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ARTICLE

Changes in the Status of Harvested Rice Fields in the Sacramento Valley, California: Implications for Wintering Waterfowl

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Abstract Harvested rice fields provide critical foraging habitat for wintering waterfowl in North America, but their value depends upon post-harvest treatments. We visited harvested ricefields in the Sacramento Valley, California, during the winters of 2007 and 2008 (recent period) and recorded their observed status as harvested (standing or mechanically modified stubble), burned, plowed, or flooded. We compared these data with those from identical studies conducted during the 1980s (early period). We documented substantial changes in field status between periods. First, the area of flooded rice increased 4–5-fold, from about 15% to >40% of fields, because of a 3–4-fold increase in the percentage of fields flooded coupled with a 37–41% increase in the area of rice produced. Concurrently, the area of plowed fields increased from <22% to >35% of fields, burned fields declined from about 40% to 1%, and fields categorized as harvested declined from 22–54% to <15%. The increased flooding has likely increased access to food resources for wintering waterfowl, but this benefit may not be available to some goose species, and may be at least partially countered by the increase of plowed fields, especially those left dry, and the decrease of fields left as harvested. We encourage waterfowl managers to implement a rice field status survey in the Sacramento Valley and other North American rice growing regions as appropriate to support long-term monitoring programs and wetland habitat conservation planning for wintering waterfowl.

Keywords Field status · Flooded · Foraging habitat · Survey

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Introduction

Rice farming has displaced much of the original wetland habitats in major waterfowl wintering regions in North America (Eadie et al. 2008). Fortunately, however, winter-flooded ricelands function much like managed seasonal wetlands for wintering waterfowl and other waterbirds by providing foraging and roosting habitats in a reduced predator environment (Elphick 2000). As such, ricelands are indispensible components of waterbird habitat (Eadie et al. 2008). In particular, the rice seeds remaining in fields following harvest provide critical food for wintering dabbling ducks (tribe Anatini), diving ducks (tribe Aythyini), geese (tribe Anserini), and swans (tribe Cygnini) (Miller 1987; Heitmeyer 1989; Reinecke et al. 1989; Ackerman et al. 2006), as well as Sandhill Cranes (*Grus canadensis*) (Littlefield 2002) and other birds and wildlife (Eadie et al. 2008). Rice is vital to sustaining large wintering waterfowl populations in the Sacramento Valley of California (Miller et al. 1989; Miller and Newton 1999; Central Valley Joint Venture 2006). In the southeastern USA, recent studies have documented declines in the amount of rice seed available in harvested fields before wintering waterfowl arrive in the region (Manley et al. 2004; Stafford et al. 2006; Havens 2007; Greer et al. 2009), but sufficient food is apparently still available to partially support wintering populations (Manley et al. 2004; Kross et al. 2008; Greer et al. 2009).

Previous studies have documented the amount of rice remaining in harvested fields in the Sacramento Valley and other rice growing regions immediately after harvest, during late winter, or both (Miller et al. 1989; Miller and Wylie 1996; Manley et al. 2004; Stafford et al. 2006; Greer et al. 2009). The abundance of waste rice and use of harvested rice fields by waterfowl and other birds has been shown to vary based on post-harvest treatments, such as burning, plowing, and flooding, which might affect seed availability and foraging conditions (Heitmeyer 1989; Day and Colwell 1998; Littlefield 2002; Havens 2007; Kross et al. 2008). Miller et al. (1989) found 388 kg/ha in newly harvested fields, but this declined 30% after burning, the common post-harvest practice at that time in the Sacramento Valley (1985, 1986), and was especially low after plowing (<25 kg/ha). Kross et al. (2008) documented the greatest abundance of waste rice in Arkansas and Mississippi in standing stubble, followed by burned, mowed, rolled, and disked stubble. These various treatments potentially control the attractiveness to foraging waterfowl. In Arkansas, Havens (2007) documented that the greatest waterfowl densities occurred in rolled and burned ricefields that had been flooded. The extent of such treatments, especially purposeful (managed) flooding and plowing, might have landscape-level effects on waterfowl distribution (Fleskes et al. 2005b).

Miller et al. (1989) recorded post-harvest status of rice fields (either harvested with no further treatment, or burned, flooded, or plowed) in the Sacramento Valley using on-site field visits (OSFV) during midwinter of 1985 and 1986, and the California Waterfowl Association (Sacramento, CA) repeated the survey in 1988 (Day 1989). Subsequently, California passed the Connelly-Areias-Chandler Rice Straw Burning Reduction Act of 1991 (AB 1378, Ch. 787, 1991), which required a phased reduction in rice field burning over a 10-year period (1992–2001). As a result, the practice and purpose of flooding harvested rice fields expanded from the original objective of providing duck hunting (Miller et al. 1989) to include promoting rice straw decomposition in the absence of burning (Bird et al. 2000; Central Valley Joint Venture 2006:15).

Studies have attempted to estimate the changes in the extent of rice field flooding in the Sacramento Valley over time. Spell et al. (1995), using analysis of satellite imagery, found no change in the amount of flooded and dry fields between winters 1988–89 and 1993–94. A similar investigation showed a marked increase in flooded fields from 1993–94 to 1999–2000 (Fleskes et al. 2005a). However, in these studies, rice flooding included saturated soils, rain-puddled fields, and rain-flooded fields, as well as managed flooding. Using a different approach, Day (1997) and Day and Colwell (1998) used roadside surveys during autumn and winter of 1993–94 and 1994–95, and found that field plowing and flooding increased as burning declined between the 2 years. In another study, Ducks Unlimited (2000) contacted cooperating rice growers in the Sacramento Valley and found that they had flooded a modestly greater area of harvested rice from 1995 to 1999. Despite these efforts, precise changes in managed flooding practices and other post-harvest treatments by landowners, as they relate to waterfowl management in the Sacramento Valley, are not fully understood.

A rigorous assessment of the winter status of rice fields is needed to determine if the extent of managed post-harvest flooding, exclusive of rainfall and other treatments, have changed since the 1980s. Unlike the unpredictable puddling and flooding that occurs from winter rainfall (Day and Colwell 1998), the managed flooding of harvested rice fields for duck hunting and straw decomposition predictably and directly impacts the extent of wintering waterfowl habitat in the Sacramento Valley, even before the rainy season begins. Additionally, recent anecdotal evidence suggests that the amount of post-harvest plowing might be increasing (M. A. Wolder, U. S. Fish and Wildlife Service, Willows, CA, personal observations, 2005). Recent habitat planning of the Central Valley Joint Venture (Central Valley Joint Venture 2006) was based on rice habitat availability data from the previous studies (Miller et al. 1989; Day 1989). However, these data may no longer be valid if post-harvest treatments and associated availability of rice seed have changed. Any such changes would require revision of estimates of the extent of wetland and rice habitats required to sustain waterfowl population objectives. Therefore, during midwinters of 2007–08 (hereafter, 2007) and 2008–09 (hereafter, 2008), we repeated the Miller et al. (1989) OSFV protocol in the Sacramento Valley. Our objectives were to record post-harvest status of rice fields in midwinter, compare our results with those obtained during the 1980s, and discuss implications and make recommendations for waterfowl management.

Methods

The study area consisted of the eight major rice-growing counties in the Sacramento Valley (Fig. 1). These counties contained 87% of the total rice harvested statewide in 1985, 95% in 1986 and 1988, and 98% in 2007 and 2008 (National Agricultural Statistics Service 2009). In 1985, Miller et al. (1989) randomly selected 444 full sections (259 ha) of riceland allocated proportionately to the area (ha) of harvested rice among the eight counties (National Agricultural Statistics Service 2009), to ensure geographic representation. These investigators then randomly selected two 32.4–ha blocks from each of those sections as sample plots (n=888 plots). These plots formed the starting point

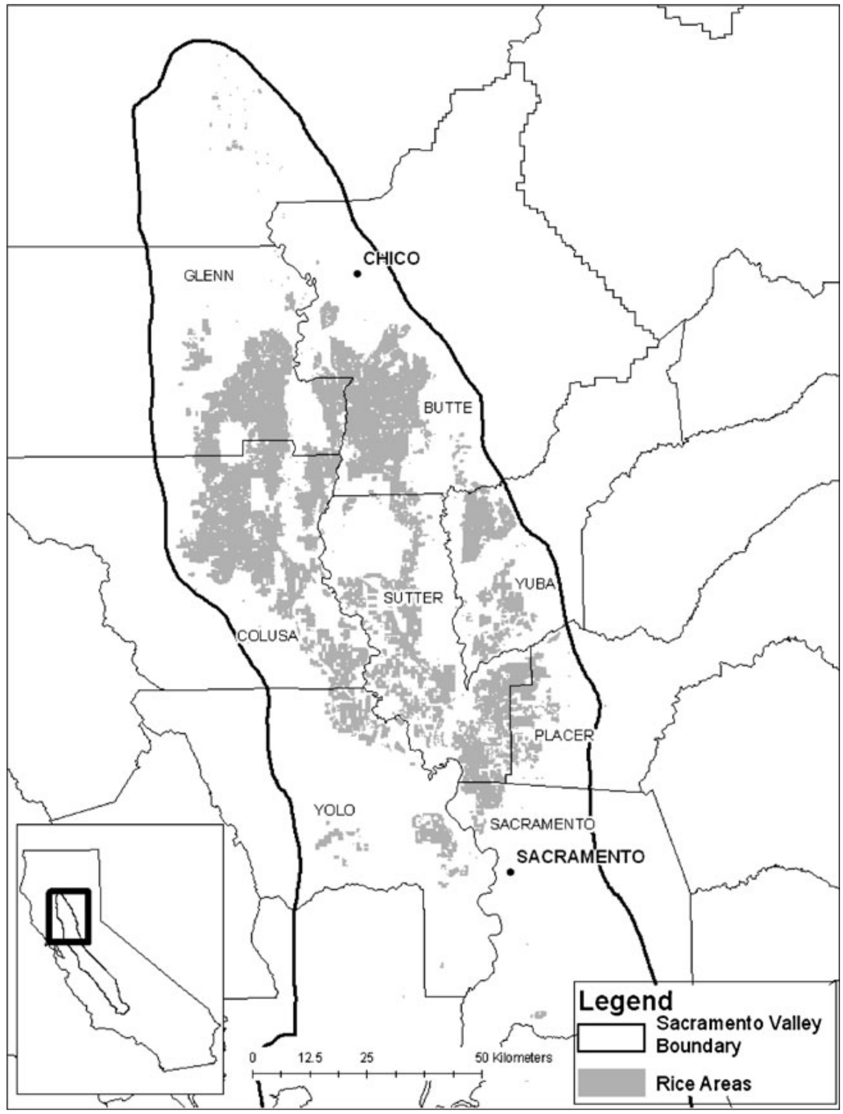

Fig. 1 The general area (gray) of rice agriculture in the eight major rice growing counties in the Sacramento Valley of California, where post-harvest treatments of rice fields were categorized during midwinter of 1985, 1986, 1988, 2007, and 2008 (adapted from Fleskes et al. 2005a)

for OSFV to assess status in 1985 and 1986 (Miller et al. 1989) and 1988 (Day 1989). Field work was generally conducted in December to mid-January each study year. This period was when field status had stabilized owing to completion of the harvest, cessation of burning and plowing, and complete flooding of duck clubs (Littlefield 2002).

In 1985, investigators visited all of the 32.4–ha sample plots during 10–25 December and recorded their status based on the most recent field treatment as: (1) Unharvested (dry); (2) Harvested (HRV; dry standing stubble); (3) Burned (BRN; harvested, dry stubble burned after harvest, otherwise untreated); (4) Plowed (PLW; harvested, dry; which includes plowing, disking, chiseling, and tilling [Day and Colwell 1998]); or (5) Flooded (FLD; harvested, flooded by landowners primarily for duck hunting, but not by rainfall, regardless of underlying treatments). Investigators assigned categories based on what the fields looked like when viewed from the ground—they did not record underlying treatments (e.g., FLD could have been plowed or burned prior to flooding), which usually could not be ascertained. If any given plot was in a crop other than rice, or if access difficulties precluded visiting a plot, then investigators assigned status to the closest plot available in an adjacent rice field. All fields during these early OSFV surveys had been conventionally harvested, as this was prior to the adoption of strip-harvesting (Miller and Wylie 1996). This protocol was repeated during 3–17 December 1986 (n=888 plots) and 5 December to 7 January 1988 (n=860 plots). The 1986 plots formed the basis of the 1988 survey (Day 1989), but plots rejected because of changes in land use or access issues were not replaced that year, and sample size declined to 860.

We followed the OSFV protocol to assess field status during 2007, but certain changes had occurred in field treatments since the 1980s. First, fields could have been harvested using either conventional or strip-harvest methods (Miller and Wylie 1996). Second, FLD fields could result from landowner flooding primarily for straw decomposition, not duck hunting. Third, the acreage of rice plantings increased markedly (National Agricultural Statistics Service 2009). Fourth, by 2007, many plots had changed permanently to urban (1.8% of all fields), orchard (3.3% of all fields), or wetland (1.9% of all fields). We did not replace any of these plots, which resulted in a reduced sample size (n=841). Fifth, chopping and baling were introduced as field treatments. We included both of these in the HRV category, and we accounted for baling as a subset of HRV fields. In year 2008, we increased the number of plots (n=988) and replaced any land uses other than rice with sample plots in the closest rice fields. We visited plots from 3 December 2007 to 16 January 2008 and 1 December 2008 to 22 January 2009. We obtained the extent of rice (ha) harvested in each sampled county each year from the National Agricultural Statistics Service (2009), except we used the Sacramento County Crop and Livestock Report for 2008 (Sacramento County 2008), and summed these for Sacramento Valley annual totals.

Statistical Analyses

We evaluated changes in post-harvest ricefield status (i.e., field treatment; TRT) over time using generalized linear mixed models (GLMM) (Zuur et al. 2009). We specified the binomial distribution. A separate analysis was conducted for each TRT using a discrete response. For example, if the analysis focused on FLD, then the model was:

$$\mathrm{Logit}(p_{\mathrm{ijk}}) = \beta_0 + \beta_1 \times \mathrm{PER}_{ijk} + u_{0j}(\mathrm{CO}) + u_{0k}(\mathrm{YR}) + e_{ijk},$$

where the response variable was coded as 1 if plot i within county (CO) j and year (YR) k was FLD and coded as 0 for all other treatments (e.g., BRN, HRV, or PLW). To detect changes in post-harvest treatment since the 1980s, we evaluated the coefficient for the fixed effect (β_1) (period; PER), which consisted of 2 categories: Early (1985, 1986, and 1988) and Recent (2007 and 2008) periods. The other part of the mixed effects model was the random variance components (Zuur et al. 2009). Specifying random effects is necessary to account for variation in the error that may otherwise confound fixed effects (Faraway 2006). We included a random component that accounted for the spatial clustering of sample fields. For example, TRT at a given plot may influence the decisions for TRT at nearby plots. Therefore, to account for potential spatial clustering, we fit a random intercept to county (u_{0j}). The county was the most appropriate level for classification based on differences in TRT by county (Miller et al. 1989) that probably reflected farming practices within counties (e.g., culture and politics). We also specified a random term for year (u_{0k}) to represent the repeated sampling and reduce potential bias associated with psuedoreplication within periods. These random effects, (u_{0j}) and (u_{0k}), indicate the deviation of higher-level unit averages (e.g., county and year averages) from the overall intercept. For example, an increase in the variance component for county indicates an increase in the difference between intercepts fit to each county.

We assessed model fit and evaluated evidence of support from the data using an information theoretic approach. We calculated Akaike's Information Criterion (AIC; Akaike 1973), with a second-order bias correction (AICc), and model weights (w; Anderson 2008), as well as likelihood ratio tests with maximum likelihood estimation. The analyses consisted of fitting and comparing two models to each other for each treatment: the mixed effects model and a random effects model. The mixed model consisted of the fixed effect (PER) and the random effects (CO and YR). The random effects models consisted of only the random effects and did not include the fixed effect. We considered the random effects model a null model. We reported the parameter estimates (i.e., coefficients) and their standard errors. If the mixed effects model fit better than the null model for each PER, we used the parameter estimates to calculate the odds (with 95% confidence limits) of increase or decrease for each TRT between early and late periods. In all analyses, we carried out the parameter estimation and model fit using package lme4 (Bates et al. 2008) for Program R (R Development Core Team 2008).

Results

Flooded Fields The model that included the fixed effect of PER for changes in FLD over time had substantial support ($w_{\mathrm{model\ 1}}$=1.0, Table 1) over the null ($w_{\mathrm{model\ 2}}$). The odds of a sample plot flooded in the recent years was 8.2 (95% CI=5.8–11.5) times greater than the odds of FLD in the early years, calculated using the model coefficient (2.10± 0.17). Confidence intervals did not include 0. The percentage of FLD fields increased from about 15% during the early period to over 50% in 2007, then declined to 43% in 2008 (Table 2). The extent of FLD fields ranged from 20,625 to 24,405 ha in the 1980s, but then increased 4–5-fold to 109,475 ha in 2007 and 88,005 ha in 2008. This increase resulted from the increased percentages of fields flooded together with a 37–41% increase in harvested area compared to the 1980s (early $\bar{x} = 149,270$ ha; recent $\bar{x} = 207,595$ ha) (Table 2).

Plowed Fields The model that included the fixed effect of PER for changes in PLW fields over time was

Table 1 Analysis of information criteria assessing generalized linear mixed models to evaluate changes in the midwinter status of harvested ricefields in the Sacramento Valley of California between early (1985–86, 1988) and recent (2007–08) periods

Data set[a]	No.	Specification[b]	K	LL	ΔAIC_C	w	χ^2	P
Flooded	1	Period	3	−72.5	0.0	1.00	15.6	<0.001
	2	Null	2	−80.5	13.1	0.00		
Plowed	3	Period	3	−74.3	0.0	0.88	5.4	0.011
	4	Null	2	−77.6	4.0	0.12		
Burned	5	Period	3	−62.2	0.0	0.99	13.8	<0.001
	6	Null	2	−69.2	11.3	0.01		
Harvested	7	Period	3	−110.5	0.0	0.85	6.03	0.014
	8	Null	2	−113.6	3.5	0.15		

K number of model parameters; *LL* log-likelihood value; *ΔAIC* difference in AIC units between model of interest and the most parsimonious model; *w* model probability (Anderson 2008). χ^2 values assess model fit

[a] Flooded, plowed, burned, and harvested were separate data sets (e.g., the response value for the flooded data set was 1 = flooded, and 0 = all other treatments)

[b] Period represents a mixed effects model that consisted of the fixed period effect (early=1985, 1986 and 1988, and recent=2007 and 2008) and a random intercept for county and repeated measurements between years. The null model consisted of only the random effects (county and year). Binomial distribution was specified

supported ($w_{\text{model 3}}$=0.88, Table 1) and was 7.3 times ($w_{\text{model 3}} \div w_{\text{model 4}}$) more likely to be better than the null model ($w_{\text{model 4}}$). Using the model coefficient (0.98± 0.25), the odds of a PLW in recent years was 2.7 (95% CI=1.61–4.39) times greater than the odds in earlier years. Confidence intervals did not include 0. The percentage of fields classified as PLW ranged from 14% to 22% during the 1980s, but this increased to 36% in 2007 and 42% in 2008 (Table 2).

Burned Fields The model that included the fixed effect of PER for changes in BRN fields ($w_{\text{model 5}}$=0.99; Table 1) over time was substantially stronger than the null ($w_{\text{model 6}}$). The odds of BRN in the earlier years was 29.1 (95% CI=12.86–65.74) times greater than recent years, calculated using the model coefficient (−3.37±0.42). Confidence intervals did not include 0. Burned fields made up the largest percentage of fields during 1985 and 1986, but then declined markedly in 1988 and nearly disappeared in 2007 and 2008 (Table 2).

Harvested Fields with No Subsequent Treatment The model that included the fixed effect PER for changes in HRV fields over time was strongly supported ($w_{\text{model 7}}$= 0.85; Table 1) and was 5.7 times ($w_{\text{model 7}} \div w_{\text{model 8}}$) more likely to be better than the null model ($w_{\text{model 8}}$). The odds of HRV in the earlier years was 3.61 (95% CI=1.75– 7.45) times greater than recent years, calculated using the model coefficient (−1.28±0.37). Confidence intervals did not include 0. From about one-quarter to one-third of fields

Table 2 The percentage (SE among counties) distribution of harvested rice fields (plots) by post-harvest treatment by year as determined with on-site field visits during December–January, and total harvested and flooded hectares of harvested rice in the Sacramento Valley, California

		Percentage				Total ha harvested	Total ha flooded
Year	Plots	Flooded	Burned	Harvested[a]	Plowed		
1985	888	14 (6.5)	38 (3.8)	34 (5.8)	14 (3.0)	147,310	20,625
1986	888	16 (6.4)	40 (5.3)	22 (4.4)	22 (3.6)	137,800	22,045
1988[b]	860	15 (5.1)	18 (3.9)	54 (4.8)	13 (2.7)	162,690	24,405
2007[c]	841	52 (9.3)	1 (0.7)	11[d] (2.3)	36 (8.2)	210,525	109,475
2008	988	43 (8.8)	1 (0.4)	14[e] (3.2)	42 (7.9)	204,660	88,005

[a] These fields remained harvested with no further treatments, except could be chopped, mowed

[b] An additional 4 plots remained Unharvested (856+4 unharvested=860)

[c] One additional plot remained Unharvested (840+1 unharvested=841)

[d] Includes 3% baled

[e] Includes 5% baled

remained HRV in 1985 and 1986, but this increased to over 50% in 1988, only to decline to 11% in 2007 and 14% in 2008 (Table 2). Baling was not used as a treatment during the 1980s, and we classified only 3% of fields as baled, a category of HRV, in 2007 and 5% in 2008. No sample rice field plots remained unharvested during 1985, 1986, or 2008, but 4 remained so in 1988 and one in 2007.

Discussion

Implications for Wintering Waterfowl

Increased Field Flooding Rice growers have fundamentally changed land management practices in harvested rice fields in the Sacramento Valley subsequent to burn restrictions that went into effect in autumn of 1992. As a result, large scale consequences for waterfowl have occurred across the rice growing landscape, the most important of which have been the sharp increases in FLD and PLW fields concurrent with the decline of HRV and near disappearance of BRN fields. In 2007, flooding covered an estimated 109,475 ha of harvested rice, representing a percentage of the rice landscape that occurred only in Yuba County during the 1980s (nearly 60%), where duck hunting clubs have traditionally flooded large tracts (Miller et al. 1989). On a wider scale, this magnitude of flooding throughout the rice growing region in the early period would only have occurred in late winter after sustained heavy precipitation and local stream flooding partially or completely filled fields for variable lengths of time.

Increased flooding of harvested rice provides an obvious habitat benefit to wintering ducks (Elphick and Oring 1998; Day and Colwell 1998; Elphick and Oring 2003). In fact, the increased flooding of rice fields in the Sacramento Valley has been associated with major shifts in the distribution of wintering ducks, geese, and swans from other regions in the greater Central Valley to the Sacramento Valley (Fleskes et al. 2005b). Importantly, this vast expanse of flooded rice has apparently increased body mass of wintering Northern Pintails (*Anas acuta*) and American Wigeon (*A. americana*), and likely Northern Shovelers (*A. clypeata*), because of the increased access to food supplies including rice seed (Thomas 2009). This is consistent with a concurrent increase in the survival rate of wintering Northern Pintails (Fleskes et al. 2007), likely caused by the greater body mass and reduced natural mortality associated with the extensive riceland flooding creating a food-rich environment with fewer avian predators than in marshlands (Elphick 2000; Elphick 2004). Tundra Swans (*Cygnus columbianus*) and Greater White-fronted Geese (*Anser albifrons frontalis*) also benefit from the expanded availability of food resources and undisturbed roosting areas in flooded fields because these species use flooded or dry rice fields for foraging (Elphick and Oring 1998; Day and Colwell 1998; Ackerman et al. 2006). However, the same might not be true for Lesser Snow (*Chen caerulescens*) and Ross' Geese (*C. rossii*). These species, together termed white geese, tend to favor feeding in HRV fields (Hobaugh 1984; Day and Colwell 1998).

Increased Plowing Experimentation by rice growers with post-harvest straw treatments may have led to the increased plowing since the 1980s. Plowing reached a greater level in 2008 than 2007, both of which exceeded any level documented during the 1980s. Importantly, we note that our estimates of the extent of PLW fields are minimums because many FLD fields could have been plowed prior to flooding.

The relatively large increase of PLW fields, with no follow-on flooding, should concern waterfowl managers. Dry plowed fields are avoided by Lesser Snow and Greater White-fronted Geese (Hobaugh 1984; Leslie and Chabreck 1984; Day 1997), and ducks (Day and Colwell 1998; Havens 2007). Early plowing probably does not benefit wintering waterfowl, because potentially available rice seed could be buried below the reach of foraging birds (Miller et al. 1989; Havens 2007; Kross et al. 2008), as shown for field corn (Baldassarre et al. 1983). If this occurs, the abundance of available rice seeds likely occurs below a required threshold needed to sustain foraging activity (50 kg/ha; Baldassarre and Bolen 1984; Reinecke and Loesch 1996; Greer et al. 2009). In support of this idea, PLW rice has been shown to be the least-used ricefield habitat of wintering Sandhill Cranes in the Sacramento Valley (Littlefield 2002) and waterfowl in Arkansas (Havens 2007). Additionally, seeds may be available in PLW fields, but could be more difficult to obtain, causing waterfowl to forage where feeding efficiency is greater.

Rice seed is relatively resistant to deterioration when submerged (Nelms and Twedt 1996), but deterioration does occur (Greer et al. 2009), and the effects of plowing on such deterioration is not known. All the seeds must still be present following plowing, even if at increased depths, and these fields do receive high use when they are flooded (Miller et al. 1989; Day and Colwell 1998). This attraction suggests that an unknown percentage of rice seed must remain within reach, perhaps down to about 10 cm based on sampling depths used in the southeastern USA (Manley et al. 2004). Field sampling in that region typically documents far lower rice seed densities than in California (Miller et al. 1989; Miller and Wylie 1996; Stafford et al. 2006; Kross et al. 2008; Greer et al. 2009). Whether or not this difference between regions was related to the 10-cm sampling depths and the potential for additional seed to be even deeper in the soil, is not known. Waterfowl foraging in flooded PLW fields could be consuming invertebrates or other seeds, a common late winter activity (Miller 1987; Manley et al. 2004). Roosting would likely not be affected by flooded fields having been plowed first (Elphick and Oring 1998).

Plowing may have been applied to post-harvest rice to a greater extent in 2007 and 2008 than otherwise would have occurred, because a smaller amount of water was expected to be available for fall flooding. The previous winters were very dry, resulting in poor snow packs (California Department of Water Resources 2008), which forced the State of California to consider reducing agricultural water deliveries to protect Sacramento-San Joaquin River Delta water quality. Ultimately, the state did not restrict water delivery in 2007, but the decision was too late to affect field management plans already adopted by some water districts, and the directive likely caused landowners to flood fewer fields, which contributed to the marked increase in plowing. In the subsequent winter, a water delivery restriction imposed in May 2008 was lifted on 15 November 2008 after early November rains (California State Water Resources Control Board 2008). But again, the restriction probably contributed to the increased plowing in 2008. These incidents demonstrate the sensitivity of water availability for fall flooding to the amount of stored water available in dry years. The increased plowing could also have reflected real estate development pressures (California Department of Conservation 2008) and endangered species issues in some Sacramento Valley counties (Natomas Basin Conservancy 2003; Manley et al. 2008).

Decline of Burned Fields The substantial reduction of BRN fields has reduced a favored foraging habitat of wintering waterfowl (Day 1997; Day and Colwell 1998; Havens 2007). In the late 1980s and early 1990s, Greater White-fronted Geese used BRN fields preferentially in the Sacramento Valley compared to other treatments (Ackerman et al. 2006). Day and Colwell (1998) found that several waterfowl and waterbird species commonly used BRN fields, whether dry, puddled, or flooded. Furthermore, Cackling Geese (*Branta hutchinsii minima*) only used dry BRN fields, which at that time accounted for about 25% of all fields. Perhaps coincidentally, the decline in the availability of BRN fields coincided with the near complete shift of Cackling Geese to the Willamette Valley, Oregon (M. A. Wolder, U.S. Fish and Wildlife Service, Willows, CA, unpublished midwinter inventory data). Geese, ducks, and other birds are rapidly attracted to BRN fields in the Sacramento Valley (Littlefield 2002), just as Lesser Snow Geese respond to burned brackish marsh (Bateman et al. 1988). The reason for preferred use of BRN fields, flooded or dry, likely is the easy accessibility of seeds that are exposed as the result of fire having removed the straw (Havens 2007), even though the amount of seed is reduced (Miller et al. 1989). The long-term effect on wintering geese of the reduction of BRN fields is not known. Ackerman et al. (2006) reported that in the late 1990s, Greater White-fronted Geese switched to FLD ricefields as burning declined. We suspect that the rate of burning will not change markedly in the future.

Decline in Fields Left Harvested (HRV) Harvested fields, with standing, chopped, or mowed stubble, have been shown to be critical waterfowl food sources in their own right (Day 1997; Day and Colwell 1998). These fields often retain a larger number of rice seeds than fields with the other postharvest treatments (Kross et al. 2008). This field type, especially with standing as opposed to chopped stubble, is preferred by Greater White-fronted Geese (Day 1997), and is used most frequently by Sandhill Cranes, supporting 58–72% of all use-days in the Sacramento Valley (Littlefield 2002). Rice in HRV fields also provides new foraging opportunities for waterfowl when winter rains puddle or flood the fields in mid to late winter (Day and Colwell 1998), a time when fields purposefully flooded earlier in the year might not retain enough rice seed to sustain continued foraging (Hobaugh 1984; Reinecke and Loesch 1996; Greer et al. 2009). Unfortunately, the increased managed flooding and plowing in the recent period is leaving a relatively small area of HRV fields available for enhancement by late season rains. The survival of the HRV status category likely depends on trends of the other categories, especially flooding and plowing. The importance of HRV fields to wintering waterfowl needs further study.

Our data suggest that rice straw baling might be increasing in the Sacramento Valley, and our estimate of the rate of baling is likely biased low because FLD and PLW fields could have been baled prior to these respective treatments. Baling is being studied as a means to reduce green house gas emissions (California Rice Commission 2009), and findings of these studies could lead to a substantial increase in baling. This should be of concern to waterfowl managers because bales likely contain seeds that might otherwise be available to foraging waterfowl (Miller et al. 1989). We included chopped and mowed fields under the HRV category because we assumed that the seeds would remain on the soil surface after the treatments. However, given the physical change to the fields, more work is needed to determine how these treatments might affect waterfowl use in the Sacramento Valley. In the southeastern USA, Havens (2007) found that rolling fields increased their attractiveness to mallards (*Anas platyrhynchos*), whereas mowing discouraged use.

Comparison of Data Sources for Flooded Ricelands

All studies have indicated increasing trends in the extent of rice field flooding in the Sacramento Valley since the 1980s. Our 2007 estimate is almost 40% greater than the 78,841 ha flooded area reported for winter 1999–2000 (Fleskes et al. 2005a) and nearly 90% greater than the 57,700 ha reported for winter 1993–94 (Spell et al. 1995). These differences reflect specific study purposes and methods used. For example, in 1988, the only year that direct comparisons can be made, our OSFV method yielded an estimated 24,405 ha of FLD fields for the 8-county area, less than half the 53,816 ha estimated by Spell et al. (1995) using satellite imagery that year. The disparity occurred because Spell et al.'s (1995) purpose was to account for moisture caused by precipitation as well as managed flooding, and even included fields with saturated soils. In contrast, the studies of Day (1989), Miller et al. (1989), Ducks Unlimited (2000), and our 2007 and 2008 surveys, only tallied managed flooding in an effort to better guide future conservation activities. The regions covered by the OSFV and satellite imagery surveys both included the vast majority of rice grown in California, and the small difference would not have influenced estimates of flooding extent. For example, the extent of rice planted in 1988 was estimated at 163,589 ha by Spell et al. (1995), very close to our estimate of 162,690 ha harvested, which tends to be somewhat less than the area planted, that year (National Agricultural Statistics Service 2009).

Management Implications

We encourage rice growers to forego deep disking or plowing of HRV fields, instead leaving them intact through the winter to provide needed late winter rain-flooded habitats for waterfowl, and dry field foraging opportunities for geese and Sandhill Cranes. We also suggest flooding rice fields that have been plowed. Perhaps landowner incentives could be implemented by appropriate partners of the Central Valley Joint Venture to accomplish these objectives. Research that examines relationships between harvest method (conventional and strip) (Miller and Wylie 1996; Stafford et al. 2006; Kross et al. 2008), post-harvest treatment, and rice availability would help inform post-harvest treatment decisions to benefit foraging opportunities for wintering waterfowl (Elphick and Oring 1998). We recommend that the Central Valley Joint Venture incorporate operational post-harvest rice field status surveys into the continuing assessment of food resources available to wintering waterfowl to better support wetland and agricultural land conservation planning activities. Our field status assessment method could be examined for application to other rice growing regions in North America.

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References

Ackerman JT, Takekawa JY, Orthmeyer DL, Fleskes JP, Yee JL, Kruse KL (2006) Spatial use by wintering greater white-fronted geese relative to a decade of habitat change in California's Central Valley. Journal of Wildlife Management 70:965–976

Akaike H (1973) Information theory and an extension of the maximum likelihood principle. In: Petrov BN, Csaki F (eds) Second International Symposium on Information Theory. Akademiai Kiado, Budapest, pp 267–281

Anderson DR (2008) Model based inference in the life sciences: a primer on evidence. Springer, New York

Baldassarre GA, Bolen EG (1984) Field-feeding ecology of waterfowl wintering on the southern high plains of Texas. Journal of Wildlife Management 48:63–71

Baldassarre GA, Whyte RJ, Quinlan EE, Bolen EG (1983) Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildlife Society Bulletin 11:25–31

Bateman HA, Joanen T, Stutzenbaker CD (1988) History and status of midcontinent snow geese on their Gulf Coast winter range. In: Weller MW (ed) Waterfowl in winter. University of Minnesota Press, Minneapolis, pp 495–516

Bates D, Maechler M, Dai B (2008) Lme4: linear mixed-effects models using S4 classes. R package version 0.99375-27. Available via DIALOG. http://lme4.r-forge.r-project.org/. Accessed 31 August 2009

Bird JA, Pettygrove GS, Eadie JM (2000) The impact of waterfowl foraging on the decomposition of rice straw: mutual benefits for rice growers and waterfowl. Journal of Applied Ecology 37:728–741

California Department of Conservation (2008) Farmland mapping and monitoring program. Division of Land Resource Protection. Available via DIALOG. http://redirect.conservation.ca.gov/DLRP/fmmp?product?page.asp Accessed 5 August 2009

California Department of Water Resources (2008) California cooperative snow surveys, DWR Bulletin 120, February 2008. Available via DIALOG. http://cdec.water.ca.gov/snow/bulletin120/ Accessed 5 August 2009

California Rice Commission (2009) CRC moves forward to prepare for climate change regulations. California Rice Commission Newsletter 11, No. 3. Sacramento, CA. Available via DIALOG. http://www.calrice.org/e2_news.htm Accessed 5 August 2009

California State Water Resources Control Board (2008) End of Term 91diversion curtailments in 2008. State Water Resources Control Board, Nov 18, 2008, item 13–executive director's report. Available via DIALOG. http://www.waterboards.ca.gov/board_info/minutes/2008/november/111808_item13_exec_rpt.pdf Accessed 5 August 2009

Central Valley Joint Venture (2006) Central Valley Joint Venture Implementation Plan—Conserving bird habitat. U.S. Fish and Wildlife Service, Sacramento, CA. Available via DIALOG. http://www.centralvalleyjointventure.org/plans Accessed 17 August 2009

Day JH (1989) Rice field status 1988. Unpublished report. California Waterfowl Association, Sacramento

Day JH (1997) Fall and winter use of harvested rice fields by Pacific Flyway white-fronted geese (*Anser albifrons*). Thesis, California State University

Day JH, Colwell MA (1998) Waterbird communities in rice fields subjected to different post-harvest treatments. Colonial Waterbirds 21:185–197

Ducks Unlimited (2000) Winter-flooded rice acres expand. Valley-Bay Care, Issue 25, Spring 2000. Ducks Unlimited Inc, Sacramento

Eadie JM, Elphick CS, Reinecke KJ, Miller MR (2008) Wildlife values of North American ricelands. In: Manley SW (ed) Conservation in ricelands of North America. The Rice Foundation, Stuttgart, pp 7–90

Elphick CS (2000) Functional equivalency between rice fields and seminatural wetland habitats. Conservation Biology 14:181–191

Elphick CS (2004) Assessing conservation trade-offs: identifying the effects of flooding rice fields for waterbirds on non-target bird species. Biological Conservation 117:105–110

Elphick CS, Oring LW (1998) Winter management of Californian rice fields for waterbirds. Journal of Applied Ecology 35:95–108

Elphick CS, Oring LW (2003) Conservation implications of flooding rice fields on winter waterbird communities. Agriculture, Ecosystems & Environment 94:17–29

Faraway JJ (2006) Extending the linear model with R: generalized linear, mixed effects and nonparametric regression models. Chapman and Hall, Boca Raton

Fleskes JP, Perry WM, Petrik KL, Spell R, Reid F (2005a) Changes in area of winter-flooded and dry rice in the northern Central Valley of California determined by satellite imagery. California Fish and Game 91:207–215

Fleskes JP, Yee JL, Casazza ML, Miller MR, Takekawa JY, Orthmeyer DL (2005b) Waterfowl distribution, movements, and habitat use relative to recent habitat changes in the Central Valley of California: A cooperative project to investigate impacts of the Central Valley Joint Venture and changing agricultural practices on the ecology of wintering waterfowl. Final report. US Geological Survey, Western Ecological Research Center, Dixon Field Station, Dixon, CA

Fleskes JP, Yee JL, Miller MR, Casazza ML (2007) Pintail and mallard survival in California relative to habitat, abundance, and hunting. Journal of Wildlife Management 71:2238–2248

Greer DM, Dugger BD, Reinecke KJ, Petrie MJ (2009) Depletion of rice as food of waterfowl wintering in the Mississippi Alluvial Valley. Journal of Wildlife Management 73:1125–1133

Havens JH (2007) Winter abundance of waterfowl, waterbirds, and waste rice in managed Arkansas rice fields. Thesis, Mississippi State University

Heitmeyer ME (1989) Agricultural/wildlife enhancement in California: the Central Valley Habitat Joint Venture. Transactions of the North American Wildlife and Natural Resources Conference 54:391–402

Hobaugh WC (1984) Habitat use by snow geese wintering in southeast Texas. Journal of Wildlife Management 48:1085–1096

Kross JP, Kaminski RM, Reinecke KJ, Pearse AT (2008) Conserving waste rice for wintering waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 72:1383–1387

Leslie JC, Chabreck RH (1984) Winter habitat preference of white-fronted geese in Louiasiana. Transactions of the North American Wildlife and Natural Resources Conference 49: 519–526

Littlefield CD (2002) Winter foraging habitat of greater sandhill cranes in northern California. Western Birds 33:51–60

Manley SW, Kaminski RM, Reinecke KJ, Gerard PD (2004) Waterbird foods in winter-managed ricefields in Mississippi. Journal of Wildlife Management 68:74–83

Manley SW, Rodrigue PB, Mutters RG, Bollich PK (2008) Conserving water quality and quantity in North American ricelands. In: Manley SW (ed) Conservation in ricelands of North America. The Rice Foundation, Stuttgart, pp 119–159

Miller MR (1987) Fall and winter foods of northern pintails in the Sacramento Valley, California. Journal of Wildlife Management 51:405–414

Miller MR, Newton WE (1999) Population energetics of northern pintails wintering in the Sacramento Valley, California. Journal of Wildlife Management 63:1222–1238

Miller MR, Wylie GD (1996) Preliminary estimate of rice present in strip-harvested fields in the Sacramento Valley, California. California Fish and Game 82:187–191

Miller MR, Sharp DE, Gilmer DS, Mulvaney WR (1989) Rice available to waterfowl in harvested fields in the Sacramento Valley, California. California Fish and Game 75:113–123

National Agricultural Statistics Service (2009) US Department of Agriculture, archived data. Available via DIALOG. http://www.nass.usda.gov/Statistics_by_State/California/index.asp Accessed 5 August 2009

Natomas Basin Conservancy (2003) Final Natomas Basin Habitat Conservation Plan, July 2003. City of Sacramento, Sutter County, and The Natomas Basin Conservancy, July 2003. Available via DIALOG. http://www.natomasbasin.org/content/new/144/118/ Accessed 18 August 2009

Nelms CO, Twedt DJ (1996) Seed deterioration in flooded agricultural fields during winter. Wildlife Society Bulletin 24:85–88

R Development Core Team (2008) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Reinecke KJ, Loesch CR (1996) Integrating research and management to conserve wildfowl (Anatidae) and wetlands in the Mississippi Alluvial Valley, USA. Gibier Faune Sauvage, Game Wildlife 13:927–940

Reinecke KJ, Kaminski RM, Moorehead KJ, Hodges JD, Nassar JR (1989) Mississippi Alluvial Valley. In: Smith LM, Pederson RL, Kaminski RM (eds) Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, pp 203–247

Sacramento County (2008) Sacramento County Crop and Livestock Report. Sacramento, CA, USA. Available via DIALOG. http://www.agcomm.saccounty.net/cropandlivestockreports/default.htm Accessed 24 August 2009

Spell R, Kempka R, Reid F (1995) Evaluation of winter flooding of ricelands in the Central Valley of California using satellite imagery. In: Campbell KL (ed) Versatility of wetlands in the agricultural landscape. American Society of Agricultural Engineers, 17–20 September 1995, Tampa, FL, pp 357–366

Stafford JD, Kaminski RM, Reinecke KJ, Manley SW (2006) Waste rice for waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 70:61–69

Thomas DR (2009) Assessment of waterfowl body condition to evaluate the effectiveness of the Central Valley Joint Venture. Thesis, University of California

Zuur AF, Leno EN, Walker NJ, Saveliev AA, Smith GM (2009) Mixed effects models and extensions in ecology with R. Springer, New York