inflorescence + volume + average inflorescence mass	5	167.76	0.0144
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	168.30	0.0110
plant height + inflorescence height + total number of inflorescence + volume + average number of inflorescence	6	171.68	0.0020

Table 3.29 Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for jungle rice seed biomass prediction model developed from normal multiple linear regression analyses using phytomorphological and seed biomass calculations from jungle rice collected Mad Island Nature Preserve 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Intercept	5.2951	1.07	4.96	0.001	3.0661	7.5224
Total Height (cm)	-0.0158	0.01	-1.73	0.099	-0.0348	0.0033
Total # Inflorescence (n)	0.29448	0.02	13.29	0.001	0.2483	0.4307
Inflorescence Volume (cm)	0.18691	0.08	2.29	0.033	0.0164	0.3575
Average Inflorescence Mass (g)	-1.138	0.10	-11.43	0.001	-1.3457	-0.9304

Table 3.30. Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for jungle rice seed biomass prediction model developed from point of origin multiple linear regression analyses using phytomorphological and seed biomass calculations from jungle rice collected Mad Island Nature Preserve 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Total Height (cm)	0.0300	0.00	6.22	0.001	0.0200	0.0400
Total # Inflorescence (*n*)	0.2812	0.03	8.60	0.001	0.2133	0.3490
Average Inflorescence Weight (g/*n*)	-1.0207	0.13	-7.91	0.001	-1.2885	-0.7530

Table 3.31. Multiple linear regression models for phytomorphological variables predicting seed yield biomass of jungle rice on Mad Island Nature Preserve (Matagorda County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_c$	AIC $_w$
total number of inflorescence + average inflorescence mass	3	-4.98	0.5356
total number of inflorescence + volume + average inflorescence mass	4	-3.06	0.2054
plant height + total number of inflorescence + volume + average inflorescence mass	5	-1.38	0.0885
plant height + total number of inflorescence + average inflorescence mass	4	-0.73	0.0641
inflorescence height + total number of inflorescence + average inflorescence mass	4	-0.26	0.0506
inflorescence height + total number of inflorescence + volume + average inflorescence mass	5	0.08	0.0302
plant height + inflorescence height + total number of inflorescence + volume + average inflorescence mass	6	1.87	0.0175
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	3.42	0.0080
total number of inflorescence + volume	3	39.25	0.0000
plant height + total number of inflorescence + volume	4	43.95	0.0000

Table 3.32. Point of origin regression models for phytomorphological variables predicting seed yield biomass of jungle rice on Mad Island Nature Preserve (Matagorda County, Texas) 2004-2005.

Model	No. parameters	Δ AIC_c	AIC_w
plant height + total number of inflorescence + average inflorescence mass	4	13.78	0.5356
inflorescence height + total number of inflorescence +average infloresçene mass	4	15.97	0.1793
plant height +total number of inflorescence + volume + average inflorescence mass	5	16.65	0.1301
inflorescence height + total number of inflorescence + volume +average inflorescence mass	5	17.77	0.0730
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	18.79	0.0438
total number of inflorescence + volume + average inflorescence mass	4	20.87	0.0155
plant height + inflorescence height + total number of inflorescence + volume + average inflorescence mass	6	22.11	0.0084
total number of inflorescence + average inflorescence mass	3	34.28	0.0000
total number of inflorescence + volume	3	37.26	0.0000
plant height + total number of inflorescence + volume	4	42.05	0.0000

Table 3.33. Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for cultivated rice seed biomass prediction model developed from stepwise multiple linear regression analyses using phytomorphological and seed biomass calculations from cultivated rice collected Mad Island Nature Preserve 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Intercept	57.4614	2.19	26.22	0.001	52.9917	61.9311
Total # Inflorescence (n)	1.86339	0.08	23.22	0.001	1.6997	2.0271
Average Inflorescence Mass (g)	-104.516	5.22	-20.02	0.001	-115.1616	-93.8705

Table 3.34 Variables, parameter estimates and Standard Errors (SE), *t* values, *P* values, and 95 % Confidence Intervals (CI) for cultivated rice seed biomass prediction model developed from no intercept multiple linear regression analyses using phytomorphological and seed biomass calculations from cultivated rice collected Mad Island Nature Preserve 2005.

Variable	Estimate	SE	*t*	*P*	Lower CI	Upper CI
Total Height (cm)	0.4847	0.04	11.95	0.001	0.4019	0.5676
Inflorescence Height (cm)	0.8624	0.27	3.17	0.003	0.3067	1.4181
Total # Inflorescence (*n*)	2.0012	0.16	12.72	0.001	1.6798	2.3226
Average Inflorescence Weight (g/*n*)	-89.4414	10.14	-8.82	0.001	-110.1412	-68.7415

Table 3.35. Multiple linear regression models for phytomorphological variables predicting seed yield biomass of rice on Mad Island Nature Preserve (Matagorda County, Texas) 2004-2005.

Model	No. parameters	Δ AIC $_c$	AIC $_w$
total number of inflorescence + average infloresene mass	3	101.02	0.7199
plant height + total number of inflorescence + average infloresene mass	4	104.93	0.1016
inflorescence height + total number of inflorescence + average infloresene mass	4	105.55	0.0746
total number of inflorescence + volume + average infloresene mass	4	105.58	0.0735
plant height + total number of inflorescence + volume + average inflorescence mass	5	109.42	0.0108
plant height + inflorescence height + total number of inflorescence + average inflorescence mass	5	109.65	0.0096
inflorescence height + total number of inflorescence + volume + average inflorescence mass	5	109.79	0.0089
plant height + inflorescence height + total number of inflorescence + volume + average inflorescence mass	6	114.13	0.0010
plant height + total number of inflorescence	3	188.59	0.0000
inflorescence height + total number of inflorescence	3	189.00	0.0000

Table 3.36. Point of origin regression models for phytomorphological variables predicting seed yield biomass of rice on Mad Island Nature Preserve (Matagorda County, Texas) 2004-2005.

Model	No. parameters	Δ AIC_c	AIC_w
plant height + inflorescence height + total number of inflorescence + average inflorescene mass	5	153.26	0.5567
plant height + total number of inflorescence + volume + average inflorescene mass	5	154.19	0.4506
plant height + inflorescence height + total number of inflorescence + volume + average inflorescene mass	6	158.06	0.0652
plant height + total number of inflorescence + average inflorescene mass	4	158.31	0.0574
plant height + total number of inflorescence	3	187.43	0.0000
plant height + total number of inflorescence + volume	4	191.93	0.0000
plant height + inflorescence height + total number of inflorescence	4	192.00	0.0000
plant height + inflorescence height + total number of inflorescence + volume	5	196.44	0.0000
total number of inflorescence + volume + average inflorescence mass	4	207.25	0.0000
inflorescence height + total number of inflorescence + average inflorescence mass	4	208.02	0.0000

Table 3.37. Regression equations for estimating seed biomass (g) of 4 moist-soil plants using dot grid estimates collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), Trinity and Petigrew Ranch (Freestone County, Texas), and Mad Island Nature Preserve (Matagorda County, Texas) sites August 2004 and 2005.

Plant Species	*n*	Regression Equation	*F*	R^2	*P*
Barnyardgrass [1]	135	0.17334 + (0.00243 x dots) [a]	120.15	0.47	< 0.001
		(0.00309 x dots) [a]	1791.43	0.93	< 0.001
Barnyardgrass [2]	31	0.30859 + (0.00134 x dots) [a]	6.48	0.18	< 0.016
		(0.00275 x dots) [b]	174.54	0.85	< 0.001
Wild Millet [1]	40	0.40541 + (0.00168 x dots) [a]	110.47	0.74	< 0.001
		(0.00233 x dots) [a]	1382.14	0.97	<0.001
Jungle Rice [2]	32	0.38114 + (0.000185 x dots) [b]	0.30	0.01	$\geq$ 0.588
		(0.00377 x dots) [a]	181.22	0.90	< 0.001
Rice [2]	22	1.30979 + (0.00652 x dots) [b]	3.14	0.13	$\geq$ 0.091
		(0.01217 x dots) [a]	470.94	0.95	< 0.001

[1] Middle trinity River Valley Collection Sites
[2] Mad Island Nature Preserve Collection Site
[a] Simple Linear Regression
[b] Point of Origin regression

Table 3.38. Pooled overall mean, maximum, minimum, Standard Error (SE) seed mass and production estimates for 4 moist-soil plant species collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), Trinity and Petigrew Ranch (Freestone County, Texas) and Mad Island Nature Preserve (Matagorda County, Texas) found in east-central and coastal Texas, 2004-2005.

Species	*n*	Seed mass (g/m^2)				Estimated Weight (kg / ha)
		Min	Max	$\bar{x}$	SE	
Barnyard Grass[1]	168	1.52	11.00	4.34	0.17	281
Barnyard Grass[2]	29	0.67	10.13	3.13	0.38	202
Wild Millet[1]	76	1.72	16.00	6.64	0.43	430
Jungle Rice[2]	25	1.23	11.13	4.69	0.45	304
Rice[2]	34	27.5	93.8	56.8	0.34	3677

[1]Middle Trinity River Valley Sites

[2]Mad Island Nature Preserve Site

Table 3.39. Pooled overall mean, maximum, minimum, Standard Error (SE) seed mass and production estimates for 4 moist-soil plant species collected on Middle Trinity River sites and Mad Island Nature Preserve found in east-central and coastal Texas, 2004-2005.

Species	*n*	Seed mass (g/m^2)				Estimated Weight (kg / ha)
		Min	Max	$\bar{x}$	SE	
Barnyard Grass[1]	168	1.52	11.00	4.34	0.17	281
Barnyard Grass[2]	29	0.67	10.13	3.13	0.38	202
Wild Millet[1]	76	1.72	16.00	6.64	0.43	430
Jungle Rice[2]	25	1.23	11.13	4.69	0.45	304
Rice[2]	34	27.5	93.8	56.8	0.34	3677

[1]Middle Trinity River Valley Sites

[2]Mad Island Nature Preserve Site

Table 3.40. Overall mean, maximum, minimum, Standard Error (SE) of seed mass and production estimates for 4 moist-soil plant species collected on Richland Creek Wildlife Management Area (Freestone County, Texas), Big Woods (Freestone County, Texas), Trinity and Petrigrew Ranch (Freestone County, Texas), and Mad Island Nature Preserve (Matagorda County, Texas) found in east-central and coastal Texas, 2004 and 2005.

Species	Year	*n*	Seed mass (g/m^2)				Production (kg / ha)
			Min	Max	$\bar{x}$	STD	
Barnyard Grass[1]	2004	60	1.00	11.00	4.95	2.62	320
Barnyard Grass[1]	2005	108	0.99	9.42	3.73	1.73	241
Barnyard Grass[2]	2005	29	0.67	10.13	3.13	2.05	202
Wild Millet[1]	2004	51	1.00	16.00	7.76	4.02	502
Wild Millet[1]	2005	25	1.72	7.00	4.13	1.55	267
Jungle Rice[2]	2005	25	1.23	11.13	4.69	2.28	304
Rice[2]	2005	34	27.5	93.8	56.8	1.99	3677

[1]Middle Trinity River Valley Sites

[2]Mad Island Nature Preserve Site

CHAPTER IV

DECOMPOSITION OF THREE COMMON MOIST-SOIL MANAGED WETLAND PLANT SPECIES ON RICHLAND CREEK WILDLIFE MANAGEMENT AREA, TEXAS

INTRODUCTION

Typically, management strategies of moist-soil wetlands promote germination and growth of annual seed producing, moist-soil plants through precisely timed drawdown and inundation, which eventually provide high quantities of food available to wintering and migrating waterfowl (Fredrickson and Taylor 1982, Haukos and Smith 1993, Gray et al. 1999, Lane and Jensen 1999, Anderson and Smith 2000, Strader and Stinson 2005). Drawdowns promote a flush of germination and growth of annual moist-soil plant species (Fredrickson and Taylor 1982, Haukos and Smith 1993, Lane and Jensen 1999, Strader and Stinson 2005) as managed wetland substrates are exposed to aerobic conditions and large quantities of minerals and nutrients are released from senescent plant material (Klopatek 1978, Atkinson and Cairns Jr. 2001, Sun et al. 2011). In sum, this cycle of water addition and removal, which drives plant decomposition and subsequent nutrient cycling, is important to overall moist-soil managed wetland function and production (Wrubleski et al. 1997), through seed production, aquatic invertebrate colonization, and waterfowl use of such managed wetlands (Murkin and Batt 1987, Wrubleski et al. 1997, Bird et al. 2000). More specifically, plant decomposition improves seed bank longevity, seed germination response, and wetland function in both natural and managed wetlands (van der Valk 1986, Murkin et al. 1989, Haukos and Smith 1993, Anderson and Smith 1999), as decomposition drives nutrient cycling via wet-dry cycles in wetlands (Anderson and Smith 2002).

Nutrient cycling in wetlands is related to two factors: (1) primary production (i.e., annual and perennial plants) and (2) decomposition (van der Valk 1986, Bedford et al.

1999), where decomposition occurs in three stages (Godshalk and Wetzel 1978, Murkin et al. 1989). During the first stage (i.e., leaching stage), organic particles and ions are leached into the surrounding water, where the greatest biomass reduction occurs within the first few days of inundation (i.e., up to 7 days). In the second phase (i.e., decomposer stage), microbial activity increases and biomass reduction continues to occur gradually, typically over a longer period of time (i.e., > 100 days). The final stage (i.e., refractory stage) occurs over an extended period of time, due to slow degradation of remaining material, such as lignins and others that are difficult to break down and resistant to decay (Ruppel et al. 2004). Therefore, to maximize decomposition, managed wetland should be inundated long enough to allow completion of the second decomposition phase (Murkin et al. 1989, Neckles and Neill 1994, Wrubleski et al. 1997, Anderson and Smith 2002).

Considerable attention has been focused on how inundation regimes control or drive litter decomposition (Brinson et al. 1981, Neckles and Neill 1994), as water directly influences decomposition via leaching and soil moisture, but also indirectly by driving influencing environmental conditions (e.g., pH, temperature, oxygen levels, and dissolved nutrient availability) that affect microbial activities (Mitch and Gosselink 1993, Kuehn and Suberkropp 1998, Lan et al. 2006). Beyond inundation duration, many studies of wetland plant litter decomposition have focused on above-ground herbaceous perennial species (Bell et al 1978, Neckles and Neill 1994, Wrubleski et al. 1997), rather than on annual species (Anderson and Smith 2002), which tend to have less structural complexity and lignin content (Brinson et al. 1981, Ruppel et al. 2004, Poi de Neiff et al. 2006). Consequently, general consensus on the impact of inundation regimes on decomposition rates is complicated, due to variability in many conditions beyond simply hydroperiod duration (Brinson et al. 1981, Neckles and Neill 1994).

Inundation also regulates macroinvertebrate abundance and can influence litter quality by controlling macrophyte species composition (Neckles and Neill 1994), as aquatic invertebrates also assist with plant material breakdown through direct consumption (see Chapter V) (Brinson et al. 1981, Gray et al. 1999, Anderson and Smith 2000, Anderson and Smith 2002). As decomposing plant material availability impacts the invertebrate assemblage throughout the inundation period, invertebrate assemblage structure will also influence plant community structure during subsequent drawdowns (Anderson and Smith 2000). Longer hydroperiods in natural and managed wetlands result in more diverse invertebrate communities because more time is available for colonization and community development (Rosenzweig 1996, Anderson and Smith 2000). Inundation duration can also be a major determinant of plant community development and pattern zonation via inundation rate, depth, duration, and frequency (Davis and van der Valk 1978, Brinson et al. 1981, Neckles and Neill 1994), although drying rate, timing and predictability of drawdown can have similar influences (Day 1982, Neckles and Neill 1994). By specifically altering inundation and drawdown timing, frequency, and duration, both decomposition rate and extent, as well as plant establishment (from the seed bank), can be manipulated to meet specific management goals and objectives (Haukos and Smith 1994, Casanova and Brock 2000, Anderson and Smith 2002).

The objectives of moist-soil management are to (1) maximize production of desirable vegetation, (2) control growth of undesirable vegetation, and (3) provide the required habitat parameters for a variety of wildlife species (Fredrickson and Taylor, 1982, Lane and Jensen 1999, Strader and Stintson 2005). Understanding and controlling the mechanisms by which hydroperiod controls litter decomposition and dynamics under field conditions is crucial to wetland managers (Haukos and Smith 1994, Neckles and Neill 1994, Wrubleski et al. 1997). Management of decomposition rates through proper management techniques are required so litter does not negatively affect germination rates of desired moist-soil plant species during drawdown periods nor inhibit aquatic invertebrate colonization or production (van der Valk 1986, Anderson and Smith 2000).

In an attempt to more clearly understand decomposition dynamics in moist-soil managed wetlands, mass loss and decay coefficients were estimated for three common annual moist-soil plant species (i.e., nodding smart weed (*Polygonum lapathifolium*), redroot flatsedge (*Cyperus erythrorhizos*), and toothcup (*Ammannia coccinea*)) occurring in moist-soil managed wetlands at the Richland Creek Wildlife Management Area in east central Texas. These species are regionally common and important moist-soil plants (Laubhan and Fredrickson 1992, Anderson and Smith 1998, Anderson and Smith 1999) due to their importance as waterfowl food (Stutzenabker 1999, Strader and Stinson 2005).

STUDY AREA

This research was conducted on the Richland Creek Wildlife Management Area's (RCWMA) North Unit moist-soil managed wetlands 1-4 (Figure 1.1). The RCWMA (31º13'N, 96º11'W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The RCWMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were fully functional. Construction of moist-soil managed wetland units 5-6 began in the summer 2006 and have been functioning since November 2009.

Local climate is considered subtropical with mild winters and warm humid summers, with an average daily summer temperature of 34º C and winter temperature of 5º C, a growing season of 246 days, and average rainfall of 101.6 cm a year (NRCS

2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, and mollisol soils (NRCS 2002).

Vegetation within the South Unit (Figure 1.4) is characterized by vast bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North Unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. The typical water management strategy consists of slow drawdown (i.e., removal of water) starting late March - early April and lasting until mid August. Inundation (i.e., flooding) begins in late August and lasts throughout fall and winter, until drawdown the following spring. These management actions produced common species such as barnyardgrass, nodding smartweed (*Polygonum lapathifolium*), toothcup (*Ammannia coccinea*), redroot flatsedge (*Cyperus erythrorshizos*), erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet, and water primrose (*Ludwigia peploides*) (Appendix A).

METHODS

Focal Plant Species

Nodding Smartweed

Nodding smartweed is an annual herb attaining heights of 1-2 m and is primarily restricted to freshwater sites. The plant grows well on clay mineral soils, but normally proliferates on organic soils that dry in summer and is typically found on slight elevations, on edges of levees, and in road ditches. Nodding smartweed needs annual late spring-early summer drawdown to promote germination. After germination and plant emergence, nodding smartweed prospers with shallow flooding (Stutzenbaker 1999; Tiner 1993), and the seed is an excellent waterfowl food (Fredrickson and Taylor 1982, Stutzenbaker 1999).

Toothcup

Toothcup is an annual herb growing up to 50 cm and grows well on moist-soils of lightly flooded sites. It is primarily a freshwater plant that requires a spring drawdown for germination, and once established, it prospers with shallow flooding regimes (Stutzenbaker1999). Waterfowl will ingest seeds when available (Fredrickson and Taylor 1982), although its lack of wide geographic distribution and abundance rank it low in waterfowl food value (Frederickson and Taylor 1982) it was found to be important on RCWMA.

Redroot flatsedge

Similar to green flatsedge (*Cyperus virens*) redroot flatsedge is an annual herb restricted to freshwater wetlands, reaching approximately 1m in height. Spring drawdown is required for germination, and once emerged and established, it will tolerate shallow flooding (Stutzenbaker 1999). Strader and Stinson (2005) list redroot flatsedge as a good waterfowl food.

Material collection and sample deployment

Mature standing nodding smartweed, redroot flatsedge, and toothcup leaves, seeds, and stems were collected (i.e., up to 1.2 kg per species) during late August and early September 2004, prior to senescence, from each moist-soil managed wetland cell in monotypic stands of each species. All plant materials were collected using hand clippers, where samples were placed into plastic garbage bags and placed on ice.

Fiberglass bags were constructed using 2 pieces of 1 mm aperture fiberglass material (i.e., window screen material) stapled together securely so a composite 20 g sample of each species (i.e., stems, leaves, and seeds) could be secured into the bag, following Anderson and Smith (2002). Individual monospecific samples of the 3 plant species were prepared by clipping 15-20 cm stem lengths and by placing whole seeds and leaves into each litter bag. All bags were labeled with a unique identification number. All bags with premeasured 20 g wet sample materials were air dried to a constant mass prior to deployment in field experiment.

On 15 September 2004, 13 bags per species were evenly distributed into the 4 moist-soil managed wetlands. Each moist-soil managed wetland received 39 bags. In total, there were 156 bags deployed; 52 bags per species (13 bags/wetland/species). One transect was established in each moist-soil managed wetland, where a fluorescent marked wooden post was placed every 10 m along the transect (12 posts in each moist-soil managed wetland). Three bags (1 of each species) were randomly attached to each pole using 20 cm of monofilament and laid on the wetland floor (Figure 4.1). Starting on September 23rd and repeated every 8th day, four litter bags were randomly collected from each moist-soil managed wetland. All litter bags were collected by July 17, 2005. At the time of bag removal, at each collection point (i.e., wooden stake), the following water quality metrics were measured: water depth (cm), water temperature (ºC), dissolved oxygen (mg/l), conductivity (US/cm^3), and pH using an YSI model 85 and YSI 200 pH meter. Litter bags were removed by cutting the monofilament and placing a 500 µm sieve under each bag to capture any escaping plant matter. Each litter bag was then placed into individually labeled bags and placed on ice. Plant material was removed from each sample bag and gently washed to remove silt and other material (Wrubleski et al. 1997). The remaining matter was then oven dried to a constant mass at 60º C for 48-92 hr and measured to the nearest 0.01g.

Data Analyses

Decay coefficients were estimated for each species overall and each species within a single moist-soil managed wetland using the single exponential decay model created by Taylor and Parkinson (1988). Data were fit to a model structure: linear mass loss

$$W_t / W_o = ln\,(-kt)$$

where t was time (weeks), W_o was the original mass (g), W_t was mass remaining at time t, and k was instantaneous mass loss rate. Data were collapsed into three different time periods, depending upon the number of days each sample bag was deployed in the field.

Samples placed into time period 1 were those collected within 45 days of deployment; samples in time period 2 were collected 46-120 days after deployment, and samples in time period 3 were collected 121-220 days after deployment. Analysis of covariance (ANCOVA) was used to examine differences in biomass lost and decay coefficients over time (i.e., 3 time periods) within moist-soil managed wetland cells. As no drawdown occurred during this study, water quality variables (i.e., depth, temperature, conductivity, pH, and dissolved oxygen) were used as covariates to examine if water quality parameters alone influenced biomass loss and decay coefficients. If differences occurred ($P < 0.05$), least squares mean separation was used to more clearly identify differences.

RESULTS

Mean decay coefficient rates for all three species ranged from 0.72-0.80 in September (within 30 days of initial deployment) to 0.36 in July (approximately 300 days after initial deployment) (Figure 4.2). Decay rates of nodding smartweed ranged from 0.73-0.75 (September), 0.43-0.58 (February), to 0.36-.37 (July) (Figure 4.3). Similarly, toothcup decay rates ranged from 0.63-0.72 (September), 0.46-0.57 (February), and 0.36-0.38 (July) (Figure 4.4). Finally, red-rooted flatnut sedge decay rates ranged from 0.56-0.64 (September), 0.50-0.69 (February), and 0.37 (July) (Figure 4.5).

Collectively, decay rates during the first stage of decomposition were 0.75 (nodding smartweed), 0.63 (toothcup), and 0.56 (red-rooted flatnut sedge), indicating that approximately 50-75% of all decomposition for all three species occurred during this first decomposition stage (Figure 4.6). During the second decomposition stage, decay rates were 0.52 (nodding smartweed and red-rooted flatnut sedge) and 0.48 (toothcup), indicating that 15-20% additional mass was lost for nodding smartweed and toothcup during this stage, but only an additional 4% was lost for red-rooted flatnut sedge (Figure 4.6). During the final decomposition stag, decay rates were 0.36 and 0.37 for all species, indicating that an additional 10-15% additional mass was lost for each species during this final state (Figure 4.6). All species lost nearly 100% of initial mass during the 11 month deployment period. Both nodding smartweed (Figure 4.7) and toothcup (Figure 4.8) approached 100% mass lost by May, whereas red-rooted flatnut sedge neared 100% mass lost by the end of April (Figure 4.9).

Nodding Smartweed

For nodding smartweed, time since deployment drove rate of mass lost (*F* = 7.87, 1, 51 df; *P* = 0.007), but individual moist-soil managed wetland cells did not (*F* = 0.77, 1, 51 df; *P* = 0.383). There were no significant water quality covariates for rate of mass lost for nodding smartweed {temperature (*F* = 0.54, 1, 51 df; *P* = 0.466), depth (*F* = 0.51, 1, 51 df; *P* = 0.478), conductivity (*F* = 0.03, 1, 51 df; P = 0.860), pH (*F* = 0.06, 1, 51 df; *P* = 0.814), and dissolved oxygen (*F* = 0.31, 1, 51 df; *P* = 0.581)}, indicating that time, rather than individual cell or water physiochemistry was most important in determining rate of mass lost. Analysis of decay coefficient rates indicated time (*F* = 0.03, 1, 51 df; *P* = 0.852), moist-soil managed wetland cell (*F* = 0.51, 1, 51 df; *P* = 0.479), and all water quality covariates; depth (*F* = 0.81, 1, 51 df; *P* = 0.373), temperature (*F* = 0.87, 1, 51 df; *P* = 0.356), conductivity (*F* = 0.64, 1, 51 df; *P* = 0.426), pH (*F* = 0.19, 1, 51 df; *P* = 0.667), and dissolved oxygen (*F* = 0.01, 1, 51 df; *P* = 0.905) had no effect on decay coefficient rates (Table 4.1).

Red-rooted flatnut sedge

For red-rooted flatnut sedge, neither time since deployment (*F* = 0.53, 1, 51 df; *P* = 0.468) nor individual moist-soil managed wetland cell (*F* = 0.06, 1, 51 df; *P* = 0.804) influenced rate of mass lost. Similarly, there were no significant water quality covariates for rate of mass lost {temperature (*F* = 0.36, 1, 51 df; *P* = 0.549), depth (*F* = 3.85, 1, 51 df; *P* = 0.055), conductivity (*F* = 1.76, 1, 51 df; *P* = 0.191), pH (*F* = 0.00, 1, 51 df; *P* = 0.984), and dissolved oxygen (F = 1.02, 1, 51 df; *P* = 0.318)}. However, decay coefficient rates were driven by time since deployment (*F* = 4.28, 1, 51 df; *P* = 0.043), but individual moist-soil managed wetland cell (*F* = 0.03, 1, 51 df; *P* = 0.871) did not influence decay coefficient rates, indicating that red-rooted flatnut sedge decay was driven by time, but independent of individual moist-soil managed wetland. Similarly, there were no significant water quality covariates for decay coefficient for red-rooted flatnut sedge {depth (*F* = 1.55, 1, 51 df; *P* = 0.218), temperature (*F* = 0.12, 1, 51 df; *P* = 0.728), conductivity (*F* = 1.57, 1, 51 df; *P* = 0.216, pH (*F* = 0.03, 1, 51 df; *P* = 0.859), and dissolved oxygen (*F* = 0.79, 1, 51 df; *P* = 0.381) (Table 4.2).

Toothcup

For toothcup time since deployment drove rate of mass lost (*F* = 29.33, 1, 51 df; *P* < 0.001), but individual moist-soil managed wetland cell did not (*F* = 0.03, 1, 51 df; *P* = 0.871). There were no significant water quality covariates for rate of mass lost for toothcup {temperature (*F* = 0.35, 1, 51 df; *P* = 0.558), depth (*F* = 0.59, 1, 51 df; *P* = 0.446), conductivity (*F* = 0.71, 1, 51 df; *P* = 0.404), pH (*F* = 1.51, 1, 51 df; *P* = 0.229), and dissolved oxygen (*F* = 0.83, 1, 51 df; *P* = 0.368)}. Analysis of decay coefficient rates indicated time (*F* = 2.51, 1, 51 df; *P* = 0.119), moist-soil managed wetland cell (*F* = 0.14, 1, 51 df; *P* = 0.710), and all water quality covariates; depth (*F* = 1.18, 1, 51 df; *P* = 0.282), temperature (*F* = 0.02, 1, 51 df; *P* = 0.893), conductivity (*F* = 0.11, 1, 51 df; *P* = 0.741), pH (*F* = 0.58, 1, 51 df; *P* = 0.453), and dissolved oxygen (*F* = 1.03, 1, 51 df; *P* = 0.316) had no effect on decay coefficient rates (Table 4.3).

DISCUSSION

Plant matter typically decomposes through fast, intermediate, and slow stages of leaching, decomposer, and refractory phases, respectively, according to the processes dominating mass loss during the three stages of decomposition (Bell et al. 1978, Valiela et al. 1985). Focal species mass loss followed this typical three stage pattern, where nodding smartweed, toothcup, and red rooted flat lost approximately a third of their biomass during the first stage of decomposition. Over the second stage decomposition, all 3 species lost up to 50 to 80%, while during the third stage, mass lost for all three species was nearly complete. Similarly, there appeared to be no direct influence of water quality nor individual moist-soil managed wetland cell on total mass lost nor rate of mass lost – it appeared to be driven solely by time since inundation, which closely mirrored these three decomposition stages.

During the course of sample deployment in the field, none of the moist-soil managed wetlands were drawn down in a fashion typical of traditional moist-soil management (Fredrickson and Taylor 1982, Lane and Jensen 1999, Strader and Stinson 2005). For example, spring drawdowns tend to concentrate colonizing aquatic invertebrates, which may promote complete decomposition more quickly in a moist or non-inundated condition (Murkin et al. 1989, Gray et al. 1999, Anderson and Smith 2000, Anderson and Smith 2002, Gingerich and Anderson 2011). Persistent inundation influences plant decomposition in shallow freshwater wetlands by increasing rates of Stage 1 (leaching) and Stage 2 (decomposer) decomposition (Neckles and Neill 1994). In their study, plant materials exposed to persistent inundation were entering the Stage 3 (refractory) decomposition phase by the end of the first growing season, but plant materials exposed to intermediate inundation did not reach the refractory phase until the middle of the second growing season. In short, constant inundation impacts the timing and/or arrival of the final decomposition stage for plant materials in shallow freshwater wetlands.

Dry conditions will result in less leaching, as well as inhibit microbial and invertebrate colonization and community development, resulting in loss of soluble plant material and slowing decomposition of readily decomposable fractions (Wrubleski et al. 1997, Weltzin et al. 2005). The physical structure of these 3 wetland plant species might allow for rapid decomposition, although none of the other measured environmental conditions (i.e., water temperature and depth, conductivity, pH, and dissolved oxygen) influence decomposition. Ruppel et al. (2004) stated that pH and dissolved oxygen appeared to be the most significant factors affecting decomposition rates, followed closely by aquatic invertebrate density. However, their work was conducted during a relatively short temporal window, whereby decomposition rates could have been much greater if their study was continued longer and in summer, where water quality variables could possibly impact decay rates.

Evidence from a variety of wetland systems suggests that, in general, litter decomposition is more rapid at sites that are inundated for at least a portion of the growing season than at sites never flooded (Brinson 1977, Day 1982, Shure et al. 1986, Neckles and Neill 1994). Neckles and Neill (1994) reported that loss of litter mass increases with frequency of flooding from intermittently flooded to flooded twice daily, but did not vary between daily and permanent submergence. As such, some have suggested that flood duration has little effect on mass loss as long as the litter is flooded for a portion of the growing season (Day 1982, Neckles and Neill 1994). Murkin et al. (1989) also suggested that to remove the most litter an area should be flooded long enough to allow the species to complete the second phase of decomposition.

Anderson and Smith (2002) concluded that *Polygonum pensylvanicum* and other annuals (Wrubleski et al 1997) have plant parts that decompose at different rates. *P. pensylvanicum* followed the three phases of decomposition (Valiela et al. 1984, Murkin et al. 1989), but the rate of mass loss varied according to plant part and hydrological regime (Anderson and Smith 2002). Although the current study focused on aboveground biomass (i.e., leaves, stems, and seeds), Murkin et al. (1989) reported that litter was quite persistent in northern priaire marshes, where 70% and 50% of shoot and root litter was still present after one year in the field. In that instance, it was clear that shoot and root parts do not decompose rapidly and release nutrients, but rather create litter mats on the wetland floor. Such litter can reduce germination by changing environmental conditions such as light or temperature regimes, burying seedlings, and releasing chemicals that inhibit seed germination or development (i.e., through allelopathy) (van der Valk 1986). These diverse responses to flooding, and specific plant part response to flooding, have hindered generalizations regarding the effects of flooding on decomposition in wetland ecosystems. In the present study, there was strong evidence that inundation duration is driving mass loss and decay, while water temperature and depth, conductivity, pH, and dissolved oxygen do not.

Neckles and Neill (1994) found that water depth and inundation duration played a major role in mass lost over time with at least 50% of the mass lost by the time plants entered into the 3rd phase of decomposition. Similarly, Anderson and Smith (2002) observed rapid (within 7 days) mass loss of *Polygonum pensylvanicum* in playas, which exhibit similar hydrological regimes to the managed moist-soil wetlands in this study. In the current study, focal species each had lost at least 40% of their mass in 45 days, with nodding smartweed at 55%.   As wetlands mature, they shift from a detritus-poor to a detritus-rich system over time, where benthic organic matter accumulates in created wetlands, but natural wetland substrates have greater organic content than created wetlands (Craft et al. 1999 and 2002, Nair et al. 2001, Campbell et al. 2002). Consequently, rates of detritus decomposition increase with age in created wetlands (Atkinson and Cairns 2001, Spieles and Mora 2007). As such, traditional moist-soil management (i.e., properly timed inundation and drawdowns) conducted on RCWMA moist-soil managed wetlands should contain greater densities of annual plants, where decomposition rates and litter removal will be more efficient and complete as these wetlands age.

Management Implications

Management practices on RCWMA should focus on a yearly to bi-yearly drawdown and inundation water regime to allow for constant cycling of nutrient and decomposition of litter. If done properly, germination of desired moist-soil plant species will not be inhibited due to accumulation of litter mats, and more reliable development of the aquatic invertebrate community should contribute litter breakdown. Using this yearly to bi-yearly drawdown/inundation water regime will allow the managers on RCWMA meet the overall objectives of moist-soil management: (1) maximize production of desirable vegetation, (2) control growth of undesirable vegetation, and (3) provide the required habitat parameters for a variety of wildlife species.

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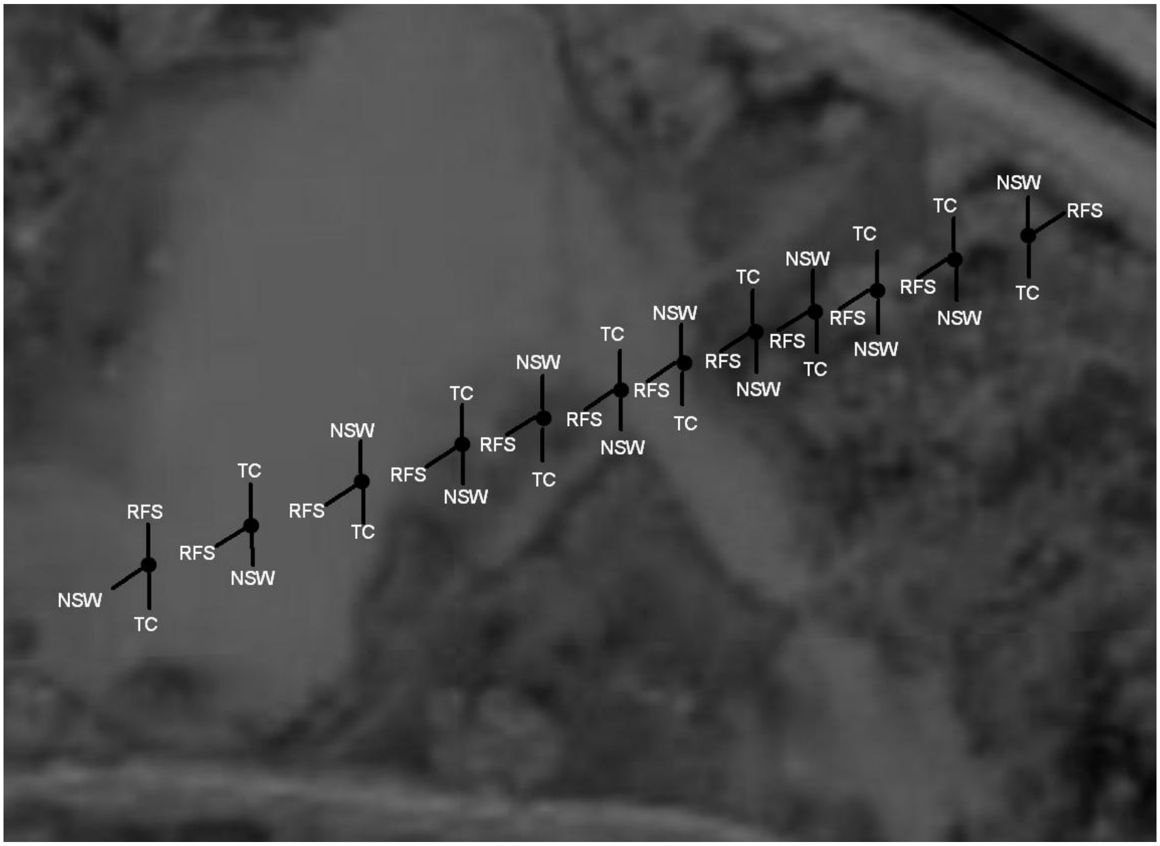

Figure 4.1. Example decomposition layout of 3 moist-soil plant species (i.e., Nodding Smartweed (NSW), Toothcup (TC), and Redroot flatsedge (RFS)) within a moist-soil managed wetland located on Richland Creek Wildlife Management Area, located in east-central Texas, 2004-2005.

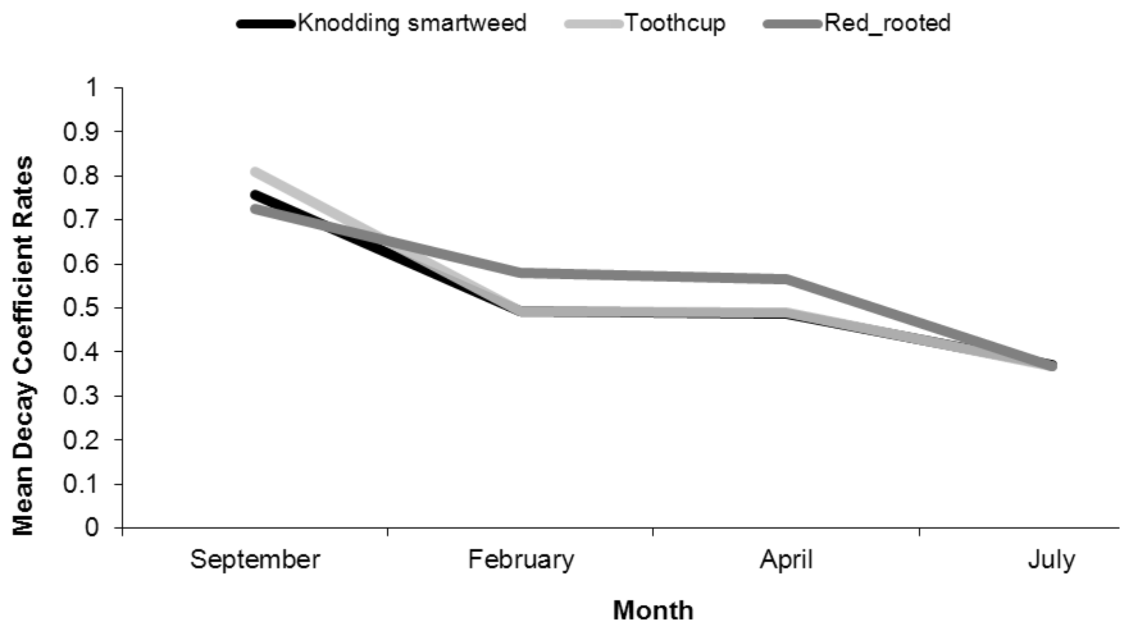

Figure 4.2 Mean decay coefficient rates of 3 moist-soil plant species samples over time from moist-soil managed wetlands on Richland Creek Wildlife Management Area, Texas starting 23 September 2004 through 15 July 2005.

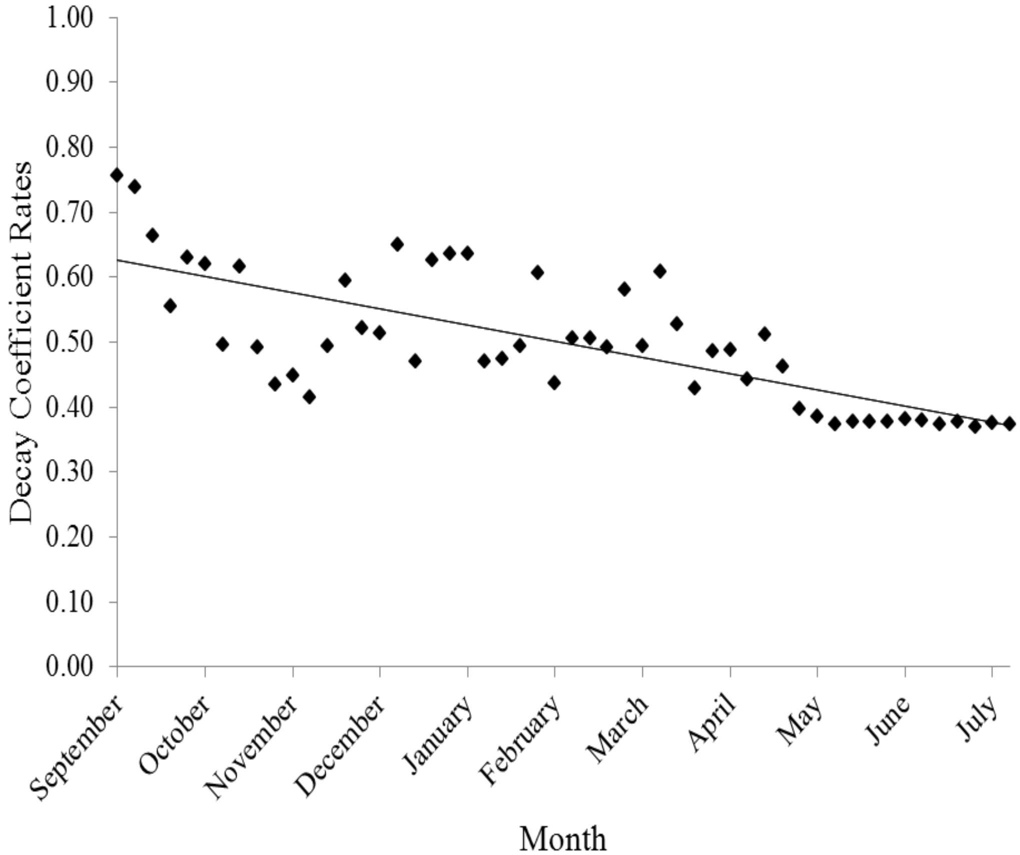

Figure 4.3 Decay coefficient rates over time of *Polygonum lapathifolium* samples collected from moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas starting 23 September and finishing 15 July 2005.

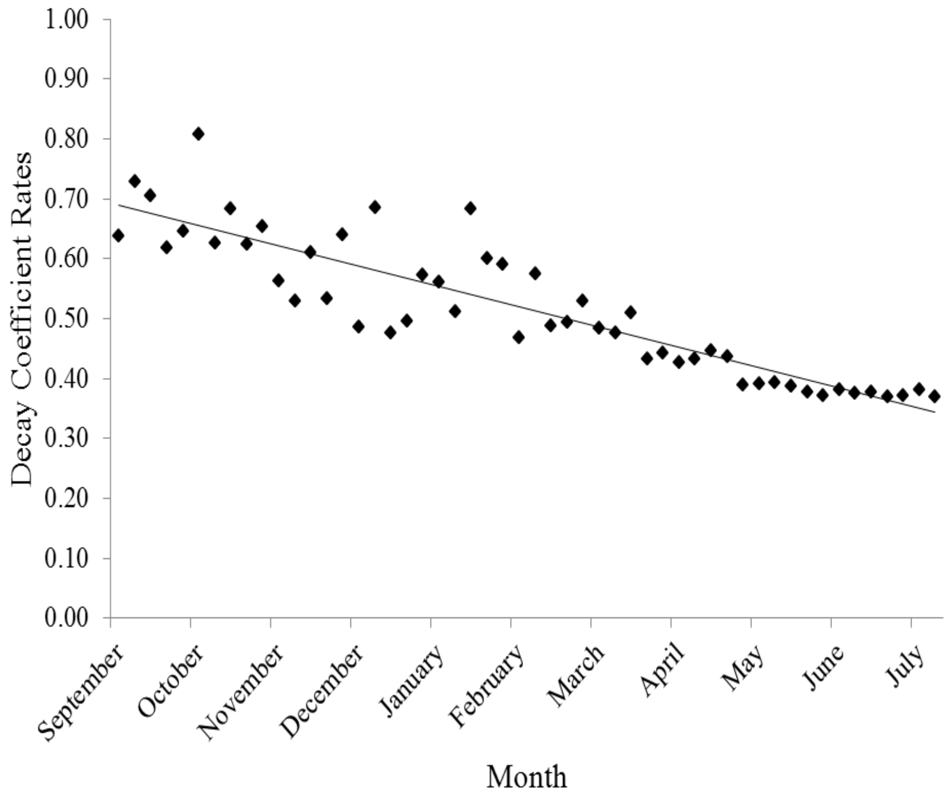

Figure 4.3 Decay coefficient rates over time of *Ammania coccinea* samples collected from moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas starting 23 September and finishing 15 July 2005.

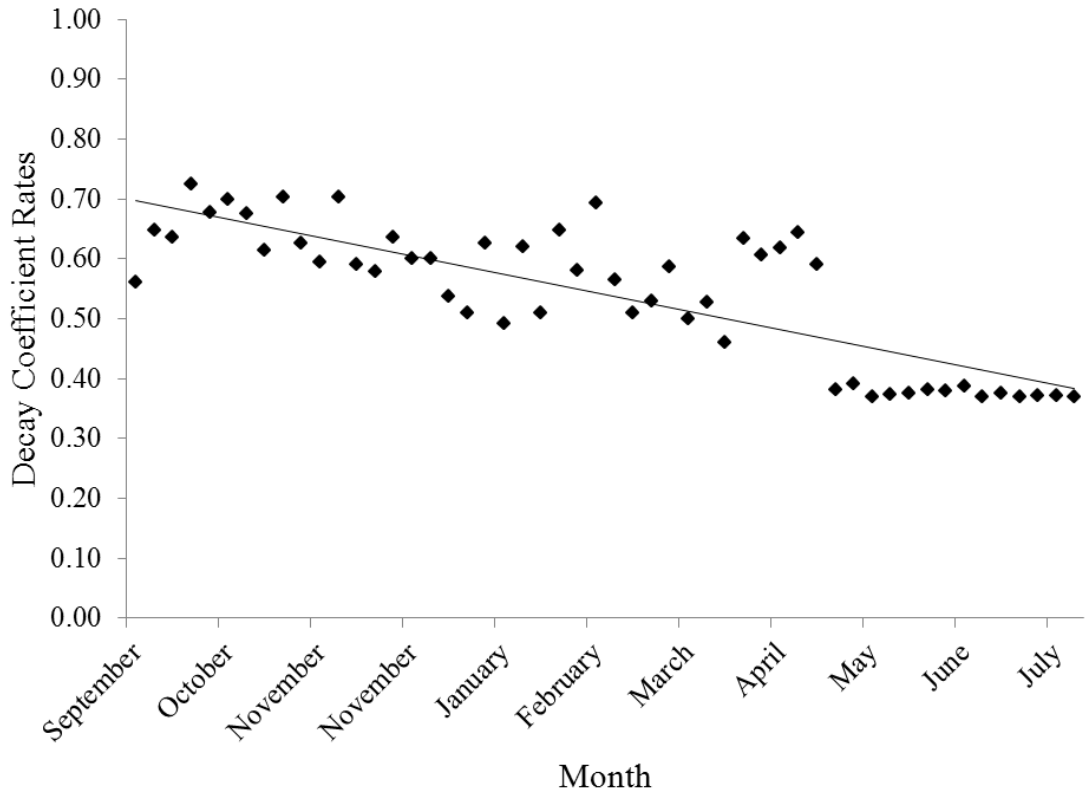

Figure 4.3 Decay coefficient rates over time of *Cyperus erythrorhizos* samples collected from moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas starting 23 September and finishing 15 July 2005.

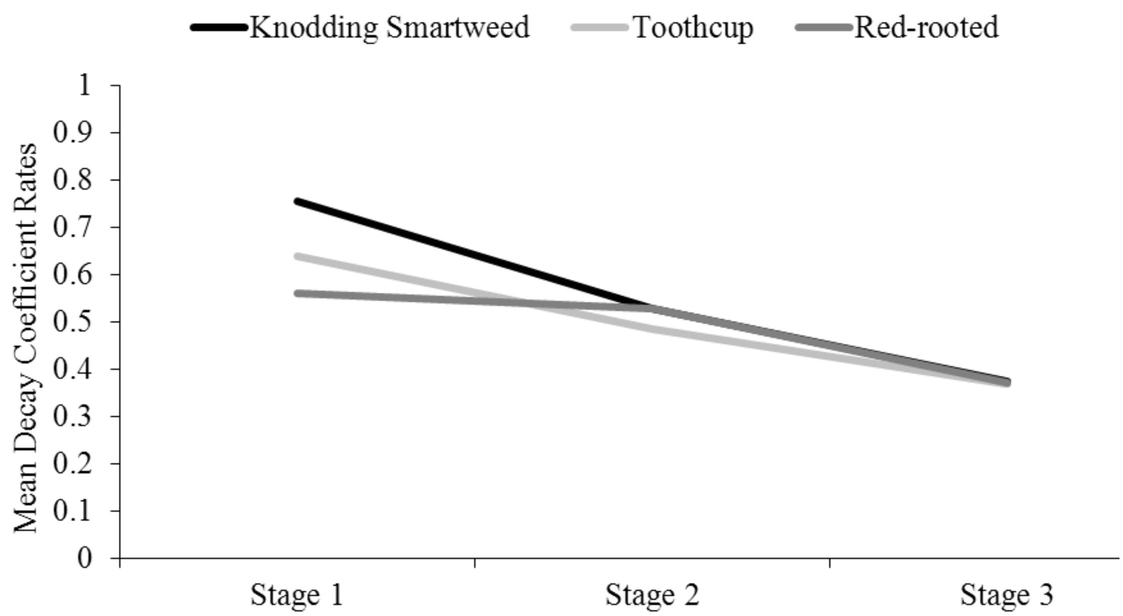

Figure 4.6. Mean decay coefficient rates of 3 moist-soil plant species samples along the 3 stages of decomposition gradient from moist-soil managed wetland on Richland Creek Wildlife Management Area, Texas over the three stages of decomposition.

Stage 1: Leaching of soluble compounds 48 hours after inundation

Stage 2: Tissues low in structural material are broken down by microbial activity

Stage3: Structural compounds remain and resist, slowing decomposition rates

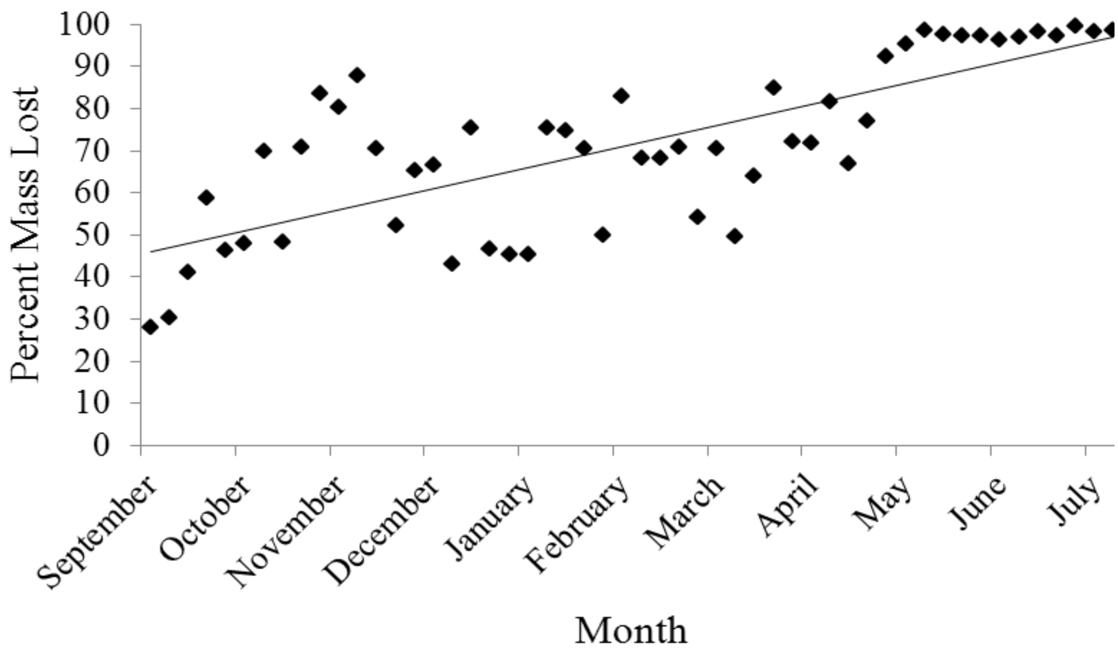

Figure 4.7 *Polygonum lapathifolium* percent mass lost over time (i.e., months) from samples collected on Richland Creek Wildlife Management Area, Texas starting 23 September 2004 through 15 July 2005.

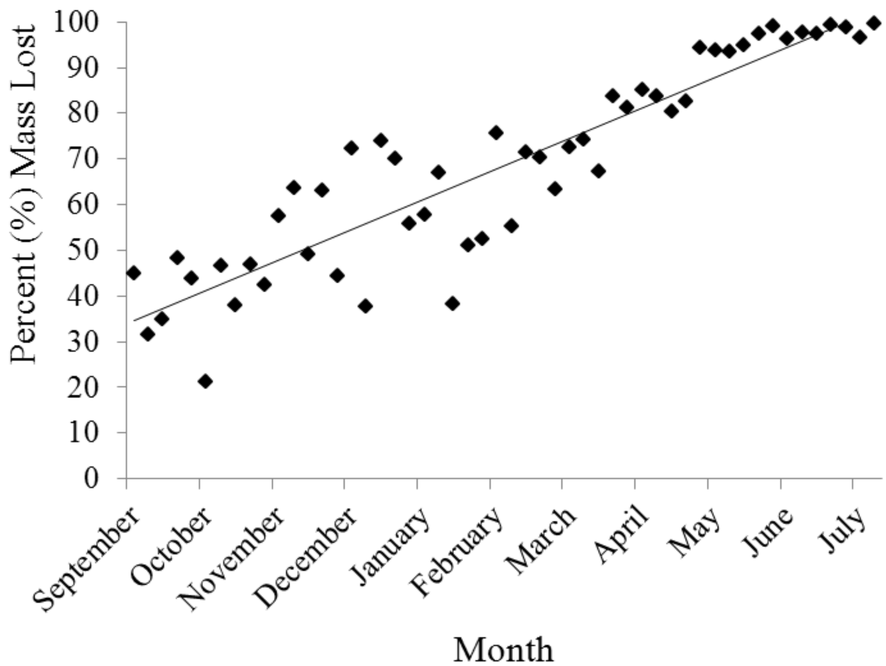

Figure 4.8 *Ammania coccinea* percent mass lost over time (i.e., months) from samples collected on Richland Creek Wildlife Management Area, Texas starting 23 September 2004 through 15 July 2005.

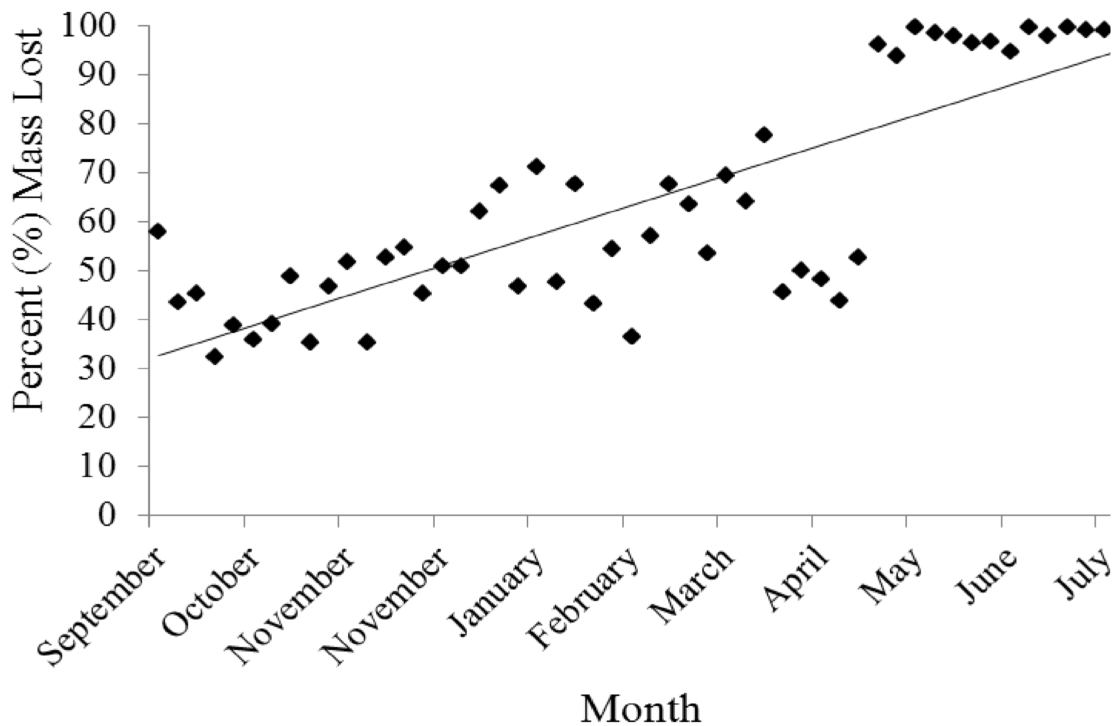

Figure 4.9 *Cyperus erythrorizos* percent mass lost over time (i.e., months) from samples collected on Richland Creek Wildlife Management Area, Texas starting 23 September 2004 through 15 July 2005.

Table 4.1. Mean ($\bar{x}$), Standard Error (SE), minimum and maximum of final mass (g), percent mass lost (%), water depth (cm), temperature (°C), conductivity (µs/cm^3), pH, dissolved oxygen (mg/l), and decay coefficient of *Polygonum lapathifolium* collected on Richland Creek Wildlife Management Area, in east-central Texas to establish decomposition rates over 3 time periods.

	Time Period											
	0-45 days				46-120 days				121 - 220 days			
	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max
% Lost	55.02	5.76	28.00	83.48	63.81	3.13	43.08	87.86	86.43	3.15	49.58	99.55
Depth (cm)	37.64	3.82	19.00	53.00	29.21	2.88	10.00	55.00	29.55	2.73	4.00	63.00
Temperature (°C)	23.05	1.69	11.80	28.90	12.79	0.54	6.90	18.50	33.55	8.78	12.20	216.00
Conductivity (µs/cm^3)	674.67	33.72	552.00	814.00	421.61	29.80	287.70	664.00	636.80	38.05	407.90	850.00
pH	7.74	0.34	6.55	10.36	8.48	0.39	5.26	11.57	7.84	0.19	7.07	8.90
Dissolved Oxygen (mg/l)	1.53	0.42	0.40	4.44	1.74	0.41	0.03	6.68	1.91	0.54	0.11	4.84
Decay Coefficient	0.58	0.03	0.43	0.76	0.53	0.02	0.42	0.65	0.43	0.01	0.37	0.61

Table 4.2. Mean ($\bar{x}$), Standard Error (SE), minimum and maximum of final mass (g), percent mass lost (%), water depth (cm), temperature (°C), conductivity (µs/cm^3), pH, dissolved oxygen (mg/l), and decay coefficient of *Cyperus erythrorizos* collected on Richland Creek Wildlife Management Area, in east-central Texas to establish decomposition rates over 3 time periods.

	Time Period											
	0-45 days				46-120 days				121 - 220 days			
	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max
% Lost	43.21	2.36	32.22	57.81	54.10	2.40	35.19	71.07	82.70	4.62	43.85	99.74
Depth (cm)	32.18	3.86	15.00	57.00	28.58	3.02	10.00	55.00	30.97	2.77	3.00	65.00
Temperature (°C)	25.05	0.66	22.10	29.00	15.31	1.14	7.90	22.10	24.67	1.21	13.10	31.60
Conductivity (µs/cm^3)	692.10	43.41	481.00	842.00	446.88	39.55	272.50	757.00	579.21	63.97	7.95	852.00
pH	7.33	0.66	3.10	9.42	8.08	0.32	5.20	9.44	7.85	0.23	7.27	9.33
Dissolved Oxygen (mg/l)	1.11	0.41	0.08	4.25	1.51	0.31	0.21	4.65	1.85	0.52	0.21	4.77
Decay Coefficient	0.65	0.02	0.56	0.72	0.59	0.01	0.49	0.70	0.45	0.02	0.37	0.65

Table 4.3. Mean ($\bar{x}$), Standard Error (SE), minimum and maximum of final mass (g), percent mass lost (%), water depth (cm), temperature (°C), conductivity (µs/cm^3), pH, dissolved oxygen (mg/l), and decay coefficient of *Ammania coccinea* collected on Richland Creek Wildlife Management Area, in east-central Texas to establish decomposition rates over 3 time periods.

	Time Period											
	0-45 days				46-120 days				121 - 220 days			
	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max	$\bar{x}$	SE	Min	Max
% Lost	41.46	2.93	21.25	57.50	59.63	2.72	37.83	75.75	89.57	2.10	67.47	99.62
Depth (cm)	38.27	2.22	30.00	49.00	25.11	2.31	5.00	40.00	30.18	1.15	14.70	30.10
Temperature (°C)	24.80	0.84	20.70	29.10	13.95	0.97	6.90	22.60	24.07	1.15	14.70	30.10
Conductivity (µs/cm^3)	677.77	38.45	501.00	848.00	399.11	41.76	8.90	733.00	639.12	37.13	378.60	849.00
pH	7.15	0.53	2.44	9.35	8.07	0.39	5.06	9.39	7.96	0.28	7.25	9.84
Dissolved Oxygen (mg/l)	1.60	0.41	0.40	4.10	1.77	0.37	0.01	5.12	2.25	0.53	0.09	4.77
Decay Coefficient	0.66	0.02	0.56	0.81	0.55	0.02	0.47	0.69	0.41	0.01	0.37	0.51

CHAPTER V

AQUATIC INVERTEBRATE PRODUCTION IN MOIST-SOIL MANAGED WETLANDS ON RICHLAND CREEK WILDLIFE MANAGEMENT AREA, TEXAS

INTRODUCTION

Aquatic invertebrates are important components of natural and moist-soil managed wetlands, as they affect wetland energy transfer, and provide food for waterfowl and other wetland-dependent fauna (Teal 1962, de Szalay and Resh 1996, Anderson and Smith 1998, Lane and Jensen 1999). Moreover, aquatic invertebrates also process organic matter through producer and detrital food webs, and physically modify wetland habitats, enhancing their values for other wildlife species (Feieraband 1989, Safran et al. 1997, Anderson and Smith 2000). The importance of aquatic invertebrates, particularly those associated with plants (either free swimming or benthic), as waterfowl food sources during migration and winter has been well established (Krull 1970, Anderson and Smith 1999), although past research emphasized waterfowl food sources provided predominantly from plants themselves (Fredrickson and Taylor 1982, Sheeley and Smith 1989, Haukos and Smith 1993). Such invertebrate food resources are key to waterfowl several times during the annual cycle, particularly when waterfowl need to complete molt, produce eggs, and store energy for successful migration and overwinter survival (Chabreck 1979, Drent and Daan 1980, Reinecke et al. 1982, Krapu et al. 1995, Safran et al. 1997, Anderson and Smith 1998, Manley et al. 2004).

Aquatic invertebrate community structure and abundance have been frequently correlated with wetland selection and distribution by waterfowl and shorebirds (Murkin and Kadlec 1984, Colwell and Landrum 1993, Haukos and Smith 1993, Safran 1997, Anderson and Smith 1999), indicating clear linkages among these taxa. Although waterfowl differentially rely upon various groups of wetland and aquatic invertebrates, their diversity can indicate wetland hydrological history, wetland function, and overall ecosystem health (White and James 1978, Nudds 1983, Haukos and Smith 1993, Anderson and Smith 1998, Anderson and Smith 1999, Twedt and Nelms 1999). However, waterfowl use of different invertebrate resources as food highlights species-specific foraging patterns and decisions, as well as overall availability. Moreover, waterfowl use of aquatic invertebrate resources are not universal (see Chapter VI), nor do all invertebrates provide similar nutritional benefits (Batzer et al. 1993, Davis, C.A. 1996, Anderson 1997, Anderson and Smith 1998, Marklund and Sandsten 2002). As such, monitoring wetlands using aquatic invertebrates, either functionally or for evaluation as potential waterfowl habitat requires some consolidation into similar functional, taxonomic, or natural history groups. To that end, Eldridge (1990) identified 4 basic groups of aquatic invertebrates: (1) passive dispersers, such as leeches, amphipods, isopods, and gastropods, (2) those that can withstand both drought and freezing, such as some Coleoptera and Diptera, (3) those that lay eggs in moist-soils of drying wetlands during summer, such as some Odonata and Diptera, and (4) those that leave shallow, ephemeral wetlands to winter in larger, more stable aquatic systems, such as some Hemiptera and Coleoptera. Knowing waterfowl food habits and invertebrate community composition and associated life history groupings, can drive management strategies and allow for evaluation of management success through short and long term monitoring.

As aquatic invertebrates are sensitive to changes in wetland hydrology and water quality, they have been described as suitable biomonitors of pollution and environmental stressors, overall wetland health, and management strategies in managed wetlands

(Rosenberg et al. 1986, Rosenberg and Resh 1993, Nzengy'a and Wishitemi 2001, Schmidt-Kloiber and Nijboer 2004). For example, responses at different levels of organization, ranging from individuals, to individual species, to the total invertebrate community, can provide insight into environmental changes (Hodkinson and Jackson 2005). Responses to a single pollutant may be detected by changes in individual species, but long-term monitoring of conservation value of particular sites may be better indicated by changes in the entire invertebrate community structure. Consequently, quantifying and monitoring aquatic invertebrate abundance and community structure is a critical element of monitoring wetland management success (Nzengy'a and Wishitemi 2001).

Community level studies of aquatic macroinvertebrates tend to be analyzed on a singular taxon basis, which involves analysis of abundance and/or biomass of individual taxa in response to management techniques or habitat features (Zimmer et al. 2001). Many studies have shown that aquatic invertebrate standing stock biomass is influenced or even driven by variation in hydroperiod, colonization rates/strategies, and species-specific persistence or life history strategies (Voigts 1976, Gray et al. 1999, Anderson and Smith 2000, de Szalay and Resh 2000, Anderson and Smith 2004). For example, invertebrate community composition in bottomland hardwood wetlands is influenced by hydroperiod, water depth, and dominant vegetation, where low standing stock biomass typically occurs in seasonally inundated floodplain wetlands (Gladden and Smock 1990). Conversely, Duffy and Labar (1994) reported that species richness was greatest in moist-soil managed wetlands, where invertebrate biomass and abundance can be dramatically increased in wetlands exposed to moist-soil management techniques (Reid 1983, Neckles et al. 1990, Batzer and Resh 1992, Gray et al. 1999, Anderson and Smith 2000). Timely addition and removal of water will provide suitable conditions for a diverse suite of aquatic invertebrates, where normal moist-soil management regimes should increase invertebrate biodiversity and abundance for wintering waterfowl (Fredrickson and Taylor 1982, Duffy and Labar 1994, Davis and Smith 1998, Gray et al. 1999, Anderson and Smith 2000). This important component of migratory bird management can easily be incorporated into moist-soil management by manipulating wet-dry cycles in managed wetlands (Smith et al. 1989, Anderson and Smith 2000). Such techniques can be useful to maximize waterfowl use of managed wetlands, but by monitoring invertebrate community development and status in these systems, management can by fine tuned and related to other potentially relevant water quality variables as well.

The objective of this portion of this study was to determine the influence of hydroperiod and other wetland management actions on aquatic invertebrate community structure over time among moist-soil managed wetlands on Richland Creek Wildlife Management Area (RCWMA) in east Texas. Specifically, the focus of this research was to estimate how flood timing and duration, as well as water quality parameters impacted aquatic invertebrate density, diversity, richness and production.

STUDY AREA

This research was conducted on the Richland Creek Wildlife Management Area’s (RCWMA) North Unit moist-soil managed wetlands 1-4 (Figure 1.1). The RCWMA (31º13'N, 96º11'W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The WMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were fully functional. Construction of moist-soil managed wetland units 5-6 began in the summer 2006 and have been functioning since November 2009.

Local climate is considered subtropical with mild winters and warm humid summers, with an average daily summer temperature of 34º C and winter temperature of 5º C, a growing season of 246 days, and average rainfall of 101.6 cm a year (NRCS

2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, and mollisol soils (NRCS 2002).

Vegetation within the South Unit (Figure 1.4) is characterized by vast bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North Unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. The typical water management strategy consists of slow drawdown (i.e., removal of water) starting late March - early April and lasting until mid-August. Inundation (i.e., flooding) begins in late August and lasts throughout fall and winter, until drawdown the following spring. These management actions produced common species such as barnyardgrass, erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet, and water primrose (*Ludwigia peploides*) (Appendix A).

METHODS

Aquatic invertebrates were collected twice monthly from April 2004 - May 2007 in each moist-soil managed wetland, when water was present. A 150 m transect was randomly placed in each wetland cell and invertebrates were collected every 10 m (Anderson and Smith 1996). At each point, a 5-cm diameter water column sampler (Swanson 1978) was used to measure water depth (cm) for water volume calculations ($cm^3 = \pi$ x radius x depth). The following water quality parameters were also recorded at each point using YSI model 85 and YSI 200 pH meter: water temperature (ºC), dissolved oxygen (mg/l), conductivity (US/cm^3), and pH. The water column sampler was used to capture aquatic invertebrates at each sample point (every 10 m along each transect). All samples were poured through a No. 60 (0.25 mm) sieve to collect aquatic invertebrates from the water column sample (Huener and Kadlec 1992). When aquatic invertebrates were present, tweezers were used to collect individuals, which were then placed into labeled plastic vials containing 10% ethanol (Anderson and Smith 2004).

Samples were stored in ethanol and refrigerated. Each sample was sorted, where all invertebrates were identified to lowest possible taxonomic designation. Samples containing aquatic invertebrates were poured through a No. 230 (0.063mm) sieve, and then placed into a clear petri dish for identification and enumeration using a Celestron dissecting scope. Once identified, all invertebrates were placed into labeled aluminum weighing dishes and placed into an oven at 55° C for > 24 hrs to estimate dry mass (g) (Gray et al. 1994). Identified specimens were also parsed into 15 taxonomically related groups, which were used to consolidate aquatic invertebrates with similar natural history and taxonomy following Voshell (2002). Groups ranged from Phylum, Subphylum, Class and Order level(s) (Table 5.1), where all identifications were performed following Merritt and Cummins (1984), Pennak (1989), and Voshell (2002).

Simpson's diversity index (*D*) was calculated using the proportion of species *i* relative to the total number of species $(p_i)^2$, where the reciprocal of the squared sum proportions are reported (*Simpson's:* $D = 1 / \sum p_i^2$). Shannon-Wiener diversity index (H') was calculated using both species richness and relative abundance of each species within a community. Shannon-Wiener is calculated by taking the proportion of individual of species *i* in community and multiplying that number by the natural log (Shannon-Wiener: $H' = -\sum (p_i)(\ln p_i)$). Both diversity indices characterize species diversity within a community (Krebs 1999).

Data Analysis

To characterize the aquatic invertebrate community composition, diversity estimates were calculated using the aforementioned taxonomically relevant groups, using Simpson's Diversity Index and Shannon-Wiener Diversity Index in each moist-soil managed wetland during each month (Ludwig and Reynolds 1988). Density (number/cm^3) and biomass (g/cm^3) were calculated for each identified group, collected for each two week period using known volumes of water estimated as previously detailed. Analyses were performed on data averaged by year and month for each moist-soil managed wetland to examine temporal variation (Anderson and Smith 1999) (i.e., years and months) and to reduce interaction effects (Milliken and Johnson 1992). A repeated measure, three-way multivariate analysis of variance (MANOVA) was used to examine differences in aquatic invertebrate density and biomass among years, months, moist-soil managed wetlands, and taxonomic groups (Anderson and Smith 2000). If differences ($P < 0.05$) occurred in MANOVA, univariate analysis of variance was used to further examine those differences. Least square mean separation was used if differences ($P < 0.05$) occurred during ANOVA.

RESULTS

Species Diversity and Abundance

Overall diversity ranged from 0.763 (Simpson's index) and 2.47 (Shannon-Weiner) (Table 5.2). Among years, both indices were relatively consistent (Table 5.2). Examining diversity by month only, August and September had the greatest diversity, while May and June had the lowest diversity (Table 5.2). As flooding regime and plant community structure varied among individual moist-soil managed wetlands, examining diversity among individual managed wetlands was of interest at the local scale. Both indices were remarkably consistent over time within each cell, where Simpson's indices varied little within each managed wetland, but were markedly lower in moist-soil managed wetland 4, which was the last wetland in the train arrangement on the RCWMA (Table 5.3).

In an attempt to more clearly delineate diversity estimates (beyond the aforementioned groups), family diversity estimates ranged from 0.77-0.81 over the course of this study (Table 5.4). Similar to the group diversity estimates, family diversity estimates were greatest during August and September, while May and June typically produced the lowest diversity (Table 5.4). Again, as flooding regime and plant community structure varied among individual moist-soil managed wetlands (see Appendix A), examining invertebrate family diversity among individual managed wetlands was of interest at the local scale. Similar to the larger groupings, family diversity estimates were remarkably consistent among years within each managed wetland, where managed wetland 4 contained the lowest family diversity estimates (Table 5.5)

Aquatic Invertebrates

Forty-one aquatic invertebrate families were identified, but grouping into higher taxonomic levels resulted in 15 groups (see Table 5.1), where a total of 12,089 individuals were captured over the course of this study (Table 5.6). The three most abundant aquatic invertebrate taxa captured were Crustacea (n = 3568), Ephemeroptera (n = 2080) and Heteroptera (n = 2038), while only a few individuals of Megaloptera (n = 2), Arachnida (n = 14) and Plecoptera (n = 21) were captured (Table 5.6). However, biomass production was allocated differently than total abundance, where Crustaceans (27.39g) accounted for the greatest total biomass, followed by Gastropods (27.11g), Odonata (14.9 g), Heteroptera (15.4 g) and Diptera (13.6 g), where cumulative biomass was nearly 120 g (Table 5.6). The most commonly collected aquatic invertebrates were Amphipods (scuds), followed by Chironomids (midges), and Corixids (water boatmen) (Table 5.7). Several specimens were infrequently encountered, such as Dryopids (long-toed water beetle), Elmids (riffle beetle), and Sialids (alderflies) (Table 5.7). Biomass production generally mirrored abundance estimates, where Scuds and midges were greatest, following by Planorbid snails and Libellulid dragonfly larva (Table 5.7).

Invertebrate density and biomass did not vary among months (Wilk's λ = 0.994, P = 0.299), years (Wilks' λ = 0.999, P = 0.788), nor moist-soil managed wetlands (Wilks' λ=0.998, P = 0.260), and there was no year x managed wetland interaction (Wilks' λ = 0.994, P = 0.083). However, there was a month x year interaction (Wilks' λ = 0.977, P <

0.001), where total biomass production declined over time (Table 5.8). For example, biomass was greatest in 2004 (71 g), but was reduced nearly 5 fold by 2006 (Table 5.8). The greatest biomass production (by month) occurred in January 2004, the earliest sampling during this study (Table 5.9), and declined to < 1 g in December 2006 (Table 5.11). In 2004, peak biomass production occurred during January and April (Table 5.9), while in 2005, greatest biomass production occurred during June and September (Table 5.10), and in 2006, biomass production was greatest in October and January, respectively (Table 5.11). Over the course of this study, the greatest cumulative biomass production occurred in January, while March and August produced the least amount of invertebrate biomass (Table 5.12).

Due to local interest in individual moist-soil managed wetland production, as related to aforementioned group designations, further analyses examined invertebrate densities and biomass among groups by individual moist-soil managed wetlands, among years and months. Biomass and density among aquatic invertebrates varied among individual moist-soil managed wetlands and groups (Wilks' $\lambda = 0.971$, $P = 0.001$), among moist-soil wetlands, years, and groups (Wilks' $\lambda = 0.977$, $P = 0.001$), moist-soil managed wetland, month, and group (Wilks' $\lambda = 0.987$, $P = 0.004$) (Appendices 5.1-5.4). Overall, it appears that the primary driver of the variation at temporal (month, year) and spatial scale (individual moist-soil managed wetland) was due to greater densities and biomass production in 2004, where there were gradual declines density and biomass production within each moist-soil managed wetland over time.

Aquatic invertebrate biomass production by month, year, and moist-soil managed wetland cell varied across the moist-soil managed wetlands. Over the course of the study, moist-soil managed wetland 1 produced the greatest cumulative biomass, while moist-soil managed wetland 2 produced the least (Appendix 5.1 and 5.2). Peak production by month varied among cells and years, depending on presence of water over time. For example, within moist-soil managed wetland 1 in 2004, greatest production occurred during January (14.3 g), but greatest production, which was considerably lower, in subsequent years occurred in September (2005; 1.3 g) and August (2006, 0.8 g). Moist-soil managed wetland 2 also had its greatest biomass production January 2004 (3.2 g), but greatest production in subsequent years in this individual wetland occurred during November (2005; 1.7 g) and July (2006; 0.2 g). In contrast, moist-soil managed wetland 3 produced its greatest biomass in April 2004 (3 g), and tended to more closely attain similar peak production over months and years (September 2005; 3.2 g; October 2006, 2.3 g) as compared to wetlands 1 and 2 (Appendix 5.2). Finally, moist-soil managed wetland 4 attained greatest biomass production in April 2004 (8.6 g), but peak production in other years declined and occurred during June (2005; 5.8 g) and January (2006, 3.6 g).

Water Quality

Water quality parameters (i.e., water depth, temperature, conductivity, pH, and dissolved oxygen) varied among months (Wilks' $\lambda = 0.151$, $P < 0.001$), among years (Wilks' $\lambda = 0.845$, $P < 0.001$), among individual moist-soil managed wetlands (Wilks' $\lambda = 0.890$, $P < 0.001$), and there were month x year (Wilks' $\lambda = 0.594$, $P < 0.001$), month x moist-soil managed wetland (Wilks' $\lambda = 0.610$, $P < 0.001$), and year x moist-soil managed wetland (Wilk's $\lambda = 0.875$, $P < 0.001$) interactions. Water depth ($F = 53.08$, $P < 0.001$), conductivity ($F = 56.66$, $P < 0.001$), and dissolved oxygen ($F = 86.16$, $P < 0.001$) varied among years (Table 5.14), where most metrics other than dissolved oxygen were greatest in 2006, perhaps indicating that water residence time may have been beyond optimal in that year (Table 5.14). Among all moist-soil managed wetlands, water depth tended to increase over time, as did temperature and conductivity, while dissolved oxygen in 2006 was half of recorded levels in 2004 (Table 5.14). Water depth ($F = 24.31$, $P < 0.001$), conductivity ($F = 2.78$, $P < 0.03$), and dissolved oxygen ($F = 47.96$, $P < 0.001$) all varied among individual moist-soil managed wetlands (Table 5.15), where water depths were typically greater in moist-soil managed wetlands 2 and 3 (Table 5.15). Finally, water depth ($F = 45.56$, $P < 0.001$), water temperature ($F = 130.25$, $P < 0.001$), conductivity ($F = 179.05$, $P < 0.001$), and dissolved oxygen ($F = 274.37$, $P < 0.001$) varied among months (Table 5.16). In contrast to typical moist-soil management flooding regimes, greatest water depths (averaged among years) were in August and lowest water depths occurred during December while greatest and lowest temperatures, as expected, occurred during August and February, respectively (Table 5.16).

As expected (and reported above) there were many interactions in water quality parameters among moist-soil managed wetlands, years, and months. These interactions are summarized, by moist-soil managed wetland, year and month (Appendix 5.5-5.8). For example, water depth ($F = 14.37$, $P < 0.001$), water temperature ($F = 14.23$, $P < 0.001$), conductivity ($F = 47.50$, $P < 0.001$), and dissolved oxygen ($F = 108.43$, $P < 0.001$) variation was related to month and year. Similarly, water depth ($F = 12.17$, $P <$

0.001), water temperature (*F* = 2.00, *P* < 0.001), conductivity (*F* = 5.36, *P* < 0.001), and dissolved oxygen (*F* = 21.62, *P* < 0.001) variation was related to month and moist-soil managed wetland. Finally, water depth (*F* = 22.56, *P* < 0.001), water temperature (*F* = 2.36, *P* < 0.001), conductivity (*F* = 7.28, *P* < 0.001), and dissolved oxygen (*F* = 11.36, *P* < 0.001) variation was related to year and moist-soil managed wetland. Overall, as expected, such metrics should fluctuate seasonally and among year, depending upon inundation duration and timing, whereby individual moist-soil managed wetlands may drive such variation (Appendix 5.5-5.8).

DISCUSSION

Aquatic invertebrate diversity metrics indicate that the moist-soil managed wetlands contained a relatively diverse invertebrate community. Overall Simpson diversity was nearly 0.8 (with 1.0 being maximum diversity; Krebs 1999), although diversity indices declined during the course of this study. As inundation duration increased, there was less opportunity for moist-soil plant germination (see Chapter II), which restricts or reduce substrate availability for diverse invertebrate communities and potentially desirable aquatic invertebrate groups. Anderson and Smith (2000) reported that aquatic invertebrate diversity was 2 to 3 times greater in moist-soil managed wetlands than in unmanaged moist-soil wetlands, indicating that proper moist-soil management techniques will promote greater diversity (and biomass). If water is not removed, new moist-soil plant growth will be limited (see Chapter II), reducing desiccated plant material that will provide foraging and habitat structural complexity for invertebrates, which will eventually decrease diversity, abundance, and biomass. I observed this trend during this study.

Aquatic invertebrate production on the moist-soil managed wetlands at RCWMA, including both density and biomass, showed strong declines over time. During the initiation of this research, moist-soil managed wetlands had been “functioning” for < 6 months, in that the initial inundation was within a few months of the initial January 2004 sampling. Typical of newly flooded and/or newly created wetlands, initial flooding events can promote relatively high invertebrate production, as both terrestrial and aquatic invertebrates arrive, colonize, establish and reproduce (Fredrickson and Taylor 1982, Neckles et al. 1990, Batzer and Resh 1992, Haukos and Smith 1993, Anderson and Smith 2000, de Szalay and Resh 2000, Anderson and Smith 2004). However, traditional moist-soil management emphasizes timely addition and removal of water, geared towards promoting seed germination, seed producing plant growth, and eventual invertebrate production (see Chapters II and III). Extended periods of dry or inundated conditions can dramatically alter seed bankcomposition, germination rates, plant production, and invertebrate production (see Chapter II, Fredrickson and Taylor 1982, Murkin and Kadlec 1986, Haukos and Smith 1993, Gray et al. 1999, de Szalay and Resh 2000, Brock et al. 2003, Anderson and Smith 2004). In the present study, there were very few instances (during a specific monthly sampling period), in which any individual moist-soil managed wetland was not inundated (i.e., no standing water) (see Appendix 5.5-5.8). In fact, drawdowns were sporadic, irregularly timed, and of short duration –combined these dramatically altered and negatively influenced invertebrate production, abundance, and biomass on these managed wetlands. For example, there was a nearly 6-fold decline in cumulative invertebrate biomass from the initiation of this research to the last sampling period, which corresponded with a nearly 3 fold decline in the number of individuals captured.

Further complicating and negatively influencing invertebrate production as related to traditional moist-soil management techniques, was the fact that the greatest water depths recorded during this study occurred during summer months (see Appendix 5.5-5.8). Typical moist-soil management focuses upon growing season drawdowns – not inundation, which is typically targeted during for fall and winter when migrant and wintering waterfowl arrive and use such habitats (see Chapter VI; Fredrickson and Taylor 1982, Haukos and Smith 1993, Gray et al. 1999, Lane and Jensen 1999, Anderson and Smith 2000, Strader and Stinson 2005). Growing season drawdowns are executed to promote germination and growth of hydrophytic (or other seed producing) plants (see Chapter II, Fredrickson and Taylor 1982, Reid et al. 1983, Haukos and Smith 1993), which should provide valuables sources of seeds, tubers, browse, and aquatic invertebrates for migrating and wintering waterfowl once flooding occurs during fall and winter (Fredrickson and Taylor 1982, Fredrickson and Reid 1986, Gray et al. 1999). Specifically in Texas, drawdowns are recommended to be executed from mid-March through early July to capitalize on growing season conditions, where inundation should begin in early September (Fredrickson and Taylor 1982, Neckles et al. 1990, Gray et al. 1999, Anderson and Smith 2000). Inundation during late growing season (September) will allow for colonization and initiation of aquatic invertebrate production, which should peak during mid-late winter as waterfowl dietary requirements include greater amounts of protein during those periods (Batzer and Resh 1992, Anderson and Smith 2000).

In essence, the only sampling window in which we recorded peak invertebrate production during the proper chronological window was during the first year of collection, where January – March 2004 produced the greatest biomass during this study. Although in 2005 and 2006 there were small flushes of invertebrate production in January, invertebrate production declined dramatically during the next two months in all four moist-soil managed wetlands.

Overall, inundation duration was (1) typically longer than and (2) out of sequence with timing recommended for moist-soil managed wetlands, which tended to make invertebrate production, abundance, and biomass very unpredictable. Although moist-soil managed wetlands should be maximizing invertebrate production during the temporal window in which waterfowl require greater dietary protein (January-March), the lack of production may not only be related to extended inundation. For example, low estimates of invertebrate biomass during March may have been due to high waterfowl use during March. It is possible that declines in invertebrate production during the January-March window in 2005 and 2006 was a function of waterfowl foraging activities removing invertebrate biomass. However, depending upon year and individual moist-soil managed wetland, duck use days, as estimated from seed and invertebrate production data (see Appendix B), varied widely. Regardless of individual moist-soil managed wetland, greatest duck use day estimates were estimated from 2004, with dramatic declines in both 2005 and 2006 in all moist-soil managed wetlands. Although data used to estimate duck use days may be related to removal of seeds and invertebrates by waterfowl during each sampling period, there was a 5-30 fold reduction in duck use days over time (see Appendix B), and it is unlikely that waterfowl food consumption depressed estimates of invertebrate production enough to drive such dramatic reductions in duck use days on these wetlands.

Obviously linked with drawdown and inundation regimes, invertebrate life cycle phenology varies widely, depending upon local environmental conditions as well as more static and fixed life cycles. For example, some invertebrates have relatively short duration life cycles (i.e., Crustaceans) whereas others may take weeks or months to achieve reproduction after colonization (Anderson and Smith 2000). Most aquatic invertebrate families identified in this study are early colonizers of wetland systems and are highly desired by waterfowl managers using moist-soil management techniques because of their desirability as important waterfowl food items (see Appendix B, Batzer et al. 1993, Safran et al. 1997, Gray et al. 1999, Anderson and Smith 2000). However, as inundation duration was extended, density and biomass of these more desirable species declined. As inundation duration increases, taxa with poor dispersal abilities will find and settle moist-soil managed wetlands (Wilson 1992, Moorhead et al. 1998, Anderson and Smith 2000), where predation and competition become issues, and desirable invertebrates (as waterfowl food items) are unable to continue to increase populations (Reid 1983, Neckles et al. 1990, Andserson and Smith 2000). Skelly (1997) found that wetlands flooded for 2 or 4 months prevented colonization by aquatic invertebrates and that increases in abundance and biomass were not observed as those taxa did not have time to become dominant elements. However, abundance and production of invertebrates in permanently (Reid 1983) and semi-permanently (Neckles et al. 1990) flooded wetlands result in declines of aquatic invertebrate density and biomass as inundation was prolonged to > 6 months (Reid 1983). As previously mentioned, well timed drawdown and inundation events will promote colonization and development of desirable invertebrate communities, but extended inundation duration will eventually depress invertebrate biomass and abundance. Future moist-soil management regimes on the

Richland Creek WMA will need to alter current inundation strategies to maximize desirable invertebrate (and seed) production (see Appendix B).

MANAGEMENT IMPLICATIONS

Moist-soil managed wetlands at RCMA tended to have relatively high diversity over the course of this study, but production declined considerably over time. Although extended inundation duration was implicated in declines in duck use days (see Appendix B), promotion of undesirable species (see Chapter II), and plant community changes from moist-soil to more aquatic or permanently flooded plant species (see Appendix A), the strongest evidence for problems associated with prolonged inundation duration was observed in aquatic invertebrate. Greatest water depths were observed during the middle of the growing season and consequent declines in aquatic invertebrate production provide clear evidence that extended inundation duration, particularly when miss-timed, will dramatically and negatively influence seed and invertebrate production. Despite declines in duck use days observed over time (see Appendix B), all three focal species tended to improve body condition and body mass during late winter, prior to spring departure (see Chapter VI), indicating that enough seed and invertebrate production occurred to mask potential negative effects of extended duration (see Chapter VI). However, if current water management practices continue on moist-soil managed wetlands at Richland Creek WMA, continued declines in duck use days may occur, followed by potential declines in waterfowl body condition and body mass. Although reductions in waterfowl use may mask such changes in production, future management actions should focus on creating regionally suitable drawdown and inundation regimes.

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Table 5.1. Invertebrate groupings used identifying aquatic invertebrates collected in moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Group
Phylum	
	Annelidae
	Platyhelminthes
Subphylum	
	Crustacea
Class	
	Arachnida
	Arachnidae
	Bivalvia
	Gastropoda
	Insecta
Order	
	Coleoptera
	Diptera
	Ephemeroptera
	Heteroptera
	Megaloptera
	Odonata
	Plecoptera
	Trichoptera

Table 5.2. Simpson's and Shannon-Wiener diversity indices estimated by year and month among years, for aquatic invertebrate groupings collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006

	Simpson's Diversity Index	Shannon-Wiener Index
Overall	0.76	2.47
Year		
2004	0.77	2.4
2005	0.75	2.47
2006	0.75	2.41
Month		
January	0.80	2.51
February	0.79	2.43
March	0.72	2.32
April	0.69	2.04
May	0.57	1.81
June	0.56	1.93
July	0.74	2.44
August	0.82	2.64
September	0.83	2.74
October	0.79	2.53
November	0.71	2.14
December	0.77	2.38

Table 5.3. Simpson's and Shannon-Wiener diversity indices estimated for aquatic invertebrate groupings for individual moist-soil managed wetlands among years on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Simpson's Diversity Index	Shannon-Wiener Index
Wetland 1		
Overall	0.80	2.28
2004	0.78	2.59
2005	0.81	2.65
2006	0.74	2.23
Wetland 2		
Overall	0.78	2.5
2004	0.78	2.5
2005	0.70	2.26
2006	0.76	2.44
Wetland 3		
Overall	0.82	2.65
2004	0.82	2.65
2005	0.78	2.56
2006	0.82	2.65
Wetland 4		
Overall	0.54	1.82
2004	0.54	1.82
2005	0.51	1.75
2006	0.57	1.84

Table 5.4. Simpson's and Shannon-Wiener diversity indices estimated for aquatic invertebrate families by year and months among for aquatic invertebrate families collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Simpson's Diversity Index	Shannon-Wiener Index
Overall	0.81	3.33
Year		
2004	0.81	3.33
2005	0.80	3.15
2006	0.77	3.34
Month		
January	0.86	3.38
February	0.87	3.41
March	0.79	3.03
April	0.72	2.53
May	0.59	2.31
June	0.58	2.49
July	0.77	3.13
August	0.90	3.65
September	0.90	3.85
October	0.83	3.17
November	0.81	2.98
December	0.82	3.13

Table 5.5. Simpson's and Shannon-Wiener diversity indices for aquatic invertebrate families for individual moist-soil managed wetlands among years on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Simpson's Diversity Index	Shannon-Wiener Index
Wetland 1		
Overall	0.87	3.56
2004	0.85	5.56
2005	0.88	3.8
2006	0.80	3
Wetland 2		
Overall	0.88	3.58
2004	0.85	3.58
2005	0.86	3.56
2006	0.87	3.47
Wetland 3		
Overall	0.89	2.22
2004	0.84	3.69
2005	0.89	3.7
2006	0.84	3.15
Wetland 4		
Overall	0.55	2.28
2004	0.56	2.28
2005	0.52	2.19
2006	0.58	2.13

Table 5.6. Cumulative total number (*n*) and biomass (g) of aquatic invertebrates organized by gross taxonomic groups from 4 moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Phylum Class Order	*n*	Total mass (g)
Annelidae	49	0.31
Platyhelminthes	70	0.74
Arthropoda		
Arachnida	14	0.07
Arthropoda		
Crustacea	3568	27.40
Insecta		
Ephemeroptera	2080	13.37
Heteroptera	2038	15.43
Diptera	1394	13.56
Odonata	1284	14.99
Coleoptera	410	3.62
Trichoptera	63	0.04
Plecoptera	21	0.10
Megaloptera	2	0.07
Mollusks		
Bivalvia	31	0.28
Gastropoda	1065	27.12
Total	12089	117.1

Table 5.7. Cumulative total number (*n*) and biomass (g) of aquatic invertebrates organized by family from 4 moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Phylum	Class	Order	Suborder	Family	*n*	Total Mass (g)
Annelidae	Hirudinea				41	0.29
	Oligochaeta				8	0.02
Platyhelminthes	Turbellaria				35	0.74
Mollusca	Bivalvia	Sphaeriidae			31	0.28
	Gastropoda	Pulmonata		Physidae	169	3.12
				Planorbidae	373	11.16
				Unidentified	356	12.83
Arthropoda	Arachnida	Acriformes			2	0
		Unidentified			12	0.07
	Crustacea	Amphipoda			3528	26.25
		Decapoda		Palaemonidae	10	0.82
		Isopoda		Asellidae	30	0.33
	Insecta	Coleoptera		Dryopidae	1	0.20
		Coleoptera		Dytiscidae	82	1.07
		Coleoptera		Elmidae	2	0
		Coleoptera		Gyrinidae	4	0.04
		Coleoptera		Haliplidae	68	0.54
		Coleoptera		Hydrophilidae	116	1.76
		Diptera		Ceratopogonidae	252	1.07

Table 5.7. Continued. Cumulative total number (*n*) and biomass (g) of aquatic invertebrates organized by family from 4 moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Phylum	Class	Order	Suborder	Family	*n*	Total Mass (g)
Arthropoda	Insecta	Diptera		Chironomidae	1523	12.02
		Diptera		Culicidae	53	0.22
		Diptera		Dixidae	2	0.01
		Diptera		Empididae	3	0.01
		Diptera		Stratiomyidae	11	0.06
		Diptera		Tabanidae	6	0.13
		Diptera		Tipulidae	7	0.04
		Ephemeroptera		Ameletidae	91	0.93
		Ephemeroptera		Baetidae	443	4.91
		Ephemeroptera		Caenidae	415	5.18
		Ephemeroptera		Epherellidae	8	0.02
		Ephemeroptera		Leptohyphidae	41	0.12
		Ephemeroptera		Siphlonuridae	412	2.21
		Hemiptera	Heteroptera	Belostomatidae	23	1.30
		Hemiptera	Heteroptera	Corixidae	1181	7.05
		Hemiptera	Heteroptera	Heteroptera	26	0.09
		Hemiptera	Heteroptera	Naucoridae	4	0.06
		Hemiptera	Heteroptera	Notonectidae	1087	6.93
		Megaloptera		Sialidae	2	0.07
		Odonata	Anisoptera	Aeshnidae	22	1.05
		Odonata	Anisoptera	Gomphidae	31	3.10
		Odonata		Anisoptera	126	7.97
		Odonata	Zygoptera	Calopterygidae	41	0.51

Table 5.7. Continued. Cumulative total number (*n*) and biomass (g) of aquatic invertebrates organized by family from 4 moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Phylum	Class	Order	Suborder	Family	*n*	Total Mass (g)
Arthropoda	Insecta	Odonata	Zygoptera	Coenagrionidae	209	1.80
		Odonata	Zygoptera	Lestidae	35	0.55
		Plecoptera		Capniidae	5	0.01
		Plecoptera		Leuctridae	7	0.01
		Plecoptera		Perlidae	11	0.09
		Trichoptera		Philopotamidae	5	0
		Trichoptera		Polycentropodidae	28	0.03
Total					12240	117.15

Table 5.8. Mean ($\bar{x}$) and standard error of aquatic invertebrate abundance and production 2004, 2005, 2006, on Richland Creek Wildlife Management Area, east-central, Texas.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
2004	6287	2.91	4.23	71.14	0.03	0.09
2005	3703	2.36	3.17	29.28	0.02	0.05
2006	2062	2.22	2.95	15.75	0.02	0.06

Table 5.9. Mean ($\bar{x}$) and standard error of aquatic invertebrate abundance and production for each month on Richland Creek Wildlife Management Area, east-central, Texas, 2004.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
January	1499	2.79	3.58	24.38	0.05	0.11
February	864	2.39	2.86	10.49	0.03	0.06
March	--	--	--	--	--	--
April	1851	3.86	5.01	17.60	0.04	0.07
May	1226	4.26	6.73	5.86	0.02	0.05
June	141	2.52	3.47	1.07	0.02	0.03
July	275	1.88	2.56	5.49	0.04	0.19
August	--	--	--	--	--	--
September	98	1.46	1.18	0.87	0.01	0.03
October	124	1.29	0.89	3.41	0.04	0.08
November	--	--	--	--	--	--
December	209	1.62	1.34	1.96	0.02	0.03

Table 5.10. Mean ($\bar{x}$) and standard error of aquatic invertebrate abundance and production for each month on Richland Creek Wildlife Management Area, east-central, Texas, 2005.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
January	178	1.44	1.08	2.93	0.02	0.05
February	117	1.34	0.99	0.93	0.01	0.02
March	62	1.27	0.70	0.81	0.02	0.04
April	226	2.17	2.26	0.99	0.01	0.01
May	542	3.90	5.04	1.87	0.01	0.03
June	810	3.52	5.26	6.99	0.03	0.08
July	44	1.38	0.71	0.18	0.01	0.01
August	33	1.32	0.63	0.26	0.01	0.02
September	632	2.14	2.17	6.69	0.02	0.07
October	120	2.00	1.81	0.57	0.01	0.01
November	476	2.14	2.16	3.91	0.02	0.05
December	463	2.34	2.72	3.14	0.02	0.04

Table 5.11. Mean ($\bar{x}$) and standard error of aquatic invertebrate abundance and production for each month on Richland Creek Wildlife Management Area, east-central, Texas, 2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
January	518	3.20	3.83	3.73	0.02	0.11
February	22	1.47	1.30	0.29	0.02	0.03
March	135	2.11	2.27	0.59	0.01	0.01
April	--	--	--	--	--	--
May	200	1.74	1.42	1.09	0.01	0.02
June	181	2.15	2.98	1.04	0.01	0.02
July	301	2.57	4.63	2.42	0.02	0.06
August	136	1.68	1.24	1.18	0.01	0.03
September	36	1.13	0.42	0.31	0.01	0.01
October	423	2.31	2.73	4.25	0.02	0.08
November	7	1.75	0.96	0.07	0.02	0.02
December	103	1.41	1.19	0.78	0.01	0.03

Table 5.12. Mean ($\bar{x}$) and standard error of aquatic invertebrate density and production among months, regardless of year on Richland Creek Wildlife Management Area, east-central, Texas, 2004 - 2006.

	Density			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
January	2195	2.66	3.42	31.04	0.04	0.11
February	1201	2.12	2.44	12.70	0.02	0.05
March	197	1.74	1.81	1.40	0.01	0.03
April	2077	3.56	4.69	18.59	0.03	0.06
May	1968	3.63	5.65	8.83	0.02	0.04
June	1132	3.06	4.61	9.10	0.02	0.06
July	620	2.10	3.45	8.09	0.03	0.14
August	169	1.59	1.14	1.44	0.01	0.03
September	766	1.94	1.97	7.87	0.02	0.06
October	667	1.97	2.24	8.22	0.02	0.07
November	484	2.13	2.14	3.99	0.02	0.05
December	775	1.94	2.15	5.88	0.01	0.04

Table 5.13. Mean ($\bar{x}$) and standard error of aquatic invertebrate abundance and production in 4 moist-soil management wetland cells, for all years combined on Richland Creek Wildlife Management Area, east-central, Texas, 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
Wetland 1	2461	2.39	3.33	33.68	0.03	0.11
Wetland 2	1904	2.16	2.38	13.82	0.02	0.04
Wetland 3	2608	2.11	2.60	22.39	0.02	0.04
Wetland 4	5278	3.27	4.80	47.28	0.03	0.08

Table 5.14. Mean ($\bar{x}$) and standard error of water quality parameters collected from 4 moist-soil managed wetlands summarized by year, on Richland Creek Wildlife Management Area, east-central, Texas, 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Overall	31.24	12.27	21.76	21.76	648.73	208.42	9.68	35.16	2.49	2.37
2004	27.27	11.77	21.51	21.51	566.42	171.20	7.84	2.68	3.47	2.73
2005	32.09	12.58	20.64	20.64	614.96	192.78	11.14	46.35	1.60	1.65
2006	34.01	11.39	23.85	23.85	807.53	187.97	10.46	44.24	1.76	1.40

Table 5.15. Mean ($\bar{x}$) and standard error of water quality parameters collected from 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas, 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Wetland 1	28.06	11.75	21.84	21.84	632.06	225.16	11.16	50.97	2.28	2.19
Wetland 2	33.81	12.69	21.66	21.66	655.12	199.86	8.39	2.28	2.26	2.33
Wetland 3	33.83	12.03	21.58	21.58	657.76	202.68	9.65	35.54	2.76	2.43
Wetland 4	29.24	11.49	21.95	21.95	648.39	206.21	9.28	29.07	2.63	2.49

Table 5.16. Mean ($\bar{x}$) and standard error of water quality parameters collected every month from 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
January	28.01	10.39	14.60	14.60	479.01	150.47	8.20	0.91	3.31	2.82
February	28.32	9.21	9.98	9.98	441.96	103.59	8.30	1.15	3.50	2.96
March	28.09	9.23	16.55	16.55	540.00	122.19	21.20	98.84	4.49	3.00
April	25.41	11.22	23.08	23.08	629.56	143.27	8.03	0.44	2.65	1.75
May	28.25	11.53	26.82	26.82	692.10	153.27	7.57	2.02	1.76	1.48
June	28.98	11.33	28.68	28.68	734.73	184.74	8.60	2.19	0.59	0.93
July	36.91	15.17	30.03	30.03	805.63	153.41	8.06	1.56	2.00	1.55
August	42.49	12.21	30.11	30.11	1059.84	119.94	7.47	0.36	--	--
September	33.32	10.54	26.66	26.66	750.05	146.24	11.67	42.76	0.49	0.42
October	35.56	11.75	24.41	24.41	703.63	127.26	7.64	2.51	1.81	1.35
November	36.02	11.07	18.30	18.30	641.49	66.60	18.46	88.70	3.52	1.51
December	27.15	10.11	12.21	12.21	517.47	167.69	7.17	1.80	1.28	0.88

Appendix 5.1. Total number (*n*), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 1 Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	g	$\bar{x}$	SE
January						
2004	613	3.21	4.25	14.25	0.07	0.16
2005	24	1.33	0.97	0.74	0.04	0.08
2006	186	3.51	4.81	0.05	0.00	0.00
February						
2004	181	2.26	2.08	1.87	0.02	0.04
2005	11	1.38	0.52	0.11	0.01	0.02
2006	15	1.88	1.73	0.27	0.03	0.04
March						
2004						
2005	16	1.14	0.36	0.35	0.03	0.06
2006	9	1.50	0.84	0.06	0.01	0.01
April						
2004	311	3.57	3.69	3.38	0.04	0.09
2005	39	2.17	1.38	0.17	0.01	0.02
2006						
May						
2004	320	3.90	6.60	1.15	0.01	0.04
2005	33	1.74	0.99	0.18	0.01	0.01
2006						
June						
2004	70	2.19	2.44	0.38	0.01	0.01
2005	92	1.37	0.74	1.20	0.02	0.02
2006						
July						
2004	57	1.97	1.90	4.58	0.16	0.41
2005	13	1.18	0.40	0.06	0.01	0.01
2006						

Appendix 5.1. Continued. Total number (n), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 1 Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
August						
2004	--	--	--	--	--	--
2005	6	1.00	0.00	0.02	0.00	0.00
2006	83	1.73	1.12	0.82	0.02	0.03
September						
2004	49	1.69	1.61	0.38	0.01	0.03
2005	60	2.07	1.69	1.31	0.05	0.18
2006	24	1.09	0.29	0.13	0.01	0.01
October						
2004	54	1.42	1.29	1.25	0.03	0.08
2005	16	1.60	1.35	0.04	0.00	0.00
2006	22	1.47	0.64	0.10	0.01	0.01
November						
2004	--	--	--	--	--	--
2005	85	1.55	1.00	0.40	0.01	0.01
2006	--	--	--	--	--	--
December						
2004	12	1.33	1.00	0.18	0.02	0.03
2005	24	1.50	1.32	0.07	0.00	0.01
2006	14	1.08	0.28	0.04	0.00	0.00

Appendix 5.2. Total number (*n*), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
January						
2004	344	2.31	2.10	3.18	0.02	0.03
2005	58	1.49	1.02	0.87	0.02	0.05
2006	94	1.81	1.25	0.03	0.00	0.00
February						
2004	197	2.90	3.99	2.10	0.03	0.06
2005	21	1.11	0.46	0.04	0.00	0.01
2006	7	1.00	0.00	0.02	0.00	0.00
March						
2004						
2005	46	1.31	0.80	0.46	0.01	0.02
2006	16	1.14	0.53	0.09	0.01	0.01
April						
2004	374	3.17	2.95	2.58	0.02	0.04
2005	35	1.46	0.83	0.15	0.01	0.01
2006						
May						
2004	104	2.42	2.46	0.27	0.01	0.01
2005	36	5.14	4.78	0.00	0.00	0.00
2006	5	1.00	0.00	0.02	0.00	0.00
June						
2004	60	3.53	5.26	0.39	0.02	0.04
2005						
2006	10	1.43	0.79	0.03	0.00	0.00
July						
2004	50	1.67	0.99	0.07	0.00	0.00
2005	5	1.00	0.00	0.01	0.00	0.00
2006	31	1.55	1.79	0.22	0.01	0.02

Appendix 5.2. Continued. Total number (*n*), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
August						
2004	--	--	--	--	--	--
2005	16	1.60	0.84	0.16	0.02	0.02
2006	4	4.00	--	0.00	0.00	--
September						
2004	21	1.31	0.70	0.11	0.01	0.01
2005	11	1.38	0.74	0.05	0.01	0.00
2006						
October						
2004	13	1.08	0.29	0.22	0.02	0.01
2005	25	1.92	1.50	0.14	0.01	0.01
2006	8	1.00	0.00	0.04	0.00	0.01
November						
2004	--	--	--	--	--	--
2005	165	2.70	2.76	1.74	0.03	0.10
2006	--	--	--	--	--	--
December						
2004	25	1.14	0.47	0.18	0.01	0.02
2005	63	2.03	1.94	0.25	0.01	0.01
2006	3	1.00	0.00	0.01	0.00	0.00

Appendix 5.3 Total number (*n*), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
January						
2004	142	1.73	0.97	0.87	0.01	0.02
2005	42	1.35	0.80	0.41	0.01	0.01
2006	18	1.80	1.93	0.09	0.01	0.01
February	n	x	SE	Mass	x	SE
2004	284	2.93	3.50	2.69	0.03	0.03
2005	47	1.52	1.50	0.25	0.01	0.01
2006						
March						
2004	--	--	--	--	--	--
2005	--	--	--	--	--	--
2006	25	1.14	0.35	0.08	0.00	0.00
April						
2004	482	3.21	4.59	3.07	0.02	0.03
2005	140	2.69	2.93	0.52	0.01	0.01
2006	--	--	--	--	--	--
May						
2004	176	3.32	3.33	0.83	0.02	0.03
2005	50	1.47	1.21	0.57	0.02	0.05
2006	39	1.44	0.70	0.43	0.02	0.04
June						
2004	11	1.57	1.13	0.30	0.04	0.05
2005	--	--	--	--	--	--
2006	44	1.22	0.59	0.36	0.01	0.02
July						
2004	37	1.37	0.74	0.41	0.02	0.02
2005	--	--	--	--	--	--
2006	83	1.66	1.60	0.86	0.02	0.06

Appendix 5.3. Continued. Total number (*n*), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
August						
2004	11	1.22	0.44	0.09	0.01	0.02
2005	--	--	--	--	--	--
2006	24	1.26	0.65	0.28	0.01	0.03
September						
2004	11	1.10	0.32	0.11	0.01	0.01
2005	315	2.19	2.63	3.20	0.02	0.06
2006	12	1.20	0.63	0.18	0.02	0.02
October						
2004	14	1.17	0.39	0.77	0.06	0.16
2005	31	1.55	1.10	0.15	0.01	0.01
2006	193	2.41	2.72	2.28	0.03	0.06
November						
2004	88	1.83	2.14	0.61	0.01	0.02
2005	1	1.00	--	0.01	0.01	--
2006	--	--	--	--	--	--
December						
2004	91	1.75	1.25	0.81	0.02	0.02
2005	108	1.61	0.94	1.58	0.02	0.07
2006	30	1.43	0.68	0.29	0.01	0.04

Appendix 5.4. Total number (n), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
January						
2004	400	3.45	4.69	6.08	0.05	0.10
2005	54	1.50	1.40	0.92	0.03	0.06
2006	220	4.68	4.23	3.56	0.08	0.20
February						
2004	202	1.74	1.50	3.83	0.03	0.08
2005	38	1.31	0.54	0.53	0.02	0.02
2006	--	--	--	--	--	--
March						
2004	--	--	--	--	--	--
2005	--	--	--	--	--	--
2006	85	3.86	3.17	0.36	0.02	0.01
April						
2004	684	5.52	7.11	8.57	0.07	0.09
2005	12	1.20	0.63	0.15	0.02	0.03
2006	--	--	--	--	--	--
May						
2004	626	5.69	8.67	3.61	0.03	0.07
2005	423	5.35	6.03	1.12	0.01	0.03
2006	156	1.88	1.60	0.64	0.01	0.02
June						
2004	--	--	--	--	--	--
2005	718	4.40	6.01	5.79	0.04	0.09
2006	127	3.10	4.03	0.65	0.02	0.02
July						
2004	131	2.18	3.67	0.43	0.01	0.01
2005	26	1.63	0.89	0.11	0.01	0.01
2006	187	3.98	6.83	1.34	0.03	0.08

Appendix 5.4. Continued. Total number (n), mean ($\bar{x}$) abundance, standard error, and biomass estimates for aquatic invertebrates collected from moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Abundance			Biomass		
	n	$\bar{x}$	SE	Mass	$\bar{x}$	SE
August						
2004	--	--	--	--	--	--
2005	--	--	--	--	--	--
2006	25	1.92	1.98	0.08	0.01	0.01
September						
2004	17	1.42	0.90	0.27	0.02	0.06
2005	246	2.14	1.66	2.14	0.02	0.04
2006						
October						
2004	43	1.26	0.57	1.16	0.03	0.05
2005	48	2.82	2.63	0.23	0.01	0.01
2006	200	2.50	3.05	1.83	0.02	0.10
November						
2004	--	--	--	--	--	--
2005	138	2.38	2.13	1.16	0.02	0.03
2006	6	2.00	1.00	0.06	0.02	0.02
December						
2004	81	1.76	1.70	0.80	0.02	0.03
2005	268	3.19	3.71	1.24	0.01	0.02
2006	56	1.56	1.59	0.44	0.01	0.03

Appendix 5.5. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 1on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
January										
2004	29.72	7.83	15.40	15.40	505.35	126.57	8.93	0.45	5.32	1.23
2005	13.86	6.51	19.37	19.37	351.31	71.91	--	--	0.25	0.02
2006	25.27	8.50	14.62	14.62	667.77	25.98	8.39	0.13	0.05	0.02
February										
2004	27.27	11.86	9.91	9.91	345.70	28.31	4.97	0.00	6.79	1.48
2005	29.70	8.27	8.95	8.95	340.00	16.73	8.58	0.34	1.09	0.11
2006	25.50	7.55	11.30	11.30	604.53	94.10	7.35	1.34	2.61	0.24
March										
2004	28.00	7.95	17.30	17.30	444.33	26.14	--	--	6.83	1.66
2005	18.30	9.89	15.53	15.53	509.08	68.65	--	--	2.47	1.38
2006	31.03	6.88	22.75	22.75	781.43	14.74	33.34	139.89	1.71	0.38
April										
2004	26.50	7.46	20.37	20.37	661.92	87.45	8.10	0.49	3.30	1.79
2005	8.48	3.54	34.70	34.70	667.43	235.99	--	--	0.60	0.12
2006	--	--	--	--	--	--	--	--	--	--

Appendix 5.5. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 1on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
May										
2004	17.39	10.70	25.03	25.03	634.97	122.89	7.02	3.09	1.94	1.24
2005	27.63	6.42	27.43	27.43	718.30	127.40	8.02	0.31	--	--
2006	--	--	--	--	--	--	--	--	--	--
June										
2004	14.70	5.79	30.02	30.02	522.40	200.92	9.55	1.67	0.92	1.24
2005	29.96	8.83	29.28	29.28	585.03	11.45	7.66	0.36	0.10	0.03
2006	--	--	--	--	--	--	--	--	--	--
July										
2004	14.95	8.35	30.26	30.26	646.54	170.45	9.02	2.42	1.95	1.33
2005	48.43	7.18	29.98	29.98	--	--	7.82	0.84	--	--
2006	--	--	--	--	--	--	--	--	--	--
August										
2004	--	--	--	--	--	--	--	--	--	--
2005	34.11	13.14	29.93	29.93	1346.93	65.89	7.38	0.29	--	--
2006	33.58	14.39	32.30	32.30	1141.22	159.15	--	--	--	--

Appendix 5.5. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 1on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
September										
2004	21.70	9.36	25.67	25.67	715.44	148.59	12.31	2.62	0.47	0.16
2005	32.47	10.90	35.18	35.18	814.10	139.24	9.01	0.72	0.40	0.00
2006	39.13	5.86	--	--	--	--	--	--	--	--
October										
2004	31.27	7.17	24.81	24.81	531.95	120.68	3.75	1.23	1.66	0.98
2005	41.67	6.84	22.02	22.02	796.10	21.18	7.29	0.13	1.25	0.72
2006	34.72	8.50	--	--	--	--	--	--	--	--
November										
2004	--	--	--	--	--	--	--	--	--	--
2005	34.27	7.60	17.79	17.79	660.22	12.51	33.20	138.72	3.43	0.76
2006	--	--	--	--	--	--	--	--	--	--
December										
2004	15.73	4.83	14.44	14.44	335.99	37.46	4.02	0.92	2.32	0.67
2005	29.13	8.00	10.70	10.70	594.78	50.58	7.88	0.37	0.00	0.00
2006	29.03	4.14	--	--	--	--	--	--	--	--

Appendix 5.6. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
January										
2004	26.13	6.43	14.07	14.07	378.10	31.78	--	--	6.09	1.04
2005	23.90	5.68	15.91	15.91	334.55	16.10	--	--	0.60	0.11
2006	28.77	6.85	14.89	14.89	715.83	37.15	7.85	0.18	--	--
February										
2004	24.73	7.49	10.97	10.97	405.57	22.18	--	--	7.48	1.70
2005	35.10	4.24	10.01	10.01	361.07	4.95	8.67	0.27	1.26	0.09
2006	30.77	7.34	12.66	12.66	637.60	24.79	8.10	0.26	2.54	0.72
March										
2004	27.77	4.22	14.30	14.30	508.10	12.70	--	--	8.42	1.71
2005	24.93	6.03	17.96	17.96	519.77	13.89	--	--	3.26	1.00
2006	35.20	5.51	21.84	21.84	700.08	132.99	9.05	0.67	2.04	0.18
April										
2004	27.92	6.87	23.08	23.08	678.88	67.75	8.35	0.33	3.19	1.36
2005	13.47	4.95	23.57	23.57	711.37	25.40	--	--	0.72	0.14
2006	--	--	--	--	--	--	--	--	--	--

Appendix 5.6. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
May										
2004	19.80	8.79	26.24	26.24	613.88	166.53	6.65	2.94	2.23	1.44
2005	--	--	--	--	--	--	--	--	--	--
2006	32.40	6.54	25.89	25.89	797.78	117.36	--	--	0.29	0.01
June										
2004	11.20	6.19	29.51	29.51	519.13	172.12	11.40	2.60	1.63	0.94
2005	33.97	4.75	--	--	--	--	--	--	0.23	0.18
2006	28.32	8.49	27.09	27.09	877.47	5.79	--	--	--	--
July										
2004	18.63	6.66	33.38	33.38	700.01	186.13	7.67	0.68	1.53	1.42
2005	59.87	5.30	29.52	29.52	--	--	7.65	0.44	--	--
2006	45.50	6.47	28.18	28.18	869.80	84.10	--	--	--	--
August										
2004	--	--	--	--	--	--	--	--	--	--
2005	46.87	5.04	26.94	26.94	--	--	7.78	0.38	--	--
2006	45.38	12.30	31.25	31.25	1037.65	24.31	--	--	--	--

Appendix 5.6. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
September										
2004	37.43	4.85	25.06	25.06	682.43	138.08	15.49	0.69	0.71	0.02
2005	43.87	6.19	26.62	26.62	676.80	126.84	8.24	1.49	0.30	0.00
2006	--	--	--	--	--	--	--	--	--	--
October										
2004	43.93	5.78	25.05	25.05	657.13	7.42	6.04	0.62	1.04	0.89
2005	46.67	5.36	22.82	22.82	791.13	9.20	9.14	0.80	1.47	1.14
2006	40.47	5.50	--	--	--	--	--	--	--	--
November										
2004	--	--	--	--	--	--	--	--	--	--
2005	45.07	7.84	17.04	17.04	624.55	36.38	8.22	0.42	2.67	1.00
2006	--	--	--	--	--	--	--	--	--	--
December										
2004	12.63	5.29	13.93	13.93	297.36	47.81	7.90	0.34	1.22	0.17
2005	39.37	5.56	10.61	10.61	590.20	79.50	7.89	0.30	0.30	0.28
2006	32.90	5.63	--	--	--	--	--	--	--	--

Appendix 5.7. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
January										
2004	39.90	7.72	13.77	13.77	447.83	30.70	9.02	0.44	6.31	1.34
2005	37.43	6.65	13.84	13.84	312.56	5.16	--	--	0.58	0.05
2006	37.03	6.16	13.26	13.26	606.00	12.71	7.01	1.34	4.95	0.75
February										
2004	27.87	10.90	11.32	11.32	413.16	6.78	--	--	7.34	1.75
2005	35.67	7.31	11.19	11.19	393.81	11.15	9.63	0.62	1.54	0.10
2006	20.73	4.22	6.67	6.67	517.60	1.85	7.65	1.46	1.50	0.17
March										
2004	38.07	6.53	10.74	10.74	425.03	8.60	--	--	8.58	1.82
2005	30.40	6.38	18.81	18.81	521.33	17.45	--	--	3.53	1.38
2006	19.40	6.86	14.55	14.55	594.37	29.43	--	--	1.81	0.10
April										
2004	29.68	10.76	26.64	26.64	732.00	66.93	7.65	0.24	3.35	1.82
2005	19.77	6.78	15.33	15.33	372.23	58.55	--	--	1.30	0.56
2006	--	--	--	--	--	--	--	--	--	--

Appendix 5.7. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
May										
2004	28.93	10.25	26.46	26.46	625.03	81.37	8.18	1.29	2.51	1.45
2005	43.77	6.51	27.82	27.82	765.22	134.37	8.32	0.60	--	--
2006	32.95	9.54	26.10	26.10	691.78	222.29	--	--	0.30	0.02
June										
2004	10.07	5.84	29.25	29.25	642.07	227.66	10.20	2.62	1.13	1.12
2005	--	--	--	--	--	--	--	--	0.25	0.25
2006	37.10	6.98	29.58	29.58	863.27	16.52	--	--	--	--
July										
2004	32.47	15.34	31.61	31.61	796.09	127.71	7.59	1.81	2.11	1.92
2005	--	--	--	--	--	--	--	--	--	--
2006	39.80	8.01	28.42	28.42	942.36	60.01	--	--	--	--
August										
2004	--	--	--	--	--	--	--	--	--	--
2005	54.13	8.11	28.90	28.90	--	--	7.24	0.12	--	--
2006	41.80	9.79	30.00	30.00	1014.98	29.95	--	--	--	--

Appendix 5.7. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
September										
2004	45.90	6.54	23.71	23.71	729.10	9.58	9.18	2.07	0.81	0.31
2005	29.75	8.17	26.30	26.30	812.45	95.35	8.32	1.38	0.22	0.13
2006	35.17	5.71	--	--	--	--	--	--	--	--
October										
2004	29.70	8.21	25.78	25.78	664.20	9.61	7.23	0.27	1.71	0.57
2005	33.80	8.12	24.47	24.47	811.57	15.48	10.16	1.26	3.69	1.04
2006	39.40	19.61	--	--	--	--	--	--	--	--
November										
2004	--	--	--	--	--	--	--	--	--	--
2005	39.47	7.37	20.19	20.19	636.50	49.72	22.85	110.43	4.73	1.19
2006	--	--	--	--	--	--	--	--	--	--
December										
2004	25.63	6.68	13.53	13.53	330.19	16.41	5.94	0.67	2.54	0.54
2005	24.12	8.29	12.57	12.57	656.83	102.06	8.22	0.21	1.10	0.07
2006	39.23	3.69	--	--	--	--	--	--	--	--

Appendix 5.8. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
January										
2004	27.90	11.03	14.86	14.86	494.37	35.23	8.29	0.86	6.78	1.33
2005	23.90	10.65	11.89	11.89	278.58	65.68	--	--	0.17	0.17
2006	20.10	8.23	12.70	12.70	625.30	17.01	8.37	0.28	3.13	1.78
February										
2004	33.37	8.44	8.37	8.37	363.03	27.96	--	--	7.85	1.45
2005	28.83	7.51	11.61	11.61	396.79	23.86	9.25	0.41	0.44	0.02
2006	20.30	7.15	6.70	6.70	525.60	14.59	7.51	0.20	1.48	0.10
March										
2004	32.40	7.37	9.10	9.10	382.20	31.14	--	--	8.92	1.59
2005	28.30	11.28	18.39	18.39	473.31	79.56	--	--	4.59	0.30
2006	23.57	7.32	17.15	17.15	617.10	14.87	--	--	1.89	0.43
April										
2004	35.27	10.87	22.97	22.97	629.82	28.87	8.03	0.38	3.79	1.48
2005	23.93	8.03	17.66	17.66	406.35	25.81	--	--	1.96	0.14
2006	--	--	--	--	--	--	--	--	--	--

Appendix 5.8. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
May										
2004	27.42	11.34	26.84	26.84	611.32	95.39	7.52	0.86	2.97	0.98
2005	39.83	10.02	28.79	28.79	817.07	17.34	8.12	0.39	0.18	0.04
2006	25.45	8.10	29.40	29.40	756.88	128.26	--	--	0.33	0.03
June										
2004	11.80	6.17	26.34	26.34	593.55	258.85	8.83	3.63	1.41	1.49
2005	32.12	11.80	28.74	28.74	679.80	40.26	7.82	0.27	--	--
2006	30.10	8.91	28.61	28.61	860.92	117.85	--	--	--	--
July										
2004	29.02	14.77	31.58	31.58	697.29	138.40	8.87	1.59	2.25	1.36
2005	30.73	8.60	28.88	28.88	--	--	7.39	0.14	--	--
2006	43.18	8.03	29.78	29.78	878.27	52.02	--	--	--	--
August										
2004	--	--	--	--	--	--	--	--	--	--
2005	--	--	--	--	--	--	--	--	--	--
2006	45.27	6.81	29.78	29.78	994.07	62.54	--	--	--	--

Appendix 5.8. Continued. Mean ($\bar{x}$) and standard error of water quality parameters collected among months in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Depth (cm)		Temperature (°C)		Conductivity (S/cm)		pH		Dissolved Oxygen (ppt)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
September										
2004	29.63	8.02	25.37	25.37	714.33	139.29	5.01	0.69	1.45	0.21
2005	27.52	10.23	26.19	26.19	771.72	197.45	20.39	95.53	0.13	0.15
2006	--	--	--	--	--	--	--	--	--	--
October										
2004	26.50	11.39	24.33	24.33	541.00	93.36	6.00	0.90	0.51	0.07
2005	26.50	7.49	26.03	26.03	835.97	25.17	11.53	0.88	3.17	1.26
2006	27.98	8.21	--	--	--	--	--	--	--	--
November										
2004	--	--	--	--	--	--	--	--	--	--
2005	25.28	10.35	18.18	18.18	644.70	115.47	9.58	1.49	3.24	1.97
2006	--	--	--	--	--	--	--	--	--	--
December										
2004	24.00	10.50	13.04	13.04	257.08	57.65	5.87	0.85	1.35	0.04
2005	22.25	7.58	11.92	11.92	652.68	68.79	9.65	1.28	1.38	0.30
2006	25.50	5.06	--	--	--	--	--	--	--	--

CHAPTER VI

BODY CONDITION, FOOD HABITS, AND MOLT CHRONOLOGY OF WATERFOWL AT RICHLAND CREEK WILDLIFE MANAGEMENT AREA

INTRODUCTION

During winter, waterfowl body mass and carcass composition are unstable due to a variety of internal and external variables influencing body condition, which is defined as an individual's ability to meet present and future energetic demands (Whyte et al. 1986, Labocha and Hayes 2012). Fluctuations in body mass and associated nutrient reserves are important to waterfowl during nonbreeding periods, as such changes can affect current and future survival and reproduction (Heitmeyer and Fredrickson 1981, Baldassarre et al. 1986, Haramis et al. 1986, Conroy et al. 1989, Moorman et al.1992), when stored lipids provide energy during periods of food storage or severe weather (Blem 1976, Baldassarre et al. 1986, Moon et al. 2007, Devries et al. 2008, Labocha and Hayes 2012). Condition indices have been recognized as valuable tools for managing waterfowl and other species for which condition has been linked to various fitness components (Odum et al. 1964, Hepp et al. 1986, Conroy et al. 1989, Bergan and Smith 1993, Heitmeyer 1995, Haukos et al. 2001, DeVault et al. 2003, Labocha and Hayes 2012). Condition estimates are particularly valuable in the context of hunted waterfowl populations, where useful condition indices for management should be estimated from easily obtained measurements in the field without requiring time-consuming dissections and analyses (Johnson et al. 1985, Haukos et al. 2001, DeVault et al. 2003, Labocha and Hayes 2011).

Despite the utility of such condition indices for waterfowl management, a number of aspects have received considerable criticism (DeVault et al. 2003). Waterfowl body condition indices (BCI) are estimated by using total body mass and then standardizing that using external and/or internal morphological measurements (i.e., total body length, wing cord, flight muscle mass, etc.) to create indices that are presumably correlated with protein or fat levels at a whole body level (Wishart 1979, Johnson et al. 1985, Ringleman and Szymczak 1985, Moser and Rusch 1988). Typically, the aim of creating body condition indices is to separate the influence of body mass on condition due to structural size from aspects that reflect fat and other energy reserves (Wishart 1979, Johnson et al. 1985, Green 2001). Many researchers have promoted development of species specific indices due to variability within and among species, at local and large spatial scales (Austin and Fredrickson 1987, Moser and Rusch 1988, Morton et al. 1990, Crook 2007, Moon et al. 2007). For example, some indices stress the importance of stored lipids as the appropriate surrogate for condition while others emphasize the combined value of protein and fat (Wishart 1979, Moser and Rusch 1988, DeVault et al. 2003). Although these criticisms raise questions about universal application of condition indices, such BCIs typically perform well enough to be useful as indicators of population health during a well defined spatial and temporal scale (Labocha and Hayes 2011).

Although estimates of condition are key elements in understanding winter ecology of waterfowl; singly, they provide limited insight into factors driving variation in condition besides obvious temporal variation due to different age-sex cohorts of interest. Variation in condition should be clearly linked to habitat and food habits as well as molt intensity during winter (see Pehrsson 1987, Lovvorn and Barzen 1988). These elements are intertwined, as food habits reflect both energetic demands and food resource availability at local and large spatial scales, which, in turn, should be correlated with temporal changes in condition (Smith and Sheeley 1993). Although wintering waterfowl diet and food habits have not been studied as extensively as during the breeding season, winter habitat (e.g., food quality and quantity) plays a key role in overall condition, mate acquisition success, short term and long-term survival, and breeding success and fitness (Heitmeyer and Fredrickson 1981, Miller 1986, Euliss and Harris 1987, Moon 2007). Therefore, food habit studies performed in conjunction with evaluations of condition should provide a more holistic view of habitat use, quality, and general resource allocation/acquisition in relation to species requirements during a given temporal window (Drobney and Fredrickson 1979, Hohman et al. 1992, Smith and Sheeley 1993*a*).

Food habit studies are one of four key objectives of research required to fully determine wintering requirements of waterfowl, which also include habitat use, time budgets, and body condition (Korschgen et al. 1988), along with many ducks of the *Anatini* tribe share similar feeding behaviors and patterns, both in quality and quantity of food items used during winter (DuBowy 1988, Guillemain et al. 2000). For example, blue-winged teal (*A. discors*), green-winged teal (*A. crecca*), and Northern shovelers (*A. clypeata*) use moderate amounts of semi-aquatic and aquatic vegetation in shallow to moderately deep water habitats (White and James 1978). However, Northern shovelers often sieve for small crustaceans in the water column, while blue-winged and green-winged teal are more generalized in their foraging behaviors and food habits and tend to focus upon plant matter (i.e., seeds, tubers, or leafy parts of vegetation) (Dirschl 1969, Baldassarre and Bolen 1984, Dubowy 1985, Eulis and Harris 1987, Botero and Rusch 1994, Anderson et al. 2000).

Although food habits are typically the product of interactions among biological and nutritional demands, physical capabilities, and environmental conditions (Swanson et al. 1974), they tend to vary by species and seasonally as food availability changes based upon local environmental conditions. For example, Dirschl (1969) reported seasonal fluctuations food habits of blue-winged teal, where invertebrates dominated diets (primarily during the breeding season), but seeds of *Carex spp.*, *Eleocharis spp.*, *Sparganium spp.*, and *Scirpus spp.* were consistently (18-35% occurrence) consumed over time. Similarly, Thompson et al. (1992) reported that wintering blue-winged teal consumed >98% Gastropods during early winter, but switched to a plant-dominated diet during mid-late winter (i.e., > 96% plant material, primarily tubercles of muskgrass, *Chara spp.*). In contrast, green-winged teal consume mostly plant matter and seeds (> 70%; Anderson et al. 2000), with considerably less (8-37%) of their diet represented by animal matter (primarily Insecta; Euliss and Harris 1987, Anderson et al. 2000). Typically, green-winged teal seed consumption will reflect food item availability, but they will consume larger seeds, such as those produced by *Polygonum spp., Eleoocharis spp., Paspalum spp., Echinochloa spp.,* and *Rumex spp.* (Anderson et al. 2000). Although early Northern shoveler food habit studies reported that they primarily consumed vegetation or seeds (Anderson 1959, Stewart 1962, McGilvery 1966), more recent work has questioned these results with shovelers typically consuming plankton-cladocerans in freshwater marshes and ostracods in saltwater marshes. Seeds comprised <25% of diets in both habitats (Tiejte and Teer 1996). Although these species consume proportionately different foods, it is clear that waterfowl change diets based upon physiological demands and food availability. As such, food habits should be related to overall body condition during winter, regardless of species, age-sex cohorts, and temporal changes in physiological demands. (e.g., molting)

Waterfowl exhibit a unique molting sequence in which adults become flightless and molt all of their primary and secondary flight feathers during post-breeding, prior to fall migration (Miller 1986, Combs and Fredrickson 1995). Hatch-year birds retain their natal flight feathers through their first year, but molt into juvenile plumage during migration and attain adult body feathers during winter (Pyle 2008). Similarly, adults also undergo significant body molt during winter, although they have already completed wing molt prior to arrival on most wintering grounds. The timing of this molt is synchronized with mate acquisition and pair bonding (which occurs during winter), where earlier pair bonding confers clear advantages in subsequent nesting success (Furness 1988, Morton and Morton 1990, Earnst 1992). As such, during winter, both hatch year and adult waterfowl experience tremendous physiological demands to recover after fall migration, complete body molt, and successfully acquire a mate, all whilst avoiding harvest and maintaining body condition to improve over-winter survival (Heitmeyer 1985, Miller 1986, Lovvorn and Barzen 1988, Smith and Sheeley 1993*b*, Hohman and Crawford 1995).

Feather molt has been studied extensively during winter because of the aforementioned life-history requisites encountered during winter months (Hohman and Crawford 1995). Regular replacement of feathers (i.e., feather molt) is essential to the protection, thermoregulation, locomotion, and communication functions of avian plumage (McKnight and Hepp 1999), but molt is nutritionally and energetically costly and its timing in the annual cycle has important ecological implications (Murphy 1996; McKnight and Hepp 1999). Timing of molt forces nutritional tradeoffs between the need to replace plumage and execution of other important events in the annual cycle, such as pair bonding during winter (Moore et al. 1982). As such, describing molt chronology during winter, in conjunction with estimates of body condition and descriptions of food habits, will provide insight into physiological status, habitat and food availability and quality, and probable fitness of wintering waterfowl.

Under poor habitat conditions during winter, delays in molt have been reported in mallards (*A. platyrhynchos*) and Northern pintails (*A. acuta*) (Heitmeyer 1987), due to food shortages (Petersen 1981). If the proper amounts of nutrition are neither available nor met, waterfowl may (1) suspend or delay feather production until better conditions arise, (2) extend molt duration, resulting in depressing feather production via reduced nutrient intake, (3) continue plumage synthesis by catabolizing somatic nutrients, or (4) use a combination of these tactics (King and Murphy 1985). Many studies of body composition of waterfowl in winter have presented data on a chronological basis (Reinecke and Stone 1982, Baldassarre et al. 1986, Rave and Baldassarre 1991, Hine et al. 1996) and have not related results to events in the annual cycle that are undertaken during winter (Heitmeyer 1988).

This research is unique in that simultaneous estimates of body condition, food habits, and molt chronology are rare, particularly for species using moist-soil managed wetlands during winter. Management of such wetlands is focused specifically upon food production during winter (see Chapter II and III), where waterfowl using moist-soil managed wetlands should avoid food shortages and consequent delays in molt progression while simultaneously maintaining body condition. Moreover, waterfowl wintering in moist-soil managed wetlands in more southerly latitudes should avoid extended periods of severe winter weather which may alleviate (1) commonly observed mid-winter declines in body condition (Fredrickson and Taylor 1982), (2) pressures to extend or delay molt, and (3) potential food shortages. As such, the objectives of this portion of this research were to quantify body condition, food habits, and feather molt progression and intensity of blue-winged teal, green-winged teal, and Northern shoveler during winter using moist-soil managed wetlands on the Richland Creek Wildlife Management Area in east central Texas. Identifying potential variables influencing the relationships among body condition, food habits, and feather molt intensity will provide key insight into how these species use moist-soil managed wetlands during winter in east central Texas.

STUDY AREA

This research was conducted on the Richland Creek Wildlife Management Area's (RCWMA) North Unit moist-soil managed wetlands 1-4 (Figure 1.1). The RCWMA (31º13'N, 96º11'W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The WMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were fully functional. Construction of moist-soil managed wetland units 5-6 began in the summer 2006 and have been functioning since November 2009.

Local climate is considered subtropical with mild winters and warm humid summers, with an average daily summer temperature of 34º C and winter temperature of 5º C, a growing season of 246 days, and average rainfall of 101.6 cm a year (NRCS

2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, and mollisol soils (NRCS 2002).

Vegetation within the South Unit (Figure 1.4) is characterized by vast bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North Unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. Typical water management strategy consists of slow drawdown (i.e., removal of water) starting late March - early April and lasting until mid August. Inundation (i.e., flooding) begins in late August and lasts throughout fall and winter, until drawdown the following spring. These management actions produced common species such as barnyardgrass, erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet, and water primrose (*Ludwigia peploides*) (Appendix A).

METHODS

Focal species collection

Specimens of each focal species (i.e., blue-winged teal, green-winged teal, and Northern shoveler) were acquired using two separate methods. First, from September-January, 2004-2005, 2005-2006, and 2006-2007, data were collected during the early teal and regular waterfowl seasons while RCWMA was open to public hunting. As hunters exited RCWMA after hunts on moist-soil managed wetlands, they were required to stop at mandatory hunter check stations to allow technicians to inspect and record basic external morphological measures (see below) on focal species prior to departure of WMA. Hereafter, these are referred to as hunter harvested birds.

Focal species were also collected on the moist-soil managed wetlands using a 12-gauge shotgun and steel shot from 1 September – 15 March, 2004-2005, 2005-2006, and 2006-2007. These samples were collected passively or using decoys, but are hereafter referred to as scientifically collected birds. All scientifically collected focal species were collected under the following permits (U.S. Fish and Wildlife Scientific Collection Permit MB093036-0 and Texas Parks and Wildlife Scientific Collecting Permit SPR-0704-399, both issued to D. Collins). For all birds (regardless of collection technique), age and sex were recorded following Carney (1992) and the following morphological features were measured: body mass (g), bill length (cm), culmen length (cm), maximum bill width (cm), keel length (cm), tarsus length (cm), and total body length (cm). Specimens were put on ice, transported back to the lab and frozen for future dissection.

Body condition indices

Prior to dissection, birds were thawed and measured to nearest 0.01 (g) to obtain total body mass. Feathers were removed, and the bill, tarsi, skin, one flight muscle and leg, and all internal organs (i.e., heart, gastrointestinal tract, liver, lungs, and gizzard) were removed and weighed to nearest 0.01 g. Mesentery fat was removed from the viscera and returned to the carcass (Morton et al. 1990), while all digestive contents were removed from the esophagus, proventriculus, gizzard, intestine, and caeca (Hohman et al. 1992). If material was present in the digestive tract it was washed into a container and stored (Morton et al. 1990). Digestive contents were measured to nearest 0.01 (g) and subtracted, with feather mass, from total body mass to obtain feather free carcass mass (DeVault et al. 2003). Omental fat was removed and measured to nearest 0.01 (g) (Woodall 1978) and the entire length of the gastrointestinal tract was measured to nearest 5 mm and nearest 0.01 (g) (Austin and Fredrickson 1987). Flight muscles (i.e., pectoralis, supracoracoideus, and coracobrachialis) on the left side were removed from the sternum (Owen and Cook 1977, Morton et al. 1990). External fat was removed and returned to the carcass from the gizzard and flight muscles. Wet mass of the gizzard, heart, liver, kidneys, and flight muscles was measured to the nearest 0.01 (g) (Austin and Fredrickson 1987).

Three morphological body condition indices were calculated for each bird (both hunter harvested and scientifically collected birds). The first BCI (BCI1) was calculated by dividing total body mass (g) by wing cord length (mm) following Hine et al. (1996)

and Haukos et al. (2001). Second, following Smith and Rhodes (1993), BCI2 was calculated for each bird by dividing total body mass (g) by the sum of total body length (cm) and wing cord length (cm). Finally, BCI3 was calculated by dividing total body mass (g) by the product of bill length (cm) and keel length (cm) following Bennett and Bolen (1978). BCI3 was not calculated for hunter harvested birds, as keel length was not able to be measured on birds that were brought through the check stations.

Food habits

As part of the above collection efforts, focal species were collected opportunistically during morning feeding flights or after observation of diurnal foraging, from 15 September – 28 February 2004-2005, 2005-2006, 2006-2007, to ensure birds contained recently consumed food (Anderson et al. 2000). Attempts were made to equalize numbers of individuals in each sex and age class within each species. Only scientifically collected birds were used for this portion of the study. Upon collection, a 75% ethanol solution was immediately injected into the esophagus to preserve material post-mortem (Anderson et al. 2000). Birds were then eviscerated, and the digestive tract was removed and stored in 75% ethanol.

In the lab, digestive tracts were dissected and washed to remove all materials contained within. Digestive tract contents were examined, where animal and plant matter were separated measured to the nearest 0.10 (g) to obtain wet mass. All items were identified to lowest taxon (i.e., genus and species when possible; Anderson et al. 2000). After all digestive items were identified and separated, they were dried at 50°C for 24 hours, and remeasured to nearest 0.10 (g) to obtain food item dry mass. After all items were identified, separated, and dry mass measured, aggregate percent (%) dry mass was calculated by dividing a single item's dry mass by total overall mass for a species or cohort within a species. For example, if an item had a cumulative dry mass of 1.5 g in all blue-winged teal, and all blue-winged teal food items summed to 10.0 g, that food item would have an aggregate percent dry mass of 15%. This approach was used for all items that were identified, such as total seeds, total invertebrates, total plant material, and grit to calculate aggregate percent dry mass.

Feather molt chronology and intensity

For this portion of the study, only scientifically collected focal species were used. Prior to plucking (see above), a total of 17 feather tracts were inspected (i.e., crown, face, rump, tail, belly, etc.) and used to score feather molt intensity (i.e., % sheathed feathers/tract) following Heitmeyer (1988) and Smith and Sheeley (1993). For each tract, the number of sheathed feathers was counted and used to calculate total molt score for each specimen. The molt score was calculated by summing the total number of feathers found erupting (containing a sheath) on all tracts and then dividing by the total number of feather tracts examined. For example, if 300 erupting feathers were counted on the 17 feather tracts examined, that individual specimen would have a molt score of 17.64 (see Smith and Sheeley 1993). Molt scores were calculated and then used in conjunction with previously calculated body condition indices (see above).

Data analyses

Body condition

Analysis of variance (ANOVA) was used to examine differences among external and internal morphological features among focal species, among age-sex cohorts (i.e., adult males, adult females, juvenile males, and juvenile females), and among 3 seasons (1 September–15 November; 16 November – 31 December; 1 January 1 – 10 March). These seasons were defined to capture migrating, wintering, and pre-migration periods rather than a calendar year. Initial analyses examining differences in body condition focused upon collection technique (i.e., hunter harvested vs. scientifically collected individuals) to determine if body condition biases associated with hunter harvested focal species occurred. If differences ($P < 0.05$) occurred using ANOVA in condition indices between collection techniques, subsequent analyses were conducted within each collection technique. Multivariate analysis of variance (MANOVA) was used to examine differences in BCI1, BCI2, and BCI3 (1) among species, regardless of age-sex cohorts and then (2) within species, among age-sex cohorts, and among seasons. If differences ($P < 0.05$) occurred in MANOVA, subsequent analyses were performed using ANOVA to more clearly identify effect size and location.

Food habits

Multivariate analysis of variance was also used to examine differences in aggregate percent (%) dry mass of all foods, among focal species, among age-sex cohorts, and among years (2004, 2005, and 2006) following Haukos and Smith (2000). Due to unequal distribution of samples collected during the previously defined seasons, food habits analyses were constrained to calendar year. If differences ($P < 0.05$) occurred in MANOVA, subsequent analyses were performed using ANOVA to more clearly identify effect size and location.

Feather molt chronology and intensity

Prior to any analyses, molt scores were arcsine-transformed to meet assumptions of homogenous variance and normality (Sokal and Rohlf 1981; Anderson et al. 2000). Multivariate analysis of variance was then used to examine differences in molt scores among species, body condition indices, sex-age cohorts, seasons (e.g., described above in body condition and food habits), months, and years. If differences ($P < 0.05$) occurred in MANOVA, subsequent analyses were performed using analysis of variance to more clearly identify effect size and location. Correlation analyses were also performed within each species to examine correlations among body condition indices and feather molt intensity scores.

RESULTS

Morphology

Blue-winged teal

Hunter harvested birds: External and internal morphology of hunter harvested blue-winged teal varied overall (*P*< 0.05) among age, sex, age-sex cohorts, and seasons, where most variation occurred between sexes and among seasons (Table 6.1). Males tended to be heavier (i.e., body mass), longer (i.e., body length), and possessed longer wing cords than females, for both age classes (Table 6.2). Birds harvested during early migration (i.e., September and October), particularly males, tended to have greater body mass than females, which continued through winter. Body mass fluctuated during winter, but all age-sex cohorts had greater body mass by January for hunter harvested blue-winged teal (Figure 6.1).

Scientifically collected birds: External and internal morphology of scientifically collected blue-winged teal varied (*P*< 0.05) among age, sex, age-sex cohorts, and seasons, where most variation in morphology occurred among age-sex cohorts and seasons (Table 6.3). Both female age-cohorts had greater fat content (i.e., omental, mesentery, and visceral) than male counterparts, but both male age-cohorts had greater body mass than female counterparts (Table 6.4, Table 6.5, Table 6.6, Table 6.7). Adults of both sexes collected during early migration (i.e., September and October), had greater body mass than juvenile cohorts, which continued throughout winter. Body mass fluctuated during winter, but by March, body mass had improved over mid winter estimates (Figure 6.2).

Green-winged teal

Hunter harvested birds: External and internal morphology of hunter harvested green-winged teal varied ($P < 0.05$) among age, sex, age-sex cohorts, and seasons, where most variation occurred between sexes and among seasons (Table 6.8). Males, regardless of age, tended to be heavier (i.e., body mass), longer (i.e., body length), and had longer wing cords than female counterparts (Table 6.9). During early migration (i.e., September and October), adult females had greater body masses than juvenile females, but showed mid-winter declines in body mass during December, as did adult males. However, most age-sex cohorts of hunter harvested green-winged teal had recovered to greater body masses by January (Figure 6.3).

Scientifically collected birds: External and internal morphology of scientifically collected green-winged teal varied ($P < 0.05$) among age, sex, age-sex cohorts, where most variation occurred among age-sex cohorts and seasons (Table 6.10). Males, regardless of age, tended to be heavier than female counterparts (Table 6.11, Table 6.12, Table 6.13, Table 6.14), but adults (male and female) had greater body mass than juveniles of both sexes during November and December. During winter, (i.e., November and December), body mass fluctuated slightly but was for the most part was maintained throughout the winter (Figure 6.4).

Northern shoveler

Hunter harvested birds: External and internal morphology of hunter harvested Northern shoveler varied ($P < 0.05$) among age, sex, age-sex cohorts, and seasons, where most variation occurred between sexes and among seasons (Table 6.15). Adults, of both sexes, tended to be heavier than juveniles, while males, of both ages, tended to be longer (i.e., body length) and had longer wing cords than females (Table 6.16). Hunter harvested Northern shoveler data were temporally concentrated towards the end of waterfowl season (Figure 6.5).

Scientifically collected birds: External and internal morphology of scientifically collected Northern shovelers varied ($P < 0.05$) among age, sex, age-sex cohorts, and seasons, where most variation occurred between ages and sexes, respectively (Table 6.17). Adults tended to be heavier and longer (i.e., body length) than their juvenile counterparts, where females (of both ages) had greater fat deposits (i.e., omental, mesentery, and visceral) than males (Table 6.18, Table 6.19, Table 6.20, Table 6.21). Adults, of both sexes, tended to have greater winter (i.e., November and December) body mass than their respective juvenile cohorts, but again, by March, Northern shovelers attained greater mass (Figure 6.6).

Body Condition Indices

Body condition indices between collection techniques (i.e., hunter harvested or scientifically collected) varied for all three indices for blue-winged teal (BCI 1: $F = 102.1$, $P < 0.001$, BCI 2: $F = 51.27$, $P < 0.001$, BCI 3: $F = 25.46$, $P < 0.001$), green-winged teal (BCI 1: $F = 58.84$, $P < 0.001$, BCI 2: $F = 129.39$, $P < 0.001$, BCI 3: $F = 83.98$, $P < 0.001$), and Northern shoveler (BCI 1: $F = 43.21$, $P < 0.001$, BCI 2: $F = 68.35$, $P < 0.001$, BCI 3: $F = 35.59$, $P < 0.001$). In general, BCIs estimated using scientifically collected birds were greater than BCIs estimated from hunter harvested birds. Subsequent analyses were performed within each collection technique respectively.

Blue-winged teal

Condition indices of hunter harvested blue-winged teal did not vary between sexes (Wilks' λ = 0.987, P = 0.209), between ages (Wilks' λ = 0.991, P = 0.355), nor among age-sex cohorts (Wilks' λ = 0.94, P = 0.355) (Table 6.22). Similarly, scientifically collected blue-winged teal condition indices did not vary between condition indices and ages (Wilks' λ = 0.942, P = 0.087) or condition indices and sexes (Wilks' λ = 0.971, P = 0.365) (Table 6.19). Mean hunter harvested BCIs were typically less (BCI1 $\bar{x}$ = 16.33; BCI2; $\bar{x}$ = 5.86) than scientifically collected condition BCIs (BCI1 $\bar{x}$ = 19.65; BCI2 $\bar{x}$ = 6.80) (Table 6.23). For both hunter harvested and scientifically collected blue-winged teal, adult and juvenile male condition indices were typically greater than female counterparts. Scientifically collected blue-winged teal tended to be in better condition than hunter harvested blue-winged teal, and both hunter harvested and scientifically collected birds showed as body mass increased body condition indices increased (Table 6.24, Table 6.25, Table 6.26, Table 6.27, Table 6.28; Figure 6.7, Figure 6.8, Figure 6.9, Figure 6. 10, Figure 6.11, Figure 6.12, Figure 6.13, Figure 6.14, Figure 6.15, Figure 6.16).

Body condition indices for hunter harvested blue-winged teal did not vary among months (Wilks' λ = 0.993, P = 0.454), among years (Wilks' λ = 0.996, P = 0.668), nor was there a month x year interaction (Wilks' λ = 0.994, P = 0.896). However, BCIs did vary among seasons (Wilks' λ = 0.849, P< 0.001), but that difference was only observed for BCI1 (F = 100.07, P< 0.001) (Table 6.29). Although few differences were observed, there was a general trend similar to body mass estimates, where hunter harvested blue-winged teal had increases in body mass, BCI1, and BCI2 during November, and declines during December and January (Figure 6.17, Figure 6.18).

Body condition indices for scientifically collected blue-winged teal did not vary among months (Wilks' $\lambda = 0.994$, $P = 0.895$), years (Wilks' $\lambda = 0.992$, $P = 0.847$), seasons (Wilks' $\lambda = 0.925$, $P = 0.207$), nor was there a month x year interaction (Wilks' $\lambda = 0.994$, $P = 0.896$) (Table 6.30). Unlike hunter harvested blue-winged teal, body condition of scientifically collected blue-winged teal showed a bimodal distribution, where birds arrived in comparatively good condition during fall and early winter, showed mid-season declines in condition, and then improved condition during late winter prior to spring migration (Figure 6.19; Figure 6.20; Figure 6.21).

Green-winged teal

Condition indices of hunter harvested green-winged teal varied between sexes (Wilks' $\lambda = 0.981$, $P = 0.013$) and age (Wilks' $\lambda = 0.983$, $P = 0.020$), but there was no age x sex ($P > 0.05$) interaction (Table 6.22). Subsequent ANOVAs indicated that condition indices varied between ages for both BCI1 ($F = 7.08$, $P < 0.001$) and BCI2 ($F = 4.47$, $P < 0.035$), where adult green-winged teal had greater condition indices than juveniles (Table 6.31, Table 6.32, Table 6.33, Table 6.34, Table 6.35). Similarly, subsequent ANOVAs indicated that condition indices varied among sexes for BCI1 ($F = 7.68$, $P < 0.005$) and BCI2 ($F = 4.66$, $P < 0.031$) (Table 6.22), where males had greater condition indices than females. Condition indices of scientifically collected green-winged teal did not vary between age (Wilks' $\lambda = 0.930$, $P = 0.072$), nor sex (Wilks' $\lambda = 0.957$, $P = 0.243$), and there were no age x sex interactions ($P > 0.05$) (Table 6.23).

Overall, scientifically collected green-winged teal condition indices were greater than hunter harvested condition indices, and both hunter harvested and scientifically collected birds showed as body mass increased body condition indices increased (Table 6.31, Table 6.32, Table 6.33, Table 6.34, Table 6.35; Figure 6.22, Figure 6.23, Figure 6.24, Figure 6.25, Figure 6.26, Figure 6.27, Figure 6.28, Figure 6.29, Figure 6.30, Figure 6.31). In general, males had greater condition indices than their female counterparts for hunter harvested birds, whereas adult females and juvenile males had greatest condition indices for scientifically collected green-winged teal.

Body condition of hunter harvested green-winged teal varied among months (Wilks' $\lambda = 0.947$, $P < 0.001$), among seasons (Wilks' $\lambda = 0.913$, $P < 0.001$), but not among years (Wilks' $\lambda = 0.999$, $P = 0.960$), although there was a month x year interaction (Wilks' $\lambda = 0.947$, $P < 0.001$). BCI1 ($F = 22.70$, $P < 0.001$) and BCI2 ($F = 23.11$, $P < 0.001$) varied among months, where green-winged teal condition was better during early months (Table 6.29), which was consistent with differences observed among seasons, where greater BCI1 ($F = 11.30$, $P < 0.001$) and BCI2 ($F = 2.84$, $P = 0.05$) were estimated during arrival and just prior to spring migration. The month x year interaction followed a similar pattern, where BCI1 ($F = 22.99$, $P < 0.001$) and BCI2 ($F = 23.38$, $P < 0.001$) varied over time. In general, for hunter harvested green-winged teal, BCI1 and BCI2 mirrored body mass trends, where increased condition was recorded during November, and declines were observed during December and January (Figure 6.32, Figure 6.33).

Body condition of scientifically collected green-winged teal varied among months (Wilks' $\lambda = 0.811$, $P < 0.001$), years (Wilks' $\lambda = 0.888$, $P = 0.011$), seasons (Wilks' $\lambda =$

0.721, $P < 0.001$) and there was a month x year interaction (Wilks' $\lambda = 0.811$, $P =< 0.001$) (Table 6.30). Scientifically collected green-winged teal body condition varied among months for BCI1 ($F = 9.70$, $P < 0.002$) and BCI2 ($F = 21.44$, $P < 0.001$), but not BCI3 ($F = 1.18$, $P = 0.280$). A similar pattern was observed among years {BCI1 ($F = 5.78$, $P < 0.02$) and BCI2 ($F = 11.46$, $P < 0.001$), but not BCI3 ($F = 0.64$, $P = 0.426$). Similarly, body condition varied among seasons for BCI1 ($F = 10.71$, $P < 0.001$) and BCI2 ($F = 17.33$, $P < 0.001$), but not BCI3 ($F = 2.09$, $P < 0.129$), and the month x year interaction showed the same pattern among BCIs {BCI1 ($F = 59.70$, $P < 0.002$) and BCI2 ($F = 21.43$, $P < 0.001$), BCI3 ($F = 1.18$, $P < 0.281$)} (Table 6.30). In general, all three BCIs followed similar patterns, where scientifically collected green-winged teal arrived in comparatively good condition and maintained good condition throughout the wintering season (Figure 6.34; Figure 6.35; Figure 6.36).

Northern shoveler

Condition indices of hunter harvested Northern shoveler varied between ages (Wilks' $\lambda = 0.948$, $P = 0.039$), was similar between sexes (Wilks' $\lambda = 0.983$, $P = 0.358$) and did not show a age x sex interaction ($P > 0.05$) (Table 6.22). Adult hunter harvested Northern shovelers had greater condition indices than juveniles for both BCI1 ($F = 6.28$, $P = 0.013$) and BCI2 ($F = 6.67$, $P < 0.011$). Condition indices of scientifically collected Northern shoveler did not vary between ages (Wilks' $\lambda = 0.936$, $P = 0.153$) or sexes (Wilks' $\lambda = 0.928$, $P = 0.113$), nor was there an age x sex interaction ($P > 0.05$) (Table 6.23). Overall, body condition indices for scientifically collected Northern shovelers were greater than estimates from hunter harvested birds. Males typically had greater condition within hunter harvested shovelers, whereas scientifically collected adult females and juvenile males were in better condition than adult males and juvenile females, and both hunter harvested and scientifically collected birds showed as body mass increased body condition indices increased (Table 6.36, Table 6.37, Table 6.38, Table 6.39, Table 6.40; Figure 6.37, Figure 6.38, Figure 6.39, Figure 3.40, Figure 3.41, Figure 3.42, Figure 3.43, Figure 3.44, Figure 6.45, Figure 6.46).

Body condition of hunter harvested Northern shovelers did not vary among months (Wilks' $\lambda = 0.964$, $P = 0.117$), years (Wilks' $\lambda = 0.990$, $P = 0.580$), season (Wilks' $\lambda = 0.967$, $P = 0.402$), nor was there a month x year interaction (Wilks' $\lambda = 0.965$, $P = 0.118$) (Table 6.29). Body condition of scientifically collected Northern shovelers was similar among months (Wilks' $\lambda = 0.955$, $P = 0.312$), among seasons (Wilks' $\lambda = 0.926$, $P = 0.419$), and there was no month x year interaction (Wilks' $\lambda = 0.955$, $P = 0.312$). However, condition indices of scientifically collected shovelers varied among years (Wilks' $\lambda = 0.842$, $P = 0.003$), for all three BCIS {BCI1 ($F = 11.77$, $P < 0.001$), BCI2 ($F = 14.13$, $P < 0.001$), BCI3 ($F = 5.74$, $P < 0.018$) (Table 6.30). Similar to both teal, scientifically collected Northern shoveler condition followed body mass trends (Figure 6.47; Figure 6.48), where shovelers were in comparatively good condition upon arrival, and maintained good condition throughout the wintering season (Figure 6.49; Figure 6.50; Figure 6.51).

Food habits

A total of 34 food items were identified, where they cumulatively occurred 677 times in all three focal species (Table 6.32). Nodding smartweed (*Polygonum* *lapthifolium*) (14%), grit (10.5 %), and *Panicum* sp. (11%) were the dominant items identified by percent occurrence (Table 6.41). When using percent occurrence by mass, grit (75 g) and nodding smartweed (5.9 g) were greatest for all species combined (Table 6.41). Nearly 6 times greater biomass of seeds than invertebrates was estimated for all species combined, while there was nearly 10 fold difference in the total number of seeds as compared to invertebrates (Table 6.41).

Aggregate percent dry mass varied among species (Wilks' $\lambda = 0.988$, $P = 0.035$), but did not vary among ages (regardless of species) (Wilks' $\lambda = 0.999$, $P = 0.921$), sex (regardless of species) (Wilks' $\lambda = 0.995$, $P = 0.097$), and there was no interaction between age and sex (Wilks' $\lambda = 0.999$, $P = 0.884$). Subsequent analysis of variance demonstrated that aggregate percent dry mass varied among species ($F = 3.35$, $P > 0.033$) where blue-winged teal had nearly double and triple the overall percent mass occurrence of the other two green-winged teal and Northern shoveler, respectively (Table 6.42, Table 6.43, Table 6.44).

Aggregate percent dry mass within blue-winged teal did not vary between ages (Wilks' $\lambda = 0.998$, $P = 0.605$), nor sex (Wilks' $\lambda = 0.991$, $P = 0.124$), nor was there an age x sex interaction (Wilks' $\lambda = 0.991$, $P = 0.922$). Aggregate percent dry mass did varied between years (Wilks' $\lambda = 0.984$, $P = 0.040$), where the greatest aggregate percent dry mass occurred in 2005 ($F = 4.24$, $P = 0.04$) (Table 6.42). Within green-winged teal, aggregate percent dry mass did not vary between ages (Wilks' $\lambda = 0.999$, $P = 0.945$), nor sexes (Wilks' $\lambda = 0.997$, $P = 0.534$), nor was there an age x sex interaction (Wilks' $\lambda =$

0.997, $P = 0.551$), nor years (Wilks' $\lambda = 0.997$, $P = 0.497$). Food habits were consistent temporally, although the greatest aggregate percent dry mass was observed in 2005 for green-winged teal (Table 6.43). Within Northern shoveler, aggregate percent dry mass did not vary between ages (Wilks' $\lambda = 0.993$, $P = 0.299$), sexes (Wilks' $\lambda = 0.999$, $P = 0.910$), years (Wilks' $\lambda = 0.995$, $P = 0.377$), nor was there a age x sex interaction (Wilks' $\lambda = 0.997$, $P = 0.569$). Again, similar to both blue-winged and green-winged teal, Northern shoveler diets were consistent temporally, and aggregrate percent dry mass tended to be greatest in 2005 (Table 6.44).

Feather molt intensity

Of 205 individual specimens examined, for all species combined, there were a total of 28,672 individual feathers erupting/molting with an overall molt score of 8.23. Blue-winged teal had a total of 8,431 individual feathers erupting / molting and an overall molt score of 5.33, while green-winged were growing 4,963 individual feathers, resulting in an overall molt score of 6.21 (Table 6.45). Northern shoveler had the greatest number of feathers erupting ($n = 15,278$), and had the greatest overall molt score (13.83) of the three focal species (Figure 6.48, Table 6.45). Similarly, shovelers had the greatest mean number of molting feathers ($\bar{x} = 235.1$), more than double that of both blue-winged teal ($\bar{x} = 90.7$) and green-winged teal ($\bar{x} = 105.6$). Among species age-sex cohorts, juvenile female blue-winged teal had the lowest molt score (4.15) of any species age-sex cohort, while juvenile male blue-winged teal (6.5), adult female green-winged teal (8.24), and adult female shoveler (16.6) had the greatest molt scores within each species, respectively. Regardless of species, overall molt score was predictably greatest during

January (12.35) and lowest during October (2.54) (Figure 6.47), where molt scores were consistently greater during later temporal periods (Figure 6.49). Within each species, molt intensity and molt score was remarkably consistent.

Within blue-winged teal, juvenile males had the greatest mean molt on the face and neck tract(s), but for remaining feather tracts, age-sex cohort molt scores were similar (Table 6.45). Within green-winged teal, adult females had the greatest mean molt on the neck and upper back tract(s) as well as their side tracts (i.e., chest side and side tracts), and there was considerable variation in molt intensity for remaining feather tracts among age-sex cohorts (Table 6.46). Adult shovelers tended to have greater molt intensity for most tracts than juveniles of either sex, although scapular and belly tracts were the only ones in which juveniles had greater molt intensity than adults (Table 6.47).

Feather molt score and BCIs varied among species (Wilk's $\lambda = 0.885$, $P < 0.001$), and there was an age x sex interaction (Wilk's $\lambda = 0.952$, $P = 0.025$). Northern shoveler had greater molt scores than either blue-winged or green-winged teal. Within blue-winged teal, molt scores varied among months (Wilk's $\lambda = 0.892$, $P = 0.028$), years (Wilk's $\lambda = 0.880$, $P = 0.020$) and seasons (Wilk's $\lambda = 0.876$, $P = 0.018$), but molt score was similar between ages (Wilk's $\lambda = 0.947$, $P = 0.131$), sexes (Wilk's $\lambda = 0.925$, $P = 0.076$), there was no age x sex interaction (Wilk's $\lambda = 0.998$, $P = 0.810$), and molt score did not vary among body condition indices (BCI1; Wilk's $\lambda = 0.999$, $P = 0.914$, BCI2; Wilk's $\lambda = 0.998$, $P = 0.792$, BCI3; Wilk's $\lambda = 0.988$, $P = 0.474$). For blue-winged teal, molt scores were consistently greater in later months ($F = 5.16$, $P = 0.020$) and seasons ($F = 6.04$,$P = 0.018$).

Within green-winged teal, molt scores did not vary among age (Wilk's $\lambda = 0.980$, $P = 0.513$), sex (Wilk's $\lambda = 0.953$, $P = 0.308$), age x sex (Wilk's $\lambda = 0.942$, $P = 0.252$), months (Wilk's $\lambda = 0.974$, $P = 0.457$), years (Wilk's $\lambda = 0.986$, $P = 0.587$) seasons (Wilk's $\lambda = 0.999$, $P = 0.906$) or body condition indices (BCI1; Wilk's $\lambda = 0.950$, $P = 0.294$, BCI2; Wilk's $\lambda = 0.981$, $P = 0.529$, BCI3; Wilk's $\lambda = 0.971$, $P = 0.431$). Overall, green-winged teal molt scores were remarkably consistent over time, as related to different age-sex cohorts and body condition. Finally, molt scores within Northern shoveler did not vary among age (Wilk's $\lambda = 0.906$, $P = 0.156$), sex (Wilk's $\lambda = 0.998$, $P = 0.867$), age x sex (Wilk's $\lambda = 0.930$, $P = 0.223$), months (Wilk's $\lambda = 0.970$, $P = 0.434$), years (Wilk's $\lambda = 0.999$, $P = 0.972$) seasons (Wilk's $\lambda = 0.986$, $P = 0.595$) or body condition indices (BCI1; Wilk's $\lambda = 0.999$, $P = 0.934$, BCI2; Wilk's $\lambda = 0.954$, $P = 0.325$, BCI3; Wilk's $\lambda = 0.989$, $P = 0.635$).

DISCUSSION

Blue-winged teal, green-winged teal, and Northern shoveler adults and males were typically heavier than their respective counterparts, a finding consistent with other studies on waterfowl body mass and body condition (Owen and Cook 1977, Delnicki and Reinecke 1986, Ringleman 1988, Hier 1989, Krementz et al. 1989, Hohman and Weller 1994, Hine et al. 1996, Tietje and Teer 1996). Changes in body mass are very common in waterfowl and are thought to be in response to seasonal weather changes as well as life history events (i.e., reproduction and breeding). Typically, body mass will increase during fall after arrival to wintering grounds, where waterfowl often experience midwinter declines, due to comparatively harsher weather and associated elevated thermoregulatory demands and then increase during late winter and early spring in preparation for spring migration and upcoming breeding season (Baldassarre et al. 1986, Miller 1986, Rave 1987, Takekawa 1987, Thompson and Baldassarre 1990, Rave and Baldassarre 1991, Miller and Eadie 2006). As body mass alone is often used as a surrogate for body condition, it can provide some predictive power regarding overall health and condition of wintering waterfowl, as well as provide insight into food quality and quantity during winter.

As expected, body condition estimates – which were heavily reliant upon body mass – followed body mass trends, where body condition was typically greatest prior to departure during spring, but was poorest during mid-winter, for all three focal species. Interestingly, body mass and condition recovery prior to spring migration would not have been detected if only hunter harvested birds were used – extending scientific collection into February and March permitted capture of these recovery trends, providing further evidence of the biases associated with relying solely upon hunter harvested birds. Regardless of collection technique, if species continue to exhibit declines in body condition and mass prior to spring departure (which was not observed) or en route to breeding areas during spring migration, then issues regarding food and habitat quality during winter may be occurring. For example, Anteau and Afton (2004) hypothesized that declines in spring lipid reserves of lesser scaup (*Aythya affinis*) negatively impact within-year and lifetime reproductive success and fitness. However, recent research has demonstrated that lesser scaup body mass during both fall and winter are greater now than estimates from the 1980s, indicating that fall migration and winter habitats remain adequate in the Mississippi Flyway (Vest 2002), and that perturbations during spring migration are negatively impacting lesser scaup populations. There has been no research to date following any of the focal species en route during migration, so estimates or correlations between body condition and within year reproductive success are lacking. Nonetheless, all three species departed the moist-soil managed wetlands in comparatively better condition than either during arrival or during mid-winter, indicating that these moist-soil managed wetlands (or other spatially close wetlands), managed primarily for waterfowl food production during winter (see Chapters II and III) are meeting or exceeding food requirements for these species.

Heitmeyer and Fredrickson (1981) postulated that poor habitat conditions on important wintering areas reduced subsequent reproductive success through bioenergetic mechanisms, and some have suggested that spring body condition and age are positively correlated with reproductive investment and success (Devries et al. 2008). If these theories hold, then exceptional or even adequate habitat conditions during winter provide suitable habitats for adults that have experience avoiding harvest and navigating migration routes. As body condition was typically greatest for adults (for both hunter harvested and scientifically collected birds), focal species wintering regionally appear to be departing in good condition and theoretically should enjoy some degree of reproductive success.

Beyond basic habitat conditions and age being strict drivers of waterfowl body condition (and subsequent reproductive success), some have proposed that compositional elements of waterfowl diets will influence, drive, and potentially change carcass composition of wintering waterfowl (Perry et al. 1986, Lovvorn 1987). In such instances, depending upon diet components, waterfowl may adjust winter distributional ranges and winter in areas further north than traditional migration patterns would indicate. Such a proposition assumes that waterfowl are opportunistic in fall migration and winter habitat decisions – that they make decisions to stop or continue migrating based upon an ability to perceive current and future food resource abundance and quality. It is well known that decreasing distance to future breeding grounds is often an expensive decision, whereby wintering in more northerly areas expose waterfowl to potentially more severe and harsh winter conditions (Hine et al. 1996). However, minimizing future migration distance will reduce energy needed to make spring migration flights and the fitness benefits are observed in earlier arrival and improved reproductive success. The mechanisms by which waterfowl evaluate such tradeoffs and make such decisions are not well understood. However, it is conceivable that waterfowl wintering in close proximity to wetlands specifically managed to produce food (see Appendix B), may enjoy improved winter survival as well as improved late winter body condition. Although east-central Texas is well within traditional wintering areas of the focal species in this study, further landscape scale evaluation of food production and suitable wetland habitats would be useful to more clearly understand the value of moist-soil managed wetlands as waterfowl wintering habitat in the region as well as to develop estimates of regional carrying capacity. For example, moving beyond site specific and localized wetland habitats that are intensively managed for food production during winter, wetland availability and overall condition at larger spatial scales can influence waterfowl body condition at larger spatial scales (see Moon et al. 2007). To address this notion, long term monitoring of body condition and body masses for the focal species at larger regional spatial scales will provide insight as to the regional quality of habitats for wintering waterfowl.

Changes in body mass are a reflection of lipid levels and can be used to determine impacts of life history events, to evaluate habitat conditions, or to relect overall population health. Due to body mass and body condition indices fluctuating within winter, and being a driving force in subsequent reproductive success and within season vulnerability to hunting (Hill et al. 2003), a variety of methods have been employed to estimate total body fat of waterfowl in order to determine overall body condition. Whole-carcass lipid extraction is the penultimate technique to precisely estimate body condition. However, this is expensive and time-consuming. DeVault et al. (2003) and Johnson et al. (1985) suggested the most effective condition indices for management are those that can be estimated from easily obtained measurements in the field and do not require time-consuming dissections and analyses, such as those used in this study. Sparling et al. (1992) reported that condition could be estimated from body mass and morphological features, but predicting which morphological feature provides the highest precision and accuracy without first comparing equations to fat extracted samples is difficult. Although body mass alone is the simplest estimation technique, it tends to yield lower precision, and is substantially improved when corrected using structural measures. BCI1 and BCI2 are reliable estimators of total body fat for wintering blue-winged teal, green-winged teal, and Northern shoveler (see DeVault et al 2003).

Easily obtained morphological measurements (i.e., body mass and wing cord) can reliably estimate body condition, and condition indices used in this study may be useful in a specific wintering area, which is usually composed of birds from many different breeding areas (Rhodes and Smith 1993, Rhodes et al. 1993, Rhodes et al. 1995, DeVault et al. 2003). However, several studies (Sheeley and Smith 1989, Dufour et al. 1993, Heitmeyer et al. 1993, McCracken et al. 2000) have suggested that hunter harvested waterfowl should be used with caution to estimate body condition, due to lower survival probabilities and higher probability of being harvested for birds in poor condition. In theory, birds that are younger or in poorer condition are more susceptible to decoying as their decision-making processes for deciding to land are compromised by energetic demands. However, Sheeley and Smith (1989) did not find differences in body condition in hunter harvested and scientifically collected Northern pintails. Similarly, in this study, both collection techniques provided similar trends - as related to body mass and condition. However, hunter harvested bird data is temporally constrained, and could potentially miss the late season increases in mass and condition observed in scientifically collected birds. Regardless, general concordance in trends indicates that focal species in this study were in relatively good condition and exhibited typical season changes in body mass, and may not have been differentially susceptible to hunting mortality (see Hepp et al. 1986, Reinecke and Shaiffer 1988, Heitmeyer et al. 1993). However, such speculation is tenuous without larger spatial scale analyses of condition and mass tends in focal species during winter.

Food Item Occurrence

Previous studies in Texas (see Anderson et al. 2000, Tietje and Teer 1996) have shown the importance of aquatic invertebrates in teal and shoveler diets during migration and winter. However, overall occurrence of native seeds was 78% in the cumulative diets of focal species, where aquatic invertebrates only accounted for 8% for all species. Biases in percent occurrence of native seed may be evident, especially for Northern shovelers which prefer aquatic invertebrates (> 90% in some studies). Sheely and Smith (1989) reported that hunter harvested teal had a greater percent occurrence of agricultural grains, and those birds tended to under-represent nonagricultural seeds and invertebrates in their diets. In the current study, native seeds (such as nodding smartweed, pink smartweed, water pepper, dock, and *Panicum* sp.) are all very desirable and were the dominant seeds recorded, perhaps due to their hardness and persistence in crops and digestive tracts. Botero and Rusch (1994) postulated that there is some postmortem digestion of invertebrates in blue-winged teal, where diets for this species tend to focus upon seeds and vegetation, as their persistence is greater and they are easier to detect than soft-bodied aquatic invertebrates. Chamberlain (1959), Rollo and Bolen (1969) and Swiderek et al. (1988) found that blue-winged teal rely primarily on plant foods, although postmortem digestion could have played a role in their findings. Regardless, it is clear that seed production and consumption are key elements to winter body mass and condition trends in teal, although their importance may be less for shovelers.

Dirschl (1967) suggested that knowledge of the composition of the total diet of waterfowl is not necessary for habitat management. However, recognizing major seasonal foods of importance that influence waterfowl use of areas and how these are obtained through management practices is key. Providing suitable habitat for waterfowl should be the main goal of any wetland/waterfowl land manager providing wintering habitat, as these resources play a key role in life history events that do not take place on the wintering grounds such as breeding and nesting success (Baldassarre et al. 1986, Miller 1986, Rave 1987, Thompson and Baldassarre 1990, Rave and Baldassarre 1991, Miller and Eadie 2006, Devries et al. 2008). Estimating and collecting long term data on vegetation and duck-use days (see Appendix A and B) will provide information on potential food production as well as managed wetland carrying capacity, which can be useful to adjust management techniques, if necessary, to maximize use of managed wetlands.

Feather Molt Intensity

Blue-winged teal, green-winged teal, Northern shoveler showed typical molting patterns during winter, where molt intensity was least during the early sampling window than later in winter. Regardless of species, adults and adult males specifically, typically had a higher molting score and percent feather molting per bird then other sex-age cohorts. In general, shovelers had greater molt scores and molt intensity, primarily due to differences in overall size and greater potential feather growth. In contrast, both teal typically have a slower rate of feather replacement due to their small size, which makes them more susceptible to molt-induced stress than larger bodied ducks, such as shovelers (Hohman 1993, Anderson et a. 2000). However, all three focal species appeared to be in comparatively good condition, where molt intensity and molt scores were not related in any way to condition – indicating that molt-induced stress may not have been occurring for focal species.

Focal species appeared to be nutritionally sound and in overall good body condition, as suggested by increases in body condition, even as molt score and intensity increased. For example, condition should improve as birds prepare for spring migration, and when molt scores are increasing simultaneously, focal species apparently were not experiencing molt induced stress and associated declines in body condition. As BCIs increased later in the season, it is plausible that birds are increasing protein intake to support new feather eruption and growth. Gates et al. (1993) reported that the rate and intensity of molting in Canada geese (*Branta canadensis*) was primarily determined by the amount of productive energy geese were able to allocate to feather growth, in addition to supplying nutrients for other physiological conditions such as body growth and nutrient deposition. They also hypothesized that energy acquisition prior to fall migration affected the progression of body molt during the ensuing fall and winter. In sum, feather molt intensity was not nutritionally stressful on focal species in this study.

Although molt chronology occurs during a specific sequence of annual events (Heitmeyer 1987), avoiding overlap of energetic costs of molt with migration, nutrient storage, courtship, and breeding is an important adaptive strategy in the annual cycle (see Lovvorn and Barzen 1988). All three focal species appeared to have synchronized most molting prior to spring migration, and had the lowest molt intensity during courtship (i.e., mid-winter), plausibly allowing them to dedicate energy to these behaviors. Molt will influence the timing of other events only if birds are unable to meet the costs of molt simultaneously with other demands (see King and Murphy 1985) which did not appear to be occurring during this study.

Management Implications

Focal species in this study displayed typical and consistently reported trends in body mass and body condition, where all three enjoyed relatively good condition during arrival, experienced slight mid-winter declines, and then improved prior to spring migration. Although mid-winter declines in body mass and condition are typically associated with harsh winter condition east-central Texas does not provide such conditions, whereby such mid-winter declines may be more endogenous than exogenously related. For example, mid-winter is also typically associated with initial courtship events, and often the peak of hunting season, whereby birds may be exerting extra resources towards pairing and avoiding harvest. Although scientifically collected focal species tended to have greater body masses and greater body condition indices, trends in both metrics were very similar between collection techniques. Moreover, there were no correlations between molting and body condition. It appears that birds using the moist-soil managed wetlands at RCMA are in good condition, exhibit well defined patterns of mass and condition during winter, and do not exhibit molt-induced stresses. Although diets were dominated by native seeds, and invertebrates are typically under-represented in food habit studies, it is clear that food production is adequate to maintain and improve body mass and condition in focal species. Despite the fact that seed and invertebrate production, as well as duck use days (DUDs) (see Chapter II, Chapter V; Appendix B) varied over time and tended to decline as inundation duration increased on these managed wetlands, focal species remained in good condition. However, more focused and well timed inundation and drawdown schedules at RCWMA should maximize food production and reverse declining trends in DUDs.

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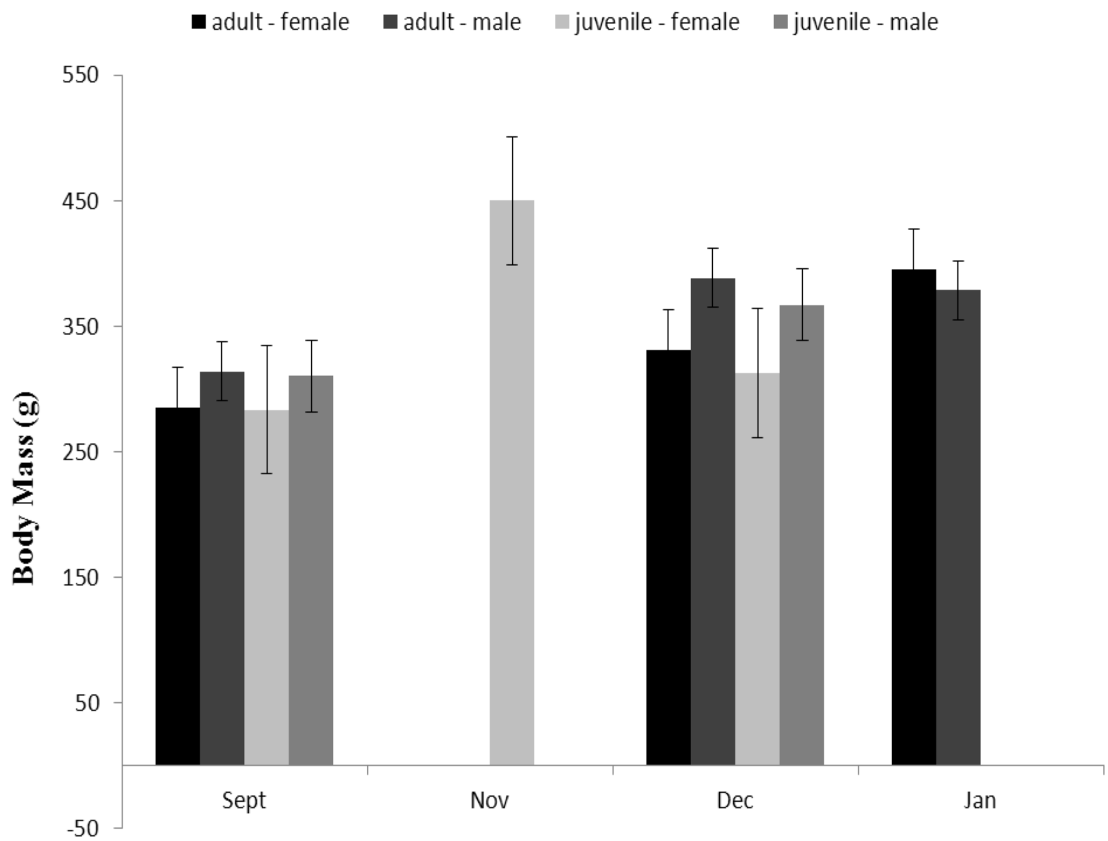

Figure 6.1 Average body mass across months of hunter harvested adult and juvenile male and female blue-winged teal (*Anas discors*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

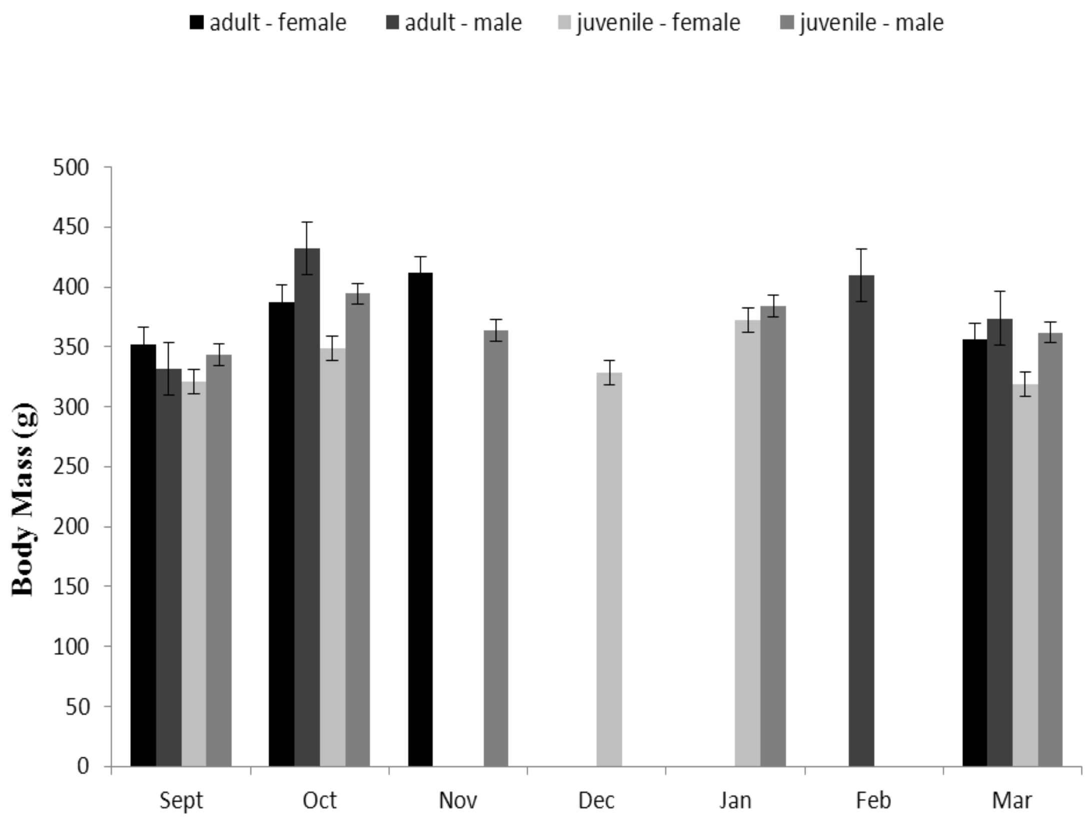

Figure 6.2 Average body mass across months of scientifically collected adult and juvenile male and female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

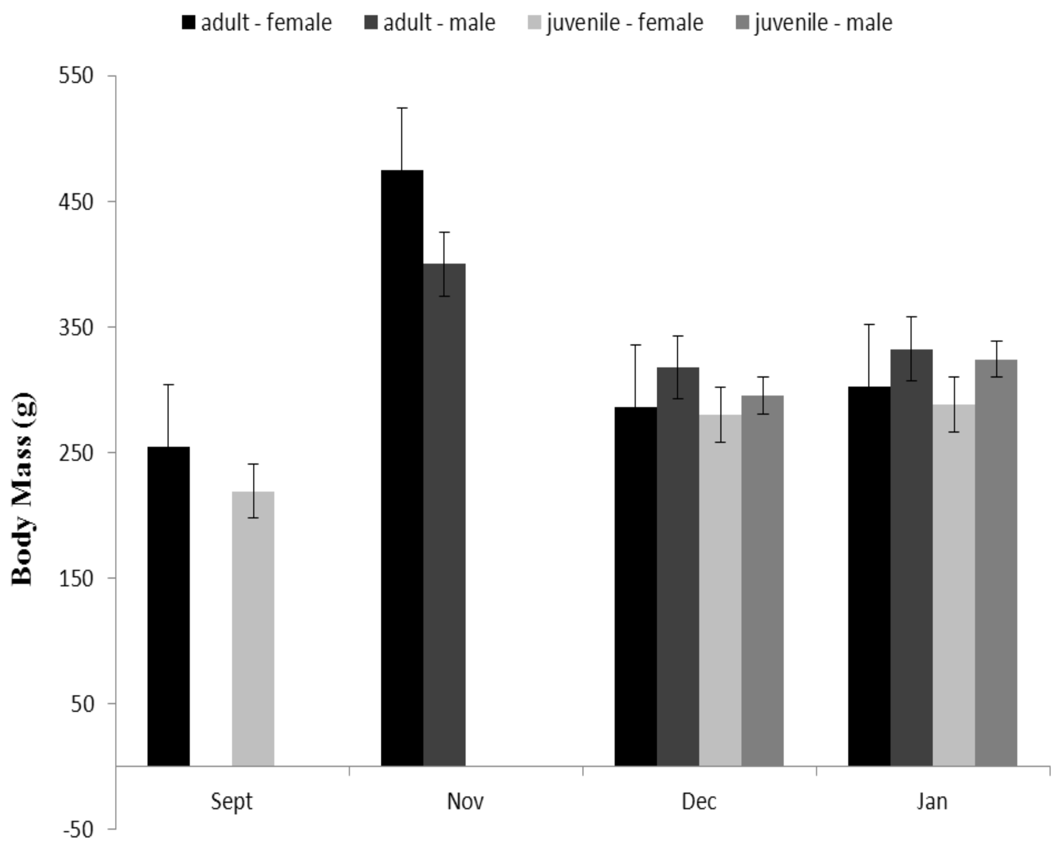

Figure 6.3. Average body mass across months of hunter harvested adult and juvenile male and female green-winged teal (*Anas crecca*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

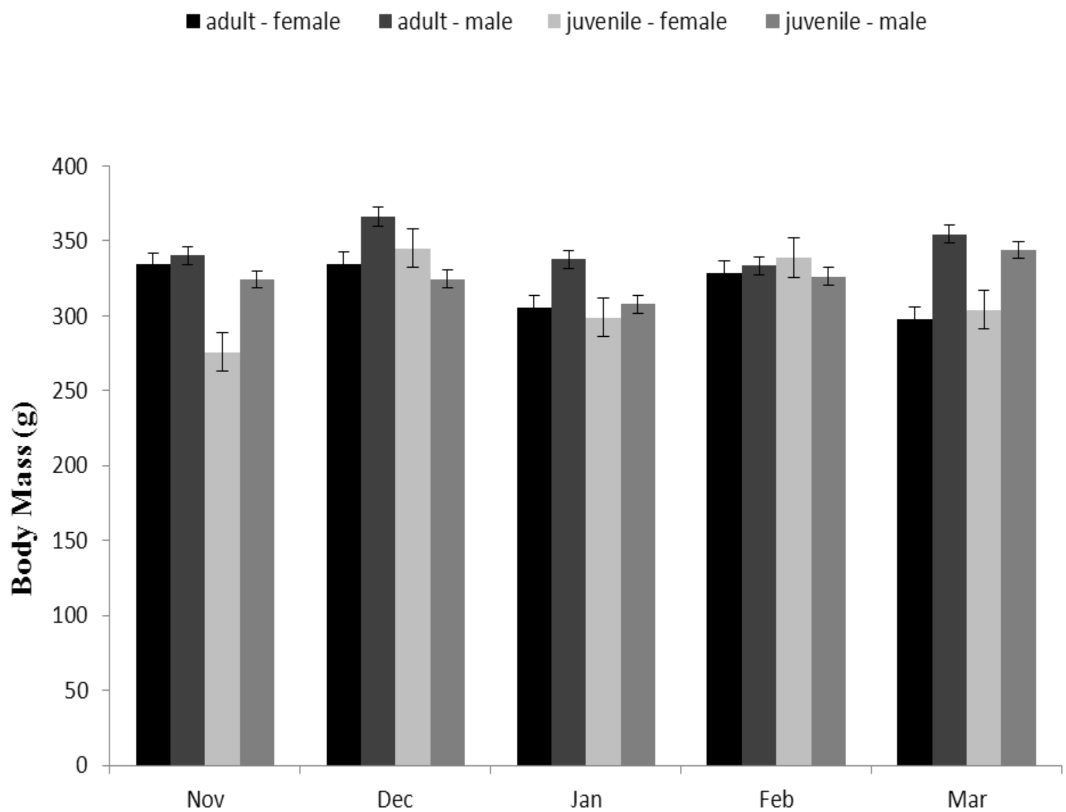

Figure 6.4. Average body mass across months of scientifically collected adult and juvenile male and female green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

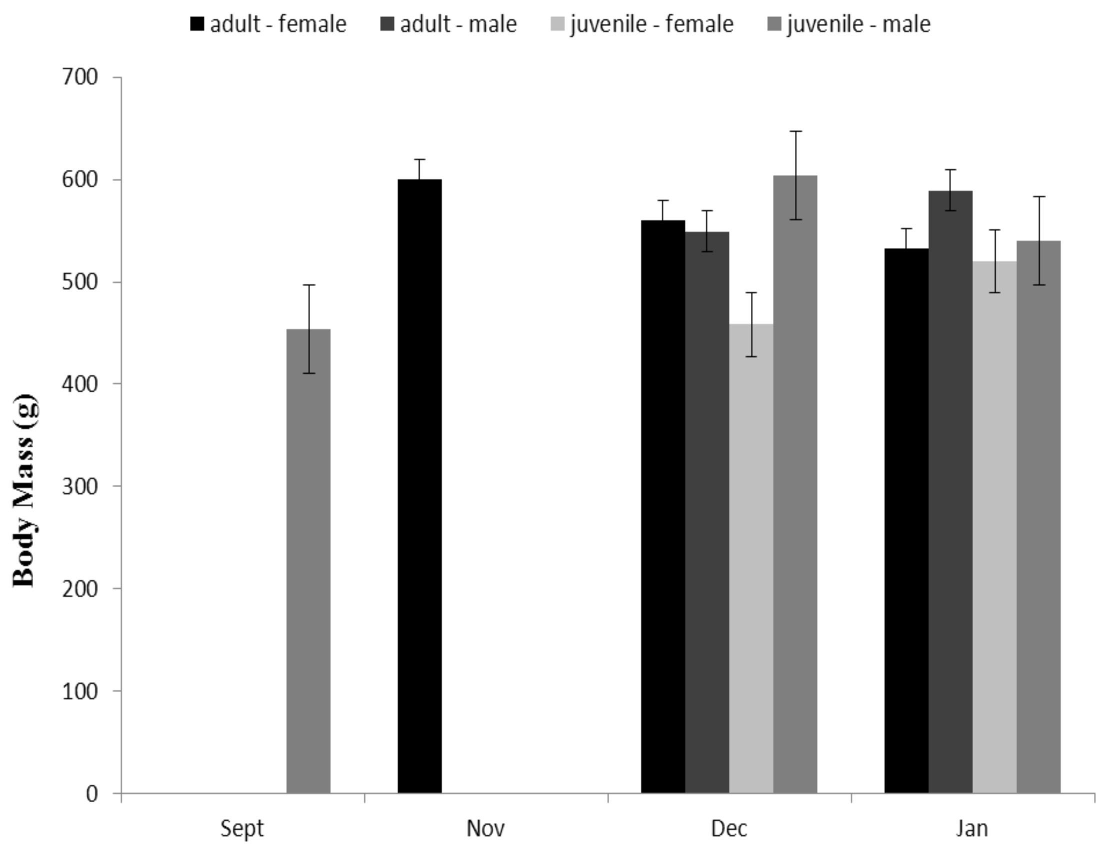

Figure 6.5. Average body mass across months of hunter harvested adult and juvenile male and female Northern shoveler (*Anas clypeata*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

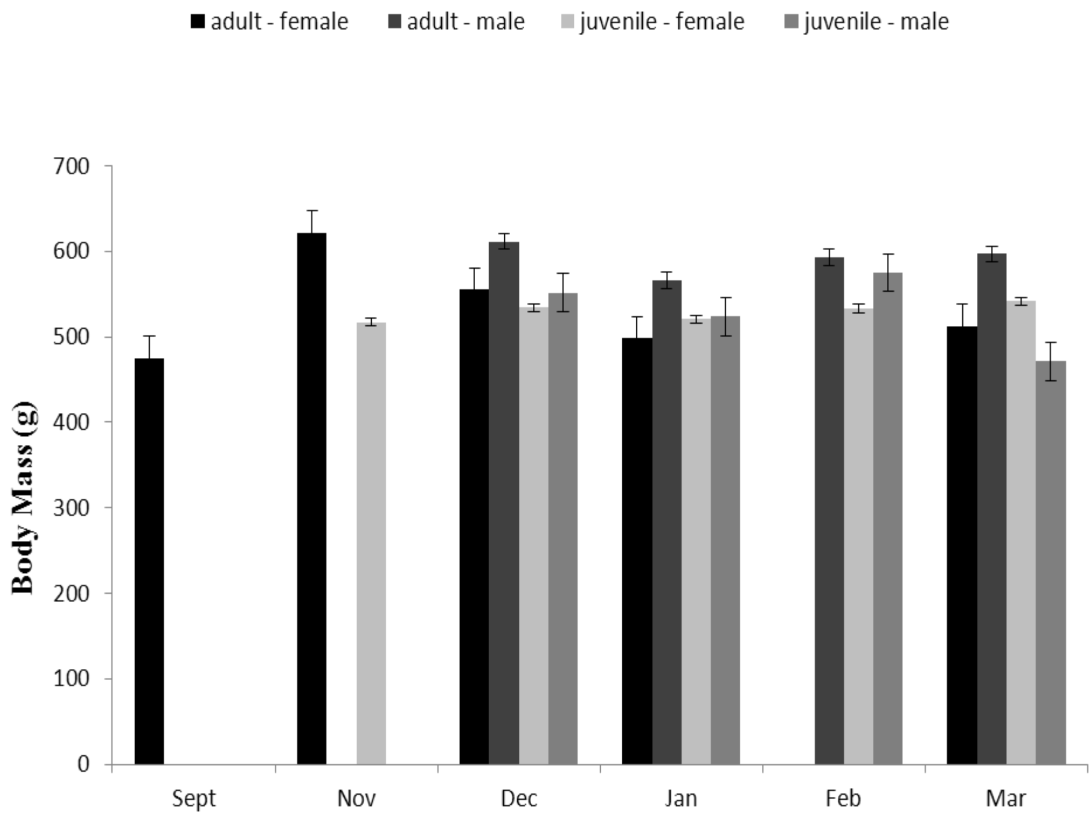

Figure 6.6. Average body mass across months of scientifically collected adult and juvenile male and female Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

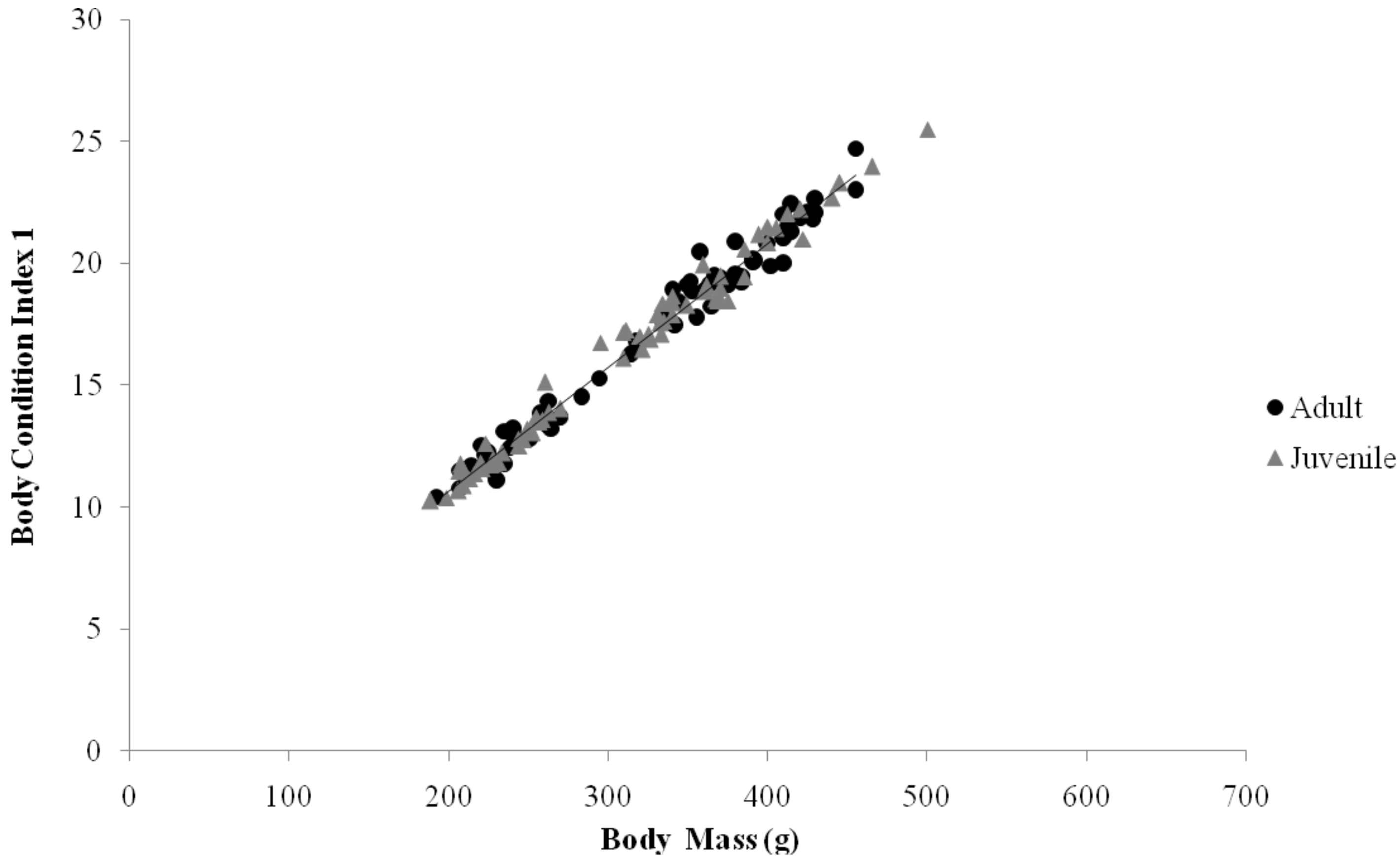

Figure 6.7. Scatterplot of body mass and body condition index 1 values of hunter harvested adult and juvenile male blue-winged teal (*Anas discors*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

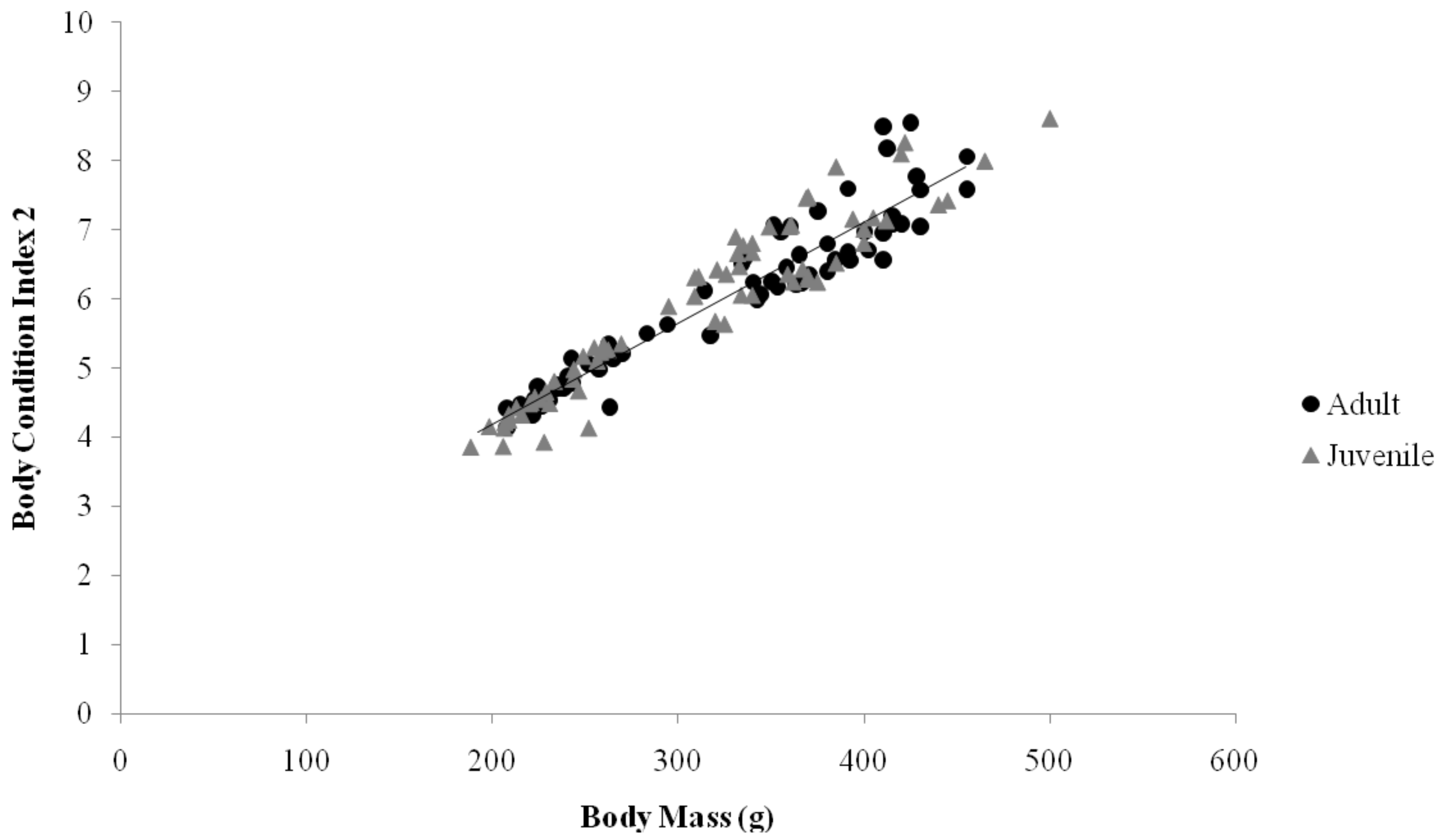

Figure 6.8. Scatterplot of body mass and body condition index 2 values of hunter harvested adult and juvenile male blue-winged teal (*Anas discors*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

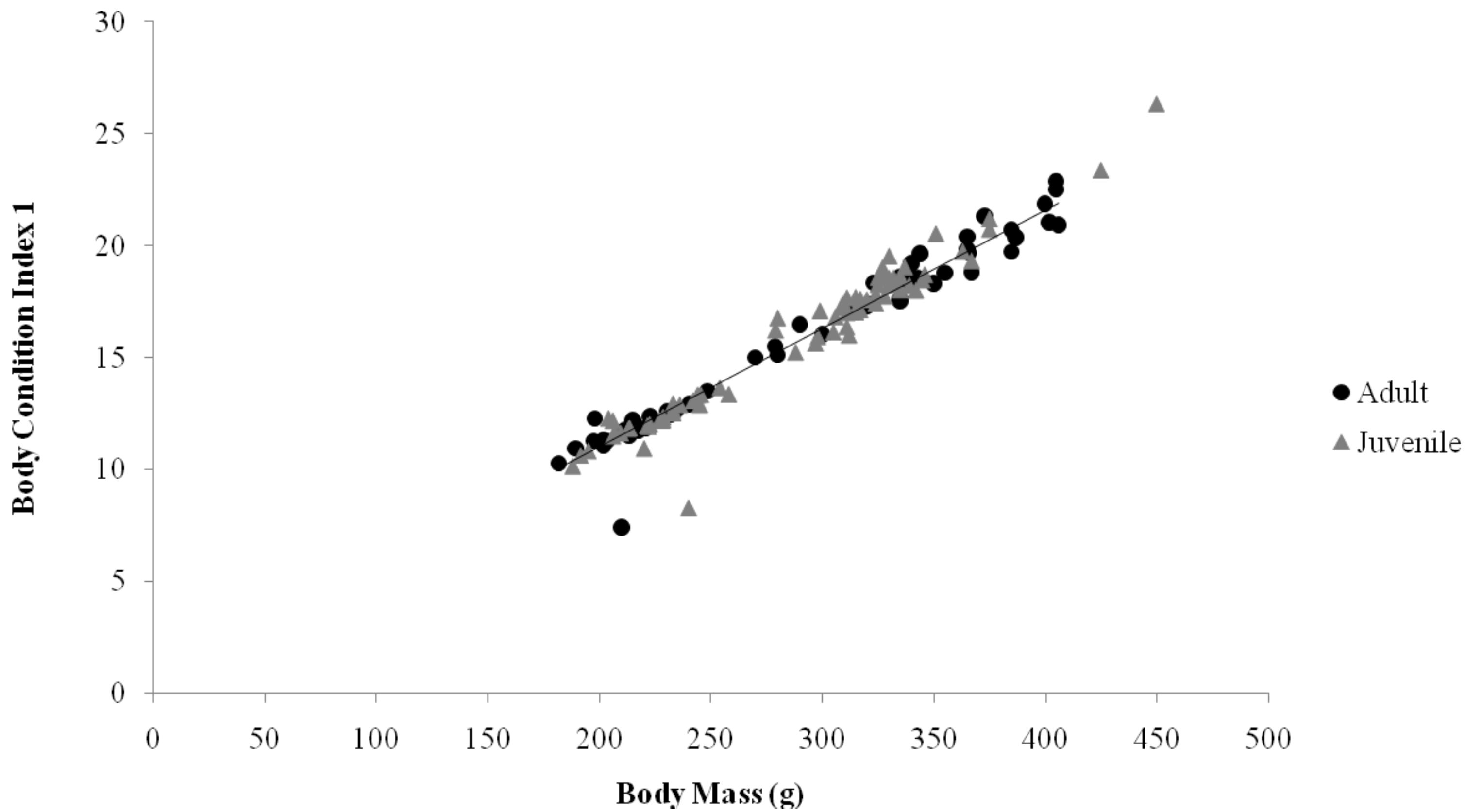

Figure 6.9. Scatterplot of body mass and body condition index 1 values of hunter harvested adult and juvenile female blue-winged teal (*Anas discors*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

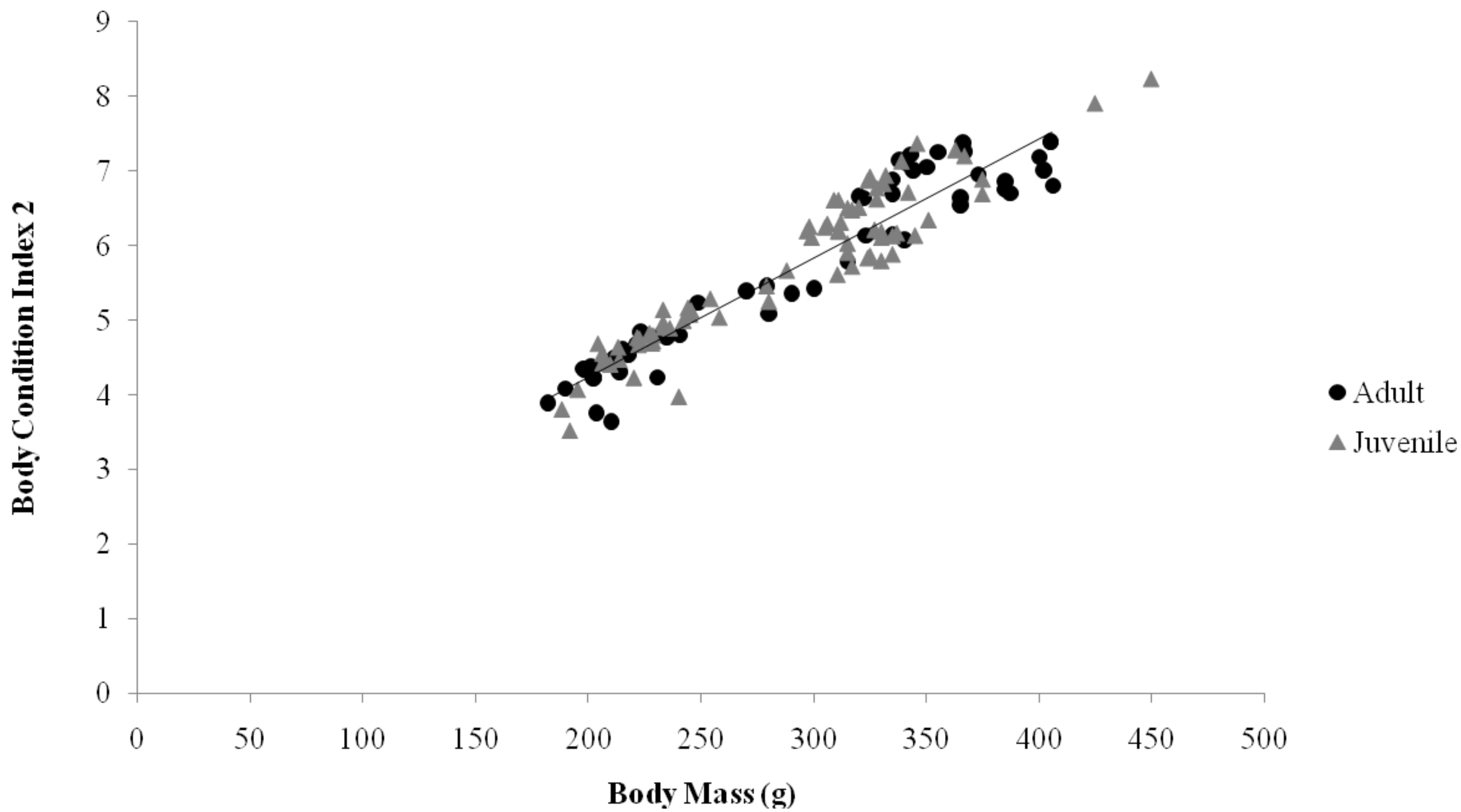

Figure 6.10 Scatterplot of body mass and body condition index 2 values of hunter harvested adult and juvenile female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

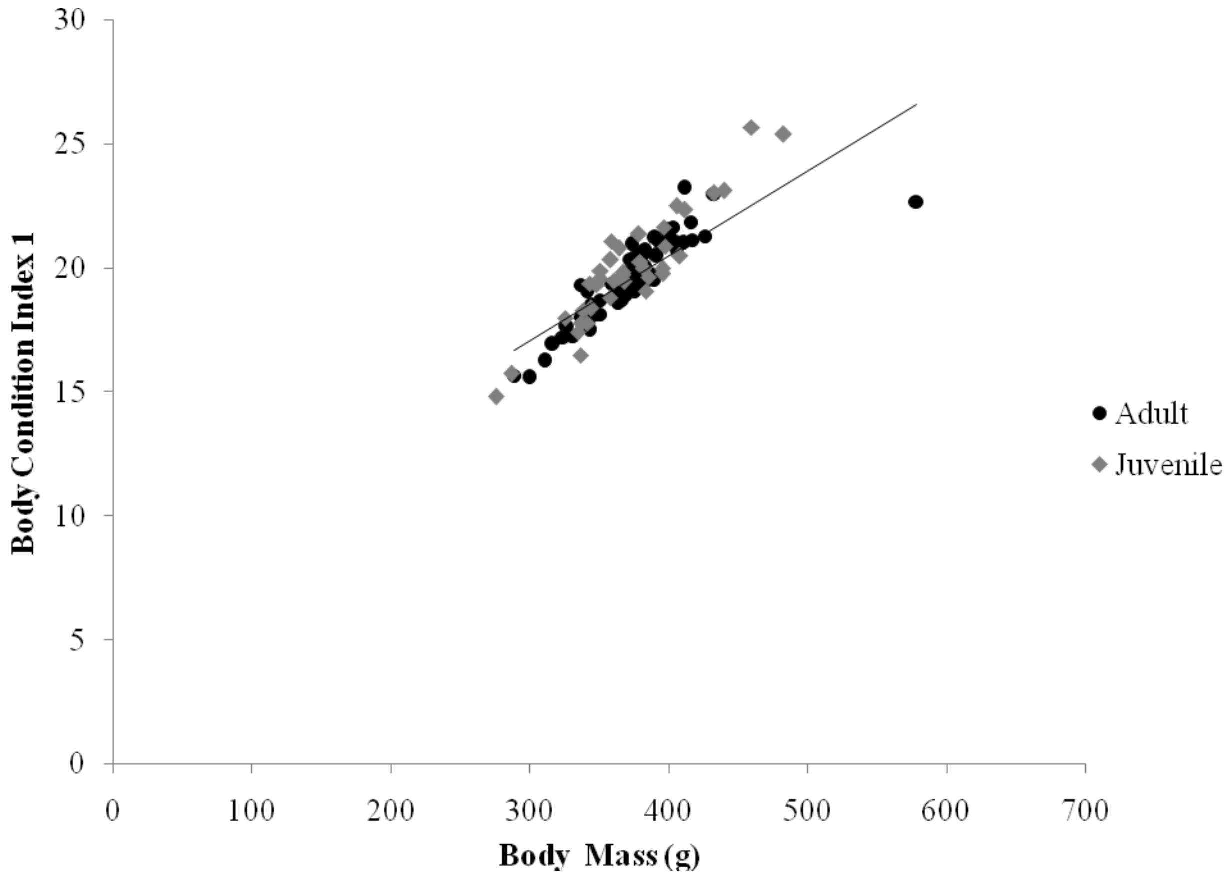

Figure 6.11. Scatterplot of body mass and body condition index 1 values of scientifically collected adult and juvenile male blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

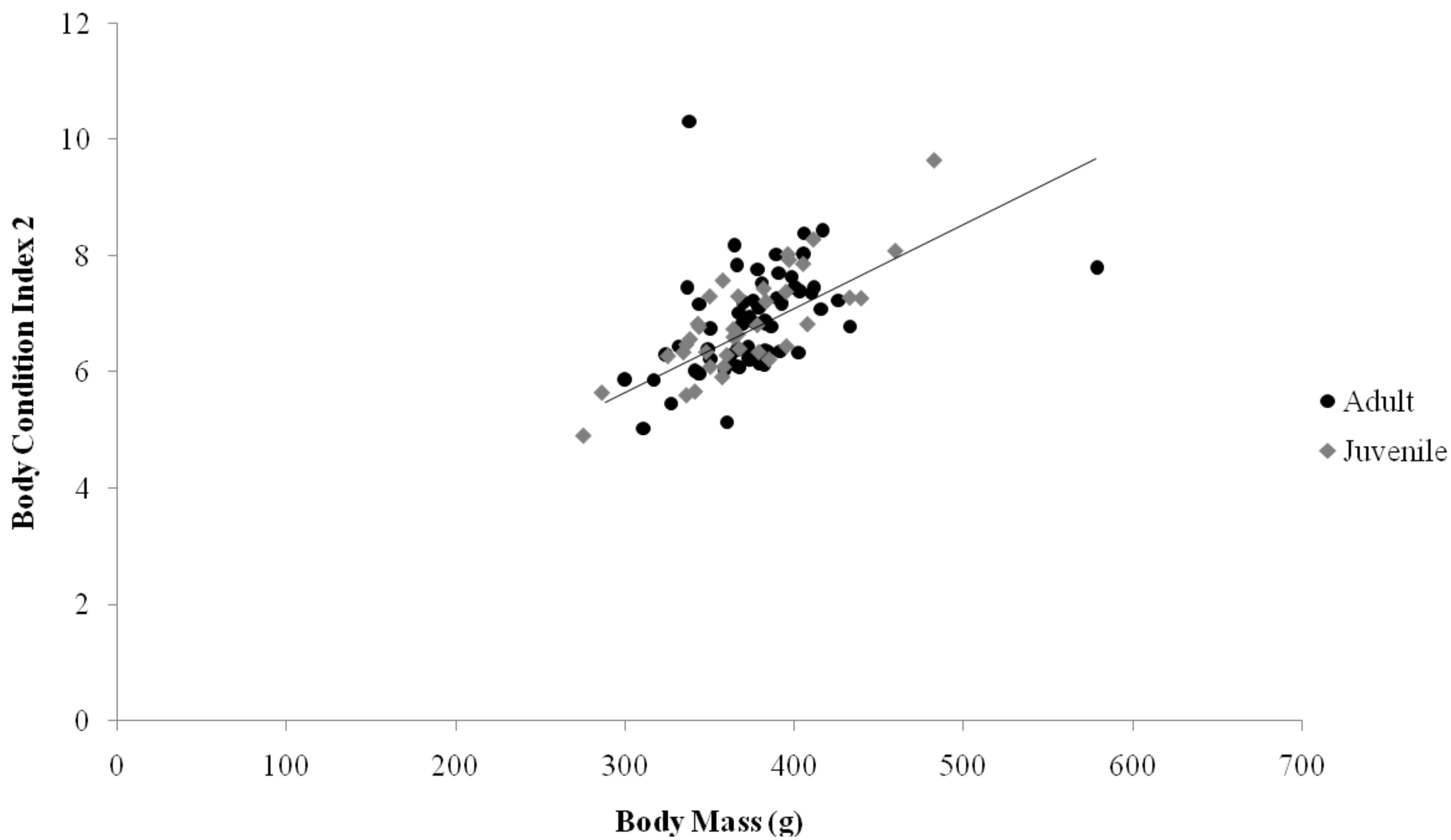

Figure 6.12.. Scatterplot of body mass and body condition index 2 values of scientifically collected adult and juvenile male blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

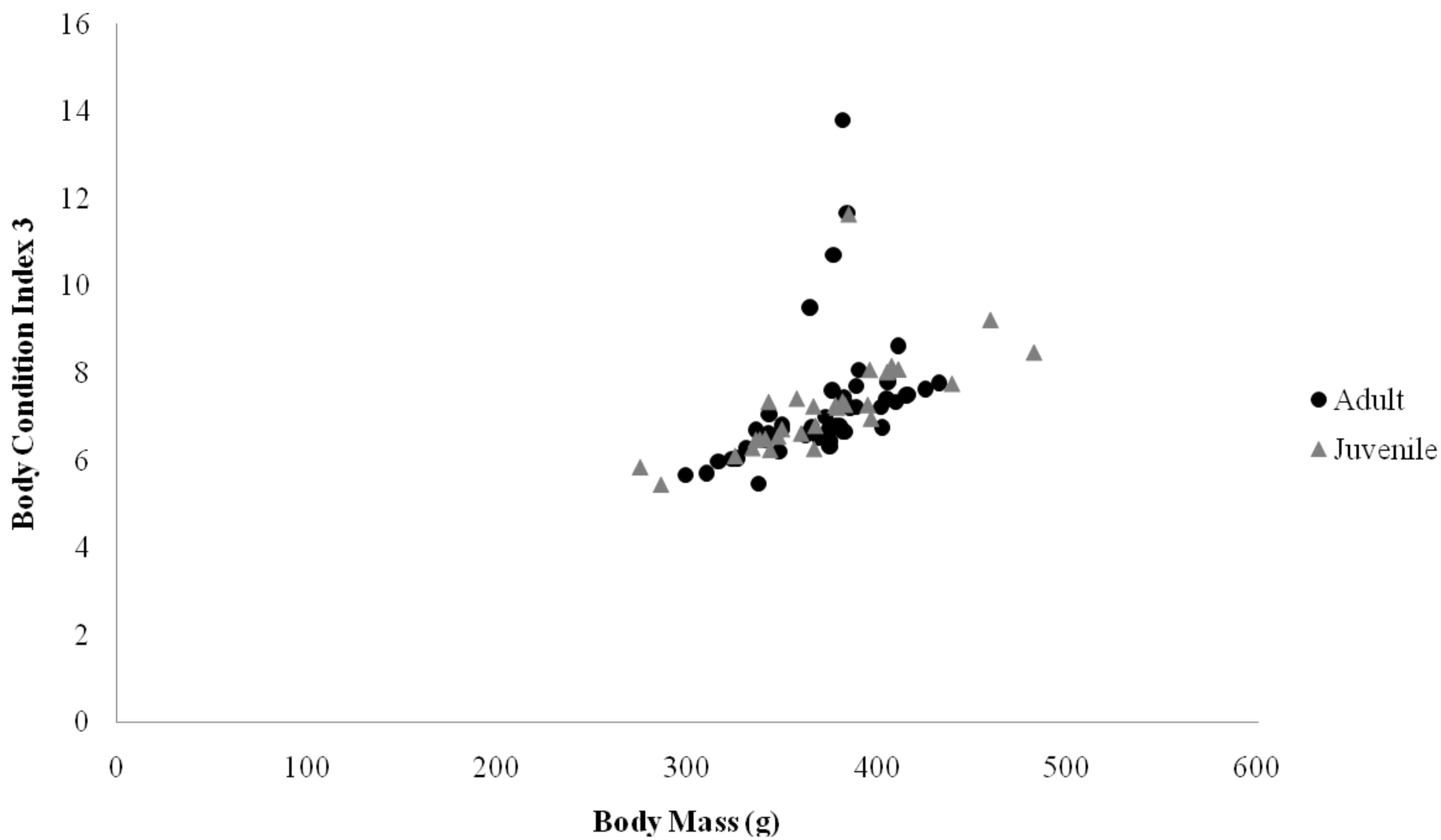

Figure 6.13. Scatterplot of body mass and body condition index 3 values of scientifically collected adult and juvenile male blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

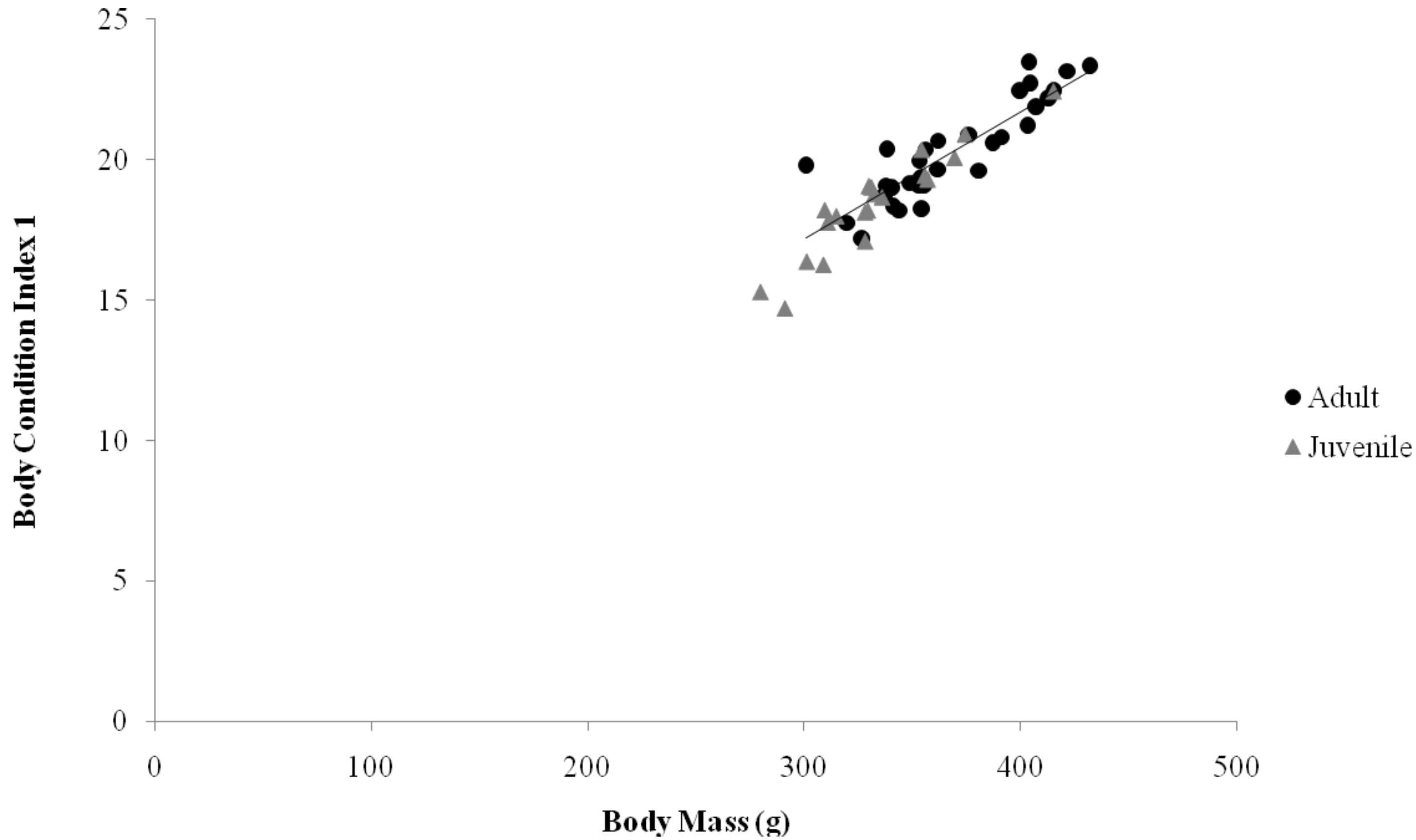

Figure 6.14. Scatterplot of body mass and body condition index 1 values of scientifically collected adult and juvenile female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

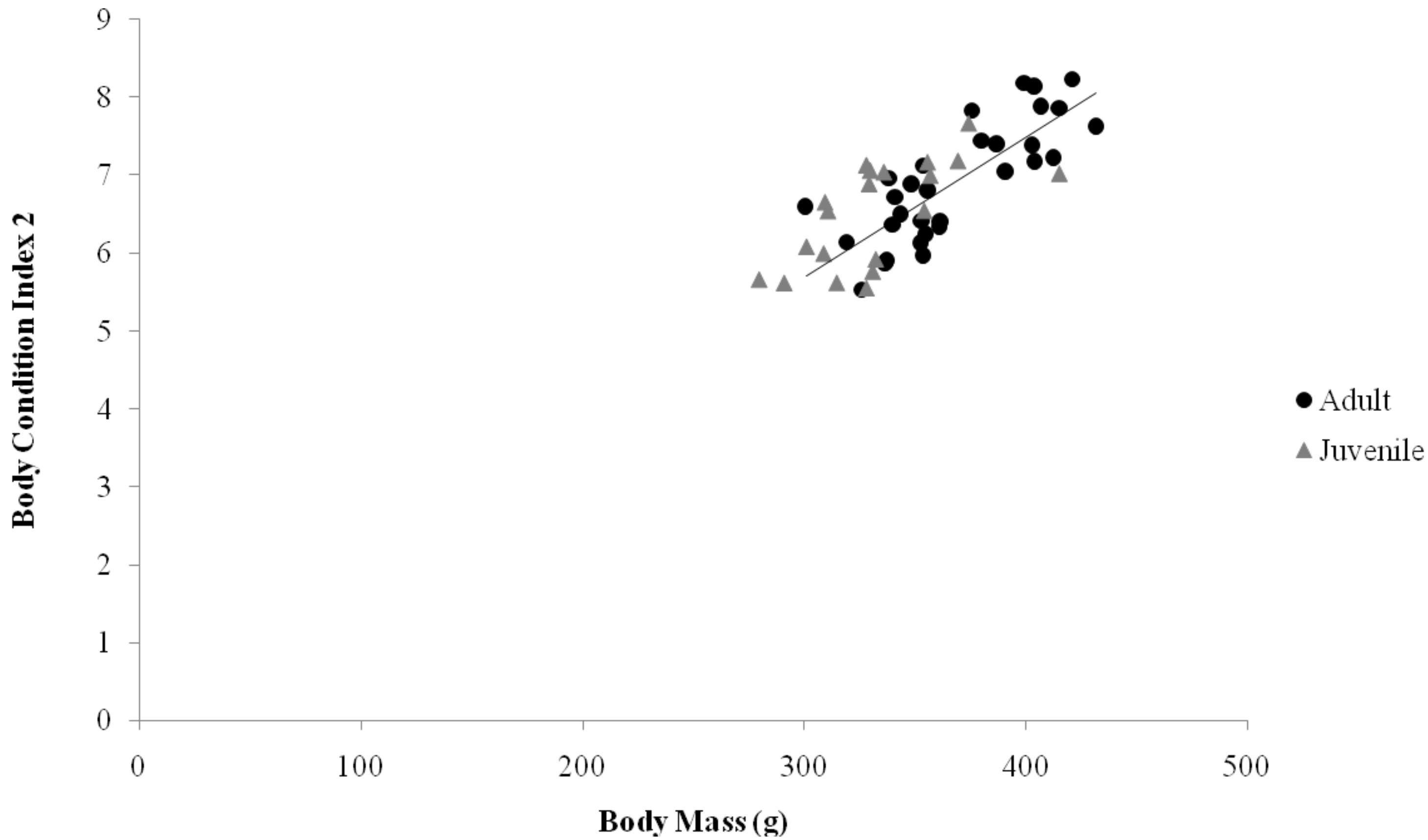

Figure 6.15. Scatterplot of body mass and body condition index 2 values of scientifically collected adult and juvenile female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006

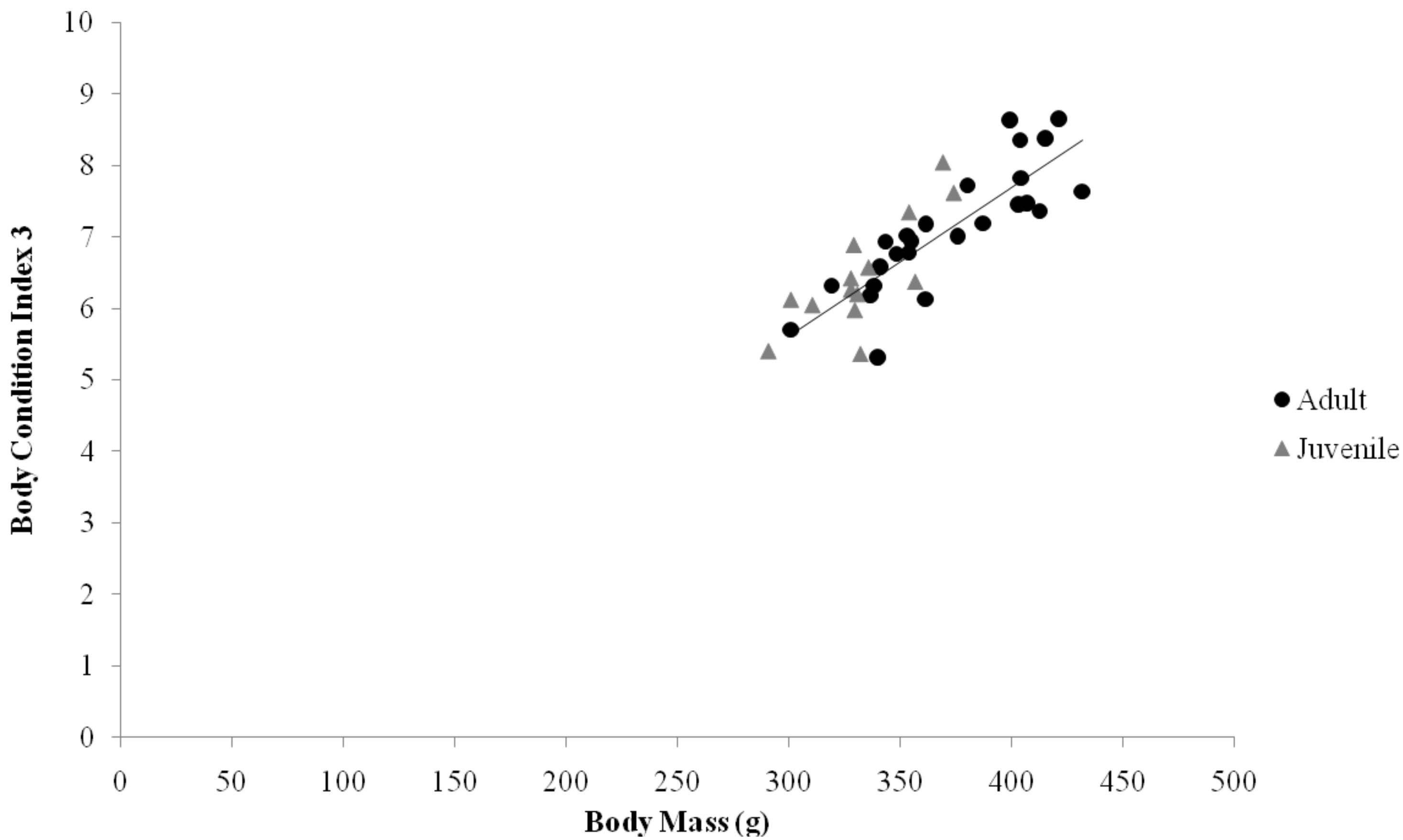

Figure 6.16. Scatterplot of body mass and body condition index 3 values of scientifically collected adult and juvenile female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006

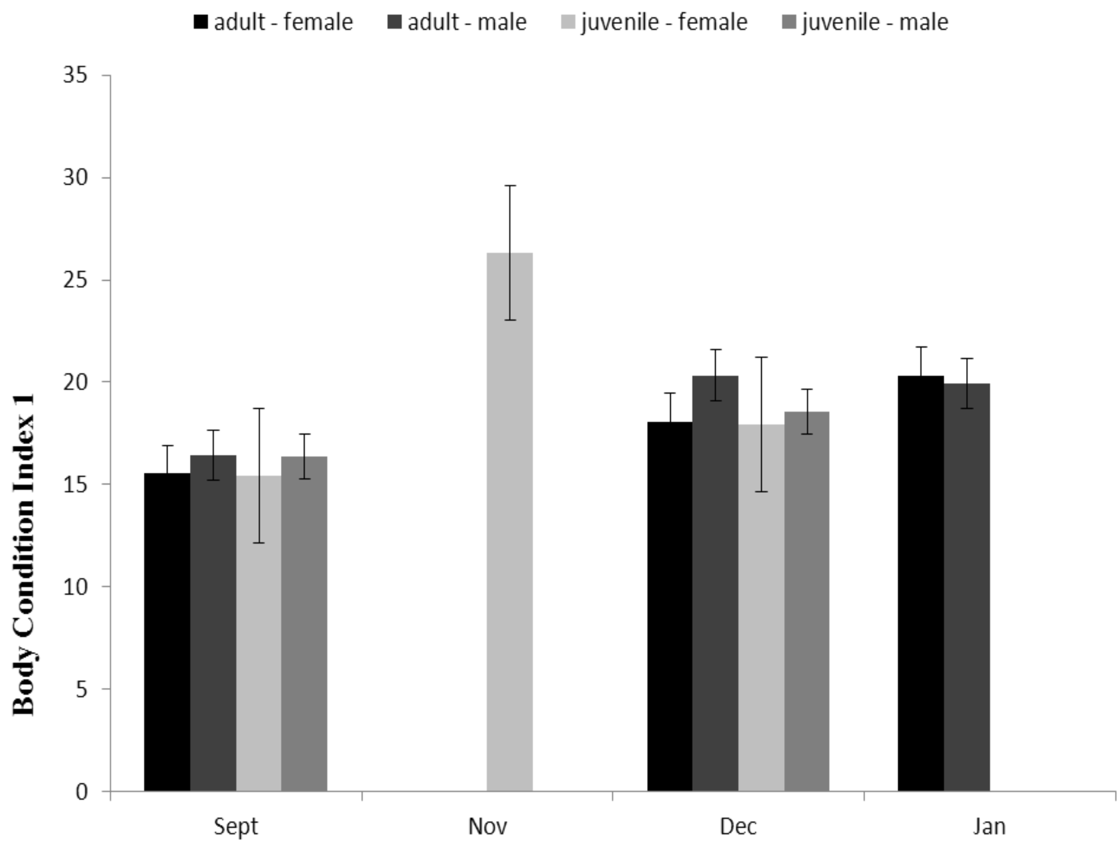

Figure 6.17. Average body condition index 1 across months of hunter harvested adult and juvenile male and female blue-winged teal (*Anas discors*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

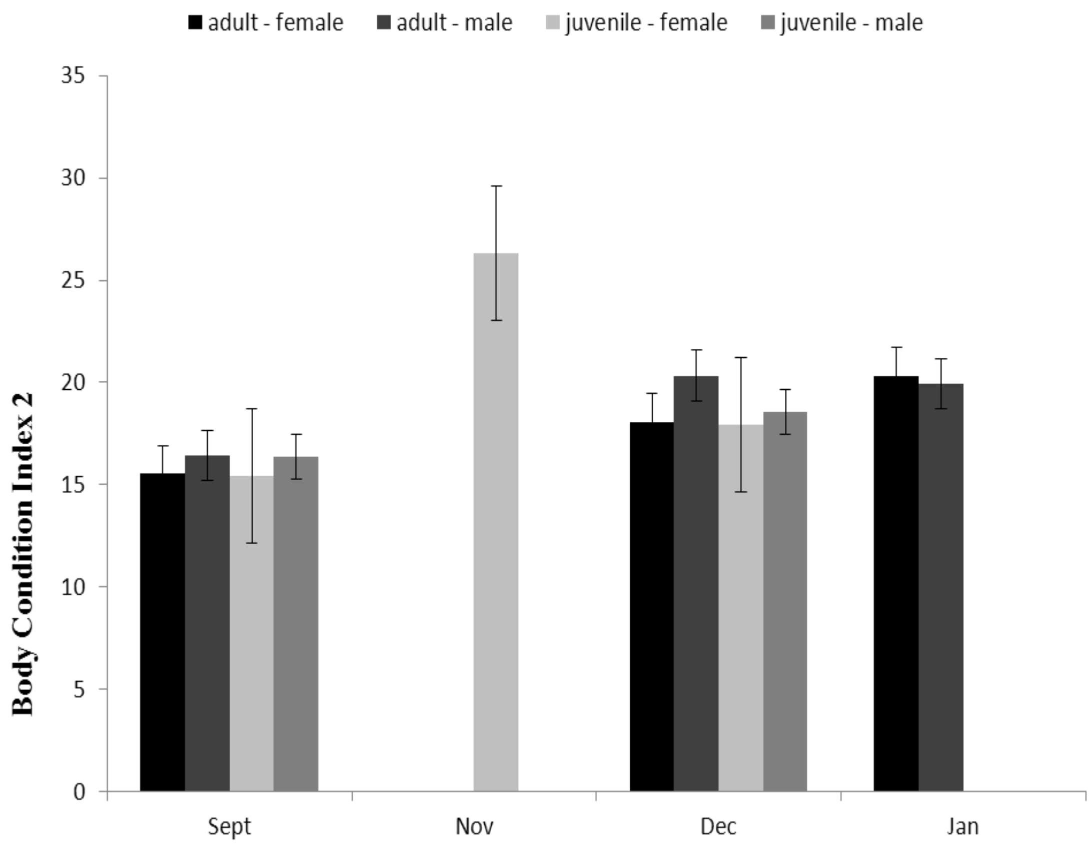

Figure 6.18. Average body condition indices 2 across months of hunter harvested adult and juvenile male and female blue-winged teal (*Anas discors*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

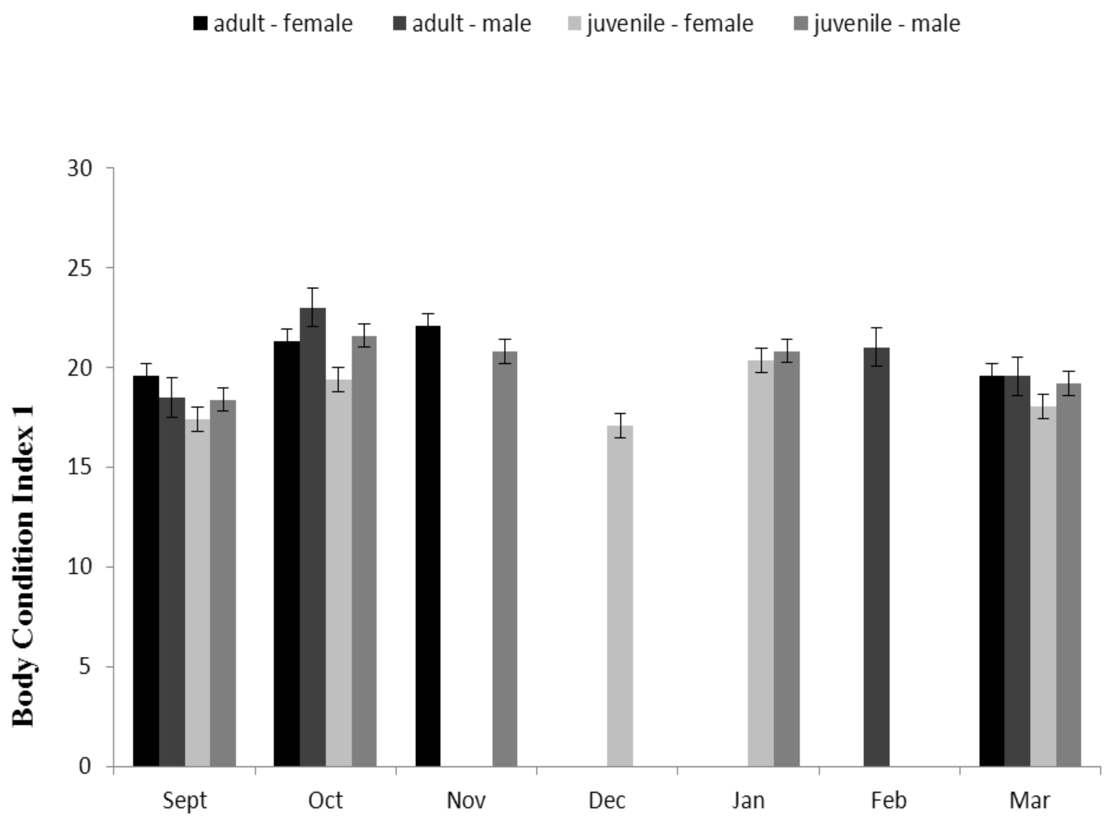

Figure 6.19. Average body condition index 1 across months of scientifically collected adult and juvenile male and female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

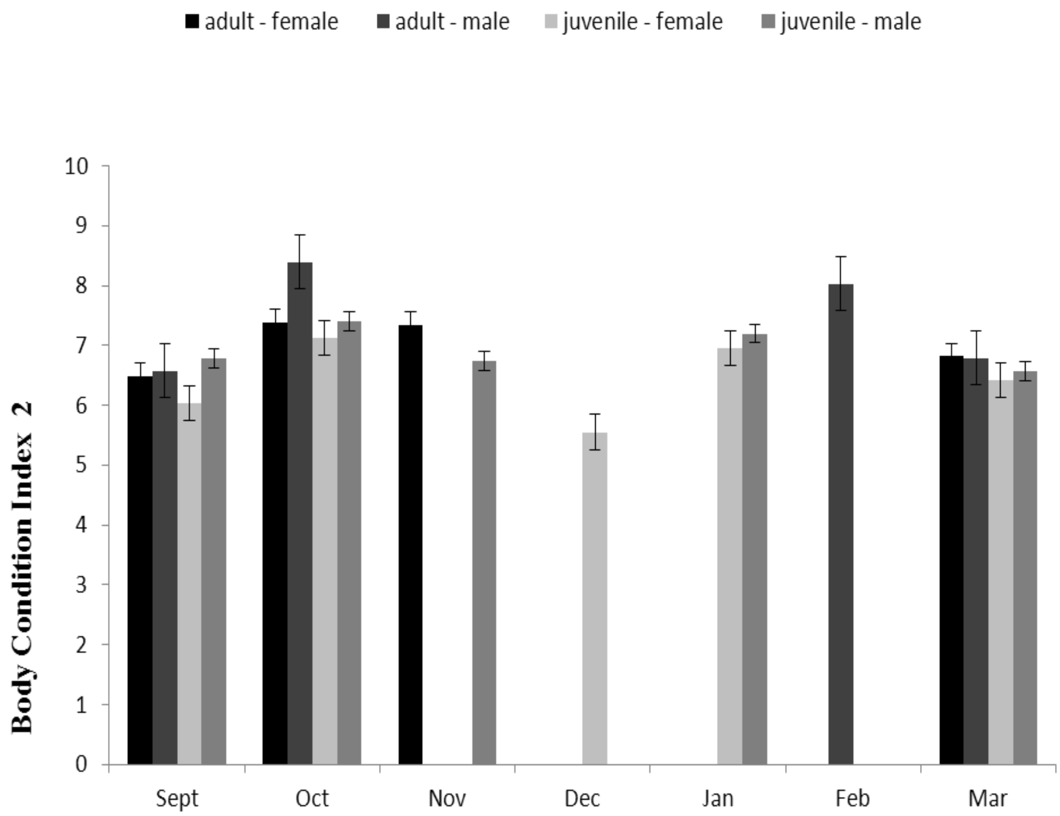

Figure 6.20. Average body condition index 2 across months of scientifically collected adult and juvenile male and female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

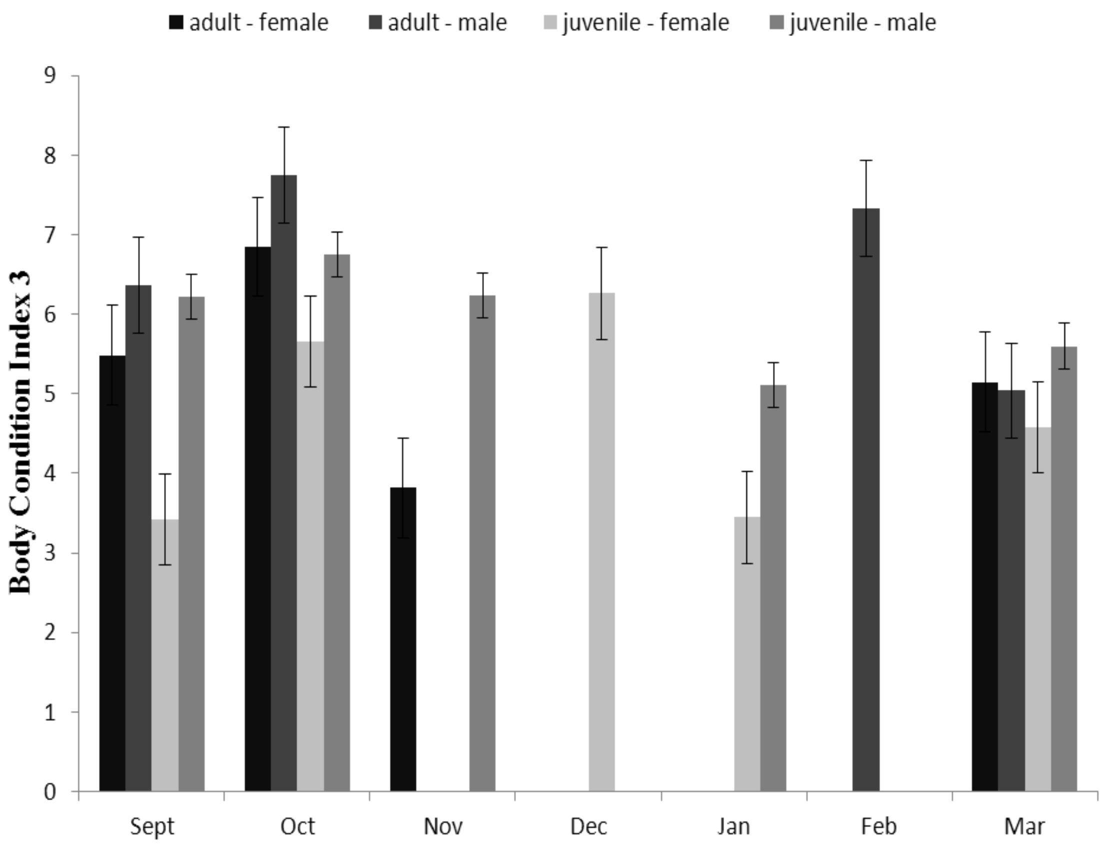

Figure 6.21. Average body condition indices 3 across months of scientifically collected adult and juvenile male and female blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

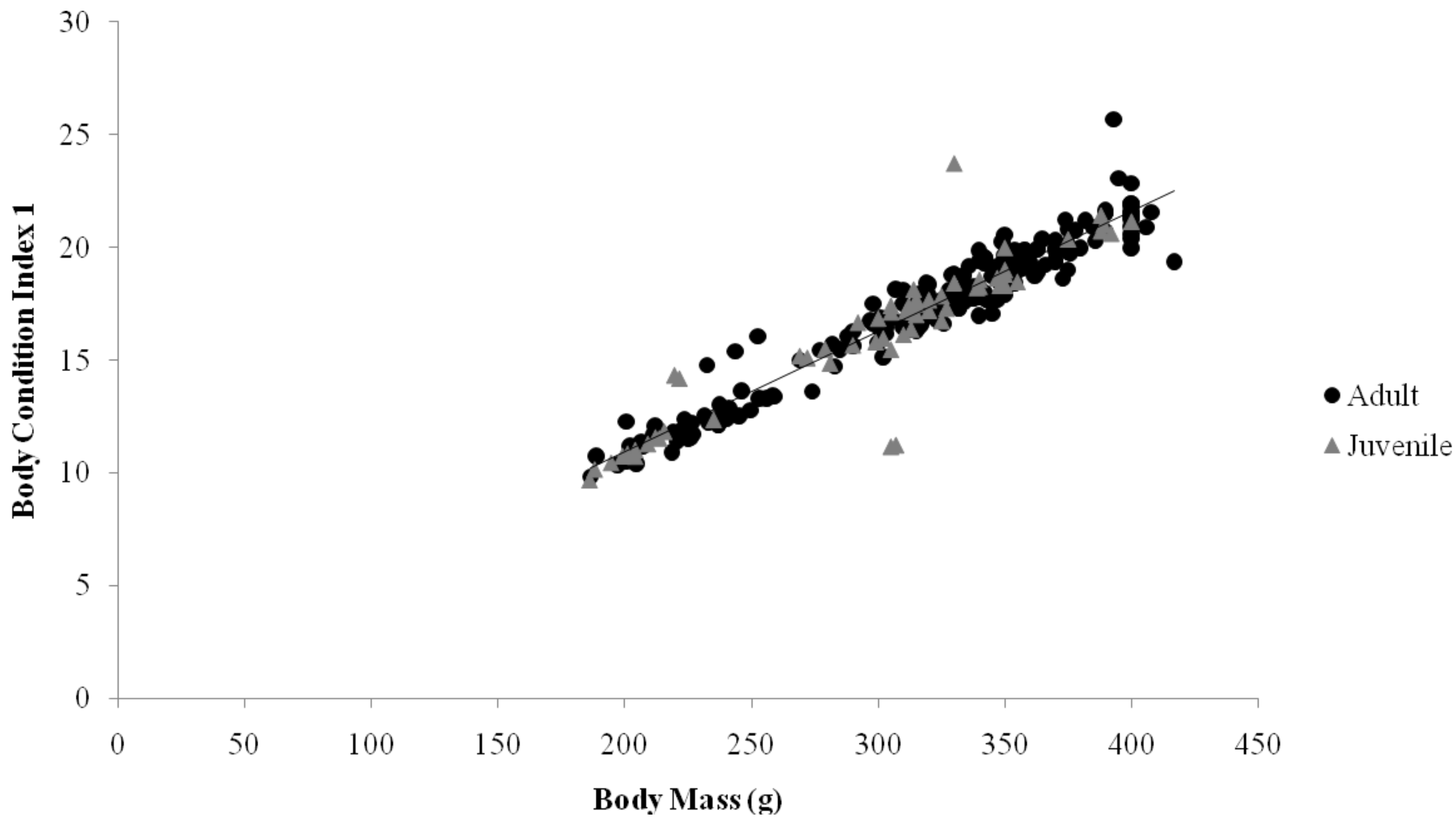

Figure 6.22. Scatterplot of body mass and body condition index 1 values of hunter harvested adult and juvenile male green-winged teal (*Anas crecca*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

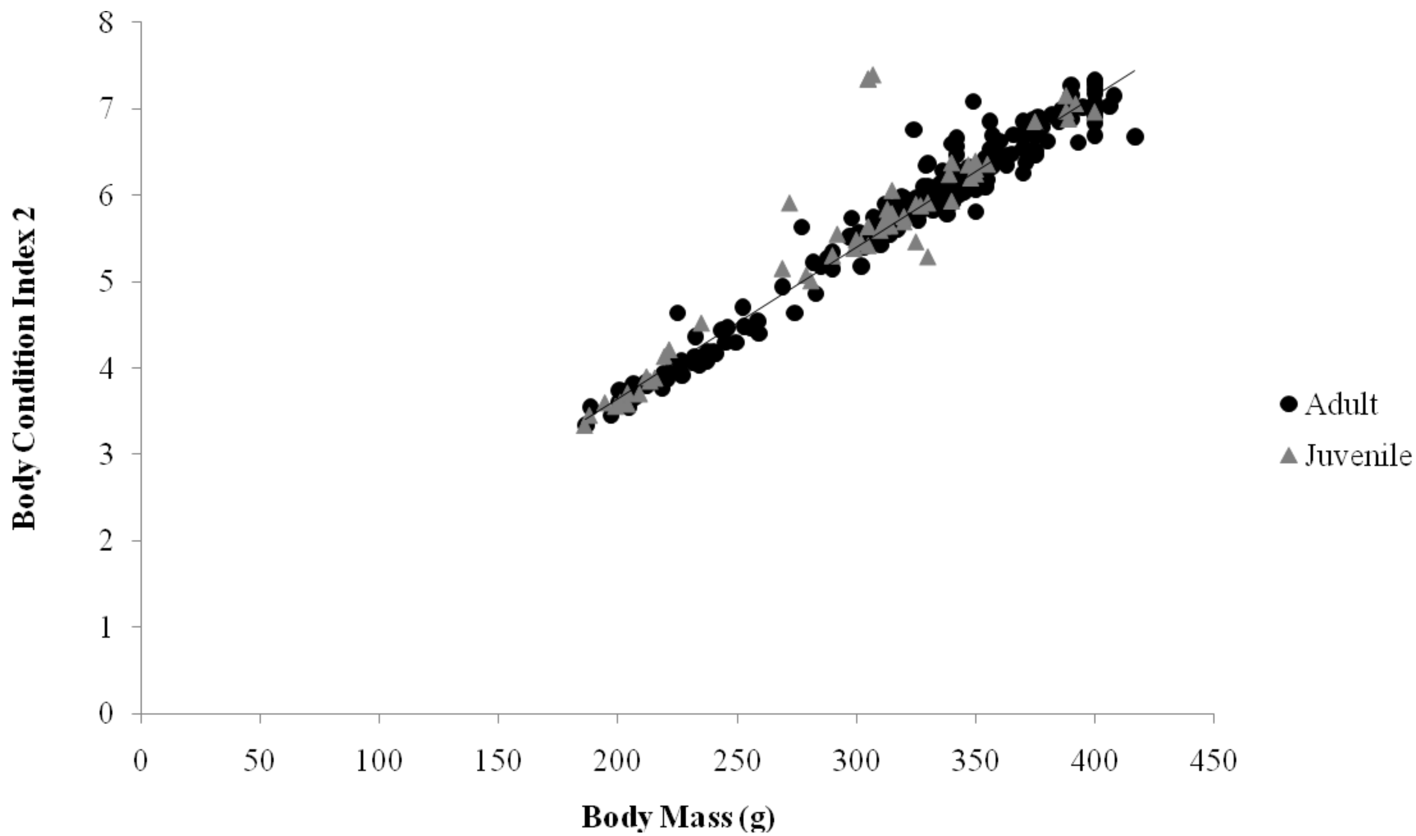

Figure 6.23. Scatterplot of body mass and body condition index 2 value of hunter harvested adult and juvenile male green-winged teal (*Anas crecca*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

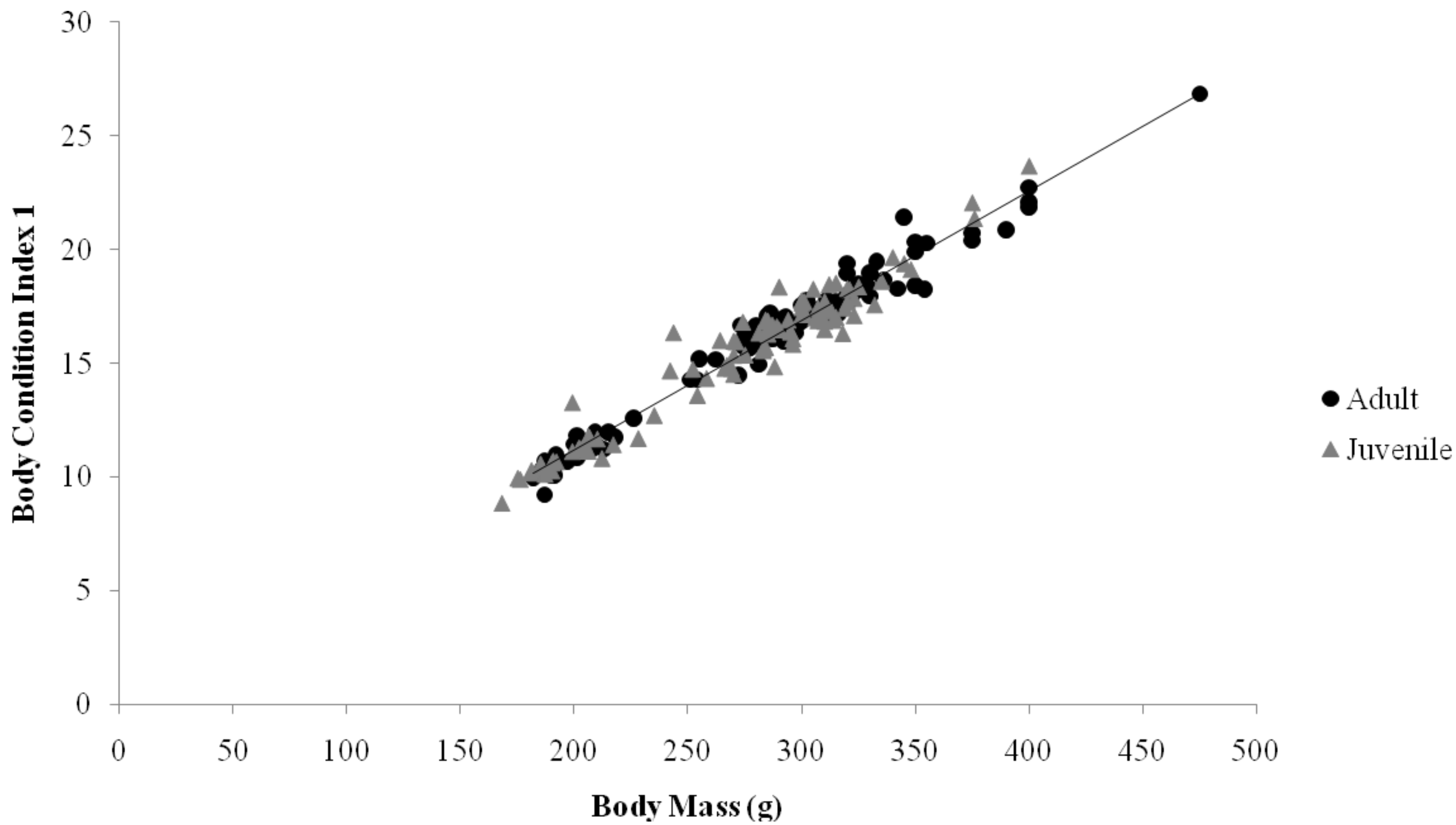

Figure 6.24. Scatterplot of body mass and body condition index 1 values of hunter harvested adult and juvenile female green-winged teal (*Anas crecca*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

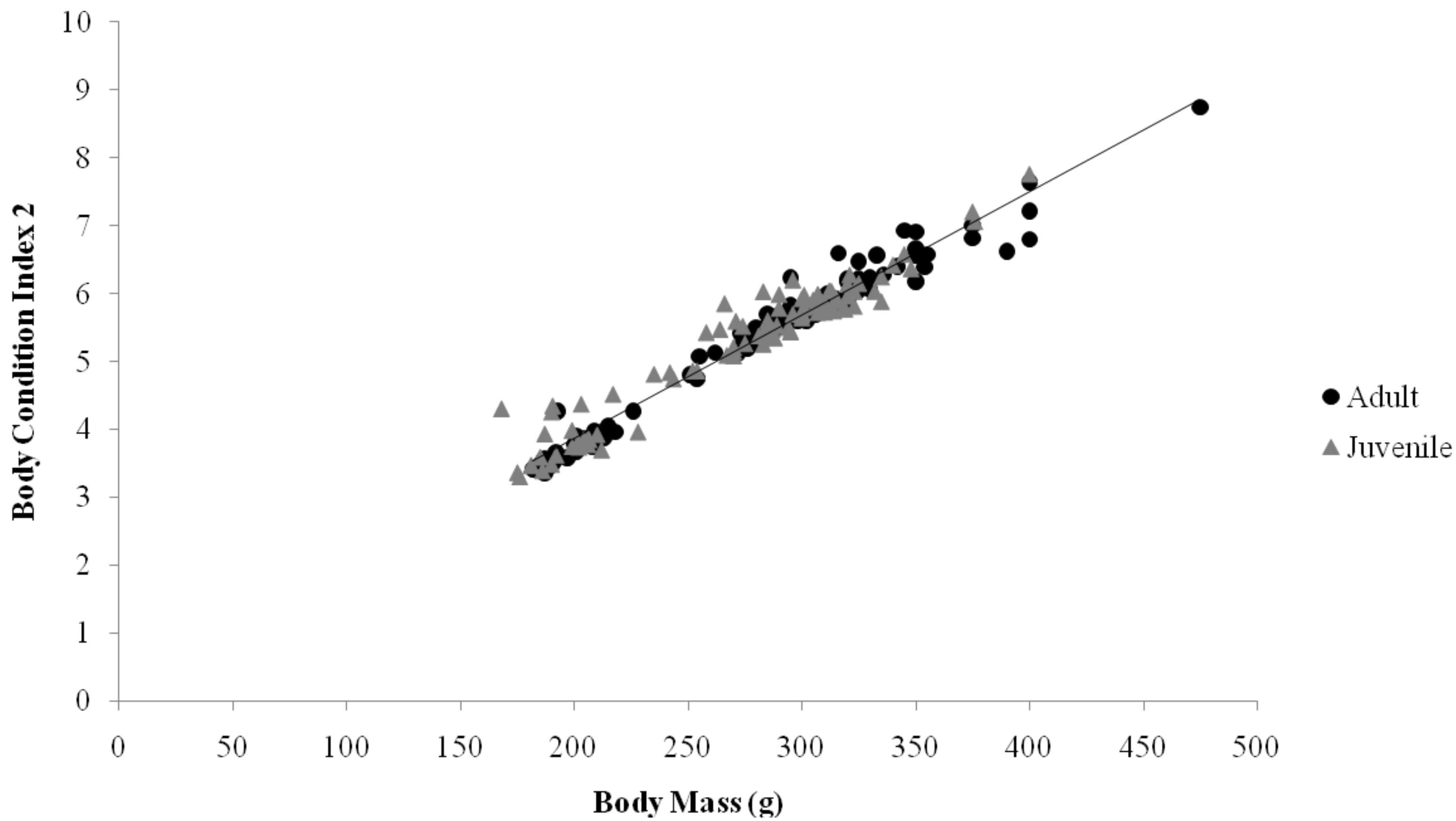

Figure 6.25. Scatterplot of body mass and body condition index 2 values of hunter harvested adult and juvenile female green-winged teal (*Anas crecca*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

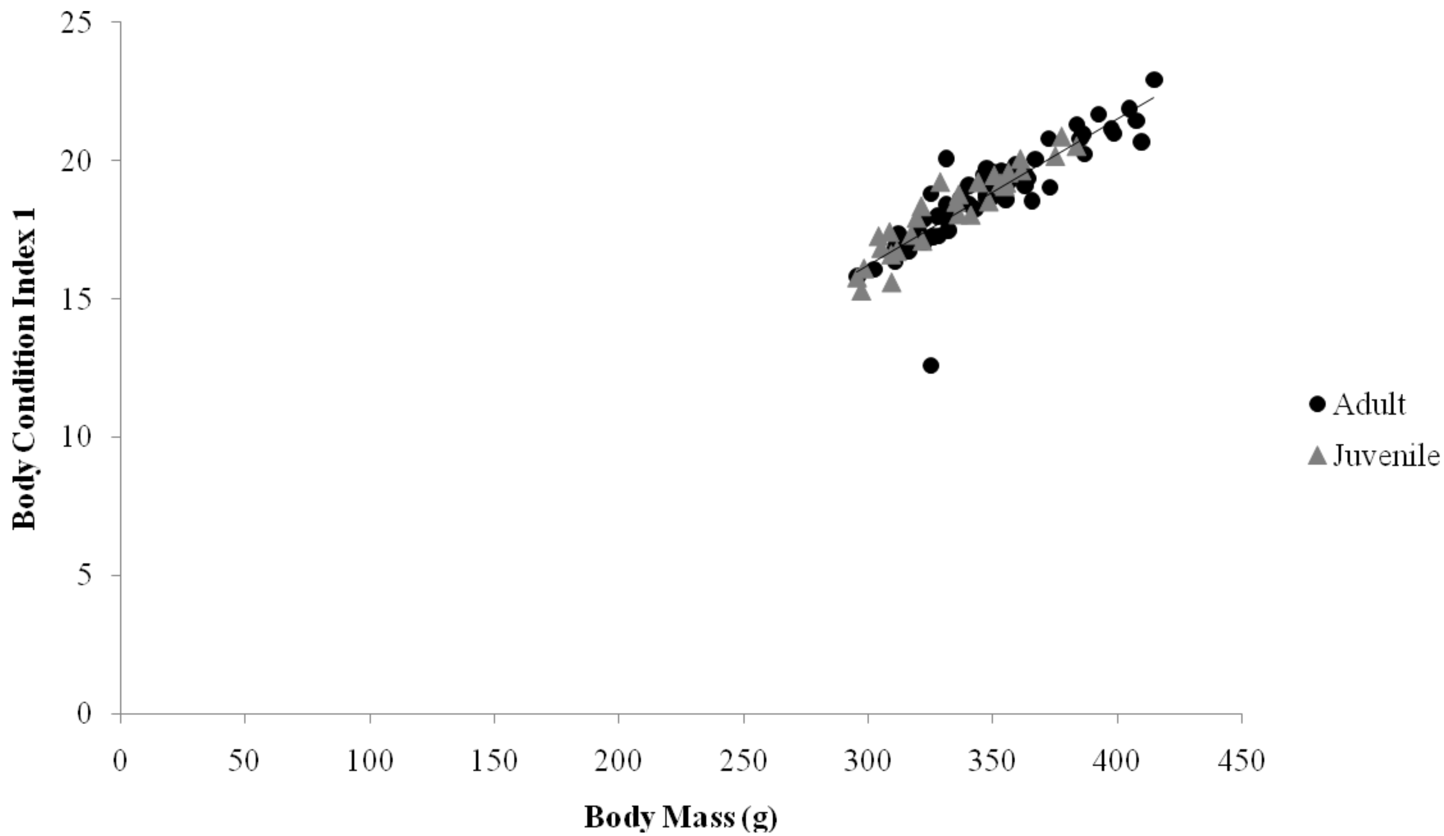

Figure 6.26. Scatterplot of body mass and body condition index 1 value of scientifically collected adult and juvenile male green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

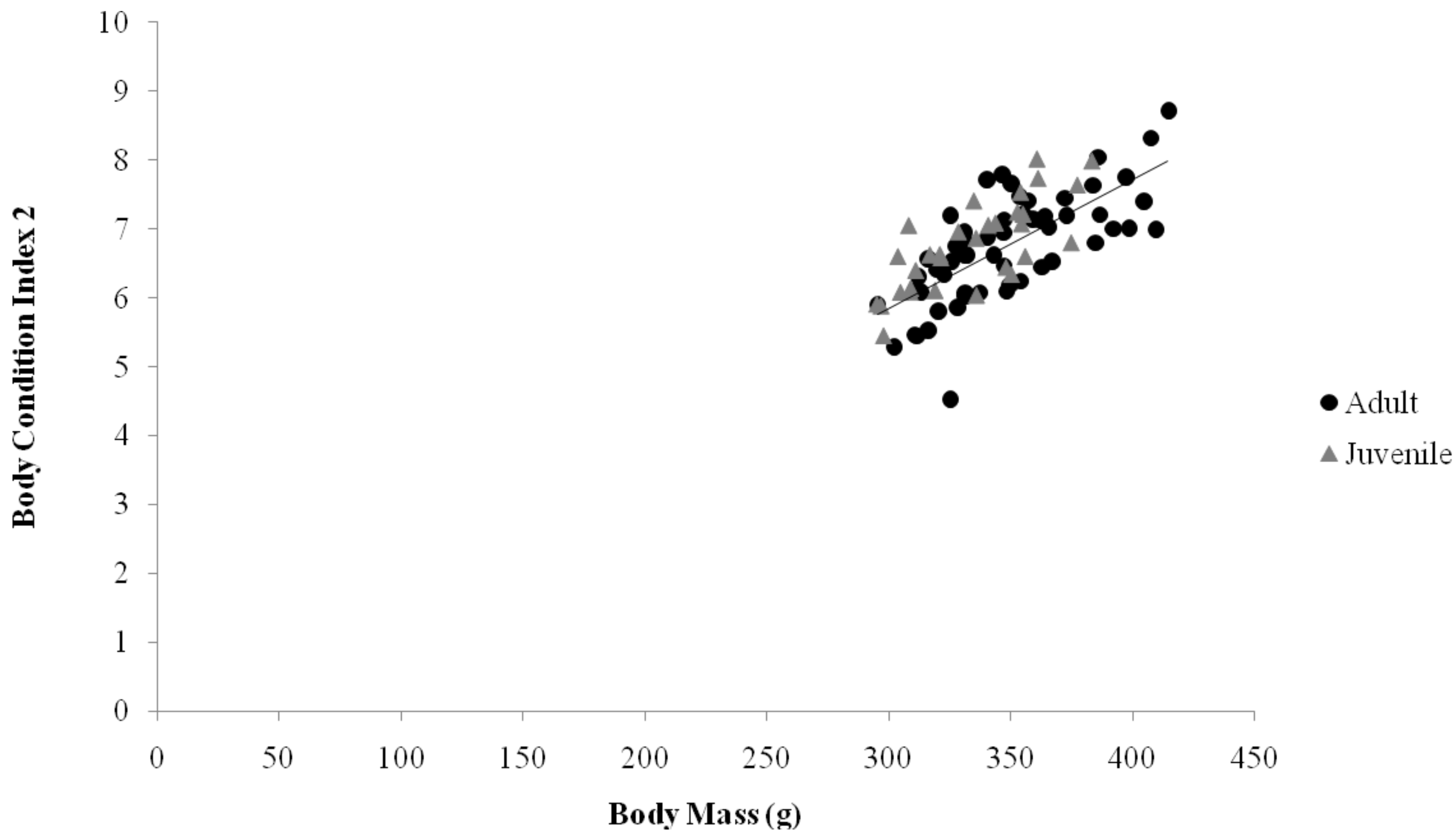

Figure 6.27. Scatterplot of body mass and body condition index 2 value of scientifically collected adult and juvenile male green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

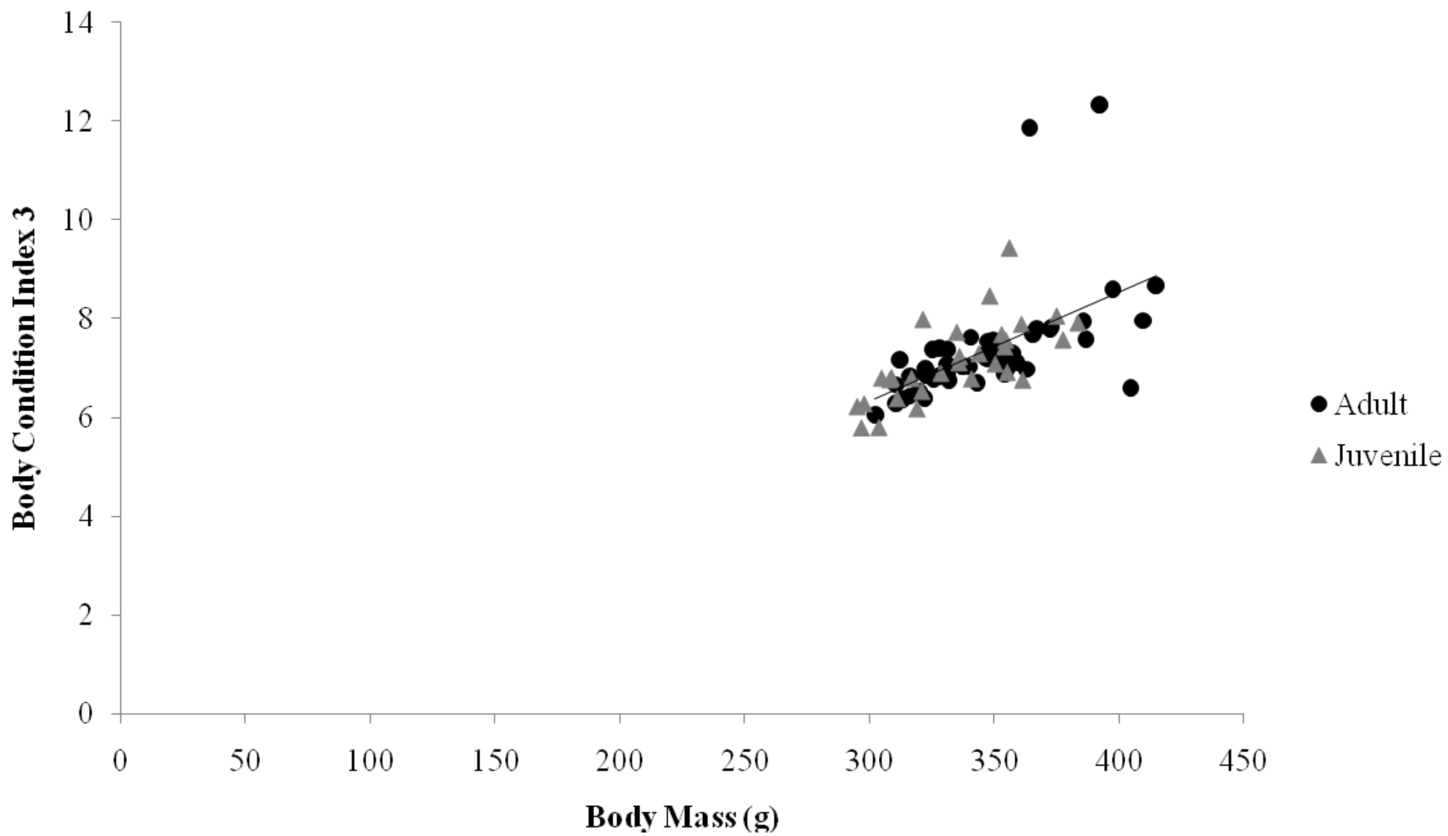

Figure 6.28. Scatterplot of body mass and body condition index 3 value of scientifically collected adult and juvenile male green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

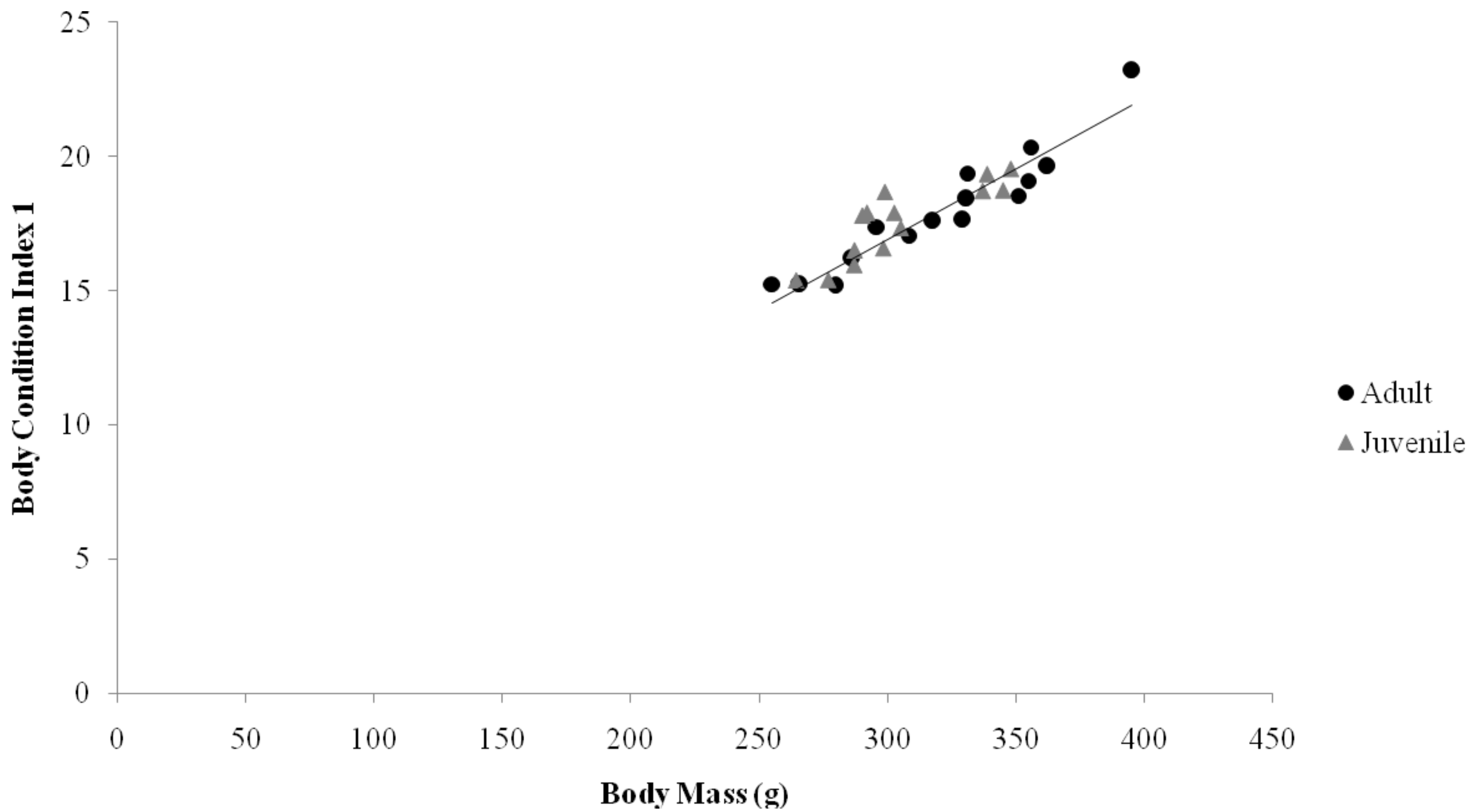

Figure 6.29. Scatterplot of body mass and body condition index 1 value of scientifically collected adult and juvenile female green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

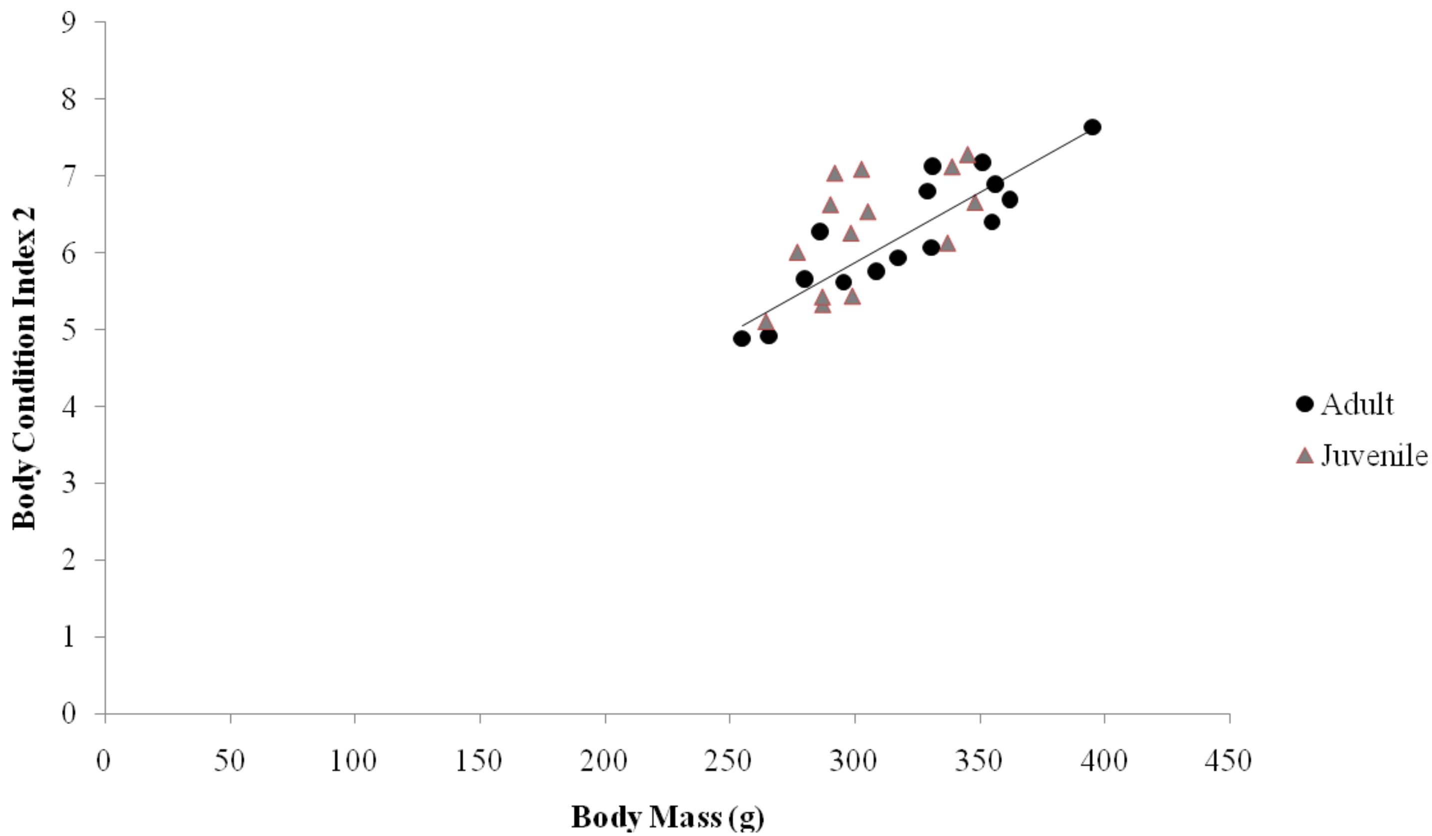

Figure 6.30. Scatterplot of body mass and body condition index 2 value of scientifically collected adult and juvenile female green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

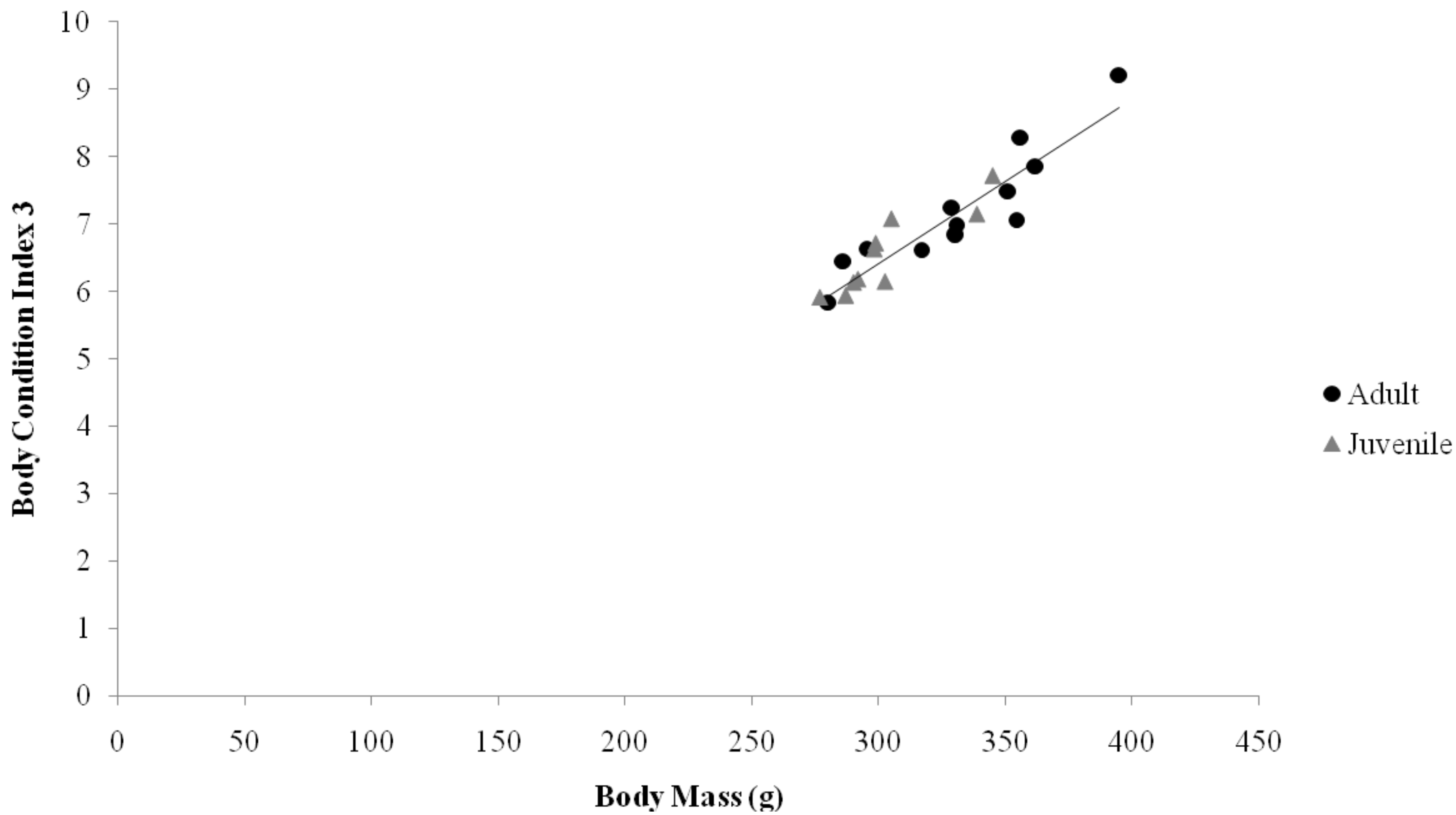

Figure 6.31. Scatterplot of body mass and body condition index 3 value of scientifically collected adult and juvenile female green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

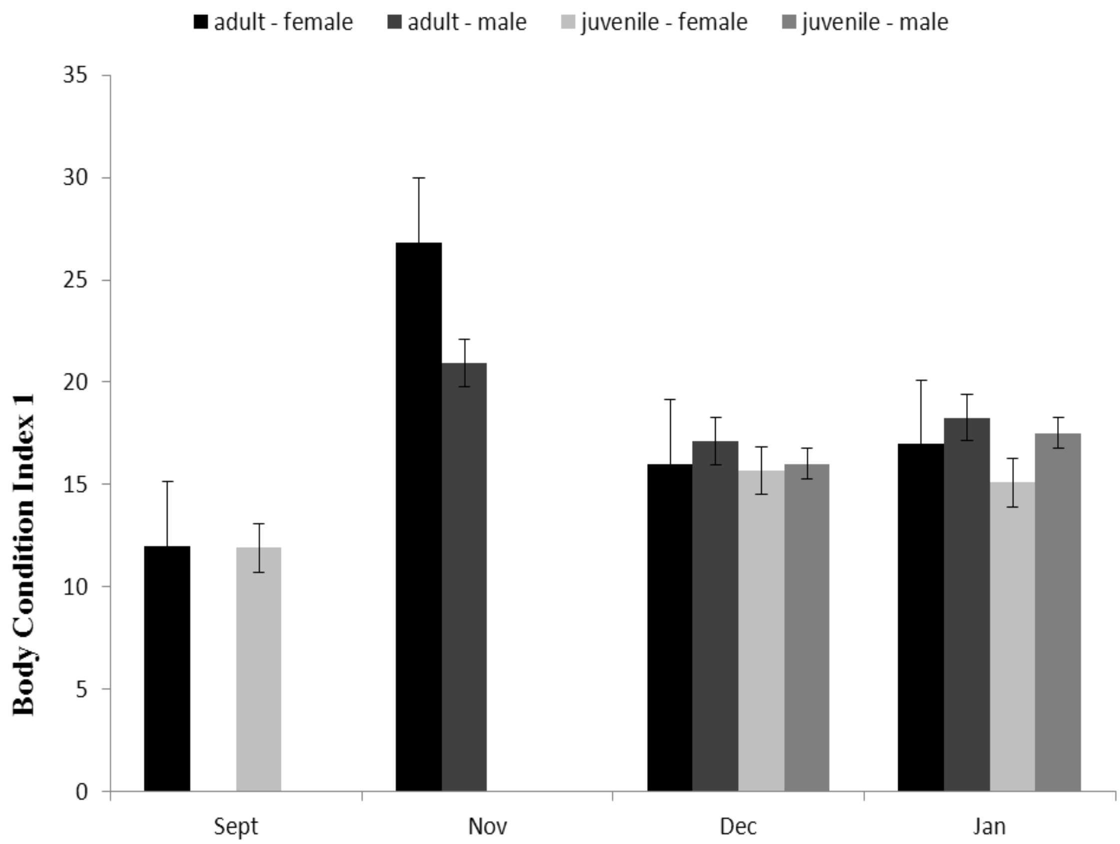

Figure 6.32. Average body condition index 1 across months of hunter harvested adult and juvenile male and female green-winged teal (*Anas crecca*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

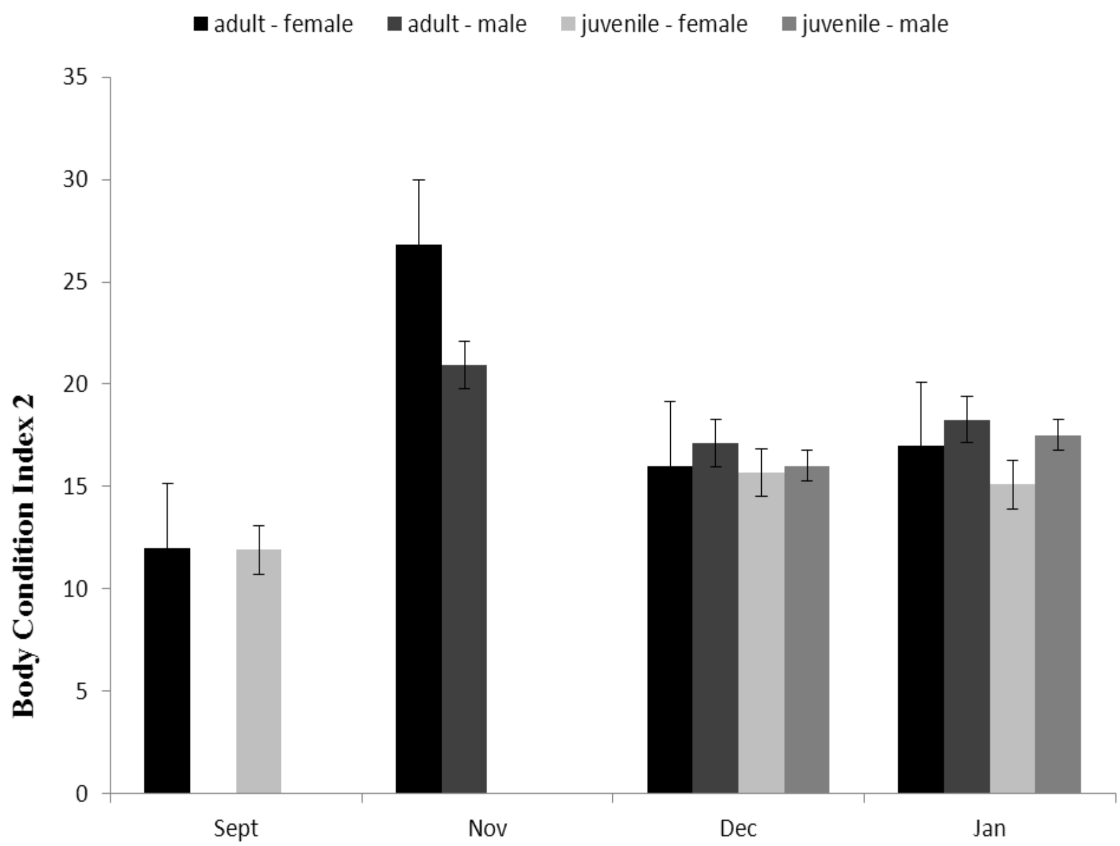

Figure 6.33. Average body condition index 2 across months of hunter harvested adult and juvenile male and female green-winged teal (*Anas crecca*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

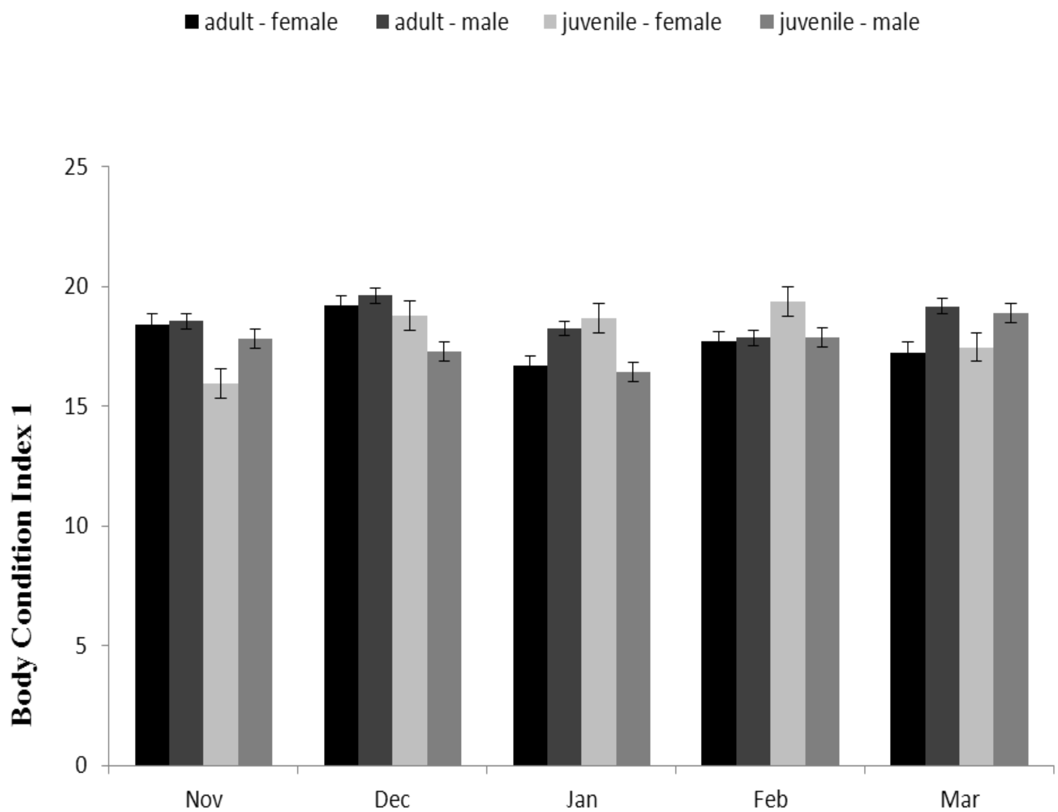

Figure 6.34. Average body condition index 1 across months of scientifically collected adult and juvenile male and female green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

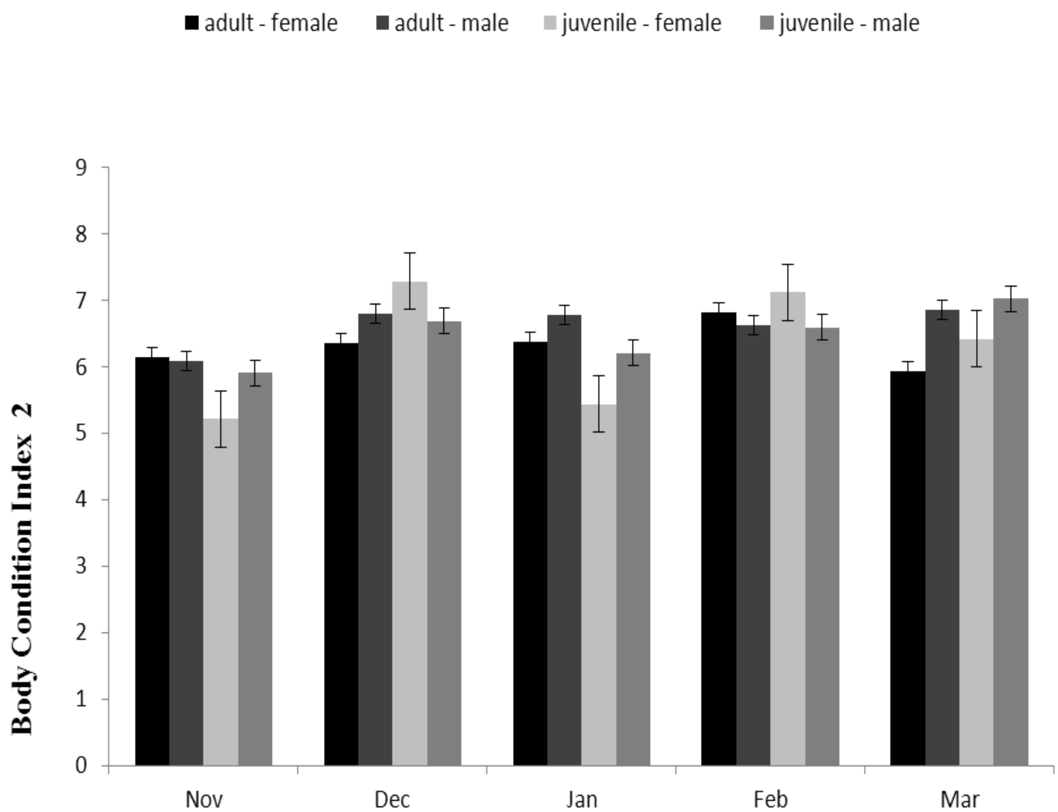

Figure 6.35. Average body condition index 2 across months of scientifically collected adult and juvenile male and female green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

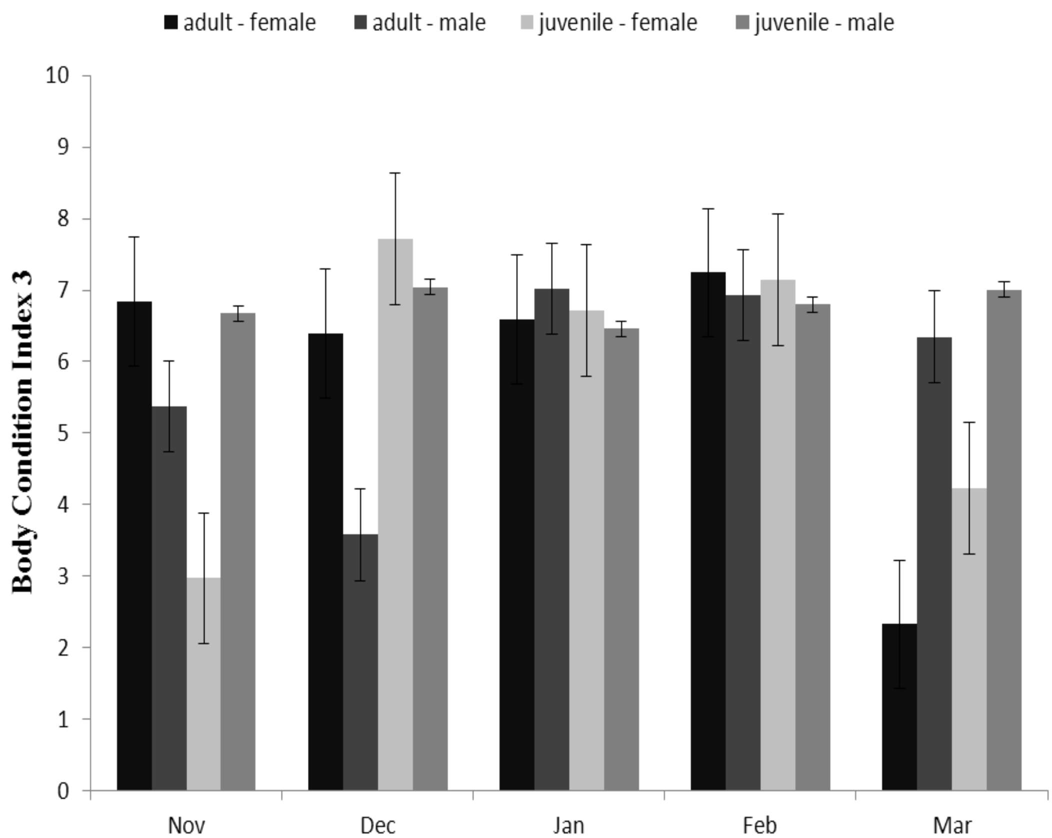

Figure 6.36. Average body condition index 3 across months of scientifically collected adult and juvenile male and female green-winged teal (*Anas crecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

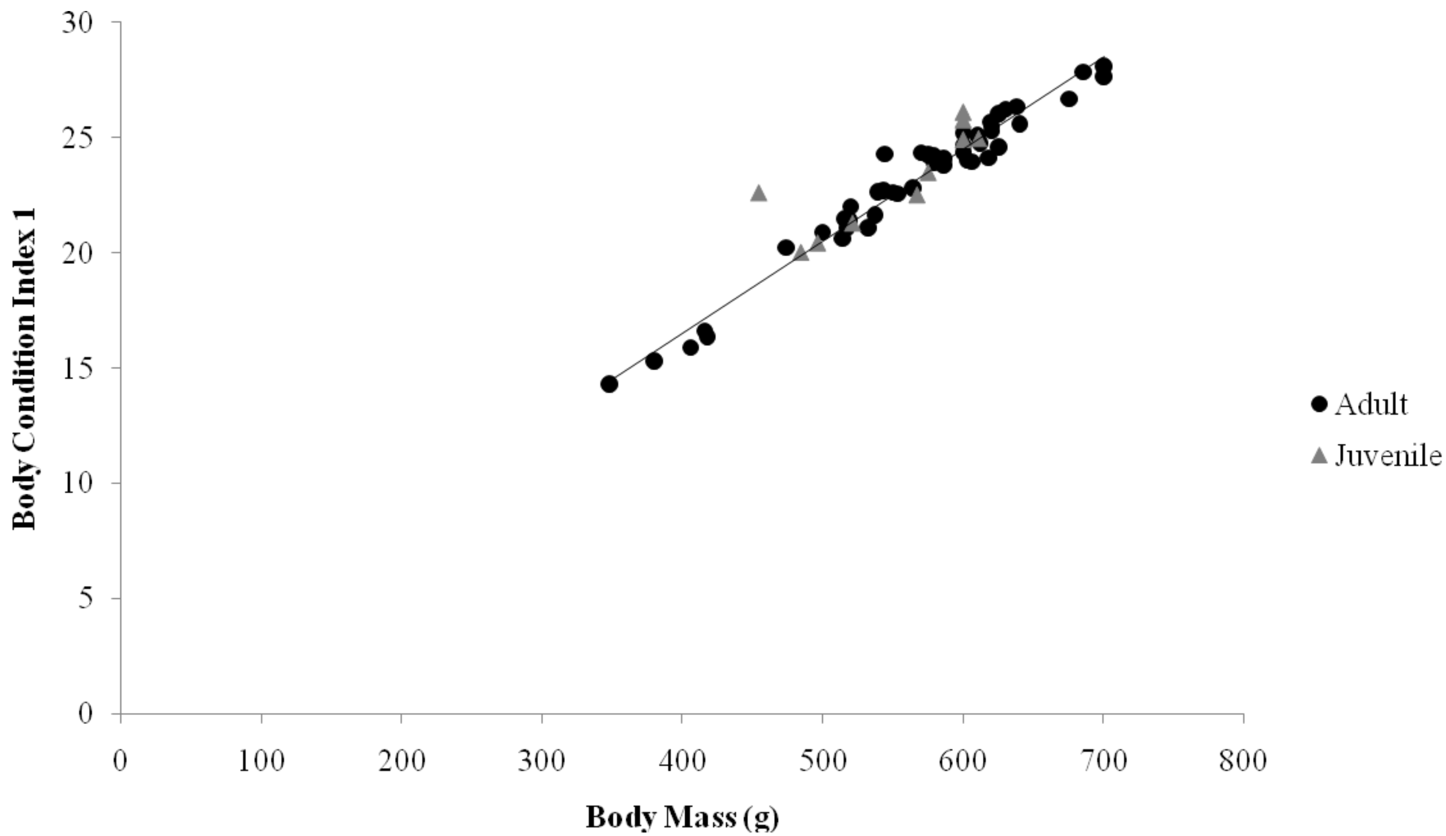

Figure 6.37. Scatterplot of body mass and body condition index 1 values of hunter harvested adult and juvenile male Northern shoveler (*Anas clypeata*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

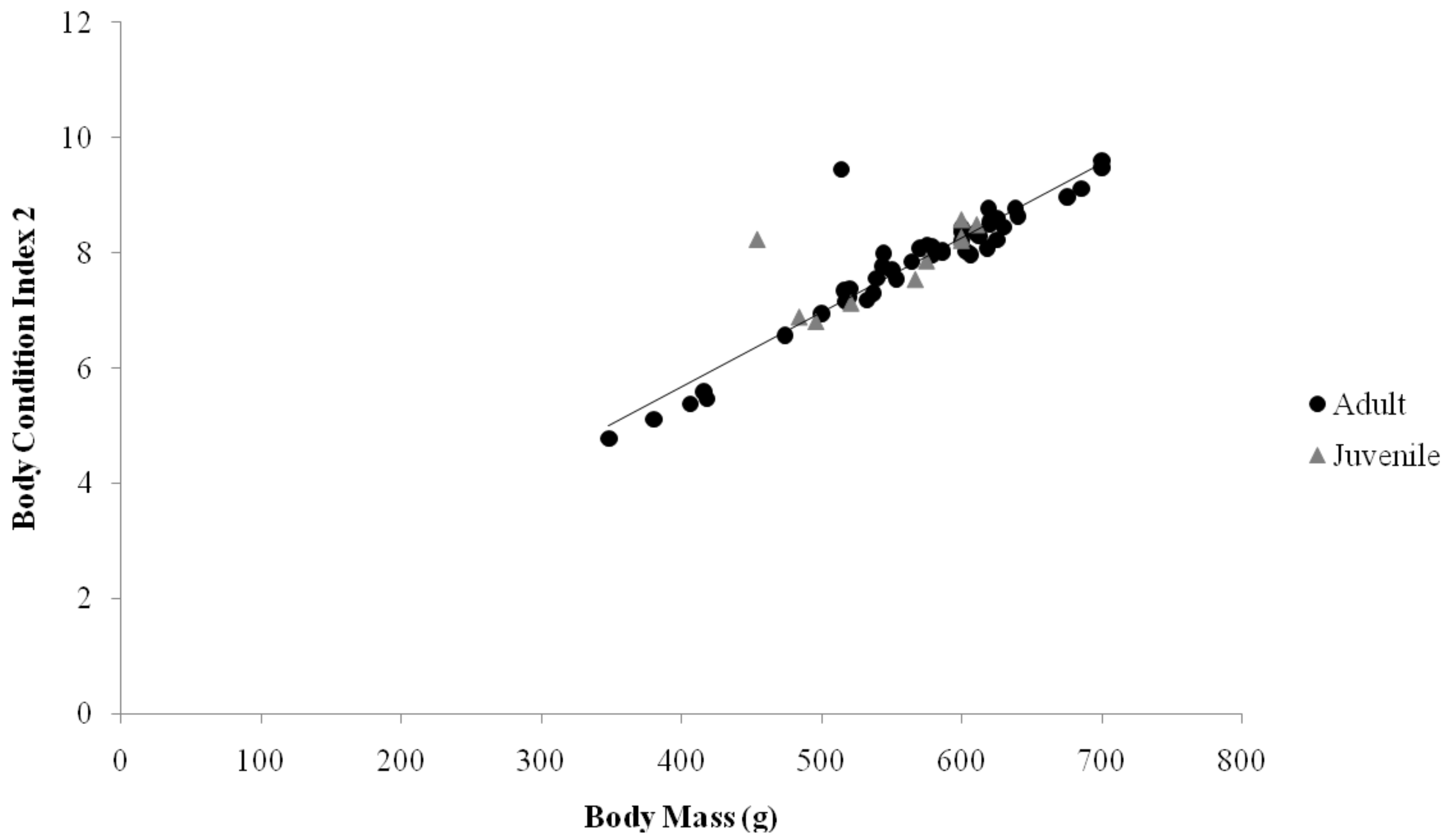

Figure 6.38. Scatterplot of body mass and body condition index 2 value of hunter harvested adult and juvenile male Northern shoveler (*Anas clypeata*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

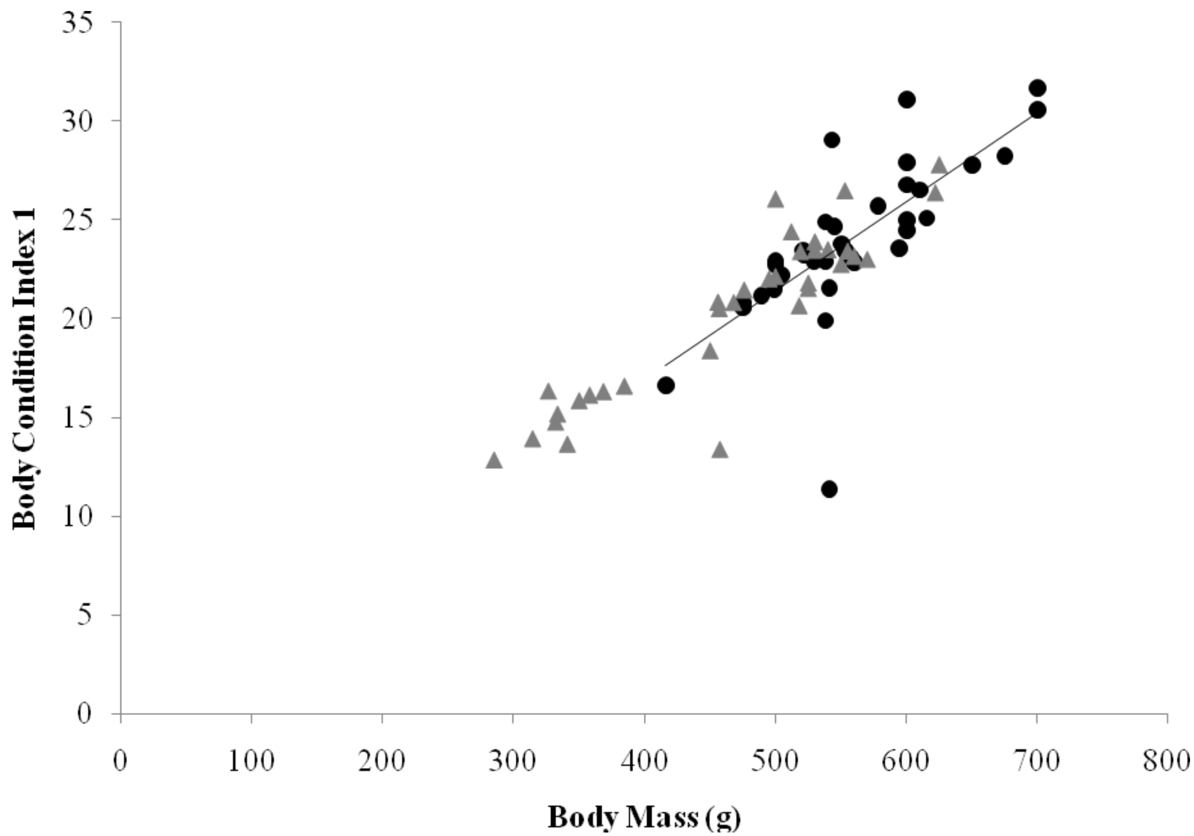

Figure 6.39. Scatterplot of body mass and body condition index 1 value of hunter harvested adult and juvenile female Northern shoveler (*Anas clypeata*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

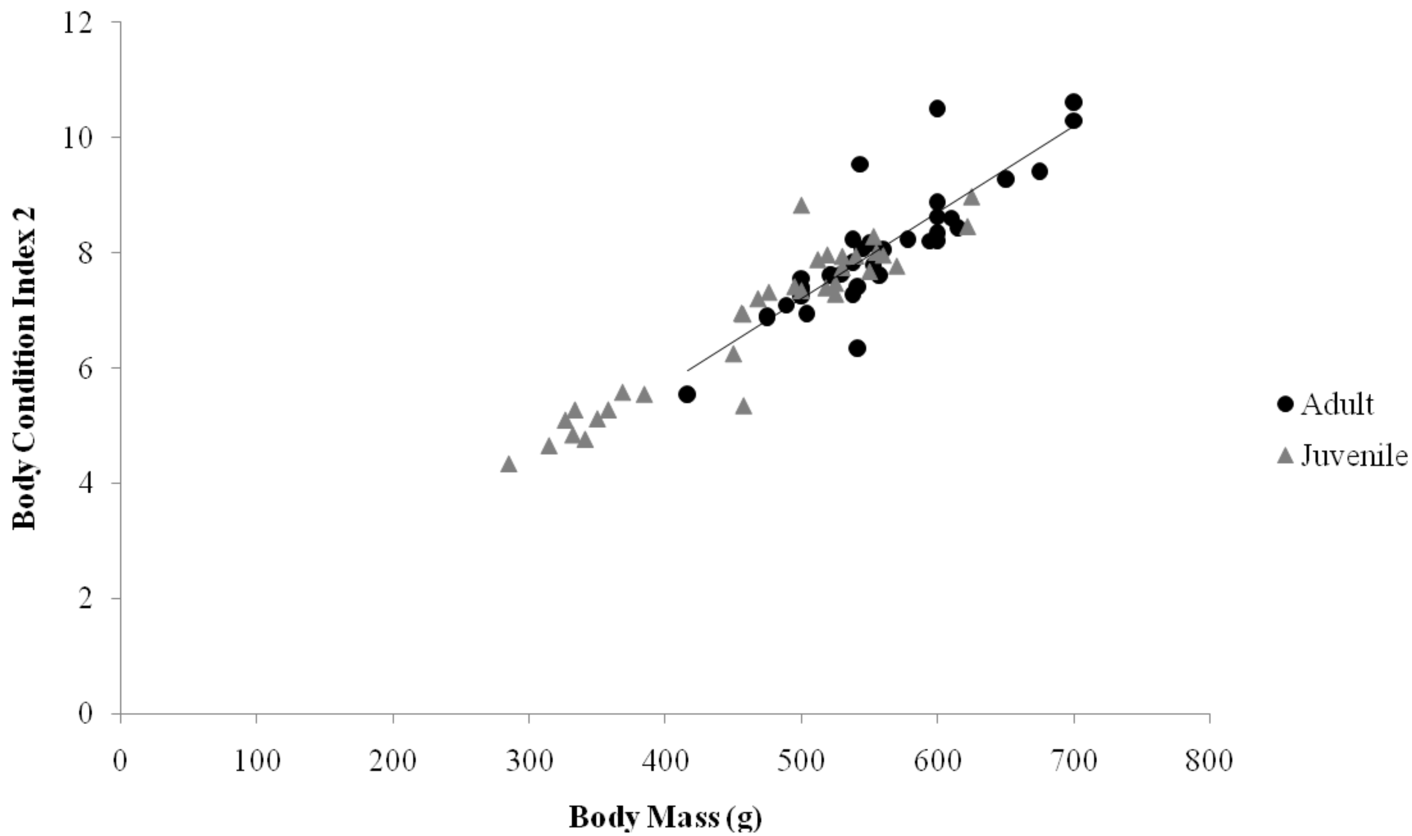

Figure 6.40. Scatterplot of body mass and body condition index 2 value of hunter harvested adult and juvenile female Northern shoveler (*Anas clypeata*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

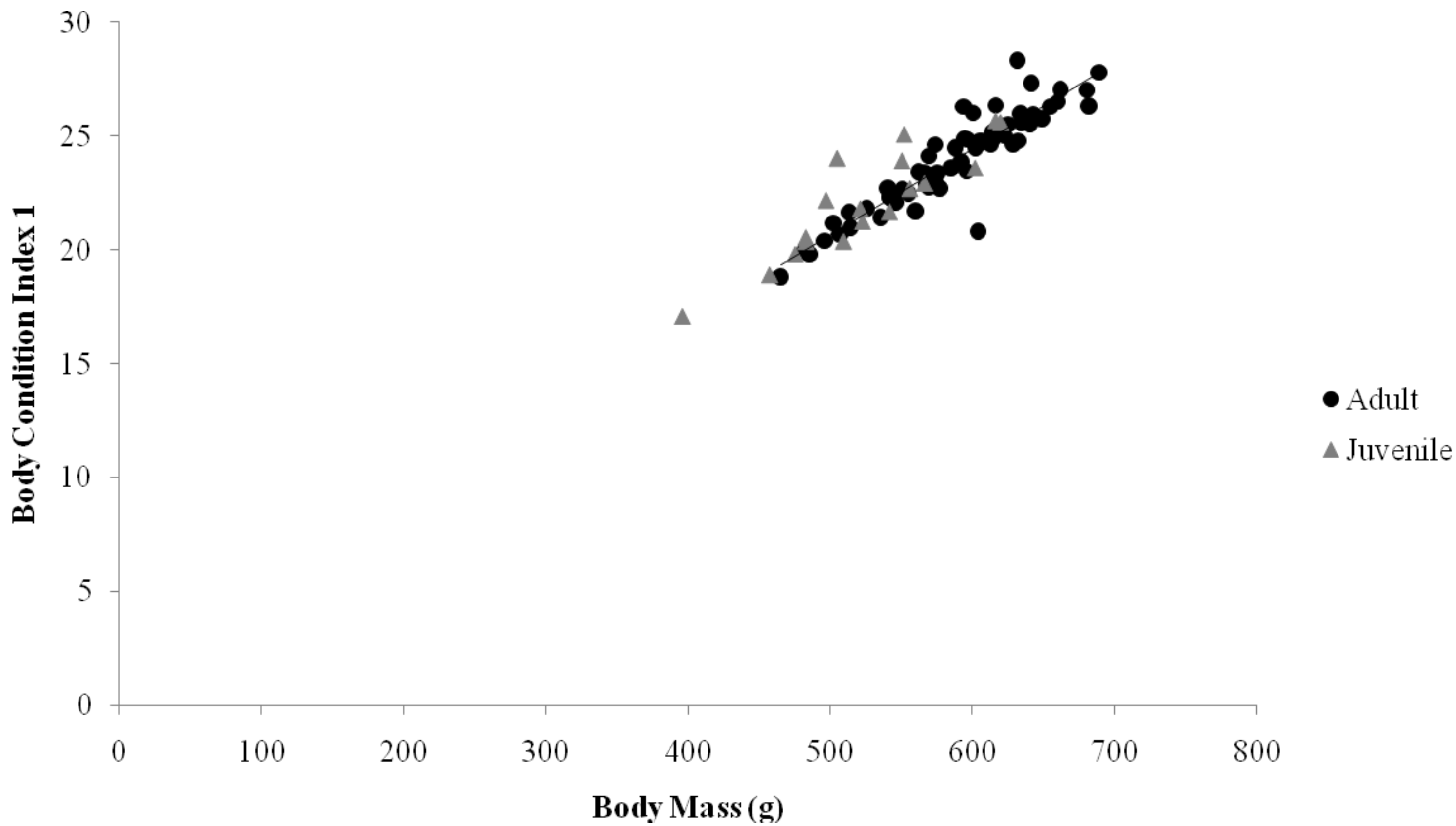

Figure 6.41. Scatterplot of body mass and body condition index 1 value of scientifically collected adult and juvenile male Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

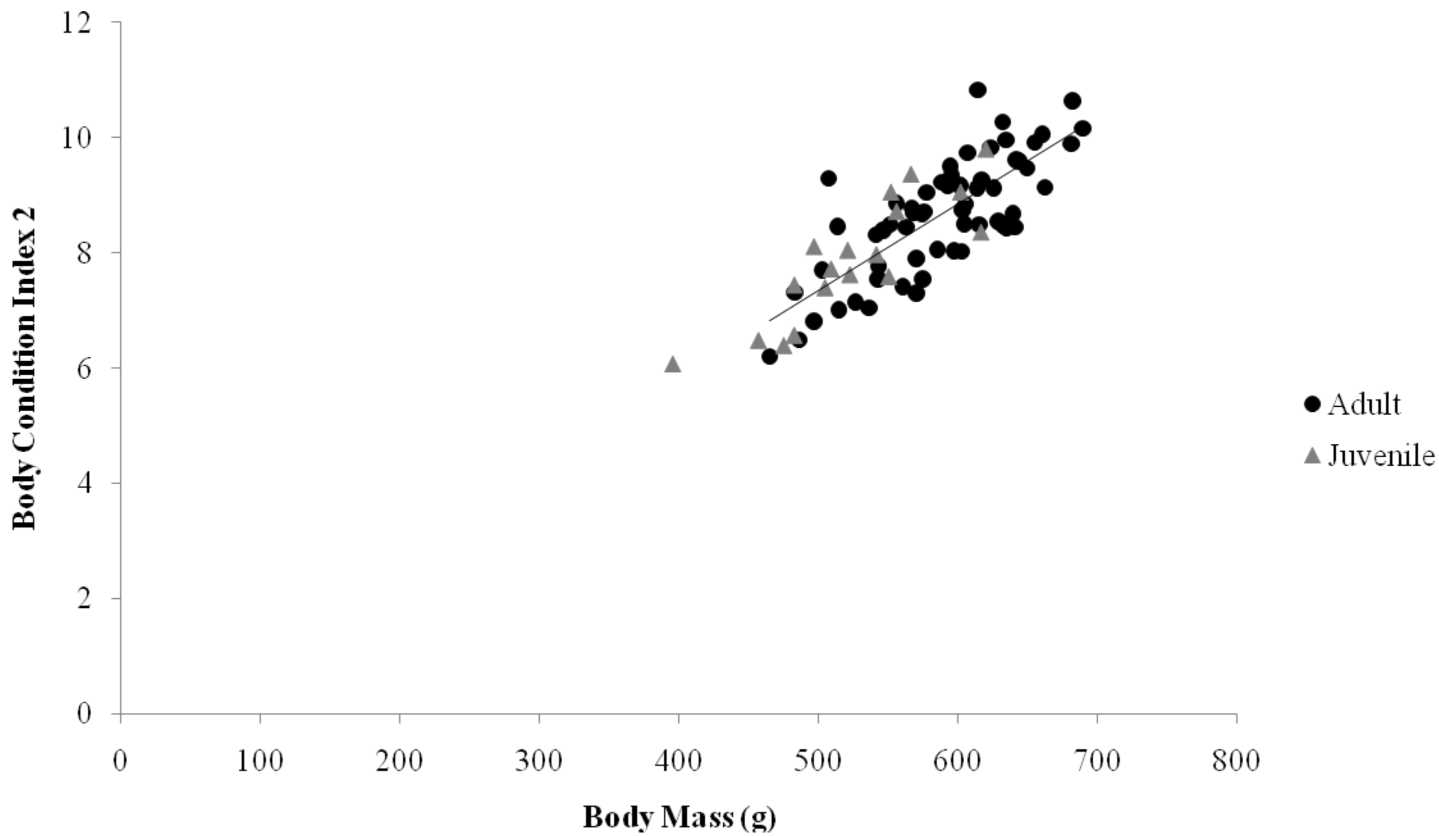

Figure 6.42. Scatterplot of body mass and body condition index 2 value of scientifically collected adult and juvenile male Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

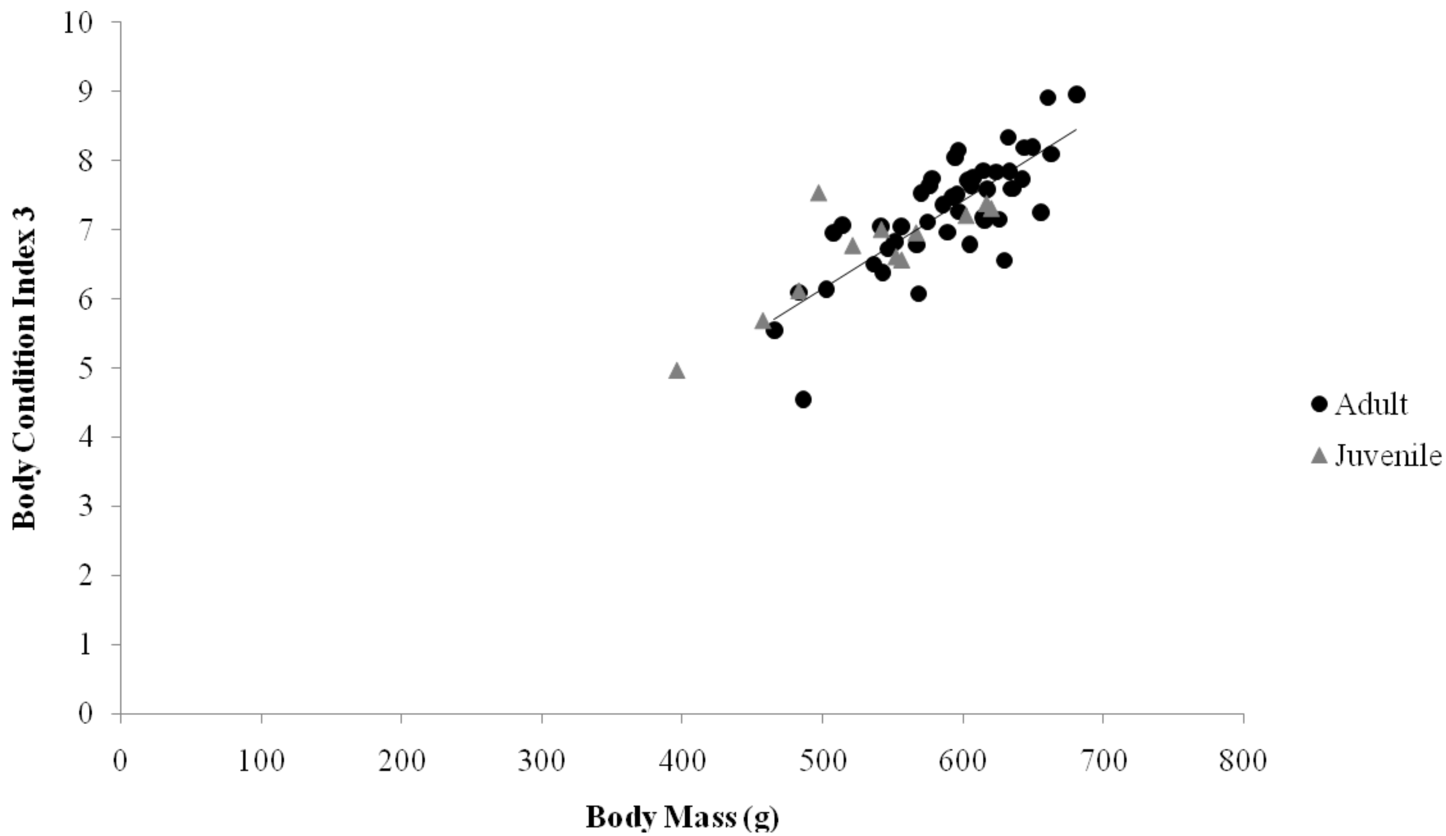

Figure 6.43. Scatterplot of body mass and body condition index 3 value of scientifically collected adult and juvenile male Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

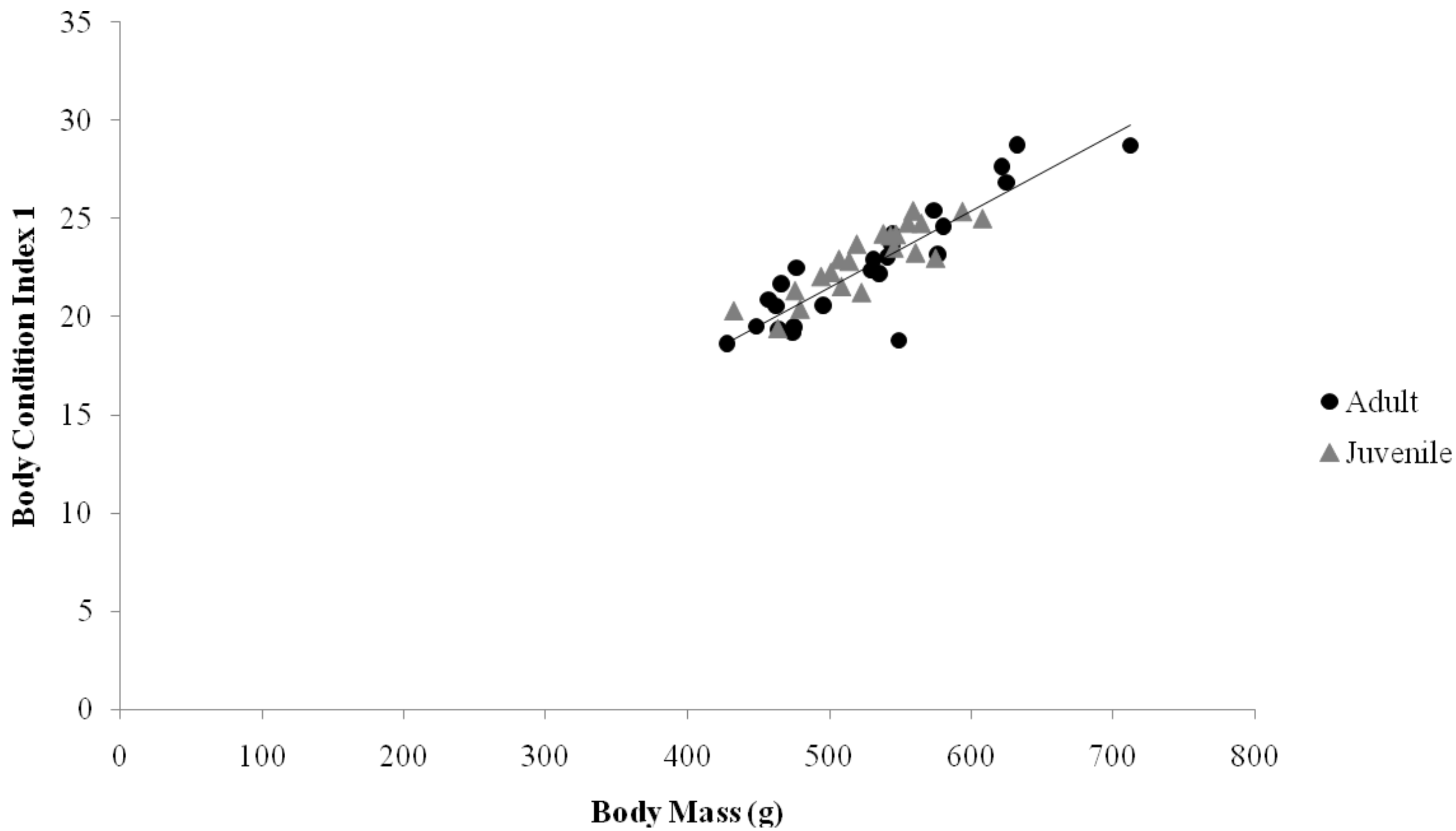

Figure 6.44. Scatterplot of body mass and body condition index 1 value of scientifically collected adult and juvenile female Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

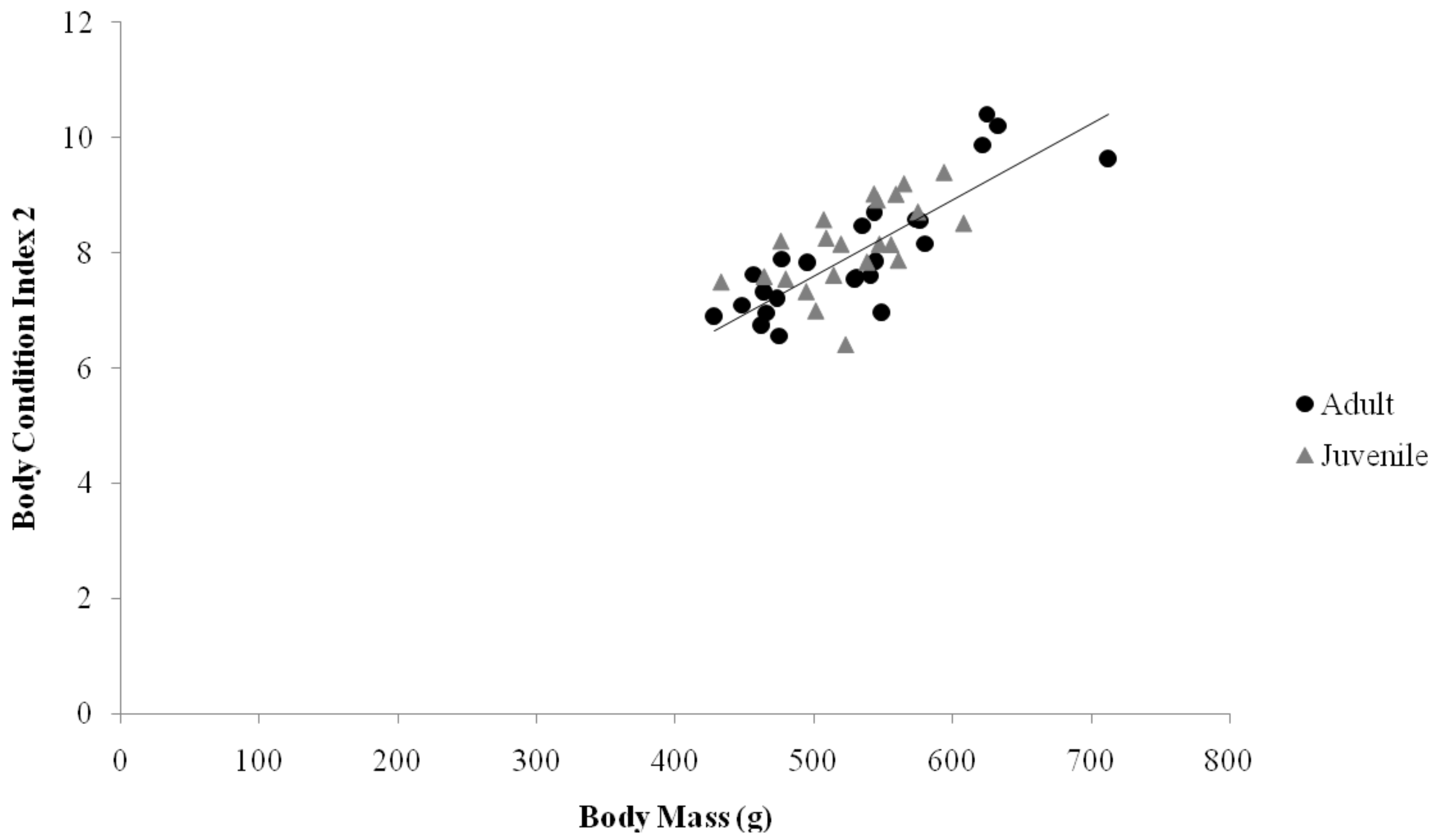

Figure 6.45. Scatterplot of body mass and body condition index 2 value of scientifically collected adult and juvenile female Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

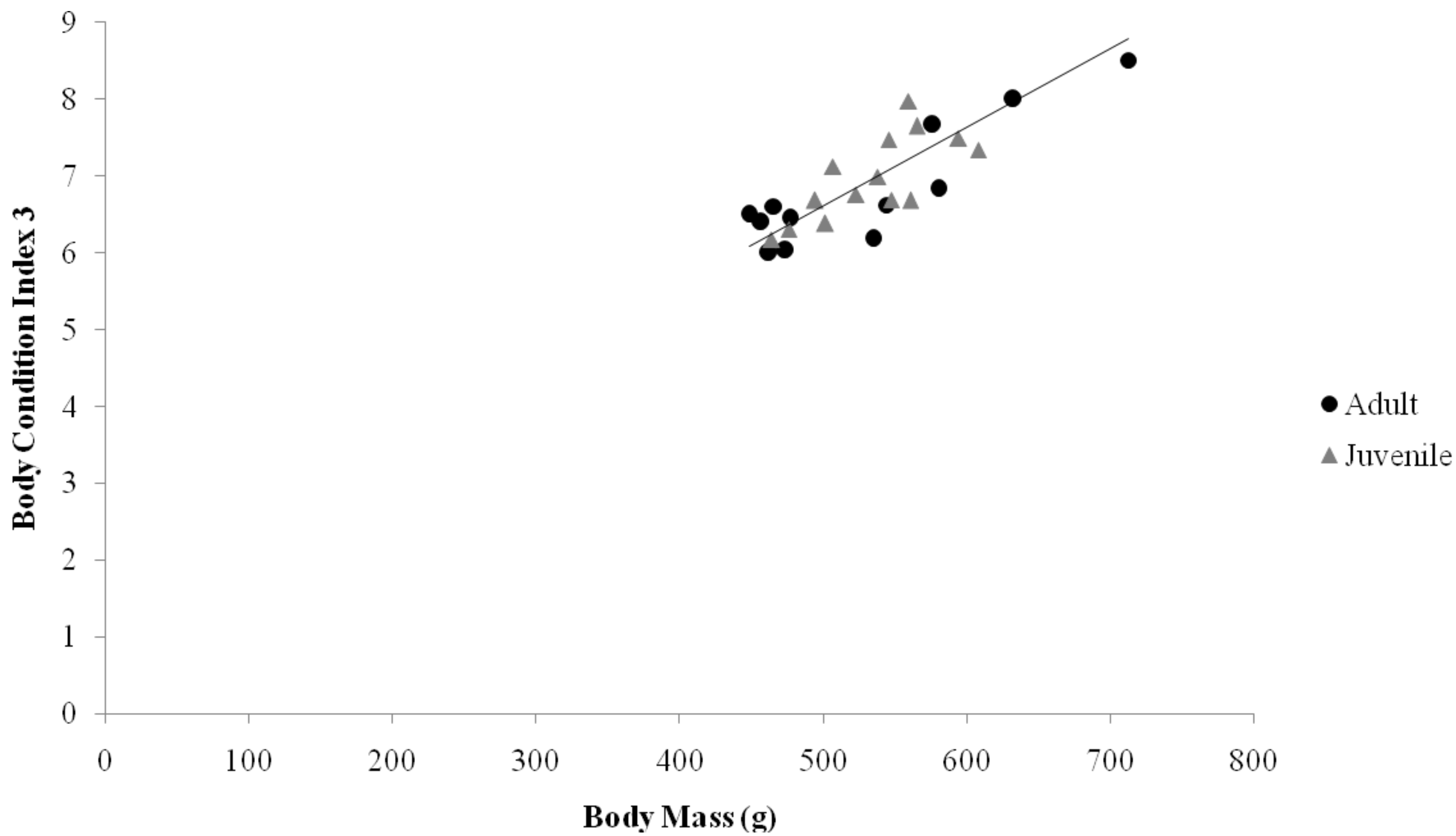

Figure 6.46. Scatterplot of body mass and body condition index 3 value of scientifically collected adult and juvenile female Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

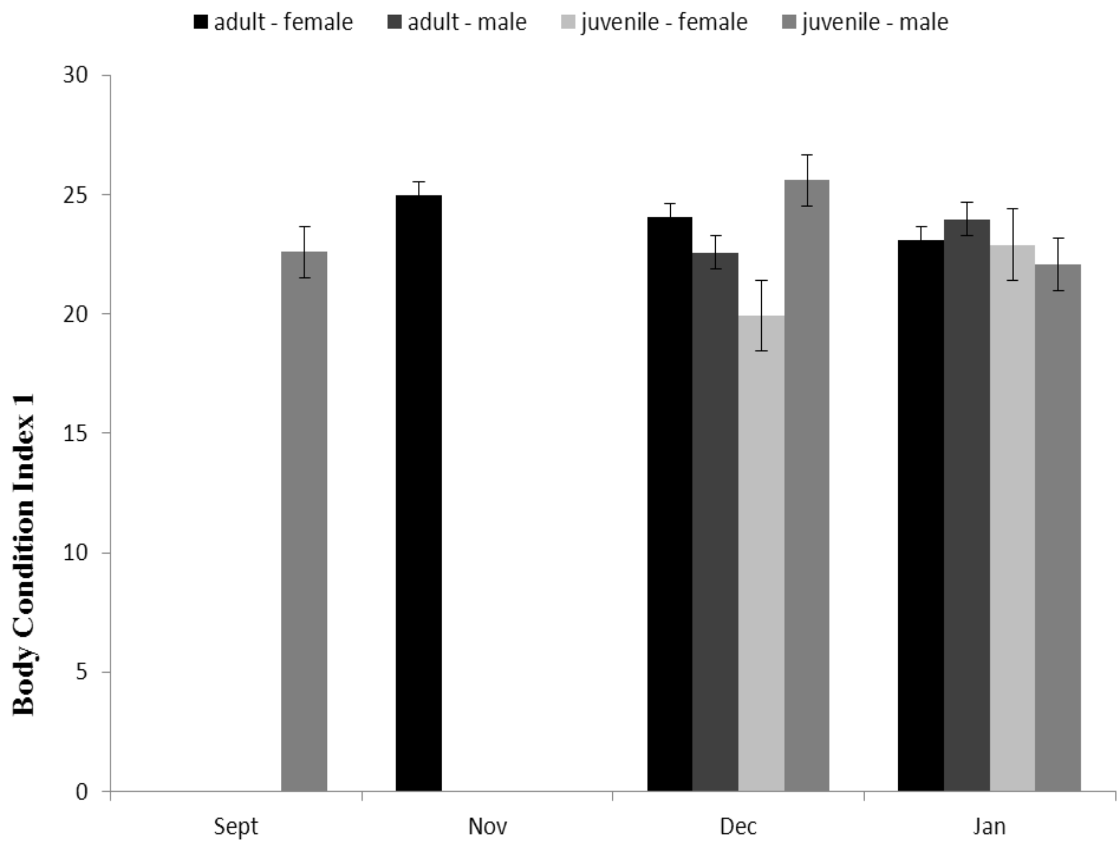

Figure 6.47. Average body condition index 1 across months of hunter harvested adult and juvenile male and female Northern shoveler (*Anas clypeata*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

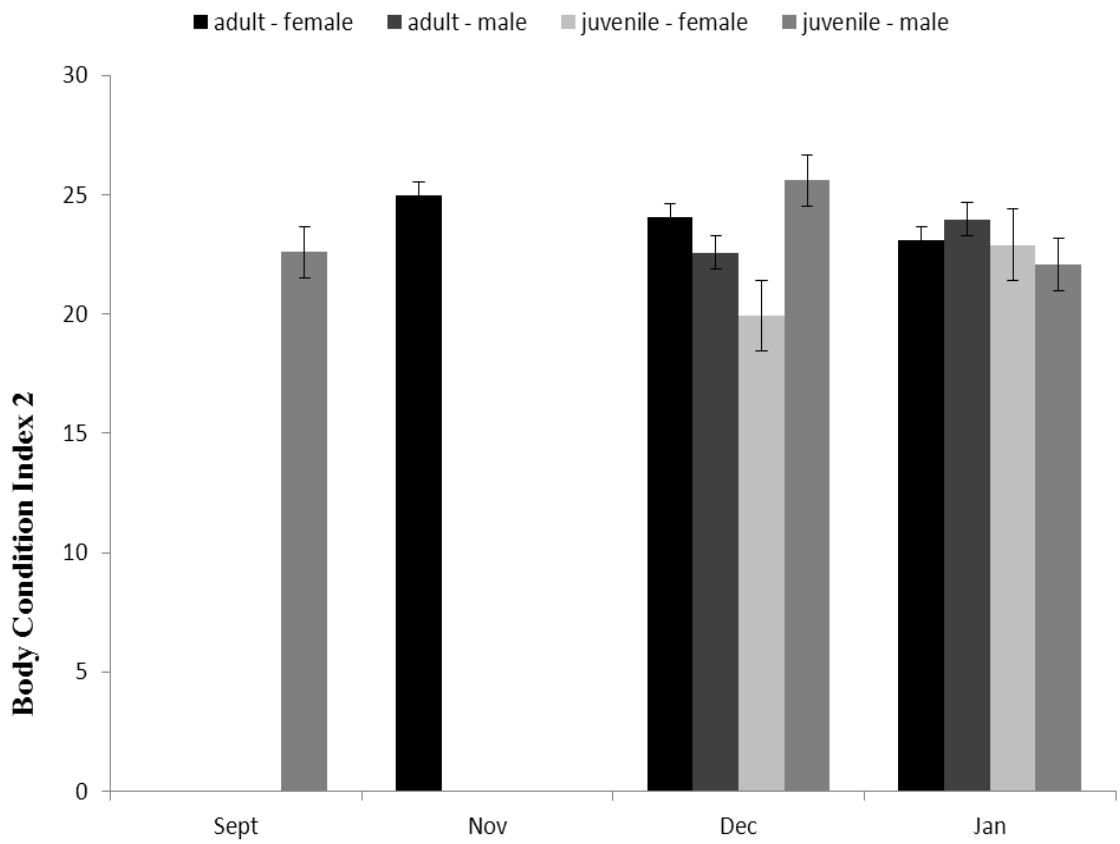

Figure 6.48. Average body condition index 2 across months of hunter harvested adult and juvenile male and female Northern shoveler (*Anas clypeata*) collected at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

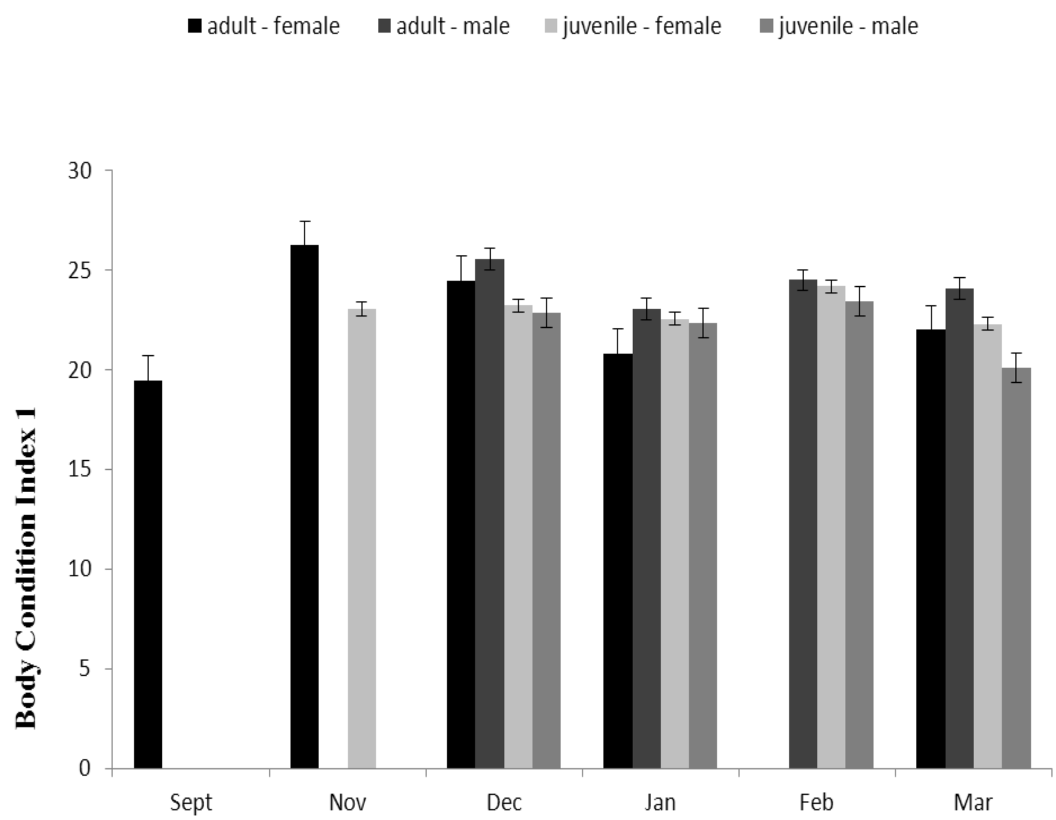

Figure 6.49. Average body condition index 1 across months of scientifically collected adult and juvenile male and female Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

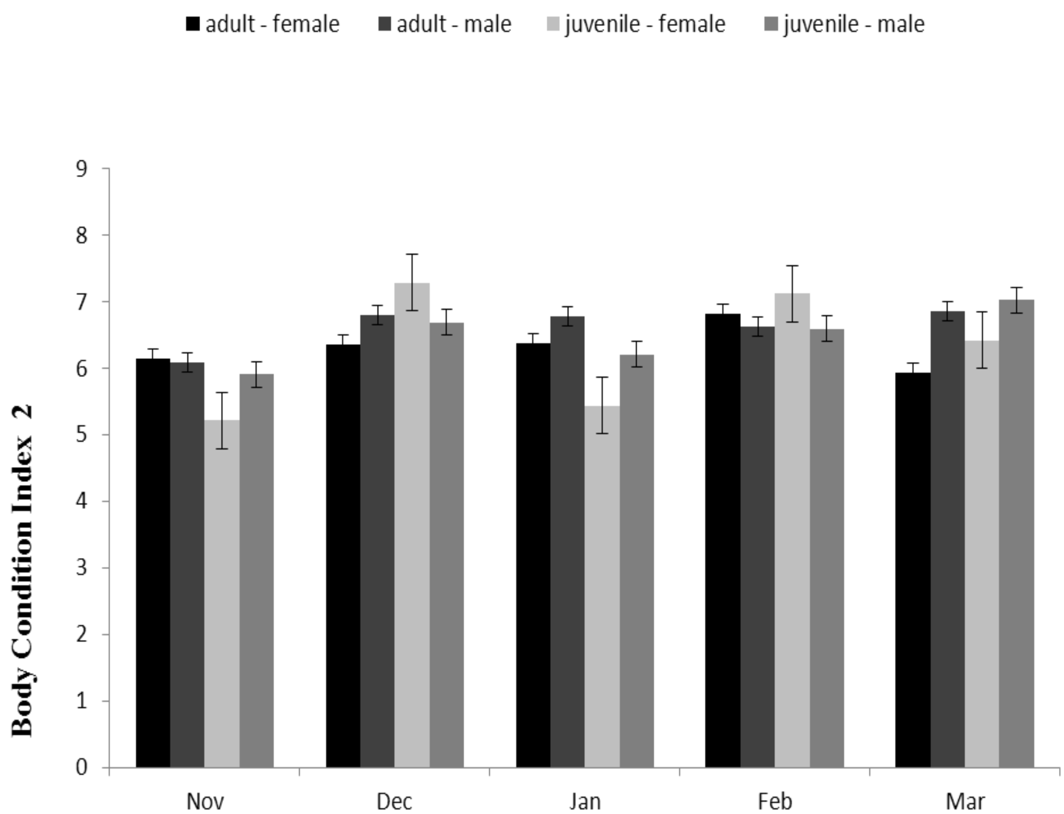

Figure 6.50. Average body condition index 2 across months of scientifically collected adult and juvenile male and female Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

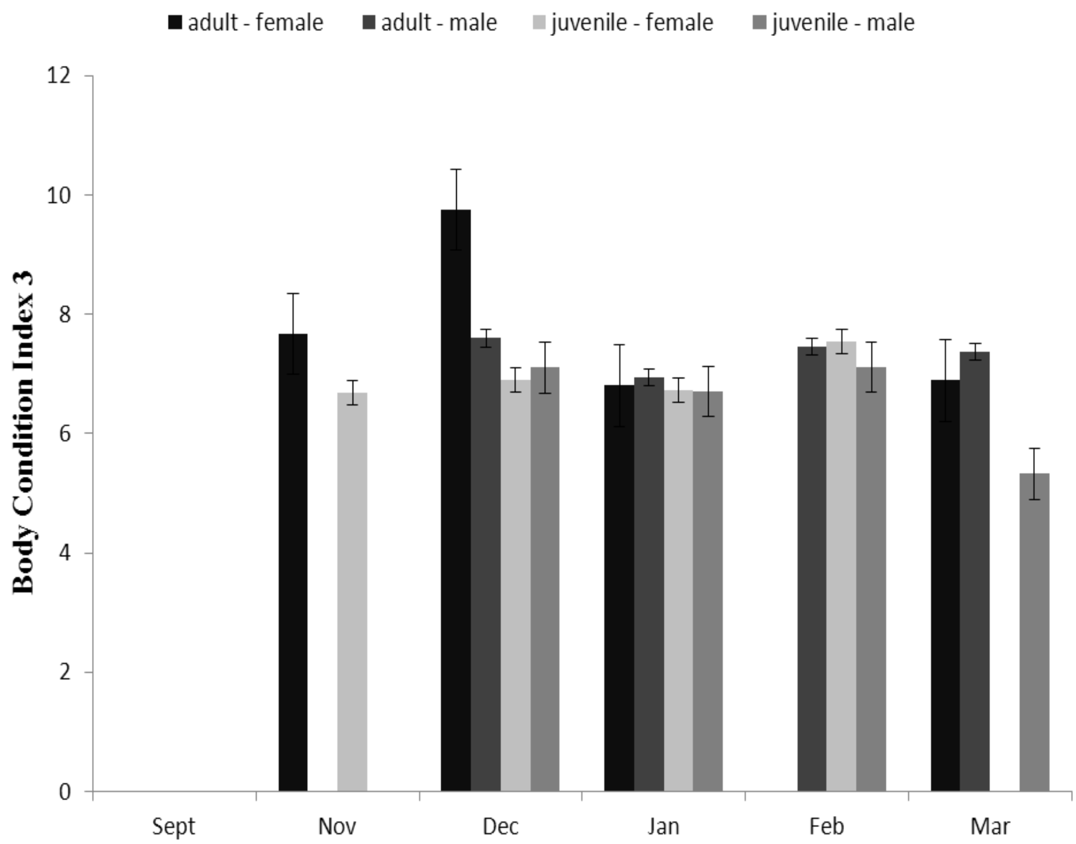

Figure 6.51. Average body condition indices 3 across months of scientifically collected adult and juvenile male and female Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

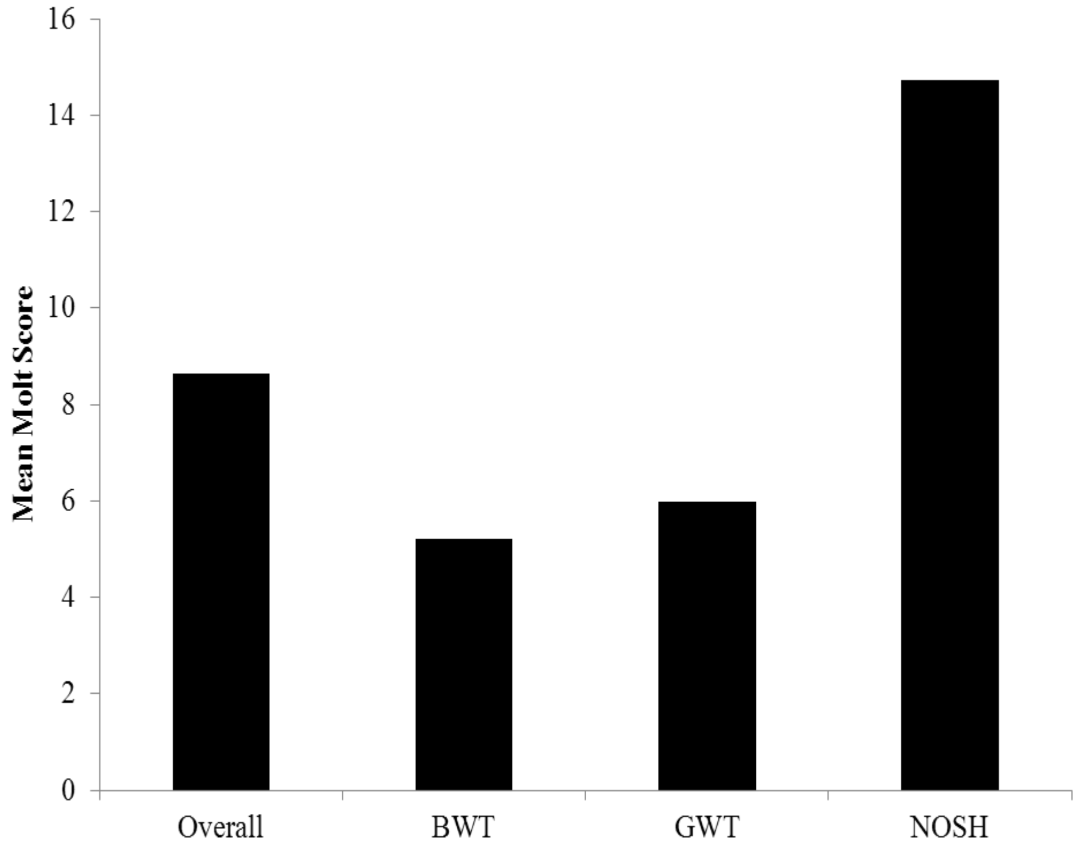

Figure 6.52. Mean molt score among and between 3 species (i.e., blue-winged teal, green-winged teal, and Northern shoveler) of dabbling ducks collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

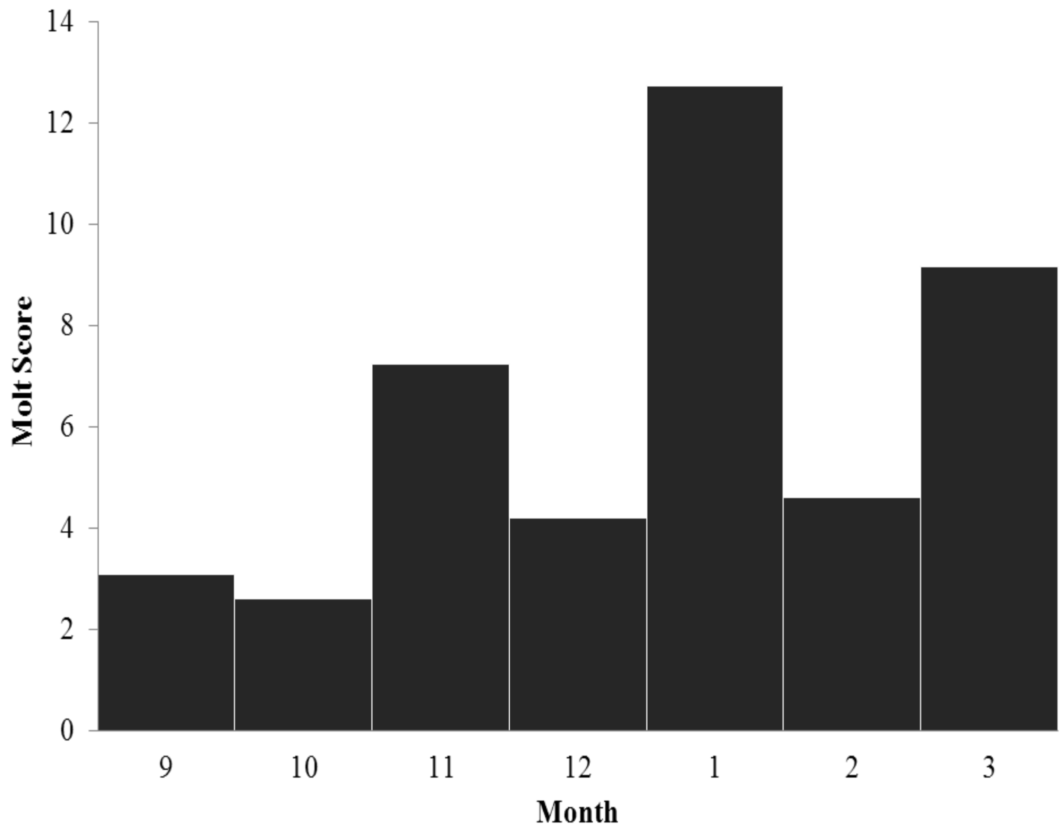

Figure 6.53. Mean molt score by month for all 3 species (i.e., blue-winged teal, green-winged teal, and Northern shoveler) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

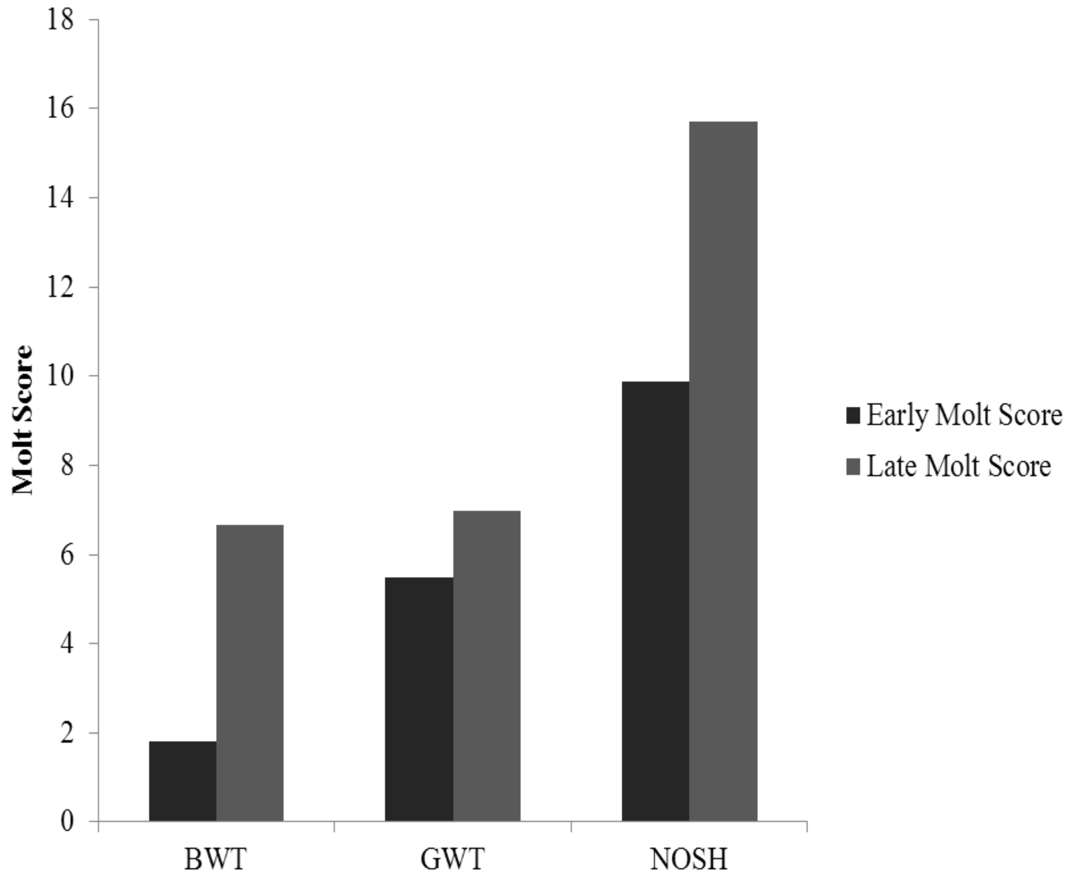

Figure 6.54. Molt scores of scientifically collected blue-winged teal, green-winged teal, and Northern shoveler during two migration/wintering (i.e., early and late) periods collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Table 6.1. Type III *F* and *P* values from analysis of variance of morphological features of hunter harvested blue-winged teal (*Anas discors*) (*n* = 262) collected at hunter check stations on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Total body mass (g)	7.75	<0.001	0.15	0.696	10.18	0.002	0.01	0.926	18.51	<0.001
Total body length (cm)	19.16	<0.001	0.31	0.576	18.58	<0.001	0.04	0.846	52.53	<0.001
Wing cord (cm)	5.37	<0.001	1.00	0.319	19.42	<0.001	0.01	0.920	0.30	0.582
Tarsus (cm)	3.47	0.009	0.51	0.478	0.95	0.330	0.04	0.851	12.64	<0.001

Table 6.2. Mean ($\bar{x}$)and standard error (SE) of morphological features collected from hunter harvested blue-winged teal (*Anas discors*) collection at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
<u>Adult Female</u>					
Total body mass (g)	53	294.65	10.07	182.00	406.00
Total body length (cm)	53	32.51	0.51	27.80	40.20
Wing cord (cm)	53	18.46	0.21	16.10	28.30
Tarsus (mm)	52	29.86	0.50	24.00	39.70
<u>Adult Male</u>					
Total body mass (g)	66	326.66	9.47	192.00	455.00
Total body length (cm)	66	34.61	0.51	28.20	42.00
Wing cord (cm)	66	19.07	0.09	17.50	20.80
Tarsus (mm)	61	30.63	0.60	8.50	40.00
<u>Juvenile Female</u>					
Total body mass (g)	75	288.39	6.73	188.00	450.00
Total body length (cm)	75	31.88	0.40	27.00	39.30
Wing cord (cm)	75	18.34	0.16	16.60	28.90
Tarsus (mm)	72	30.14	0.46	22.00	40.00
<u>Juvenile Male</u>					
Total body mass (g)	68	311.00	9.40	188.50	500.00
Total body length (cm)	68	33.49	0.47	28.70	41.70
Wing cord (cm)	68	18.95	0.07	17.20	20.30
Tarsus (mm)	64	30.33	0.39	25.00	36.00

Table 6.3. Type III *F* and *P* values from analysis of variance of morphological features of scientifically collected blue-winged teal (*Anas discors*) (*n* = 155) collected on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Total body mass (g)	5.45	<0.001	8.67	0.004	13.36	<0.001	3.79	0.053	2.39	0.124
Plucked body mass (g)	5.48	0.004	7.01	0.009	14.46	<0.001	4.59	0.034	2.37	0.126
Ingesta mass (g)	0.64	0.634	0.04	0.849	0.95	0.331	0.62	0.431	1.19	0.278
Corrected body mass (g)	5.46	<0.001	7.12	0.009	14.32	<0.001	4.48	0.036	2.21	0.139
Total body length (cm)	2.23	0.069	2.31	0.131	3.14	0.078	2.55	0.112	0.58	0.448
Wing cord (cm)	8.63	<0.001	2.41	0.123	11.61	<0.001	0.67	0.416	1.79	0.183
Culmen (cm)	0.28	0.890	0.46	0.497	0.30	0.583	0.50	0.482	0.12	0.727
Total bill length (cm)	0.18	0.948	0.11	0.745	0.12	0.733	0.06	0.808	0.60	0.439
Tarsus length (cm)	1.15	0.334	1.51	0.221	0.02	0.883	0.88	0.350	2.14	0.145
Bill width (cm)	0.62	0.647	0.17	0.681	2.09	0.150	0.08	0.776	1.07	0.302
Keel length (cm)	3.46	0.010	10.55	0.002	1.36	0.246	1.71	0.194	0.87	0.354
Esophagus-proventriculus length (cm)	3.74	0.007	3.35	0.070	2.56	0.113	0.95	0.331	1.57	0.213

Table 6.3. Continued Type III *F* and *P* values from analysis of variance of morphological features of scientifically collected blue-winged teal (*Anas discors*) (*n* = 155) collected on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Intestine length (cm)	0.80	0.525	0.86	0.355	0.00	0.992	0.90	0.346	1.97	0.163
Gizzard mass (g)	0.58	0.677	0.34	0.559	0.63	0.430	0.20	0.654	1.94	0.166
Heart mass (g)	1.49	0.210	2.85	0.094	1.66	0.201	0.28	0.598	0.33	0.568
Liver mass (g)	3.21	0.015	0.16	0.688	0.80	0.372	1.23	0.270	7.73	0.006
Esophagus-proventriculus mass (g)	2.75	0.030	2.98	0.087	6.17	0.015	1.20	0.275	3.34	0.070
Flight muscle mass (g)	8.70	<0.001	7.36	0.008	5.31	0.023	3.99	0.048	9.89	0.002
Leg muscle mass (g)	6.72	<0.001	1.40	0.240	5.97	0.016	0.60	0.441	3.50	0.064
Kidney mass (g)	4.00	0.006	2.12	0.150	1.00	0.322	0.01	0.941	10.64	0.002
Intestine mass (g)	4.30	0.002	2.51	0.116	1.85	0.176	0.72	0.397	6.25	0.014
Omental fat mass (g)	10.91	<0.001	5.79	0.018	0.02	0.891	4.87	0.029	18.29	<0.001
Mesentery fat mass (g)	10.06	<0.001	1.33	0.251	0.00	0.982	5.72	0.019	15.76	<0.001
Visceral fat mass (g)	0.68	0.610	1.14	0.288	0.23	0.636	0.38	0.539	1.07	0.303
Skin mass (g)	9.49	<0.001	6.40	0.013	3.39	0.068	12.53	<0.001	13.52	<0.001

Table 6.4 Mean ($\bar{x}$) and standard error (SE) of morphological features of adult female blue-winged teal (*Anas discors*) scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	31	368.20	6.02	300.88	431.88
Plucked body mass (g)	31	335.73	5.74	271.84	391.05
Ingesta mass (g)	31	2.60	0.33	0.00	5.84
Corrected body mass (g)	31	333.12	33.70	271.84	391.05
Total body length (cm)	31	35.29	0.58	30.00	40.00
Wing cord (cm)	31	18.16	0.15	15.20	19.40
Culmen (cm)	31	40.38	0.68	38.70	56.00
Total bill length (cm)	31	45.35	0.68	38.70	56.00
Tarsus (cm)	31	35.82	0.26	26.50	52.10
Bill width (cm)	31	16.56	0.26	12.00	18.70
Keel length (cm)	25	7.59	0.11	6.60	8.50
Esophagus-proventriculus length (cm)	25	16.69	0.64	9.50	20.50
Intestine length (cm)	25	165.17	3.56	114.60	194.30
Gizzard mass (g)	25	15.43	0.58	9.46	20.04
Heart mass (g)	25	3.83	0.08	3.10	4.48
Liver mass (g)	25	9.10	0.37	5.48	12.86
Esophagus-proventriculus mass (g)	25	3.28	0.28	0.95	5.84
Flight muscle mass (g)	25	33.26	0.83	25.29	41.53
Leg muscle mass (g)	25	9.67	0.34	5.68	13.28
Kidney mass (g)	13	3.19	0.29	1.12	4.68
Intestine mass (g)	25	17.19	1.14	6.46	27.16
Omental fat mass (g)	25	5.77	0.89	0.38	15.26
Mesentery fat mass (g)	25	2.76	0.41	0.00	8.56
Visceral fat mass (g)	25	0.15	0.03	0.00	0.51
Skin mass (g)	25	52.85	3.60	23.62	92.20

Table 6.5. Mean ($\bar{x}$) and standard error (SE) of morphological features of adult male blue-winged teal (*Anas discors*) scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	66	373.88	4.76	288.02	578.16
Plucked body mass (g)	66	340.59	4.00	269.86	477.41
Ingesta mass (g)	66	338.23	3.93	266.14	467.47
Corrected body mass (g)	66	2.36	0.27	0.00	9.94
Total body length (cm)	66	36.00	0.50	29.40	43.00
Wing cord (cm)	66	19.07	0.12	17.40	25.50
Culmen (cm)	65	39.39	0.69	4.90	45.00
Total bill length (cm)	65	45.37	0.71	21.00	54.30
Tarsus (cm)	66	36.21	0.56	20.00	46.00
Bill width (cm)	65	16.93	0.13	13.70	20.00
Keel length (cm)	48	7.66	0.06	6.70	9.30
Esophagus-proventriculus length (cm)	47	18.95	0.47	9.00	23.10
Intestine length (cm)	48	164.27	3.61	105.00	250.00
Gizzard mass (g)	48	15.30	0.47	10.59	22.73
Heart mass (g)	48	4.01	0.13	2.85	6.60
Liver mass (g)	48	7.99	0.31	4.28	11.97
Esophagus-proventriculus mass (g)	47	3.88	0.20	1.06	7.74
Flight muscle mass (g)	48	36.63	0.75	26.25	54.47
Leg muscle mass (g)	48	11.56	0.30	6.36	15.75
Kidney mass (g)	35	3.01	0.18	1.02	5.86
Intestine mass (g)	48	14.60	0.58	6.66	25.59
Omental fat mass (g)	48	2.35	0.31	0.00	8.92
Mesentery fat mass (g)	48	1.12	0.10	0.00	2.88
Visceral fat mass (g)	48	0.13	0.02	0.00	0.47
Skin mass (g)	48	40.65	1.65	25.10	69.37

Table 6.6. Mean ($\bar{x}$) and standard error (SE) of morphological features of juvenile female blue-winged teal (*Anas discors*) scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	20	332.75	7.06	279.72	415.06
Plucked body mass (g)	20	304.95	5.98	259.85	376.77
Ingesta mass (g)	20	302.84	5.99	259.85	376.77
Corrected body mass (g)	20	2.11	0.45	0.00	6.29
Total body length (cm)	20	33.24	0.92	27.90	40.60
Wing cord (cm)	20	18.12	0.16	17.00	19.80
Culmen (cm)	20	39.15	0.56	35.00	44.50
Total bill length (cm)	20	45.04	0.87	39.00	55.00
Tarsus (cm)	20	34.25	0.79	29.00	39.00
Bill width (cm)	20	16.43	0.20	14.00	18.00
Keel length (cm)	14	7.21	0.09	6.60	7.80
Esophagus-proventriculus length (cm)	13	18.58	0.38	16.40	20.70
Intestine length (cm)	13	172.42	6.55	127.10	208.20
Gizzard mass (g)	12	15.07	0.71	10.73	19.43
Heart mass (g)	13	3.54	0.14	2.67	4.18
Liver mass (g)	13	8.00	0.53	5.12	10.87
Esophagus-proventriculus mass (g)	13	3.84	0.15	2.70	4.76
Flight muscle mass (g)	14	29.09	2.29	3.01	39.23
Leg muscle mass (g)	14	9.71	0.36	7.81	12.21
Kidney mass (g)	7	3.47	0.34	2.19	4.26
Intestine mass (g)	13	18.80	1.46	11.67	30.17
Omental fat mass (g)	13	2.14	0.75	0.25	9.92
Mesentery fat mass (g)	13	1.38	0.31	0.16	4.15
Visceral fat mass (g)	13	0.11	0.01	0.05	0.17
Skin mass (g)	14	33.92	2.63	19.71	55.44

Table 6.7. Mean ($\bar{x}$) and standard error (SE) of morphological features of juvenile male blue-winged teal (*Anas discors*) scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	38	370.89	6.73	275.25	482.34
Plucked body mass (g)	38	340.83	6.21	252.03	459.40
Ingesta mass (g)	38	338.10	6.13	250.09	449.87
Corrected body mass (g)	38	2.73	0.40	0.00	10.16
Total body length (cm)	38	35.94	0.67	29.60	42.30
Wing cord (cm)	38	18.64	0.13	17.00	20.40
Culmen (cm)	38	39.34	1.12	4.50	55.00
Total bill length (cm)	38	45.11	0.74	25.70	55.00
Tarsus (cm)	38	35.61	1.00	15.20	51.00
Bill width (cm)	38	16.80	0.55	7.25	32.40
Keel length (cm)	30	7.47	0.08	6.50	8.30
Esophagus-proventriculus length (cm)	30	19.22	0.42	11.00	22.50
Intestine length (cm)	30	165.92	4.71	110.60	205.90
Gizzard mass (g)	30	14.97	0.53	7.43	19.30
Heart mass (g)	30	3.84	0.09	2.82	5.04
Liver mass (g)	30	8.69	0.53	4.05	17.47
Esophagus-proventriculus mass (g)	30	4.15	0.17	1.65	5.33
Flight muscle mass (g)	30	35.01	0.87	23.23	43.13
Leg muscle mass (g)	30	10.64	0.30	7.19	13.88
Kidney mass (g)	21	3.57	0.18	2.09	5.03
Intestine mass (g)	30	15.94	0.83	9.53	26.58
Omental fat mass (g)	30	3.01	0.61	0.07	13.93
Mesentery fat mass (g)	30	1.82	0.33	0.00	7.32
Visceral fat mass (g)	30	0.13	0.02	0.00	0.36
Skin mass (g)	30	46.41	2.60	20.47	83.09

Table 6.8. Type III *F* and *P* values from analysis of variance of morphological features of hunter harvested green-winged teal (*Anas crecca) (n* = 461*)* collected at hunter check stations on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Total body mass (g)	13.56	<0.001	7.72	0.006	16.99	<0.001	0.57	0.449	8.34	0.004
Total body length (cm)	26.39	<0.001	7.62	0.006	45.12	<0.001	3.51	0.062	8.92	0.003
Wing cord (cm)	2.63	0.034	0.02	0.889	6.34	0.012	0.22	0.641	4.75	0.030
Tarsus (cm)	1.21	0.307	0.32	0.574	0.41	0.525	0.02	0.888	3.11	0.079

Table 6.9 Means ($\overline{x}$) and standard error (SE) of morphological features collected from hunter harvested green-winged teal (*Anas crecca)* collection at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\overline{x}$	SE	Minimum	Maximum
Adult Female					
Total body mass (g)	92	289.69	6.16	182.00	475.00
Total body length (cm)	92	34.57	0.38	13.30	40.50
Wing cord (cm)	92	18.13	0.19	16.10	28.20
Tarsus (mm)	92	31.53	0.55	11.00	20.45
Adult Male					
Total body mass (g)	209	320.55	3.91	186.50	417.00
Total body length (cm)	209	37.22	0.11	29.00	44.20
Wing cord (cm)	209	18.49	0.06	15.30	21.50
Tarsus (mm)	209	31.94	0.44	18.00	42.30
Juvenile Female					
Total body mass (g)	100	275.65	6.33	168.00	625.00
Total body length (cm)	100	34.21	0.27	20.00	38.90
Wing cord (cm)	100	18.06	0.31	14.90	28.10
Tarsus (mm)	100	30.97	0.61	15.90	40.00
Juvenile Male					
Total body mass (g)	60	298.51	7.54	186.00	400.00
Total body length (cm)	60	35.79	0.63	14.20	48.50
Wing cord (cm)	60	18.58	0.24	13.90	27.30
Tarsus (mm)	60	31.62	0.84	11.50	47.00

Table 6.10. Type III *F* and *P* values from analysis of variance of morphological features of scientifically collected green-winged teal (*Anas crecca)* (*n* = 120) collected on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Total body mass (g)	7.17	<0.001	4.89	0.029	18.92	<0.001	0.02	0.882	0.17	0.679
Plucked body mass (g)	4.60	0.002	1.41	0.238	8.54	0.004	2.06	0.154	0.05	0.818
Ingesta mass (g)	2.26	0.067	0.02	0.901	0.00	0.953	1.24	0.268	7.18	0.009
Corrected body mass (g)	4.64	0.002	1.41	0.238	8.36	0.005	2.30	0.132	0.21	0.651
Total body length (cm)	8.05	<0.001	4.96	0.028	0.41	0.525	0.33	0.568	21.07	<0.001
Wing cord (cm)	6.32	0.001	2.98	0.087	19.20	<0.001	0.20	0.657	0.00	0.948
Culmen (cm)	4.03	0.004	1.56	0.214	13.05	0.001	1.93	0.167	0.29	0.590
Total bill length (cm)	2.01	0.097	0.15	0.704	3.46	0.066	0.33	0.567	4.29	0.041
Tarsus length (cm)	1.03	0.393	0.07	0.786	0.33	0.569	0.98	0.324	1.23	0.270
Bill width (cm)	2.35	0.059	1.78	0.185	1.98	0.162	2.51	0.116	4.36	0.039
Keel length (cm)	0.69	0.599	0.13	0.715	0.53	0.466	0.54	0.466	0.19	0.662
Esophagus-proventriculus length (cm)	2.38	0.057	0.16	0.692	8.64	0.004	0.02	0.887	0.00	0.980

Table 6.10 Continued. Type III *F* and *P* values from analysis of variance of morphological features of scientifically collected green-winged teal (*Anas crecca)* (*n* = 120) collected on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Intestine length (cm)	1.64	0.171	0.46	0.500	0.64	0.427	0.36	0.547	2.48	0.119
Gizzard mass (g)	3.65	0.008	0.52	0.474	10.02	0.002	0.45	0.502	0.01	0.903
Heart mass (g)	0.69	0.598	0.31	0.579	0.71	0.402	0.60	0.440	0.13	0.717
Liver mass (g)	0.82	0.516	0.08	0.776	1.82	0.180	1.28	0.260	0.15	0.699
Esophagus-proventriculus mass (g)	4.37	0.003	0.12	0.731	16.32	0.000	0.64	0.424	1.49	0.226
Flight muscle mass (g)	2.81	0.030	4.18	0.044	2.33	0.130	0.01	0.939	1.42	0.236
Leg muscle mass (g)	0.71	0.589	0.39	0.533	0.34	0.560	0.05	0.832	1.02	0.314
Kidney mass (g)	0.50	0.738	0.01	0.926	0.01	0.926	0.36	0.551	0.88	0.350
Intestine mass (g)	3.02	0.022	0.01	0.911	0.03	0.855	1.89	0.173	10.32	0.002
Omental fat mass (g)	1.38	0.245	4.15	0.044	0.30	0.588	0.18	0.669	0.07	0.798
Mesentery fat mass (g)	0.55	0.697	0.66	0.418	0.67	0.415	0.04	0.845	0.14	0.711
Visceral fat mass (g)	0.87	0.484	0.36	0.552	0.05	0.822	0.26	0.613	2.15	0.146
Skin mass (g)	0.27	0.894	0.37	0.545	0.18	0.673	0.07	0.790	0.43	0.512

Table 6.11 Mean ($\bar{x}$) and standard error (SE) of morphological features of adult female green-winged teal (*Anas crecca)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	15	321.16	10.20	254.83	395.00
Plucked body mass (g)	15	285.04	7.31	236.03	330.45
Ingesta mass (g)	15	282.08	6.96	236.03	328.53
Corrected body mass (g)	15	2.96	0.70	0.00	9.36
Total body length (cm)	15	33.59	0.80	27.90	36.80
Wing cord (cm)	15	17.82	0.18	16.70	18.95
Culmen (cm)	15	33.60	1.48	14.50	39.90
Total bill length (cm)	15	39.45	0.44	36.50	42.30
Tarsus (cm)	15	34.85	0.77	28.40	38.00
Bill width (cm)	14	13.42	0.22	12.30	14.80
Keel length (cm)	12	6.88	0.19	6.30	8.40
Esophagus-proventriculus length (cm)	10	15.59	0.94	10.80	18.40
Intestine length (cm)	12	102.85	3.20	83.00	114.00
Gizzard mass (g)	12	13.18	0.50	11.06	16.31
Heart mass (g)	12	3.47	0.10	2.86	3.98
Liver mass (g)	12	6.30	0.32	3.61	8.00
Esophagus-proventriculus mass (g)	10	2.21	0.18	0.69	2.85
Flight muscle mass (g)	12	31.89	0.62	28.48	35.99
Leg muscle mass (g)	12	9.38	0.25	7.17	10.47
Kidney mass (g)	7	2.40	0.21	1.51	3.18
Intestine mass (g)	12	10.41	1.17	6.11	21.34
Omental fat mass (g)	12	1.94	0.46	0.17	5.74
Mesentery fat mass (g)	12	1.08	0.23	0.00	2.94
Visceral fat mass (g)	12	0.11	0.03	0.00	0.37
Skin mass (g)	12	41.69	3.12	17.45	59.00

Table 6.12. Mean ($\bar{x}$) and standard error (SE) of morphological features of adult male green-winged teal (*Anas crecca)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	60	347.95	3.83	295.45	414.73
Plucked body mass (g)	60	310.72	3.75	250.17	398.50
Ingesta mass (g)	60	307.86	3.81	250.17	398.50
Corrected body mass (g)	60	2.86	0.30	0.00	12.52
Total body length (cm)	60	33.42	0.50	26.30	46.00
Wing cord (cm)	60	18.60	0.14	16.50	25.80
Culmen (cm)	60	36.37	0.22	31.00	40.60
Total bill length (cm)	60	41.17	0.72	23.50	72.70
Tarsus (cm)	60	33.28	0.46	27.00	41.00
Bill width (cm)	60	13.78	0.11	12.00	15.40
Keel length (cm)	50	7.31	0.20	6.40	16.80
Esophagus-proventriculus length (cm)	50	17.44	0.36	9.60	22.10
Intestine length (cm)	50	110.07	2.09	78.50	166.40
Gizzard mass (g)	51	15.78	0.45	2.70	21.08
Heart mass (g)	51	3.67	0.08	2.74	5.03
Liver mass (g)	51	6.17	0.16	4.21	9.10
Esophagus-proventriculus mass (g)	50	3.11	0.13	0.86	5.52
Flight muscle mass (g)	51	33.87	0.44	26.60	38.72
Leg muscle mass (g)	51	12.39	1.92	7.74	107.74
Kidney mass (g)	36	2.15	0.11	0.87	3.29
Intestine mass (g)	51	10.53	0.47	5.76	20.61
Omental fat mass (g)	51	1.94	0.27	0.10	8.85
Mesentery fat mass (g)	51	1.45	0.32	0.00	16.38
Visceral fat mass (g)	51	0.15	0.02	0.00	0.57
Skin mass (g)	51	43.02	1.85	20.23	77.95

Table 6.13. Mean ($\bar{x}$) and standard error (SE) of morphological features of juvenile female green-winged teal (*Anas crecca)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	14	305.10	7.10	264.39	348.00
Plucked body mass (g)	14	286.15	7.17	260.09	348.00
Ingesta mass (g)	14	283.34	7.43	257.47	348.00
Corrected body mass (g)	14	2.81	0.61	0.00	6.67
Total body length (cm)	14	31.50	1.19	25.20	39.00
Wing cord (cm)	14	17.39	0.20	16.00	18.40
Culmen (cm)	14	35.02	0.54	30.00	38.00
Total bill length (cm)	14	39.12	0.58	35.20	42.00
Tarsus (cm)	14	34.04	1.24	26.00	43.00
Bill width (cm)	14	14.99	1.55	12.60	35.00
Keel length (cm)	10	7.02	0.15	6.30	7.90
Esophagus-proventriculus length (cm)	10	15.23	0.66	12.00	18.00
Intestine length (cm)	10	104.58	3.67	84.00	121.80
Gizzard mass (g)	10	13.18	0.70	9.47	17.06
Heart mass (g)	10	3.39	0.22	2.60	4.92
Liver mass (g)	10	6.72	0.55	4.16	9.83
Esophagus-proventriculus mass (g)	10	2.36	0.15	1.60	3.20
Flight muscle mass (g)	10	30.21	0.81	25.96	34.67
Leg muscle mass (g)	10	9.28	0.37	7.50	10.80
Kidney mass (g)	8	2.20	0.32	0.98	3.43
Intestine mass (g)	10	10.65	1.13	5.24	16.33
Omental fat mass (g)	10	0.92	0.24	0.16	2.36
Mesentery fat mass (g)	10	0.75	0.27	0.08	2.90
Visceral fat mass (g)	10	0.16	0.03	0.00	0.34
Skin mass (g)	10	39.78	2.60	27.41	51.35

Table 6.14. Mean ($\bar{x}$) and standard error (SE) of morphological features of juvenile male green-winged teal (*Anas crecca)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	31	334.44	4.57	295.29	383.54
Plucked body mass (g)	31	295.10	4.04	253.61	339.96
Ingesta mass (g)	31	291.58	4.09	252.55	338.48
Corrected body mass (g)	31	3.52	0.42	0.00	10.92
Total body length (cm)	31	31.25	0.55	26.00	37.70
Wing cord (cm)	31	18.35	0.10	17.10	19.80
Culmen (cm)	31	36.28	0.32	31.00	39.30
Total bill length (cm)	31	40.20	0.61	31.00	46.20
Tarsus (cm)	31	34.29	0.72	25.00	40.60
Bill width (cm)	31	13.69	0.16	12.00	15.30
Keel length (cm)	30	7.03	0.07	6.30	7.70
Esophagus-proventriculus length (cm)	30	17.27	0.48	7.30	20.60
Intestine length (cm)	29	105.49	2.68	66.70	126.90
Gizzard mass (g)	30	14.85	0.36	9.74	20.47
Heart mass (g)	30	4.82	1.16	2.80	38.42
Liver mass (g)	30	5.90	0.27	3.14	9.23
Esophagus-proventriculus mass (g)	30	3.03	0.14	1.58	4.58
Flight muscle mass (g)	30	31.88	1.08	3.54	38.28
Leg muscle mass (g)	30	10.31	0.27	6.36	14.22
Kidney mass (g)	26	2.30	0.16	0.38	3.96
Intestine mass (g)	29	9.67	0.36	6.40	13.18
Omental fat mass (g)	30	1.30	0.19	0.19	4.60
Mesentery fat mass (g)	30	1.02	0.16	0.00	3.03
Visceral fat mass (g)	30	0.15	0.02	0.00	0.42
Skin mass (g)	30	41.96	2.10	19.56	58.40

Table 6.15. Type III *F* and *P* values from analysis of variance of morphological features of hunter harvested Northern shoveler (*Ana sclypeata*) (*n* = 127) collected at hunter check stations on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Total body mass (g)	9.45	<0.001	10.03	0.002	5.60	0.020	4.60	0.034	2.18	0.143
Total body length (cm)	6.19	<0.001	1.90	0.170	6.65	0.011	0.38	0.539	3.66	0.058
Wing cord (cm)	4.92	0.001	1.22	0.272	6.54	0.012	0.92	0.338	0.92	0.340
Tarsus (cm)	8.68	<0.001	0.18	0.673	2.45	0.120	0.23	0.631	23.62	<0.001

Table 6.16. Means ($\bar{x}$) and standard error (SE) of morphological features collected from hunter harvested Northern shoveler (*Anas clypeata)* collection at hunter check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Adult Female					
Total body mass (g)	37	555.57	10.36	416.00	700.00
Total body length (cm)	37	45.78	0.47	37.60	50.00
Wing cord (cm)	37	23.14	0.28	18.70	27.50
Tarsus (mm)	37	38.33	1.21	21.10	49.60
Adult Male					
Total body mass (g)	46	565.02	11.79	348.00	700.00
Total body length (cm)	46	48.06	0.46	29.50	51.00
Wing cord (cm)	46	24.45	0.10	22.40	25.60
Tarsus (mm)	46	42.62	1.06	20.00	51.00
Juvenile Female					
Total body mass (g)	34	467.26	16.11	285.00	625.00
Total body length (cm)	34	45.25	0.43	37.50	51.30
Wing cord (cm)	34	23.08	0.41	19.20	34.20
Tarsus (mm)	34	39.34	1.15	19.20	48.60
Juvenile Male					
Total body mass (g)	10	550.80	18.09	454.00	611.00
Total body length (cm)	10	46.93	1.38	35.00	50.00
Wing cord (cm)	10	23.77	0.45	20.10	25.20
Tarsus (mm)	10	43.24	3.06	21.30	49.40

Table 6.17. Type III *F* and *P* values from analysis of variance of morphological features of scientifically collected Northern shoveler (*Anas clypeata)* (*n* = 125) collected on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Total body mass (g)	10.76	<0.001	10.52	0.002	10.55	0.002	7.22	0.008	5.47	0.021
Plucked body mass (g)	4.53	0.002	5.00	0.027	4.06	0.046	1.87	0.174	7.47	0.007
Ingesta mass (g)	2.07	0.089	0.34	0.558	0.89	0.349	3.34	0.070	0.87	0.354
Corrected body mass (g)	10.50	<0.001	12.69	0.001	9.26	0.003	4.78	0.031	13.67	<0.001
Total body length (cm)	1.01	0.407	0.63	0.430	2.19	0.142	0.07	0.797	2.42	0.123
Wing cord (cm)	10.38	<0.001	7.37	0.008	12.06	0.001	0.33	0.564	1.27	0.261
Culmen (cm)	3.36	0.012	0.04	0.847	10.34	0.002	0.03	0.873	0.10	0.751
Total bill length (cm)	3.25	0.014	0.02	0.882	6.01	0.015	2.39	0.125	0.18	0.670
Tarsus length (cm)	1.78	0.138	4.60	0.034	0.54	0.462	0.05	0.822	1.96	0.164
Bill width (cm)	0.56	0.691	0.01	0.914	1.21	0.273	0.02	0.895	0.15	0.695
Keel length (cm)	0.48	0.747	0.00	0.967	0.00	0.991	1.09	0.300	0.36	0.551
Esophagus-proventriculus length (cm)	0.86	0.494	0.05	0.823	2.32	0.131	0.31	0.580	0.05	0.820

Table 6.17. Continued. Type III *F* and *P* values from analysis of variance of morphological features of scientifically collected Northern shoveler (*Anas clypeata)* (*n* = 125) collected on Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Age		Sex		Age*Sex		Period	
Morphological feature	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Intestine length (cm)	0.39	0.813	0.29	0.592	0.62	0.432	0.83	0.366	0.03	0.854
Gizzard mass (g)	0.20	0.940	0.38	0.541	0.11	0.739	0.03	0.854	0.04	0.833
Heart mass (g)	1.92	0.115	0.48	0.489	2.67	0.106	0.51	0.476	5.48	0.022
Liver mass (g)	1.65	0.170	1.58	0.213	1.00	0.322	1.14	0.289	2.85	0.095
Esophagus-proventriculus mass (g)	2.82	0.030	2.94	0.090	2.84	0.096	0.08	0.387	5.00	0.028
Flight muscle mass (g)	2.16	0.081	0.01	0.943	3.43	0.068	2.94	0.090	0.48	0.490
Leg muscle mass (g)	3.36	0.014	0.23	0.633	2.05	0.156	5.45	0.022	0.06	0.807
Kidney mass (g)	3.00	0.025	5.80	0.019	0.09	0.763	0.21	0.648	0.42	0.522
Intestine mass (g)	6.91	<0.001	12.74	0.001	0.23	0.634	1.17	0.283	14.70	<0.001
Omental fat mass (g)	2.54	0.046	0.19	0.661	3.41	0.068	0.92	0.339	8.33	0.005
Mesentery fat mass (g)	1.67	0.165	2.26	0.137	0.61	0.436	0.57	0.452	3.17	0.079
Visceral fat mass (g)	0.17	0.951	0.01	0.909	0.22	0.639	0.07	0.790	0.03	0.858
Skin mass (g)	3.70	0.008	3.07	0.084	0.37	0.544	3.92	0.051	8.06	0.006

Table 6.18. Mean ($\bar{x}$) and standard error (SE) of morphological features of adult female Northern shoveler (*Anas clypeata)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	24	530.88	14.39	427.87	712.23
Plucked body mass (g)	24	486.90	13.69	384.83	655.67
Ingesta mass (g)	24	484.42	13.41	384.83	646.50
Corrected body mass (g)	24	2.48	0.65	0.00	9.58
Total body length (cm)	24	43.00	0.83	36.80	49.50
Wing cord (cm)	24	23.47	0.32	21.20	29.20
Culmen (cm)	24	60.45	0.99	50.10	69.90
Total bill length (cm)	24	66.40	1.89	27.30	76.10
Tarsus (cm)	24	42.13	0.67	34.00	46.20
Bill width (cm)	24	29.91	0.32	27.60	34.00
Keel length (cm)	13	8.53	0.16	7.50	9.50
Esophagus-proventriculus length (cm)	13	20.79	0.83	14.00	25.90
Intestine length (cm)	13	270.12	8.69	214.30	321.50
Gizzard mass (g)	13	15.01	1.07	10.22	23.71
Heart mass (g)	13	5.15	0.18	3.91	6.27
Liver mass (g)	13	12.10	0.96	7.07	18.66
Esophagus-proventriculus mass (g)	13	5.00	0.52	2.46	8.59
Flight muscle mass (g)	13	46.33	1.68	37.62	58.61
Leg muscle mass (g)	13	13.86	0.59	10.84	17.48
Kidney mass (g)	4	6.24	0.64	4.46	7.38
Intestine mass (g)	13	33.69	3.65	14.62	63.66
Omental fat mass (g)	13	5.77	1.85	0.18	21.33
Mesentery fat mass (g)	13	3.43	1.01	0.12	12.56
Visceral fat mass (g)	13	0.20	0.04	0.00	0.40
Skin mass (g)	13	65.18	8.90	29.39	128.00

Table 6.19. Mean ($\bar{x}$) and standard error (SE) of morphological features of adult male Northern shoveler (*Anas clypeata)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	61	588.15	6.73	464.86	689.21
Plucked body mass (g)	61	520.22	11.05	0.00	681.73
Ingesta mass (g)	61	523.95	6.90	401.75	681.73
Corrected body mass (g)	61	5.17	0.57	0.00	17.52
Total body length (cm)	61	43.66	0.63	30.00	53.00
Wing cord (cm)	61	24.55	0.12	22.30	29.00
Culmen (cm)	61	64.88	0.88	24.50	80.00
Total bill length (cm)	61	72.42	0.67	64.20	87.00
Tarsus (cm)	61	40.33	1.10	4.60	84.00
Bill width (cm)	61	31.07	0.75	3.20	41.00
Keel length (cm)	47	9.57	0.56	7.30	35.00
Esophagus-proventriculus length (cm)	47	22.87	0.66	4.46	28.50
Intestine length (cm)	45	267.71	11.95	16.10	625.00
Gizzard mass (g)	47	18.49	5.96	2.40	292.00
Heart mass (g)	47	7.06	1.07	3.88	55.40
Liver mass (g)	46	13.17	0.46	4.53	20.26
Esophagus-proventriculus mass (g)	47	5.64	0.21	2.43	8.90
Flight muscle mass (g)	47	53.57	1.44	1.80	65.36
Leg muscle mass (g)	47	17.62	0.66	11.00	42.35
Kidney mass (g)	38	6.38	0.24	3.04	10.72
Intestine mass (g)	46	27.43	1.15	15.67	46.98
Omental fat mass (g)	46	5.31	0.49	0.77	13.28
Mesentery fat mass (g)	46	2.92	0.29	0.29	7.55
Visceral fat mass (g)	46	0.26	0.05	0.00	2.49
Skin mass (g)	47	72.27	3.00	38.93	119.68

Table 6.20. Mean ($\bar{x}$) and standard error (SE) of morphological features of juvenile female Northern shoveler (*Anas clypeata)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	22	527.85	9.23	432.84	608.12
Plucked body mass (g)	22	479.43	8.13	418.92	555.64
Ingesta mass (g)	22	475.06	8.17	415.97	555.64
Corrected body mass (g)	22	4.37	0.88	0.00	12.50
Total body length (cm)	22	42.19	1.12	35.70	56.90
Wing cord (cm)	22	22.96	0.21	21.30	25.00
Culmen (cm)	22	60.95	1.12	44.00	71.00
Total bill length (cm)	22	68.55	1.17	58.00	81.00
Tarsus (cm)	22	39.49	0.87	33.40	46.50
Bill width (cm)	22	29.85	0.51	26.60	36.00
Keel length (cm)	14	9.36	0.72	7.90	18.60
Esophagus-proventriculus length (cm)	14	21.58	0.74	14.00	24.50
Intestine length (cm)	14	246.85	9.25	177.30	305.00
Gizzard mass (g)	14	11.72	0.47	8.99	14.72
Heart mass (g)	14	5.27	0.36	4.04	8.16
Liver mass (g)	14	12.00	0.62	7.24	16.24
Esophagus-proventriculus mass (g)	14	4.70	0.43	2.45	7.19
Flight muscle mass (g)	14	50.21	1.39	40.30	61.49
Leg muscle mass (g)	14	15.61	0.48	12.74	18.10
Kidney mass (g)	12	5.16	0.46	1.06	6.75
Intestine mass (g)	14	25.07	1.50	18.01	32.82
Omental fat mass (g)	14	3.62	0.93	0.50	14.28
Mesentery fat mass (g)	14	3.03	0.69	0.38	8.61
Visceral fat mass (g)	14	0.21	0.03	0.00	0.45
Skin mass (g)	14	66.81	4.64	40.23	95.45

Table 6.21. Mean ($\bar{x}$) and standard error (SE) of morphological features of juvenile male Northern shoveler (*Anas clypeata)* scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Variable	*n*	$\bar{x}$	SE	Minimum	Maximum
Total body mass (g)	18	525.12	13.60	395.57	620.00
Plucked body mass (g)	18	472.74	11.17	373.53	555.98
Ingesta mass (g)	18	468.64	10.86	370.82	545.70
Corrected body mass (g)	18	4.09	0.97	0.00	10.65
Total body length (cm)	18	43.26	1.07	35.80	50.40
Wing cord (cm)	18	23.80	0.27	21.00	25.50
Culmen (cm)	18	64.96	1.49	52.00	83.00
Total bill length (cm)	18	69.96	2.81	27.10	87.00
Tarsus (cm)	18	36.89	2.49	4.60	47.00
Bill width (cm)	17	31.26	0.96	19.80	38.00
Keel length (cm)	12	8.70	0.30	5.90	10.50
Esophagus-proventriculus length (cm)	12	22.58	0.92	14.50	26.50
Intestine length (cm)	12	274.18	9.51	198.40	329.00
Gizzard mass (g)	12	12.55	0.61	10.14	15.89
Heart mass (g)	12	5.70	0.22	4.17	6.97
Liver mass (g)	12	11.60	1.01	5.85	15.85
Esophagus-proventriculus mass (g)	12	4.80	0.42	1.98	6.80
Flight muscle mass (g)	12	50.31	2.11	39.43	61.76
Leg muscle mass (g)	12	14.91	0.96	8.80	20.64
Kidney mass (g)	10	4.84	0.50	1.98	7.03
Intestine mass (g)	12	23.95	1.10	18.78	31.32
Omental fat mass (g)	12	6.99	4.37	0.66	54.80
Mesentery fat mass (g)	12	1.80	0.30	0.11	3.66
Visceral fat mass (g)	12	0.23	0.06	0.00	0.69
Skin mass (g)	12	55.37	4.32	37.88	76.80

Table 6.22. Mean ($\bar{x}$) and standard error body condition indices of blue-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	262	16.33	0.24	7.42	26.32
BCI2	262	5.86	0.07	3.51	8.61
			Scientifically		
BCI1	155	19.65	0.15	14.70	25.66
BCI2	155	6.80	0.07	4.91	10.31
BCI3	116	7.11	0.12	5.30	13.78

Table 6.23. Mean ($\bar{x}$) and standard error body condition indices of adult male blue-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	66	17.11	0.49	10.43	24.73
BCI2	66	6.04	0.15	3.98	8.55
			Scientifically		
BCI1	66	19.59	0.19	15.58	23.22
BCI2	66	6.83	0.11	5.04	10.31
BCI3	47	7.24	0.22	5.46	13.78

Table 6.24. Mean ($\bar{x}$) and standard error body condition indices of adult female blue-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	53	16.01	0.55	7.42	22.88
BCI2	53	5.75	0.17	3.65	7.40
			Scientifically		
BCI1	31	20.28	0.31	17.17	23.48
BCI2	31	6.91	0.14	5.53	8.23
BCI3	25	7.11	0.17	5.30	8.65

Table 6.25. Mean ($\bar{x}$) and standard error body condition indices of juvenile female blue-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	75	15.81	0.40	8.30	26.32
BCI2	75	5.73	0.12	3.51	8.23
			Scientifically		
BCI1	20	18.40	0.42	14.70	22.44
BCI2	20	6.51	0.15	5.55	7.67
BCI3	14	6.47	0.21	5.36	8.05

Table 6.26. Mean ($\bar{x}$) and standard error body condition indices of juvenile male blue-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	68	16.39	0.48	10.24	25.51
BCI2	68	5.90	0.15	3.85	8.61
			Scientifically		
BCI1	38	19.91	0.37	14.80	25.66
BCI2	38	6.83	0.15	4.91	9.65
BCI3	30	7.22	0.22	5.43	11.63

Table 6.27. Type III F and P values from multivariate analysis of variance of body condition indices of hunter harvested blue-winged teal (*Anas discors*) (*n* = 262), green-winged teal (*Anas crecca*) (*n* = 461), and Northern shoveler (*Anas clypeata*) (*n* = 127), collected at hunter check stations at Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

			Source of variability					
	Overall model		Age		Sex		Age*Sex	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
BWTE								
BCI 1	1.51	0.2129	0.92	0.3373	3.12	0.0783	0.3	0.5865
BCI 2	1.04	0.3735	0.3	0.5824	2.58	0.1098	0.19	0.6668
GWTE								
BCI 1	8.05	<0.001	7.08	0.0081	7.68	0.0058	0.5	0.4795
BCI 2	4.6	0.0035	4.47	0.035	4.66	0.0314	0	0.9455
NOSH								
BCI 1	7.41	0.0001	6.28	0.0135	1.5	0.2226	6.75	0.0105
BCI 2	7.78	0.0001	6.67	0.011	1.95	0.1652	6.64	0.0112

Table 6.28. Type III F and P values from multivariate analysis of variance of body condition indices of scientifically collected blue-winged teal (*Anas discors*) (n = 155), green-winged teal (*Anas crecca*) (n = 120), and Northern shoveler (*Anas clypeata*) (n = 125), collected at Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Source of variability: Age		Sex		Age*Sex	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
BWTE								
BCI 1	4.6	0.0041	5.88	0.0165	1.66	0.2002	11.61	0.0008
BCI 2	1.06	0.3662	1.93	0.1668	0.64	0.4256	1.97	0.1626
BCI 3	1.48	0.2232	1.65	0.2013	3.04	0.0841	1.51	0.2215
GWTE								
BCI 1	2.27	0.0838	1.72	0.1923	3.6	0.0603	0	0.9579
BCI 2	2.96	0.0351	0.03	0.8616	8.78	0.0037	0	0.976
BCI 3	2	0.1185	3.48	0.0649	2.43	0.1219	0.75	0.3885
NOSH								
BCI 1	4.03	0.009	2.87	0.0931	0.16	0.6857	5.67	0.0189
BCI 2	4.72	0.0038	2.85	0.0941	0.98	0.3251	5.4	0.0218
BCI 3	1.89	0.138	5.46	0.022	1.12	0.292	0.05	0.8239

Table 6.29. Type III F and P values from multivariate analysis of variance of body condition indices of hunter harvested blue-winged teal (*Anas discors*) (*n* = 262), green-winged teal (*Anas crecca*) (*n* = 461), and Northern shoveler (*Anas clypeata*) (*n* = 127), collected at hunter check stations at Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

			Source of variability							
	Overall model		Month		Year		Month*Year		Season	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
BWTE										
BCI 1	100.07	<0.0001	1.5	0.2223	0.35	0.5565	1.52	0.2193	7.91	0.0005
BCI 2	59.45	<0.0001	1.51	0.2196	0.05	0.8221	1.53	0.2174	0.86	0.4229
GWTE										
BCI 1	124.54	<0.0001	22.7	<0.0001	0.05	0.8259	22.99	<0.0001	11.3	<0.0001
BCI 2	122.07	<0.0001	23.11	<0.0001	0.08	0.7776	23.38	<0.0001	2.84	0.0595
NOSH										
BCI 1	12.54	<0.0001	2.69	0.1034	0.21	0.6456	2.68	0.1039	0.04	0.9601
BCI 2	12.7	<0.0001	3.91	0.0503	0.02	0.8985	3.9	0.0506	0.18	0.8362

Table 6.30. Type III F and P values from multivariate analysis of variance of body condition indices of scientifically collected blue-winged teal (*Anas discors*) (*n* = 155), green-winged teal (*Anas crecca*) (*n* = 120), and Northern shoveler (*Anas clypeata*) (*n* = 125), collected at Richland Creek Wildlife Management Area in east-central Texas, 2004-2006.

	Overall model		Source of variability: Month		Year		Month*Year		Season	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
BWTE										
BCI 1	2.27	0.0504	0.92	0.3385	0.14	0.7121	0.92	0.3392	2.91	0.0574
BCI 2	1.38	0.236	0.1	0.753	0.01	0.9393	0.1	0.754	2.08	0.1288
BCI 3	0.66	0.6555	0.43	0.5128	0.05	0.8169	0.43	0.5138	1.38	0.2565
GWTE										
BCI 1	7.38	<0.0001	15.38	0.0002	6.3	0.0134	15.38	0.0002	11.9	<0.0001
BCI 2	14.56	<0.0001	29.77	<0.0001	11.4	0.001	29.77	<0.0001	18.6	<0.0001
BCI 3	1.21	0.3123	1.18	0.2808	0.64	0.4262	1.18	0.281	2.09	0.1298
NOSH										
BCI 1	6.91	<0.0001	1.81	0.181	20.6	<0.0001	1.81	0.1806	0.45	0.6412
BCI 2	8.59	<0.0001	0.9	0.3451	25.6	<0.0001	0.9	0.3445	1.13	0.3261
BCI 3	3.37	0.0082	0.09	0.7612	5.74	0.0189	0.09	0.7614	0.25	0.7813

Table 6.31. Mean ($\bar{x}$) and standard error body condition indices of green-winged teal (*Anas crecca*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	461	16.55	0.16	6.51	35.31
BCI2	461	5.57	0.05	3.30	11.84
			Scientifically		
BCI1	120	18.39	0.16	12.60	23.24
BCI2	120	6.63	0.07	4.53	8.71
BCI3	102	7.20	0.10	5.79	12.33

Table 6.32. Mean ($\bar{x}$) and standard error body condition indices of adult male green-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	209	17.36	0.22	9.87	25.69
BCI2	209	5.76	0.07	3.34	7.33
			Scientifically		
BCI1	60	18.76	0.23	12.60	22.91
BCI2	60	6.73	0.10	4.53	8.71
BCI3	50	7.37	0.16	6.06	12.33

Table 6.33. Mean ($\bar{x}$) and standard error body condition indices of adult female green-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	92	16.14	0.38	6.84	26.84
BCI2	92	5.51	0.12	3.35	8.75
			Scientifically		
BCI1	15	18.03	0.56	15.22	23.24
BCI2	15	6.26	0.21	4.89	7.64
BCI3	12	7.21	0.26	5.83	9.21

Table 6.34. Mean ($\bar{x}$) and standard error body condition indices of juvenile female blue-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	100	15.46	0.38	6.51	35.31
BCI2	100	5.28	0.12	3.30	11.84
			Scientifically		
BCI1	14	17.56	0.38	15.37	19.55
BCI2	14	6.29	0.20	5.10	7.28
BCI3	10	6.56	0.19	5.92	7.72

Table 6.35. Mean ($\bar{x}$) and standard error body condition indices of juvenile male blue-winged teal (*Anas discors*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	60	16.18	0.44	9.69	23.74
BCI2	60	5.51	0.15	3.33	7.40
			Scientifically		
BCI1	31	18.25	0.27	15.31	20.86
BCI2	31	6.77	0.12	5.46	8.02
BCI3	30	7.13	0.15	5.79	9.42

Table 6.36. Mean ($\bar{x}$) and standard error body condition indices of Northern shoveler (*Anas clypeata*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	127	22.68	0.33	12.84	31.67
BCI2	127	7.63	0.11	4.34	10.62
			Scientifically Collected		
BCI1	125	23.28	0.22	17.05	28.75
BCI2	125	8.34	0.09	6.07	10.82
BCI3	86	7.19	0.12	4.54	14.66

Table 6.37. Mean ($\bar{x}$) and standard error body condition indices of adult male Northern shoveler (*Anas clypeata)* collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	Std Error	Minimum	Maximum
			Hunter Harvest		
BCI1	46	23.12	0.48	14.32	28.11
BCI2	46	7.81	0.16	4.78	9.60
			Scientifically		
BCI1	61	23.97	0.28	18.82	28.32
BCI2	61	8.67	0.13	6.21	10.82
BCI3	47	7.28	0.12	4.54	8.95

Table 6.38. Mean ($\bar{x}$) and standard error body condition indices of adult female Northern shoveler (*Anas clypeata)* collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	37	24.14	0.54	16.64	31.67
BCI2	37	8.09	0.17	5.55	10.62
			Scientifically		
BCI1	24	22.68	0.63	18.60	28.75
BCI2	24	8.01	0.22	6.56	10.40
BCI3	13	7.65	0.64	6.00	14.66

Table 6.39. Mean ($\bar{x}$) and standard error body condition indices of juvenile female Northern shovler (*Anas clypeata*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			Hunter Harvest		
BCI1	34	20.36	0.73	12.84	27.78
BCI2	34	6.85	0.23	4.34	8.97
			Scientifically		
BCI1	22	23.00	0.37	19.41	25.42
BCI2	22	8.14	0.16	6.42	9.40
BCI3	14	6.92	0.14	6.18	7.98

Table 6.40. Mean ($\bar{x}$) and standard error body condition indices of juvenile male Northern shovler (*Ana sclypeata*) collected scientifically and hunter harvest at check stations on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

BCI	*n*	$\bar{x}$	SE	Minimum	Maximum
			<u>Hunter Harvest</u>		
BCI1	10	23.19	0.69	20.00	26.09
BCI2	10	7.80	0.21	6.80	8.58
			<u>Scientifically</u>		
BCI1	18	22.08	0.56	17.05	25.69
BCI2	18	7.87	0.25	6.07	9.79
BCI3	12	6.68	0.22	4.96	7.54

Table 6.41. Mean ($\bar{x}$), standard error, and % occurrence by mass and number of food items recovered from blue-winged teal (*Anas discors*), green-winged teal (*Anas crecca*), and Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

				% Occurrence	
Species	$\bar{x}$	SE	*n*	Mass (g)	Total Number
Polygonumlapathifolium	0.061	0.101	95	5.85	14.05
Panicum spp.	0.024	0.040	74	1.76	10.95
Grit	1.413	0.754	71	74.85	10.52
Polygonumhydropiper	0.026	0.042	56	1.48	8.28
Polygonumpennsylvanicum	0.099	0.159	45	4.49	6.67
Rumexcrispus	0.039	0.094	41	1.62	6.07
Echinodorusrostru	0.015	0.028	38	0.08	5.62
Gastroposda spp.	0.080	0.245	35	2.83	5.18
Echinochloacrusgalli	0.013	0.021	27	0.37	4.00
Eleocharis spp.	0.005	0.004	22	0.11	3.25
Eleocharisquadrangulata	0.029	0.048	21	0.62	3.11
Chenopodium album	0.006	0.008	18	0.11	2.67
Unidentified Vegetation	0.092	0.222	15	1.40	2.22
Shoenoplectuscalifornicus	0.011	0.026	13	0.14	1.93
Paspalum spp.	0.007	0.009	13	0.09	1.92
Amaranthustuberculata	0.008	0.019	12	0.10	1.78
Leptochloafascicularis	0.016	0.029	11	0.17	1.63
Echinochloawalteri	0.082	0.222	8	0.66	1.18

Table 6.41. Continued. Mean ($\bar{x}$), standard error, and % occurrence by mass and number of food items recovered from blue-winged teal (*Anas discors*), green-winged teal (*Anas crecca*), and Northern shoveler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

				% Occurrence	
Species	$\bar{x}$	SE	*n*	Mass (g)	Total Number
Eclipta prostrate	0.022	0.029	7	0.16	1.04
Cyperus spp.	0.030	0.035	6	0.03	0.89
Planorbidae	0.114	0.215	6	0.69	0.89
Cyperuserthrorshizos	0.006	0.011	6	0.04	0.89
Carex spp.	0.119	0.246	5	0.60	0.74
Juncuseffusus	0.009	0.009	5	0.05	0.74
Shot	0.115	0.070	5	0.58	0.74
Ammaniacoccinea	0.003	0.002	5	0.02	0.74
Physidae	0.042	0.033	4	0.17	0.59
Odonata	0.004	0.001	3	0.01	0.44
Unidentified Invertebrate	0.001	0.001	2	0.00	0.30
Hydrophilidae	0.002	0.001	2	0.00	0.30
Bivalvia	0.010	na	1	0.00	0.01
Hermetiaillucens	0.174	na	1	0.18	0.15
Corixa sp.	0.002	na	1	0.00	0.15
Ludwigiapeploides	0.103	na	1	0.10	0.15
Overall Seeds	0.036	0.085	529	19.27	78.37
Overall Invertebrates	0.070	0.208	55	3.89	8.15
Overall Vegetation	0.092	0.222	115	1.40	2.22
Overall Other	0.980	0.765	76	75.42	11.26

Table 6.42. Total mass (g), standard error, and aggregate percent dry mass found in adult and juvenile blue-winged teal (*Anas discors*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	n	mass	SE	Aggregate dry mass (%)
Overall	269	11.841	0.122	100.00
2004				
Adult Female	7	1.60	0.54	13.53
Juvenile Female	--	--	--	0.00
Adult Male	--	--	--	0.00
Juvenile Male	3	0.08	0.04	0.64
2005				
Adult Female	34	1.21	0.07	10.24
Juvenile Female	54	2.89	0.11	24.40
Adult Male	54	1.61	0.08	13.62
Juvenile Male	40	2.10	0.10	17.72
2006				
Adult Female	13	0.28	0.05	2.40
Juvenile Female	19	1.43	0.13	12.07
Adult Male	27	0.50	0.03	4.21
Juvenile Male	18	0.14	0.02	1.17

Table 6.43. Total mass (g), standard error, and aggregate percent dry mass found in adult and juvenile green-winged teal (*Anascrecca*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	n	mass	SE	Aggregate dry mass (%)
Overall	172	4.166	0.06	100.00
2004				
Adult Female	6	0.761	0.22	18.26
Juvenile Female	2	0.071	0.05	1.70
Adult Male	10	0.032	0	0.77
Juvenile Male	4	0.028	0.01	0.67
2005				
Adult Female	37	0.582	0.02	13.97
Juvenile Female	27	0.674	0.05	16.19
Adult Male	53	1.001	0.04	24.04
Juvenile Male	24	0.7	0.04	16.81

Table 6.44. Total mass (g), standard error, and aggregate percent dry mass found in adult and juvenile Northern shoveler (*Ana sclypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

		n	mass	SE	Aggregate dry mass (%)
	Overall	164	8.843	0.12	100.00
2004					
	Adult Female	13	0.735	0.1	8.32
	Juvenile Female	--	--	--	0.00
	Adult Male	--	--	--	0.00
	Juvenile Male	5	0.232	0.02	2.62
2005					
	Adult Female	23	1.857	0.2	21.00
	Juvenile Female	16	0.833	0.1	9.43
	Adult Male	41	2.798	0.14	31.65
	Juvenile Male	35	1.382	0.08	15.62
2006					
	Adult Female	15	0.307	0.06	3.47
	Juvenile Female	3	0.031	0.01	0.35
	Adult Male	7	0.523	0.14	5.92
	Juvenile Male	6	0.143	0.04	1.62

Table 6.45. Total number (#) of feathers molting, molt score, and % feathers molting on blue-winged teal (*Anas discors*), green-winged teal (*Anas crecca*), and Northern shoverler (*Anas clypeata*) collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

	Total # of Feathers Molting	*n*	Molt Score	% feathers molting
	Overall			
All species	28672	205	8.23	100.00
Blue-winged teal	8431	93	5.33	29.40
Green-winged teal	4963	47	6.21	17.31
Northern shoveler	15278	65	13.83	53.29
	Blue-winged teal			
Adult female	1058	15	4.15	12.55
Adult male	3200	35	5.38	37.96
Juvenile female	987	14	4.15	11.71
Juvenile male	3186	29	6.46	37.79
	Green-winged teal			
Adult female	1680	12	8.24	33.85
Adult male	2488	21	6.97	50.13
Juvenile female	465	5	5.47	9.37
Juvenile male	330	9	2.16	6.65
	Northern shoveler			
Adult female	4804	17	16.62	31.44
Adult male	4787	20	14.08	31.33
Juvenile female	2875	12	14.09	18.82
Juvenile male	2812	16	10.34	18.41

Table 6.46. Average feather molt intensity per feather tract of blue-winged teal (*Anas discors*) scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Feather Tract	Adult female	Adult male	Juvenile female	Juvenile male
crown	2.13	6.46	4.93	12.66
face	3.13	9.51	6.14	16.45
chin-throat	3.07	4.43	6.21	10.52
neck	18.00	18.43	13.93	24.48
upper back	6.20	3.54	5.14	3.69
scapular	3.47	6.34	4.93	3.45
lower back	3.07	4.00	3.57	2.03
rump	1.73	3.80	2.36	5.69
upper tail covert	2.13	1.03	0.86	1.14
tail	1.00	0.69	0.86	2.24
lower tail covert	2.20	1.31	1.79	2.45
belly	4.80	5.80	7.07	6.38
chest-center	1.53	7.71	3.14	1.90
chest side	4.20	4.89	4.43	2.97
side	9.00	6.51	2.50	7.69
flank	2.67	2.34	1.36	2.28
leg	2.20	4.63	1.29	3.86

Table 6.47. Average feather molt intensity per feather tract of green-winged teal (*Anas crecca*) scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Feather Tract	Adult female	Adult male	Juvenile female	Juvenile male
crown	2.83	5.05	0.00	0.11
face	1.00	6.05	0.00	0.00
chin-throat	1.33	5.19	0.20	0.56
neck	25.58	17.67	8.40	16.67
upper back	14.83	12.62	8.00	3.22
scapular	27.25	17.95	14.00	4.00
lower back	2.58	10.86	4.00	1.00
rump	7.08	3.81	4.00	0.89
upper tail covert	1.50	2.24	0.00	0.00
tail	2.58	1.62	0.00	0.00
lower tail covert	11.58	2.29	2.40	0.67
belly	2.17	5.76	6.00	0.00
chest-center	3.00	3.95	6.00	0.22
chest side	11.08	7.48	17.80	0.00
side	23.67	7.43	12.00	8.56
flank	1.00	4.62	5.80	0.44
leg	0.92	3.90	4.40	0.33

Table 6.48. Average feather molt intensity per feather tract of Northern shoveler (*Anas clypeata*) scientifically collected on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Feather Tract	Adult female	Adult male	Juvenile female	Juvenile male
crown	30.06	22.30	13.75	12.88
face	25.82	32.50	15.17	22.56
chin-throat	30.65	19.25	29.08	14.31
neck	72.18	89.40	63.00	39.00
upper back	9.76	5.75	8.75	6.38
scapular	15.94	8.60	14.75	18.63
lower back	11.41	2.65	12.92	6.50
rump	5.12	2.70	5.08	4.06
upper tail covert	5.82	3.75	3.92	3.00
tail	1.76	2.25	1.83	1.75
lower tail covert	6.18	5.05	3.75	3.31
belly	19.06	11.20	21.83	4.31
chest-center	7.47	7.30	11.00	2.44
chest side	9.35	7.80	9.75	11.38
side	15.24	11.70	9.25	13.25
flank	6.76	1.90	5.83	7.38
leg	10.00	5.25	9.92	4.63

APPENDIX A

TEMPORAL CHANGES IN VEGETATION WITHIN MOIST-SOIL MANAGED WETLANDS ON RICHLAND CREEK WILDLIFE MANAGEMENT AREA

INTRODUCTION

Wetland plant habitats are exceptionally diverse, and management of the vegetation within these wetlands should focus on macrophytic species, as they play a critical role in the complex biogeochemical processes occurring in wetlands (Klopatek and Stearns 1978). This requires accurate and reliable information on vegetative ecology and community structure and development. However, wetland vegetative composition can change rapidly in response to several factors such as water depth can have tremendous impacts on the distribution of wetland species and plant communities (Spence 1982). A long-term change in water level, particularly an increase, can result in dramatic changes in vegetative composition. Species, communities and, in extreme cases, nearly all emergent vegetation can be eliminated (van der Valk 1981). Destruction of all or some existing vegetation by pathogens, herbivores, or man that favor the growth of some species will also rapidly change vegetative communities. Furthermore, interactions among plants via competition or allelopathy, can also influence community development, maintenance, and stability (van der Valk 1981).

Water regime can be a major determinant of plant community development and patterns of zonation by way of depth, duration, frequency, rate of filling and drying, timing and predictability of flood and dry phases. Within moist-soil managed wetlands, altering inundation and drawdown can affect plant establishment from the seed bank by stimulating or inhibiting germination (Casanova and Brock 2000). Many studies have concentrated on the effects of moist-soil management practices upon plant colonization after restoration. Galatowitsch and van der Valk (1996) found that after 3 years of water manipulation, vegetation in restored wetlands was not similar to that of natural wetlands, which had many more species than the restored wetlands. Specifically, species guilds had significantly fewer (e.g., sedge meadow) or more (e.g., submersed aquatics) species in restored than natural wetlands. Kellogg and Bridgham (2002) found that low density planting in restored wetlands offered no clear advantage over restoration through natural dispersal and colonization.

Annual plants are an important component of vegetation communities (Leck and Simpson 1993). Their presence will be impacted if germination conditions are not met (i.e., inundation too long), which may severely impact seedling recruitment and survival (Galinato and van der Valk 1986, Battaglia and Collins 2006). Typically moist-soil managed wetlands are shallow water areas impounded by levees which contain water control structures that enable wetland managers to manipulate water across the landscape routinely through inundation (i.e., flooding) and drawdown (i.e., water removal). Inundation provides an aspect of vegetation control as well as foraging habitat to wetland dependent species. Drawdowns promote germination and growth of desirable moist-soil plant species (Fredrickson and Taylor 1992), leading to the encouragement of naturally occurring wetland vegetation through the emulation of hydrological manipulation. This process also allows manager to make realistic predictions about vegetation change if sufficient information about the life history characteristics (propagule, dispersal, seed germination, growth rate under various conditions, seed productions, susceptibility to specific pathogens, competitive ability, life-span, etc.) of all species in a given wetland is known (i.e., seed bank potential; Chapter II) (van der Valk 1981, Wilcox 2004). Through precise control of hydrology and manipulation of plant succession, wetland managers can achieve desired plant communities and provide habitat requirements for a variety of wildlife species if management practices are done correctly through-out the moist-soil managed wetland annual cycle of proper inundation and drawdown (Lane and Jensen 1999). The objectives of this portion of the study were to monitor temoral vegeatative community changes within moist-soil managed wetlands on Richland Creek Wildlife Management Area, in east central Texas.

STUDY AREA

This research was conducted on the Richland Creek Wildlife Management Area's (RCWMA) North Unit moist-soil managed wetlands 1-4 (Figure 1.1). The RCWMA (31º13'N, 96º11'W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The WMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were fully functional. Construction of moist-soil managed wetland units 5-6 began in the summer 2006 and have been functioning since November 2009.

Local climate is considered subtropical with mild winters and warm humid summers, with an average daily summer temperature of 34º C and winter temperature of

5º C, a growing season of 246 days, and average rainfall of 101.6 cm a year (NRCS 2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, and mollisol soils (NRCS 2002).

Vegetation within the South Unit (Figure 1.4) is characterized by vast bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North Unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. The typical water management strategy consists of slow drawdown (i.e., removal of water) starting late March - early April and lasting until mid August. Inundation (i.e., flooding) begins in late August and lasts throughout fall and winter, until drawdown the following spring. These management actions produced common species such as barnyardgrass, erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet, and water primrose (*Ludwigia peploides*).

METHODS

Wetland vegetative characteristics were quantified using the line intercept method and $1m^2$ permanent plots to estimate plant species occurrence, dominance, density, and percent cover. Three transects were systematically located lengthwise within each moist-soil managed wetland during 2004. One transect was in the approximate middle, and the second two transects were located 50 m from the moist-soil managed wetland edges.

Along each 100-m transect any plant that fell under the tape were recorded from the start of the plant to the end of the plant, from which species percent cover, frequency, density, and dominance were estimate measured. Vegetative percent cover (%) within each moist-soil managed wetland was calculated by dividing the total length (cm) intercepted by a species by total transect length multiplied by 100. Species frequency (%) was calculated by dividing the intervals in which a species occured by the total number of intercept intervals sampled and multiplied by 100. Species density (#/ total area) was calculated by dividing the total number of individuals of a species encountered for all transects by the total number of individuals of all species counted for all transects and then multiplied by 100. Absolute percent dominance (%) for each species was calculated by dividing total intercept lengths for a species by total intercept lengths sampled, and multiplied by 100. Absolute dominance (m^2/ha) for each species was then be calculated by dividing absolute dominance (%) by 100 then multiplying it by 10,000m^2/ha to obtain m^2/ha. Data were collected using these established transects four different times during the growing season in 2004, 2005, and 2006 (March, May, July, and September each year).

Permanent 1m^2 plots were established within each moist-soil managed wetland using a random number generator and a transect running the length of each moist-soil managed wetland. At every 50 m interval, a 2-digit number was removed from the random number generator. If the number was odd, the plot was placed to the left, and if even, the plot was placed to the right of the transect. Plots were marked with a t-post in the southeast cornerAt each plot, plant percent cover, frequency, density, and dominance was measured as outlined previously, using the same formulas as previously detailed. . Data were collected using these established plots four different times during the growing season in 2004, 2005, and 2006 (March, May, July, and September each year).

Data Analysis

Analysis of variance (ANOVA) were used to examine differences in plant species absolute dominance per hectare, absolute dominance per sample, surface area covered, and relative dominance between and among species, sampling periods (i.e., March, May, July, and August), years (i.e., 2004, 2005, 2006), and individual moist-soil managed wetlands. If differences occured ($P < 0.05$) least squares mean separation were used to more closely examine differences among sampling periods, years, and moist-soil managed wetland cells.

RESULTS

Species Occurrence, Growth Form, Duration, and Wetland Classification

A total of 27 families, 47 genera, and 57 species were recorded over a three year data collection period (Table A.1). Many of the species were forb/herbs and ranged from forb/herb, graminoides, to trees. Perennial species dominated, but many annual species were recorded as well. The dominant wetland plant classification were Obligate (OBL) and Facultative Wet (FACW), although individuals belonging to the the remaining 3 classifications were also recorded (Upland (UP), Facultative Upland (FACU), Facultative (FAC))(Tiner 1993).

Density, Dominance, Frequency, and Surface Area Covered: 2004

In August 2004 for three of the four moist-soil managed wetlands, redroot flatsedge (*Cyperus erythrirhozis*) dominated, while cocklebur (*Xanthium strumarium*), sesbania (*Sesbania drummondii*), buttonbush (*Cephalanthus occidentalis*), ballon vine (*Cardiospermum halicacabum*), square stem spike rush (*Eleocharis quadrangulata*), spider lily (*Hymenocallis caroliniana*) wild millet (*Echinochloa walteri*), prairie mimosa (*Desmathus* spp.) and pink smartweed (*Polygonum pennsylvanicum*) were recorded, but infrequently (Table A.2).

Density, Dominance, Frequency, and Surface Area Covered: 2005

In March 2005, water primrose (*Ludwigia peploides*) and black willow (*Salix nigra*) were most dense in moist-soil managed wetlands 1-4, while curly dock (*Rumex crispus*), climbing hemp vine (*Mikania scandens*), water pepper (*Polygonum hydropiper*) eleocharis spp., duck potato (*Sagittaria* spp.), cattail (*Typha domeingensis*), pigweed

(*Amaranthus* spp), teal-love grass (*Eragrostic hypoides*), and softstem bulrush (*Shoenoplectus californicus*) were only detected 1 or 2 times (Table A.4). Within moist-soil managed wetland 1 water primrose covered 0.62 acres, within moist-soil managed 2 wetland it covered 0.60 acres, and in moist-soil managed wetland 4 it covered 0.12 acres. Within moist-soil managed wetland 3, black willow covered nearly 1.5 acres (Table A.5).

In May 2005, water primrose was most frequently encountered in three of the moist-soil managed wetlands, and duck potato dominated the fourth (Table A.6). Spider lily, red-rooted flatnut sedge, buttonbush, pigweed, and curly dock were also detected, but infrequently (Table A.6). Water primrose again covered significant surface area within each moist-soil managed wetland, ranging from 3-8 acres (Table A.7).

In August 2005, barnyard grass (*Echinochloa crus-galli*), nodding smartweed (*Polygonum lapathifolium*), frog fruit (*Phyla lanceolata*), and duck potato were the most frequently encountered in all four moist-soil managed wetlands (Table A.8). Nodding smartweed dominated managed wetland 1, covering nearly 7.5 acres, while water primrose covered 2.2 acres in moist-soil managed wetland 2. In moist-soil managed wetland cell 3 water primrose, red-rooted flatnut sedge, frog fruit dominated, covering 6.1, 4.2, and 3.5 acres respectively (Table A.9), while duck potato dominated moist-soil managed wetland 4 (Table A.9).

Density, Dominance, Frequency, and Surface Area Covered: 2006

Again in May 2006 water primrose and duck potato were the densest species found throughout the 4 moist-soil managed wetlands, while a variety of species were infrequently detected, such as climbing hemp vine, alligator weed (*Alternathera* *philoxeroides*), erect burhead (*Echinodorus rostratus*), nodding smartweed (*Polygonum lapathifolium*), and toothcup (*Ammania coccinea*) (Table A.10). Duck potato dominated moist-soil managed wetlands 1 and 4, covering 2.8 and 6.2 acres, respectively (Table A. 11), while water primrose dominated moist-soil managed wetlands 2 and 3 covering 1.2 . and 1.3 acres of surface area, respectively (Table A.11).

In August 2006, nodding smartweed and barnyard grass dominated in moist-soil managed wetland 1, while water primrose dominated moist-soil managed wetland cells 2 and 3, and duck potato dominated moist-soil managed wetland cell 4 (Table A.12). Other species infrequently detected were pink smartweed, *Potomageton* spp., sprangletop (*Lepthochloa fascularis*), and soft stem bulrush (Table A.12). Nodding smartweed covered 6.6 acres in moist-soil managed wetland 1, while water primrose covered 1 and 4.2 acres in moist-soil managed wetland cells 2 and 3, respectively (Table A.13). Finally, duck potato remained dominant in moist-soil managed wetland cell 4, and covered nearly 5 acres (Table A.13).

Percent Cover: 2004

In August 2004, 22 species were recorded. Within moist-soil managed wetland 1, *Aster* spp. (11.5 %), water primrose (8.4 %), and nodding smartweed (7.2 %) had the greatest coverage, while square-stem spike rush (*Eleocharis quadrangulata*), curly dock, and spider lily were detected, but infrequently (Table A.14). Within moist-soil managed wetland 2 water primrose (19.6 %), red-rooted flatnut sedge (*Cyperus erythrorhizos*) (9.1 %), and duck potato (9.9 %) had the highest percent cover. Spider lily, curly dock, and soft stem bulrush (*Shoenoplectus californicus*) accounted for < 1 % of the coverage

(Table A.14). Within moist-soil managed wetland 3, red-rooted flatnut sedge (8.9 %), *Paspalidium geminatum* (6.5 %), and water primrose (5.3 %), dominated while nodding smartweed, spider lily, accounted for < 1 % respectively. Finally, within moist-soil managed wetland 4 duckweed (24.4 %), erect burhead (*Echinodorus rostrus*) (7.2 %), and square-stem spike rush (6.7 %) had the greatest percent cover within the cell (Table A.14).

Percent Cover: 2005

During March, May, and August 2005, 27 species were recorded on all moist-soil managed wetlands. In March, square-stem spike rush (2.9 %), *Azolla carolinia* (6.6 %), and algae dominated all four moist-soil managed wetlands (Table A.14). During May 2005, nodding smartweed (13.2 %), *Paspalidium geminatum* (11.7 %), algae (14.6 %), and duckweed (14.0 %) had the greatest percent cover, while spider lily, black willow, crow's foot sedge, barnyard grass, and ballow vine all occurred < 1% (Table A.14). In August, nodding smartweed (32.9 % and 30.8 %) dominated moist-soil managed wetlands 1 and 2, respectively (Table A.14). Within moist-soil managed wetland cell 3 water primrose had the greatest percent cover (32.7 %) while duckweed (40.8 %) dominated moist-soil managed wetland 4 (Table A.14).

Percent Cover: 2006

During March and August 2006, only 16 species were recorded. March 2006 had sparse plant composition, where was sparse in comparison to previous years and found that *Azolla* (20.4 % and 10.3 %), *Carex* spp. (3.6 %), and algae (3.6 %) had the greatest percent cover (Table A.14). During August 2006, nodding smartweed (40.5 %), water primrose (18.2 % and 35.6 %), and duckweed (42.4 %) had the greatest percent cover among the moist-soil managed wetlands (Table A.14).

Species Diversity

Simpson's and Shannon-Wiener diversity indices were created for all 4 moist-soil managed wetland cells. In general, low diversity indices were estimated over the sampling periods (among years and months). Within moist-soil managed wetland 1, diversity indices were consistent over time, where March 2005 had the lowest diversity (Simpson's = 0.82; Shannon-Wiener = 2.74) (Table A.15). Moist-soil managed wetland cells 2 and 3 diversity indices for March 2005 also had the lowest diversity estimates, (Simpson's = 0.66; Shannon-Wiener = 1.90; and Simpson's = 0.53; Shannon-Wiener = 1.70), respectively. Moist-soil managed wetland cell 4 had the lowest diversity in May 2006 (Simpson's = 0.49; Shannon-Wiener = 1.586) (Table A.15).

Analysis of Variance

Fifty-seven plant species were present while conducting line transect surveys in 4 moist-soil managed wetland cells over 3 sampling periods (March, May, and August) for 3 years (2004 (partial data), 2005, 2006). Absolute dominance per hectare varied (F = 1.49, $P < 0.017$), as did absolute dominance per sample window (F = 3.17, P < 0.001), surface area covered (F = 1.63, P = 0.004), and relative dominance (F = 3.01, $P < 0.001$) respectively (Table A.16). Absolute dominance per hectare varied among moist-soil managed wetlands (F = 4.19, P = 0.006) and species (F = 1.53, P = 0.016) (Table A.16). Surface area covered varied among moist-soil managed wetlands (F = 4.19, P = 0.006) (Table A.16). Least squares mean separation was used to examine where differences occurred. Absolute dominance per sample, surface area covered, and relative dominance as well as absolute dominance per hectare varied among months, and were related to moist-soil managed wetland and year (Table A.17).

DISCUSSION

Over time, in dynamic and ephemeral systems like moist-soil managed wetlands, the vegetative component is the first exterior component to show changes happening over the temporal scale (van der Valk 1981). The moist-soil managed wetlands located on RCWMA are no different than any other. Generally, the most prolific seed producers which are most desirable plants for waterfowl are annuals that dominate early successional seral stage (Fredrickson and Taylor 1982). Strader and Stinson (2005) suggested that moist-soil managed wetlands if inventoried have the potential to have over 100 species present within them over the course of a calendar year. However, most moist-soil managed wetlands are typically dominanted by 25 or fewer species depending on the succesional stage the moist-soil managed wetland is found in (Strader and Stinson 2005).

Data collected on the moist-soil managed wetlands on RCWMA found 50 species were present over the 3 years of data collection, and typically averaged 25 species per calendar year of data collection. Over the 3 years of data collection there was a change in species composition, density, surface area covered, and percent cover. Because these moist-soil managed wetlands are managed for wintering and migrating waterfowl use the change over time from desirable to non-desirable species (non-desirable species are not necessarily unbeneficial species with regard to wetland ecosystem health) has the potential to impact the number of waterfowl the moist-soil managed wetlands can support. Early research on moist-soil managed wetlands showed moist-soil managed wetlands reached peak waterfowl use soon after flooding and then slowly lose their attractiveness to ducks (Hartman 1949, MacNamara 1957, Kadlec 1962) and recently Haukos and Smith (1993 and 1995) reported that moist-soil management will greatly increase quantiy of seeds available to wintering ducks and other wetland dependent species if proper management actions are undertaken.

Extended inundation duration had the largest impact on vegetation changes over time within each moist-soil managed wetland. The effects of prolonged inundation on vegetative growth and seedling recruitment on many moist-soil plant species has been widely documented (Galinato and van der Valk 1986, McKee and Mendelssohn 1989, Ernst 1990, Armstrong et al. 1994). Baldwin et al. (2001) reported that higher water levels negatively influenced vegetation growth and seed germination in field, green-house, and seed-bank experiements and subsequently stated that shallow flooding for a month early in the growing season was a more important determinant of community composition than later flooding even if it occurred longer. Such evidence suggests that water management during the early growing season has the most impact on annual moist-soil plant community establishment.

van der Valk et al. (1994) also found deeper water typically reduced percent cover of emergent plant species and promotes increases in cover of free-floating and submersed species. Increases in surface area coverage of water primrose over time provide evidence that extended inundation duration can drives community composition. These results are consistent with many previous studies on the impact of a long term increase in water level on wetlands (Harris and Marshall 1963, Millar 1973, Bukata et al. 1988, Wallsten and Forgren 1989, van der Valk and Davis 1980, van der Valk et al. 1994, Baldwin et al.

2001). If timing of drawdown or water was kept at a minimum, more desirable species such as nodding smartweed and barnyard grass could have persisted in larger stands over time. For example, moist-soil managed wetland cell 1 did experience sporadic and pooely timed drawdowns and often had minimum water depths to promote large stands of nodding smartweed over the 3 years. However, duck potato, erect burhead, and water primrose coverage in all four moist-soil managed wetlands indicates a water regime that has deep standing water for long durations. Howard and Mendelssohn (1995) found that as water depth and duration increased *Sagittaria* species were not negatively impacted. Kadlec and Smith (1984) also reported that too much water inhibits germination of seeds of moist-soil emergent plant species. They found that 5-10 cm of standing water inhibited germination and growth of these plant species, while submersed plants re-established rapidly on their research site. The longer water stays on the moist-soil managed wetlands the more submersed (i.e., potamegeton) and free floating (i.e., water primrose) plant species will dominate.

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Table A.1. Family, genus, and species occurrence of moist-soil plant species found within moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

Family	Genus	Species	Year 2004	2005	2006	Duration	Growth	Wetland Indicator
Alismataceae	*Echinodorus*	*rostrus*	X	X	X	Perennial	Forb/Herb	OBL
	Sagittaria	spp.	X	X	X	Perennial	Forb/Herb	OBL
Amaranthaceae	*Alternanthera*	*philoxeriods*	X	X	X	Perennial	Forb/Herb	OBL
	Amaranthus	spp.		X	X	Annual	Forb/Herb	OBL
Amaryllidaceae	*Hymenocallis*	*caroliniana*	X	X	X	Perennial	Forb/Herb	FACW
Asteraceae	*Aster*	spp.	X			Annual	Forb/Herb	FACW
	Mikania	*scandens*		X	X	Perennial	Vine	FACW
	Xanthium	*strumarium*	X	X	X	Annual	Forb/Herb	FAC
	Eclipta	*prostrate*		X	X	Annual	Forb/Herb	FACW
	Iva	*annua*		X		Annual	Forb/Herb	FACW
Chenopodiaceae	*Chenopodium*	*album*	X	X		Annual	Forb/Herb	FAC
Cyperaceae	*Carex*	spp.	X	X		Perennial	Grass-like	OBL
	Carex	*crus-corvi*		X	X	Perennial	Grass-like	OBL
	Cyperus	*erthrorhizos*	X			Annual	Grass-like	OBL
	Eleocharis	spp.		X		Perennial	Grass-like	OBL
	Eleocharis	*quadrangulata*	X			Perennial	Grass-like	OBL
	Shoenoplectus	*californicus*	X	X	X	Annual	Graminoid	OBL

Table A.1. Continued. Family, genus, and species occurrence of moist-soil plant species found within moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

Family	Genus	Species	Year 2004	2005	2006	Duration	Growth	Wetland Indicator
Fabaceae	*Aeschynomene*	L.	X		X	Annual	Forb/Herb	FACW
	Desmanthus	spp.		X	X	Perennial	Forb/Herb	FAC
	Sesbania	*drummondii*	X		X	Perennial	Shrub	FACW
Juncaceae	*Juncus*	*effusus*		X		Perennial	Grass-like	OBL
Lythraceae	*Ammania*	*coccinea*	X	X		Annual	Forb/Herb	FACW
Malvaceae	*Hibscus*	*laevis*	X	X		Perennial	Forb/Herb	OBL
Marsileaceae	*Marsilea*	spp.		X		Perennial	Forb/Herb	OBL
Nelombonaceae	*Nelumbo*	*lutea*			X	Perennial	Forb/Herb	OBL
Oleaceae	*Fraxinus*	*pennsylvanicum*	X	X		Perennial	Tree	FACW
Onagraceae	*Ludwigia*	*peploides*	X	X	X	Perennial	Forb/Herb	OBL
Poaceae	*Cynodon*	*dactylon*		X	X	Perennial	Graminoid	FACU
	Echinochloa	*curs-galli*	X	X	X	Annual	Graminoid	FACW
	Echinochloa	*walteri*	X	X		Annual	Graminoid	FACW
	Eragrostis	*hypnoides*		X		Annual	Graminoid	OBL
	Leptochloa	*fascicularis*	X	X		Annual	Graminoid	FACW
	Panicum	*virgatum*	X			Annual	Graminoid	FACW
	Paspalidium	*geminatum*		X		Perennial	Graminoid	OBL
	Paspalum	*leave*			X	Perennial	Graminoid	FACW

Table A.1. Continued. Family, genus, and species occurrence of moist-soil plant species found within moist-soil managed wetlands on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

Family	Genus	Species	Year 2004	Year 2005	Year 2006	Duration	Growth	Wetland Indicator
Poaceae	*Setaria*	*geniculata*		X		Perennial	Graminoid	FAC
	Zizaniopsis	*millaceae*			X	Perennial	Graminoid	OBL
	Elymus	*repens*		X		Perennial	Graminoid	FACU
Polygonaceae	*Polygonum*	*hydropiper*	X	X	X	Perennial	Forb/Herb	OBL
	Polygonum	*lapathifolium*	X	X	X	Perennial	Forb/Herb	FACW
	Polygonum	*pensylvanicum*	X			Perennial	Forb/Herb	FACW
	Rumex	*crispus*	X	X		Perennial	Forb/Herb	FACW
Potamegetonaceae	*Potamogeton*	spp.		X	X	Perennial	Forb/Herb	OBL
Rubiaceae	*Cephalanthus*	*occidentalis*	X	X		Perennial	Shrub	OBL
Salicaceae	*Salix*	*nigra*	X	X	X	Perennial	Tree	OBL
Sapindaceae	*Cardiospermum*	*halicacabum*	X	X	X	Annual	Forb/Herb	FAC
Saururaceae	*Saururus*	*cernuus*			X	Perennial	Forb/Herb	OBL
Typhaceae	*Typha*	*domeingensis*		X	X	Perennial	Forb/Herb	OBL
Verbenaceae	*Phyla*	*lanceolata*	X	X		Perennial	Forb/Herb	FACW
Vitaceae	*Ampelopsis*	*arborea*	X			Perennial	Vine	FAC

Table A.2. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2004 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Carex spp.	76	0.29	29.34	100.00	15.25
Echinochloa walteri	54	0.21	20.85	77.78	11.86
Echinodorus rostratus	28	0.11	10.81	66.67	10.17
Echinochloa crus-galli	25	0.10	9.65	55.56	8.47
Phyla lanceolata	21	0.08	8.11	55.56	8.47
Desmanthus spp.	16	0.06	6.18	66.67	10.17
Saururus cernus	10	0.04	3.86	44.44	6.78
Ludwigia peplodies	7	0.03	2.70	33.33	5.08
Amaranthus spp.	6	0.02	2.32	33.33	3.39
Ammania coccinea	5	0.02	1.93	22.22	5.08
Cardiospermum halicacbum	2	0.01	0.77	22.22	3.39
Ampelopsis arborea	2	0.01	0.77	22.22	3.39
Sesbania drummondii	1	0.00	0.39	11.11	1.69
Xanthium strumarium	1	0.00	0.39	11.11	1.69

Table A.2. Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2004 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Carex spp.	178	0.2332	23.32	100	0.1209
Ammania coccinea	165	0.2162	21.62	86.66	0.1048
Echinochloa crus-galli	132	0.1730	17.30	80.00	0.0967
Echinochloa walteri	66	0.0865	8.65	53.33	0.0645
Amaranthus spp.	49	0.0642	6.42	66.67	0.0806
Echinodorus rostratus	40	0.0524	5.24	53.33	0.0645
Desmanthus spp.	34	0.0445	4.45	53.33	0.0645
Phyla lanceolata	33	0.0432	4.32	86.66	0.1048
Leptochloa fascicularis	20	0.0262	2.62	40.00	0.0483
Xanthium strumarium	7	0.0091	0.91	26.67	0.0322
Aster spp.	7	0.0091	0.91	26.67	0.0322
Polygonum lapathifolium	6	0.0078	0.78	20.00	0.0241
Salix nigra	6	0.0078	0.78	20.00	0.0241
Panicum virgatum	5	0.0065	0.65	26.67	0.0322
Ludwigia peploides	4	0.0052	0.52	20.00	0.0241

Table A.2. Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2004 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Chenopodium album	3	0.0039	0.3931	20.00	0.0241
Sagittaria spp.	3	0.0039	0.3931	6.67	0.0080
Polygonum hydropiper	2	0.0026	0.2621	13.33	0.0161
Cephalanthus occidentalis	1	0.0013	0.1310	6.67	0.0080
Cardiospermum halicacabum	1	0.0013	0.1310	6.67	0.0080
Eleocharis quadrangulata	1	0.0013	0.1310	6.67	0.0080

Table A.2. Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2004 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Carex spp.	199	0.0317	31.73	100.00	13.72
Ammania coccinea	145	0.2312	23.12	100.00	13.72
Phyla lanceolata	73	0.1164	11.64	100.00	13.72
Echinochloa crus-galli	54	0.0861	8.612	78.57	10.78
Amaranthus spp.	52	0.0829	8.293	28.57	3.921
Suarurus cernuus	20	0.0318	3.189	42.85	5.88
Echinodorus rostratus	19	0.0303	3.030	50.00	6.86
Sagittaria spp.	15	0.0239	2.392	42.85	5.88
Leptochloa fascicularis	11	0.0175	1.754	35.71	4.90
Ludwigia peploides	9	0.0143	1.435	21.42	2.94
Polygonum hydropiper	7	0.0095	0.956	14.28	1.96
Sesbania drummondii	5	0.0079	0.797	7.14	0.98
Salix nigra	5	0.0079	0.797	14.28	1.96
Shoenoplectus californicu	3	0.0047	0.478	21.42	2.94
Cephalanthus occidentalis	2	0.0031	0.318	14.28	1.96

Table A.2. Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2004 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Eleocharis quadrangulata	2	0.0031	0.318	7.14	0.98
Hibiscus laevis	2	0.0031	0.318	14.28	1.96
Hymenocallis caroliniana	1	0.0015	0.159	7.14	0.98
Echinochloa walteri	1	0.0015	0.159	7.14	0.98
Desmanthus spp.	1	0.0015	0.159	7.14	0.98
Polygonum pennsylvanicum	1	0.0015	0.159	7.14	0.98

Table A.3. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2004 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Carex spp.	379.9	42.21	3.79	60.26
Echinochloa walteri	69.91	7.73	0.69	11.04
Echinodorus rostratus	20.00	2.22	0.20	3.17
Echinochloa crus-galli	68.90	7.66	0.68	10.93
Phyla lanceolata	19.30	2.14	0.19	3.06
Desmanthus spp.	13.60	1.51	0.13	2.15
Saururus cernus	2.20	0.24	0.02	0.34
Ludwigia peplodies	41.90	4.66	0.41	6.64
Amaranthus spp.	3.00	0.33	0.03	0.47
Ammania coccinea	1.90	0.21	0.01	0.30
Cardiospermum halicacbum	0.40	0.04	0.004	0.06
Ampelopsis arborea	0.30	0.03	0.003	0.04
Sesbania drummondii	0.80	0.09	0.008	0.12
Xanthium strumarium	0.80	0.09	0.008	0.12
Total	630.41	70.05	6.30	100

Table A.3 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2004 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Carex spp.	551.71	36.78	5.517	43.33
Ammania coccinea	302.50	20.17	3.025	23.76
Echinochloa crus-galli	148.33	9.89	1.483	11.65
Echinochloa walteri	49.66	3.31	0.497	3.90
Amaranthus spp.	41.80	2.79	0.418	3.28
Echinodorus rostratus	44.88	2.99	0.449	3.52
Desmanthus spp.	12.90	0.86	0.129	1.01
Phyla lanceolata	37.51	2.50	0.375	2.94
Leptochloa fascicularis	19.85	1.32	0.199	1.55
Xanthium strumarium	6.70	0.45	0.067	0.52
Aster spp.	6.40	0.43	0.064	0.50
Polygonum lapathifolium	1.45	0.10	0.015	0.113
Salix nigra	7.00	0.47	0.070	0.549
Panicum virgatum	2.10	0.14	0.021	0.165
Ludwigia peploides	3.30	0.22	0.033	0.259

Table A.3 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2004 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Chenopodium album	12.90	0.86	0.129	1.013
Sagittaria spp.	0.75	0.05	0.008	0.058
Polygonum hydropiper	0.75	0.05	0.008	0.058
Cephalanthus occidentalis	0.80	0.05	0.008	0.062
Cardiospermum halicacabum	0.30	0.02	0.003	0.023
Eleocharis quadrangulata	0.50	0.03	0.005	0.039

Table A.3 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2004 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Carex spp.	533.83	38.13	5.33	0.488
Ammania coccinea	215.45	15.38	2.15	0.196
Phyla lanceolata	167.89	11.99	1.67	0.153
Echinochloa crus-galli	52.21	3.729	0.52	0.047
Amaranthus spp.	24.05	1.717	0.24	0.021
Suarurus cernuus	20.76	1.482	0.20	0.018
Echinodorus rostratus	4.62	0.33	0.04	0.004
Sagittaria spp.	1.84	0.13	0.05	0.005
Leptochloa fascicularis	10.95	0.78	0.10	0.010
Ludwigia peploides	5.75	0.41	0.057	0.005
Polygonum hydropiper	8.2	0.585	0.082	0.007
Sesbania drummondii	9.15	0.653	0.091	0.008
Salix nigra	12.65	0.903	0.126	0.011
Shoenoplectus californicus	16.36	1.168	0.163	0.014
Cephalanthus occidentalis	1.95	0.139	0.019	0.001

Table A.3 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2004 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Eleocharis quadrangulata	6.45	0.4607	0.0645	0.005
Hibiscus laevis	1.35	0.096	0.0135	0.001
Hymenocallis caroliniana	0.10	0.0071	0.001	0.00009
Echinochloa walteri	0.05	0.003	0.0005	0.0001
Desmanthus spp.	0.15	0.0107	0.0015	0.0001
Polygonum pennsylvanicum	0.1	0.007	0.001	0.005

Table A.4. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during March 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peplodies	13	0.2766	27.65	17.64	18.74
Carex spp.	11	0.234	23.40	11.76	12.49
Phyla lanceolata	7	0.1489	14.89	17.64	18.74
Hymenocalis caroliniana	5	0.1064	10.63	5.88	6.24
Shoenoplectus califonicus	4	0.0851	8.51	11.76	12.49
Salix nigra	3	0.0638	6.38	5.88	6.24
Eleocharis quadrangulata	2	0.0426	4.25	11.76	12.49
Rumex crispus	1	0.0213	2.12	5.88	6.24
Mikania scandens	1	0.0213	2.12	5.88	6.24

Table A.4 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during March 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peplodies	57	0.50	50.00	63.63	29.16
Carex spp.	23	0.201	20.17	45.45	20.83
Hymenocalis caroliniana	23	0.201	20.17	45.45	20.83
Salix nigra	5	0.043	4.385	36.36	16.66
Eleocharis spp.	4	0.035	3.508	18.18	8.33
Shoenoplectus califonicus	2	0.017	1.75	9.09	4.16

Table A.4 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during March 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Salix nigra	125	0.592	59.24	88.23	38.46
Ludwigia peplodies	56	0.265	26.54	58.82	25.64
Carex spp.	11	0.052	5.21	29.41	12.82
Polygonum hydropiper	7	0.033	3.31	5.88	2.564
Hymenocalis caroliniana	6	0.028	2.84	11.76	5.12
Polygonum hydropiper	1	0.004	0.473	5.882	2.564
Eleocharis spp.	1	0.004	0.473	5.882	2.564
Rumex crispus	1	0.004	0.473	5.882	2.564
Sagittaria spp.	1	0.004	0.473	5.882	2.564
Typha domeingensis	1	0.004	0.473	5.882	2.564
Amaranthus spp.	1	0.004	0.473	5.882	2.564
Eragrotis hypoides	1	0.004	0.473	5.882	2.564

Table A.4 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during March 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peplodies	25	0.3623	36.23	88.88	29.62
Carex spp.	16	0.2319	23.18	66.66	22.22
Hymenocalis caroliniana	8	0.1159	11.59	33.33	11.11
Polygonum hydropiper	7	0.1014	10.14	44.44	14.81
Eleocharis spp.	6	0.087	8.69	22.22	7.47
Salix nigra	5	0.0725	7.246	22.22	7.47
Phyla lanceolata	1	0.0145	1.44	11.11	3.70
Shoenoplectus californicus	1	0.0145	1.44	11.11	3.70

Table A.5. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected March 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peplodies	61.55	3.62	0.615	45.80
Carex spp.	19.15	1.12	0.191	14.25
Phyla lanceolata	10.65	0.626	0.106	7.92
Hymenocalis caroliniana	1.1	0.064	0.011	0.818
Shoenoplectus califonicus	21.30	1.252	0.213	15.85
Salix nigra	9.15	0.538	0.091	6.809
Eleocharis quadrangulata	11.02	0.648	0.110	8.20
Rumex crispus	0.30	0.017	0.003	0.223
Mikania scandens	0.15	0.008	0.0015	0.111

Table A.5 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected March 2005 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peplodies	60.3	5.481	0.603	54.57
Carex spp.	40.0	3.636	0.400	36.19
Hymenocalis caroliniana	7.40	0.672	0.074	6.696
Salix nigra	0.50	0.045	0.005	0.452
Eleocharis spp.	0.70	0.063	0.007	0.633
Shoenoplectus califonicus	1.60	0.145	0.016	1.447

Table A.5 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected March 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Salix nigra	133.45	8.896	1.334	46.25
Ludwigia peplodies	122.50	8.186	1.225	42.46
Carex spp.	23.95	1.596	0.239	8.301
Polygonum hydropiper	1.30	0.086	0.013	0.450
Hymenocalis caroliniana	2.80	0.018	0.028	0.970
Eleocharis spp.	0.20	0.013	0.002	0.069
Rumex crispus	0.30	0.020	0.003	0.103
Sagittaria spp.	0.30	0.020	0.003	0.103
Typha domeingensis	0.20	0.013	0.002	0.069
Amaranthus spp.	1.6	0.106	0.016	0.554
Eragrotis hypoides	1.9	0.126	0.019	0.658

Table A.5 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected March 2005 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peplodies	12.0	1.33	0.12	32.43
Carex spp.	8.3	0.922	0.083	22.43
Hymenocalis caroliniana	1.3	0.144	0.013	3.51
Polygonum hydropiper	3.4	0.377	0.034	9.18
Eleocharis spp.	3.6	0.40	0.036	9.72
Salix nigra	2.8	0.311	0.028	7.56
Phyla lanceolata	0.10	0.011	0.001	0.27
Shoenoplectus californicus	5.5	0.611	0.055	14.86

Table A.6. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peploides	117	0.2056	20.56	95.23	12.57
Polygonum lapathifolium	105	0.1845	18.45	85.71	11.32
Paspalidium geminatum	92	0.1616	16.16	80.95	10.69
Sagittaria spp.	62	0.1089	10.89	76.19	10.06
Echinochloa crus-galli	51	0.0896	8.96	57.14	7.54
Phyla lanceolata	25	0.0439	4.39	47.61	6.28
Shoenoplectus californicus	20	0.0351	3.51	47.61	6.28
Salix nigra	18	0.0316	3.16	47.61	6.28
Carex crus-corvi	14	0.0246	2.46	28.57	3.77
Marsilea spp.	13	0.0228	2.28	33.33	4.40
Polygonum hydropiper	9	0.0158	1.58	19.04	2.51
Chenopodium album	9	0.0158	1.58	23.80	3.14
Rumex crispus	7	0.0123	1.23	23.80	3.14
Echinodorus rostratus	7	0.0123	1.23	23.80	3.14
Eclipta prostate	4	0.0070	0.70	14.28	1.88

Table A.6 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Seteria geniculata	3	0.0052	0.52	9.52	1.25
Mikania scandens	3	0.0052	0.52	4.76	0.62
Xanthium strumarium	2	0.0035	0.351	9.52	1.25
Carex spp.	2	0.0035	0.351	4.76	0.62
Iva annua	2	0.0035	0.351	4.76	0.62
Juncus effusus	1	0.0017	0.175	4.76	0.62
Fraxinus pennsylvanicum	1	0.0017	0.175	4.76	0.62
Hymenocallis caroliniana	1	0.0017	0.0175	4.76	0.62
Cyperus erythrorhizos	1	0.0017	0.0175	4.76	0.062

Table A.6 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2005 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Sagittaria spp.	100	0.1872	18.72	87.5	11.11
Ludwigia peploides	83	0.1554	15.54	87.5	11.11
Polygonum lapathifolium	69	0.1292	12.92	75.0	9.52
Phyla lanceolata	55	0.1029	10.29	62.5	7.9
Carex spp.	46	0.0861	8.61	87.5	11.11
Paspalidium geminatum	37	0.0692	6.92	68.75	8.73
Salix nigra	33	0.0580	5.80	50.0	6.34
Echinodorus rostratus	26	0.0486	4.86	56.25	7.14
Hymenocallis caroliniana	22	0.0411	4.11	37.5	4.76
Echinochloa crus-galli	21	0.0393	3.93	43.75	5.55
Polygonum hydropiper	17	0.0318	3.18	37.5	4.76
Xanthium strumarium	5	0.0093	0.93	12.5	1.58
Rumex crispus	5	0.0093	0.93	12.5	1.58
Eleocharis spp.	4	0.0074	0.74	12.5	1.58
Cardiospermum halicacbum	4	0.0074	0.74	12.5	1.58

Table A.6 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2005 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Desmanthus spp.	4	0.0074	0.74	12.5	1.58
Seteria geniculata	1	0.0018	0.18	6.25	0.79
Cephalanthus occidentalis	1	0.0018	0.018	6.25	0.79
Hibiscus laevis	1	0.0018	0.018	6.25	0.79

Table A.6 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peploides	76	0.4342	43.42	75.0	22.64
Salix nigra	49	0.2800	28.00	62.5	18.86
Carex spp.	12	0.0685	6.857	37.5	11.32
Echinodorus rostratus	12	0.0685	6.857	37.5	11.32
Potamogeton spp.	8	0.0457	4.57	25.0	7.54
Rumex crispus	5	0.0285	2.85	18.75	5.66
Sagittaria spp.	3	0.0171	1.71	18.75	5.66
Polygonum hydropiper	3	0.0171	1.71	12.5	3.77
Hymenocallis caroliniana	2	0.0114	1.14	12.5	3.77
Typha domeingensis	2	0.0114	1.14	12.5	3.77
Seteria geniculata	1	0.0057	0.57	6.25	1.88
Amaranthus spp.	1	0.0057	0.57	6.25	1.88
Elymus repens	1	0.0057	0.57	6.25	1.88

Table A.6 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2005 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peploides	96	0.3529	35.29	100.0	18.46
Sagittaria spp.	63	0.2316	23.16	83.33	15.38
Echinodorus rostratus	35	0.1286	12.86	66.66	12.30
Eclipta prostrate	27	0.0992	9.92	66.66	12.30
Salix nigra	19	0.0698	6.98	50.0	9.23
Carex spp.	8	0.0294	2.94	50.0	9.23
Polygonum hydropiper	6	0.0220	2.20	25.0	4.61
Typha domeingensis	5	0.0183	1.83	16.66	3.07
Hymenocallis caroliniana	3	0.0110	1.10	16.66	3.07
Polygonum lapathifolium	2	0.0073	0.73	8.33	1.53
Echinochloa crus-galli	2	0.0073	0.73	16.66	3.07
Fraxinus pennsylvanicum	2	0.0073	0.73	8.33	1.53
Shoenoplectus californicus	1	0.0036	0.36	8.33	1.53
Rumex crispus	1	0.0036	0.36	8.33	1.53
Cephalanthus occidentalis	1	0.0036	0.36	8.33	1.53
Elymus repens	1	0.0036	0.36	8.33	1.53

Table A.7. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peploides	797.8	37.99	7.978	43.45
Polygonum lapathifolium	377.93	17.99	3.779	20.58
Paspalidium geminatum	175.70	8.366	1.757	9.570
Sagittaria spp.	1.3	0.061	0.013	0.070
Echinochloa crus-galli	89.9	4.28	0.899	4.89
Phyla lanceolata	76.1	3.62	0.761	4.14
Shoenoplectus californicus	55.6	2.64	0.556	3.028
Salix nigra	3.3	0.157	0.033	0.179
Carex crus-corvi	23.9	1.138	0.239	1.301
Marsilea spp.	85.1	4.052	0.851	4.635
Polygonum hydropiper	29.3	1.395	0.293	1.596
Chenopodium album	4.9	0.233	0.049	0.266
Rumex crispus	4.2	0.2	0.042	0.228
Echinodorus rostratus	45.2	2.15	0.452	2.462
Eclipta prostate	2.9	0.138	0.239	1.301

Table A.7 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Seteria geniculata	1.3	0.061	0.013	0.070
Mikania scandens	3.4	0.161	0.034	0.185
Xanthium strumarium	0.1	0.0047	0.001	0.005
Carex spp.	0.9	0.0428	0.009	0.049
Iva annua	4.6	0.219	0.046	0.250
Juncus effusus	3.8	0.180	0.038	0.206
Fraxinus pennsylvanicum	0.8	0.038	0.008	0.043
Hymenocallis caroliniana	0.1	0.004	0.001	0.005
Cyperus erythrorhizos	0.5	0.023	0.005	0.027

Table A.7 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2005 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Sagittaria spp.	37.3	2.331	0.373	6.091
Ludwigia peploides	253.45	15.84	2.534	41.39
Polygonum lapathifolium	98.1	6.131	0.981	16.02
Phyla lanceolata	26.75	1.672	0.267	4.36
Carex spp.	90.0	5.625	0.9	14.69
Paspalidium geminatum	24.65	1.54	0.2465	4.025
Salix nigra	10.6	0.662	0.106	1.73
Echinodorus rostratus	3.15	0.196	0.0315	0.514
Hymenocallis caroliniana	16.95	1.059	0.169	2.768
Echinochloa crus-galli	9.82	0.613	0.981	16.02
Polygonum hydropiper	18.65	1.16	0.186	3.045
Xanthium strumarium	0.95	0.059	0.0095	0.155
Rumex crispus	3.1	0.193	0.031	0.506
Eleocharis spp.	5.8	0.362	0.058	0.947
Cardiospermum halicacbum	0.9	0.056	0.009	0.146

Table A.7 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2005 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Desmanthus spp.	0.65	0.040	0.0065	0.1061
Seteria geniculata	0.5	0.031	0.005	0.081
Cephalanthus occidentalis	0.2	0.0125	0.002	0.032
Hibiscus laevis	0.2	0.0125	0.002	0.032

Table A.7 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peploides	416.5	23.03	4.165	78.28
Salix nigra	23.2	1.45	0.232	4.36
Carex spp.	43.3	2.70	0.433	8.13
Echinodorus rostratus	26.7	1.66	0.267	5.01
Potamogeton spp.	10.4	0.65	0.104	1.95
Rumex crispus	5.7	0.356	0.057	1.07
Sagittaria spp.	0.7	0.043	0.007	0.13
Polygonum hydropiper	1.7	0.106	0.017	0.319
Hymenocallis caroliniana	0.9	0.056	0.009	0.169
Typha domeingensis	2.3	0.143	0.023	0.432
Seteria geniculata	0.1	0.006	0.001	0.018
Amaranthus spp.	0.3	0.018	0.003	0.056
Elymus repens	0.2	0.012	0.002	0.037

Table A.7 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2005 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peploides	307.5	25.625	3.075	60.18
Sagittaria spp.	42.7	3.55	0.427	8.35
Echinodorus rostratus	71.0	5.916	0.71	13.89
Eclipta prostrate	34.9	2.90	0.349	6.83
Salix nigra	8.4	0.7	0.084	1.64
Carex spp.	13.1	1.091	0.131	2.56
Polygonum hydropiper	6.6	0.55	0.066	1.29
Typha domeingensis	7.6	0.633	0.076	1.48
Hymenocallis caroliniana	2.2	0.18	0.022	0.43
Polygonum lapathifolium	1.6	0.133	0.016	0.313
Echinochloa crus-galli	1.6	0.133	0.016	0.313
Fraxinus pennsylvanicum	0.6	0.5	0.006	0.117
Shoenoplectus californicus	11.1	0.925	0.111	2.17
Rumex crispus	0.4	0.033	0.004	0.078
Cephalanthus occidentalis	1.4	0.116	0.014	0.274
Elymus repens	0.2	0.016	0.002	0.039

Table A.8. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Echinochloa crus-galli	107	0.2736	27.36	88.23	14.15
Polygonum lapathifolium	76	0.1943	19.43	94.11	15.09
Ludwigia peploides	48	0.1227	12.27	88.23	14.15
Sagittaria spp.	41	0.1048	10.48	64.70	10.37
Paspalidium geminatum	29	0.0741	7.41	52.94	8.49
Echinochloa walteri	26	0.0664	6.64	47.05	7.54
Leptochloa fascicularis	22	0.0562	5.62	47.05	7.54
Shoenoplectus californicus	11	0.0281	2.81	35.29	5.66
Phyla lanceolata	10	0.0255	2.55	29.41	4.71
Polygonum hydropiper	4	0.0127	1.27	5.88	0.943
Echinodorus rostratus	4	0.010	1.02	17.64	2.83
Typha Domeingensis	4	0.010	1.02	23.52	3.77
Rumex crispus	1	0.0025	0.25	5.88	0.94
Alternanthera philoxeroides	1	0.0025	0.25	5.88	0.94
Carex crus-corvi	1	0.0025	0.25	5.88	0.94

Table A.8 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2005 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Polygonum lapathifolium	35	0.4666	46.66	87.5	25.92
Ludwigia peploides	21	0.2800	28.00	100.0	29.62
Paspalidium geminatum	12	0.1600	16.00	62.50	18.51
Carex spp.	3	0.0400	4.00	37.50	11.11
Salix nigra	2	0.0266	2.66	25.00	7.40
Echinochloa crus-galli	2	0.0266	2.66	25.00	7.40

Table A.8 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Phyla lanceolata	141	0.1676	16.76	64.0	9.75
Echinodorus rostratus	118	0.1403	14.03	80.0	12.19
Salix nigra	104	0.1236	12.36	48.0	7.31
Cyperus erythrorhizos	95	0.1129	11.29	56.0	8.53
Cardiospermum halicacabum	91	0.1082	10.82	60.0	9.14
Echinochloa crus-galli	78	0.0927	9.27	56.0	8.53
Ludwigia peploides	73	0.0868	8.68	80.0	12.19
Paspalidium geminatum	48	0.0570	5.70	56.0	8.53
Xanthium strumarium	22	0.0261	2.61	24.0	3.65
Panicum repens	20	0.0237	2.37	28.0	4.26
Desmanthus spp.	13	0.0154	1.54	20.0	3.04
Rumex crispus	6	0.0071	0.71	8.00	1.21
Polygonum lapathifolium	6	0.0071	0.71	12.00	1.82
Sagittaria spp.	5	0.0059	0.59	4.00	0.609
Carex spp.	4	0.0047	0.47	8.00	1.21
Mikania scandens	3	0.0035	0.35	8.00	1.21

Table A.8 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Sesbania drummondii	3	0.0035	0.35	4.0	0.609
Polygonum hydropiper	3	0.0035	0.35	8.0	1.21
Leptochloa fascicularis	2	0.0023	0.23	8.0	1.21
Carex crus-corvi	2	0.0023	0.23	8.0	1.21
Eleocharis quadrangulata	1	0.0011	0.11	4.0	0.609
Hibiscus laevis	1	0.0011	0.11	4.0	0.609
Hymenocallis caroliniana	1	0.0011	0.11	4.0	0.609
Cephalanthus occidentalis	1	0.0011	0.11	4.0	0.609

Table A.8 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2005 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Sagittaria spp.	39	0.4482	44.82	77.77	19.99
Echinodorus rostratus	16	0.1839	18.39	66.66	17.14
Salix nigra	10	0.1149	11.49	66.66	17.14
Ludwigia peploides	7	0.0804	8.04	55.55	14.28
Echinochloa crus-galli	3	0.0344	3.44	33.33	8.57
Paspalidium geminatum	3	0.0344	3.44	11.11	2.85
Polygonum lapathifolium	2	0.0229	2.29	22.22	5.71
Cephalanthus occidentalis	2	0.0229	2.29	22.22	5.71
Shoenoplectus californicus	2	0.0229	2.29	22.22	5.71

Table A.9. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2005 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Echinochloa crus-galli	79.59	5.30	0.795	4.85
Polygonum lapathifolium	73.03	48.69	7.30	44.53
Ludwigia peploides	49.98	33.32	4.99	30.48
Sagittaria spp.	37.35	2.49	0.373	2.27
Paspalidium geminatum	34.20	2.28	0.342	2.08
Echinochloa walteri	33.50	2.23	0.335	2.04
Leptochloa fascicularis	31.65	2.11	0.316	1.93
Shoenoplectus californicus	43.95	2.93	0.439	2.68
Phyla lanceolata	51.95	3.46	0.519	3.16
Polygonum hydropiper	41.5	2.76	0.415	2.53
Echinodorus rostratus	3.20	0.21	0.032	0.195
Typha domeingensis	9.70	0.646	0.097	0.591
Rumex crispus	0.20	0.013	0.002	0.012
Alternanthera philoxeroides	0.30	0.02	0.003	0.018
Carex crus-corvi	1.00	0.066	0.010	0.060

Table A.9 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2005 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Polygonum lapathifolium	177.5	22.18	1.775	42.18
Ludwigia peploides	221.1	27.63	2.211	52.54
Paspalidium geminatum	17.00	2.125	0.17	4.039
Carex spp.	3.00	0.375	0.03	0.71
Salix nigra	0.20	0.025	0.002	0.047
Echinochloa crus-galli	2.00	0.25	0.02	0.475

Table A.9 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2005 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Phyla lanceolata	353.31	23.55	3.53	16.90
Echinodorus rostratus	194.7	12.98	1.94	9.317
Salix nigra	220.85	14.72	2.208	10.56
Cyperus erythrorhizos	420.8	28.05	4.208	20.13
Cardiospermum halicacabum	116.2	7.74	1.162	5.56
Echinochloa crus-galli	88.01	5.86	0.880	4.21
Ludwigia peploides	613.6	40.906	6.136	29.36
Paspalidium geminatum	30.8	2.053	0.308	1.47
Xanthium strumarium	11.0	0.733	0.11	0.526
Panicum repens	0.50	0.033	0.005	0.239
Desmanthus spp.	4.66	0.310	0.046	0.223
Rumex crispus	2.65	0.176	0.0265	0.126
Polygonum lapathifolium	2.15	0.143	0.0215	0.102
Sagittaria spp.	1.32	0.088	0.0132	0.063
Carex spp.	0.90	0.06	0.009	0.043

Table A.9 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2005 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Sagittaria spp.	113.2	12.57	1.132	46.52
Echinodorus rostratus	61.9	6.87	0.619	25.44
Salix nigra	3.0	0.33	0.03	1.23
Ludwigia peploides	27.1	3.01	0.271	11.13
Echinochloa crus-galli	3.9	0.433	0.039	1.60
Paspalidium geminatum	5.4	0.60	0.054	2.21
Polygonum lapathifolium	19.7	2.18	0.197	8.09
Cephalanthus occidentalis	1.2	0.133	0.012	0.49
Shoenoplectus californicus	6.4	0.711	0.064	2.63

Table A.10. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2006 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Sagittaria spp.	82	0.3082	30.82	85.71	20.00
Ludwigia peploides	40	0.1503	15.03	61.90	14.44
Echinochloa crus-galli	32	0.1203	12.03	47.61	11.11
Paspalidium geminatum	29	0.1090	10.90	52.38	12.22
Polygonum lapathifolium	22	0.0827	8.27	38.09	8.88
Shoenoplectus californicus	22	0.0827	8.27	38.09	8.88
Phyla lanceolata	13	0.0488	4.88	19.04	4.44
Ammania coccinea	9	0.0338	3.38	23.80	5.55
Polygonum hydropiper	5	0.0187	1.87	4.76	1.11
Eleocharis spp.	3	0.0112	1.12	9.52	2.22
Leptochloa fascicularis	3	0.0112	1.12	9.52	2.22
Eclipta prostrata	2	0.0075	0.75	9.52	2.22
Mikania scadens	1	0.0037	0.37	4.76	1.11
Typha domeingensis	1	0.0037	0.37	4.76	1.11
Alternanthera philoxeroides	1	0.0037	0.37	4.76	1.11
Potamogetan spp.	1	0.0037	0.37	4.76	1.11

Table A.10 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2006 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peploides	32	0.4155	41.55	54.54	22.22
Sagittaria spp.	11	0.1428	14.28	45.45	18.51
Carex spp.	9	0.1168	11.68	27.27	11.11
Paspalidium geminatum	8	0.1038	10.38	36.36	14.81
Phyla lanceolata	7	0.0909	9.09	27.27	11.11
Polygonum lapathifolium	4	0.0519	5.194	9.09	3.703
Mikania scadens	3	0.0389	3.89	18.18	7.407
Shoenoplectus californicus	1	0.0129	1.29	9.09	3.703
Eleocharis spp.	1	0.0129	1.29	9.09	3.703
Echinodorus rostratus	1	0.129	1.29	9.09	3.703

Table A.10 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2006 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peploides	38	0.3166	31.66	60.0	20.93
Paspalidium geminatum	24	0.2000	20.00	46.66	11.62
Echinochloa crus-galli	17	0.1416	14.16	33.33	16.27
Sagittaria spp.	12	0.1000	10.00	33.33	11.62
Phyla lanceolata	6	0.0500	5.00	13.33	4.65
Potamogeton spp.	6	0.0500	5.00	26.66	9.30
Carex spp.	4	0.0333	3.33	26.66	9.30
Polygonum hydropiper	4	0.0333	3.33	6.66	2.32
Eleocharis spp.	3	0.025	2.5	13.33	4.65
Echinodorus rostratus	3	0.025	2.5	13.33	4.65
Leptochloa fascicularis	2	0.016	1.66	6.66	2.32
Polygonum lapathifolium	1	0.0083	0.833	6.66	2.32

Table A.10. Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during May 2006 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Sagittaria spp.	51	0.6891	68.91	91.66	39.28
Ludwigia peploides	11	0.1486	14.86	66.66	28.57
Shoenoplectus californicus	4	0.0540	5.405	25.00	10.71
Hymenocallis caroliniana	3	0.0405	4.05	8.33	3.57
Echinochloa crus-galli	2	0.0270	2.70	16.66	7.14
Cephalanthus occidentalis	1	0.0135	1.35	8.33	3.57
Typha domeingensis	1	0.0135	1.35	8.33	3.57
Ammania coccinea	1	0.0135	1.35	8.33	3.57

Table A.11. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2006 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Sagittaria spp.	280.01	13.33	2.80	42.56
Ludwigia peploides	82.17	3.913	0.821	12.49
Echinochloa crus-galli	76.6	3.647	0.766	11.64
Paspalidium geminatum	34.4	1.638	0.344	5.229
Polygonum lapathifolium	32.7	1.557	0.327	4.971
Shoenoplectus californicus	91.0	4.333	0.91	13.83
Phyla lanceolata	20.3	0.966	0.203	3.086
Ammania coccinea	2.10	0.1	0.021	0.319
Polygonum hydropiper	13.1	0.623	0.131	1.991
Eleocharis spp.	2.81	0.133	0.028	0.427
Leptochloa fascicularis	3.0	0.142	0.03	0.456
Mikania scadens	4.6	0.219	0.046	0.699
Typha domeingensis	6.6	0.314	0.066	1.003
Alternanthera philoxeroides	0.1	0.004	0.001	0.015
Potamogetan spp.	4.4	0.209	0.044	0.668

Table A.11 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2006 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peploides	121.7	11.06	1.217	51.02
Sagittaria spp.	36.2	3.29	0.362	15.17
Carex spp.	26.8	2.43	0.268	11.23
Paspalidium geminatum	7.9	0.718	0.079	3.312
Phyla lanceolata	18.9	1.718	0.189	7.92
Polygonum lapathifolium	10.0	0.909	0.10	4.19
Mikania scadens	14.8	1.345	0.148	6.205
Shoenoplectus californicus	1.20	0.109	0.012	0.503
Eleocharis spp.	0.70	0.063	0.007	0.293
Echinodorus rostratus	0.30	0.027	0.003	0.125

Table A.11 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2006 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peploides	128.55	8.57	1.285	52.38
Paspalidium geminatum	16.55	1.103	0.165	6.74
Echinochloa crus-galli	23.3	1.55	0.233	9.49
Sagittaria spp.	13.4	0.893	0.134	5.46
Phyla lanceolata	11.1	0.74	0.111	4.52
Potamogeton spp.	1.60	0.106	0.016	0.651
Carex spp.	10.9	0.726	0.109	4.441
Polygonum hydropiper	17.5	1.16	0.175	7.13
Eleocharis spp.	11.7	0.78	0.117	4.76
Echinodorus rostratus	1.1	0.073	0.011	0.448
Leptochloa fascicularis	6.30	0.42	0.063	2.56
Polygonum lapathifolium	3.40	0.226	0.034	1.38

Table A.11 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected May 2006 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Sagittaria spp.	612.9	51.825	6.219	91.14
Ludwigia peploides	28.50	2.375	0.285	4.177
Shoenoplectus californicus	25.1	2.091	0.251	3.678
Hymenocallis caroliniana	1.7	0.141	0.017	0.249
Echinochloa crus-galli	1.7	0.141	0.017	0.249
Cephalanthus occidentalis	0.50	0.0416	0.005	0.073
Typha domeingensis	2.70	0.225	0.027	0.395
Ammania coccinea	0.20	0.016	0.002	0.029

Table A.12. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2006 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Polygonum lapathifolium	161	0.2588	25.88	100.0	14.59
Echinochloa crus-galli	157	0.2524	25.24	100.0	14.59
Lepthochloa fascicularis	74	0.1190	11.90	90.0	13.13
Phyla laceolata	44	0.0707	7.07	50.0	7.29
Carex spp.	43	0.0691	6.91	55.0	8.02
Cyperus erythtothizos	32	0.0514	5.14	30.0	4.37
Paspalidium geminatum	24	0.0386	3.86	35.0	5.10
Ludwigia peploides	22	0.0354	3.54	50.0	7.29
Shoenoplectus californicus	21	0.0338	3.38	45.0	6.56
Echinochloa walteri	9	0.0145	1.45	15.0	2.18
Ammania coccinea	6	0.0096	0.96	15.0	2.18
Xanthium strumarium	6	0.0096	0.96	15.0	2.18
Eragrostis hypoides	5	0.0080	0.80	10.0	1.45
Alternathera philoxeroides	3	0.0048	0.48	10.0	1.45
Eleocharis spp.	3	0.0048	0.48	5.0	0.72

Table A.12 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2006 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Sagittaria spp.	2	0.0032	0.32	10.0	1.45
Eclipta prostatus	2	0.0032	0.32	10.0	1.45
Cardiospermum halicacabum	2	0.0032	0.32	10.0	1.45
Salix nigra	1	0.0016	0.16	5.0	0.72
Chenopodium album	1	0.0016	0.16	5.0	0.72
Polygonum pennsylvanicum	1	0.0016	0.16	5.0	0.72
Fraxinus pennsylvanicum	1	0.0016	0.16	5.0	0.72

Table A.12 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2006 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peploides	18	0.3273	32.73	33.33	16.66
Sagittaria spp.	15	0.2727	27.27	33.33	16.66
Phyla laceolata	5	0.0909	9.09	22.22	11.11
Mikania scandens	4	0.727	7.27	22.22	11.11
Polygonum lapathifolium	3	0.545	5.45	22.22	11.11
Carex spp.	3	0.545	5.45	22.22	11.11
Paspalidium geminatum	3	0.545	5.45	11.11	5.55
Carex crus-corvi	2	0.0364	3.64	11.11	5.55
Potamogenton spp.	1	0.0182	1.82	11.11	5.55
Echinochloa crus-galli	1	0.0182	1.82	11.11	5.55

Table A.12 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2006 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Ludwigia peploides	30	0.2941	29.41	66.66	24.99
Sagittaria spp.	16	0.1569	15.68	46.66	17.49
Echinochloa crus-galli	16	0.1569	15.68	20.0	7.49
Paspalidium geminatum	13	0.1275	12.75	26.66	9.99
Echinodorus rostratus	7	0.0686	6.86	26.66	9.99
Polygonum hydropiper	6	0.0588	5.88	13.33	4.99
Echinochloa walteri	5	0.049	4.90	20.00	7.49
Phyla laceolata	3	0.0294	2.94	13.33	4.99
Potamogenton spp.	3	0.0294	2.94	13.33	4.99
Typha domeingensis	1	0.0098	0.98	6.66	2.49
Lepthochloa fascularis	1	0.0098	0.98	6.66	2.49
Eleocharis spp.	1	0.0098	0.98	6.66	2.49

Table A.12 Continued. Density, relative density, frequency, and relative frequency of moist-soil plant species collected during August 2006 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	*N*	Density	Relative Density	Frequency	Relative Frequency
Sagittaria spp.	50	0.5263	52.63	100.0	30.00
Ludwigia peploides	23	0.2421	24.21	88.88	26.66
Echinochloa crus-galli	8	0.0842	8.42	33.33	10.00
Zizaniopsis millaceae	4	0.0421	4.21	22.22	6.66
Polygonum lapathifolium	2	0.0211	2.11	11.11	3.33
Mikania scandens	2	0.0211	2.11	11.11	3.33
Phyla laceolata	1	0.0105	1.05	11.11	3.33
Polygonum hydropiper	1	0.0105	1.05	11.11	3.33
Carex spp.	1	0.105	1.05	11.11	3.33
Ammania coccinea	1	0.105	1.05	11.11	3.33
Shoenoplectus claifornicus	1	0.0105	1.05	11.11	3.33
Eleocharis spp.	1	0.0105	1.05	11.11	3.33

Table A.13. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2006 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Polygonum lapathifolium	661.4	33.07	6.614	34.80
Echinochloa crus-galli	409.2	20.46	4.092	21.53
Lepthochloa fascicularis	197.35	9.86	1.973	10.38
Phyla laceolata	134.25	6.71	1.342	7.06
Carex spp.	86.0	4.3	0.86	4.52
Cyperus erythtothizos	130.7	6.53	1.307	6.87
Paspalidium geminatum	51.3	2.56	0.513	2.69
Ludwigia peploides	63.8	3.19	0.638	3.35
Shoenoplectus californicus	113.7	5.68	1.137	5.98
Echinochloa walteri	3.7	0.185	0.037	0.194
Ammania coccinea	2.2	0.11	0.022	0.115
Xanthium strumarium	4.35	0.217	0.043	0.228
Eragrostis hypoides	7.65	0.382	0.076	0.402
Alternathera philoxeroides	6.5	0.325	0.076	0.402
Eleocharis spp.	11.1	0.555	0.111	0.584

Table A.13 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2006 in moist-soil managed wetland 1 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Sagittaria spp.	0.1	0.005	0.001	0.005
Eclipta prostatus	5.2	0.26	0.052	0.273
Cardiospermum halicacabum	1.5	0.075	0.015	0.078
Salix nigra	0.9	0.045	0.009	0.047
Chenopodium album	0.1	0.005	0.001	0.005
Polygonum pennsylvanicum	0.8	0.04	0.008	0.042
Fraxinus pennsylvanicum	0.2	0.01	0.002	0.010

Table A.13 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2006 in moist-soil managed wetland 2 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peploides	100.9	11.21	1.009	40.83
Sagittaria spp.	77.8	8.64	0.778	31.48
Phyla laceolata	9.5	1.05	0.095	3.84
Mikania scandens	24.3	2.70	0.243	9.83
Polygonum lapathifolium	8.30	0.92	0.083	3.35
Carex spp.	19.1	2.12	0.191	7.72
Paspalidium geminatum	4.20	0.46	0.042	1.69
Carex crus-corvi	1.0	0.11	0.01	0.40
Potamogenton spp.	0.70	0.077	0.007	0.283
Echinochloa crus-galli	1.3	0.14	0.013	0.526

Table A.13 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2006 in moist-soil managed wetland 3 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Ludwigia peploides	427.05	28.47	4.270	63.78
Sagittaria spp.	84.60	5.64	0.846	12.63
Echinochloa crusgalli	43.4	2.89	0.434	6.48
Paspalidium geminatum	30.95	2.06	0.3095	4.62
Echinodorus rostratus	5.8	0.38	0.058	0.86
Polygonum hydropiper	11.8	0.78	0.118	1.76
Echinochloa walteri	40.7	2.71	0.407	6.07
Phyla laceolata	16.5	1.10	0.165	2.46
Potamogenton spp.	2.35	0.15	0.023	0.35
Typha domeingensis	0.30	0.02	0.003	0.04
Lepthochloa fascularis	2.3	0.15	0.023	0.34
Eleocharis spp.	3.8	0.25	0.038	0.56

Table A.13 Continued. Absolute dominance, surface area covered, and relative dominance of moist-soil plant species collected August 2006 in moist-soil managed wetland 4 on Richland Creek Wildlife Management Area, east-central Texas.

Species	Absolute Dominance / ha	Absolute Dominance / Sample	Surface Area Covered	Relative Dominance
Sagittaria spp.	468.6	52.06	4.686	72.54
Ludwigia peploides	103.4	11.48	1.034	16.00
Echinochloa crus-galli	21.6	2.4	0.216	3.34
Zizaniopsis millaceae	7.40	0.822	0.074	1.14
Polygonum lapathifolium	3.70	0.411	0.037	0.57
Mikania scandens	3.30	0.366	0.033	0.519
Phyla laceolata	1.20	0.133	0.012	0.185
Polygonum hydropiper	0.60	0.066	0.006	0.092
Carex spp.	1.10	0.122	0.011	0.170
Ammania coccinea	0.20	0.022	0.002	0.030
Shoenoplectus claifornicus	32.6	3.62	0.326	5.04
Eleocharis spp.	2.20	0.244	0.022	0.340

Table A.14. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
			Wetland 1			
Algae	6.73	--	--	--	--	7.50
Aster spp.	11.54	--	--	--	--	--
Azolla carolinia	--	--	--	--	20.38	16.58
Carex crus-corvi	--	--	0.58	--	--	--
Carex spp.	--	0.19	--	1.35	--	1.42
Cyperus erythrorhizos	1.73	--	--	--	--	--
Desmanthus spp.	0.15	--	--	--	--	--
Duckweed	0.08	0.07	0.16	1.79	1.45	1.22
Echinochloa crus-galli	--	--	--	6.73	--	0.27
Echinochloa walteri	--	--	--	5.95	--	--
Echinodorus rostrus	1.58	--	--	--	--	--
Eclipta	0.54	--	--	--	--	--
Eleocharis quadrangulata	0.01	2.88	1.35	--	--	--
Hibiscus	0.001	--	--	--	--	--

Hymenoclias carolinia	0.001	0.19	0.19	--	0.08	--

Table A.14. Continued. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
			Wetland 1			
Ludwigia peploides	8.35	0.27	23.27	26.35	--	15.24
Mikania scandens	--	0.08	0.58	6.73	--	0.41
Panicum repens	--	1.38	7.04	2.88	--	--
Paspalidium geminatum	0.01	--	11.73	--	--	--
Phyla lancelota	5.96	0.08	8.65	--	--	2.62
Polygonum lapathifolium	7.15	--	7.00	32.88	--	40.52
Rumex crispus	0.08	--	--	--	--	--
Sagittaria spp.	2.88	--	--	0.19	--	--
Sauruus cernuus	0.73	--	--	--	--	--
Shoenoplectus californicus	6.73	--	--	8.92	--	8.95
Typha domeingensis	--	--	--	2.88	--	5.21

Table A.14. Continued. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
			Wetland 2			
Aster spp.	0.04	--	--	--	--	--
Azolla carolinia	--	6.64	--	--	--	--
Bermuda	--	--	0.35	--	--	--
Cardiospermum halicacabum	--	--	0.11	--	--	--
Carex crus-corvi	--	0.83	--	--	--	--
Carex spp.	--	1.78	8.45	9.52	3.57	10.50
Clover	--	--	0.95	--	--	--
Cyperus erythrorhizos	9.09	--	--	--	--	--
Desmanthus spp.	0.41	--	0.16	--	--	--
Duckweed	4.40	--	--	--	--	--
Echinochloa crus-galli	--	--	0.47	--	--	--
Echinochloa walteri	0.04	--	--	0.04	--	0.11
Echinodorus rostrus	1.07	--	0.59	--	--	--
Eclipta	0.11	--	0.35	--	--	--

Table A.14. Continued. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
			<u>Wetland 2</u>			
Eleochairs quadrangulata	0.04	--	--	--	0.11	--
Hibiscus	1.78	--	--	--	--	--
Hymenoclias carolinia	0.23	0.35	1.78	--	--	--
Ludwigia peploides	19.61	2.54	8.92	13.69	0.11	18.24
Mikania scandens	--	--	--	--	0.04	0.41
Panicum repens	3.09	3.83	--	0.83	--	--
Paspalidium geminatum	1.78	--	6.78	--	--	--
Phyla lancelota	3.61	--	2.66	3.61	--	2.39
Polygonum lapathifolium	0.23	--	13.21	30.76	--	5.23
Rumex crispus	0.04	--	1.78	0.11	--	--
Sagittaria spp.	9.97	1.40	4.97	--	2.57	3.30
Salix nigra	--	0.04	0.04	--	--	--
Sauruus cernuus	0.83	--	--	--	--	--
Shoenoplectus californicus	0.04	--	--	5.21	--	5.89

Table A.14. Continued. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
Wetland 3						
Algae	--	11.39	14.58	--	3.64	--
Azolla carolinia	--	--	--	--	3.20	--
Cardiospermum halicacabum	--	--	--	1.68	--	--
Carex crus-corvi	--	--	--	--	0.72	--
Carex spp.	--	--	--	6.77	0.31	--
Clover	0.31	0.31	0.31	--	--	--
Cyperus erythrorhizos	8.95	031	0.10	8.33	--	--
Desmanthus spp.	--	--	--	0.56	--	--
Duckweed	3.64	--	--	3.64	--	--
Echinochloa crus-galli	--	--	0.04	0.64	--	0.21
Echinochloa walteri	0.93	--	--	--	--	--
Echinodorus rostrus	2.39	--	--	18.8	--	22.0
Eleocharis quadrangulata	--	0.72	0.20	0.20	0.31	--
Hymenoclias carolinia	0.10	--	0.41	0.12	--	--

Juncus effuses	--	--	0.31	--	--	--

Table A.14. Continued. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
			Wetland 3			
Leptochloa	--	--	--	--	0.08	--
Ludwigia peploides	5.31	0.95	6.81	32.70	1.39	35.61
Mikania scandens	--	0.04	--	0.72	--	--
Panicum repens	1.66	0.08	--	--	--	--
Paspalidium geminatum	6.45	--	3.22	0.25	--	1.03
Phyla lancelota	0.62	--	3.37	3.16	--	--
Polygonum lapathifolium	0.10	--	--	--	--	--
Rumex crispus	--	--	--	--	0.10	--
Sagittaria spp.	0.52	--	--	--	--	2.49
Salix nigra	--	7.06	4.31	5.20	0.10	--
Typha domeingensis	--	--	0.104	2.54	--	5.13
Xanthium	--	--	0.10	--	--	--

Table A.14. Continued. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
			Wetland 4			
Algae	--	33.65	--	--	7.30	--
Aster spp.	0.07	--	--	--	--	--
Azolla carolinia	--	--	--	--	10.26	19.61
Carex crus-corvi	--	--	0.19	0.57	1.34	--
Carex spp.	0.19	0.19	--	--	--	--
Desmanthus spp.	2.88	--	--	--	--	--
Duckweed	24.42	--	14.00	40.8	--	42.35
Echinochloa walteri	1.34	--	--	--	--	--
Echinodorus rostrus	7.19	--	8.26	20.19	--	30.57
Eclipta	0.07	--	0.26	--	--	--
Eleocharis quadrangulata	6.73	1.34	6.73	--	0.07	--
Hibiscus	0.07	--	--	--	--	--

Hymenoclias carolinia	0.07	0.19	0.19	--	0.08	--

Table A.14. Continued. Percent cover (%) of moist-soil plant species found in moist-soil managed wetlands 1-4 on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Percent Cover (%)					
Species	August 2004	March 2005	May 2005	August 2005	March 2006	August 2006
			Wetland 4			
Ludwigia peploides	0.76	2.19	2.34	7.38	1.88	8.94
Mikania scandens	--	--	0.19	--	--	--
Panicum repens	5.76	--	--	--	--	--
Paspalidium geminatum	0.07	--	--	--	--	--
Phyla lancelota	6.34	--	12.69	0.07	--	--
Polygonum hydropiper	--	--	0.19	--	--	--
Polygonum lapathifolium	3.07	--	--	--	--	--
Rumex crispus	0.07	--	--	--	--	--
Sagittaria spp.	1.19	0.07	0.57	1.53	0..56	3.72
Sauruus cernuus	0.07	--	--	--	--	--
Shoenoplectus californicus	0.57	--	--	--	--	1.29
Typha domeingensis	--	0.57	1.88	--	--	--

Table A.15. Diversity indices on moist-soil managed wetlands 1-4 found on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Simpson's Diversity Index	Simpson's Diversity Index	Shannon-Wiener Diversity Index
Wetland 1			
March 05	0.8211	5.592	2.742
May 05	0.8713	7.773	3.411
May 06	0.8380	6.175	3.051
Aug 04	*na*	*na*	*na*
Aug 05	0.8462	6.503	3.107
Aug 06	0.8382	6.183	3.159
Wetland 2			
March 05	0.6651	2.986	1.901
May 05	0.8908	9.164	3.508
May 06	0.7694	4.337	2.591
Aug 04	0.8355	6.081	3.062
Aug 05	0.6752	3.078	1.914
Aug 06	0.7940	4.855	2.698

Table A.15. Continued. Diversity indices on moist-soil managed wetlands 1-4 found on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

	Simpson's Diversity Index	Simpson's Diversity Index	Shannon-Wiener Diversity Index
Wetland 3			
March 05	0.5738	2.346	1.706
May 05	0.7197	3.568	2.393
May 06	0.8208	5.581	2.902
Aug 04	0.8495	6.664	3.166
Aug 05	0.8913	9.203	3.480
Aug 06	0.8354	6.077	2.950
Wetland 4			
March 05	0.7779	4.504	2.472
May 05	0.7884	4.727	2.722
May 06	0.4970	1.988	1.586
Aug 04	0.8146	5.394	2.973
Aug 05	0.7403	3.851	2.497
Aug 06	0.6539	2.889	2.125

Table A.16. Type III *F* and *P* values from analysis of variance of vegetative characteristics collected on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

Model Structure	SS	df	*F*	*P*
Overall Absolute dominance / ha				
Model	1127650.6	63	1.49	0.0171
Error	3126572.5	260		
Absolute dominance / ha				
Year	37089.42	2	1.54	0.2159
Month	66831.98	3	1.85	0.1381
Cell	151199.4	3	4.19	0.0064
Species	1010421.2	55	1.53	0.0157
Overall Absolute dominance / sample				
Model	11924.1	63	1.49	0.0171
Error	27199.5	260		
Absolute dominance /sample				
Year	84.77	2	0.72	0.4870
Month	234.3	3	1.33	0.2651
Cell	161.09	3	0.91	0.4347
Species	11497.4	55	3.49	0.0001
Overall Surface area covered				
Model	125.45	64	1.63	0.0043
Error	312.65	260		
Surface area covered				
Year	3.709	2	1.54	0.2158
Month	6.683	3	1.85	0.1381
Cell	15.120	3	4.19	0.0064
Species	112.22	56	1.67	0.0043

Table A.16 Continued. Type III *F* and *P* values from analysis of variance of vegetative characteristics collected on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

Model Structure	SS	df	*F*	*P*
Overall Relative Dominance				
Model	28073.2	64	3.01	0.0001
Error	37930.9	260		
Relative Dominance				
Year	206.51	2	0.71	0.4937
Month	438.09	3	1.00	0.3929
Cell	210.53	3	0.48	0.6957
Species	25491.4	56	3.12	0.0001

Table A.17. Least means separation results of dominance, surface area covered, and relative dominance using month, year, and moist-soil wetlands on Richland Creek Wildlife Management Area, east-central Texas 2004-2006.

Variable	Absolute Dominance/ Hectare	Absolute Dominance Sample	Surface Area Covered	Relative Dominance
Month				
March	-41.392	-0.566	-0.353	7.244
May	5.643	2.015	0.117	2.476
June	36.237	4.020	0.423	1.778
August	36.237	4.020	0.423	1.778
Year				
2004	12.813	2.894	0.188	1.601
2005	25.074	2.814	0.311	3.693
2006	-10.342	1.407	-0.042	4.662
Cell				
One	47.163	3.350	0.532	2.160
Two	-20.001	1.256	-0.139	4.214
Three	9.088	2.052	0.151	4.199
Four	0.475	2.829	0.065	2.703

APPENDIX B

ESTIMATING DUCK USE DAYS OF MOIST-SOIL MANAGED WETLANDS

LOCATED IN EAST-CENTRAL TEXAS

INTRODUCTION

Within a year waterfowl will experience events (i.e., migration, molt, and reproduction) that demand energy and other nutritional requirements above the maintenance level. These processes influence the resources needed as well as the need for high quality habitat availability (Fredrickson and Taylor 1982). Many have suggested that wintering waterfowl sustain themselves on a carbohydrate rich diet of mostly seeds and submerged aquatic vegetation (Bardwell et al. 1962, Junca et al. 1962, Winslow 2001). These carbohydrate rich seeds are a means of lipid accumulation (Blem 1976, Miller 1987, Anderson and Smith 1999). However, current research has also documented the importance of aquatic invertebrates to migrating and wintering waterfowl which provides an essential source of protein (Krapu and Reinecke 1992, Anderson and Smith 1998). B ecause of the dynamics associated with waterfowl management, biologist need to better understand how these two variables (i.e., seeds and invertebrates) influence waterfowl to determine habitat quality as well as quantity of food available to waterfowl during migration and wintering periods.

The idea of carrying capacity and duck-use days (DUD) incorporates quality and quantity of food provided within wetland habitats over a period of time (Prince 1979, Haukos and Smith 1993, Anderson and Smith 1998, Brasher et al. 2007). By predicting DUD waterfowl managers can select the best management practice(s) (BMP) on site to maintain or increase its conservation value (Sutherland and Allport 1994; Goss-Custard et al. 2003), and understanding how waterfowl use resources managers are able to attract and hold waterfowl on managed habitats (Brasher et al 2007). Monocultures should be avoided, whether natural plant communities (such as large expanses of dense cattail) or agricultural crops (Fredrickson and Taylor 1982).

Moist-soil managed wetlands and management techniques have become a significant practice within the waterfowl community because both seed producing plants and aquatic invertebrates provide habitat, energy, and other nutritive requirements for wetland dependent wildlife (Fredrickson and Taylor 1982, Haukos and Smith 1993, Lane and Jensen 1999, Strader and Stinson 2005). Moist-soil managed wetlands have been shown to be of value for many waterfowl species if they are properly managed (Haukos and Smith 1993, Anderson 1994, Brasher et al. 2007). Moist-soil plants provide seeds for consumption, attachment sites for aquatic invertebrates, and after desiccation detritus for aquatic invertebrates to feed on (Haukos and Smith 1993, Anderson and Smith 1998 and 1999). The seeds themselves have low deterioration rates after flooding and provide energy and nutrients in higher capacity then in common agricultural grains (Anderson and Smith 1998, Strader and Stinson 2005). Correct moist-soil management techniques will promote production of naturally occurring moist-soil plant seed producing species and aquatic invertebrates by emulating and manipulating natural wetland wet/dry cycles (i.e., flooding and drawdown) (Fredrickson and Taylor 1982, Smith et al. 1989, Haukos and Smith 1993, Lane and Jensen 1999, Strader and Stinson 2005).

Typically in southern climates slow drawdown (i.e., removal of water) occurs mid spring (March-April) through the end of the summer months (August-September), while flooding occurs from fall (i.e., September-October) through early spring (i.e., March-April). Slow drawdown of water during the spring and summer months allows wetland managers to provide foraging habitat to migrant shorebird and wading bird species, while early flooding in September provides wetland habitat to early migrating waterfowl species such as blue-winged teal (*Anas discors*). Successional stages of a vegetative area and climax of invertebrate production can also be manipulated by this water manipulation technique. Fredrickson and Taylor (1982) suggested to maximize the ability of a moist-soil managed wetland, depth and timing of inundation (i.e., flooding) and drawdown (i.e., water removal) should be done with migrating bird phenology in mind.

The objectives of this portion of the research were to (1) determine DUD’s of 4 moist-soil managed wetlands found on Richland Creek Wildlife Management Area and (2) compare DUD’s between and among moist-soil managed wetland cells as well as seeds v. aquatic invertebrates over a 3 year period of data collection to allow for proper timing and management decisions on the wildlife management area.

STUDY AREA

This research was conducted on the Richland Creek Wildlife Management Area's (RCWMA) North Unit moist-soil managed wetlands 1-4 (Figure 1.1). The RCWMA (31º13'N, 96º11'W) is located 40 km southeast of Corsicana, Texas, along U.S. highway 287 and FM 488 between Richland-Chambers Reservoir and the Trinity River in Freestone and Navarro counties, Texas (Figure 1.2). The WMA contains two units (North and South) (Figure 1.3) encompassing 6,271 ha located in the ecotone separating the Post Oak Savannah and Blackland Prairie ecological regions (TPWD 2005) and lies almost entirely within the Trinity River floodplain. Management of RCWMA moist-soil managed wetlands is a cooperative effort between the Texas Parks and Wildlife Department and the Tarrant County Regional Water District. Constructed moist-soil managed treatment wetlands were aligned as a chain (Figure 1.1) to allow independent water manipulation among cells to provide (1) suitable wetland habitat for wetland dependent species and (2) clean water from the Trinity River prior to delivery to Richland Chambers Reservoir. Four of sixteen proposed moist-soil managed wetlands covering approximately 257 ha have been functioning since January 2003. During the course of this research moist-soil managed wetland units 1-4 were fully functional. Construction of moist-soil managed wetland units 5-6 began in the summer 2006 and have been functioning since November 2009.

Local climate is considered subtropical with mild winters and warm humid summers, with an average daily summer temperature of 34º C and winter temperature of 5º C, a growing season of 246 days, and average rainfall of 101.6 cm a year (NRCS

2002). Rainfall is typically distributed evenly throughout the year. Soils on the area are predominately of the Trinity series, which are fine, montmorillonitic, thermic, very haplaquolls, and mollisol soils (NRCS 2002).

Vegetation within the South Unit (Figure 1.4) is characterized by vast bottomland hardwood forest (BHF) communities dominated by Eastern red cedar (*Juniperus virginiana*), sugarberry (*Celtis laevigata*), and green ash (*Fraxinus pennsylvanica*). Other species include honey locust (*Gleditisia triacanthos*), boxelder (*Acer negundo*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), water oak (Q. *nigra*), overcup oak (*Q. lyrata*), willow oak (*Q. phellos*), and pecan (*Carya illinoensis*).

The North Unit (Figure 1.5) contains the moist-soil managed wetlands, which are large non-forested areas characterized by a diverse herbaceous community. The typical water management strategy consists of slow drawdown (i.e., removal of water) starting late March - early April and lasting until mid August. Inundation (i.e., flooding) begins in late August and lasts throughout fall and winter, until drawdown the following spring. These management actions produced common species such as barnyardgrass, erect burhead (*Echinodorus* spp.), delta duck potato (*Sagittaria* spp.), square-stem spike rush (*Eleocharis quadrangulata*), wild millet, and water primrose (*Ludwigia peploides*) (Appendix A).

METHODS

Invertebrates

Aquatic and benthic invertebrates were collected twice monthly from April 2004 to May 2007 in each moist-soil managed wetland, when water was present. A 150 m transect was randomly placed in each wetland cell and invertebrates were collected every 10 m. At each point, two 5-cm diameter water column samples were collected run through a 4.5mm sieve to allow for the assortment of aquatic invertebrate(s) and then into appropriately labeled vials and filled with alcohol for preservation. Aquatic invertebrate(s) samples were then transported to the lab, refrigerated, sorted and identified to the lowest taxonomic level possible. Once identified samples were weighed to the nearest gram (i.e., wet weight) and then dried in an oven at 75º F for at least 24 hrs and weighed after drying (i.e., dry weight) to obtain total grams available.

Vegetation

Samples used for regression model construction (see Chapter III) using the phytomorphological technique (Laubhan and Fredrickson 1992) and vegetative data collected (see Appendix A) were used to determine the amount of area beneficial species occurred and how much did they produce. The phytomorphological technique data were obtained by randomly placing a 0.0625-m^2 sample frame in monotypic stands of targeted moist-soil wetland plants (i.e., barnyard grass, wild millet, jungle rice, and rice), at each study site in August / September 2004/2005. Morphological features were measured on the “average” plant within each plot: plant height (cm), inflorescence height (cm), inflorescence diameter (cm), total number of inflorescence present (#), and inflorescence volume (cm^3) as well as other calculations that include the average mass of seed on each seed head found within the sample frame (SSHD) and standardized group values associated with # of seed heads present (GV1) and average mass per seed head (GV2). After field data were collected, inflorescence within the plot were clipped and placed into a brown paper bag, which were air dried for at least two weeks at room temperature (20°C). Once dry, all seeds were threshed and measured to the nearest 0.1g, oven dried at 50ºC for >24 hrs, and then re-measured to the nearest 0.1g. Dry seed mass was the difference between wet mass and dry mass.

Wetland vegetative characteristics were quantified using the line intercept method to estimate plant species occurrence, dominance, density, and percent cover. Three transects were systematically located lengthwise within each moist-soil managed wetland. One transect was in the approximate middle, and the second two transects were located 50 m from the moist-soil managed wetland edges.

Along each 100-m transect any plant that fell under the tape was recorded from the start of the plant to the end of the plant in order to create a stand of the species, allowing species percent cover, frequency, density, and dominance to be measured. Vegetative percent cover (%) within each moist-soil managed wetland was calculated by dividing the total length (cm) intercepted by a species by total transect lengths multiplied by 100. Species frequency (%) was calculated by dividing the intervals in which a species occurs by the total number of intercept intervals sampled and multiplied by 100. Species density (#/ total area) was calculated by dividing the total number of individuals of a species encountered for all transects by the total number of individuals of all species counted for all transects and then multiplied by 100. Absolute percent dominance (%) for each species was calculated by dividing total intercept lengths for a species by total intercept lengths sampled, and multiplied by 100. Absolute dominance (m^2/ha) for each species was then calculated by dividing absolute dominance (%) by 100 then multiplying it by 10,000m^2/ha to obtain m^2/ha. Transects were read 4 times throughout the growing season (i.e., March, May, July, and August/September 2004, 2005, and 2006). However, data from each August/September data collection was used when calculating area for the creation on DUD's.

Species that were found within the moist-soil managed wetland units and did not have regression equations created were assigned values from a commonly used publication by Fredrickson and Taylor (1982) to allow for a baseline number to be created in order to develop DUD's on RCWMA as well as other managed properties within the ecosystem.

Production

To estimate the amount of seed production for individual lbs of moist-soil plant seed per acre, a conversion factor of grams per 0.0625 m^2 x 142.74 will produce pounds / acre (ex. 6 grams x 142.74 = 856.44 (±SD) lbs / acre) (Laubhan 1992). This can then be extrapolated out to the entire area and or moist-soil units for potential seed production. This is done by taking the average seed weight x the area sampled (ex. 856.44 (± SD) lbs per acre x 12 acres = 10,277.28 lbs in the unit).

DUD estimation

Duck-use days (DUD's) are the estimated number of days a given area (i.e., moist-soil managed wetland) duck(s) can survive on for 1 day based on either seed or invertebrate abundance or combination of both (Reinecke et al. 1986, Haukos and Smith 1993). We followed Anderson and Smith (1999) calculation of potential use days as:

$$\text{DUDs} = \frac{[\text{Food Abundance (g dry mass) x metabolized energy (kcal/g dry mass)}]}{[\text{Daily energy requirement (kcal / day)}]}$$

Where metabolized energy = 2.5 kcal/gram for seeds and 3.5 kcal/gram for invertebrates and the daily energy requirement = 292 kcal / day (Prince 1979) for species that were intensively collected.

RESULTS

Moist-soil managed wetland cell 1

During the 2004 collection season vegetative data collection was not possible due to work being done within the cell. However, invertebrates were collected during the necessary months and ranged from 182,379 DUD during January 2004 and 2,336 during December. Both invertebrates and vegetation were collected for 2005. The plant species that provided the highest DUD's within the moist-soil managed cell was nodding smartweed (27,835), while September 2005 was the highest invertebrate DUD provided (33,647). During 2006, nodding smartweed was once again the highest plant species, providing 25,207 DUD's with February invertebrates providing 3,058 DUD's (Table B.1). Moist-soil managed wetland cell 1 had an overall mean DUD of 10,621 (± 29,264, n = 50). The first year 2004 had the highest mean DUD of 53,213 (± 63,962) and 2006 the lowest mean DUD of 1,773 (± 5,202) (Table B.2).

Moist-soil managed wetland cell 2

In 2004, January had the highest DUD of 84,835 and the plant species producing the highest DUD was red-root flatnut sedge 2,961. During the 2005 year November produced the highest DUD for invertebrates 46,590 while most of the seed producing plant species, 4 species in all, had low DUD's ranging from 676 – 23 DUD's. Data from 2006 resulted in very low production from both invertebrate and seed producing plant species as far as DUD were concerned. March resulted in 979 DUD's for invertebrates and duck potato resulted in 296 DUD's as the highest respectively (Table B.1). Overal mean DUD was 8,598 (± 19,820) with 2004 having the highest (15,796 ± 28,687) and 2006 the lowest (204 ± 255) (Table B.2).

Moist-soil managed wetland cell 3

Data from 2004 found that March invertebrates had the highest DUD of 85,562 and Carex sp. produced 4,300 DUD's for seed production. 2005 resulted in invertebrate DUD's being highest in September (44,511) and red-root flatnut sedge (3,280) for seed producing plants. Production of DUD's seemed to drop off a bit in 2006. Invertebrate DUD's were highest in October (12,867) and seed producing plants had highest DUD with duck potato (1,042) (Table B.1). Overall mean DUD's for moist-soil managed wetland cell 3 was 6,686 ± 16,408 with 2004 at 10,979 ± 23,526, 2005 at 6397 ± 12,939, and 2006 at 1,505 ± 3,065 (Table B.2).

Moist-soil managed wetland cell 4

Results from 2004 found that invertebrates had the highest DUD in March (96,735) with Carex sp. as the highest seed producing plant (4,161). During 2005, December had the highest DUD (14,034) of all months for invertebrates while 6 plant species resulted in DUD ranging from 20 to 431. Invertebrates in 2006 had 2 months October and January that had similar DUD (20,682 and 20,105) respectively. Duck use days for seed producing plants was very low, barnyard grass and bul rush were similar in DUD's (212 and 254) respectively (Table B.1). Overall mean DUD for moist-soil managed wetland cell 4 was 7,636 ± 17,888. Mean DUD in 2004 was 12,092 ± 26,429 while 2005 and 2006 were very similar: 4,659 ± 5645 and 4,274 ± 7,088 respectively (Table B.2).

Group/Species DUD

A total of 22 species/groups were used to calculate DUD for all 4 moist-soil managed wetlands, with 21 being seed producing plant species and all collected aquatic invertebrates put into the invertebrate group. The invertebrate group had a mean overall DUD of 18,443 ± 29,558 (*n* = 84). The 2 highest seed producing species were nodding smartweed and red-root flatnutsedge. Producing DUD's of 5,985 ± 11,663 and 2,149 ± 1,599 (*n* = 9 and 2) respectively, while the 2 lowest seed producing plant species DUD's were pink smartweed and square stem spike rush (1.71 ± 1.88 and 4.87 ± 5.51) (Table B.3).

DISCUSSION

The estimated DUD's for seeds, invertebrates, and cell production were higher in some regards and lower in many others. The mean DUD's per cell over the 3 years showed a steady decline in the number of ducks a moist-soil managed wetland cell could handle. It is natural to see the overall production of wetlands to decrease over time; however these moist-soil managed wetlands are relatively young in age and should still be peaking. Fredrickson and Taylor (1982) reported that wetlands that have been under moist-soil management for 4 or more years tend to gradually increase in non-desirable moist-soil plant species if timing of annual drawdown is different or nonexistent as well as the stage of succession. Timing of water removal and inundation will ultimately influence species composition within each moist-soil managed wetland cell. For example, two general types of drawdowns will produce different results. Slow drawdowns where water is removed over a period of 2 weeks or longer will produce a more diverse vegetative cover than a fast drawdown where water is removed with days and regardless of whether drawdown is slow or fast, total seed production usually is higher on impoundments after early drawdowns (Fredrickson and Taylor 1982). Prolonged inundation and lack of any type of drawdown is the main cause for the production of the wetlands to decrease as rapidly as they did; it was more obvious in moist-soil wetland cell(s) 2 and 3. Moist-soil wetland 2 specifically went from an overall mean DUD in 2004 of 15,769 to a mean overall DUD in 2006 of 204. That alone is 77.29 % decrease in DUD's over 3 years. Moist-soil managed wetland cell 2 and for the most part the remaining 3 moist-soil managed wetland cells after August 2004 had the presence of water within the cells for the remainder of the study (see Chapter IV). Seed production over the three years showed a decrease in total number of plant species present which in turn meant less vegetative cover on the ground. The overall estimated DUD of all the plant species present was not surprising. However, Anderson and Smith (1998) felt that estimated DUD between the months of September and November were reduced by 2000 / ha because consumption of seeds was higher in these months as well as decomposition. The peak production of invertebrate DUD's was a bit erratic but typically large peaks were during months of the year that birds would be looking for protein in order to build fat reserves to migrate north.

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Table B.1. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Invertebrate	1	2004	1	182,379
Invertebrate	2	2004	1	47,936
Invertebrate	3	2004	1	86,486
Invertebrate	9	2004	1	4,835
Invertebrate	10	2004	1	32,090
Invertebrate	11	2004	1	16,429
Invertebrate	12	2004	1	2,336
Invertebrate	1	2005	1	18,896
Invertebrate	2	2005	1	2,843
Invertebrate	3	2005	1	8,967
Barnyard Grass	8	2005	1	774
Bul Rush	8	2005	1	342
Crows foot	8	2005	1	7
Duck potato	8	2005	1	142
Erect burhead	8	2005	1	12
Frog Fruit	8	2005	1	198
Nodding Smart Weed	8	2005	1	27,835
Paspalidium	8	2005	1	130
Curly Dock	8	2005	1	0.76
Sprangle Top	8	2005	1	120
Water pepper	8	2005	1	158

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Wild Millet	8	2005	1	1,232
Invertebrate	9	2005	1	33,647
Invertebrate	10	2005	1	10,313
Invertebrate	11	2005	1	10,256
Invertebrate	12	2005	1	1,776
Invertebrate	1	2006	1	558
Invertebrate	2	2006	1	3,058
Invertebrate	3	2006	1	636
Barnyard Grass	8	2006	1	3,980
Bul Rush	8	2006	1	886
Carex	8	2006	1	670
Cockel Bur	8	2006	1	7
Duck Potato	8	2006	1	0.38
Eclipta	8	2006	1	19
Frog Fruit	8	2006	1	511
Nodding Smart Weed	8	2006	1	25,207
Paspalum	8	2006	1	195
Pink Smart Weed	8	2006	1	3
Red-root flatnut sedge	8	2006	1	1,018
Spike rush	8	2006	1	42
Sprangle top	8	2006	1	752

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Teal love grass	8	2006	1	13
Tooth cup	8	2006	1	8
Wild Millet	8	2006	1	136
Invertebrate	9	2006	1	1,498
Invertebrate	10	2006	1	575
Invertebrate	11	2006	1	803
Invertebrate	12	2006	1	214
Invertebrate	1	2004	2	84,835
Invertebrate	2	2004	2	56,106
Invertebrate	3	2004	2	69,010
Barnyard Grass	8	2004	2	670
Carex	8	2004	2	2,961
Cockel Bur	8	2004	2	1
Erect Burhead	8	2004	2	76
Frog Fruit	8	2004	2	73
Nodding Smartweed	8	2004	2	14
Tooth cup	8	2004	2	7
Wild Millet	8	2004	2	2,560
Invertebrate	9	2004	2	3,011
Invertebrate	10	2004	2	5,886
Invertebrate	11	2004	2	8,932

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Invertebrate	12	2004	2	2,403
Invertebrate	1	2005	2	23,334
Invertebrate	2	2005	2	9,966
Invertebrate	3	2005	2	12,256
Barnyard Grass	8	2005	2	19
Carex	8	2005	2	23
Nodding Smartweed	8	2005	2	676
Paspalidium	8	2005	2	64
Invertebrate	9	2005	2	1,204
Invertebrate	10	2005	2	3,791
Invertebrate	11	2005	2	46,590
Invertebrate	12	2005	2	6,605
Invertebrate	1	2006	2	287
Invertebrate	2	2006	2	186
Invertebrate	3	2006	2	977
Barnyard Grass	8	2006	2	12
Carex	8	2006	2	148
Crows Foot	8	2006	2	7
Duck Potato	8	2006	2	296
Frog Fruit	8	2006	2	36
Nodding Smartweed	8	2006	2	31

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Paspalum	8	2006	2	16
Invertebrate	9	2006	2	421
Invertebrate	10	2006	2	199
Invertebrate	11	2006	2	176
Invertebrate	12	2006	2	66
Invertebrate	1	2004	3	24,314
Invertebrate	2	2004	3	74,874
Invertebrate	3	2004	3	85,562
Barnyard Grass	8	2004	3	1,442
Carex	8	2004	3	4,300
Cockel Bur	8	2004	3	11
Duck Potato	8	2004	3	2
Erect Burhead	8	2004	3	171
Frog Fruit	8	2004	3	142
Nodding Smartweed	8	2004	3	5
Pig Weed	8	2004	3	159
Ragweed	8	2004	3	49
Sprangle Top	8	2004	3	75
Square stem spike rush	8	2004	3	0.87
Switch Grass	8	2004	3	8
Tooth cup	8	2004	3	1,152

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Water pepper	8	2004	3	2
Wild Millet	8	2004	3	1,826
Invertebrate	9	2004	3	3,091
Invertebrate	10	2004	3	21,440
Invertebrate	11	2004	3	11,740
Invertebrate	12	2004	3	11,182
Invertebrate	1	2005	3	11,323
Invertebrate	2	2005	3	7,008
Invertebrate	3	2005	3	14,590
Barnyard Grass	8	2005	3	856
Carex	8	2005	3	7
Cockel Bur	8	2005	3	19
Crows Foot	8	2005	3	11
Duck Potato	8	2005	3	5
Erect Burhead	8	2005	3	742
Frog Fruit	8	2005	3	1,346
Nodding Smartweed	8	2005	3	8
Paspalidium	8	2005	3	117
Red-root flatnut sedge	8	2005	3	3,280
Curly Dock	8	2005	3	10
Sprangle Top	8	2005	3	1

Table B.1 Continued. Estimated duck us days (DUD's) by month and year for 4 moist-soil managed wetlands and associated food items found on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Square Stem Spike Rush	8	2005	3	2
Switch Grass	8	2005	3	27
Water Pepper	8	2005	3	34
Invertebrate	9	2005	3	44,511
Invertebrate	10	2005	3	4,294
Invertebrate	11	2005	3	8,490
Invertebrate	12	2005	3	44,052
Invertebrate	1	2006	3	1,004
Invertebrate	2	2006	3	952
Invertebrate	3	2006	3	1,042
Barnyard Grass	8	2006	3	425
Duck Potato	8	2006	3	1,785
Eleocharis	8	2006	3	14
Erect Burhead	8	2006	3	22
Frog Fruit	8	2006	3	62
Paspalum	8	2006	3	117
Sprangle Top	8	2006	3	8
Water Pepper	8	2006	3	44
Wild Millet	8	2006	3	1,496
Invertebrate	9	2006	3	2,013
Invertebrate	10	2006	3	12,867

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Invertebrate	11	2006	3	167
Invertebrate	12	2006	3	3,247
Invertebrate	1	2004	4	68,615
Invertebrate	2	2004	4	43,271
Invertebrate	3	2004	4	96,735
Barnyard Grass	8	2004	4	507
Bul Rush	8	2004	4	127
Carex	8	2004	4	4,161
Duck Potato	8	2004	4	7
Erect BUrhead	8	2004	4	17
Frog Fruit	8	2004	4	639
Pig Weed	8	2004	4	91
Pink Smartweed	8	2004	4	0.38
Sprangle Top	8	2004	4	41
Square Stem Spike Rush	8	2004	4	11
Tooth cup	8	2004	4	821
Water Pepper	8	2004	4	31
Wild Millet	8	2004	4	1
Invertebrate	9	2004	4	3,033
Invertebrate	10	2004	4	13,139
Invertebrate	11	2004	4	6,108

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Invertebrate	12	2004	4	4,490
Invertebrate	1	2005	4	10,337
Invertebrate	2	2005	4	5,967
Invertebrate	3	2005	4	1,702
Barnyard Grass	8	2005	4	37
Bul Rush	8	2005	4	49
Duck Potato	8	2005	4	431
Erect Burhead	8	2005	4	235
Nodding Smartweed	8	2005	4	75
Paspalidium	8	2005	4	20
Invertebrate	9	2005	4	12,057
Invertebrate	10	2005	4	2,580
Invertebrate	11	2005	4	13,045
Invertebrate	12	2005	4	14,034
Inverebrate	1	2006	4	20,105
Invertebrate	2	2006	4	3,537
Invertebrate	3	2006	4	4,119
Barnyard Grass	8	2006	4	212
Bul Rush	8	2006	4	254
Carex	8	2006	4	8

Table B.1 Continued. Estimated duck us days (DUD's) for 4 moist-soil managed wetlands located on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	Month	Year	Wetland	DUD's
Frog Fruit	8	2006	4	4
Nodding Smartweed	8	2006	4	14
Spike Rush	8	2006	4	8
Tooth cup	8	2006	4	0.76
Water Pepper	8	2006	4	2
Invertebrate	9	2006	4	9,530
Invertebrate	10	2006	4	20,682
Invertebrate	11	2006	4	662
Invertebrate	12	2006	4	4,976

Table B.2. Overall mean and standard error duck-use days provided by food items located within moist-soil managed wetland on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	$\bar{x}$	SE	*n*
Barnyard Grass	812.73	28.50	11
Bul Rush	332.11	18.22	5
Carex	1,535.31	39.18	8
Cockel Bur	9.89	3.14	4
Crows Foot	9.09	3.14	3
Duck Potato	332.66	18.23	9
Eclipta	19.818	--	1
Eleocharis	14.4	--	1
Erect burhead	182.44	13.51	7
Frog Fruit	335.13	18.3	9
Invertebrate	18,443.55	135.80	84
Nodding Smartweed	5,985.34	77.36	9
Paspalidium	83.27	9.13	4
Paspalum	109.82	10.47	3
Pig Weed	125.48	6.92	2
Pink Smartweed	1.71	1.30	2
Ragweed	49.16	--	1
Red-root flatnut sedge	2,149.67	46.36	2
Rumex	5.43	2.33	2
Spike Rush	25.34	4.89	2
Sprangle top	166.80	12.92	6
Square stem spike rush	4.87	2.20	3

Table B.2. Continued. Overall mean and standard error duck-use days provided by food items located within moist-soil managed wetland on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Species / Group	$\bar{x}$	SE	*n*
Switch Grass	17.72	4.21	2
Teal love grass	13.25	--	1
Tooth cup	398.08	19.95	5
Water Pepper	61.76	7.85	7
Wild Millet	1,208.85	34.76	6

Table B.3. Overall mean and standard error duck-use days provided by moist-soil managed wetland on Richland Creek Wildlife Management Area, east-central, Texas 2004-2006.

Unit	$\bar{x}$	SE	n
<u>Wetland 1</u>			
Overall	10,621.95	103.06	50
2004	5,3213.00	230.67	
2005	5,890.53	76.75	
2006	1,773.74	42.11	
<u>Wetland 2</u>			
Overall	8,598.48	92.72	40
2004	15,769.83	125.57	
2005	9,502.739	97.48	
2006	2,04.410	14.29	
<u>Wetland 3</u>			
Overall	6,686.68	81.77	61
2004	10,979.82	104.78	
2005	6,397.19	79.98	
2006	1,505.50	38.80	
<u>Wetland 4</u>			
Overall	7,636.26	87.38	48
2004	12,092.59	109.96	
2005	4,659.450	68.26	
2006	4,274.4132	65.37	