Articles

Waste Rice Seed in Conventional and Stripper-Head Harvested Fields in California: Implications for Wintering Waterfowl

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Abstract

Waste rice seed is an important food for wintering waterfowl and current estimates of its availability are needed to determine the carrying capacity of rice fields and guide habitat conservation. We used a line-intercept method to estimate mass-density of rice seed remaining after harvest during 2010 in the Sacramento Valley (SACV) of California and compared results with estimates from previous studies in the SACV and Mississippi Alluvial Valley (MAV). Posterior mean (95% credible interval) estimates of total waste rice seed mass-density for the SACV in 2010 were 388 (336–449) kg/ha in conventionally harvested fields and 245 (198–307) kg/ha in stripper-head harvested fields; the 2010 mass-density is nearly identical to the mid-1980s estimate for conventionally harvested fields but 36% lower than the mid-1990s estimate for stripped fields. About 18% of SACV fields were stripper-head harvested in 2010 vs. 9–15% in the mid-1990s and 0% in the mid-1980s; but due to a 50% increase in planted rice area, total mass of waste rice seed in SACV remaining after harvest in 2010 was 43% greater than in the mid-1980s. However, total mass of seed-eating waterfowl also increased 82%, and the ratio of waste rice seed to seed-eating waterfowl mass was 21% smaller in 2010 than in the mid-1980s. Mass-densities of waste rice remaining after harvest in SACV fields are within the range reported for MAV fields. However, because there is a lag between harvest and waterfowl use in the MAV but not in the SACV, seed loss is greater in the MAV and estimated waste seed mass-density available to wintering waterfowl in SACV fields is about 5–30 times recent MAV estimates. Waste rice seed remains an abundant food source for waterfowl wintering in the SACV, but increased use of stripper-head harvesters would reduce this food. To provide accurate data on carrying capacities of rice fields necessary for conservation planning, trends in planted rice area, harvest method, and postharvest field treatment should be tracked and impacts of postharvest field treatment and other farming practices on waste rice seed availability should be investigated.

Keywords: California; rice; Sacramento Valley; seed density; waste grain; waterfowl

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Introduction

The Central Valley of California is a critical wintering area for many species of waterfowl and other wetland-dependent birds in the Pacific Flyway (Gilmer et al. 1982; U.S. Fish and Wildlife Service [USFWS] and Canadian Wildlife Service 1986; Heitmeyer et al. 1989; Western Hemisphere Shorebird Reserve Network 2003).

Once estimated at 1.6–2 million ha, Central Valley wetlands were reduced by >90% by the early 1900s (USFWS 1978). In the northern Central Valley (i.e., Sacramento Valley [SACV]), rice fields replaced many wetlands and provide valuable foraging habitat (Elphick 2000). Birds use both dry and flooded fields (Day and Colwell 1998; Elphick and Oring 1998) with ≥118 species during winter and 140 species overall observed using SACV rice fields (Eadie et al. 2008). Most waterfowl and many other bird species (e.g., mourning dove *Zenaida macroura*, ring-necked pheasant *Phasianus colchicus*, blackbirds *Agelaius* sp., *Xanthocephalus xanthocephalus, Euphagus cyanocephalus*) feed extensively on waste rice seed remaining in fields after harvest (Ferrel et al. 1949; Cowan 1952; Crase and Dehaven 1978; Miller 1987; Eadie et al. 2008). Waste rice is an especially important food source for wintering waterfowl (Miller 1987; Heitmeyer 1989; Fleskes et al. 2005b; Ackerman et al. 2006) and vital for sustaining the large populations of waterfowl that winter in California (Miller and Newton 1999; Central Valley Joint Venture 2006).

Consisting of 21 federal, state, and nongovernmental organizations, the Central Valley Joint Venture (CVJV; Joint Ventures are partnerships established under the North American Waterfowl Management Plan to help conserve the continent's waterfowl populations and habitats) has been the main organization conserving habitats for waterfowl and other birds in the Central Valley since 1988 (CVJV 2006). The CVJV uses a bioenergetics-based model (Heitmeyer 1989) to determine habitat restoration and enhancement objectives necessary to support desired levels of wintering waterfowl populations. This model requires accurate estimates of the rice seed mass-density to quantify the carrying capacity of rice fields for wintering waterfowl (CVJV 2006). Studies in the 1980s and early 1990s provided estimates of waste rice seed remaining in SACV rice fields after harvest by conventional cutter-bar (Miller et al. 1989) and stripper-head (Miller and Wylie 1996) harvesters. However, changes in harvester efficiency, plant genetics, and farming practices may make past estimates of rice seed mass-density obsolete. For example, Miller and Wylie's (1996) study was undertaken soon after stripper-head harvesters had been introduced, and the researchers predicted that waste rice mass-density in stripped fields would decline as farmers fine-tuned harvester operation and improved harvest efficiency. Development of higher yielding rice varieties has resulted in more waste rice in some regions (Eadie et al. 2008). However, in the Mississippi Alluvial Valley (MAV), development of faster maturing rice varieties has permitted harvest to occur well before most wintering waterfowl arrive, which allows more time for germination, decomposition, and consumption of waste rice by nonwaterfowl species and reduces the amount available for wintering waterfowl (Manley et al. 2004; Stafford et al. 2006; Kross et al. 2008; Havens et al. 2009). The timing of rice harvest in the SACV has not changed substantially in the past 25 y (U.S. Department of Agriculture 2011) but climate change may alter future farming practices (Cayan et al. 2008; California Climate and Agricultural Network 2011). The CVJV recognized the dynamic nature of the Central Valley landscape and identified the monitoring of rice habitats as a high priority (CVJV 2009).

In this study, we implemented a modified line-intercept method (Halstead et al. 2011) across the SACV to determine the average mass-density (kg/ha) of rice seeds remaining in fields after harvest before depletion by migratory birds. We compare current rice seed mass-density estimates in the SACV with those obtained previously and with estimates from the MAV (Eadie et al. 2008) and discuss implications for wintering waterfowl.

Methods

Field sampling

We estimated mass-density of rice seed remaining after harvest in 101 rice fields distributed throughout the SACV, 16 September–5 November 2010. We distributed sampling among the eight main SACV rice-growing counties (Figure 1) in approximate proportion to each county's percentage of the eight-county total rice crop grown during 2008 (Butte: 19% of rice area in 2008, n = 17 fields sampled; Colusa: 30%, n = 30; Glenn: 17%, n = 15; Placer: 2%, n = 3; Sacramento: 3%, n = 2; Sutter: 19%, n = 22; Yolo: 5%, n = 8; Yuba: 7%, n = 4; U.S. Department of Agriculture 2011). We used this sampling distribution to account for potential variation caused by geographic differences related to soils, local weather, water supplies, and local farming traditions (Miller et al. 1989). Before harvest season, we identified rice fields using Google Earth and obtained rice-grower contact information via county-specific crop pesticide and other databases. We then randomly selected growers in each county and attempted to contact them until we obtained access permission to enough fields (with limits on number of fields per grower as described below) to meet our sample goals for each county plus 25% extra in the event that access permission fell through or harvesting occurred too rapidly for us to sample some fields immediately after harvest. Beginning in early September, we monitored field status by driving public roads each day and identifying fields where preparations were being made for harvest or where harvest was occurring. To sample seed mass-density before depletion by migratory birds and to be consistent with previous work (Miller et al. 1989), we sampled fields as soon as possible after harvest and before any postharvest field treatment (e.g., chopping, burning, disking, plowing, or flooding); most fields were sampled within a few days after harvest. Because rice seed mass-density could vary with farming and harvester method and equipment, we followed procedures of Miller et al. (1989), and sampled ≤2 fields per grower unless they were large multioperator farms. We did not make an effort to secure a sample of conventional vs. stripper-head harvested fields after the farmer was selected; but instead, we selected fields by chance. The 101 fields we sampled were from 44 different growers (1 field from 8 growers, 2 from 24 growers, 3 from 7 growers, 4 from 3 growers, 5 from 1 grower, and 7 from 1 grower).

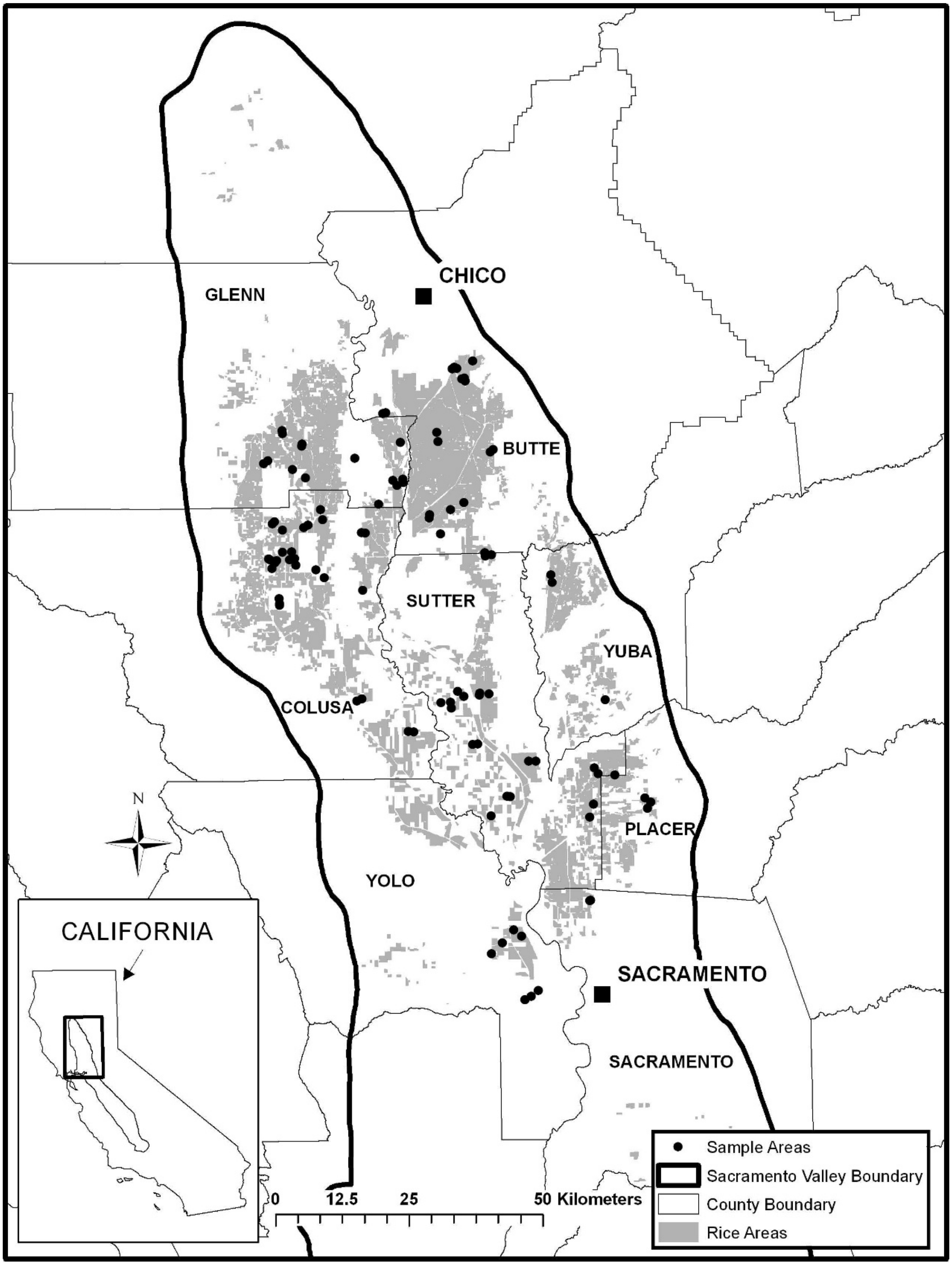

Figure 1. Generalized areas of rice agriculture in the eight major rice-growing counties of the Sacramento Valley of California and field locations where postharvest waste rice seed mass-densities were estimated in 2010 (adapted from Fleskes et al. 2005a).

We used a modified line-intercept sampling method developed in SACV rice fields (Halstead et al. 2011) to estimate waste rice seed mass-density. The line-intercept method uses segments of a line as observational units (Daubenmire 1968; Bonham 1989). We selected three random points within each field to serve as the starting point for each line-intercept sample. At each of the three random starting points we set a stake. If the stake was at a rice check levee, we randomly selected a direction, moved 10 m, and reset the stake. If the new point fell outside the field border, we randomly selected a direction that led back into field, and moved the stake 10 m in that direction. Starting at the stake, we removed the straw (if present) away from a 1-m–wide, 6-m–long path that was perpendicular to the direction that the harvester had traveled. We then set a second stake at the far end of the cleared path and attached a 6-m–long, 6.35-mm–wide plastic tape measure on which alternating red and black 10-cm sections were marked (i.e., 30 red and 30 black sections). We initially kept the tape measure above the stubble but then clipped and removed enough stubble to allow the tape measure to touch the ground. We then counted and recorded the number of whole and >half rice seeds (for broken and/or partial seeds) that were under or touching each of the 30 red sections of the 6-m tape (>half seed counted as one seed, <half seed and empty hulls not counted). We used a wire or pocket knife to flick chaff away (without moving seeds) if necessary to expose the soil surface. One sample is the total number of seeds on the ground that were intercepted (touched on either side of the line or lying wholly or partly under the line) by the 30 (10-cm) red sections of a line. For each sample, we recorded field identification (1–101), date, sample number (1–3), grower identification, harvest method (conventional, stripper-head, unknown), rice variety (short, medium, or long grain), and presence or absence of straw.

Data analyses

We converted the number of seeds counted on the ground (Table S1, *Supplemental Material*) to mass-density (kg/ha) via the regression formula in Halstead et al. (2011), slightly modified to use a square-root transformation (to approximate the Box–Cox transformation with $\lambda = 0.54$ from Halstead et al. [2011]). The regression equation converts the total count of the seeds observed in the 30 sampled 10-cm sections for each sampled plot to mass-density in kg/ha via the correlation of counts with mass densities. Because the width of the tape (6.35 mm) is nonnegligible relative to the dimensions of a rice seed, and because we counted all seeds within or touching the vertical projection of the tape, the sample was areal, consisting of a series of very narrow rectangular quadrats, rather than a linear distance. We did not use a simple scaling relationship because this does not account for errors associated with potential edge effects (mis-specifying the buffer to estimate the actual sampled area [e.g., because many counted seeds had much of their area outside the vertical projection of the tape], bias with regard to including or excluding seeds, etc.), whereas the regression equation properly propagates these uncertainties (Halstead et al. 2011).

To estimate above-ground seed mass-density (needed for adding to the ground estimates to calculate total seed mass-density for comparisons with other regions), we used data from previous SACV rice-field studies (Miller et al. [1989] and B. Halstead, unpublished data for conventionally harvested fields and unknown fields; Miller and Wylie [1996] for stripped fields). To properly account for uncertainty of the above-ground estimates and correctly propagate error, rather than simply using the estimated mean values, we simulated an above-ground mass-density value from previous mean and standard deviation estimates from the SACV for each plot at each iteration of the Markov chain (Kéry 2010; Link and Barker 2010). We added the simulated value for each plot to the 2010 ground estimate for that plot to calculate total seed mass-density for each plot at each iteration.

We compared mass-density estimates from this study with previous SACV estimates (Table S1, *Supplemental Material*) within harvest types and evaluated the mass-density of waste rice remaining by different harvest methods (conventional vs. stripper-head) in 2010 by calculating the difference between posterior mean densities of waste rice (Kéry 2010). Note that these differences won't exactly equal differences derived by subtracting estimated means shown in Table 1, because we are testing the difference between the estimated means at each iteration of the Markov chain to obtain the posterior distribution of the differences between means, rather than estimating the posterior distribution of the means and then calculating the difference between them. For estimates from this study, we used the posterior mean predicted rice mass-density for each iteration as data. To obtain ground and straw estimates for fields conventionally harvested in 1985 and 1986, we multiplied total rice mass-density of each sample by the proportions on the ground (0.7362) and in the straw (0.2638) reported by Miller et al. (1989).

We conducted all analyses by calling WinBUGS 1.4.3 (Lunn et al. 2000) from R 2.12.2 (R Development Core Team 2011) using the package R2WinBUGS (Sturtz et al. 2005). We ran each analysis on five chains of 1,000 iterations each, after discarding the first 200 iterations as burn-in. We assessed convergence visually with history plots and with the $\hat{R}$ statistic (Gelman et al. 2004) as calculated by R2WinBUGS. No evidence for lack of convergence existed in any analysis (maximum $\hat{R}$ = 1.0). Unless otherwise indicated, we report the posterior mean and 95% symmetrical credible interval.

Results

Posterior mean (95% credible interval) estimates of rice seed ground mass-density in the SACV in 2010 ranged from 186 (151–231) kg/ha in stripper-head harvested fields to 284 (248–323) kg/ha in conventionally harvested fields (Table 1), with conventional harvesters resulting in 98 (67–129) kg/ha more waste rice on the ground than stripper-head harvesters. Posterior mean estimates of total waste rice seed mass-density for the SACV in 2010

Table 1. Ground, above-ground, and total postharvest waste rice mass-densities during this 2010 study and earlier studies (1985–1986, 1993) in the Sacramento Valley, California.

		Mean (95% CI[a]; *n*) rice mass-density (kg/ha)		
Fraction	**Harvest method**	**1985–1986[b]**	**1993[c]**	**2010[d]**
Ground	Conventional	284 (273–295; 341)	—	284 (248–323; 238)
	Stripped	—	291 (274–308; 136)	186 (151–231; 48)
	Unknown	—	—	276 (226–330; 13)
	Overall	—	—	267 (234–306; 299)
Above-ground[e]	Conventional	102 (94–110; 341)	—	103 (70–151; 238)
	Stripped	—	53 (41–66; 136)	59 (34–104; 48)
	Unknown	—	—	108 (38–267; 13)
	Overall	—	—	97 (69–140; 299)
Total	Conventional	386 (376–396; 341)	—	388 (336–449; 238)
	Stripped	—	344 (326–360; 136)	245 (198–307; 48)
	Unknown	—	—	384 (291–553; 13)
	Overall	—	—	364 (320–425; 299)

[a] Confidence or credible intervals.
[b] Miller et al. (1989).
[c] Miller and Wylie (1996).
[d] Data from this 2010 study for ground estimates. For above-ground estimates, values were simulated using Markov chain Monte Carlo methods (Kéry 2010; Link and Barker 2010) based on the lognormal mean and standard deviation of values from 2009 (B. Halstead, unpublished data) and Miller et al. (1989; which were nearly identical) for conventionally harvested and unknown fields and from Miller and Wylie (1996) for stripped fields.
[e] Seeds in straw for conventionally harvested fields and on standing stalks for stripped fields.

ranged from 245 (198–307) kg/ha in stripper-head harvested fields to 388 (336–449) kg/ha in conventionally harvested fields (Table 1), with conventional harvesters resulting in 143 (114–172) kg/ha more total waste rice than stripper-head harvesters. Estimates of waste rice resulting from conventional harvest in 2010 were nearly identical to 1985–1986 (Ground difference: 0 [−17–18] kg/ha; Total difference: −2 [−18–15] kg/ha). In contrast, estimates of waste rice resulting from stripper-head harvest were lower in 2010 than in 1993 (Ground difference: −98 [−129 to −67] kg/ha; Total difference: −142 [−172 to −114] kg/ha). Of the 101 fields we sampled in 2010, 79 were conventionally harvested, 17 were stripper-head harvested, and 5 unknown; 98 were medium-grain rice and 3 were short grain.

Discussion

Sacramento Valley 2010 vs. earlier

Our study shows that waste rice seeds are still abundant in SACV fields. However, whereas our 2010 mass-density estimate is nearly identical to the mid-1980s estimate for conventionally harvested fields (Miller et al. 1989), our 2010 mass-density estimate of waste rice seed remaining on the ground in stripper-head harvested fields is about 36% lower than the 1993 estimate (Miller and Wylie 1996). Stripper-head harvesters were first used by California rice growers in the early 1990s (Thompson and Blank 2000), and although Miller and Wylie (1996) found similar waste rice densities remaining on the ground in conventionally and stripper-head harvested fields in 1993, they predicted that operators would learn to more efficiently operate stripper-head harvesters and waste rice mass-density would decline. We suspect that both improved stripper-head design (Shelbourne Reynolds Inc. 2011) and more efficient operation likely explains the reduction between 1993 and 2010 in waste seed remaining in stripped fields in the SACV.

Stripper-head harvesters were used in the SACV to harvest 17.7% of the known-type rice fields during our 2010 study (16.8% if the five unknowns were conventionally harvested; 21.8% if the five unknowns were stripper-head harvested) compared with 9% of the rice fields in 1994 and 15% in 1995 (Day and Colwell 1998). Although this suggests little change or a slight increase in use of stripper-head harvesters in the SACV since the mid-1990s, because most California operators (Thompson and Blank 2000) avoid using stripper-head harvesters in fields where rice is flattened by high winds or lodging (i.e., permanent displacement of plant stems from the vertical due to buckling of the stem or failure of root system; Government of Alberta 2011), differences among years could simply be due to annual variation in the amount of rice that is flattened by winds or lodging. Unfortunately, no data are available on extent of flattened rice fields.

Sacramento Valley vs. Mississippi Alluvial Valley

In contrast to our results, Stafford et al. (2006) reported more waste rice in stripped fields than conventional fields, and Kross et al. (2008) reported no difference in the MAV. If rates at which stripper-head harvesters are used in fields where rice is flattened by wind or lodging (which likely would have greater waste seed densities than would undamaged fields [Government of Alberta 2011]) differ regionally, then regional estimates would differ. However, it is unknown whether farmers in the

MAV, like those in California (Thompson and Blank 2000), also avoid using stripper-head harvesters where rice is flattened. Long-grain varieties of rice comprise >90% of rice grown in the MAV, whereas medium-grain varieties comprise >90% of rice grown in California (U.S. Department of Agriculture 2011); differences in harvester efficiency among rice varieties (Delta Farm Press 2000) would result in regional differences in waste rice densities. Field-sampling methods differed for the MAV (soil core: Manley et al. 2004; Stafford et al. 2006; Kross et al. 2008; Havens et al. 2009) and SACV (vacuuming plot: Miller et al. 1989; Miller and Wylie 1996; visual modified line-transect: this study) studies, and if rates at which seeds were missed differed by sampling method then regional comparisons would be biased. Stafford et al. (2006) reported that 90% of waste rice seeds were recovered with soil cores. Although seed detection rates for the SACV studies are unknown, we assume they are similarly high and any regional bias in comparisons small.

Our estimates of postharvest waste rice seed mass-densities for the SACV are within the range reported for the MAV, but our estimates of waste seed mass-density remaining for wintering waterfowl are about 4–32 times the most recent estimates from the MAV (Table 2). Arrival of wintering waterfowl in the SACV is earlier than in the MAV, and large numbers of wintering waterfowl are present as SACV rice fields are being harvested and flooded (Heitmeyer et al. 1989). Thus, in SACV, the mass-density of rice available to waterfowl at the start of the wintering period is approximately equal to the mass-density of waste rice in fields immediately after harvest. In contrast, rice harvest in the MAV occurs about 2 wk earlier than in the SACV, and arrival of large numbers of wintering waterfowl is several weeks later than in SACV (Stafford et al. 2006). Thus, loss of rice seeds in MAV fields to nonwaterfowl consumers, decomposition, and germination is much greater than in the SACV, and rice densities available for wintering waterfowl are much lower than in the SACV; development of earlier maturing rice varieties has increased this loss in the MAV since the 1980s (Table 2).

Data limitations

Our study provides estimates of waste rice seed densities immediately after harvest. Although our estimates likely also accurately represent seed availability in flooded fields that do not receive any stubble treatment prior to being flooded, burning destroys some seeds and tillage (such as plowing) buries and greatly reduces seed availability in dry fields (Miller et al. 1989). Based on relatively high use by foraging waterfowl (Miller et al. 1989; Day and Colwell 1998), flooding apparently exposes or otherwise makes available at least some buried seeds to foraging waterfowl; however, additional research is needed to determine actual availability of seeds in flooded fields that have undergone preflooding tillage. Sampling dry fields is much easier than sampling flooded fields, so research that includes investigation of the relationship between postharvest waste rice mass-density immediately before and after flooding for fields treated with each postharvest tillage practice is recommended to possibly eliminate the need to again sample flooded fields when updated estimates are needed.

Additional research is needed to better understand annual variation in waste seed mass-density and rice harvest method related to harvest timing and other factors. Our 2010 study was conducted in a year of delayed rice harvest, and although timing of our sampling matched the long-term average progression of harvest (U.S. Department of Agriculture 2011) and was similar to timing of the 1985–1986 sampling (Miller et al. 1989), it did not match seasonal harvest progression as well (e.g., 1985–2010 average harvest completion by 1 November was 88%; percent sampling vs. percent harvest completed by 1 November was 93% vs. 75% in 2010, 88% vs. 85% in 1985, and 93% vs. 90% in 1986). Thus, our 2010 estimates do not include data from the greater than normal portion of fields harvested after early November, which may have different waste rice mass-density or harvest methods than do fields harvested during September–October.

We collected data on mass-density of rice seeds remaining on the ground during this study but used earlier above-ground estimates. These earlier estimates were appropriate for our use because the data were also collected in SACV rice fields immediately after harvest and the nearly identical above-ground rice seed mean mass-density estimates in the mid-1980s (Miller et al. 1989) and 2009 (B. Halstead, unpublished data) indicate no change among years. Thus, although our use of earlier data does not account for annual variability in above-ground mass-density, we are confident no significant bias was introduced into our estimates.

Implications for waterfowl

Our study shows that although most SACV fields are still harvested with conventional harvesters and most have similar mass-density of waste rice seed as did fields in the mid-1980s (Miller et al. 1989), stripper-head harvesting has reduced waste seed mass-density in about 18% of SACV fields (Table 1). However, the amount of waste rice actually available to each duck, goose, or swan varies not only with factors that impact the mass-density of waste rice seed in fields (e.g., harvester type [this study], depletion by nonwaterfowl seed eaters, loss to decomposition [Eadie et al. 2008]), but also with the total extent of rice fields, the total biomass of waterfowl competing for seeds, and factors that impact the accessibility of waste rice seeds to foraging waterfowl (e.g., postharvest flooding; Miller et al. 1989, 2010). Area of planted rice in the SACV was 52% greater in 2010 (220,477 ha) than in 1985–1986 (1985–1986 mean: 144,881 ha; U.S. Department of Agriculture 2011) resulting in 43% more waste rice in 2010 ([{220,477 ha × 0.177 stripped} × 245 kg/ha] + {[220,477 ha × 0.823 conventional} × 388 kg/ha] = 80.0 metric tons) than in 1985–1986 (144,881 ha × 386 kg/ha = 55.9 metric tons). During the same interval, the total mass of seed-eating waterfowl wintering in the SACV increased 82% from 1.90 metric tons in 1985–1986 to 3.45 metric tons in 2010 (calculated by multiplying midwinter abundance of each species [USFWS 1986,

Table 2. Comparison of the total waste rice mass-density (kg/ha) in Sacramento Valley (SACV) and Mississippi Alluvial Valley (MAV) fields during 1983–2010 immediately after harvest (Postharvest) and by the time large numbers of wintering waterfowl are first present in the region (Remaining for wintering waterfowl [Rem. for WW]). In the SACV, wintering waterfowl are abundant when fields are being harvested so "Postharvest" and "Rem. for WW" densities are assumed to be equal.

			Mean (95% CI[a]) rice mass-density (kg/ha)		
Period	Region (year)	Source	Conventional	Stripped	Overall
Postharvest	SACV (2010)	This study	388 (336–449)	245 (198–307)	364 (320–425)
	SACV (1993)	Miller and Wylie (1996)	—	344 (326–360)	—
	SACV (1985–1986)	Miller et al. (1989)	386 (376–396)	—	—
	MAV - Arkansas (2004)	Havens et al. (2009)	177 (122–232)[b]	—	—
	MAV (2003)	Kross et al. (2008)	—	—	304 (261–355)[c]
	MAV (2000–2002)	Stafford et al. (2006)	226 (160–292)	355 (259–452)	271 (203–338)
	MAV - Mississippi (1996)	Manley et al. (2004)	493 (352–634)	—	—
	MAV - Mississippi (1995)	Manley et al. (2004)	491 (327–655)	—	—
Rem. for WW	MAV - Arkansas (2004)	Havens et al. (2009)	35 (25–45)[b]	—	—
	MAV (2003)	Kross et al. (2008)	—	—	66 (51–85)[c]
	MAV (2000–2002)	Stafford et al. (2006)	85 (53–117)	68 (34–102)	78 (55–102)
	MAV - Mississippi (1996)	Manley et al. (2004)	12 (9–16)[d]	—	—
	MAV - Mississippi (1995)	Manley et al. (2004)	69 (46–92)[d]	—	—
	MAV - Arkansas (1984)	Reinecke et al. (1989)	140[e]	—	—
	MAV - Arkansas (1983)	Reinecke et al. (1989)	223[e]	—	—

[a] Presented values in parentheses are 95% confidence or credible intervals. Where necessary, confidence intervals were calculated from published sample sizes and standard errors using the *t* distribution.
[b] Values estimated from figure 2A in Havens et al. (2009).
[c] Found no difference in waste rice mass-density by harvest method and reported only an overall estimate.
[d] Values approximated by multiplying mean and confidence limits by the median percent decline for each year (86% in 1995 and 97.5% in 1996) in Manley et al. (2004).
[e] Based on nine fields in 1983 and eight fields in 1984; no variance estimate provided.

1987, 2011] by the proportion of each species' diet that the CVJV assumes is composed of seeds [1.0, except 0.7 for gadwall *Anas strepera* and American wigeon *A. americana,* 0.5 for northern shovelers *A. clypeata* and all diving ducks *Aythya* sp., and 0.0 for mergansers *Mergus* sp., *Lophodytes cucullatus;* CVJV 2006] and by the approximate mean body mass of each waterfowl species [calculated from Bellrose {1980} values assuming equal age and sex ratios]). Thus, 21% fewer grams of waste rice seed per gram of seed-eating duck, goose, and swan was present in SACV rice fields after harvest in 2010 (23.2 g rice/g waterfowl) than in 1985–1986 (29.4 g rice/g waterfowl). Postharvest flooding of SACV rice fields greatly increased during the same interval (Fleskes et al. 2005a; Miller et al. 2010). Based upon the greater improvement in body condition of rice-eating dabbling ducks than other SACV waterfowl (Fleskes et al. 2009; Thomas 2009), this increased flooding apparently improved dabbling duck access to waste rice seed and countered the impact of a smaller ratio of waste rice seed to seed-eating waterfowl mass.

Management Recommendations

Although the total amount of waste rice in the SACV has increased during the past 25 y, as data from the MAV and stripper-head harvested fields show, changes in crop genetics and agricultural practices can greatly impact the amount of waste rice seed that is available to waterfowl. For example, our data indicate that increased use of stripper-head harvesters would lower carrying capacity of SACV rice fields for wintering waterfowl and other birds. In addition, climate change, changes in water supply prioritization, urbanization, and other factors may impact water supplies and area of rice that is planted and flooded after harvest (Fleskes 2012). To provide accurate data on carrying capacity of the SACV that is necessary for informed conservation planning, trends in rice extent and agricultural practices should be tracked every few years and impacts of harvest method, postharvest field treatment (Miller et al. 2010), and other agricultural practices on waste rice seed availability should be investigated. Increased postharvest flooding could be used by managers to improve foraging conditions for dabbling ducks and counteract reductions in the amount of waste rice seed resulting from increased use of stripper-head harvesters, reduced rice extent, or other factors. However, habitat needs of other bird species that forage primarily in unflooded rice fields (Elphick and Oring 1998; Elphick 2004) should also be considered.

Supplemental Material

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Table S1. Microsoft Excel® file containing individual data sheets for 1985–1986, 1993, and 2010 data used in the analysis of rice seed mass-density remaining in fields after harvest in the Sacramento Valley, California. Data for 1985–1986 and 1993 consist of the year that data were collected; the field unique identifier; the plot identifier within each field; the harvester type that had been applied to each plot; and the mass density (kg/ha) of rice seeds on the ground, straw, and total for each plot. Data for 2010 consist of the year that data were collected, the field unique identifier, the plot identifier within each field, the sample identifier within each plot, the harvester type that had been applied to each plot, and the number of rice seeds counted on the ground in each sample.

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Found at DOI: http://dx.doi.org/10.3996/022012-JFWM-014.S6; also available at http://www.centralvalleyjointventure.org/assets/pdf/CVJV_Wintering_Waterfowl_Monitoring_Evaluation_Plan.pdf (370 KB PDF).

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