Seed and waterbird abundances in ricelands in the Gulf Coast Prairies of Louisiana and Texas

By

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Rice not collected by harvesters and natural seeds are important foods for waterfowl. Estimation of abundance of these seeds is necessary for calculating waterfowl habitat conservation needs in the Louisiana Chenier Plain (LCP) and Texas Mid-Coast (TMC). My objectives were to quantify dry mass of rice and other seeds from August-November 2010, and estimate waterbird abundances on farmed and idle ricelands in these regions from December 2010-March 2011. Rice abundance in farmed ricelands ranged from 159.7 kg/ha (CV = 66.6%) to 1,014.0 kg/ha (CV = 8.3%). Natural seed abundance in idle ricelands ranged from 99.7 kg/ha (CV = 32.9%) to 957.4 kg/ha (CV = 17.2%). Greatest waterbird densities occurred in shallowly flooded disked ricelands (mean = 7.35 waterbirds/ha, 90%; CI = 2.37-19.70). Ratoon, disked, and shallowly flooded ricelands are important habitat for non-breeding waterbirds but variable estimates of seed and waterbird abundances warrant continuation of this study.

DEDICATION

This work is dedicated to my father,

Paul Marty.

He was the first person to take me hunting and fishing. The times we spent together were the best and most memorable of my life. I am looking forward to many more adventures together. Through your love and respect for nature and our relationship, I have become an aspiring scientist and conservationist.

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CHAPTER I

RICE AND MOIST-SOIL SEED ABUNDANCES IN LOUISIANA AND TEXAS GULF COAST PRAIRIE RICELANDS

Introduction

Ricelands are important waterbird habitats and a seminal example of integrated agriculture and natural resource conservation in major rice growing regions in North America and worldwide (Manley 2008, Elphick et al. 2010). The Gulf Coast region of the United States is composed of two large rice growing regions – the Chenier Plain (CP) of southwest Louisiana and southeast Texas and the Texas Mid-Coast (TMC). These regions annually attract and provide habitat for millions of waterfowl and other waterbirds and produce about 15% of the rice grown in the United States (U.S. Department of Agriculture [USDA] 2010*a*). Ricelands in the Gulf Coast largely occur amid historical coastal prairie and wetland systems (Chabreck et al. 1989). Despite great losses in these systems, ricelands provide critical food and other resources for migrating and wintering waterfowl and other waterbirds (Baldassarre and Bolen 1984; Delnicki and Reinecke 1986; Hobaugh et al. 1989; Stafford et al. 2006*a*, 2010). Additionally, rice seeds are more resistant to decomposition (Shearer et al. 1969, Nelms and Twedt 1996, Manley et al. 2004) and are energetically superior to most other agricultural and natural seeds (Loesch and Kaminski 1989, Kaminski et al. 2003, Greer et al. 2009).

In the United States, rice agriculture extends from southeastern Missouri in the Mississippi Alluvial Valley (MAV) southward to the CP and TMC, and also occurs prominently in the California Central Valley (Reinecke et al. 1989, Heitmeyer et al. 1989, Eadie et al. 2008). However, farming practices differ among rice growing regions and are influenced by local physiography, climate, water resources, economics, and other factors (Manley et al. 2004, 2008; Stafford et al. 2010). Previous research in rice fields in the MAV demonstrated that waste rice (i.e., grain not collected by harvesters) decreased to low levels by late fall-early winter, leaving little grain available for migrating and wintering waterfowl (Manley et al. 2004, Stafford et al. 2006*b*, Manley et al. 2008, Greer et al. 2009). Thus, understanding contemporary patterns in abundance and availability of rice and other seeds in ricelands is important for region-specific habitat conservation planning and to assess effectiveness of conservation or management initiatives (Canadian Wildlife Service, U.S. Fish and Wildlife Service, and Mexico National Institute of Ecology 1986, 2012; Esslinger and Wilson 2001; United States Department of Agriculture 2010*b*; Wilson and Esslinger 2002).

Gulf Coast rice-growing regions experience longer growing seasons than the MAV, which may extend for up to nine months (March-November), making two rice crops within a single growing season (i.e., the second termed a “ratoon”) possible and economically justified. Within the CP and TMC, rice is harvested initially in July-August, followed by the ratoon crop in late fall (Bollich and Turner 1988, Eadie et al. 2008). Following harvest of the first crop, fertilizer is applied and fields are re-flooded to encourage production of the ratoon crop (Hottel et al. 1975, Hobaugh et al. 1989). In the MAV, growing seasons are usually too short to enable production of ratoon crops.

The Gulf Coast Joint Venture (GCJV) of the North American Waterfowl Management Plan (NAWMP) is a partnership among federal and state agencies, non-profit organizations, and private landowners dedicated to conservation of priority bird habitat in Gulf Coast Prairie ecosystem. The GCJV endeavors to provide foraging habitat to support nearly 14 million ducks and >1.6 million geese within their planning regions annually (Esslinger and Wilson 2001; Figure 1.1). The GCJV identifies 6 subgeographies, referred to as "Initiative Areas," reflecting patterns of common geomorphology, land use, waterfowl habitats, political boundaries, and resource threats to enable more efficient and strategic conservation planning and delivery. Riceland agriculture within the GCJV region occurs in only 3 of these 6 subgeographies – the Louisiana Chenier Plain (LCP), Texas Chenier Plain (TCP), and Texas Mid-Coast (TMC) Initiative Areas. From 2000-2010, farmers in the LCP and TMC planted an average of 129,240 ha and 45,292 ha of rice per year, respectively, accounting for 95% of total rice produced in the GCJV region (USDA 2010*a*).

Flooded, post-harvested rice fields are important habitats for migrant and resident waterfowl and other wildlife. Additionally, ricelands in the Gulf Coast region are cultivated on a rotational basis, with a percentage of fields left idle during years when not in rice production. In idled rice fields, natural grasses, sedges, and forbs (i.e., moist-soil vegetation [Schummer et al. 2012]) may germinate and produce abundant seeds or tubers and aquatic invertebrates when flooded (Kross et al. 2008, Hagy and Kaminski 2012). These seeds nutritionally complement waste rice for waterfowl and other granivorous waterbirds. Waterfowl habitat objectives of the GCJV are calculated based on knowledge of total energy demands of waterfowl populations; abundance of post-harvest waste-rice, moist-soil seeds, and tubers in rice production systems; temporal patterns of seed depletion and deterioration; and metabolizable energy content of available forage to (Reinecke et al. 1989, Esslinger and Wilson 2001, Kaminski et al. 2003).

Despite its importance to waterfowl, few contemporary studies have examined temporal dynamics of rice and moist-soil seed abundance in the CP and TMC (cf., Michot and Norling, unpublished data). In addition to rice and natural foods in these regions, commercial culturing of crayfish (*Procambrus* spp.), primarily in Louisiana, is another significant use of ricelands but rarely in the MAV. Thus, given differences in rice and crayfish agriculture in the CP and TMC compared to the MAV, contemporary estimates of waste rice from the MAV were not applicable. Estimates of abundance of waste-rice and moist-soil seeds are needed to calculate waterfowl carrying capacity (duck energy days; DEDs) of important habitats and guide conservation planning and delivery within the GCJV region.

In addition to the aforementioned needs of the GCJV, the USDA Natural Resources Conservation Service (NRCS) implemented the Migratory Bird Habitat Initiative (MBHI) following the April 2010 Deepwater Horizon Oil Spill in the Gulf of Mexico (USDA 2010*b*). The MBHI financially incentivized private landowners in the CP and TMC to flood and manage active and idle ricelands to increase availability of these habitats inland from habitats along the Gulf Coast that were at greater risk of contamination. The MBHI habitats attracted waterfowl, shorebirds, and waders (Chapter 2). The NRCS desired estimates of waste-rice and natural seeds in lands under MBHI management in the CP and TMC to compute their contributions to meeting resource needs of migratory and wintering waterfowl and other waterbirds.

My primary objective was to conduct a pilot study to estimate waste-rice and moist-soil seed abundance in Gulf Coast ricelands during autumn 2010. Due to logistical constraints, this pilot study focused on rice agriculture in only the LCP and TMC. I defined seed abundance as the dry mass quantity of whole or partially intact rice or other seeds (i.e., ≥ 50% of seed remaining; Stafford et al. 2006*b*). More specifically, I sought to estimate seed abundance among regions and time periods relevant to waterfowl conservation planning in the GCJV region. The GCJV identifies two time periods during autumn – winter (early = 16 August – 31 October; late = 1 November – 31 March) that generally correspond to the arrival of early and late migrants, and it is within these time periods that habitat conservation planning activities are focused. I hypothesized that waste-rice and moist-soil seed abundance would not differ between the LCP and TMC because of similar rice production practices in these regions. My second objective was to determine optimal sample sizes of primary (landowners), secondary (fields within landowners), and tertiary (soil cores within fields) sample survey units necessary to achieve a coefficient of variation (CV) of ≤ 15% for estimates of rice and moist-soil seed abundances (Stafford et al. 2006*b*, Kross et al. 2008). These results are needed to inform proper design of a more comprehensive study to estimate rice and moist-soil seed abundances in these regions. Overall, my goal was to provide initial, contemporary estimates of waste-rice and moist-soil seed abundances in ricelands within the LCP and TMC to enable refinements to conservation planning models and habitat objectives for migrating and wintering waterfowl in the GCJV region.Second level subheading sample

Study Area

Chenier Plain, Louisiana and Texas

The Chenier Plain ecoregion extends throughout southwest Louisiana (29° 31' - 31° 00' N; 91° 57' - 93° 54' W; Figure 1.2) and southeast Texas (29° 21' - 30° 29' N; 93° 41' - 95° 10' W; Figure 1.2). Historically, this region was comprised of diverse savannahs and wetlands that extended approximately 322 km from Vermilion Bay in Louisiana to Galveston Bay in Texas (Esslinger and Wilson 2001). The Chenier Plain includes coastal marshes along the Gulf of Mexico and extends 64 to 112 km inland through former coastal savannahs that today are intensively cultivated for rice and other agronomic crops (Esslinger and Wilson 2001). The climate in the Chenier Plain is sub-tropical and humid with an average growing season of 270 days, 13 freeze days per year, and temperatures ranging from ~14° C in December-January to ~30° C July-August (Gosselink et al. 1979, Chabreck et al. 1989, Visser et al. 2000). From east to west through the Chenier Plain, average annual precipitation decreases from 144 to 113 cm per year (Gosselink et al. 1979, Visser et al. 2000). The Chenier Plain is subject also to frequent and sometimes intense weather disturbances, where tropical storms make landfall every 1.6 years and hurricanes every 3.3 years on average (Roth 1999).

Within the Chenier Plain, there are several large tracts of land managed as wildlife refuges either by the state of Louisiana, including Rockefeller (30,756 ha) and Russell Sage (6,812 ha), or the U. S. Fish and Wildlife Service, including Sabine (50,387 ha) and Lacassine (14,163 ha) National Wildlife Refuges (Visser et al. 2000). Historically, the regional landscape contained numerous and interspersed small depressional wetlands important to migratory and resident birds (Chabreck et al 1989, Esslinger and Wilson 2001). The region's abundant average annual rainfall, long growing season, and the combination of fertile soils and a shallow clay pan, created ideal conditions for widespread conversion of Chenier Plain into rice and other agriculture (Esslinger and Wilson 2001). The Chenier Plain includes the Louisiana parishes of Acadia, Allen, Calcasieu, Cameron, Evangeline, Jefferson Davis, and Vermilion and the Texas counties of Chambers, Jefferson, Liberty, and Orange. For my study, I focused specifically on the Louisiana parishes of Acadia, Allen, Evangeline, Jefferson Davis, St. Martin, and Vermilion, as they accounted for approximately 90% of the total rice production in the LCP in 2009 (USDA 2010*a*). I did not sample in the Texas Chenier Plain (TCP) in 2009 because of time limitations, and accessibility of rice producers.

Texas Mid-Coast

The Texas Mid-Coast includes 16 counties that extend from the coast at Galveston Bay to Corpus Christi and inland approximately 170 km (27° 48' - 30° 13' N; 94° 43' - 97° 54' W; Figure 1.3). Native plant communities in the Mid-Coast primarily consisted of tall grass savannahs, with patches of post oak savannah in upland areas (Gould 1975, Hobaugh et al. 1989). Currently, the region consists of remnant coastal savannahs inland and adjacent to expansive bays and estuaries, in addition to inland areas dominated by agriculture (Wilson and Esslinger 2002). Within the TMC I studied ricelands within only the three most prominent rice producing counties of Colorado, Matagorda, and Wharton (Figure 1.3). These counties accounted for 75% of the total rice production in the TMC in 2009 (USDA 2010*a*). "Rice Prairies" is a frequently used term to reference former coastal prairies that today are intensively cultivated for rice and other agronomic crops (Hobaugh et al. 1989). Rice prairies in the TMC are characterized by nearly level to gently sloping topography with elevations ranging from 10-70 m above mean sea level (MSL; Hobaugh et al. 1989). Rice prairie soils have a surface layer of fine sandy loam above several layers of clay and sandy clay (McEwen and Crout 1974, Westfall 1975, Hobaugh et al. 1989). The region receives average annual rainfall of 104 cm (range 90-140 cm), which is generally evenly distributed throughout the year (Hobaugh et al. 1989). The area has a humid climate with hot summers and mild winters, the growing season averages 270 days per year, and low temperatures rarely dip below -6° C during winter (McEwen and Crout 1974, Hobaugh 1989).

Methods

Sampling Design

I used a stratified, 3-stage multi-stage sampling (MSS) design with the following sampling units: 1) *primary*, corresponding to the landowner or farm, 2) *secondary*, corresponding to rice fields within farms, and 3) *tertiary*, which were soil core samples collected within secondary sampling units (Stafford et al. 2006*a*). I acquired landowner contact information from two datasets: 1) rice producers who cooperated with the Louisiana State University Agricultural Center (LSUAC) regarding rice production, and 2) landowners that cooperated with Ducks Unlimited, Inc. (DU) in the Texas Prairie Wetlands Project wetland restoration program. I contacted additional producers with assistance from the LSUAC parish agents. After I identified all possible candidate landowners, I randomly selected landowners using PROC SURVEYSELECT in SAS v9.2 (SAS Institute 2009) and stratified samples by region (i.e., LCP and TMC). We sampled privately owned farms in proportion to rice acreage grown in these respective regions in 2010 (LCP, n = 15; TMC, n = 10). I then randomly selected and sampled two active and two idle rice fields per landowner (Stafford et al. 2006*b*). I defined a rice field as the area surrounded by exterior levees used in standard rice production practices.

In each selected rice or idle field, I established a single random directional (0-180 degrees) transect and extracted 10 soil cores at evenly spaced intervals (i.e., 25 paces; Stafford et al. 2006*b*). I collected soil cores using a cylindrical metal sampler (diameter = 10 cm) to a depth of 10 cm (Manley et al. 2004, Stafford et al. 2006*b*) from each selected field between 15-30 August 2010 (n = 1,000) and 1-22 November 2010 (n = 1,000). These calendar periods corresponded to the start of the early and late planning periods for waterfowl resource needs developed by the GCJV. In addition to August and November collection periods, I collected soil cores in early October from 25 idle rice fields (i.e., 15 in LCP, 10 in TMC; 10 cores/field [n = 250]), because seeds of many moist-soil plants had not matured and dehisced seeds by mid-August 2010 sampling event and we desired a finer scale examination of temporal dynamics of moist-soil seed abundance in these fields. I collected soil cores from rice fields only after harvest (i.e., 1 - 7 days), or upon maturation of rice plants if the landowner indicated the field would not be harvested.

I categorized actively farmed and idle rice fields as follows: 1) fields harvested only once in July-August (no ratoon); 2) fields harvested twice per season (i.e., August-early September and October-early November (harvested ratoon); 3) fields with a ratoon crop but not harvested and left standing for crawfish aquaculture or waterfowl habitat (standing ratoon); 4) idle rice fields with standing natural vegetation (standing idle); and 5) disked idled fields (disked idle). Additionally, I replicated all sampling protocols from previous studies in the MAV to legitimize among-region comparisons of waste rice abundance (Manley et al. 2004, Stafford et al. 2006*a*).

Immediately after extracting a soil core, I placed it into a 3.78 liter plastic bag. I labeled each bag with the sampling date, time, and location and placed bags in a cooler with ice to prevent seed decomposition. I transported coolers to the National Wetlands Research Center in Lafayette, Louisiana or the College of Forest Resources lab at Mississippi State University (MSU) and immediately froze samples until processing them at MSU.

Sample Preservation and Processing

I stored all soil cores at -13° C to preserve seed biomass and deter germination and decomposition (Murkin et al. 1994, Stenroth and Nyström 2003). I randomly selected soil cores for processing from the freezer regardless of collection dates to minimize bias resulting from potential decomposition of seeds within samples. Once thawed, I used a mixture of 3% solution of hydrogen peroxide ($H_2O_{2)}$, a mixture of ≤ $250cm^3$ of baking soda and approximately 1L of water, or a combination of ingredients, to separate soil particles (Bohm 1979, Kross et al. 2008). Mixing these solutions with soil cores oxidized the clays and facilitated sediment transport through wire-mesh sieves. I washed the cores through a series of sieves containing mesh sizes 4 (4.75 mm), 10 (2.0 mm), and 50 (300 µm) to remove rice and moist-soil seeds containing whole or partially intact endosperm (i.e., ≥ 50% of seed remaining; Stafford et al. 2006*b*). I allowed samples to air dry before being sorted. When dry, I extracted by hand rice and moist-soil seeds containing whole or partially intact (i.e., ≥ 50% of seed remaining) endosperm. I considered germinated seeds to be potential waterfowl food if the primary root was less than or equal to the length of the seed and if the endosperm was firm (Stafford et al.

2006*b*). I dried seed samples to constant mass (± 0.5 mg) at 87º C before weighing to the nearest 0.0001g (Manley et al. 2004, Stafford et al. 2006*b*).

Statistical Analyses

Estimation of Rice and Moist-Soil Seed Abundance

I applied size-specific seed bias correction factors to account for rice and natural seed loss during sieving and non-detection or non-recovery of seeds by technicians (Hagy et al. 2011). I partitioned seeds into small, medium, and large size classes and applied correction factors of 1.35, 1.10, and 1.07, respectively (Table 1.6; Hagy et al. 2011). I applied correction factors at the core sample level, because it was the level at which most bias was generated (Hagy et al. 2011). I used PROC SURVEYMEANS in SAS v9.3 (SAS Institute 2011) to estimate waste-rice and moist-soil seed abundances separately and combined. I analyzed data collected under the multi-stage survey design by incorporating appropriate weights and selection probabilities corresponding to the 3 levels of sampling (Stafford et al. 2006*b*). The probability of selecting a landowner was n_i/N_i, where n_i and N_i were numbers of landowners selected, and enrolled each year in each stratum (i.e., GCJV initiative area), respectively. The probability of selecting a field was m_i/M_i, where m_i was the number of fields (2) randomly selected among M_i fields farmed by landowner *i*. Finally, the probability of selecting a soil core within a field was $10/(K_{ij}/8.107 \times 10^{-7})$, where the number of cores collected in each field was 10 and the potential number of cores was the area (K_{ij}; ha) of field_j within landowner_i divided by the area of a core sample (8.107×10^{-7} ha; Stafford et al. 2006*b*). The inverse of the product of the 3 selection probabilities was the sampling weight used in the SURVEYMEANS procedure (Stafford et al. 2006*b*). The SURVEYMEANS procedure uses Taylor series linearization to estimate variances of estimators from data collected within MSS designs (SAS Institute 2009:6466, Stafford et al. 2003).

Gross and Ecological Abundance

I calculated 'gross' and 'ecological' abundances of waste-rice and moist-soil seeds. Gross abundance of waste-rice and moist-soil seeds was mean dry mass of waste-rice and moist-soil seeds separately and combined. Ecological abundance of waste rice was gross abundance minus 50 kg/ha, an amount that may not be accessible or energetically profitable by waterfowl (i.e., "giving-up" density; GUD; Stephen and Krebs 1986, Reinecke et al. 1989, Stafford 2006*b*, Greer et al. 2009). There are no published GUD values for natural seeds (Hagy 2010); however, there is evidence that waterfowl locate and consume specific seeds but not others (Baldassarre and Bolen 1984, Hobaugh et al. 1989, Kaminski et al. 2003, Baldassarre and Bolen 2006, Hagy and Kaminski 2012). Thus, I deemed ecological abundance of natural seeds to include only plant seeds known to be consumed by waterfowl, all other seeds were excluded from analysis (Hagy and Kaminski 2012; Table 1.6). Although my designation of ecological abundance of natural seeds may be negatively biased by an unknown magnitude, it yielded a conservative estimate of the 'functional density' of seeds likely used by waterfowl and future carrying capacity estimates of foraging habitats.

Sample Size Estimation and Validation

I used PROC MEANS in SAS v9.3 (SAS Institute 2011) to estimate variance among landowners to derive an optimal (i.e., lowest variance and minimal cost) number of primary sample units (Stafford et al. 2006*a*). I predicted precision of estimated means for samples of 10 to 100 landowners by calculating coefficients of variation as:

$$(v\hat{a}r/n)^{1/2}/\bar{x} \tag{1.1}$$

where $v\hat{a}r$ represented variances among landowner means, n was the number of landowners, and $\bar{x}$ the mean seed abundance (Stafford et al. 2006*a*).

To estimate optimal secondary (rice fields within landowners) and tertiary (core samples within rice fields) sample sizes, I computed variance components associated with each of the primary (landowner), secondary (field within a landowner), and tertiary (soil core with in a field) sampling units using Type I sums of squares in PROC VARCOMP between sampling periods and field types (actively farmed rice or idle) (Milliken and Johnson 1992:419, SAS Institute 2011, Stafford et al. 2006*a*). For this analysis, the optimal number of fields per landowner, m_{opt}, and optimal number of core samples per field, k_{opt} was computed as (Cochran 1977:288):

$$m_{opt} = \frac{\sqrt{S_2^2 - S_3^2/K}}{\sqrt{S_1^2 - S_2^2/M}} \sqrt{\frac{C_1}{C_2}} \tag{1.2}$$

$$k_{opt} = \frac{S_3}{\sqrt{S_2^2 - S_3^2/K}} \sqrt{\frac{C_2}{C_3}} \tag{1.3}$$

where $S_{1,}$ S_2, and S_3 were the estimated variance components for primary, secondary, and tertiary sample units, respectively. I used values of 120 for $c_{1,}$ 20 for c_2, and 2 for c_3 to represent the cost (time in minutes) to sample additional primary, secondary, and tertiary sampling units, respectively. Additionally, M was the mean number of secondary units per landowner, and *K* was the mean number of potential tertiary units per field (i.e., mean field size divided by the area of a core sample).

Results

Louisiana Chenier Plain Seed Abundance

Rice Abundance

In actively farmed rice fields following first harvest (i.e., late July-August 2010), waste rice abundance was 164.2 kg/ha (CV = 50.2%; 0). In November 2010, waste rice in fields with a harvested ratoon crop was 332.4 kg/ha (i.e., 102% increase), but variation in waste rice abundance decreased by 56% (CV = 22.2%; 0). Rice abundance in fields with a standing, unharvested ratoon crop in November was greatest, increasing after first harvest to 1,014.3 kg/ha (i.e., 518% increase) and varying least among sampling periods and management practices (CV = 8.3%; 0). Rice abundance was least in singly harvested fields without a ratoon crop (i.e., 159.7 kg/ha, CV = 66.6%; 0). In disked idle rice fields, rice abundance was 0.2 kg/ha (CV = 32.9%) in August but increased to 3.4 kg/ha in November (CV = 55.0%; 0). Residual rice from a previous year(s) in standing idle rice fields was negligible and variable (i.e., August, 0.4 kg/ha [CV = 90.7%]; November, 1.6 kg/ha [CV = 45.8%]; 0).

Moist-Soil Seed Abundance

In actively farmed rice fields following first harvest (i.e., late July-August 2010), moist-soil seed abundance was 190.3 kg/ha (CV = 47.7%; 0). In November 2010, moist-soil seed in fields with a standing, unharvested ratoon crop increased 284% to 730.4 kg/ha but variation in moist-soil seed abundance decreased 64% (CV = 17%; 0). Among production rice fields, moist-soil seed abundance was least in fields with no ratoon crop (i.e., 168.6 kg/ha, CV = 41.9%; 0). In idle rice fields with standing vegetation, moist-soil seed abundance increased 59% from 362.3 kg/ha in August (CV = 33.7%) to 576.4 kg/ha in October (CV = 63.6%) and was 534.8 kg/ha in November (CV = 19.4%; i.e., 7% change; 0). In disked idle rice fields, moist-soil seed abundance increased 462% from 99.7 kg/ha in August (CV = 32.9%) to 561.0 kg/ha in October (CV = 21.1%) and declined 50% from October-November (276.2 kg/ha, CV = 39.7%; 0).

Texas Mid-Coast Seed Abundance

Rice Abundance

In actively farmed rice fields following first harvest (i.e., late July-August 2010), waste rice abundance was 252.6 kg/ha (CV = 32.9%; 0). In November 2010, waste rice in fields with a harvested ratoon crop was 224.8 kg/ha (i.e., 11% decline), and variation in rice abundance declined 70% (CV = 9.6%; 0). In standing idle rice fields, rice abundance was 3.0 kg/ha in August (CV = 99.0%) and 2.2 kg/ha in November (CV = 65.2%; 0). Residual rice from previous year(s) in disked idle fields was negligible and variable (i.e., August, none; November, 6.2 kg/ha [CV = 88.8%]; 0).

Moist-Soil Seed Abundance

In actively farmed rice fields following first harvest (i.e., late July-August 2010), moist-soil seed abundance was 110.3 kg/ha (CV = 19.9%) and was 91.5 kg/ha in November (CV = 20.2%; i.e., 17% change; 0). In idle rice fields with standing vegetation, moist-soil seed abundance was 309.7 kg/ha in August (CV = 23.3%), 407.8 kg/ha in October (CV = 19.6%; i.e., 31% change), and 538.6 kg/ha in November (CV =

20.3%; i.e., 32% change), In disked idle rice fields, moist-soil seed abundance was 365.5 kg/ha in August (CV = 0.3%), 957.4 kg/ha in October (CV = 17.2% i.e., 161% change), and 548.9 kg/ha in November, (CV = 56.0%; i.e., 42% change; 0).

Seed Abundance in Louisiana and Texas MBHI Lands

Rice Abundance

I calculated seed abundances from a subset of actively farmed (n = 15) and idle (n = 10) rice fields that were enrolled in the MBHI or resembled MBHI practices (i.e., fields that were intentionally flooded for the purpose of hunting, crayfishing, or creating waterbird habitat) in 2010. Waste rice abundance in actively farmed rice fields following the first harvest in August was 89.1 kg/ha (CV = 59.4%). In November 2010, waste rice abundance was 117.9 kg/ha (i.e., 32% increase) but variation in rice abundance decreased 63% (CV = 22%). Waste rice abundance in fields with a standing ratoon crop in November was 1,082.6 kg/ha in November (CV = 0.1 %); however, precision of the latter estimate was uncertain, being based on a sample of only two fields with very similar abundances of waste rice. Waste rice abundance in idle rice fields (i.e., standing vegetation and disked combined) was low among all periods and ranged from none to 6.9 kg/ha (CV = 45.4%).

Moist-Soil Seed Abundance

Residual moist-soil seed in actively farmed MBHI rice fields was 285.5 kg/ha in August (CV = 36.0%) and was 108.0 kg/ha in November (CV = 38.1%; i.e., 62% decrease). Moist-soil seed abundance in actively farmed rice fields with a standing ratoon crop in November 2010, was 802.6 kg/ha (CV = 8.5%). In idle rice fields (i.e., standing and disked combined), moist-soil seed abundance was 451.6 kg/ha (CV = 60.8%), 594.2 kg/ha (CV = 32.6%), and 610.3 kg/ha (CV = 21.5%) in August, October, and November, respectively.

Ecological Rice and Moist-Soil Seed Abundance

In the LCP, ecological abundance of waste rice ranged from 114.2 kg/ha following the first harvest to 964.3 kg/ha during November in fields with a standing ratoon crop (0). In the TMC, ecological abundance of waste rice was 196.7 kg/ha following the first harvest and declined to 176.4 kg/ha following the harvest of the ratoon crop (0). After I subtracted giving up density of rice from the gross estimate for idle fields, the estimate was zero for all management practices and survey periods.

The combined ecological abundance for rice and moist-soil seeds in the LCP ranged from 304.4 kg/ha in first harvested rice fields to 1,694.7 kg/ha during November in actively farmed rice fields with a standing ratoon crop. Combined ecological seed abundance ranged from 381.0 kg/ha to 534.8 kg/ha and 99.7 kg/ha to 276.2 kg/ha from August through November in standing idle and disked idle fields, respectively (0). In the TMC, combined ecological seed abundance in actively farmed rice fields was 278.4 kg/ha and 242.9 kg/ha in August and November, respectively (0). From August to November, combined ecological seed abundance ranged from 342.9 kg/ha to 614.5 kg/ha in standing idle fields and 365.5 kg/ha to 548.9 kg/ha in standing and disked idle fields (0).

Sample Size Estimation and Estimated Variance Components

I invoked a multi-stage sampling design to examine variance associated with the three components inherent to my study, including the farm, field, and soil core. Collectively, I sampled fields from 25 landowners throughout the LCP and TMC, and collected 2,250 core samples between 15 August and 25 November 2010. Most variation in estimates of seed abundance was attributed to cores (tertiary level; 45.4-82.1%, 0), while variance associated with primary (landowners) and secondary (fields within landowners) sample units was 12.1-47.0% and 0.5-26.8%, respectively (0). To achieve desired precision (CV ≤ 15%), sampling a range of 10 - >100 farms would be required depending on sample period and field type (actively farmed rice or idle; 0, Figure 1.4). For the number of fields (secondary; m_{opt}) within farms, the estimated optimum number of sample units was one. For tertiary (k_{opt}) or soil core estimates, optimum numbers of sample units ranged from 6-722 per field in 2010 (Table 1.5).

Discussion

Residual Seed Abundance

My study is the latest to evaluate dynamics of waste-rice and moist-soil seed abundances among important rice growing regions in North America, but the first to rigorously estimate waste-rice and natural seed abundances in Gulf Coast ricelands over multiple time periods during autumn – winter. Although I provided contemporary estimates of seed abundances, my work is ongoing and values related to seed abundances will change as additional data emerge from existing unprocessed and future collected samples. Nonetheless, my study provides an important baseline of residual rice and moist-soil seed abundance in important rice growing regions of Louisiana and Texas.

Perhaps most revealing from my pilot study is how observed trends differ between neighboring rice growing regions of the Gulf Coast and MAV. In the MAV, where ratoon crops of rice are rare, abundance of residual rice significantly declined from early fall harvest through early December (Reinecke et al. 1989, Manley et al 2004, Stafford et al. 2006*b*).

In almost all rice production fields in the MAV, grain is harvested once in late summer or early fall (Stafford et al. 2006*b*). During the lengthy period between harvest and subsequent fall-winter arrival of waterfowl in the MAV, significant germination, decomposition, and granivory of residual rice seed occur (Stafford et al. 2006*b*). The longer growing season in the LCP and TMC compared to the MAV fosters ratoon rice crops in November. Residual ratoon rice was abundant after the harvest of the ratoon crop, and mitigated seed loss that likely occurred after first harvest.

Unharvested mature ratoon crops (i.e., standing ratoon) only existed in the LCP during 2010. In such cases, first harvested fields were fertilized and re-flooded to promote growth of a ratoon crop for crayfish production. In November, seed abundance in fields with a standing ratoon crop was at least 3 times greater than in other actively farmed rice fields (e.g., harvested ratoon and no ratoon). Farmers may opt to not harvest the ratoon crop because the stubble or stalk provides the foundation of a detritus-based food web for crayfish forage (McClain and Romaire 2004). Residual rice in these rice-crawfish fields mostly would have been available to early migrating and resident waterbirds early in fall (e.g., teal) during re-growth of the ratoon crop, before landowners flooded fields 20-60 cm for crayfish harvesting (McClain and Romaire 2004).

In most cases, abundance of moist-soil seed in LCP and TMC idle fields was greater than that reported by Davis et al. (1961; 364 kg/ha) in the same regions. Moist-soil seed was the most common seed type observed in idle fields, and any rice seed observed was likely volunteer rice from the previous growing season. Farmers in the LCP and TMC actively disked idle rice fields in summer and early fall, which encouraged growth of early successional moist-soil plant communities (Fredrickson and Taylor 1982, Gray et al. 1999, Kross 2008). In standing and disked idle fields in the LCP and TMC, I observed an overall increase in moist-soil seed abundance from August-November. Between the August and October sampling periods, abundance of moist-soil seed increased substantially, presumably because most moist-soil seeds finished maturing and subsequently shattered from the panicle during those months (>90%; Reinecke and Hartke 2005, Kross 2008). Likewise, moist-soil seed abundance increased in disked fields likely because those fields contained standing vegetation in August but were disked from October- early November. Disking likely contributed substantial seed to seed banks of those fields. Despite an overall increasing trend in residual seed in disked fields from August-November, seed abundances declined from October to November in both regions of my study. This decline was likely expedited by seed decomposition, germination, granivory, and increased frequency of fields being disked to prep them for the forthcoming growing season (e.g., 2011).

Residual Seed and Waterfowl

The GCJV seeks to provide foraging habitat necessary to support nearly 14 million ducks and >1.6 million geese annually within their planning region (Esslinger and Wilson 2001). Agricultural lands devoted to rice production likely provide significant contributions to potential foraging requisites of waterfowl (Wilson and Esslinger 2002). The GCJV calculates waterfowl carrying capacity by first estimating energy (kcal/ha) potentially available to waterfowl in a particular landscape of interest (M. G. Brasher, Gulf Coast Joint Venture, personal communication). Overall, waste-rice and moist-soil seed abundance estimates observed in this study and those used in conservation planning models by the GCJV currently are 1-325% greater than those derived from the MAV and Central Valley of California (Manley et. al. 2004, Central Valley Joint Venture 2006, Stafford et al. 2006*b*).

Waterfowl require dietary energy to complete physiological and behavioral events during the nonbreeding period that include replenishing lipid and other nutrient stores lost during fall migration (Ankney 1982, Hobaugh 1984, Chabreck et al. 1989), completing pre-alternate molt (Paulus 1983), undergoing pre-basic molt by females (Richardson and Kaminski 1992), pair formation, avoiding potentially threatening disturbances, and elevating nutrient stores prior to spring migration (Chabreck et al. 1989). Reinecke and Loesch (1996) emphasized the importance of quality winter habitats because of their influence on biological events, such as reproduction (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Raveling and Heitmeyer 1989, Nichols et al. 1995). According to my data, the LCP and TMC ricelands provide an abundance of residual rice and moist-soil seed for waterfowl. Not only do they produce nutritious seeds, but they are home to invertebrate communities which also provide high quality nutrients lacking in agricultural seeds (Fredrickson and Taylor 1982, Kaminski et al. 2003). Nutritious agricultural seeds (e.g., rice), moist-soil seeds, and invertebrates that waterfowl obtain on wintering grounds can positively influence body condition. Loesch and Kaminski (1989) found that mallards fed an ad libitum nutritionally balanced diet maintained better body condition during winter than individuals eating only agricultural seeds. As evidenced by my results, an abundance of residual rice and moist-soil seed exists within Gulf Coast ricelands, and these data will be important to future planning by the GCJV. After one year of collecting soil cores, my data is generally imprecise. Therefore, I recommend continuing and expanding this study in future years to improve precision of waste-rice and moist-soil seed estimates in the Gulf Coast Prairies. Seed rice fields (i.e., rice fields in which rice seed will be harvested, treated, used for rice seed, and planted in subsequent years) are becoming increasingly common in the TMC and LCP (M. R. Kaminski, Ducks Unlimited, Inc., Southern Region Office, Richmond, Texas, personal communication). Seed rice fields may be treated differently by rice producers and have different wildlife values than conventional fields (i.e., no ratoon crop or winter flooding). Therefore, I recommend sampling seed rice fields to determine if management practices and seed abundances differ from conventional rice fields.

Sample Size Estimation

Developing a successful survey sampling design requires planning, evaluation, and iterative improvements (Buckland 1994:149, Stafford et al. 2006*a*). Using results from my pilot study I employed data simulation techniques to identify an optimal sampling design for primary (landowners), secondary (fields within landowners), and tertiary (core samples within fields) sample units between periods (August and November) and field type (actively farmed rice and idle fields. The number of primary sampling units required for desired precision (CV ≤15%) ranged from 10 to >100, depending on field type and sampling period (0). The optimal number of fields to sample from each landowner was one for all management practices and sampling periods. However, for tertiary sample units, there was great variation, ranging from 6-722 soil cores needed for precision (0).

Alternatively, there are important logistical considerations that should be realized in pursuit of achieving precision of ≤15% in future research like mine. I recommend that future studies increase the sample size of primary (landowner) sample units. However, increasing landowner sample size may not be feasible because of limited and declining number of rice farmers (28% decline since 2010; Fletcher 2013), and the difficulty of acquiring permission (i.e., time required to contact and meet with landowners) to obtain samples. There may also be budget constraints associated with procuring increased numbers of soil cores. For example, thus far, the average cost to analyze a soil core in our laboratory has been $14.50. Compared with cost estimates of Stafford et al. (2006*a*; $1.37), our cost per core is about 954% greater. Increase in sample processing cost was likely attributed to the additional time required to sort moist-soil seeds and the fact that technician wages have risen since Stafford et al. (2006*b*). Because my results indicated that the optimum tertiary sample size is ≥20 in most cases, which doubles the number of soil cores needed, this would substantially elevate total costs of the current study. Although I was unable to estimate precisely (CV ≤15%) for both time periods and multiple management practices across regions in 2010, continued collection of the same number of soil cores for two additional years should enhance the precision of the overall regional and composite estimates (Williams et al. 2002:44-45, Stafford et al. 2006*a*).

Management and Research Implications

Waste-Rice and Moist-Soil Seed Abundance

Biologically, abundances of waste-rice and moist-soil seed in my study either remained unchanged or increased through fall in both active and idle rice fields, which clearly contrast that in the MAV (Manley et al. 2004, Stafford et al. 2006*b*). Temporal increases in seed abundance in active and idle rice fields should benefit waterfowl foraging during winter. I believe these trends are important because it seems likely that restrictions on flooding agricultural fields will only increase in the future, especially in Texas because of droughts and diverted uses of water supplies toward expanding urban areas (LCRA 2013*a*). For rice fields, I endorse harvesting a first and second (ratoon) crop, or leaving a ratoon crop standing in actively farmed rice fields. Leaving as much standing stubble as possible conserves waste rice for wintering waterfowl (Stafford et al. 2005, Kross et al 2008). Additionally, agricultural, economic, and environmental benefits accrue through rice straw and plant litter decomposition in flooded production and idled rice fields and improve water quality (Bird et al. 2000; Manley et al. 2004, 2005, 2009). I recommend allowing early succession moist-soil vegetation to grow in idle rice fields to provide critical foraging habitat for waterfowl when flooded. I encourage landowners to shallowly-flood active and idled rice fields (e.g., 1-30 cm), especially those containing annual seed producing species that benefit waterfowl (Chapter 2, Hagy and Kaminski 2012). A combination of actively farmed, idle rice fields, and moist-soil habitats provide habitat heterogeneity, and moist-soil plant seed and aquatic invertebrates contain nutrients otherwise not found or unavailable in agricultural seeds (Fredrickson and Taylor 1982, Kaminski et al. 2003). Interspersion of stubble and open water may be a proximate cue attracting waterfowl to actively farmed and idle rice fields, similar to other waterbirds being attracted to natural wetlands with interspersion of live or dead emergent vegetation (Kaminski and Weller 1992, Havens et al. 2009). Agricultural lands that conserve residual rice and moist-soil seed after harvest may also benefit landowners because they can lease land for hunting as an alternative source of income (Grado et al. 2001).

Evidence is overwhelming that water resources in GCJV region, especially in the TMC, are becoming more limiting for agricultural producers (LCRA 2013*a*). During periods of drought, water regulations are imposed on rice farmers in the TMC, restricting them to growing one rice crop, if any at all (M. R. Kaminski, Ducks Unlimited, Inc., Southern Region Office, Richmond, Texas, personal communication). The Lower Colorado River Authority (LCRA) controls the water supply for most of the TMC and supplies about 60% of total irrigation demands for agriculture (LCRA 2010). The additional 40% of irrigation demands are met by pumping ground water through wells which costs $38-$1079/ha depending on pump type (electric or diesel) and fuel costs (LSU Ag. Center 2012). Costs of receiving water from LCRA irrigation canals or through pumping from groundwater wells can also be expensive for agricultural producers (i.e., $151/acre-foot; LCRA 2013*b*). Therefore, I recommend that farmers close water control structures to capture rain water following crop harvest. I also recommend future studies that investigate conservation of water in rice fields. Studies that monitor pumping costs and efficiency, net losses and gains in daily water supplies, and potential methods to hold and reuse water, such as tail water recovery systems, are also needed (Bouldin et al. 2004).

I recommend that the USDA and NRCS continue to fund and implement the MBHI. Creating mudflats and flooding ricelands (i.e., 1-30 cm) creates habitat for migrating and wintering waterbirds. Waterbirds may have used MBHI ricelands for roosting and foraging. Without the financial incentives provided by the MBHI, pumping water to create habitat would likely not have occurred; unless, the landowner intended to flood ricelands for hunting purposes (Louisiana and Texas rice farmers, personal communication).

As natural wetland and marsh habitats continue to decline in the Gulf Coast regions, the importance of winter-flooded ricelands as foraging habitats for waterfowl will likely increase. I envision the GCJV needing to monitor several factors that will influence dynamics of residual seed in these regions, including rice seed varieties, planting and harvesting dates, and flooding regimes for both active and idle rice fields. Commercial agricultural production practices are influenced by myriad variables, many of which exceed the powers of waterfowl and wetland conservationists. However, my study provides an important baseline of information for the GCJV planning team. Moreover, I recommend the GCJV continue and expand this study, and ideally without delay from the current study, to maintain consistency that will ultimately yield more robust estimate of residual seed abundance in these important landscapes. However, if agricultural management practices change noticeably, such as rice being replaced by different crops (e.g., cotton, corn, soybeans, sugarcane), or different varieties of rice that markedly alter planting and harvest dates, then I recommend that the GCJV consider replicating studies like mine when necessary to maintain contemporary estimates of abundance of residual seed. For now, the subtropical climate of the Gulf Coast enables a unique rice production system that results in a landscape rich in food resources and that provide critical habitats for millions of wintering waterfowl.

Optimizing Sample Design

When designing and implementing a complex sample survey such as mine, it is not uncommon for researchers to err in not collecting data optimally, or to analyze data incorrectly relative to the sampling design (Cassell and Rousey 2003). I attempted to design a survey study that provided preliminary but rigorous estimates of residual seed abundance while also minimizing sampling costs and maximizing precision. I recommend using survey sampling techniques, because when designed correctly, they can reduce costs, be completed with greater speed, allow for a greater scope, and generate greater accuracy (Cochran 1977:1-2). Similar to recommendations by Stafford et al. (2006*a*), if future surveys are needed in other regions where seeds in agricultural fields are important parameters, I recommend using a multi-stage sampling design where landowners are the primary sample units, 1 or 2 fields are sampled per landowner, and ≥10 core samples are collected per field to estimate seed abundance. The number of landowners can be determined by choosing desired precision, followed by analyzing variation in annual mean residual seed abundance among landowners.

Table 1.1 Bias corrected estimates of mean waste-rice and moist-soil seed in the Louisiana Chenier Plain

Sample period	Management practice[b,c]	n cores	Rice			Moist-soil		
			$\bar{x}$	SE	CV	$\bar{x}$	SE	CV
Aug	FH	300	164.2	82.4	50.2	190.3	90.7	47.7
Nov	HR	180	332.4	73.7	22.2	243	105.3	43.3
	SR	70	1,014.0	84.2	8.3	730.4	124.1	17.0
	NR	50	159.7	106.3	66.6	168.6	70.6	41.9
Aug	SI	160	0.4	0.4	90.7	362.3	122.2	33.7
Oct		40	1.0	0.8	81.3	576.4	366.7	63.6
Nov		100	1.6	0.7	45.8	534.8	103.9	19.4
Aug	DI	140	0.2	0.1	44.3	99.7	32.8	32.9
Oct		90	0	0	.	561.0	118.6	21.1
Nov		200	3.4	1.9	55.0	276.2	109.7	39.7

Sample periods, management practices, n cores, and gross bias corrected estimates[a] of mean ($\bar{x}$) waste-rice and moist-soil seed abundances (kg[dry]/ha), standard errors (SE), and coefficients of variation (CV; %) for actively farmed rice and idle fields in the Louisiana Chenier Plain, August-November 2010.

[a] Estimates corrected for seed loss during sieving and non-detection or non-recovery of seeds by technicians.

[b] FH, first harvest; HR, harvested ratoon; SR, standing ratoon; NR, no ratoon; SI, standing idle; DI, disked idle.

[c] Blanks denote same management practice.

Table 1.2 Bias corrected estimates of mean waste-rice and moist-soil seed in the Texas Mid-Coast

Sample period	Management practice[b,c]	*n* cores	Rice			Moist-soil		
			$\bar{x}$	SE	CV	$\bar{x}$	SE	CV
Aug	FH	200	252.6	83.2	32.9	110.3	21.9	19.9
Nov	RH	200	224.8	19.1	8.5	91.5	18.5	20.2
Aug	SI	160	3	3	99	309.7	72.4	23.3
Oct		70	0.7	0.7	97.9	407.8	80	19.6
Nov		120	2.2	1.4	65.2	538.6	109.4	20.3
Aug	DI	40	0	0	.	365.5	1.34	0.3
Oct		30	2	0.6	32.1	957.4	165	17.2
Nov		80	6.2	5.5	88.8	458.7	245.1	53.4

Sample periods, management practices, *n* cores, and gross bias corrected estimates[a] of mean ($\bar{x}$) waste-rice and moist-soil seed abundances (kg[dry]/ha), standard errors (SE), and coefficients of variation (CV; %) for actively farmed rice and idle fields in the Texas Mid-Coast, August-November 2010.

[a] Estimates corrected for seed loss during sieving and non-detection or non-recovery of seeds by technicians.

[b] FH, first harvest; HR, harvested ratoon; SI, standing idle; DI, disked idle.

[c] Blanks denote same management practice.

Table 1.3 Ecological bias corrected estimates of mean waste-rice and moist-soil seed abundances in the Louisiana Chenier Plain.

Sample period	Management practice[b,c]	Rice	Moist-soil	Total
Aug	FH	114.2	190.3	304.4
Nov	RH	282.4	243.0	525.4
	RS	964.3	730.4	1694.7
	NR	109.7	168.6	278.3
Aug	SI	0	381.0	381.0
Oct		0	514.7	514.7
Nov		0	534.8	534.8
Aug	DI	0	99.7	99.7
Oct		0	561.0	561.0
Nov		0	276.2	276.2

Sample periods, management practices, and ecological bias corrected estimates[a] of mean ($\bar{x}$) waste-rice and moist-soil seed abundances (kg[dry]/ha), in actively farmed rice and idle fields in the Louisiana Chenier Plain, 2010.

[a] Estimates of waste-rice and moist-soil seed abundance minus the giving up density (50 kg/ha).

[b] FH, first harvest; HR, harvested ratoon; SR, standing ratoon; NR, no ratoon; SI, standing idle; DI, disked idle.

[c] Blanks denote same management practice.

Table 1.4 Ecological bias corrected estimates of mean waste-rice and moist-soil seed abundances in the Texas Mid-Coast

Sample period	Management practice[b,c]	Rice	Moist-soil	Total
Aug	FH	182.1	96.3	278.4
Nov	RH	162.7	80.2	242.9
Aug	SI	0	342.9	342.9
Oct		0	407.8	407.8
Nov		0	614.5	614.5
Aug	DI	0	365.5	365.5
Oct		0	957.4	957.4
Nov		0	548.9	548.9

Sample periods, management practices, and ecological bias corrected estimates[a] of mean ($\bar{x}$) waste-rice and moist-soil seed abundances (kg[dry]/ha), in actively farmed rice and idle fields in the Texas Mid-Coast 2010.

[a] Estimates of waste- rice and moist-soil seed abundance minus the giving up density (50 kg/ha).

[b] FH, first harvest; HR, harvested ratoon; SI, standing idle; DI, disked idle.

[c] Blanks denote same management practice.

Table 1.5 Variance components and optimal sample size for multi-stage sample survey in the Louisiana Chenier Plain and Texas Mid-Coast.

		Landowner		Field		Core sample	
Field type[a, b]	Sample period	VC[c] (%)	OSS[d]	VC	OSS	VC	OSS
AR	Aug	46,674.8 (12.2)	20	22,029 (5.7)	1	315,929 (82.1)	45
	Nov	129,183 (25.8)	>100	2977 (0.6)	1	367,737 (73.6)	722
I	Aug	116,989 (47.5)	10	17,210 (7.0)	1	112,019 (45.5)	20
	Oct	64,215 (23.6)	50	73,220 (26.9)	1	135,060 (49.6)	6
	Nov	53,726 (12.2)	30	98,023 (22.2)	1	290,160 (65.7)	9

Field types, sample periods, variance components and optimal sample sizes for measurements of seed mass from a multi-stage sample survey in which landowners were primary sample units, rice fields within landowners were secondary units, and soil cores within rice fields were tertiary units, Louisiana Chenier Plain and Texas Mid-Coast, 2010.

[a] AR, actively farmed rice; I, idle.

[b] Blank denotes same field type.

[c] VC, variance component.

[d] OSS, optimal sample size.

Table 1.6 Seed taxa known to be consumed by dabbling ducks in the Louisiana Chenier Plain and Texas-Mid Coast.

Common name	Taxon	Size classification	Reference[a]
Sedge (seeds)	*Cyperus* spp.	Small	1, 4, 5, 6, 7, 8, 10, 11, 14, 15
Sedge (tubers)	*Cyperus* spp.	Large	2, 14
Crabgrass	*Digitaria* spp.	Small	8, 9, 10
Virginia buttonweed	*Diodia virginiana*	Large	8, 9, 14
Barnyardgrass	*Echinochloa* spp.	Large	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15
Spikerush	*Eleocharis* spp.	Small	1, 5, 6, 8, 10, 11, 14, 15
Morningglory	*Ipomoea* spp.	Medium	16
Sprangletop	*Leptochloa* spp.	Small	16
Rice	*Oryza sativa*	Large	1, 3, 4, 5, 6, 7, 8, 11, 14, 15
Panicgrass	*Panicum* spp.	Small	1, 4, 5, 6, 7, 8, 9, 13, 14, 15
Dallisgrass	*Paspalum* spp.	Large	1, 5, 6, 7, 8, 9, 11, 15
Swamp smartweed	*Polygonum hydropiperoides*	Medium	3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15
Curltop smartweed	*P. lapathifolium*	Medium	3, 9, 10, 13, 15
Pennsylvania smartweed	*P. pensylvanicum*	Medium	3, 7, 9, 10, 13, 15
Beaksedge	*Rhynchospora corniculata*	Large	5, 6, 9, 15
Curly Dock	*Rumex crispus*	Medium	16
Arrowhead	*Sagittaria* spp.	Medium	9
Foxtail grass	*Setaria* spp.	Medium	8, 9, 16
Signal grass	*Urochloa* spp.	Large	4, 6, 8, 9, 15

[a] 1 - Chamberlain (1959), 2 - Combs and Fredrickson (1996), 3 - Dabbert and Martin (2000), 4 - Delnicki and Reinecke (1986), 5 - Dillon (1957), 6 - Dillon (1959), 7 – Forsythe (1965), 8 - Glasgow and Junca (1962), 9 – Hagy (2012), 10 - Heitmeyer (2006), 11 – Martin and Uhler (1939), 12 - Schoffman (1947), 13 - Tabatabai et al. (1983), 14 - Wills (1971), 15 -Wright (1959,) 16- Survey of Gulf Coast biologists.

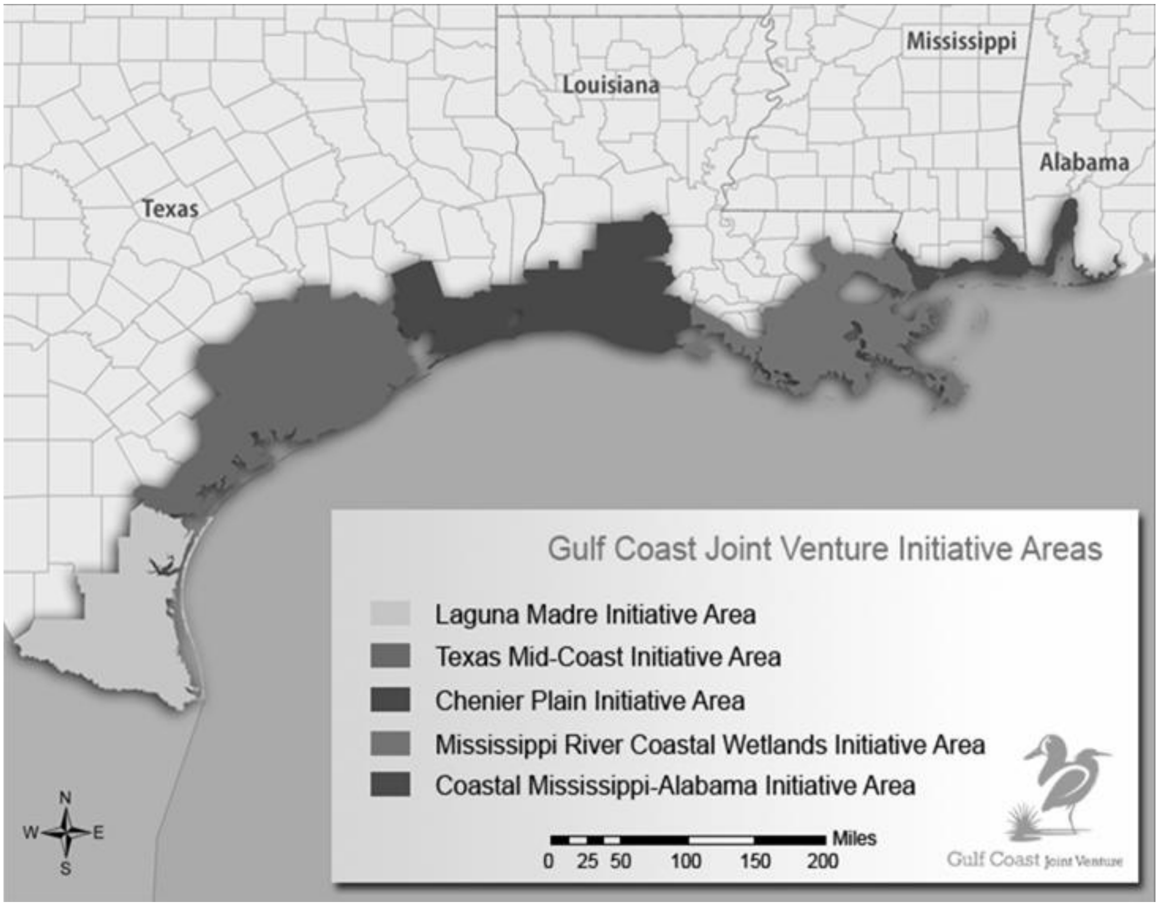

Figure 1.1 Gulf Coast Joint Venture Initiative Areas.

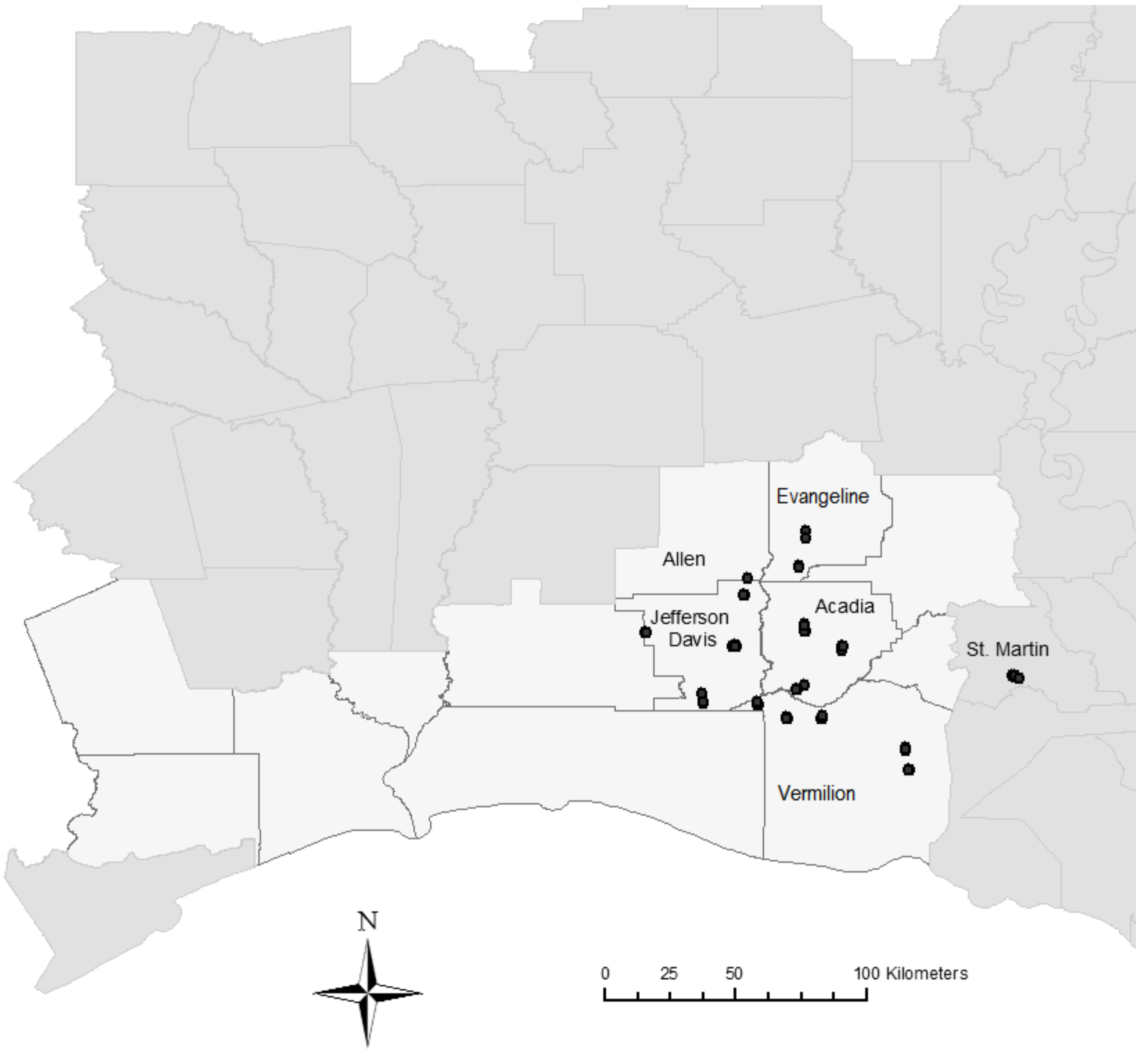

Figure 1.2 Locations of actively farmed and idle rice fields in the Louisiana Chenier Plain where soil cores were collected in August, October, and November 2010.

Figure 1.3 Locations of actively farmed and idle rice fields in the Texas Mid-Coast where soil cores were collected in August, October, and November 2010.

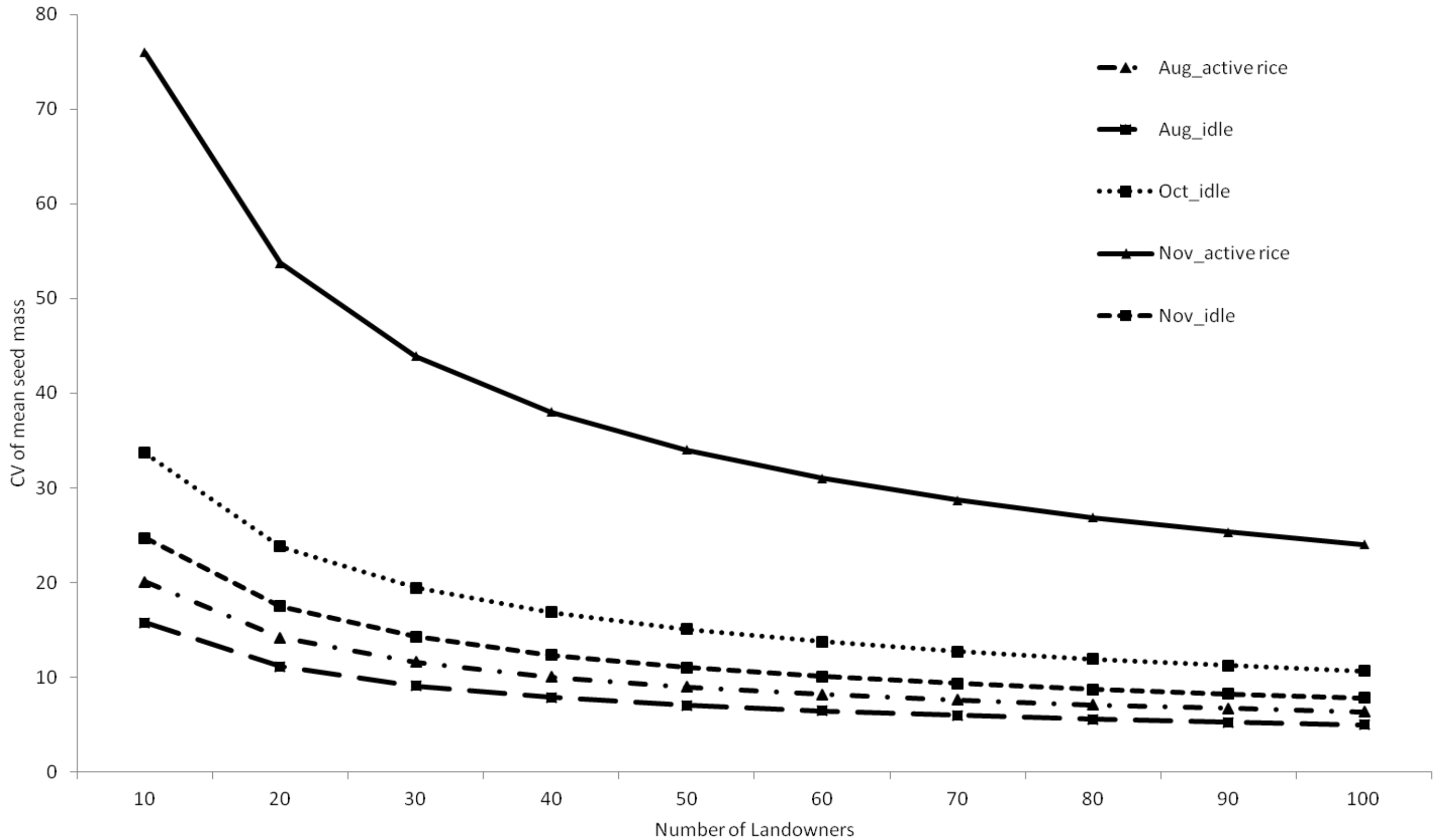

Figure 1.4 Predicted relationships between coefficients of variation of mean seed mass and number of riceland owners (primary sample units), partitioned by sample period (August-November) and land management (actively farmed or idle riceland), based on a multi-stage sample survey conducted in the Louisiana Chenier Plain and Texas Mid-Coast, fall 2010.

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CHAPTER II

WATERBIRD USE OF RICELANDS IN THE GULF COAST PRAIRIES OF LOUISIANA AND TEXAS

Introduction

Anthropogenic modifications have induced loss of an estimated 10.8 million hectares of wetlands in the United States since the 1950's (Dahl 2011). Following loss of natural wetlands, flooded agricultural lands have become important habitat for waterfowl and other waterbirds (Tiner 1984, Reinecke et al. 1989, Czech and Parsons 2002, Eadie et al. 2008). Among agricultural systems, rice is an important habitat for waterbirds in the United States and worldwide (Elphick and Oring 1998, Czech and Parsons 2002, Taft and Elphick 2007, Eadie et al. 2008, Pierluissi 2010, Stafford et al. 2010). Rice is typically grown in alluvial and artificially irrigated soils, often where wetlands once predominated (Eadie et al. 2008). Rice fields are not as ecologically diverse or dynamic as wetlands, but vegetation structure within them is similar to emergent wetlands, and about 86% of ricelands worldwide are shallowly flooded (i.e., <30 cm) at least part of the year (Elphick et al. 2010). Thus, rice fields facilitate meeting annual-cycle needs of resident and migratory waterbirds (Reinecke et al. 1989, Fasola and Ruiz 1996, Eadie et al. 2008, King et al. 2010, Stafford et al. 2010).

Among all wildlife, birds are some of the most diverse and abundant vertebrates that use rice fields in North America (Eadie et al. 2008, Elphick et al. 2010). Acosta et al. (2010) identified 335 bird species (i.e., 169 aquatic birds and 166 landbirds) that used rice fields in ten countries, and most waterbird species detected occurred in rice fields in the United States. The Gulf Coast landscapes in Louisiana and Texas are significant rice producing regions in North America and critical to migratory and resident birds, given loss and degradation of wetlands in this region (Chabreck et al. 1989, Hobaugh et al. 1989). Rice fields near the Gulf Coast provide breeding and wintering habitats for at least 68 species of birds, including anhingas (Anhingidae), coots (Rallidae), cormorants (Phalacrocoracidae), gallinules (Rallidae), grebes (Podicipedidae), gulls (Laridae), kingfishers (Cerylidae), pelicans (Pelecanidae), rails (Rallidae), shorebirds (Charadriidae, Recurvirostridae, Scolopacidae), terns (Sternidae), wading birds (Ardeidae, Threskiornithidae), waterfowl (Anatidae; Hohman et al. 1994, Elphick 2000, Huner et al. 2002, Eadie et al. 2008).

The North American Waterfowl Management Plan (NAWMP; Canadian Wildlife Service, U.S. Fish and Wildlife Service, and Mexico National Institute of Ecology 1986, 2012) was established between the United States, Canada, and Mexico. Joint Ventures (JV) are subunits of NAWMP that work to create, conserve, and sustain waterbird habitats (Miller 1987, Hobaugh et al. 1989, Reinecke et al. 1989, Eadie et al. 2008). The JVs assume food energy may be limiting during migration and winter, substantiating need for habitats containing energy-rich seeds such as rice (Reinecke et al. 1989, Kaminski et al. 2003). Common species of waterfowl using rice fields include American green-winged teal (*Anas crecca*), lesser snow geese (*Chen caerulescens*), greater white-fronted geese (*Anser albifrons*), mallards (*Anas platyrhynchos*), northern pintail (*A. acuta*), and northern shoveler (*A. clypeata*; Alisauskas et al. 1988 Hobaugh et al. 1989;

Cox and Afton 1997, 1998). Shorebird use of flooded agricultural fields in the Gulf Coast can be extensive, $\geq$30 species of shorebirds have been observed in the Gulf Coast region (Rettig 1994), whereas at least 22 species of shorebirds use agricultural and seasonal wetlands in the MAV (Twedt et al. 1998). Dunlins (*Caladris alpine*), killdeer (*Charadrius vociferous*), lesser yellowlegs (*Tringa flavipes*), long-billed dowitchers (*Limnodromus scolopaceus*), pectoral sandpipers (*C. melanotos*), and western sandpipers (*Caladris mauri*) are common species in the MAV (Remsen et al. 1991, Rettig 1994).

Rice fields in the Gulf Coast region may be managed several ways following harvest typically in July-August: 1) growing a second or "ratoon" rice crop, 2) managing fields for crayfish production, 3) disking residual rice stubble from first or ratoon harvests, 4) idling fields to promote natural vegetation, or 5) allowing fields to idle for varying times followed by disking. First and ratoon harvested rice fields are often deeply flooded (e.g., <30 cm) to attract waterfowl for hunting. In addition to waterfowl hunting, agricultural economic and environmental benefits accrue through rice straw and plant litter decomposition in flooded production and idled rice fields and improved water quality (Bird et al. 2000; Manley et al. 2004, 2005, 2009).

Abundance and species diversity of waterbirds are generally greater in flooded than non-flooded rice fields (Elphick and Oring 1998, Elphick 2004, Stafford et al. 2010). However, although flooding attracts waterbirds to rice fields, inundation may not be the overriding factor that determines use of these fields by some species. For example, Lourenco and Piersma (2009) found that densities of generalist species, such as cattle egret (*Bubulcus ibis*), common snipe (*Gallinago gallinago*; Maeda 2001), and gulls (Moreira 1995, Tourenq et al. 2001) used flooded and dry rice fields. Waterfowl species such as lesser snow geese and greater white-fronted geese have been documented foraging in dry agriculture fields (Hobaugh 1984, Day and Colwell 1988, Miller et al. 2010). Several other biotic and abiotic factors may influence avian use of active and idle rice fields including soil or fire disturbance, vegetation succession, and surrounding landscapes (Elphick and Oring 1998, 2003; Taylor and Schulz 2006, Lourenco and Piersma 2009, Havens et al. 2009, and Elphick et al. 2010). Nonetheless, depth and duration of flooding influence avian abundance and diversity in rice and other agricultural fields (Ibáñez et al. 2010). Partially flooded rice fields also benefit foraging and roosting birds, because protruding soil and crop stubble provide cover and loafing sites (Elphick and Oring 2003, Elphick et al. 2010).

Following the April 2010 Deepwater Horizon Oil Spill in the Gulf of Mexico, the Natural Resources Conservation Service (NRCS) established the Migratory Bird Habitat Initiative (MBHI). The MBHI was intended to provide flooded rice fields and other habitats for resident and migrant waterbirds inland away from potentially oil-impacted areas in coastal wetlands. Part of MBHI's mission was to incentivize private landowners in eight states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, and Texas) to flood croplands (e.g., active and idle ricelands) and natural wetlands to increase availability of habitats away from the oil spill areas. Specifically for ricelands, the primary MBHI management practice was shallow flooding of post-harvested production and idle fields during autumn and winter in the coastal parishes and counties of Louisiana and Texas. To assess these management actions, I studied waterbird use of enrolled MBHI and non-MBHI lands in the Louisiana Chenier Plain (LCP) and Texas Mid-Coast (TMC). My specific objectives were to quantify and compare waterbird use of ricelands relative to different management practices, survey periods, and flooding categories. I hypothesized that 1) waterbird density and species richness would be greater in flooded than dry fields, and 2) density and species richness would differ among different survey periods and management practices. I predicted greatest densities of birds would occur in flooded ratoon harvested rice fields because of potentially increased food resources (i.e., waste-rice and moist-soil seeds) and flooded disked idle fields because of sparse vegetation and ease of access to food and other resources (Chapter 1).

Study Area

Chenier Plain, Louisiana and Texas

The Chenier Plain ecoregion extends throughout southwest Louisiana (29° 31' - 31° 00' N; 91° 57' - 93° 54' W; Figure 2.1) and southeast Texas (29° 21' - 30° 29' N; 93° 41' - 95° 10' W; Figure 2.1). Historically, this region was comprised of diverse savannahs and wetlands that extended approximately 322 km from Vermilion Bay in Louisiana to Galveston Bay in Texas (Esslinger and Wilson 2001). The Chenier Plain includes coastal marshes along the Gulf of Mexico and extends 64 to 112 km inland through former coastal savannahs that today are intensively cultivated for rice and other agronomic crops (Esslinger and Wilson 2001). The climate in the Chenier Plain is sub-tropical and humid with an average growing season of 270 days, 13 freeze days per year, and temperatures ranging from ~14° C in December-January to ~30° C July-August (Gosselink et al. 1979, Chabreck et al. 1989, Visser et al. 2000). From east to west through the Chenier Plain, average annual precipitation decreases from 144 to 113 cm per year (Gosselink et al. 1979, Visser et al. 2000). The Chenier Plain is subject also to frequent and sometimes intense weather disturbances, where tropical storms make landfall every 1.6 years and hurricanes every 3.3 years on average (Roth 1999).

Within the Chenier Plain, there are several large tracts of land managed as wildlife refuges either by the state of Louisiana, including Rockefeller (30,756 ha) and Russell Sage (6,812 ha), or the U. S. Fish and Wildlife Service, including Sabine (50,387 ha) and Lacassine (14,163 ha) National Wildlife Refuges (Visser et al. 2000). Historically, the regional landscape contained numerous and interspersed small depressional wetlands important to migratory and resident birds (Chabreck et al 1989, Esslinger and Wilson 2001). The region's abundant average annual rainfall, long growing season, and fertile soils, created ideal conditions for widespread conversion of Chenier Plain into rice and other agriculture (Esslinger and Wilson 2001). The Chenier Plain includes the Louisiana parishes of Acadia, Allen, Calcasieu, Cameron, Evangeline, Jefferson Davis, and Vermilion and the Texas counties of Chambers, Jefferson, Liberty, and Orange. For my study, I focused specifically on the Louisiana parishes of Acadia, Allen, Evangeline, Jefferson Davis, St. Martin, and Vermilion, as they accounted for approximately 90% of the total rice production in the LCP in 2009 (USDA 2010*a*). I did not sample in the Texas Chenier Plain (TCP) in 2009 because of time limitations, and accessibility of rice producers.

Texas Mid-Coast

The Texas Mid-Coast includes 16 counties that extend from the coast at Galveston Bay to Corpus Christi and northward 170 km (27° 48' - 30° 13' N; 94° 43' - 97° 54' W; Figure 2.2). The original plant community in the Mid-Coast primarily consisted of tall grass savannahs, with patches of post oak savannah in upland areas

(Gould 1975, Hobaugh et al. 1989). Currently, the region consists of remnant coastal savannahs inland and adjacent to expansive bays and estuaries, in addition to inland areas dominated by agriculture (Wilson and Esslinger 2002). Within the TMC I studied ricelands within only the three most prominent rice producing counties of Colorado, Matagorda, and Wharton (Figure 2.2). These counties accounted for 75% of the total rice production in the TMC in 2009 (USDA 2010*a*). "Rice Prairies" is a frequently used term to reference former coastal prairies that today are intensively cultivated for rice and other agronomic crops (Hobaugh et al. 1989). Rice prairies in the TMC are characterized by nearly level to gently sloping topography with elevations ranging from 10-70 m above mean sea level (MSL; Hobaugh et al. 1989). Rice prairie soils have a surface layer of fine sandy loam above several layers of clay and sandy clay (McEwen and Crout 1974, Westfall 1975, Hobaugh et al. 1989). The region receives average annual rainfall of 104 cm (range 90-140 cm), which is generally evenly distributed throughout the year (Hobaugh et al. 1989). The area has a humid climate with hot summers and mild winters, the growing season averages 270 days per year, and low temperatures rarely dip below -6° C during winter (McEwen and Crout 1974, Hobaugh 1989).

Methods

Field Selection

I randomly selected 10 active and 10 idle rice fields in each of the Louisiana Chenier Plain and Texas Mid-Coast areas for waterbird surveys. Randomly selected fields were a subset (40%) of ones from my other study of dynamics of waste-rice and moist-soil seeds (Chapter 1). Actively farmed and idle rice fields included six categories: 1) fields harvested twice per season, first in August-early September and second, October-early November (harvested ratoon); 2) fields in which a ratoon crop was grown, not harvested, and left standing, generally for crawfish aquaculture or waterfowl habitat (standing ratoon); 3) fields in which a ratoon crop was harvested and stubble and soil disked (disked ratoon); 4) fields harvested once in August-early September (no ratoon); 5) idle fields with standing natural vegetation (idle standing); or 6) disked idled fields (idle disked).

Waterbird Surveys

In an attempt to detect all or most waterbirds present during surveys, I conducted direct count/whole area surveys, which allowed me to view entire fields from one or multiple locations and reduced possibilities of omission (Integrated Waterbird Management and Monitoring Program 2010). Ricelands usually contained some visual obstructions (e.g., vegetation, levees), which may have hindered my detection of birds and negatively biased survey data. Thus, my data represented relative abundance of waterbirds, which suffice for evaluating predictions of waterbird use of differently managed rice fields. To minimize multiple counting of individual birds, I visually followed flushed birds and noted their location if they alighted in areas yet to be surveyed (Kaminski and Prince 1981, Fleming 2010). I surveyed waterbirds diurnally from sunrise to sunset. I conducted surveys only in favorable weather and not on days with fog, rain, and winds >20 mph (O'Neal et al. 2008, Fleming 2010). In each state, I rotated survey routes so fields would be sampled at different time periods each survey. I drove an all-terrain vehicle to suitable vantage point(s) or walked along roads and levees bordering fields. To ensure randomness in surveys of fields, I never followed the same directional route in consecutive surveys. I measured the water depth of a field to designate flooding status using a meter stick, and used ArcMap10 to estimate wetland area (ha) within each field, which enabled me to convert waterbird relative abundance data to density estimates (i.e., *n* birds/wetland ha of shallowly flooded [mudflat- 30 cm], deeply flooded [≥30 cm].

I conducted six ground surveys of waterbirds during four-day periods and in 2-3 week time intervals from mid-December 2010 – mid-March 2011. My specific survey periods were: 1) 14-18 December 2010; 2) 7-11 January 2011; 3) 21-25 January 2011; 4) 10-14 February 2011; 5) 24-28 February 2011; and 6) 9-13 March 2011. Thus, I completed 6 surveys of 40 ricelands in Louisiana and Texas, totaling 240 waterbird-wetland observations.

Statistical analyses

I natural log transformed waterbird density and species richness data (i.e., dependent variables) to achieve normality and homogenous variances before performing analysis of variance (ANOVA; Kamamura 1999, Conquest 2000). I used repeated measures ANOVA in PROC MIXED (SAS v.9.3; SAS Institute 2011) to test if densities of all waterbird species combined varied in relation to fixed effects of management practices applied to active and idle rice fields, survey periods, flooding statuses, and all possible 2- and 3-way interactions. The random effect was the landowner, and the repeated measure was the survey. I combined all waterbird species for analysis because of only six survey periods, occurrence of zero values for numerous fields, and to normalize residuals. I used an autoregressive covariance structure, because I collected data every 2-3 weeks (Gutzwiller and Riffell 2007). To test for differences in bird densities and species richness among fixed effects, I assumed my detection probability of waterbirds was similar across fields and species. I chose $\alpha = 0.10$ a priori because of relatively small number of survey periods (n = 6) and fields from which I collected waterbird data (n = 10 active and 10 idle rice fields in each of Louisiana and Texas (Tacha et al. 1982). I performed all pair-wise comparisons of least-squared means using an adjusted Tukey's test when I detected an overall treatment main effect (Adjusted $P \leq 0.10$; Kross et al. 2008, Wiseman 2009). I back-transformed dependent variables and reported their associated means and 90% confidence limits (Zar 1999).

Results

Waterbird Species Richness

I neither detected differences in mean species richness among management practices ($F_{5,158}$ = 0.33, P = 0.896), survey periods ($F_{5,158}$ = 0.35, P = 0.880), flooding statuses ($F_{2,158}$ = 1.35, P = 0.985). Nor did I detect differences between interactive effects of survey period and flooding status ($F_{10,158}$ = 1.35, P = 0.210), management practice and flooding status ($F_{10,158}$ = 1.17, P = 0.313), survey period and management practice ($F_{25,158}$ = 0.84, P = 0.681), and the 3-way interaction of these effects ($F_{26,158}$ = 1.26, P = 0.196). Although not significantly different, disked ratoon fields contained the greatest species richness ($\bar{x}$ = 0.95 waterbird species/survey; 90% CI = 0.34-1.83), and harvested ratoon fields had the lowest species richness ($\bar{x}$ = 0.65 waterbird species/survey; 90% CI = 2.37-19.70; Figure 2.3). I observed 13 species of waterfowl and 17 other species of waterbirds (i.e., wading birds, shorebirds, gulls, and terns; Table 2.1). Despite only being observed in 11% of the surveys, lesser snow and greater white-fronted geese (n = 22,882) were the most abundant species, which comprised 62% of all waterbird observations. Other waterfowl species comprised 23% of observations, and all other waterbirds comprised 15% of observations (Table 2.1).

Waterbird Density

Field management practices and flooding statuses interacted to explain variation in waterbird densities in winter ($F_{10, 184}$ = 2.04, P = 0.031; Figure 2.4). As predicted, mean waterbird density in dry fields was lowest among all management practices ($\bar{x}$ = ≤0.25 waterbirds/ha; 90% CI = 0.21-0.96; Figure 2.4). In actively farmed ricelands with a ratoon crop that was harvested and subsequently disked (i.e., disked ratoon) waterbird density was 4 times greater when these fields were shallowly flooded ($\bar{x}$ = 5.04 waterbirds/wet ha, 90% CI = 3.61-6.64) instead of deeply flooded ($\bar{x}$ = 1.22 waterbirds/wet ha, 90% CI = 0.66-9.14; t_{184} = -3.35, Adj P = 0.087; Figure 2.4). Mean waterbird density in disked ratoon fields that were dry ($\bar{x}$ = 0.00 waterbirds/wet ha, 90% CI = 0.00-0.72) was significantly less than 1) deeply flooded harvested ratoon fields ($\bar{x}$ = 4.75 waterbirds/wet ha, 90% CI = 2.75-5.27; t_{184} = -3.51, Adj P = 0.054), 2) deeply flooded standing idle fields ($\bar{x}$ = 5.27 waterbirds/wet ha, 90% CI = 3.66-8.81; t_{184} = -3.31, Adj P = 0.096), and 3) shallowly flooded fields with no ratoon ($\bar{x}$ = 7.35 waterbirds/wet ha, 90% CI = 4.98-12.35; t_{184} = -3.64, Adj P = 0.036; Figure 2.4).

In dry harvested ratoon fields, mean waterbird density ($\bar{x}$ = 0.25 waterbirds/wet ha, 90% CI = 0.04-0.71) was 11-29 times less than 1) shallowly flooded harvested ratoon fields ($\bar{x}$ = 2.78 waterbirds/wet ha, 90% CI = 1.60-2.77; t_{184} = -3.30, Adj P = 0.099), 2) deeply flooded harvested ratoon fields ($\bar{x}$ = 4.75 waterbirds/wet ha, 90% CI = 2.75-5.27; t_{184} = -4.01, Adj P = 0.010), and 3) shallowly flooded no ratoon fields ($\bar{x}$ = 7.35 waterbirds/wet ha, 90% CI = 4.98-12.35; t_{184} = -3.68, Adj P = 0.032; Figure 2.4).

Mean waterbird density in dry disked idle fields ($\bar{x}$ = 0.06 waterbirds/wet ha, 90% CI = 0.00-0.61) was 46-122 times less than 1) deeply flooded disked idle fields ($\bar{x}$ = 3.35

waterbirds/wet ha, 90% CI = 1.72-2.84; t_{184} = -4.30, Adj P = 0.003), 2) shallowly flooded harvested ratoon fields ($\bar{x}$ = 2.77 waterbirds/wet ha, 90% CI = 1.60-2.78; t_{184} = -3.65, Adj P = 0.035), 3) deeply flooded harvested ratoon fields ($\bar{x}$ = 4.75 waterbirds/wet ha, 90% CI = 2.75-5.27; t_{184} = -4.36, Adj P = 0.002), 4) deeply flooded standing idle fields ($\bar{x}$ = 5.27 waterbirds/wet ha, 90% CI = 3.66-8.81; t_{184} = -3.55, Adj P = 0.049), and 5) shallowly flooded no ratoon fields ($\bar{x}$ = 7.35 waterbirds/wet ha, 90% CI = 4.98-12.35; t_{184} = -4.03, Adj P = 0.009; Figure 2.4). In dry standing idle fields, mean waterbird density ($\bar{x}$ = 0.07 waterbirds/wet ha, 90% CI = 0.00-0.75) was 75-105 times less than 1) deeply flooded standing idle fields ($\bar{x}$ = 5.27 waterbirds/wet ha, 90% CI = 3.66-8.81; t_{184} = -3.40, Adj P = 0.075), and 2) shallowly flooded no ratoon fields ($\bar{x}$ = 7.35 waterbirds/wet ha, 90% CI = 4.98-12.35; t_{184} = -3.85, Adj P = 0.018; Figure 2.4).

Waterbird density also varied in relation to interactive effects of survey periods and flooding statuses ($F_{10,\,184}$ = 2.90, P = 0.002; Figure 2.5). During all survey periods, mean waterbird density was lowest in dry ricelands (i.e., active and idle rice fields combined; $\bar{x}$ = ≤0.32 waterbirds/ha; 90% CI = 0-1.60; Figure 2.5). During the first 3 surveys (December 2010 – January 2011) of shallowly flooded ricelands, mean waterbird density was similar, ranging from 3.13 waterbirds/wet ha (90% CI = 0.32-11.94) to 3.83 waterbirds/wet ha (90% CI = 1.63-7.87; Figure 2.5).

Mean waterbird density was at least 24 times greater in deeply flooded ricelands during survey period 4 ($\bar{x}$ = 7.82 waterbirds/wet ha, 90% CI = 3.94-14.93), than in dry ricelands during survey period 1 ($\bar{x}$ = 0.32 waterbirds/wet ha, 90% CI = 0.00-1.28; t_{184} = -4.21, Adj P = 0.004), survey period 2 ($\bar{x}$ = 0.00 waterbirds/wet ha, 90% CI = 0.00-0.85; t_{184} = -4.78, Adj P = 0.0005), and survey period 4 ($\bar{x}$ = 0.00 waterbirds/wet ha, 90% CI =

0.00-0.72; t_{184} = -4.77, Adj P = 0.0005; Figure 2.5). Additionally, during survey period 4 mean waterbird density in deeply flooded ricelands ($\bar{x}$ = 7.82 waterbirds/wet ha, 90% CI = 3.94-14.93) was 6 times greater than those shallowly flooded ($\bar{x}$ = 1.22 waterbirds/wet ha, 90% CI = 0.82-1.30; t_{184} = -3.73, Adj P = 0.027; Figure 2.5).

During survey period 3 mean waterbird density was significantly greater in shallowly flooded ricelands ($\bar{x}$ = 3.31 waterbirds/wet ha, 90% CI = 1.69-6.10) than in dry ricelands ($\bar{x}$ = 0.00 waterbirds/wet ha, 90% CI = 0.00-0.72; t_{184} = -4.62, Adj P = 0.001; Figure 2.5). During survey period 2, mean waterbird density in shallowly flooded ricelands ($\bar{x}$ = 3.38 waterbirds/wet ha, 90% CI = 2.20-4.04) was significantly greater than in dry ricelands ($\bar{x}$ = 0.00 waterbirds/wet ha, 90% CI = 0.00-0.85; t_{184} = -3.69, Adj P = 0.034; Figure 2.5).

Discussion

Waterbird Species Richness

Despite detection of 30 species of waterbirds in active and idle rice fields and contrary to results of Elphick and Oring (2003), I was unable to detect any differences in species richness among fixed effects of management practice, survey period, or flooding status, as well as all 2- and 3-way interactions. Elphick and Oring (1998) reported that rice fields in California flooded to depths of 15-20 cm attracted the greatest variety of waterbird species. Hagy and Kaminski (2012) reported that ~90% of all observed foraging dabbling ducks (Anatini) in managed moist-soil wetlands in the MAV were in areas <16 cm of water. However, rarely did I encounter rice fields that were flooded to this range of depths. Consequently, a preponderance of dry or deeply flooded (≥30 cm) ricelands in my study areas may have promoted use primarily by geese and ducks. For example, the most common species of waterfowl using MBHI ricelands in the Gulf Coast region were greater white-fronted geese, lesser snow geese, northern shovelers, northern pintails, and green-winged teal, similar to other investigations (Remsen et al. 1991; Cox and Afton 1997, 1998). The absence of some common species also may have been related to the short duration of my surveys (i.e., December 2010- March 2011). Perhaps species such as green heron (*Butorides virescens*), little blue heron (*Egretta caerulea*), roseate spoonbill (*Platalea ajaja*) and other migratory species had departed my areas for more southerly wintering grounds prior to initiation of surveys.

The MBHI guidelines were broad, varying from simply incentivizing landowners to close water-control structures to create mudflats or flooding fields 1-30 cm deep, in addition to vegetation manipulations such as disking and rolling. For this pilot study, I selected all fields included in the 2010-2011 waterbird surveys prior to implementation of MBHI field practices in fall 2010. Thus, my study may not have fully reflected all MBHI management practices. Over 72% of all observed waterbirds occurred in fields dry or flooded ≥30 cm. Future waterbird surveys should incorporate a greater representation of shallowly flooded fields managed by landowners enrolled in MBHI, which may further explain observed patterns of waterbird use in these important landscapes. Nonetheless, wet and dry MBHI and other ricelands provided habitat for at least 30 migrating or wintering waterbird species.

Waterbird Density

Waterbird density in dry ricelands remained low (i.e., ≤0.32 waterbirds/ha) during winter 2010-2011. I observed killdeer, lesser snow geese, and greater white-fronted geese in dry, disked idle fields and dry rice fields with a harvested ratoon crop. Greater white-fronted and lesser snow geese use flooded and dry rice fields for foraging and loafing (Hobaugh 1984, Day and Colwell 1998, Miller et al. 2010); whereas, deeply flooded fields may have provided foraging and roosting areas for geese, ducks, herons, egrets, and ibis (Day and Colwell 1998, Elphick and Oring 1998, Ackerman et al. 2006, Havens et al. 2009, Miller et al. 2010). Given the prevalence of dry fields, I was not surprised to observe predominately habitat generalist species, such as the aforementioned species.

Variation in waterbird density was explained by the interaction of management practice and flooding status. The interaction was caused by increased use of active open rice fields (e.g., disked ratoon and single harvested fields) that were shallowly flooded from MBHI or other water sources. Disked ratoon and no ratoon rice fields typically had sparse vegetation and were used frequently and abundantly by waterbirds when shallowly flooded (Figure 2.4). However, in spite of being shallowly flooded, harvested ratoon, standing ratoon, and standing idle fields presumably had low densities of waterbirds because of dense vegetation. Generally waterfowl and shorebirds avoid fields with tall, dense vegetation until it topples or openings are created (Anderson and Smith 1999, Gray et al. 1999, Havens et al. 2009, Stafford et al. 2010, Hagy and Kaminski 2012). Disked idle fields had sparse vegetation similar to no ratoon and disked ratoon rice fields. However, waterbird density in disked idle fields was greater when fields were deeply than when shallowly flooded, and were primarily used by waterfowl such as northern pintail and northern shoveler. None of my study sites with deeply flooded disked idle fields were hunted; thus, these fields may have acted as sanctuaries for waterfowl. Cox and Afton (1997) reported that northern pintails in southwestern Louisiana used sanctuary areas diurnally during hunting seasons. Similarly, St. James et al. (2013) found that diurnal use of sanctuaries by waterfowl on MAV Wildlife Management Areas increased 30% during hunting season. Additionally, disked idle fields may have afforded waterfowl easy access to large abundances of food resources (Chapter 1).

Field conditions promoted by MBHI (e.g., shallow flooding of disked ratoon and no ratoon rice fields) had the greatest densities of waterbirds. Additionally, waterbird density was greater in ricelands with conditions promoted by MBHI during 4 out of 6 survey periods than conditions not promoted by MBHI (e.g., dry and deeply flooded ricelands). Thus, it is evident that waterbirds used riceland habitat provided through MBHI.

Waterbird densities in shallowly and deeply flooded ricelands varied among survey periods. In early January 2011, waterbird density was significantly greater in shallowly flooded fields than in deeply flooded fields. However, in early February 2011, waterbird density in deeply flooded fields was significantly greater than in shallowly flooded fields. Egrets, herons, ibises, gulls, and terns that used shallowly flooded fields in December 2010 and January 2011 may have begun using deeply flooded fields during February because of possible increased availability of these fields and food resources within them (e.g., crayfish, *Procambrus* spp.; Huner 2002). Waterbird density subsequently declined in deeply flooded fields and increased in shallowly flooded fields from early–late February 2011. Perhaps waterbird density decreased in deeply flooded fields in February because farmers began draining these fields after the waterfowl hunting season, causing birds to disperse. Additionally, rainfall, run-off and ponding, and high river levels contributed to shallow flooding of previously dry fields, affording new foraging and other habitats (Elphick and Oring 2003).

Crayfish production in ricelands of southwest Louisiana is an important commercial enterprise (McClain and Romaire 2004). Water depths in rice fields where crayfish are cultured are typically maintained between 20-60 cm (McClain and Romaire 2004). Previous studies have indicated that colonial wading bird populations have increased in Louisiana in response to increased crayfish production fields (Fleury and Sherry 1995). However, I found that crayfish production fields attracted low numbers of waterbirds (i.e., flooded standing ratoon fields; 1.73 waterbirds/wet ha). Because surveys did not continue into April when crayfish fields are typically drawn down, I likely did not observe peak waterbird densities in crayfish rice fields. Disturbance was another factor that likely influenced waterbird use of crayfish fields in Louisiana. Agricultural producers use boats to harvest crayfish from active and idle rice fields multiple times per week. This activity undoubtedly disturbed and dispersed waterbirds. Producers also frequently placed air cannons or bright colored flags and streamers in rice fields to deter depredation of crayfish by waterbirds.

Recent high soybean prices greatly influenced area of idle lands in the LCP (S. Linscombe, Louisiana State University Agricultural Center [LSUAC], personal communication). When commodity prices become favorable, farmers plant soybeans in otherwise idle rice fields. For example, area of planted soybeans more than doubled between 2005 and 2009, when farmers in the LCP planted 17,077 and 36,867 ha, respectively (GCJV unpublished data). Soybeans are not energy- and nutrient-rich for waterfowl and decompose quickly in southern environments (Loesch and Kaminski 1989, Foster et al. 2010). Therefore, flooded idled rice fields may be critical supplemental sources of moist-soil seed and aquatic invertebrates for waterbirds in the LCP and TMC. For example, in LCP idle fields with standing vegetation, moist-soil seed abundance increased from 342 kg/ha to 614 kg/ha from August to November 2010 (Chapter I). Similarly, in idle fields that were disked in 2010, moist-soil seed abundance increased from 365 kg/ha to 548 kg/ha over the same period (Chapter I). Contrary to trends in the MAV (Hagy and Kaminski 2012), disking in the LCP and TMC idle fields subsequently increased seed abundance as seeds were incorporated with soil. I attribute this trend to the fact that many fields containing standing vegetation in August were disked in October or early November. Seeds that had not yet shattered from the panicle in standing idle fields were incorporated into the soil surface when disked in October and November.

Stringent water regulations in the TMC and LCP are challenging relative to flooding of agriculture fields for farming and provision of waterbird habitat. The Lower Colorado River Authority (LCRA) controls the water supply for most of the TMC and supplies about 60% of total irrigation demands for agriculture (LCRA 2010). The additional 40% of irrigation demands are met by pumping ground water, which costs $38-$1,079/ha depending on pump type (e.g., electric or diesel) and fuel costs (LSUAC 2012). Costs of receiving water from LCRA irrigation canals or through pumping from groundwater wells also can be expensive for agricultural producers (e.g., $151/acre-foot; LCRA 2013). Farmers often close water control structures in fields to capture rainwater after rice harvest to save money and conserve water. The financial incentives that MBHI provided farmers to pump and flood ricelands were greatly sought by producers in Louisiana and Texas; the NRCS signed contracts and obligated approximately 93,388 ha of land (U.S. Department of Agriculture 2010*b*, 2010*c*). Financial incentives from NRCS allowed farmers to provide waterbird habitats which were especially important during the widespread severe drought during summer-fall 2010 (NOAA 2013).

Management and Research Implications

In my study I observed an interaction between flooding status and management practice and flooding status and survey period. A complex of wetland and agricultural habitat resources is attractive to diverse guilds of waterbirds (Elphick and Oring 2003, Hagy and Kaminski 2012, Pearse et al. 2012). I advocate that landowners and other resource managers encourage a diversity of flooded fields, such as active and idle rice fields or moist-soil wetlands. I also recommend the following strategies: 1) close water control structures to capture rainfall following the first and ratoon harvests in actively farmed rice fields, as well as in idle rice fields to capture rainwater; and 2) create openings in rice production fields after harvest in rice fields and in idled fields, using mechanical devices or fire (Kross et al. 2008, Havens et al. 2009, Hagy and Kaminski 2012). Although I did not quantify bird response to vegetation manipulations, previous research has documented the importance of interspersed vegetation and water (e.g., hemi-marsh) to foraging waterbirds on both breeding and wintering areas (Kaminski and Prince 1981, Smith et al. 2004, Havens et al. 2010, Hagy and Kaminski 2012). However, when landowners manage agricultural vegetation, I caution them not to manipulate standing rice because such creates a “baited” site that cannot be legally hunted (U.S. Fish and Wildlife Service 2013).

Although I did not analyze my data by waterbird taxa, a second important consideration in attracting a diversity of waterbirds is providing appropriate water depths for desired taxa. I recommend flooded fields with a range of water depths to provide habitat for multiple waterbird guilds. Ideal depths range from 3-13 cm for shorebirds, 9-20 cm for herons and ibis, 14-22 cm for dabbling ducks (*Anas*), 18-26 cm for geese, and 24-34 cm for diving waterfowl species (*Aythya*; Elphick and Oring 2003, Hagy and Kaminski 2012). Post-harvested rice fields and idled fields often attract several guilds of birds when flooded. These resources provide critical surrogate habitats mitigating losses of coastal and inland wetlands in these or other regions especially following environmental catastrophes such as oil spills and hurricanes.

Future research should address waterbird use of post-harvest active and idle rice fields in the LCP and TMC to more completely understand how vegetation height and density, drought, flooding, hurricanes, frequent disturbance (i.e., crayfishing or hunting activities) and other factors influence waterbird use of active and idle rice fields. In addition to understanding patterns of habitat use, studies of diet preferences of birds in active and idle rice fields in the LCP and TMC seem warranted. Studies designed to address spatial and temporal movements of birds to and within the Gulf coast prairies may be assessed with stable isotopes derived from tissue, blood, or feather samples. These data could help conservationists improve land management techniques, such as targeted flooding of specific habitats based on migration or other regional movements. Lastly, I advocate conducting nocturnal surveys of waterbirds. Species such as northern pintail, plovers (*Pluvialis, Charadrius*), sandpipers (*Caladris*), stilts (*Himantopus*), and most other Scolopacidae regularly forage diurnally and nocturnally (Miller 1987, McNeil and Rodriguez 1996). Little is known about nocturnal ecology of waterfowl and other waterbirds, and studies in these regions may be especially important because of the apparent frequent and prolonged diurnal disturbances from hunting, crayfishing, and other sources. Perhaps use of unmanned aerial vehicles would enable researchers to quantify accurately diurnal and nocturnal use of rice land habitats in the Gulf Coast regions.

Table 2.1 Common and scientific names and total detections (*n*) of waterbirds during surveys of active and idled rice fields in the Louisiana Chenier Plain and Texas-Mid Coast, December 2010 – March 2011.

Common name	Scientific name	*n*
Waterfowl		
Lesser snow goose	*Chen caerulescens*	12,253
White-fronted goose	*Anser albifrons*	10,629
Northern shoveler	*Anas clypeata*	3,569
Northern pintail	*A. acuta*	1,624
American green-winged teal	*A. crecca*	1,339
Canada goose	*Branta canadensis*	1,020
Mallard	*Anas platyrhynchos*	388
Wood duck	*Aix sponsa*	255
Gadwall	*Anas strepera*	191
Blue-winged teal	*A. discors*	56
American wigeon	*A. americana*	16
Lesser scaup	*Aythya affinis*	15
Mottled duck	*Anas fulvigula*	2
Other waterbirds		
Sandpipers	*Calidris* spp.	1,013
Ibises	*Plegadis* spp.	908
Dowitchers	*Limnodromus* spp.	862
American coot	*Fulica americana*	815
Killdeer	*Charadrius vociferus*	773
Black-necked stilt	*Himantopus mexicanus*	293
Yellowlegs	*Tringa* spp.	193
Sandhill crane	*Grus canadensis*	96
Great egret	*Ardea alba*	93
Ring-billed gull	*Larus delawarensis*	77
Great blue heron	*Ardea herodias*	60
Dunlin	*Calidris alpine*	51
Herring gull	*Larus argentatus*	25
Snowy egret	*Egretta thula*	7
Gull-billed tern	*Gelochelidon nilotica*	2
Cattle egret	*Bubulcus ibis*	1
Pied-billed grebe	*Podilymbus podiceps*	1

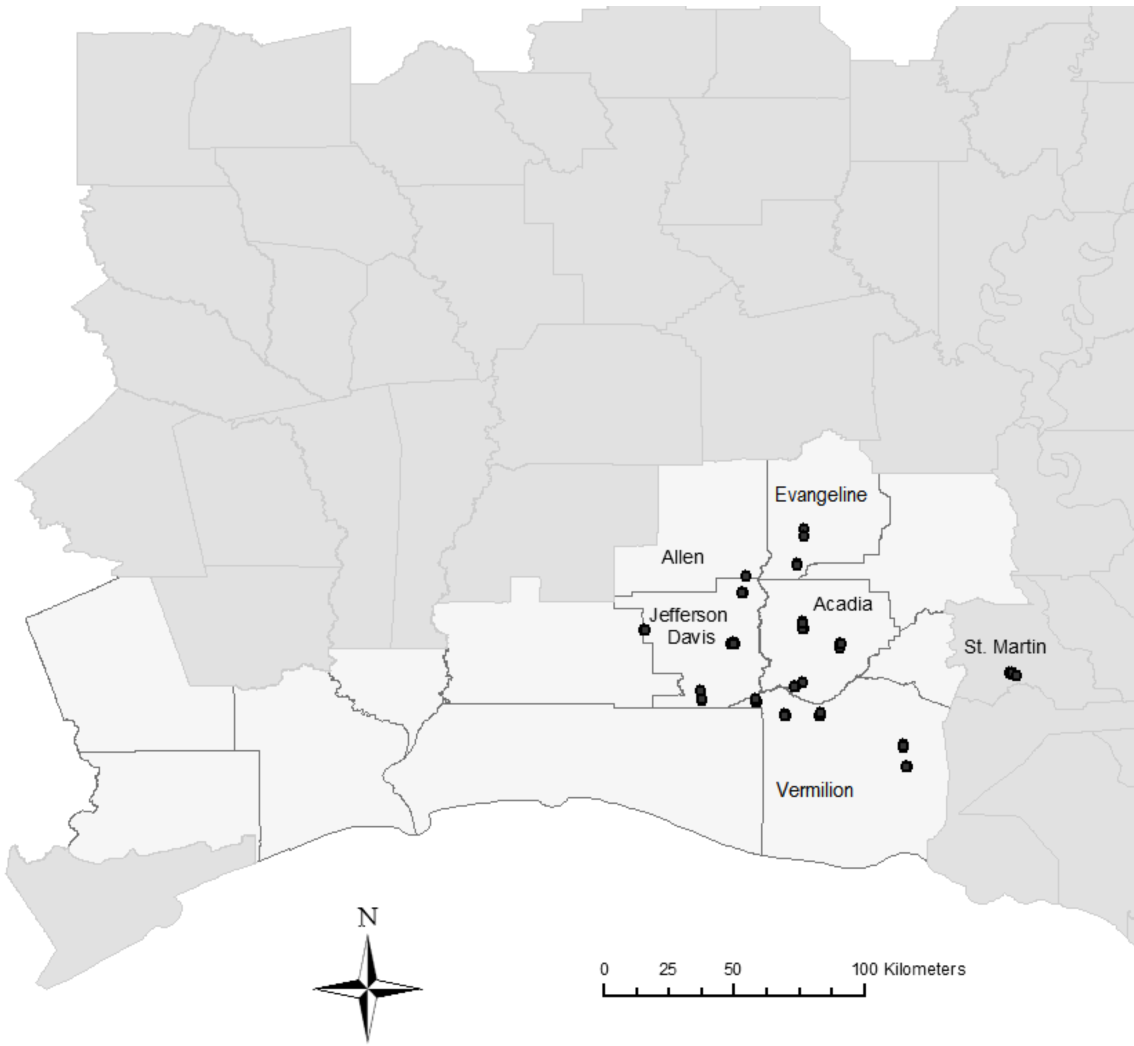

Figure 2.1 Study areas within the Louisiana Chenier Plain where waterbird surveys were conducted in active and idle rice fields during December 2010-March 2011 sampling periods.

Figure 2.2 Study areas within the Texas Mid-Coast where waterbird surveys were conducted in active and idle rice fields during December 2010-March 2011 sampling periods.

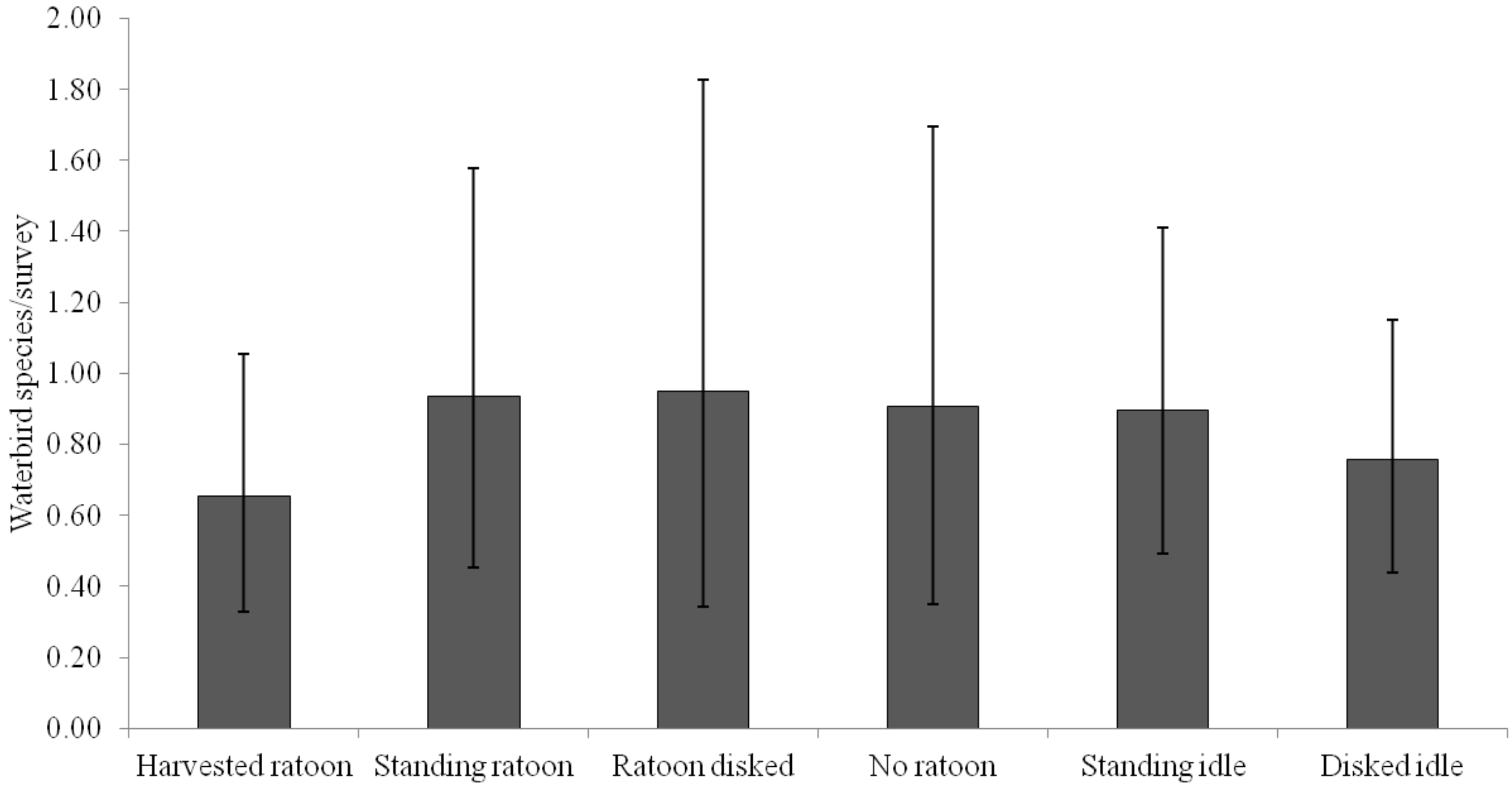

Figure 2.3 Natural log back-transformed mean ($\bar{x}$) species richness (waterbirds/survey) for effects management practice with 90% confidence limits in Louisiana Chenier Plain and Texas Mid-Coast ricelands (i.e., actively farmed rice and idle fields), December 2010 – March 2011.

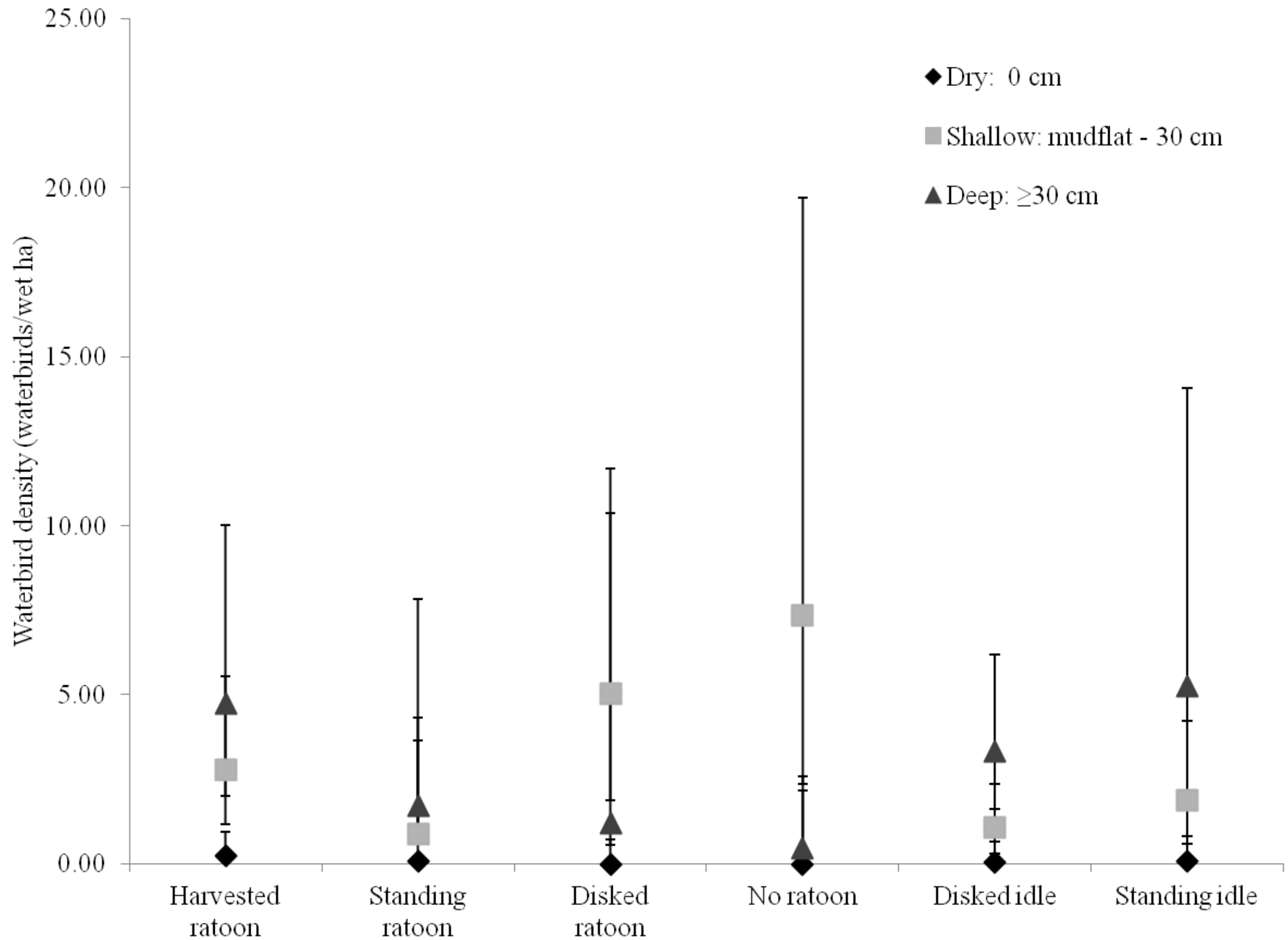

Figure 2.4 Natural log back-transformed mean ($\bar{x}$) densities (waterbirds/ha) for effects of management practice and flooding status (i.e., management practice x flooding status interaction) with 90% confidence limits in Louisiana Chenier Plain and Texas Mid-Coast ricelands, December 2010 – March 2011.

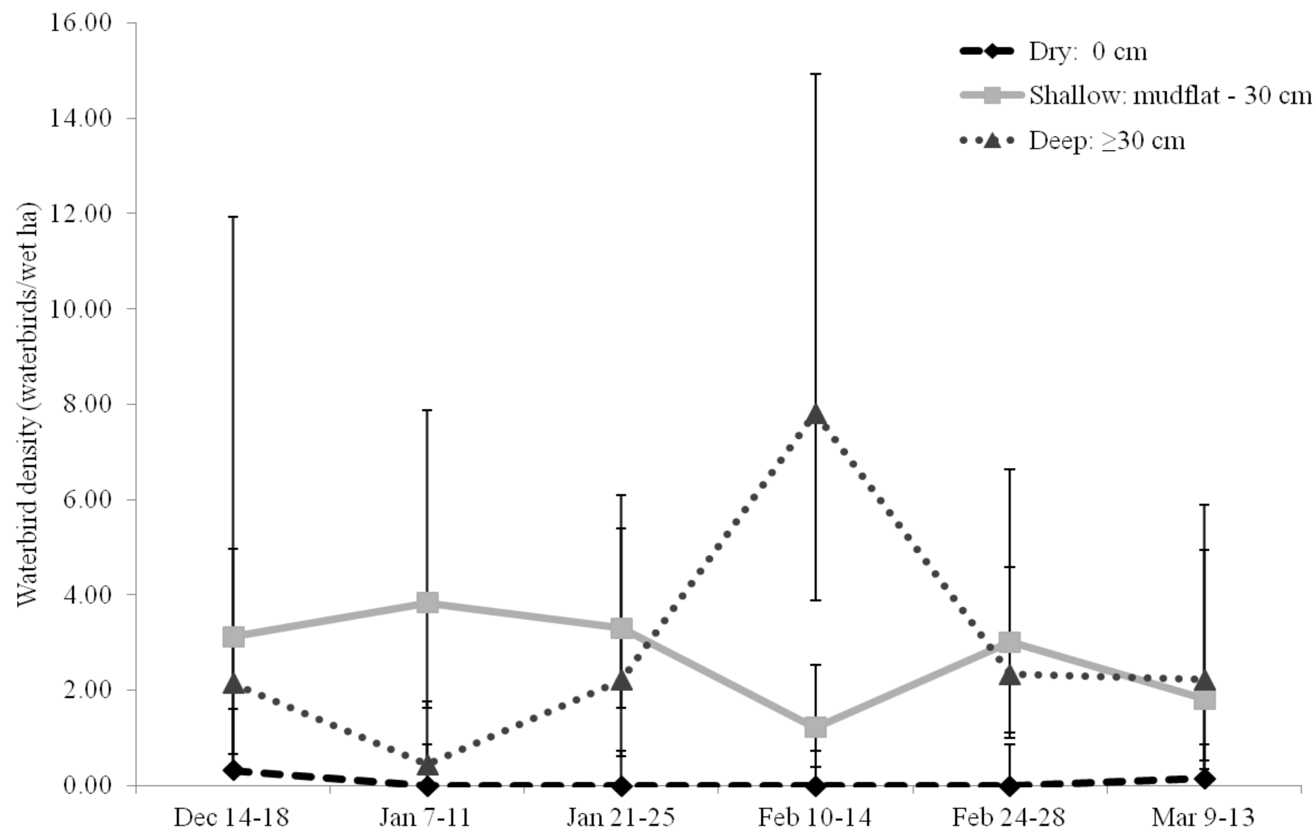

Figure 2.5 Natural log back-transformed mean ($\bar{x}$) densities (waterbirds/ha) for effects of survey period and flooding status (i.e., survey period x flooding status interaction) with 90% confidence limits in Louisiana Chenier Plain and Texas Mid-Coast ricelands (i.e., actively farmed rice and idle fields), December 2010 – March 2011.

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CHAPTER III

SYNTHESIS

Until the 20th century, tall grass prairies and post oak (*Quercus stellata*) savannahs covered most of the 6.2 million hectares of the Gulf Coast Joint Venture (GCJV) initiative areas throughout the Louisiana Chenier Plain (LCP) and the Texas Mid-Coast (TMC). Additionally, almost 10.8 million hectares of wetlands have been lost in the United States through anthropogenic activities since the 1950's (Dahl 2011). Following loss of natural wetlands, flooded agricultural land has become important habitat for waterbirds and other wildlife (Tiner 1984, Dahl 1990, Czech and Parsons 2002, Eadie et al. 2008). Prior studies in the Mississippi Alluvial Valley (MAV) documented 71-93% reductions in waste rice abundance between crop harvest and late fall in rice fields (Manley et al. 2004, Stafford et al. 2006*b*). In addition to waste rice, waterfowl also consume moist-soil seeds and aquatic invertebrates which occur in farmed and idle rice fields and managed wetlands (Manley et al. 2004, Hagy and Kaminski 2012).

Unlike other rice growing regions of the United States, few contemporary studies have examined temporal dynamics of rice and moist-soil seed abundance in the LCP and TMC (cf., Michot and Norling, unpublished data; Manley et al. 2004; Stafford et al. 2006*b*; Greer et al. 2009; Kross et al. 2008, 2010; Hagy and Kaminski 2012). Nonetheless, the LCP and TMC are among the most important areas in North America for migrating and wintering waterfowl and waterbirds (Bellrose 1980). Thus, studies that address dynamics of waste-rice and moist-soil seed abundances in these regions are critical to identifying management practices that influence abundance of residual grain and moist-soil seeds (e.g., Kross et al. 2008, 2010; Havens et al. 2009; Hagy and Kaminski 2012) and help natural resource planners estimate carrying capacity of active and idle rice fields for migrating and wintering waterfowl. My objectives were to conduct a pilot study to 1) estimate spatial and temporal seed abundance among regions (i.e., LCP and TMC) and time periods (i.e., August, October, and November) relevant to waterfowl conservation planning by partners in the GCJV region and in response to USDA Natural Resources Conservation Service's Migratory Bird Habitat Initiative (MBHI), 2) estimate optimal sample size of primary (landowner), secondary (fields with a landowner), and tertiary (soil cores within a field) sampling units for a continuation study (i.e., 2011-2014), and 3) estimate relative abundances of waterfowl and other waterbirds using actively farmed and idle rice fields enrolled in MBHI in the LCP and TMC. The MBHI was implemented in fall 2010 to create critical habitat for migrating and wintering waterbirds and to mitigate effects of the Gulf Oil spill in April 2010 (Chapters 1 and 2).

In Chapter 1, I estimated dry mass of rice and moist-soil seeds in actively farmed and idle rice fields from August through November 2010 in the LCP and TMC. Unlike previous studies that documented significant declines in waste rice during autumn in the MAV (Manley et al. 2004, Stafford et al. 2006*b*, Greer et al. 2009), I did not detect such patterns in the LCP and TMC between initial harvest in August and November, and rice abundances never approached the estimated waterfowl foraging giving-up-density (GUD) of 50 kg/ha (Greer et al. 2009). Rice abundance in the MAV in late autumn approached 80 kg/ha (Stafford et al. 2006*b*), compared to 109.7 kg/ha-964.3 kg/ha in my study areas. I observed increasing trends of moist-soil seed abundance in idled rice fields (i.e., standing and disked) in both the LCP and TMC from August-November 2010. Overall, waste-rice and moist-soil seed abundances estimated in this study and those currently used in conservation planning models by the GCJV are as much as 325% greater than those from the MAV and Central Valley of California (Manley et. al. 2004, Central Valley Joint Venture 2006, Stafford et al. 2006*b*). I recommend the GCJV continue this study to generate increasingly precise estimates of seed abundances in the LCP and TMC and among field management practices accounting for most fall and winter waterfowl use (i.e., CV ≤ 15%; Stafford et al. 2006*b*, Kross et al. 2008, Chapter 1).

Optimizing sample design to improve efficiency and reduce costs is important in any large scale natural resources study. I used methods similar those recommended by Cochran (1977) and Stafford et al. (2006*a*) and estimated optimal sample size for primary (landowners), secondary (fields within landowners), and tertiary (soil cores within fields). I recommend that future research in these regions invoke a similar multi-stage sampling strategy to obtain precise estimates while controlling for survey costs.

In Chapter 2, I reported that variation in waterbird densities were influenced by interactions of water depth and survey period, as well as water depth and management practice. Some management practices mimicked those implemented by MBHI; however, most of my study fields were either flooded too deeply for most waterbirds (i.e. ≥30 cm) or were dry. I recommend landowners and resource managers shallowly flood (i.e., ≤30 cm) farmed and idle rice fields to promote waterbird use. Hagy and Kaminski (2012) reported that most foraging by dabbling ducks in managed moist-soil wetlands occurred in depths of ≤16 cm. Future studies should focus on fields enrolled in MBHI to further evaluate variation in bird densities and communities among field management practices through fall-early spring.

Waterfowl are the most common guild of waterbirds that consume waste rice and other agricultural and moist-soil seeds (Reinecke et al. 1989, Kaminski et al. 2003). Using PROC CORR (SAS v.9.3; SAS Institute 2011), I tested whether waterfowl densities were positively correlated to combined rice and moist-soil seed abundance and management practice within farmed and idle ricelands in November 2010. I neither detected correlations between waterfowl abundance and seed abundance (r = -0.317, P = 0.723, n = 26) nor waterfowl abundance and field management practice (r = -0.072, P = 0.113, n = 26). Therefore, I conclude that waterfowl use of fields did not vary with seed abundances, and other variables not measured (e.g., weather, vegetation height and density, aquatic invertebrates, and human disturbance) may have been separate or interacting factors.

Continuing research on active and idle rice fields in the LCP and TMC should focus on 1) improving precision of estimates of seed abundance (CV ≤ 15%), 2) evaluating rice and moist-soil seed dynamics in relation to rice variety, farming practices, and environmental conditions (e.g., mean monthly precipitation and temperature; tropical storms and hurricanes), 3) estimating area of flooded cropland through the use of satellite imagery and crop land data bases to improve estimates of ricelands accessible to waterbirds, 4) management of ricelands to increase availability of foraging habitat (e.g., flooding ≤ 30 cm) for migrating and wintering waterbirds (e.g., Havens et al. 2009, Hagy and Kaminski 2012), 5) characterizing bird communities using active and idled ricelands, and 6) continuing to link waterbird use to food abundance and other aforementioned variables. I deem these critical actions in LCP and TMC because of persistent loss of coastal wetlands loss, decreasing aquifers and impounded waters in reservoirs for cropland irrigation and human use especially in arid Texas, and other anthropogenic activities that may jeopardize important wetland habitats for wildlife (Dahl 1990, 2011; Lower Colorado River Authority 2010, 2013).

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