CONSERVATION OF WASTE RICE AND ESTIMATES OF MOIST-SOIL
SEED ABUNDANCE FOR WINTERING WATERFOWL
IN THE MISSISSIPPI ALLUVIAL VALLEY

By
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Waste rice in harvested fields and seeds in moist-soil wetlands are important foods for waterfowl in the Mississippi Alluvial Valley (MAV). I conducted experiments in 19 rice fields in Arkansas and Mississippi during autumns 2003 and 2004 to evaluate the ability of post-harvest practices to conserve waste rice. Standing stubble contained the greatest abundance of waste rice ($\bar{x} = 105 \text{ kg/ha}; \text{ CL } = 72.84, 150.16 \text{ kg/ha}$) followed by burned ($\bar{x} = 72 \text{ kg/ha}; 49.57, 105.81 \text{ kg/ha}$), mowed ($\bar{x} = 67 \text{ kg/ha}; 46.65, 97.42 \text{ kg/ha}$), rolled ($\bar{x} = 51 \text{ kg/ha}; 35.54, 73.076 \text{ kg/ha}$), and disked stubble ($\bar{x} = 48 \text{ kg/ha}; 33.26, 68.41 \text{ kg/ha}$). I recommend leaving stubble or burning fields to create interspersion of stubble and water after flooding. I estimated abundance of moist-soil seed throughout the MAV for 2002-2004. Mean seed abundance was 496 kg/ha ($\text{SE } = 62$). I recommend active management of moist-soil wetlands to mitigate decreased waste-rice abundance.
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CHAPTER I

CONSERVING WASTE RICE FOR WINTERING WATERFOWL
IN THE MISSISSIPPI ALLUVIAL VALLEY


Large-scale projects to control flooding of the Mississippi River began in the late 1920s and facilitated conversion of the MAV from a vast seasonally flooded, bottomland hardwood ecosystem to a landscape dominated by agriculture and protected from major floods (Reinecke et al. 1989, Loesch et al. 1995, Fredrickson et al. 2005). Fortunately, waterfowl wintering in the MAV adapted to use agricultural foods to fulfill part of their nutritional requirements (Wright 1959, Delnicki and Reinecke 1986, Combs and Fredrickson 1996). Accordingly, the LMVJV has incorporated estimates of abundance of
agricultural seeds into conservation plans designed to provide sufficient food when waterfowl populations attain levels of abundance targeted by the North American Waterfowl Management Plan (NAWMP; LMVJV Management Board 1990).

Rice is an important agricultural crop and an energy-rich food for waterfowl in the MAV (Delnicki and Reinecke 1986). In 2004, producers planted >1 million ha of rice in Arkansas, Mississippi, Louisiana, and Missouri, most (70%) of which was grown in Mississippi and Arkansas (National Agriculture Statistics Service 2004). True metabolizable energy (TME) of rice for mallards (Anas platyrhynchos) is 3.34 kcal/g (dry mass), which is slightly less than corn (3.67 kcal/g) but greater than soybean (2.65 kcal/g) (Reinecke et al. 1989, Kaminski et al. 2003). Additionally, rice is more resistant to decomposition when flooded than corn or soybean (Neely 1956, Shearer et al. 1969, Nelms and Twedt 1996).

Levees and water-control structures used to flood rice for weed control and irrigation during the growing season also facilitate flooding of harvested fields for waterfowl in winter, which is a tradition in the MAV (Glasgow 1964). Furthermore, incentives from conservation organizations have increased interest in flooding fields during winter. In the mid 1990s, Uihlein (2000:58) estimated 80,830 ha of harvested rice were flooded in the MAV, whereas Ducks Unlimited, Inc. (Southern Regional Office, Ridgeland, Mississippi, unpublished data) estimated 126,515 ha of rice were flooded in January 2003. Winter flooding of rice fields provides habitat for waterfowl, reduces soil erosion, improves quality of discharge water, and promotes decomposition of rice straw (Bird et al. 2000, Manley et al. 2005). Flooding fields through early spring also
suppresses growth of cool-season weeds and potentially increases farm income by reducing costs of herbicides and tillage needed to prepare for spring planting (Anders et al. 2005, Manley et al. 2005).

The abundance of rice grain that falls to the ground before or during harvest (i.e., waste rice) is used by the LMVJV to estimate carrying capacity of harvested rice fields as foraging habitat for waterfowl wintering in the MAV (Reinecke et al. 1989, Loesch et al. 1994). However, Manley et al. (2004) discovered waste rice in Mississippi fields was significantly less abundant in early winter than estimated by the LMVJV from historical data (i.e., 180 kg/ha [dry mass]; Reinecke and Loesch 1996). To obtain reliable estimates of abundance of waste rice for conservation planning, Stafford et al. (2005a, 2006) sampled >150 harvested fields throughout the MAV and reported rice abundance averaged 78 kg/ha in early winter 2000-2002. Decreases in waste-rice availability are important because, when abundance approaches 50 kg/ha, energetic costs of foraging apparently exceed nutritional benefits and ducks cease feeding in fields (Reinecke et al. 1989, Rutka 2004). Thus, the difference between potential availability of waste rice in early winter (78 kg/ha) and the “giving-up” density (50 kg/ha) is < 30 kg/ha, and waterfowl carrying capacity (i.e., duck use days [DUD]) of harvested rice fields in the MAV is decreased nearly six-fold (i.e., from 1,858 DUD/ha to 325 DUD/ha; Stafford et al. 2006).

Manley et al. (2004) and Stafford et al. (2006) recommended evaluation of post-harvest treatments of rice fields to determine if commonly used practices may differentially conserve waste rice during autumn. Stafford et al. (2005b) conducted pilot
experiments in Mississippi and used domain analysis with data from sample surveys in the MAV to estimate abundance of waste rice in fields where rice stubble was burned, disked, rolled, or left standing after harvest. Stafford et al. (2005b) suggested abundance of waste rice in fields with standing stubble averaged nearly 2 times that in disked, rolled, or burned fields in late autumn. My research goal was to determine if any post-harvest management practices effectively conserved waste rice for wintering waterfowl in controlled experiments. Accordingly, I designed an experiment using production rice fields in Mississippi and Arkansas in 2003 and 2004 to compare abundance of waste rice among 5 post-harvest management practices used in the MAV (i.e., burn, disk, mow, roll, or standing stubble [control]). Based on results from Stafford et al. (2005b), I hypothesized abundance of waste rice in standing stubble would be greater in late autumn than the combined mean for other treatments.

**STUDY AREA**

I conducted the experiment in 6 harvested rice fields in 2003 and 13 fields in 2004 in major rice growing regions of the MAV in Mississippi (n = 10) and Arkansas (n = 9; Figure 1.1). I selected rice fields on private (n =11) and public lands (National Wildlife Refuges [NWR]; n = 8), where I received cooperation of landowners or staff to apply prescribed field treatments. I used fields containing straight (n = 5) or contour (n = 14) levees, and crops were harvested using stripper-header (n = 7) or conventional (n = 12) harvesters. Whether fields were on public or private lands, farmers used standard production and harvesting practices that were representative of rice agriculture in the
MAV (e.g., Miller and Street 2000, Baldwin et al. 2001). Farmers planted common varieties of rice, including Priscilla, Wells, Cocodrie, Clearfield, and Francis.

**METHODS**

**Experimental Design and Field Methods**

I used a randomized complete block design to structure my experiment (Fisher 1966). I designated rice fields as blocks and used levees within fields to separate treatments, because I anticipated uncontrolled sources of variation among fields (i.e., harvest date, treatment date, rice variety, yield, initial abundance of waste rice, local environmental conditions, etc.). I chose 5 paddies (i.e., area between levees) within each field and randomly assigned one of 5 post-harvest treatments to each. Landowners or NWR staff treated ≥ 0.4 ha of rice stubble within each paddy 1-7 days after harvest. Landowners or NWR staff burned fields by igniting rice stubble with a drip torch. In fields where there was risk of fire entering other treatment units, cooperators disked firebreaks. For disked treatments, cooperators tilled paddies with an offset disk one or 2 times. For mowed treatments, cooperators cut stubble to about 15 cm above the ground with a rotary mower. For rolled treatments, cooperators pulled a smooth roller over paddies one or 2 times as needed until most rice stubble was flattened.

One to 3 days after treatments were applied, I collected 10 randomly located soil core samples (10 cm diameter and depth; 785.4 cm³) from each paddy using standard techniques (Manley et al. 2004, Stafford et al. 2006). I collected post-harvest samples between 11 September and 17 October 2003-2004, depending on weather conditions and
dates of harvest and treatment application. I collected a second set of samples between 12 and 23 November 2003-2004 to estimate abundance of waste rice in late autumn. I chose dates for the second sampling period to reflect practices of public land managers, who generally flooded rice fields about 15 November to provide habitat for wintering waterfowl.

Laboratory Methods

I stored core samples in a freezer at -10°C until processing. I thawed and soaked samples for 1 hour in a 3% solution of hydrogen peroxide (H₂O₂), a mixture of ≤ 250 cm³ of baking soda and ~ 1 liter of water, or a combination of these to oxidize clays and facilitate washing sediments through sieves (Bohm 1979:117). I assumed these agents did not influence mass of rice in samples, because a 3% solution of H₂O₂ did not affect mass of barnyardgrass (*Echinochloa crusgalli*) seeds after similar processing (Reinecke and Hartke 2005). However, if these agents affected mass of rice seeds, the potential bias would be similar among treatments. I removed rice seeds from samples, dried, and weighed seeds following procedures used in related studies (Manley et al. 2004, Stafford et al. 2005b, 2006).

Statistical Methods

I deleted 3 paddies from analysis because 1) wet conditions prevented burning stubble in one paddy; 2) dry, windy, and hazardous conditions prevented burning stubble in another paddy; and 3) a mowed paddy was inadvertently burned. I calculated mean dry mass (kg/ha) of waste rice from 10 core samples taken during the 2 sampling periods
from each of 5 experimental paddies in 19 rice fields and performed statistical analyses on the paddy means for each sample period.

Because estimates of mean waste rice in fields often are imprecise (Stafford et al. 2006), I expected statistical power would be low to detect differences among treatments. Therefore, I designated a priori a Type I error rate of $\alpha = 0.10$, which is considered acceptable for management-oriented experiments (Tacha et al. 1982). To assess homogeneity of variances, I plotted residuals against predicted values from preliminary models of post-harvest and late-autumn abundance of waste rice. This assessment suggested variances were heterogeneous; therefore, I transformed ($\log_e$) all means before analysis (Zar 1974:184-185).

I performed analysis of variance (ANOVA) on the log$_e$-transformed post-harvest means to test the null hypothesis of no differences in abundance of waste rice among treatments (PROC MIXED; SAS Institute 1999). I tested for a year effect to determine if year-specific analyses were warranted. Because Stafford et al. (2006) reported harvest method (i.e., stripper-header or conventional harvester) explained variation in abundance of waste rice, I modeled this parameter and its interactions with year as potential explanatory variables. I designated rice fields nested within combinations of years and harvest methods as a random effect to account for use of different fields in 2003 and 2004 and to determine proper error terms for testing effects of treatments and other explanatory variables. When effects of explanatory variables and interactions were not significant ($P > 0.10$), I pooled them into the error term and reanalyzed data to test remaining effects.
I performed analysis of covariance (ANCOVA) on log_e-transformed late-autumn means to test the null hypothesis of no differences in abundance of waste rice among treatments. I again tested for a year effect and established the log_e-transformed post-harvest abundance of rice as a covariate. I also included the interaction of treatment and the covariate to test if the effect of the covariate varied among treatments (Gotelli and Ellison 2004). I included fields nested within years as a random effect to account for use of different fields in 2003 and 2004 and to determine proper error terms for testing treatment effects and other explanatory variables. I did not include harvest method in the ANCOVA, because I assumed post-harvest treatments nullified any possible effect on late-autumn abundance of rice. When model effects and their interactions were not significant \((P > 0.10)\), I pooled them into the error term and reanalyzed data to test remaining effects.

In 2004, I obtained accurate information on harvest dates of 13 rice fields to determine number of days waste rice was exposed to various pathways of loss between harvest and late autumn (i.e., decomposition, germination, granivory; Stafford et al. 2006). I hypothesized the percentage loss of waste rice from harvest to late autumn would be correlated positively with exposure days. To test this hypothesis, I calculated a simple correlation (Zar 1974:236-238) between the ratio of late-autumn to post-harvest abundance of waste rice and number of exposure days across the 13 fields sampled in 2004.

I formulated an a priori contrast to test if mean abundance of waste rice in standing stubble in late autumn was greater than the combined mean abundance for other
treatments. Finally, when I detected a treatment effect ($P \leq 0.10$), I performed all pairwise multiple comparisons of differences among log$_e$-transformed late-autumn abundance using an adjusted Tukey’s test (Freund and Wilson 2003:256).

To determine if fire possibly affected gross energy (GE) of waste rice I conducted a $t$-test to determine if GE differed between burned and unburned samples of rice. Staff at the H. W. Essig Nutrition Laboratory of Mississippi State University conducted the GE analysis of 5 samples of burned rice and 5 samples of unburned rice; each sample contained $\sim 5$ g (dry mass) of rice.

**RESULTS**

**Post-harvest Abundance of Waste Rice**

I did not detect an effect of year ($F_{1,16} = 0.32, P = 0.577$) or harvest method ($F_{1,16} = 0.11, P = 0.745$) on post-harvest abundance of waste rice, nor did I detect interactions of treatment by year ($F_{4,62} = 1.24, P = 0.303$) or treatment by harvest method ($F_{4,62} = 0.80, P = 0.531$). I also failed to reject the hypothesis of no difference in post harvest abundance of waste rice among treatments ($F_{4,70} = 0.88, P = 0.483$; Figure 1.2). The overall back-transformed mean and confidence limits for post harvest abundance of waste rice was $304.30$ kg/ha (90% CI = $267.70, 345.91$ kg/ha).

**Late-autumn Abundance of Waste Rice**

Thirteen experimental fields were harvested on different dates in 2004, and waste rice in these fields had a range of exposure days from 52-75 days between September and November sampling periods. However, I did not detect a relationship between
percentage loss of waste rice and number of exposure days between sampling periods ($r^2 = 0.15$, $P = 0.19$, $n = 13$).

I did not detect effects of year ($F_{1,17} = 0.00$, $P = 0.994$) or an interaction of treatment with the covariate post-harvest abundance of waste rice ($F_{4,64} = 1.60$, $P = 0.185$) on late-autumn abundance of waste rice. I detected a positive effect of the covariate ($\beta = 0.749$, SE = 0.150; $F_{1,68} = 24.97$; $P < 0.001$) on late-autumn abundance of waste rice. Hence, an increase of 1 unit in the covariate (i.e., log$_e$-transformed post-harvest abundance of waste rice) would increase late-autumn abundance of waste rice (kg/ha) by 111%. Finally, I rejected my null hypothesis of no difference in abundance of waste rice among treatments in late autumn ($F_{4,68} = 3.08$, $P = 0.022$).

Results of the a priori contrast indicated mean abundance of waste rice in standing stubble ($\bar{x} = 104.57$ kg/ha; 90% CI = 72.84, 150.16 kg/ha) was greater than the combined mean among other treatments ($\bar{x} = 58.78$ kg/ha; 90% CI = 45.58, 75.81 kg/ha; $F_{1,68} = 8.21$; $P = 0.006$). The a posteriori pair-wise comparisons revealed mean abundance of waste rice in standing stubble ($\bar{x} = 104.57$ kg/ha; Figure 1.2) was $>2$ times that in rolled ($\bar{x} = 50.96$ kg/ha; 90% CI = 35.54, 73.076 kg/ha; $t_{68} = 18.19$; $P = 0.044$) or disked stubble ($\bar{x} = 47.70$ kg/ha; 90% CI = 33.26, 68.41 kg/ha; $t_{68} = 17.87$; $P = 0.022$). I did not detect a difference in mean abundance of waste rice between standing stubble and mowed ($\bar{x} = 67.41$ kg/ha; 90% CI = 46.65, 97.42 kg/ha; $t_{68} = 19.07$; $P = 0.435$) or burned stubble ($\bar{x} = 72.42$ kg/ha; 90% CI = 49.57, 105.81 kg/ha; $t_{68} = 18.84$; $P = 0.636$). No other pair-wise comparisons of means were significant ($P \geq 0.435$). The overall mean
for late-autumn abundance of waste rice across all treatments ($\bar{x} = 66.12$, 90% CI = 53.62, 81.54) was about 78% less than the overall post-harvest mean.

The mean GE of burned rice seeds ($\bar{x} = 3.57$ kcal/g, SE = 0.01 kcal/g) exceeded that for unburned seeds ($\bar{x} = 3.43$ kcal/g, SE = 0.04 kcal/g) slightly, yet significantly ($t_8 = 3.17, P = 0.01$).

**DISCUSSION**

Although experimental study sites were on public and private lands, cooperating rice producers used standard agricultural practices, planted common rice varieties, harvested entire fields, and had a primary goal to produce rice for the grain market. Therefore, I concluded my study fields and results were representative of rice fields and rice farming in the MAV, although I did not randomly select fields. Importantly, because mean abundance of waste rice did not vary among treatments in the initial post-harvest period, all treatments began the experiment with similar abundances of waste rice.

Two different combine methods (i.e., conventional or stripper-header combines) were used to harvest rice from experimental fields. Miller and Wylie (1996) reported stripper-header combines left less waste rice after harvest than conventional combines in California. In contrast, Stafford et al. (2006) reported abundance of waste rice in the MAV was greater after harvest in fields harvested by stripper headers than conventional combines, but they did not detect a difference in rice abundance between harvest methods in late autumn. Unlike Stafford et al. (2006), I did not detect an effect of harvest method on post-harvest abundance of waste rice, and I did not include this effect in analyses of late-autumn abundance of waste rice. Because of inconsistencies in results among
studies, I recommend further evaluation of the potential effect of harvest methods on abundance of waste rice and waterfowl carrying capacity in the MAV and other regions.

I designed my experiment to apply specific treatments, estimate treatment effects on abundance of waste rice, and test hypotheses based on results of pilot experiments and post-hoc analyses of Stafford et al. (2005b). My estimate of mean abundance of waste rice in standing stubble in late autumn ($\bar{x} = 104.57$ kg/ha; 90% CI = 72.84, 150.16 kg/ha) was similar to the abundance of waste rice reported by Stafford et al. (2005b) not corrected for non-recovery of seeds during sample processing ($\bar{x} = 111.70$ kg/ha, SE = 23.10). Additionally, Stafford et al. (2006) reported an overall decrease of 71% in abundance of waste rice between harvest and late autumn, similar to the 78% decrease in abundance between sample periods across all my experimental treatments.

Stafford et al. (2006) reported post-harvest abundance of waste rice was a predictor of abundance of waste rice in late autumn. My results were consistent with this finding, as evidenced by the positive effect of the covariate (i.e., post-harvest abundance of waste rice) on late-autumn abundance of waste rice. Hence, increased abundance of waste rice in a field after harvest apparently resulted in greater abundance in late autumn.

Time elapsed between rice harvest and late autumn (i.e., exposure days) may affect abundance of waste rice for wintering waterfowl in the MAV (Stafford et al. 2006). In my experiment, only 15% of the variation in percentage loss of waste rice was attributed to number of exposure days, although inferences from my data were limited by small sample size ($n = 13$ fields) and one year of exposure-day data (2004). Additionally, field treatments may have confounded the effect of exposure days; hence, further
assumption regarding effects of exposure time is beyond the inferential limits of my experiment.

Loss of waste rice in fields during autumn has been attributed to germination, decomposition, and granivory by invertebrates and vertebrates (McGinn and Glasgow 1963, Stafford 2004:49). Additionally, when rice is stored in grain bins or silos, temperature, moisture, and storage duration influence decomposition (Loewer et al. 2003, Brooker et al. 1992). I assume these factors also influence decomposition of waste rice in field environments and thus speculate how these may have interacted with post-harvest treatments to influence loss of waste rice during fall.

Although waste rice germinated in standing stubble, this treatment may have inhibited germination more than other treatments. Optimum ambient temperature for rice germination ranges from 20-35°C (Yoshida, 1981). Standing stubble may have created shade that combined with decreasing fall ambient temperatures to reduce ground temperatures below optimum for germination (Northen 1968:221). Additionally, cover created by standing stubble may have inhibited detection of waste rice by granivores (e.g., rodents and birds). Finally, bacteria and fungi (i.e., primary microbes responsible for decomposition) grow best on stored rice at relative humidities between 95-100% and temperatures from 20-30°C (Loewer 2003). While I did not measure these ambient conditions, relative humidity and temperature may have been less in standing stubble during fall, thereby decreasing microbial growth and decomposition of waste rice.

Fire may involve processes that retard loss of waste rice to germination. At storage temperatures $\geq 55^\circ$C, seed germination rates decrease (Loewer 2003). Fire may
heat rice seeds sufficiently to kill embryos and render seeds incapable of germinating. However, rice kernels sometimes crack during storage when air in the bin is heated above 38°C (Miller and Street 2000:81). If fire affects rice seed similarly in the field by cracking the kernels, microbes may colonize seeds more readily and increase rates of microbial decomposition.

The overall GE for my samples was slightly less than the GE of white medium-grain rice (3.60 kcal/g; USDA 2005). The slight increase in GE of burned versus unburned rice may be attributed to partial combustion of the hull and consequent decrease in crude fiber of the seed relative to the seed biomass, which may result in increased TME. Petrie et al. (1998) suggested crude fiber was an important factor in assessing energy value of waterfowl foods, because fiber content decreases TME and digestibility of seeds and tubers. Although burned rice seeds may have increased GE and TME, combustion of the protective seed hull also may increase susceptibility to decomposition.

Mowing conserved a similar abundance of waste rice to burning and standing stubble. Mowing leaves litter similar to that created by combines during harvest operations (Stafford et al. 2005b). This litter may shade and cover waste rice and lessen its exposure to various pathways of loss similarly to standing stubble. Rolling and disking provided the least protection to waste rice from pathways of loss. Unless rolled stubble covered individual rice seeds, their vulnerability to pathways of loss may have increased. Additionally, rollers press rice seeds into the soil and may function as a cultipacker and facilitate germination (Northen 1968:226). Disking
decreases stubble density and exposes rice to increased light, potentially influencing germination (Northen 1968:222), granivory, and decomposition. Additionally, disking may have enhanced germination by incorporating rice into the soil or disking may have buried seed below the depth of core sampling (i.e., 10 cm).

**MANAGEMENT AND RESEARCH IMPLICATIONS**

The “giving-up” density of waste rice in a field is an important consideration when assessing the value of managing harvested rice fields for waterfowl (Reinecke et al. 1989, Rutka 2004, Stafford et al. 2006). Standing stubble, burning, and mowing provided a mean abundance of waste rice above this level in late autumn, but standing stubble was the only treatment with a lower confidence limit above 50 kg/ha (Figure 1.2). Thus, I recommend leaving standing stubble in rice fields for managers who wish to conserve maximum waste rice for wintering waterfowl in the MAV. Flooding standing stubble during winter through early March will make waste rice and aquatic invertebrates available to wintering waterfowl as well as provide agronomic advantages, such as rice straw decomposition, red rice and winter weed control, and potentially reduce herbicide applications at spring planting (Manley et al. 2005).

Alternatively, burning may create a combination of 2 beneficial treatments at minimal cost. As fire burns across a field, it may consume rice stubble in some areas more than others and produce completely burned, partially burned, and unburned patches. After flooding, burned rice fields may mimic wetlands with an interspersion of open water and emergent vegetation, which often attract the greatest abundance and diversity of waterfowl and waterbirds on breeding and wintering ranges (Kaminski and Prince
1981, Murkin et al. 1982, Smith et al. 2004). I recommend burning as an economical and efficient practice to maintain waste rice abundance and decrease rice straw. However, the future of burning harvested rice fields in the MAV is uncertain. Already, burning has been banned in rice-growing regions of California due to air quality concerns (Lindberg 2003).

If mechanical treatment of stubble is necessary, I recommend limiting the area treated to minimize labor and equipment costs and maximize areas with standing stubble for reasons described earlier. Mowing to create openings in rice stubble is an option; however, this treatment is time consuming and requires fuel and equipment (Mississippi Agricultural and Forestry Experiment Station [MAFES] 2004). Rolling and disking had the poorest ability to conserve waste rice; these post-harvest treatments should be used minimally, because they resulted in mean abundance of waste rice below the “giving-up” density.

Leaving standing stubble required no additional management costs, and burning required only limited labor. Costs of mowing range from $12.92-$20.76/ha depending on the size and power of the cutting implement, rolling costs approximately $7.49/ha, and disking with an 8.23-m wide disk and a 190 horsepower mechanical front wheel drive tractor costs $14.65/ha (2004 U.S. currency; Laughlin and Spurlock 2003, MAFES 2004). If 2 passes are required for rolling and disking, the total cost/ha would be $14.97 and $29.31/ha, respectively.

Weather also may affect abundance of waste rice available for waterfowl in late autumn. Warmer autumns with high rainfall may encourage more loss to germination
than drier, cooler autumns. Cold-hardy rice varieties, planted early in spring, harvested in mid-summer, and which produce a second crop (i.e., rattoon), may provide an opportunity to increase the forage value of harvested rice fields for wintering waterfowl. Increased forage in rice fields may increase waterfowl use and provide potential hunting and viewing opportunities. Increased waterfowl use may enable rice producers to supplement their farm income through recreational and uses.

Leaving standing stubble in rice fields can help conserve waste rice for waterfowl; however, a significant amount of waste rice is lost annually between harvest and late autumn (Stafford et al. 2006, this study). Increasing availability of managed moist-soil habitat can help mitigate loss of waste rice and soybeans in the MAV (Penny 2003, Stafford et al. 2006, Kaminski et al. 2005). Research in the MAV and elsewhere has shown that moist-soil habitats can provide substantially more DUD/ha than harvested rice fields and a greater diversity of natural plant and animal foods (Reinecke et al. 1989, Penny 2003, Chapter II).
LITERATURE CITED


Stafford, J. D. 2004. Abundance and conservation of waste rice for wintering waterfowl in the Mississippi Alluvial Valley. Dissertation, Mississippi State University, Mississippi State, Mississippi, USA.


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Figure 1.1. Locations (■♦✦★▲▼◆▼) of 19 rice fields used in experiments to evaluate ability of 5 post-harvest management practices to conserve waste rice for waterfowl wintering in Mississippi and Arkansas in 2003 and 2004. Sites were located on private and public lands (i.e., National Wildlife Refuges [NWR]).
Figure 1.2. Post-harvest mean abundance of waste rice (●) and late-autumn least-square mean abundance of waste rice (■) and 90% confidence intervals (back-transformed from loge values) by experimental treatment. Horizontal dashed line at 50 kg/ha represents the “giving-up” density at which waterfowl generally cease foraging in rice fields (Reinecke et al. 1989, Rutka 2004).
CHAPTER II

ESTIMATION, MODELING, AND MANAGEMENT
OF MOIST-SOIL SEED ABUNDANCE IN THE
MISSISSIPPI ALLUVIAL VALLEY

The Mississippi Alluvial Valley (MAV) is an important region for migrating and wintering waterfowl in North America (Bellrose 1976:20, Reinecke et al. 1989). Several conservation initiatives, including the North American Waterfowl Management Plan (NAWMP; Canadian Wildlife Service and U. S. Fish and Wildlife Service 1986), the North American Bird Conservation Initiative (NABCI 2000), and the Ducks Unlimited Conservation Plan (Ducks Unlimited Inc. 2001:106) have emphasized the importance of the MAV to continental waterfowl and other avian populations. Historically, the MAV contained about 10 million ha of seasonally flooded bottomland-hardwood forest, which mallards (*Anas platyrhynchos*), wood ducks (*Aix sponsa*), and other waterfowl used to support their life-cycle needs (Fredrickson 2005). Only 2.8 million ha of the original forested ecosystem remains, much of which has been degraded and modified by various anthropogenic influences (Reinecke et al. 1988, Fredrickson 2005, King et al. 2005). Although partial restoration of this ecosystem is occurring, historic flooding and productivity probably never will be fully re-established (King et al. 2005). Because the potential for restoring bottomland hardwoods as waterfowl habitat is limited, managed
moist-soil wetlands and flooded croplands have become critical habitats for waterfowl in the MAV.

Primary foraging habitats of waterfowl in the MAV now include flooded croplands, forested wetlands, green-tree reservoirs, naturally flooded hardwood bottomlands, and moist-soil areas on public and private lands (Reinecke et al. 1989, Fredrickson et al. 2005). The Lower Mississippi Valley Joint Venture (LMVJV), of the NAWMP, assumes foraging habitat is the limiting factor for waterfowl during winter (Loesch et al. 1994). The LMVJV uses science-based estimates of the carrying capacity (i.e., duck-use days [DUD]) for waterfowl foraging habitats to index the number of waterfowl the MAV may support during winter (LMVJV Management Board 1990, Loesch et al. 1994). Among the primary foraging habitats, managed moist-soil wetlands have the greatest potential waterfowl carrying capacity (LMVJV Waterfowl Working Group, Vicksburg, Mississippi, personal communication).

Moist-soil areas provide abundant and diverse animal and plant foods for migrating and wintering waterfowl (Fredrickson and Taylor 1982, Reinecke et al. 1989). Moist-soil seeds and tubers persist when flooded (Neely 1956, Shearer et al. 1969) and provide true metabolizable energy (TME) for mallards (≈ 2.5 kcal/g) comparable to rice (3.3 kcal/g) and soybean (2.6 kcal/g; Checkett et al. 2002, Kaminski et al. 2003). Additionally, moist-soil areas support aquatic invertebrate communities and provide habitat for life-cycle functions of waterfowl and other wetland wildlife (Reinecke et al. 1989, Gray et al. 1999a, Fredrickson 2005).
Moist-soil management is the manipulation of soil, hydrology, and vegetation to promote production of native food and cover for wildlife (Fredrickson 1996, Fredrickson and Taylor 1982). Active management is fundamental to maintaining productive moist-soil plant communities, and managing hydrology, soil disturbance, soil pH and nutrient levels, and plant species composition can influence plant species diversity and seed and invertebrate abundance (Low and Bellrose 1944, Fredrickson and Taylor 1982, de Szalay and Resh 1997, Gray et al. 1999).

The LMVJV has used a combined estimate of seed and tuber abundance of 450 kg/ha (dry mass) to calculate DUD for moist-soil habitats in the MAV (Reinecke et al. 1989, Loesch et al. 1994, Reinecke and Loesch 1996). The LMVJV considered this preliminary estimate to be conservative but representative of the MAV; however, Reinecke et al. (1989) and Loesch et al. (1994) acknowledged it was based on limited temporal and spatial sampling. Therefore, my primary objective was to conduct a MAV-wide survey to obtain a current estimate of moist-soil seed and tuber abundance for managed public lands during falls 2002-2004 with a desired coefficient of variation (CV) \( \leq 15\% \). This segment of my research continued work initiated by Penny (2003), who estimated abundance of moist-soil seed and tubers in the MAV in fall 2002. My other objectives were to relate mean abundance of moist-soil seeds and tubers in managed units to management practices (i.e., active vs. passive categories), soil pH and nutrient abundance, and percentage occurrence of plant-growth forms, and to make management recommendations consistent with my results.
STUDY AREA

My study areas included managed moist-soil units on state (Wildlife Management Areas; WMA) and federal (National Wildlife Refuges; NWR) management areas in the MAV of Arkansas, Louisiana, Missouri, and Mississippi. Together, Penny (2003) and I sampled 2 moist-soil units within 3 management areas in 4 states in 3 consecutive years (2002-2004) totaling 72 moist-soil units (Appendix). All moist-soil units had water-control structures which enabled flooding and drainage. The water supply on study units came from multiple sources, including rain, runoff, river overflow, or pumping. Some moist-soil units were managed actively and others passively (see definitions of active and passive management categories below). Vegetation in study units consisted of plants adapted to moist-soil conditions and included annual grasses (e.g., *Echinochloa* spp., *Leptochloa* spp., *Panicum* spp.), sedges (e.g., *Carex* spp., *Cyperus* spp.), forbs (e.g., *Bidens* spp., *Polygonum* spp., *Xanthium strumarium*), vines (e.g., *Campsis radicans*, *Brunnichia cirrhosa*), and woody vegetation (e.g., *Salix* spp., *Cephalanthus occidentalis*; Penny 2003:49).

METHODS

Study Site Selection

I used a stratified multi-stage sampling design to estimate abundance of moist-soil seeds in the MAV (Stafford et al. 2006). I designated states (i.e., Arkansas, Louisiana, Mississippi, and Missouri) as strata to ensure moist-soil units were
sampled throughout the MAV. I designated management areas (NWR or WMA) as primary sampling units, moist-soil units within management areas as secondary sample units, and core samples within moist-soil units as tertiary sample units (Penny 2003:54, Stafford et al. 2006).

I created the sampling frame of management areas within each state by querying the database of state and federal waterfowl management units in the MAV Conservation Planning Atlas (CPA; U.S. Fish and Wildlife Service 2002). I initially determined if management areas contained eligible moist-soil units based on the CPA description of habitat types (i.e., moist soil) in waterfowl management units. I used PROC SURVEYSELECT in SAS version 8.02 (SAS Institute 1999) to select 3 management areas randomly, with equal probabilities, and without replacement in each of the 4 states (Stafford et al. 2006). After randomly selecting management areas, I interviewed managers on site to determine management practices applied to moist-soil units. During field reconnaissance with managers, I determined eligibility of management areas for sampling based on the number of moist-soil units present (i.e., ≥2), if units had water management capability, and if units had herbaceous vegetation that was capable of producing seeds which could be sampled, rather than recently disked soil or primarily woody vegetation. I selected randomly 2 moist-soil units from all eligible units within management areas and extracted 15 core samples from random locations within each unit. Penny (2003:61) collected 20 random core samples from each moist-soil unit; however, he recommended reducing sample size to 10-15 cores to optimize time required to collect and process samples.
Based on information from managers, I categorized each sampled moist-soil unit as actively or passively managed. I classified units with yearly or alternate-year soil disturbance by disking or alternate-year cropping as actively managed, whereas I classified units as passively managed if soil disturbance occurred \( \geq 3 \) years before sampling (Penny 2003:56). Additional management practices that occurred on actively managed units generally included gradual spring-summer drawdown, summer irrigation during drought, control of undesirable vegetation (e.g., hemp sesbania, *Sesbania exaltata*; cocklebur, *Xanthium strumarium*) by mowing or herbicide, and some fertilization of desirable vegetation. Of the actively managed units sampled \( (n = 56) \), 71% had water-pumping capabilities enabling managers to flood units as needed. Other active units relied on rainfall, runoff, or flooding from nearby rivers. Generally, passively managed units lacked ability to irrigate and flood by pumping and did not control undesirable vegetation nor fertilize desirable plants.

**Field Methods**

Penny (2003:55) and I sampled moist-soil units during autumns 2002-2004 before they were flooded (i.e., mid-October - mid-November). He and I collected soil samples using a 10-cm-depth-and-diameter (785.4 cm\(^3\)) core sampler and recorded plant species/genera present within a 0.5-meter radius around each sampling site. Additionally, at each core-sampling site in 2003 and 2004, I used a 2-cm diameter soil probe inserted 16 cm into the ground to collect a separate soil sample for pH and nutrient analysis. I combined the latter 15 soil samples from each moist-soil unit into
one aggregate sample following methods for sampling soil in croplands (Crouse and McCarty 1999). I stored all samples at -10°C until processed.

**Laboratory Methods**

I immersed frozen core samples for moist-soil seeds in a 3% solution of hydrogen peroxide (H$_2$O$_2$; Bohm 1979:117), a mixture of ≤ 250 cm$^3$ of baking soda and ≤ 1 liter of water, or a combination of these for 1-3 hours to oxidize clays and facilitate washing sediments through sieves. I assumed these agents did not influence mass of moist-soil seeds, because a 3% solution of H$_2$O$_2$ did not affect mass of barnyard grass (*Echinochloa crusgalli*) seeds in a test done by Reinecke and Hartke (2005). I processed core samples by first washing them through a series of graduated sieves (sizes 4 [4.75-mm aperture], 10 [2.0-mm aperture], and 50 [300-µm aperture]) to remove soil and separate plant litter from seeds and tubers (Penny 2003:56, Stafford et al. 2006). Next, I consolidated fine debris and seeds collected in the size 50 sieve in a 6.5-cm diameter aluminum-weighing dish and dried the contents at 87°C for 24 hours (Gray et al. 1999b, Stafford et al. 2006). I also removed large seeds and tubers retained by the size 4 and 10 sieves and dried them with the fine debris.

I recovered tubers and large seeds, such as those from the genera *Echinochloa, Polygonum, Sesbania,* and *Setaria,* by visually separating them from the remaining dry soil and debris. I distributed the residual fine debris evenly over a grid of 100 equal sized cells (1.5 cm$^2$) and randomly selected a subsample of 25 cells (Reinecke and Hartke 2005). I examined the subsample using a 1.25x magnifying lens and light source to remove small seeds, such as those from the genera *Ammannia, Cyperus,*
Leptochloa, and Panicum. To determine the combined mass of small and large seeds and tubers, I obtained separate weights for the pooled large seeds and tubers and the subsample of small seeds after drying each to a constant mass at 87°C for 24 hours (Gray et al. 1999b, Penny 2003:56, Stafford et al. 2006). I multiplied the mass of small seeds by 4 (25% subsample) and added this value to the mass of large seeds and tubers in each sample. Finally, I converted the combined mass of all seeds and tubers to kg/ha (dry mass) for statistical analyses.

The Mississippi State University Extension Service, Soil Testing Laboratory (Mississippi State, Mississippi), analyzed aggregate soil samples from each moist-soil unit for pH, potassium (K [kg/ha]), and phosphorus (P [kg/ha]). The Extension Service uses these soil characteristics as a basis for providing lime and fertilizer recommendations. Accordingly, I predicted soil pH and nutrients might affect moist-soil seed abundance in sampled units. I did not measure nitrogen (N), because my soil collection method did not enable accurate estimation of soil N (Hoeft et al. 2000:115).

Statistical Analyses

Year-Specific Estimates

I used PROC SURVEYMEANS in SAS version 8.02 to generate annual estimates of moist-soil seed abundance in the MAV for 2002-2004 (SAS Institute 1999). This procedure incorporated appropriate selection probabilities and sampling weights for the strata of states (Arkansas, Louisiana, Mississippi, and Missouri) and 3
stages of sampling (i.e., management areas, units within areas, and core samples within units). I calculated the probability of selecting a management area within each state by dividing number of selected areas (i.e., 3) by number of management areas with moist-soil units in each state (U.S. Fish and Wildlife Service 2002). I then calculated the probability of selecting a moist-soil unit from a management area by dividing number of units selected within areas (i.e., 2) by number of units available at each area. Finally, I calculated the probability of selecting a core sample from a moist-soil unit by dividing number of core samples taken (i.e., 15 or 20) by number of possible cores given the sample area of the core sampler and area of the management unit. I calculated the sampling weight used for estimation by taking the inverse of the product of the 3 probabilities (Stafford et al. 2006).

From the among-year data set of plant species/genera recorded at each core sample site, I calculated the percentage occurrence of each plant species/genus within units by determining the frequency of core sample locations where a species/genus occurred and divided it by number of samples extracted from the unit (i.e., 15 or 20). I then calculated a mean and SE of the percentage occurrence of each plant species/genus across sampled moist-soil units by management category (active, \( n = 56 \) units; passive, \( n = 16 \) units). Finally, I performed an unbalanced 2-sample \( t \)-test in SAS version 8.02 to test for differences (\( \alpha = 0.10 \)) in mean percentage occurrence of each plant species/genus between actively and passively managed moist-soil units (SAS Institute 1999).
Among-Year Estimate

I calculated a pooled estimate of moist-soil seed abundance among years as an unweighted mean of yearly means for 2002, 2003, and 2004 (Stafford et al. 2006). I used moist-soil seed abundance data from Penny (2003) to calculate the 2002 estimate. Before calculating the 2002 estimate, I deleted data from Noxubee NWR, because this NWR was not located within the MAV. I estimated variance of the overall mean by summing the year specific variances and dividing by the square of the number of years sampled (Stafford et al. 2006).

Modeling Moist-soil Seed Abundance

I used multiple regression analysis to model relationships between moist-soil seed abundance and plant-growth form occurrence, management category, and soil pH and nutrients for 2003 and 2004 data. I used mean seed abundance (kg/ha, dry mass) for each moist-soil unit as the dependent variable. For each moist-soil unit, I calculated the percentage occurrence of selected plant-growth forms (i.e., grass/flatsedge/rush, forb, vine, and woody; Table 2.2) by determining the frequency of core sample locations where a growth form occurred and divided it by 15 (i.e., the number of core samples per unit). I designated percentage occurrence of plant-growth forms, soil pH and nutrients (i.e., P [kg/ha], and K [kg/ha]), and management category (i.e., active [1] or passive [0]) as explanatory variables.

Multicollinearity can invalidate interpretation of the effects of explanatory variables on the dependent variable in multiple regression (Gotelli and Ellison 2004:278). I assessed potential multicollinearity of explanatory variables using
PROC CORR in SAS version 8.02 (Cody and Smith 1997:115). When 2 explanatory variables were correlated ($r \geq 0.30$; Graham 2003), I determined which variable of the pair was correlated with $\geq 2$ variables and then excluded the latter from the regression model (Cody and Smith 1997:115, Gotelli and Ellison 2004:278).

After removing variables exhibiting multicollinearity, I used PROC REG in SAS version 8.02 to calculate and plot residual and predicted values of moist-soil seed abundance for each moist-soil unit (Cody and Smith 1997:221, SAS Institute 1999). To detect outliers, I calculated Cook’s Distance (CD) statistic for the mean moist-soil seed abundance in each unit. The CD statistic measures the change in linear fit of the regression model when a single observation is deleted from the data set and helps detect outliers and influential data (Berk 2004:159). I inspected the plot of residuals for funnel-shaped or non-random patterns indicating unequal variances among the residuals, a non-linear relationship between the dependent and explanatory variables, and outliers (Gotelli and Ellison 2004:259). I used backward elimination of explanatory variables in PROC REG (SAS Institute 1999) for the final regression analyses, and I deemed the best-fit model as the one with the greatest adjusted $R^2$ value (Gotelli and Ellison 2004:285).

RESULTS

Moist-soil Seed Abundance

I computed yearly estimates of mean moist-soil seed abundance in the MAV, standard errors (SE), and coefficients of variation (CV) for 2002, 2003, and 2004.
The estimates exceeded 530 kg/ha in 2002 and 2004 and approached 400 kg/ha in 2003 (Table 2.1). Mean abundance of moist-soil seed among years was approximately 500 kg/ha (Table 2.1). Within years, CVs were greater than my desired level of precision (CV ≤ 15%); however, the CV for the among-year estimate was 12.5% (Table 2.1).

**Percent Occurrence of Plant Species/Genera**

I tested for differences in mean percentage occurrence of 48 plant species/genera between actively and passively managed units and detected differences ($P < 0.10$) for 7 (14.6%) species/genera (Table 2.2). Barnyard grasses (*Echinochloa* spp.) and panic grasses (*Panicum* spp.) occurred more frequently in actively than passively managed units, whereas teal grass (*Eragrostis hypnoides*), toothcup (*Ammannia* sp.), water primroses (*Ludwigia* spp.), buckwheat vine (*Brunnichia cirrhosa*), and willow (*Salix* sp.) occurred more frequently in passively managed units.

**Modeling Moist-soil Seed Abundance**

I lost the soil sample from one moist-soil unit in 2004 (Coon Island WMA, Missouri) and excluded this unit from multiple regression analysis. Because no obvious pattern was apparent in the plot of model residuals, I concluded variances of residuals were equal and there was a linear relationship between seed abundance and the explanatory variables. The residual from one datum deviated substantially from the others, and it influenced (CD = 0.18) the regression model more than other data.
This estimate was from Wapanocca NWR, Unit A-3, fall 2004 (Appendix). Seed abundance in this moist-soil unit was 71% greater than the next greatest abundance of seeds (i.e., Yazoo NWR, Cox 13; $\bar{x} = 1,361.39$ kg/ha, SE = 203.43) and 300% greater than the mean seed abundance for 2002-2004 ($\bar{x} = 496.33$, SE = 61.96). I concluded evidence was adequate to omit this estimate and based results from the multiple regression analysis on data from the remaining 46 units sampled in 2003 and 2004.

I determined percentage occurrence of vines correlated with percentage occurrence of woody vegetation ($r = 0.43$, $P = 0.003$), grasses/flatsedges/rushes ($r = -0.35$, $P = 0.016$), forbs ($r = 0.30$, $P = 0.04$), and soil K ($r = 0.52$, $P = 0.0002$). I also found soil P positively correlated with pH ($r = 0.40$, $P = 0.006$) and K ($r = 0.57$, $P \leq 0.001$). Because percentage occurrences of vines and P correlated with ≥ 2 explanatory variables, I excluded these from multiple regression analysis to alleviate multicollinearity.

The best regression model (i.e., greatest adjusted $R^2$) that explained variation in moist-soil seed abundance included the explanatory variables percentage occurrence of woody vegetation, pH, and management category ($F_{3,42} = 3.36; P = 0.03; R^2_{adj} = 0.14$). Percentage occurrence of woody vegetation ($\beta = -2,501.31; SE = 918.19; F_{3,42} = 7.42; P = 0.01$ [$\bar{x} = 2.03\%, SE = 0.65\%, n = 46$]) was related negatively to seed abundance; whereas, pH ($\beta = 71.83; SE = 68.47; F_{3,42} = 1.10; P = 0.30$ [$\bar{x} = 5.8, SE = 0.09, n = 46$]) and management category ($\beta = 100.61, SE = 95.91, F_{3,42} = 1.10, P = 0.30$ [35 actively managed units; 11 passively managed units]).
units]) were positively related. Although the 3-variable model was significant, it explained only 14% of the variation in mean seed abundance among moist-soil units in 2003 and 2004.

**DISCUSSION**

The LMVJV desired a current estimate of moist-soil seed abundance for the MAV to represent the ability of managed public moist-soil units to provide seed resources for migrating and wintering waterfowl (Loesch et al. 1994). My research provided an estimate of this parameter for the MAV based on an explicit robust sample design. The original LMVJV mean (450 kg/ha; Reinecke et al. 1989) was within the confidence limits of my 3-year estimate (i.e., 95% CL = 426 – 566 kg/ha) and therefore was a reasonable preliminary value. However, I did not correct my estimate for seeds not recovered during sample processing and thus my estimate may be biased low. Reinecke and Hartke (2005) reported underestimating seed abundance in core samples from moist-soil units in Mississippi by approximately 12%. They conducted their bias assessment using blind samples containing known numbers of seeds but only evaluated recovery of relatively large seeds (i.e., barnyard grass). Because I processed core samples similarly to Reinecke and Hartke (2005), I probably also underestimated seed abundance by at least 12%. However, no studies have determined numbers of small seeds missed during processing. The mean contribution of small seeds to moist-soil seed abundance per management unit was 24.69% (SE = 1.66%, n = 72); hence, the magnitude of the bias from missed small seeds remains an important issue for future research.
Although my 3-year estimate of moist-soil seed abundance may be conservative because an unknown percentage of small seeds were missed, my estimate was the first multi-year estimate for the MAV. Penny (2003) conducted the initial MAV-wide sample survey of moist-soil seed abundance on managed public lands in 2002 and estimated seed abundance at 611 ± 146 kg/ha that year. Reinecke et al. (1989) and Bowyer et al. (2005) assembled available estimates of moist-soil seed abundance from other locations in the MAV and the U.S. Although reported estimates cannot be compared directly because of differences in collection, processing, and estimation methodologies, my 3-year estimate of 496 ± 62 kg/ha generally fell within the reported ranges but toward the lower end of these ranges (Bowyer et al. 2005). The latter trend may be related to the negative bias in my estimate from missed small seeds, interannual variation in seed production, and various site-specific environmental influences including, but not limited to, weather, soil and seed bank characteristics, and management strategies.

The precision of my 3-year estimate (CV = 12.48%) satisfied an a priori goal (CV ≤ 15%). However, year-specific CVs were greater than the CV for the 3-year estimate, because the variance of the 3-year estimate was the average sampling variance and did not include interannual variation among means (Burnham et al. 1987:22). I calculated the overall variance in this manner, because I desired an average estimate of variance for the 3-year estimate of mean moist-soil seed abundance (Franklin et al. 2002).
My analysis of differences in percentage occurrence of plant species/genera between management categories indicated barnyard and panic grasses occurred more often in actively than passively managed units. I believe this result was reasonable because these grasses are early successional species that typically grow in disturbed soils (Fredrickson and Taylor 1982). In actively managed units, soil is frequently disked (i.e., yearly or alternate year) and other management activities used, such as control of undesirable, competing plant species that enhances growth and seed production of grasses and sedges (Fredrickson and Taylor 1982).

Teal grass and toothcup occurred more frequently in passively than actively managed units. Teal grass often colonizes mudflats where water is slowly drawn down in spring and summer or where a late-season drawdown occurs (i.e., after 1 July), but presence of this species generally is not associated with early plant succession (Tobe et al. 1998). Toothcup typically occurs in units with a late season drawdown; however, this genus is considered an early successional plant (Fredrickson and Taylor 1982). Persistent flooding in passively managed units may deter highly competitive species from germinating and enable establishment of teal grass and toothcup.

Buckwheat vine and willow also occurred more frequently in passively than actively managed units. Extensive coverage of these plants usually occurs when moist-soil units transition to a later successional stage (Fredrickson and Taylor 1982). This situation is generally considered undesirable in managed moist-soil units and can
decrease growth of seed producing plants due to shading and competition for nutrients and water (Fredrickson and Taylor 1982).

Moist-soil units with a greater proportion of seed- and tuber-producing grasses and sedges are more valuable foraging habitat than units dominated by perennial forbs (Kaminski et al. 2003). Nonetheless, my regression analysis did not indicate a positive correlation between seed abundance and percentage occurrence of grasses/flatsedges/rushes. The mean percentage occurrence of grasses/flatsedges/rushes across sampled moist-soil units was 93.98% (SE = 1.84%, n = 46). This growth form included diverse species/genera and contained some plants that do not produce desirable seeds for waterfowl (e.g., broomsedge bluestem, *Andropogon virginicus*; little bluestem, *Andropogon scoparius*; Table 2.2), as well as some grasses not associated with early successional communities (e.g., tealgrass, broomsedge bluestem, and rice cutgrass, *Leersia oryzoides*; Fredrickson and Taylor 1982). The explanatory variable, mean percentage occurrence of grasses/flatsedges/rushes, probably was not retained in my final regression model because of little variation in percentage occurrence of this growth form among moist-soil units.

Regression analysis revealed woody vegetation correlated negatively with variation in seed abundance among moist-soil units. Grasses and sedges produce more seed with a greater TME value than seeds of most forbs and woody vegetation (Low and Bellrose 1944, Checkett et al. 2002, Kaminski et al. 2003). The occurrence of perennial and woody vegetation in a moist-soil unit is influenced by management
activities (e.g., timing and rate of drawdown, soil disturbance) and stage of succession (Fredrickson and Taylor 1982). Actively managed units generally have dominant coverage of grasses and sedges and, when perennial forbs (e.g., water primrose), vines (e.g., buckwheat vine), and woody plants (e.g., willow) colonize a unit, soil disturbance or a change in water regime usually is needed (Fredrickson and Taylor 1982).

Soil nutrients and pH influence seed production in agriculture systems (Hoeft et al. 2000:107); thus, I predicted the same would be true for moist-soil plant communities. Sampled moist-soil units had a pH range of 4.5-7.1, and I detected a positive relationship between seed abundance and soil pH. Soil pH influences uptake of nutrients by plants, and optimum pH is 5.8-7.0 (Potash and Phosphate Institute et al. 1997). I sampled 24 moist-soil units with relatively acidic soils (i.e., pH ≤ 5.8), which probably affected the ability of plants in these units to obtain essential nutrients and resulted in decreased seed production (Potash and Phosphate Institute et al. 1997, Foth 1984:204, Hoeft 2000:119).

Other measured soil nutrients did not influence variation in moist-soil seed abundance. However, some managers in the MAV believe their units needed added nutrients to improve seed yield. Managers at Ten Mile Pond WMA (Missouri) applied N/P/K fertilizer to their moist-soil units and produced nearly twice (i.e., 917 kg/ha; Appendix) the overall mean amount of seed in the MAV (i.e., 496 kg/ha). I suggest maintaining soil pH near neutral and monitor soil to ensure sufficient soil nutrients (e.g., 67–168 kg/ha N, ≥ 84 kg/ha P, and ≥ 246 kg/ha K; Hoeft et al.
are available during the growing season to improve seed production of moist-soil plants.

Managed moist-soil units provide foraging habitat that can mitigate decreased availability of waste rice and other agricultural seeds for waterfowl in the MAV. Stafford et al. (2006) reported mean abundance of waste rice decreased 71% between harvest and early winter. My estimate of moist-soil seed abundance in the MAV (i.e., 496 kg/ha) was > 6 times the abundance of waste rice in early winter. Although post-harvest management of rice stubble may help conserve waste rice (Chapter I), moist-soil units usually provide more forage than harvested rice fields. Specifically, managed moist-soil units provide about 4,198 DUD/ha compared to 897 DUD/ha for harvested rice fields (Stafford et al. 2006).

**MANAGEMENT AND RESEARCH IMPLICATIONS**

I recommend increased development and management of moist-soil units in the MAV to mitigate decreased abundance of waste rice and other agricultural seeds, such as soybeans (Stafford et al. 2006, Kaminski et al. 2005). I also recommend active management of these units to maintain early succession vegetation, which will prevent establishment of woody vegetation, promote plant species diversity, and increase seed yield by annual grasses and sedges (Fredrickson and Taylor 1982, Gray et al. 1999a).

Although the only soil pH affected with seed abundance in my regression analysis, I encourage managers to assay soil nutrients in their management units because growth of vegetation is limited if an essential nutrient(s) is lacking (Bennett
1993:1). If monitoring vegetation in moist-soil units reveals poor production of desired vegetation, soil augmentation may be necessary to promote plant growth and seed production (Hoeft 2000:119).

Multiple regression analysis revealed correlations between moist-soil seed abundance and soil pH, management category, and presence of woody vegetation. To test causal effects of management activities on seed production, controlled experiments should be conducted (e.g., Gray et al 1999a). Controlled experiments that test effects of different levels of soil nutrients and pH on moist-soil plants are needed to determine their contribution to seed production and corresponding costs and benefits. I was unable to conduct a cost:benefit analysis as part of my study because of incomplete and incompatible records of expenses and management practices among management areas.

The initial estimate of moist-soil seed abundance used by the LMVJV was similar to my estimate for the MAV. However, neither estimate was corrected for seeds not recovered during processing. To account partially for seed recovery bias and increase accuracy of my estimate of moist-soil seed abundance, I recommend adding 12% to my estimate based on Reinecke and Hartke’s (2005) estimate of large seeds not recovered. Adding 12% to my estimate would increase the estimate to 556 kg/ha. Thus, the LMVJV may consider selecting a value between 550-600 kg/ha to calculate waterfowl carrying capacity of managed moist-soil units on public lands in the MAV. This value accounts for large seed recovery bias (Reinecke and Hartke 2005), but may be conservative because it assumes equal recovery rates for small and
large seeds. I recommend future investigators determine recovery bias of small seeds during processing of moist-soil core samples. Estimating recovery rates for known numbers of small seeds (e.g., sprangletop, *Leptochloa* spp.; tealgrass, panic grasses, and pigweed, *Amaranthus* spp.) and large seeds (e.g., barnyard grasses, bristle grasses, *Setaria* spp.; and hemp sesbania) in blind samples (Reinecke and Hartke 2005) will improve ability of core sampling to estimate accurately the abundance of all seeds in moist-soil units.

**LITERATURE CITED**


Table 2.1. Mean (\( \bar{\mu} \)) moist-soil seed and tuber combined abundances (kg/ha, dry mass), standard errors (SE), and coefficient of variations (CV) on managed public lands in the Mississippi Alluvial Valley, autumns 2002-2004. Mean seed abundance for 2002-2004 was calculated as a simple mean of annual estimates. Variance of the overall mean was estimated by summing the year specific variances and dividing by the square of the number of years sampled (Stafford et al. 2006). Areas are the number of state or federal management areas sampled (i.e., State Wildlife Management Area or National Wildlife Refuge), units are the number of moist-soil units sampled within areas (i.e., 2 units per area), and cores are the number of core samples taken within units.

<table>
<thead>
<tr>
<th>Year</th>
<th>( n ) areas</th>
<th>( n ) units</th>
<th>( n ) cores</th>
<th>Seed abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( \bar{\mu} )</td>
</tr>
<tr>
<td>2002</td>
<td>12</td>
<td>24</td>
<td>480</td>
<td>537.05</td>
</tr>
<tr>
<td>2003</td>
<td>12</td>
<td>24</td>
<td>360</td>
<td>396.77</td>
</tr>
<tr>
<td>2004</td>
<td>12</td>
<td>24</td>
<td>360</td>
<td>555.19</td>
</tr>
<tr>
<td>2002-2004</td>
<td>36</td>
<td>72</td>
<td>1,200</td>
<td>496.33</td>
</tr>
</tbody>
</table>

\(^a\) CV = (SE/\( \bar{\mu} \)) \times 100
Table 2.2. Mean percentage occurrence and standard errors (SE) of plant species/genera in managed moist-soil units ($n = 72$) on state and federal lands in the Mississippi Alluvial Valley, autumns 2002-2004. Homogenous variance was assumed for $t$-tests of the null hypothesis of no difference in mean percentage occurrence of plant species/genera between active and passive management categories.

<table>
<thead>
<tr>
<th>Growth form/species/genus</th>
<th>Active ($n = 56$)</th>
<th>Passive ($n = 16$)</th>
<th>$t_{70}$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{x}$</td>
<td>SE</td>
<td>$\bar{x}$</td>
<td>SE</td>
</tr>
<tr>
<td>Grasses/flatsedges/rushes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little bluestem (<em>Andropogon scoparius</em>)</td>
<td>5.83</td>
<td>2.68</td>
<td>2.08</td>
<td>1.17</td>
</tr>
<tr>
<td>Broomsedge bluestem (<em>Andropogon virginicus</em>)</td>
<td>0.83</td>
<td>0.61</td>
<td>0.84</td>
<td>0.57</td>
</tr>
<tr>
<td>Broadleaf signalgrass (<em>Brachiaria platyphylla</em>)</td>
<td>6.0</td>
<td>2.1</td>
<td>0.73</td>
<td>0.50</td>
</tr>
<tr>
<td>Carex sedges (<em>Carex spp.</em>)</td>
<td>2.98</td>
<td>1.10</td>
<td>5.42</td>
<td>2.52</td>
</tr>
<tr>
<td>Flatsedges (<em>Cyperus spp.</em>)</td>
<td>22.74</td>
<td>3.47</td>
<td>25.21</td>
<td>7.58</td>
</tr>
<tr>
<td>Hairy panicgrass (<em>Dicanthelium scoparium</em>)</td>
<td>1.07</td>
<td>1.07</td>
<td>a</td>
<td></td>
</tr>
<tr>
<td>Crabgrasses (<em>Digitaria spp.</em>)</td>
<td>8.07</td>
<td>2.36</td>
<td>2.81</td>
<td>1.93</td>
</tr>
<tr>
<td>Barnyardgrasses (<em>Echinochloa spp.</em>)</td>
<td>44.04</td>
<td>4.70</td>
<td>14.07</td>
<td>4.79</td>
</tr>
<tr>
<td>Spike rushes (<em>Eleocharis spp.</em>)</td>
<td>12.56</td>
<td>2.63</td>
<td>14.47</td>
<td>5.92</td>
</tr>
<tr>
<td>Teal grass (<em>Eragrostis hypnoides</em>)</td>
<td>0.09</td>
<td>0.09</td>
<td>7.09</td>
<td>4.57</td>
</tr>
<tr>
<td>Rice cutgrass (<em>Leersia oryzoides</em>)</td>
<td>1.43</td>
<td>0.79</td>
<td>3.33</td>
<td>3.33</td>
</tr>
<tr>
<td>Sprangletop (<em>Leptochloa spp.</em>)</td>
<td>19.08</td>
<td>3.93</td>
<td>12.91</td>
<td>4.92</td>
</tr>
<tr>
<td>Panic grasses (<em>Panicum spp.</em>)</td>
<td>48.01</td>
<td>4.65</td>
<td>31.04</td>
<td>8.72</td>
</tr>
<tr>
<td>Paspalum grasses (<em>Paspalum spp.</em>)</td>
<td>4.52</td>
<td>1.80</td>
<td>7.50</td>
<td>4.71</td>
</tr>
<tr>
<td>Horned beakrush (<em>Rhynchospora corniculata</em>)</td>
<td>4.52</td>
<td>1.94</td>
<td>9.59</td>
<td>5.41</td>
</tr>
<tr>
<td>Bullrush (<em>Scirpus californicus</em>)</td>
<td>2.86</td>
<td>1.67</td>
<td>5.00</td>
<td>2.76</td>
</tr>
<tr>
<td>Bristle grasses (<em>Setaria spp.</em>)</td>
<td>11.64</td>
<td>2.49</td>
<td>18.54</td>
<td>6.78</td>
</tr>
<tr>
<td>Johnson grass (<em>Sorghum halepense</em>)</td>
<td>2.02</td>
<td>1.68</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>Forbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pigweed (<em>Amaranthus spp.</em>)</td>
<td>5.92</td>
<td>1.78</td>
<td>1.78</td>
<td>1.05</td>
</tr>
<tr>
<td>Common ragweed (<em>Ambrosia artemisiifolia</em>)</td>
<td>5.81</td>
<td>1.63</td>
<td>7.08</td>
<td>5.88</td>
</tr>
<tr>
<td>Toothcup (<em>Ammannia sp.</em>)</td>
<td>6.88</td>
<td>1.69</td>
<td>21.25</td>
<td>6.36</td>
</tr>
<tr>
<td>Beggarticks (<em>Bidens spp.</em>)</td>
<td>5.06</td>
<td>2.22</td>
<td>-1.21</td>
<td>0.23</td>
</tr>
<tr>
<td>Partridge pea (<em>Chamaecrista fasciculata</em>)</td>
<td>1.43</td>
<td>1.08</td>
<td>-0.70</td>
<td>0.49</td>
</tr>
<tr>
<td>Growth form/species/genus</td>
<td>Active (n = 56)</td>
<td></td>
<td>Passive (n = 16)</td>
<td></td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>----------------</td>
<td>----------</td>
<td>-----------------</td>
<td>----------</td>
</tr>
<tr>
<td>Buttonweed (Diodia virginiana)</td>
<td>6.79 ± 2.09</td>
<td>1.26 ± 0.68</td>
<td>-1.40</td>
<td>0.17</td>
</tr>
<tr>
<td>Fleabane (Erigeron spp.)</td>
<td>7.03 ± 2.43</td>
<td>1.25 ± 1.25</td>
<td>-1.25</td>
<td>0.22</td>
</tr>
<tr>
<td>Swamp rosemallow (Hibiscus palustris)</td>
<td>0.36 ± 0.26</td>
<td>-0.72 ± 0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lespedeza (Lespedeza cuneata)</td>
<td>1.67 ± 1.35</td>
<td>-0.66 ± 0.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water-primroses (Ludwigia spp.)</td>
<td>2.26 ± 0.84</td>
<td>15.42 ± 5.30</td>
<td>4.12</td>
<td>0.01*</td>
</tr>
<tr>
<td>Stink weed (Pluchea odorata)</td>
<td>0.84 ± 0.51</td>
<td>1.25 ± 1.25</td>
<td>0.36</td>
<td>0.72</td>
</tr>
<tr>
<td>Smartweeds (Polygonum spp.)</td>
<td>51.45 ± 4.82</td>
<td>45.73 ± 8.19</td>
<td>-0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>Curly dock (Rumex crispus)</td>
<td>2.18 ± 1.15</td>
<td>-1.01 ± 0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common arrowhead (Sagittaria latifolia)</td>
<td>0.12 ± 0.12</td>
<td>-0.53 ± 0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lizard’s tail (Saururus cernus)</td>
<td>2.74 ± 1.20</td>
<td>-1.21 ± 0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goat weed (Scoparia dulcis)</td>
<td>0.83 ± 0.64</td>
<td>-0.70 ± 0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sicklepod (Senna obtusifolia)</td>
<td>0.12 ± 0.12</td>
<td>-0.53 ± 0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemp sesbania (Sesbania exaltata)</td>
<td>18.98 ± 3.77</td>
<td>11.25 ± 3.64</td>
<td>-1.05</td>
<td>0.30</td>
</tr>
<tr>
<td>Fanpetal (Sida sp.)</td>
<td>10.24 ± 2.73</td>
<td>12.92 ± 5.36</td>
<td>0.46</td>
<td>0.65</td>
</tr>
<tr>
<td>Goldenrods (Solidago spp.)</td>
<td>1.19 ± 0.72</td>
<td>-0.88 ± 0.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cattail (Typha sp.)</td>
<td>0.23 ± 0.23</td>
<td>-0.53 ± 0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vervain (Verbena brasiliensis)</td>
<td>7.14 ± 2.85</td>
<td>-1.33 ± 0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cocklebur (Xanthium strumarium)</td>
<td>12.26 ± 3.28</td>
<td>10.42 ± 4.87</td>
<td>-0.28</td>
<td>0.78</td>
</tr>
</tbody>
</table>

**Vines**

| Buckwheat vine (Brunnichia cirrhosa)      | 0.72 ± 0.50    | 7.5 ± 5.12 | 2.38           | 0.02*    |
| Trumpet creeper (Campsis radicans)       | 2.26 ± 1.30    | 4.58 ± 1.93 | 0.88           | 0.38     |
| Balloonvine (Cardiospermum halicacabum)   | 7.14 ± 2.54    | 6.67 ± 3.22 | -0.09          | 0.93     |
| Morningglory (Ipomoea hederacea)         | 11.19 ± 3.21   | 4.58 ± 2.26 | -1.07          | 0.29     |

**Woody**

| Button bush (Cephalanthus occidentalis)   | 0.83 ± 0.51    | 0.84 ± 0.57 | 0.00           | 0.99     |
| Sweetgum (Liquidambar styraciflua)       | 0.24 ± 0.24    | -0.53 ± 0.60 |                |          |
| Willow (Salix sp.)                       | 0.24 ± 0.17    | 2.09 ± 1.00 | 3.01           | 0.01*    |

* Blanks denote absence of plant species or genus.

* Denotes a significant difference ($P \leq 0.10$) between means.
APPENDIX A
Table A. Mean ($\bar{x}$) moist-soil seed and tuber combined abundances (kg/ha, dry mass), standard errors (SE), coefficients of variation (CV), and numbers of core samples ($n$) taken from state wildlife management areas (WMA) or National Wildlife Refuges (NWR) in the Mississippi Alluvial Valley, October–November 2002-2004. Number of core samples reflects total number collected across years at each area. In all years, 2 moist-soil units were sampled per management area. In 2002, 20 core samples were collected per moist-soil unit (Penny 2003:55). In 2003 and 2004, 15 core samples were collected per unit. Management strategy for each area was denoted as active (A), passive (P), or both (B). Management strategy was denoted B if, among sampled units within an area, one unit was passively managed and another was actively managed.

<table>
<thead>
<tr>
<th>State</th>
<th>NWR/WMA</th>
<th>Nearest city</th>
<th>Year(s) sampled</th>
<th>Seed/tuber abundance</th>
<th>Management strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\bar{x}$</td>
<td>SE</td>
</tr>
<tr>
<td>Arkansas</td>
<td>Bald Knob NWR</td>
<td>Bald Knob</td>
<td>2002-2003</td>
<td>435.53</td>
<td>55.51</td>
</tr>
<tr>
<td></td>
<td>Overflow NWR</td>
<td>Crossett</td>
<td>2002-2003</td>
<td>647.73</td>
<td>90.07</td>
</tr>
<tr>
<td></td>
<td>White River NWR</td>
<td>St. Charles</td>
<td>2002-2003</td>
<td>1,103.77</td>
<td>140.70</td>
</tr>
<tr>
<td></td>
<td>Cache River NWR</td>
<td>South Augusta</td>
<td>2004</td>
<td>485.34</td>
<td>41.03</td>
</tr>
<tr>
<td></td>
<td>Holland Bottoms WMA</td>
<td>Jacksonville</td>
<td>2004</td>
<td>433.15</td>
<td>93.87</td>
</tr>
<tr>
<td></td>
<td>Wapanocca NWR</td>
<td>Turrell</td>
<td>2004</td>
<td>1,985.43</td>
<td>422.55</td>
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<tr>
<td>Louisiana</td>
<td>Lake Ophelia NWR</td>
<td>Marksville</td>
<td>2002-2003</td>
<td>526.56</td>
<td>39.80</td>
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<td></td>
<td>Tensas River NWR</td>
<td>Tallulah</td>
<td>2002, 2004</td>
<td>726.54</td>
<td>30.48</td>
</tr>
<tr>
<td>State</td>
<td>NWR/WMA</td>
<td>Nearest city</td>
<td>Year(s) sampled</td>
<td>Seed/tuber abundance</td>
<td>Management strategy</td>
</tr>
<tr>
<td>---------------</td>
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<td></td>
<td></td>
<td></td>
<td>$\bar{x}$</td>
<td>SE</td>
</tr>
<tr>
<td>Upper Ouachita NWR</td>
<td>Farmerville</td>
<td>2002-2003</td>
<td>206.54</td>
<td>7.42</td>
<td>3.59</td>
</tr>
<tr>
<td>Grand Cote NWR</td>
<td>Marksville</td>
<td>2003</td>
<td>454.97</td>
<td>96.58</td>
<td>21.23</td>
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<tr>
<td>Buckhorn WMA</td>
<td>Ferriday</td>
<td>2004</td>
<td>524.84</td>
<td>57.55</td>
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</tr>
<tr>
<td>Catahoula NWR</td>
<td>Rhinehart</td>
<td>2004</td>
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<td>10.48</td>
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<td>Mississippi</td>
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<tr>
<td>Morgan Brake NWR</td>
<td>Tchula</td>
<td>2002</td>
<td>926.65</td>
<td>126.53</td>
<td>13.65</td>
</tr>
<tr>
<td>Yazoo NWR</td>
<td>Hollandale</td>
<td>2002-2003</td>
<td>871.50</td>
<td>180.92</td>
<td>20.76</td>
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<tr>
<td>St. Catherine Creek NWR</td>
<td>Natchez</td>
<td>2002, 2004</td>
<td>196.76</td>
<td>6.67</td>
<td>3.39</td>
</tr>
<tr>
<td>Noxubee NWR</td>
<td>Starkville</td>
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<td>131.87</td>
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<tr>
<td>Hillside NWR</td>
<td>Yazoo City</td>
<td>2003</td>
<td>1,039.85</td>
<td>13.89</td>
<td>1.34</td>
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<tr>
<td>Coldwater NWR</td>
<td>Charleston</td>
<td>2003</td>
<td>420.62</td>
<td>37.09</td>
<td>8.82</td>
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<tr>
<td>Dahomey NWR</td>
<td>Cleveland</td>
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<td>470.70</td>
<td>46.67</td>
<td>9.92</td>
</tr>
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<td>State</td>
<td>NWR/WMA</td>
<td>Nearest city</td>
<td>Year(s) sampled</td>
<td>Seed/tuber abundance</td>
<td>Management strategy</td>
</tr>
<tr>
<td>---------</td>
<td>---------------</td>
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<td>Missouri</td>
<td>Mahannah WMA</td>
<td>Redwood</td>
<td>2004</td>
<td>(\bar{x} = 534.71)</td>
<td>SE = 35.40 CV = 6.62</td>
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<tr>
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<td>Duck Creek WMA</td>
<td>Puxico</td>
<td>2002-2004</td>
<td>(\bar{x} = 881.08)</td>
<td>SE = 58.53 CV = 6.64</td>
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<td>East Prairie</td>
<td>2002-2003</td>
<td>(\bar{x} = 917.53)</td>
<td>SE = 86.20 CV = 9.39</td>
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<td>Dexter</td>
<td>2002, 2004</td>
<td>(\bar{x} = 540.04)</td>
<td>SE = 65.17 CV = 12.07</td>
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<tr>
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<td>Coon Island WMA</td>
<td>Qulin</td>
<td>2003-2004</td>
<td>(\bar{x} = 537.65)</td>
<td>SE = 76.56 CV = 14.24</td>
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</tbody>
</table>

\(^a CV = (SE/\bar{x})*100\)