

# Winter management of Californian rice fields for waterbirds

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## Summary

1. Recent legislation designed to reduce air pollution has restricted Californian rice-farmers from burning rice stubble after harvest. Intentional flooding of fields during winter to speed straw decomposition is becoming increasingly common as growers seek alternatives to burning residual straw. The potential for flooded fields to act as a surrogate for destroyed wetland habitat may be an additional benefit in a region that hosts a large proportion of North America's wintering waterbirds. We investigated the degree to which waterbirds use flooded fields and whether the method of flooding affects their use. Specifically, we tested whether waterbird use (a) was greater in intentionally flooded fields than in unflooded fields, (b) differed among flooded fields receiving different straw manipulations and (c) varied with water depth.

2. Intentionally flooded rice fields received significantly greater use by 24 of 31 species studied. Only great blue herons *Ardea herodias* and sandhill cranes *Grus canadensis* were significantly more common in unflooded fields. Geese densities did not differ between flooded and unflooded fields.

3. We found no differences in the densities of most species in flooded fields that received different straw manipulations to improve decomposition rates. Exceptions included several small shorebirds which occurred at highest densities in fields where straw was incorporated into the soil.

4. Species differed in their use of different water depths. For 14 species we tested whether preferred depths, suggested in the literature, received disproportionately higher use. Most of these species were more likely to be encountered within the suggested depth ranges. Depth, however, was a poor predictor of bird density. Depths of 15–20 cm resulted in frequent use by the greatest number of species.

5. We conclude that flooding rice fields increased suitable habitat for most, but not all, species studied. Different straw manipulation methods had little effect on most species. Water depth, however, was important in determining species occurrence. During the first half of the winter, water depths were greater than the median depths used by most species.

*Key-words:* agriculture, shorebirds, waterfowl, water depth, wetland management.

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## Introduction

Worldwide, aquatic ecosystems are being destroyed and altered at an increasing rate. In the conterminous United States, more than half of all wetlands have been lost in the last two centuries (Tiner 1984; Dahl 1990; National Research Council 1992), primarily through draining for agriculture (Wilén 1989). Declines in waterfowl populations, and the growing recognition of the biological and economic value of wetlands, have led to increasing concern about these

losses in North America (e.g. Canadian Wildlife Service/US Fish and Wildlife Service 1986; Sharitz & Gibbons 1989; Smith, Pederson & Kaminski 1989; Bildstein *et al.* 1991; Finlayson & Moser 1991). This concern has resulted in the creation of a variety of programmes to protect extant wetlands, primarily through acquisition by government agencies and non-profit conservation groups. While these efforts have preserved numerous sites and enabled restoration at others, they have not prevented a net loss of wetland habitat nor continued declines of wildlife populations

(Payne & Wentz 1992). Reversing these trends therefore will probably require providing suitable wetland habitats on privately owned land (Payne & Wentz 1992). Successful development of such strategies is contingent on land management practices that maximize benefits for wildlife in ways compatible with the primary use of private lands.

Wetland losses in California have been particularly great, with only 9% of the wetlands that existed in the 1780s remaining (Dahl 1990; National Research Council 1992). The majority of these losses have occurred in the Central Valley of California where over a million hectares of aquatic habitat are estimated to have been drained, primarily for agricultural use (Frayer *et al.* 1989). For many species of waterbirds, the Central Valley is the major wintering area in western North America. More than 40 million waterfowl are estimated to have used the region in the past, although numbers now are reduced to 3 000 000–6 000 000 birds (Heitmeyer, Connelly & Pederson 1989; Reid & Heitmeyer 1995). Few data exist for other species, although recent surveys have shown there to be 200 000–400 000 shorebirds wintering in the Central Valley (Point Reyes Bird Observatory, unpublished data).

Rice agriculture has long been recognized as having considerable potential value for waterfowl (e.g. Wright 1959; McGinn & Glasgow 1963; Miller 1987; Miller *et al.* 1989; Brouder & Hill 1995) and, more recently, for other aquatic birds (Fasola & Barbieri 1978; Fasola 1983; Remsen *et al.* 1991; Pain 1994; Fasola, Canova & Saino 1996; Fasola & Ruiz 1996, 1997). In the Central Valley, between 140 000 and 180 000 ha of rice are grown annually (Hill *et al.* 1992), predominantly in the Sacramento Valley which comprises its northern half. To improve air quality, recent legislation by the State of California (Rice Straw Burning Act, AB 1378 1991) mandated that rice growers phase out their practice of burning rice stubble after harvest. In response to this legislation, many growers flood fields during winter to enhance straw decomposition. This flooding is seen as having potential not only to provide farmers with a means of straw disposal, but simultaneously to recreate, albeit in a very artificial manner, some of the region's lost wetland habitat (Brouder & Hill 1995).

We anticipated that seed eating birds (e.g. waterfowl) would be less abundant, and predators of invertebrates (e.g. shorebirds) more abundant, in fields with extensive straw manipulation. Many rice growers use some form of straw manipulation in conjunction with flooding, to increase decomposition rates. These methods increase contact between the soil and straw through compaction, or partial burial and/or increase the straw's surface area by chopping it up. Methods similar to these have been advocated as ways of increasing invertebrate densities and benefiting waterbirds (especially shorebirds) in managed wetlands (e.g. Helmers 1992). The logistical difficulties associated

with conducting land-use experiments have limited tests of the efficacy of such methods to studies involving few replicates, little experimental control and comparisons of only a small subset of the management options. These studies generally have supported the idea that management actions that increase the rate of vegetation decomposition also lead to increased shorebird use (e.g. Rundle & Fredrickson 1981). These methods, which are expected to increase food abundance for invertebrate predators, are also expected to reduce food abundance for seed eaters through burial and increased decomposition.

Water depth has also been considered a major factor determining the abundance of individual waterbird species in wetlands (e.g. Boshoff, Palmer & Piper 1991a,b,c; Fredrickson 1991; Helmers 1992; Velasquez 1992). The variation in depth in most wetlands, however, has prevented rigorous tests of the impact of small depth differences on species abundance. Californian rice fields provide an ideal setting for conducting such tests because they are laser-levelled to create uniform water depths.

Our goals in this study were two-fold. First, we set out to evaluate how Californian rice fields might be managed during winter to maximize their potential as surrogate wetlands. In addition, we used the fact that rice fields are an excellent experimental system (e.g. many treatments and replicates were available, fields were uniform, etc.) to examine ideas of broader significance to wetland bird management. Specifically, we tested the hypotheses that densities of individual bird species differ between: (1) fields that are flooded by rice growers and those that are not; (2) flooded fields that receive different straw management treatments; and (3) fields that are flooded to different water depths. In addition, we compared bird densities during two winters with extremely different weather conditions to see whether increased rainfall affected bird use.

## Materials and methods

We collected data at several sites in the Sacramento Valley, California, during the winters (November–March) of 1993/94 and 1994/95. Sites were grouped into three areas: Richvale-Biggs, Sutter and Princeton (Fig. 1). We chose these areas to ensure that observations represented the entire region in which rice is grown.

Within these three areas, we arbitrarily selected rice fields to census. In 1993/94, we censused 53 fields, of which 37 were flooded (total area = 797.2 ha; mean area  $\pm$  SE = 21.5  $\pm$  4.1 ha) and 16 were not (486.5 ha; 30.4  $\pm$  7.1 ha). In 1994/95, 25 flooded fields (699.3 ha; 28.0  $\pm$  5.4 ha) and 15 unflooded fields (398.3 ha; 26.6  $\pm$  6.4 ha) were sampled. Fifteen of the flooded fields and five of the unflooded fields were sampled in both years. A flooded field was defined as one that was flooded intentionally to enhance straw decomposition

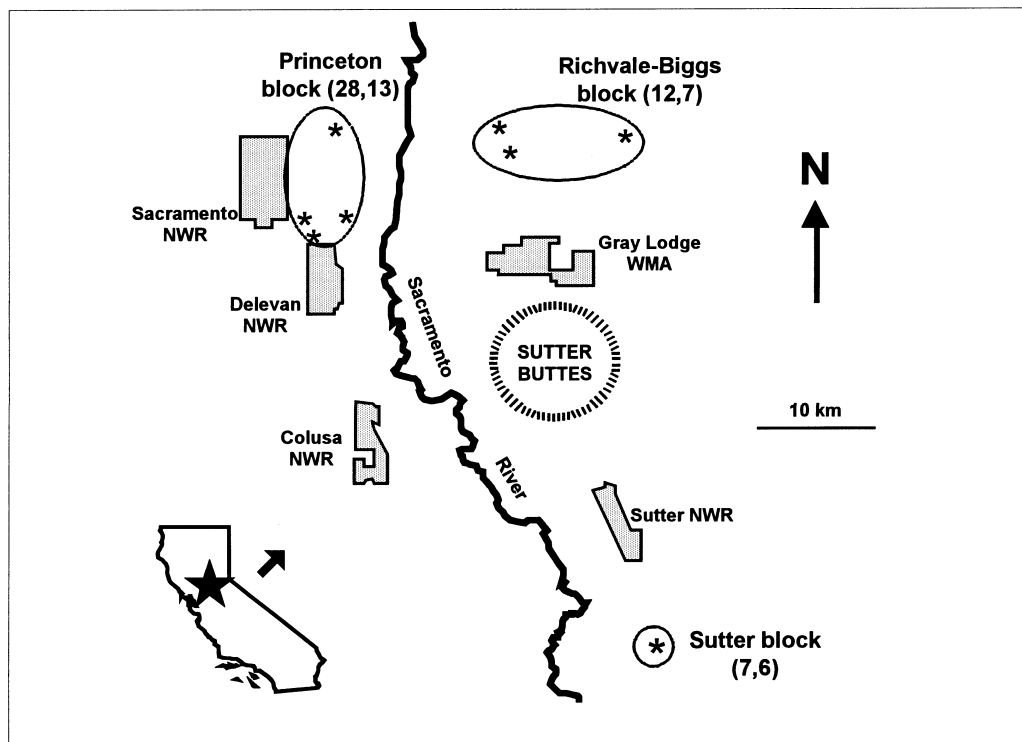


Fig. 1. Study area, showing Sacramento National Wildlife Refuge (NWR) Complex and Gray Lodge Waterfowl Management Area (WMA). Study sites are marked with asterisks. Geographic blocks of sites are enclosed within ellipses with numbers of flooded and unflooded fields given after block names. Inset shows location of study area in California.

and/or attract birds. Fields defined as unflooded, therefore, were not necessarily dry and sometimes held standing water due to heavy rain or river flooding. The two years of the study were characterized by very different weather patterns. The winter of 1993/94 was relatively dry in the Sacramento Valley, whereas 1994/95 was much wetter (e.g. in the centre of our study area at US National Weather Service station 041948 in Colusa, California, precipitation was 22.7 and 74.9 cm for November–March of 1993/94 and 1994/95, respectively; NCDC 1997). During the second winter, there was deeper flooding (Fig. 2) and more unflooded fields with standing water.

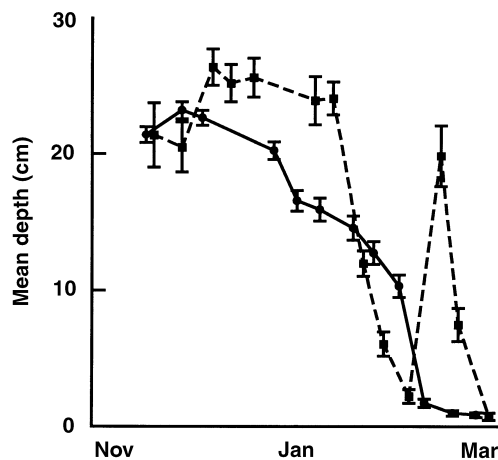


Fig. 2. Mean ( $\pm$ SE) water depth in flooded rice fields. Solid line = 1993/94, dashed line = 1994/95.

Flooded fields were chosen such that a variety of straw management methods were represented within the sample. Six management methods were sampled during the study. Fields were either: (1) flooded without straw management; (2) rolled to flatten the straw and stubble, and then flooded; (3) rolled after flooding to increase the extent that straw stuck in the mud; (4) flooded after chopping the straw to increase its surface area; (5) disked or chiselled to both cut up the straw and partially bury it, and then flooded; or (6) flooded after removing the straw either by burning or baling. The first treatment acted as a control for the need to manipulate straw and the last controlled for the presence of straw on the fields.

Logistical and land-access constraints prevented complete randomization in selecting fields and assigning treatments. Consequently, we selected fields such that the various management treatments were spatially interspersed, in order to reduce the likelihood that unknown factors confounded our experimental design. In addition, we ensured that flooded and unflooded fields were represented in the three geographical areas in similar proportions and that straw treatments occurred in as many of the three areas as possible.

#### BIRD CENSUSES

We censused fields on foot, counting and identifying all waterbirds (here defined as Podicipediformes,

Ciconiiformes, Anseriformes, Gruiformes and Charadriiformes; Table 1) seen within the boundary of the field. Given the open nature of the habitat these counts were likely to assess absolute abundance accurately for most species. Species for which this was unlikely to be true (e.g. common snipe *Gallinago gallinago*) are not considered here. Birds disturbed from a field were included in our counts, but birds only seen flying overhead were not. We combined data for snow geese *Chen caerulescens* and Ross's geese *C. rossii* as accurate species counts were not always possible for large flocks. Hereafter, these species are treated jointly and referred to as 'white' geese.

We censused fields at  $\approx 10$ -day intervals, except during the hunting season when the spacing between censuses occasionally was altered to accommodate hunting on study fields. The order in which fields were visited was determined arbitrarily and varied among census periods to reduce the likelihood that systematic biases influenced our data (e.g. due to regular movements by the birds or due to our presence). Constraints on access prevented complete randomization of census order.

In general, we were able to avoid disturbing birds during our censuses. Some species (primarily waterfowl), however, occasionally were flushed during counts. Usually, we were able to obtain complete counts before the birds flew and often were able to see where they went, thus enabling us to ensure we were not counting the birds more than once. In situations where we were uncertain whether a field's count was

influenced by our activities, we omitted that count from analyses.

#### COLLECTION OF WATER DEPTH DATA

Most rice fields were subdivided into 'checks' by narrow earthen levees. Water depth within each check varied by only a few centimetres, but the depths of each check in a field were often quite different. We therefore collected depth data at the scale of the check, rather than the field. Depth stakes were placed in each check and the water depth was read on each census date. These depths were calibrated by taking additional depth measurements at randomly selected points in each check, and comparing the mean depth to that at the stake. In 1993/94, 25 measurements were made in each check. Examination of these data indicated that estimates of mean depth stabilized with fewer data points, so in 1994/95 only 15 measurements were taken in each check. We assumed that the difference between mean depth and the depth at the stake remained constant throughout the winter. During bird censuses we recorded the numbers of each species seen in each check, allowing us to subdivide field counts by check. In total, bird and depth data were collected for 116 checks in 1993/94 and 51 checks in 1994/95.

#### DATA ANALYSIS

Prior to analysis, census data were converted to densities to enable comparison among fields/checks of

**Table 1.** Species of waterbirds recorded during surveys of California rice fields 1993–95 (after American Ornithologists' Union 1983, 1995). Four letter acronyms follow US Bird Banding Laboratory. Species that occurred with sufficient frequency to permit statistical analyses are marked in bold

Species	Species
<b>Pied-billed grebe</b> <i>Podilymbus podiceps</i> (PBGR)	Bufflehead <i>Bucephala albeola</i> (BUFF)
<b>American bittern</b> <i>Botaurus lentiginosus</i> (AMBI)	Common merganser <i>Mergus merganser</i> (COME)
<b>Great blue heron</b> <i>Ardea herodias</i> (GBHE)	Ruddy duck <i>Oxyura jamaicensis</i> (RUDU)
<b>Great egret</b> <i>Ardea albus</i> (GREG)	Sora <i>Porzana carolina</i> (SORA)
<b>Snowy egret</b> <i>Egretta thula</i> (SNEG)	Common moorhen <i>Gallinula chloropus</i> (COMO)
Black-crowned night-heron <i>Nycticorax nycticorax</i> (BCNH)	<b>American coot</b> <i>Fulica americana</i> (AMCO)
<b>White-faced ibis</b> <i>Plegadis chihii</i> (WFIB)	<b>Sandhill crane</b> <i>Grus canadensis</i> (SACR)
Tundra swan <i>Cygnus columbianus</i> (WHSW)	<b>Black-bellied plover</b> <i>Pluvialis squatarola</i> (BBPL)
<b>Greater white-fronted goose</b> <i>Anser albifrons</i> (GWFG)	<b>Killdeer</b> <i>Charadrius vociferus</i> (KILL)
'White' goose <i>Chen caerulescens</i> & <i>C. rossii</i> (WHGO)	<b>Black-necked stilt</b> <i>Himantopus mexicanus</i> (BNST)
<b>Canada goose</b> <i>Branta canadensis</i> (CAGO)	<b>American avocet</b> <i>Recurvirostra americana</i> (AMAV)
Wood duck <i>Aix sponsa</i> (WODU)	<b>Greater yellowlegs</b> <i>Tringa melanoleuca</i> (GRYE)
<b>Green-winged teal</b> <i>Anas crecca</i> (AGWT)	Lesser yellowlegs <i>Tringa flavipes</i> (LEYE)
<b>Mallard</b> <i>Anas platyrhynchos</i> (MALL)	<b>Long-billed curlew</b> <i>Numenius americanus</i> (LBCU)
<b>Northern pintail</b> <i>Anas acuta</i> (NOPI)	Western sandpiper <i>Calidris mauri</i> (WESA)
<b>Cinnamon teal</b> <i>Anas cyanoptera</i> (CITE)	<b>Least sandpiper</b> <i>Calidris minutilla</i> (LESA)
<b>Northern shoveler</b> <i>Anas clypeata</i> (NSHO)	<b>Dunlin</b> <i>Calidris alpina</i> (DUNL)
<b>Gadwall</b> <i>Anas strepera</i> (GADW)	Ruff <i>Philomachus pugnax</i> (RUFF)
<b>Eurasian wigeon</b> <i>Anas penelope</i> (EUWI)	<b>Long-billed dowitcher</b> <i>Limnodromus scolopaceus</i> (LBDO)
<b>American wigeon</b> <i>Anas americana</i> (AMWI)	Common snipe <i>Gallinago gallinago</i> (COSN)
Canvasback <i>Aythya valisineria</i> (CANV)	<b>Ring-billed gull</b> <i>Larus delawarensis</i> (RBGU)
Redhead <i>Aythya americana</i> (REDH)	California gull <i>Larus californicus</i> (CAGU)
<b>Ring-necked duck</b> <i>Aythya collaris</i> (RNDU)	<b>Herring gull</b> <i>Larus argentatus</i> (HERG)

different sizes. Field areas were either obtained from farmers or calculated from 1:24 000 topographic maps. Tests were conducted on all species that were seen frequently enough to detect significant differences among treatments (Table 1). We used a significance level of  $\alpha = 0.10$ , set *a priori*. This  $\alpha$ -level was chosen because the applied nature of the study justified an increased risk of making Type I errors (i.e. concluding a treatment effect where none existed), in exchange for a reduced chance of making Type II errors (i.e. concluding no treatment effect where one existed). To allow us to interpret non-significant tests (i.e.  $P > 0.1$ ) we determined power using tables in Cohen (1988). For non-parametric tests, we used guidelines on power-efficiency to adjust our sample sizes to their parametric equivalents and obtain conservative power estimates (Siegel & Castellan 1988). In each case, we viewed power  $> 0.8$  as evidence for no difference among treatments and determined power for small, medium and large effect sizes following Cohen (1988). Note that quantitative values for these effect sizes vary between tests. For clarity, we have given these values for each power calculation (see Cohen 1988 for qualitative descriptions of these effect sizes).

Before testing our treatment hypotheses, we determined whether the abundance of each species differed between the two years of the study. We used a Wilcoxon signed rank test (Siegal & Castellan 1988) to compare mean densities of each species in the 20 fields censused in both winters. We analysed each winter's data separately for all species occurring at different densities in the two winters. For the remaining species, we combined data for both winters; in all cases, estimated power was high ( $1 - \beta > 0.78$ ) when using a large effect size ( $d = 0.8$ ; Cohen 1988), supporting the conclusion of no difference between years. Fields censused in both winters generated two data points for each species. To avoid pseudoreplication (Hurlbert 1984) we randomly selected data for one season to use in our analyses. Tests for non-normal distributions and heterogeneous variances indicated a need to use non-parametric tests to compare management treatments. For these tests we used the mean density for each field. Dunn's multiple comparison test for non-parametric data of unequal sample sizes was used to make *post hoc* comparisons following Kruskal-Wallis tests (Zar 1984).

Differences in species density among the three geographical areas (blocks) studied were a concern because not all straw management treatments were represented in every block; hence, geographical differences could confound straw management treatments. Where differences among blocks were significant, we examined the results of our straw management tests. If treatment differences could be explained simply by correlations between geographical patterns of bird abundance and the distribution of treatments, we viewed the result as confounded. When this occurred, we re-analysed data

from each block separately and only drew conclusions about straw treatment differences based on the results of these supplemental tests.

We examined relationships between water depth and species use in three ways. Two methods tested whether 'preferred' depths taken from the literature (Fredrickson 1991; Helmers 1992; Table 6) actually received greater use. For the 14 species treated by these authors, we classified observations according to whether the observed water depth lay within the range thought to be favoured by the species. These data were first analysed using log-likelihood ratio tests to determine whether birds were more likely to be present in checks of the 'preferred' depths than in other checks (Zar 1984). Secondly, we used one-tailed separate-variance *t*-tests to determine whether the density of a species, when it was present, was higher at 'preferred' depths. These two tests were necessary because our data include a high proportion of observations when no individuals of a species were seen. These zeros could arise because of active avoidance of certain checks or they could simply reflect random site-selection (i.e. birds do not use a suitable check because they found another one first). This latter explanation is especially likely for species with highly clumped distributions characteristic of many waterfowl and shorebirds. The first test determined whether zeros simply reflect a background level of empty sites (which predicts no difference) or whether active avoidance occurred (which predicts fewer zeros at preferred depths). The second test excluded observations where birds were not present and determined whether densities were higher at preferred depths for the remaining observations.

Our third test of the relationship between water depth and species use involved modelling the relationship between depth and bird density. For each species, we tested linear, negative quadratic, and logarithmic regression models, both with and without date as an additional variable.

In all depth analyses, the experimental unit was a single check on a single date. Consequently, each check is represented in the data set a number of times, causing concern that data points may not be independent. Pooling data for each site, as was done in tests of the flooding and straw management hypotheses, was not possible because water depths fluctuated over time. We believed that non-independence among our data points was probably minimal because checks were very small relative to the area over which most waterbirds move on a weekly basis (C.S. Elphick, personal observation). This difference in scale reduced the degree to which the birds seen in a check on one census were likely to be the same as those seen 10 days later. To determine whether multiple data points for each site were statistically independent, we tested for autocorrelation. For each species, we randomly selected up to 20 of the checks the species used (10 from each winter) and looked for evidence of auto-

correlation. Where fewer than 20 checks were used by a species, we used every check. Of 501 autocorrelation tests, only in three cases was there evidence of significant autocorrelation among samples. These are considerably fewer significant cases than would be expected by chance (Chatfield 1980), so we considered all data points to be statistically independent.

## Results

### DIFFERENCES BETWEEN YEARS

There was no significant difference in the densities of most (21/31) species in the two years. For all tests,  $1 - \beta > 0.78$  ( $> 0.8$  in most cases) when assuming a large effect size ( $d = 0.8$ ). Significant differences were detected for 10 species (Table 2). Five occurred at higher densities in the drier winter of 1993/94 and five at higher densities in the wetter winter of 1994/95. In addition, the densities of long-billed curlews *Numenius americanus* using flooded fields were higher in 1993/94 than in 1994/95 ( $z = -2.040$ ;  $P = 0.041$ ).

### EFFECTS OF FLOODING

We found differences in density ranks, between flooded and unflooded fields, for 26 species (Table 3). Of these, only great blue herons and sandhill cranes were more common in unflooded fields. Results for species which occurred at different densities in the two winters were generally the same for both winters. Two species, killdeer *Charadrius vociferus* and long-billed curlew, however, were found only to differ in their habitat use in 1993/94, the winter in which they occurred at higher densities.

Only great egrets *Ardea albus*, Eurasian wigeon *Anas penelope* and the geese taxa did not differ significantly between the two treatments. Estimates of statistical power for these tests indicated a high probability ( $1 - \beta = 0.76-0.93$ ) of detecting a large treatment effect ( $d = 0.8$ ) if one existed, but much smaller

chances of detecting medium ( $d = 0.5$ ;  $1 - \beta = 0.43-0.63$ ) or small ( $d = 0.2$ ;  $1 - \beta = 0.16-0.20$ ) effects.

### EFFECTS OF STRAW MANIPULATION

Differences in the density ranks of birds using flooded fields that had received different straw management treatments were found for 14 species (Table 4). Only for eight, however, could these differences be unambiguously attributed to the straw management treatment. In five cases there was no effect of geographical block, in one there was a block effect, but it could not account for the treatment effect, and in two the block effect was potentially confounding, but the treatment effects remained after analyses were conducted for each block separately. Four of the species that occurred at different densities in the two winters (mallard *Anas platyrhynchos*, killdeer, least sandpiper *Calidris minutilla* and dunlin *C. alpina*), showed different patterns in the two years. In all cases, there was a significant difference in 1994/95 only.

Dunn's multiple-comparison test was used to examine pair-wise differences in bird use for all significant differences among treatments. Although precise details of the results differed among species, there were two main groups (Table 5). First, the three long-legged species (American bittern *Botaurus lentiginosus*, white-faced ibis *Plegadis chihi*, American avocet *Recurvirostra americana*) were most abundant in fields that had been just flooded. These species appeared to avoid fields that had been rolled prior to flooding and, depending on the species, certain other treatments. The second group included the four small shorebirds (killdeer, least sandpiper, dunlin, long-billed dowitcher *Limnodromus scolopaceus*), which occurred at highest densities in fields where straw had been incorporated before flooding. These species tended to avoid fields where straw had been chopped or rolled prior to flooding (Table 5).

We did not detect differences for the remaining 16 species. Unfortunately, power of these tests was too

**Table 2.** Differences in density between 1993/94 and 1994/95. Wilcoxon's signed rank tests compared mean densities of birds in 20 fields sampled in both winters; only significant differences are given

Species	Wilcoxon $z$	$P$	Winter of higher density
Pied-billed grebe	2.845	0.004	94/95
Green-winged teal	2.542	0.011	94/95
Mallard	-2.277	0.023	93/94
Ring-necked duck	1.826	0.068	94/95
American coot	2.249	0.025	94/95
Killdeer	-3.061	0.002	93/94
American avocet	1.992	0.046	94/95
Greater yellowlegs	-3.516	<0.001	93/94
Least sandpiper	-2.429	0.015	93/94
Dunlin	-2.134	0.033	93/94

**Table 3.** Densities of birds in flooded and unflooded rice fields. Test statistics are for Mann–Whitney *U*-tests. Separate densities and statistical tests are given for species occurring at significantly different densities in the two winters; otherwise data for both winters are combined. Sample sizes for flooded and unflooded fields, respectively, were: 37 and 16 (1993/94), 25 and 15 (1994/95), 47 and 26 (both years combined). Species with significant differences ( $P < 0.10$ ) are marked in bold

Species	Winter	Mean ( $\pm$ SE) density (birds km <sup>-2</sup> )*		U	P
		Flooded	Unflooded		
<b>Pied-billed grebe</b>	<b>1993/94</b>	<b>0.2 (0.1)</b>	<b>0</b>	<b>352.0</b>	<b>0.065</b>
	<b>1994/95</b>	<b>1.5 (0.7)</b>	<b>0.4 (0.3)</b>	<b>252.0</b>	<b>0.038</b>
<b>American bittern</b>	<b>Both</b>	<b>1.2 (0.4)</b>	<b>0.4 (0.2)</b>	<b>767.0</b>	<b>0.049</b>
<b>Great blue heron</b>	<b>Both</b>	<b>0.5 (0.1)</b>	<b>0.9 (0.2)</b>	<b>810.0</b>	<b>0.017</b>
Great egret	Both	2.1 (0.3)	2.0 (0.4)	613.0	0.982
<b>Snowy egret</b>	<b>Both</b>	<b>1.5 (0.5)</b>	<b>0.03 (0.03)</b>	<b>850.5</b>	<b>0.001</b>
<b>White-faced ibis</b>	<b>Both</b>	<b>49.5 (25.1)</b>	<b>0</b>	<b>728.0</b>	<b>0.018</b>
Greater white-fronted goose	Both	32.4 (22.6)	118.6 (53.3)	708.0	0.175
'White' goose	Both	2.2 (1.9)	187.3 (102.6)	643.5	0.658
Canada goose	Both	2.4 (1.7)	1.6 (0.9)	627.0	0.758
<b>Green-winged teal</b>	<b>1993/94</b>	<b>151.8 (58.2)</b>	<b>0</b>	<b>520.0</b>	<b>&lt; 0.001</b>
	<b>1994/95</b>	<b>178.2 (79.3)</b>	<b>5.8 (3.1)</b>	<b>258.5</b>	<b>0.043</b>
<b>Mallard</b>	<b>1993/94</b>	<b>110.0 (20.7)</b>	<b>9.1 (5.0)</b>	<b>526.0</b>	<b>&lt; 0.001</b>
	<b>1994/95</b>	<b>97.5 (19.4)</b>	<b>22.1 (6.3)</b>	<b>302.0</b>	<b>0.001</b>
<b>Northern pintail</b>	<b>Both</b>	<b>212.9 (53.4)</b>	<b>38.6 (21.2)</b>	<b>1030.0</b>	<b>&lt; 0.001</b>
<b>Cinnamon teal</b>	<b>Both</b>	<b>2.6 (1.0)</b>	<b>0.5 (0.3)</b>	<b>781.0</b>	<b>0.011</b>
<b>Northern shoveler</b>	<b>Both</b>	<b>154.5 (27.7)</b>	<b>5.7 (3.0)</b>	<b>1109.0</b>	<b>&lt; 0.001</b>
<b>Gadwall</b>	<b>Both</b>	<b>11.9 (4.5)</b>	<b>0.6 (0.4)</b>	<b>916.0</b>	<b>&lt; 0.001</b>
Eurasian wigeon	Both	0.1 (0.1)	0.05 (0.04)	654.0	0.386
<b>American wigeon</b>	<b>Both</b>	<b>48.8 (16.4)</b>	<b>8.9 (4.8)</b>	<b>899.0</b>	<b>0.001</b>
<b>Ring-necked duck</b>	<b>1994/95</b>	<b>1.1 (0.7)</b>	<b>0.1 (0.1)</b>	<b>235.0</b>	<b>0.070</b>
<b>American coot</b>	<b>1993/94</b>	<b>445.7 (65.6)</b>	<b>0</b>	<b>576.0</b>	<b>&lt; 0.001</b>
	<b>1994/95</b>	<b>651.8 (148.6)</b>	<b>293.7 (225.9)</b>	<b>313.0</b>	<b>&lt; 0.001</b>
<b>Sandhill crane</b>	<b>Both</b>	<b>0</b>	<b>0.6 (0.3)</b>	<b>681.5</b>	<b>0.018</b>
<b>Black-bellied plover</b>	<b>Both</b>	<b>1.2 (0.8)</b>	<b>0</b>	<b>715.0</b>	<b>0.027</b>
<b>Killdeer</b>	<b>1993/94</b>	<b>10.1 (2.5)</b>	<b>2.9 (1.2)</b>	<b>434.0</b>	<b>0.007</b>
	<b>1994/95</b>	<b>7.0 (3.0)</b>	<b>1.8 (0.6)</b>	<b>219.0</b>	<b>0.376</b>
<b>Black-necked stilt</b>	<b>Both</b>	<b>3.3 (1.4)</b>	<b>0</b>	<b>728.0</b>	<b>0.018</b>
<b>American avocet</b>	<b>1994/95</b>	<b>6.1 (3.3)</b>	<b>0</b>	<b>255.0</b>	<b>0.010</b>
<b>Greater yellowlegs</b>	<b>1993/94</b>	<b>21.1 (3.9)</b>	<b>0.1 (0.1)</b>	<b>565.5</b>	<b>&lt; 0.001</b>
	<b>1994/95</b>	<b>9.3 (5.3)</b>	<b>0.2 (0.2)</b>	<b>332</b>	<b>&lt; 0.001</b>
<b>Long-billed curlew</b>	<b>1993/94</b>	<b>11.3 (2.4)</b>	<b>12.1 (6.6)</b>	<b>395.0</b>	<b>0.051</b>
	<b>1994/95</b>	<b>3.3 (1.2)</b>	<b>7.5 (4.5)</b>	<b>189.5</b>	<b>0.950</b>
<b>Least sandpiper</b>	<b>1993/94</b>	<b>6.2 (3.0)</b>	<b>0</b>	<b>424.0</b>	<b>0.002</b>
	<b>1994/95</b>	<b>16.5 (10.7)</b>	<b>0</b>	<b>247.5</b>	<b>0.016</b>
<b>Dunlin</b>	<b>1993/94</b>	<b>80.8 (23.2)</b>	<b>0</b>	<b>472.0</b>	<b>&lt; 0.001</b>
	<b>1994/95</b>	<b>93.7 (61.4)</b>	<b>0</b>	<b>270.0</b>	<b>0.003</b>
<b>Long-billed dowitcher</b>	<b>Both</b>	<b>87.3 (39.0)</b>	<b>0</b>	<b>897.0</b>	<b>&lt; 0.001</b>
<b>Ring-billed gull</b>	<b>Both</b>	<b>11.3 (2.9)</b>	<b>2.8 (1.5)</b>	<b>903.0</b>	<b>0.001</b>
<b>Herring gull</b>	<b>Both</b>	<b>0.2 (0.1)</b>	<b>0.02 (0.01)</b>	<b>762.0</b>	<b>0.019</b>

\* Directions of density and ranking differences concord in all cases except for long-billed curlew (1993/94) where the rank test indicates that birds used flooded fields significantly more than unflooded, contrary to expectation based on examination of densities.

low to conclude no difference ( $1 - \beta = 0.34 - 0.59$ , assuming a large effect size:  $d = 0.4$ ). These results therefore cannot be taken as evidence that these species were not affected by straw management treatments.

#### EFFECTS OF WATER DEPTH

Most species were found to use a wide range of water depths (Fig. 3), although densities varied considerably

among depths. Species patterns varied in a predictable fashion. Median water depths for checks in which a species occurred were deepest for diving species (24–33 cm) and most shallow for shorebirds (3–13 cm). Intermediate between these groups were geese (18–26 cm), dabbling ducks (14–22 cm), and herons and ibis (9–20 cm).

Our first set of tests determined whether each species was more likely to occur at depths suggested as

**Table 4.** Effects of straw management treatments and geographical block on waterbird densities. Test statistics are for Kruskal–Wallis tests. Separate statistical tests were conducted for species occurring at significantly different densities in the two winters; otherwise data for both winters are combined. Treatment sample sizes given in Table 5; block sample sizes given in Fig. 1. Significant differences are marked in bold

Species	Winter	Geographic block effect		Effect of straw management	
		H	P	H	P
<i>Treatment effect</i>					
American bittern	Both	1.10	0.576	15.55	<b>0.008</b>
White-faced ibis*	Both	7.28	<b>0.026</b>	17.22	<b>0.004</b>
Mallard	1994/95	0.40	0.820	11.21	<b>0.047</b>
Killdeer	1994/95	2.72	0.256	11.44	<b>0.043</b>
American avocet*	1994/95	10.10	<b>0.006</b>	11.08	<b>0.050</b>
Least sandpiper	1994/95	2.49	0.288	15.58	<b>0.008</b>
Dunlin	1994/95	1.44	0.487	13.65	<b>0.018</b>
Long-billed dowitcher	Both	4.68	<b>0.096</b>	11.42	<b>0.044</b>
<i>No treatment effect</i>					
Pied-billed grebe	1994/95	0.27	0.875	1.11	0.775
Great egret	Both	1.26	0.533	7.24	0.203
Snowy egret	Both	1.03	0.599	8.03	0.155
G. white-fronted goose	Both	3.87	0.144	8.14	0.149
'White' goose	Both	2.26	0.323	4.83	0.437
Green-winged teal	1993/94	0.91	0.636	2.29	0.514
	1994/95	0.05	<b>0.048</b>	8.68	0.123
Mallard	1993/94	11.56	<b>0.003</b>	6.04	0.110
Northern pintail	Both	1.81	0.404	7.90	0.162
Cinnamon teal	Both	0.84	0.657	3.77	0.583
Gadwall	Both	3.19	0.203	9.17	0.103
Eurasian wigeon	Both	6.51	<b>0.039</b>	2.95	0.708
American wigeon	Both	9.32	<b>0.009</b>	6.50	0.261
Ring-necked duck	1994/95	5.00	<b>0.082</b>	9.07	0.107
American coot	1993/94	2.34	0.310	5.20	0.158
	1994/95	3.04	0.217	8.48	0.132
Black-bellied plover	Both	1.86	0.395	6.12	0.295
Killdeer	1993/94	1.33	0.514	1.37	0.714
Black-necked stilt	Both	4.36	0.113	3.83	0.574
Greater yellowlegs	1994/95	0.85	0.655	6.36	0.273
Least sandpiper	1993/94	4.86	<b>0.088</b>	4.04	0.257
Dunlin	1993/94	0.13	0.935	1.71	0.635
Ring-billed gull	Both	2.17	0.339	6.56	0.256
Herring gull	Both	3.81	0.149	8.60	0.126
<i>Treatment effect confounded by block effect</i>					
Pied-billed grebe	1993/94	8.77	<b>0.012</b>	11.96	<b>0.035</b>
Great blue heron	Both	18.71	< <b>0.001</b>	13.18	<b>0.022</b>
Canada goose	Both	6.91	<b>0.032</b>	12.08	<b>0.034</b>
Northern shoveler	Both	10.10	<b>0.006</b>	10.86	<b>0.054</b>
Greater yellowlegs	1993/94	8.08	<b>0.018</b>	8.48	<b>0.037</b>
Long-billed curlew	1993/94	7.44	<b>0.024</b>	14.35	<b>0.002</b>
	1994/95	4.64	<b>0.098</b>	9.89	<b>0.078</b>

\* Treatment effect also found within geographical blocks.

favoured by that species. For 11 of the 14 species, *G*-tests indicated that occurrence rates within these depth ranges were significantly higher than expected by chance, although for one (least sandpiper) this difference was weak (Table 6). When we looked only at those checks where birds occurred, however, we found that only three of these 11 species occurred at significantly greater densities at 'preferred' depths. Only for greater yellowlegs *Tringa melanoleuca* was this difference highly significant. We therefore concluded that these 11 species disproportionately used the depth

ranges that Fredrickson (1991) and Helmers (1992) proposed. In most cases, however, this differential use only affected whether a species would be present at a site and not how common it would be. For both greater yellowlegs and long-billed dowitcher, different (though overlapping) depth ranges were proposed by each of the earlier papers. For these species, both hypothesized ranges had a greater frequency of occurrence than expected, but only one had greater densities of birds when the species was present.

The remaining species (American bittern, great



**Table 5.** (a) Results of *post hoc* comparisons for significant tests of straw management treatments (Table 4). Treatments with different letters were significantly different using Dunn's multiple comparison test. Treatments denoted *a* had higher mean ranks than those denoted *b*. A dash indicates that a treatment was not included in the test that confirmed a treatment effect. Sample sizes are for 1993/94, 1994/95 and both years combined, respectively. (b) Water depths found in each treatment. Treatment means differed significantly ( $F_{5,2045} = 11.852, P < 0.001$ ) Treatments with different letters were significantly different using Tukey's multiple comparison test (in all cases  $P < 0.005$  after sequential Bonferroni adjustment). See Methods for detailed treatment descriptions

	Winter	Treatment					
		Flood only	Roll & Flood	Flood & Roll	Chop & Flood	Incorporate & Flood	Remove & Flood
(a) Species differences							
<i>n</i>		8, 7, 10	21, 4, 19	4, 4, 6	0, 4, 4	0, 3, 3	3, 3, 5
American bittern	Both	a	b	b	b	a, b	a, b
White-faced ibis	Both	a	b	–	–	a, b	b
Mallard	94/95	a	a	a	a	a	a
Killdeer	94/95	b	a, b	a, b	b	a	a, b
American avocet	94/95	a	b	–	–	a, b	–
Least sandpiper	94/95	a, b	b	a, b	a, b	a	a, b
Dunlin	94/95	a, b	b	a, b	b	a	a, b
Long-billed dowitcher	Both	<i>b</i>	<i>b</i>	<i>a, b</i>	<i>b</i>	<i>a</i>	<i>b</i>
(b) Water depths (cm)							
Mean ± SE		16.3 ± 0.7	16.0 ± 0.4	12.6 ± 0.4	16.9 ± 1.1	10.4 ± 1.0	13.9 ± 1.4
<i>n</i>		276	639	683	199	141	113
Pairwise differences		a	a	b	a	b	a, b

blue heron and black-necked stilt (*Himantopus mexicanus*) were no more likely to occur in checks of 'preferred' depths, than in checks of other depths. Nor were there differences in the mean densities of birds when occupied checks in the two categories were compared (Table 6).

Regression models proved to be poor descriptors of the relationships between depth and bird density. In none of our analyses was more than 10% of the variance explained, probably because of the large number of instances when a species was absent from a check.

## Discussion

Californian rice fields were used by a wide variety of waterbird species during the winter months (Table 1). Thirty-one species occurred with sufficient frequency to detect treatment effects. Both flooded and unflooded fields were used by most of these species (Table 3). In general, densities were greater in flooded fields, and several species (mostly shorebirds) never used unflooded fields. Although not intentionally inundated, many unflooded fields did have standing water during some surveys, especially in 1994/95. These fields, however, drained rapidly after heavy rainfall or flood conditions ended, and were rarely flooded for long periods. Consequently, these fields were unsuitable for most waterbirds during a large proportion of censuses. Furthermore, the short periods during which unflooded fields were inundated

may have been insufficient to allow invertebrate numbers to increase to levels found in flooded fields.

Several species were less common in flooded fields. Most notable were sandhill cranes and great blue herons, which occurred at significantly higher densities in unflooded fields. Greater white-fronted geese *Anser albifrons* and 'white' geese also occurred at much higher densities in unflooded fields, although these differences were not significant after ranking the data (Table 3). Anecdotal observations suggest that when geese occurred in flooded fields they tended to be roosting, rather than feeding. This pattern could arise because geese are unable to access spilled grain in flooded fields that are underwater. Both flooded and unflooded habitats, therefore, may be important for geese, although used for different activities.

For most species, we found no evidence that the method of straw management used on flooded fields had an effect on density. Most species for which we did find a difference fell into one of two groups. Three species (American bittern, white-faced ibis and American avocet) were most abundant in fields that had received no treatment other than flooding, and four (killdeer, least sandpiper, dunlin and long-billed dowitcher) were most abundant in fields where straw had been incorporated into the soil prior to flooding (Table 5). All of these species tend to feed on invertebrate prey (Ehrlich, Dobkin & Wheye 1988) and were expected *a priori* to prefer fields where straw was heavily manipulated. We also found no evidence for the idea that granivorous species tend to avoid fields

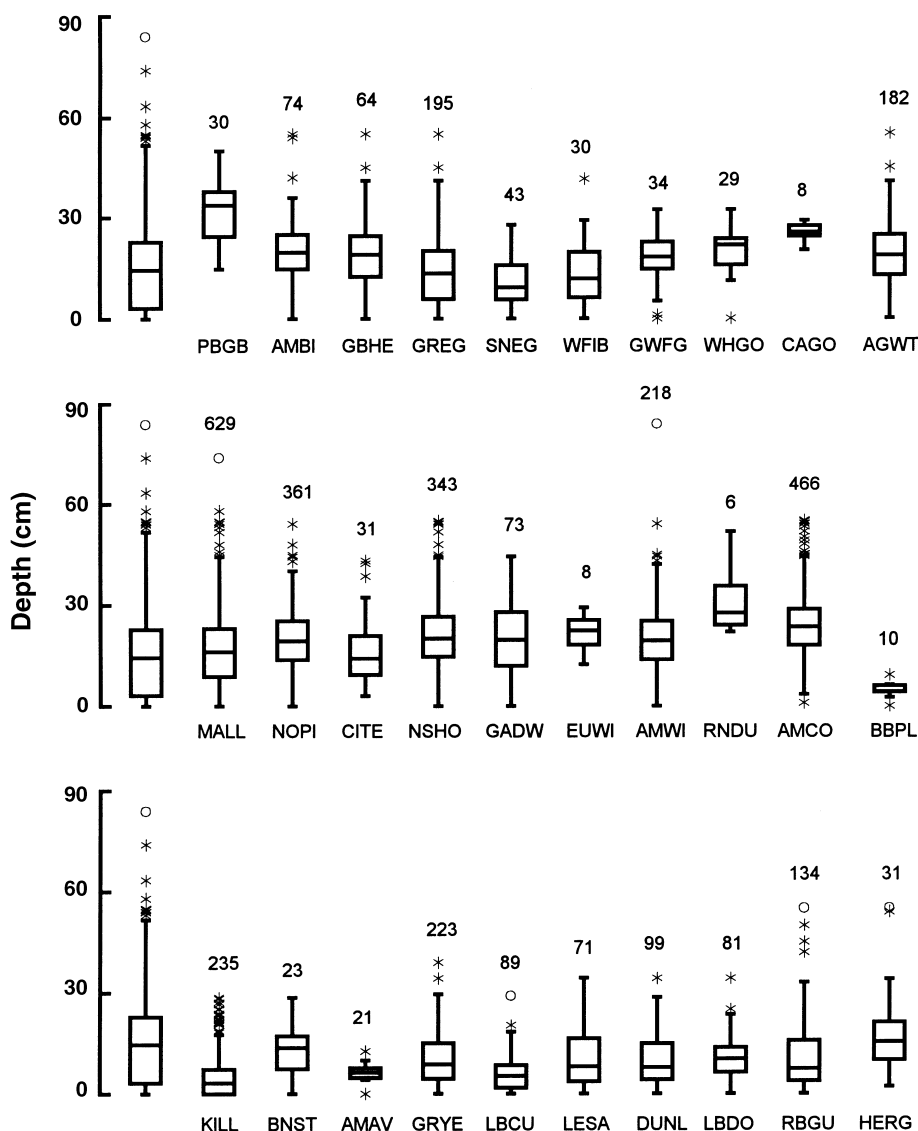


Fig. 3. Box plots representing the range of water depths used by each species. Boxes represent the interquartile range of depths at which each species was recorded, and are bisected by the median values; whiskers encompass the majority of points; outliers are identified by stars or circles (see SYSTAT 1996 for details). Sample sizes for each species are given above box plots. Four-letter species acronyms are defined in Table 1. Boxes at extreme left of each row give distribution of depths available to birds, for comparison to depths used ( $n = 2054$ ).

where straw management was likely to have made grain less available. These divergences from our expectations may indicate that food abundance does not change as expected as a function of straw manipulations. Evidence that this might be the case comes from surveys that found higher invertebrate densities in fields that had just been flooded or had straw removed than in fields that were rolled after flooding (D. Loughman & D. Batzer, unpublished data). An alternative explanation is that, for most species, bird density does not increase with food abundance. This could happen if food was not limiting, or if other factors (e.g. predation, disturbance) modified the bird's distributions (e.g. Lima & Dill 1990; Gill, Sutherland & Watkinson 1996). Finally, it is possible that food abundance follows the predicted pattern,

but availability does not. The two groups for which straw treatment effects were detected can be separated into long- and short-legged species, suggesting that water depth may be important. In fact, water depth did differ among straw management treatments with the shallowest depths found in fields where straw was incorporated into the soil (Table 5). This difference suggests that water depth, rather than straw treatment, may have caused differences for the four short-legged shorebirds that favoured this treatment.

It is important to recognize that some of the significant results we found may arise simply from the large number of tests conducted. In testing our primary hypotheses, we chose not to correct for multiple tests because we could not clearly identify sets of tests that should be grouped (cf. Rice 1989). For example,

**Table 6.** The dependence of bird use on water depth. 'Preferred' ranges are those hypothesized to be preferred by particular species. Significant *G*-tests show that occurrence rates were higher for depths within these ranges than for other depths. Significant *t*-tests show that when a species was present, densities were higher for these depths. d.f. = degrees of freedom (non-integer values arise from adjustments for unequal variance); *n* = number of observations. Significant *P*-values are marked in bold

Species	'Preferred' range (cm)	<i>G</i> (d.f., <i>n</i> )	<i>P</i>	<i>t</i> (d.f.)	One-tailed <i>P</i>
American bittern	0–7*	2.20 (1, 2054)	0.138	−0.22 (7.8)	0.415
Great blue heron	10–17*	0.20 (1, 2054)	0.652	2.02 (39.0)	0.975
Green-winged teal	9–20*	45.91 (1, 2038)	<0.001	−0.59 (175.3)	0.280
Mallard	7–14*	35.60 (1, 2038)	<0.001	0.44 (323.7)	0.671
Northern pintail	14–21*	47.72 (1, 2035)	<0.001	−0.93 (213.2)	0.178
Northern shoveler	17–23*	8.57 (1, 2038)	0.003	0.09 (138.2)	0.538
American coot	27–33*	69.38 (1, 2053)	<0.001	−1.80 (120.9)	0.037
Killdeer	0–3†	39.69 (1, 2054)	<0.001	0.88 (68.7)	0.810
Black-necked stilt	8–21†	2.55 (1, 2054)	0.110	−0.34 (21.0)	0.370
Greater yellowlegs	1–7*	49.90 (1, 2054)	<0.001	−0.99 (116.4)	0.163
	2–12†	92.71 (1, 2054)	<0.001	−2.45 (146.4)	0.008
Long-billed curlew	0–16†	63.46 (1, 2054)	<0.001	−0.17 (50.7)	0.433
Least sandpiper	0–5†	3.18 (1, 2054)	0.075	0.475 (29.2)	0.681
Dunlin	0–10†	44.79 (1, 2054)	<0.001	−0.77 (96.9)	0.222
Long-billed dowitcher	2–8*	12.32 (1, 2054)	<0.001	−1.45 (30.0)	0.079
	0–10†	24.01 (1, 2054)	<0.001	−1.05 (68.3)	0.149

\* Depth range taken from Fredrickson (1991).

† Depth range taken from Helmers (1992).

each of our main hypotheses could be treated in its general form, which would require adjustment of *P*-values, or could be applied separately to each species, which would not require adjustment. We had no basis for choosing one approach over the other. In addition, multiple comparison tests can be overly conservative and lead one to ignore patterns that may be important. For example, using the sequential Bonferroni adjustment (Rice 1989) to judge the significance of our tests of a straw management effect would lead us to conclude that no differences were significant. From 39 tests, however, we would expect only four significant tests by chance, when in fact we found 15 (Table 4). This observation suggests that the use of multiple comparisons would have led to a loss of information. Consequently, we conclude that the overall patterns found are real, but that individual test results should be viewed with caution, and that further studies of the behaviour and habitat selection of species exhibiting treatment differences may be warranted.

We found that water depth influenced whether a species was present at a site, but not how abundant it was. We examined the relationship between water depth and bird use of rice fields in two ways. First, we evaluated depth ranges that have been proposed as preferred by certain species. For most of the species for which preferred depths have been proposed, we found evidence for an increased incidence of the species within the proposed range. When we considered only those checks where birds were present, however, we found that densities generally were not greater for these depths. Our second approach did not involve

any *a priori* prediction as to which depths were preferred. Instead, we attempted to describe the relationship between water depth and species densities by fitting various regression models. In all cases, variance was extremely high and we were unable to find any models with high predictive power. These results suggest that birds assessed the suitability of a check's water depth in a simple yes/no fashion and that there is not a gradation of suitability. Either a depth is suitable or it is not. Previous studies, however, have not only demonstrated relationships between water depth and species occurrence, but have been able to explain far more of the variance in the abundance of certain species (Boshoff, Palmer & Piper 1991a,b,c; Velasquez 1992; Colwell & Dodd 1995; Nagarajan & Thiyagesan 1996). Part of this difference may be statistical in nature, arising from differences in the ranges of depths and/or bird densities found in the different studies and the extremely high variation in densities found in our study. There may, however, be a qualitative difference in the way birds respond to planned water level drawdowns (e.g. Velasquez 1992) and to uncontrolled depth fluctuations (e.g. this study). The former will gradually concentrate prey, allowing bird densities to build up over time, whereas the latter will not concentrate prey in such a predictable fashion.

Given that birds feeding in rice fields appear to select water depths in a yes/no fashion, it makes sense to identify depth ranges, rather than an optimal depth, when designing guidelines for water depth management for individual species. Support for the

hypothesis that a particular depth range is used disproportionately by a species does not necessarily indicate that bird use will be optimized within that range. Fredrickson (1991) and Helmers (1992) identified ranges for a variety of species, 14 of which were included in this study. Our analyses support the ranges they identified for 11 of these species. Two species were considered by both authors, with different (but overlapping) ranges proposed by each. For these species, we found increased occurrence rates for both hypothesized ranges. In each case, however, significantly greater densities were found for only one of the hypotheses (Table 6). For each species, therefore, there may be several depth ranges that would have produced significant results given our analysis. It is also possible that some of these other ranges would receive greater bird use according to both occurrence and density criteria. A more appropriate way to determine which depths receive greatest use is to examine the distribution of depths a species uses directly (e.g. Fig. 3). Comparing these data across species allows one to evaluate the effects that different flooding regimes will have on the entire community. Examination of the interquartile distances for all species suggests that depths of 15–20 cm will lead to the greatest number of species using flooded areas (Fig. 3). Currently, most fields are flooded deeper than this during the first half of the winter (Fig. 2). Reductions in water depth during this period therefore can be expected to increase the number of species using each flooded field.

In general, it seems that flooding rice fields will lead to greater use by most waterbirds. As we have shown (Table 3), however, this is not true for all species. We also have evidence that increased flooding reduces use by certain raptor and passerine species (C.S. Elphick, unpublished data). It appears, however, that those species that occur at lower densities in flooded fields are generally some of the commonest birds occurring in the Sacramento Valley; in contrast, those that occur at higher densities in flooded fields are species that are likely to have undergone the most significant declines in the region as a result of wetland destruction. Furthermore, limitations on the availability of water make it unlikely that the extent of winter flooding will increase to the point where all rice fields are submerged in winter. It is therefore likely that there will always be a mixture of flooded and unflooded fields. Whether a reduction in unflooded land will have adverse effects on species that use this habitat is unclear.

Despite very different weather conditions, most species occurred at similar densities in the two years. This result suggests that our general conclusions are robust to a range of rainfall conditions, although a longer time series is needed to test fully this hypothesis. Most of the differences we did find can be attributed to differences in water depth between the two years (Fig. 2). Species that occurred at higher densities

in the drier year were predominantly species that prefer shallow conditions, while species more abundant in 1994/95 when fields were flooded deeper tended to be deeper water species (Table 2).

Studies in Europe have indicated that rice fields play a vital role in the maintenance of some waterbird populations (Fasola & Barbieri 1978; Fasola, Canova & Saino 1996) and it has been suggested that flooded agriculture can act as a substitute for declines in wetland habitat (Fasola & Ruiz 1996, 1997). Evaluating the relative importance of Californian rice fields is difficult because many birds move back and forth between flooded fields and other managed wetland habitats on a daily basis, and because we do not know whether habitat availability currently limits populations. The extent to which waterbirds use flooded fields during the winter, however, suggests that rice agriculture is also very important in California (Miller 1987; Miller *et al.* 1989; this study). For example, millions of waterfowl winter in the Central Valley and large numbers of these birds make daily trips from roost sites in areas protected from hunting to feed in rice fields. Similarly, recent aerial surveys demonstrated that the majority of the shorebirds using the Sacramento Valley during winter occurred in rice fields (Point Reyes Bird Observatory, unpublished data).

Although the main goal of this study was to assess different methods of managing Californian rice fields and produce guidelines for improving their quality as waterbird habitat in winter, we believe the results are also of use in other settings. By studying these species in an agricultural system we were able to overcome a number of problems encountered in many studies of natural or managed wetlands. First, rice fields are much simpler than most wetland systems. Consequently, many variables that could confound results and increase variability (e.g. vegetation type and structure) were standardized both within and across sampling units. In addition, we could ensure that our management treatments (e.g. water depth) were applied uniformly across units. The price paid for simplification is a decreased certainty that conclusions will be applicable to more complex situations. Testing the relevance of our results in more natural settings is clearly an important step in assessing the generality of our conclusions.

A second advantage of studying habitat use questions in an agricultural setting is that there are typically many potential sites that can be used. This fact enabled us to obtain fairly large sample sizes, to examine a variety of different treatments and to select sites such that different treatments were interspersed amongst each other. Consequently, we were able to attain a relatively high level of experimental control, even though we were carrying out a study at a scale where truly controlled experiments were not feasible.

Limited research has been done in rice fields elsewhere in the world (though see references in Fasola &

Ruíz 1997). Studies from Europe and the south-eastern United States, however, suggest that shallow flooding of fields in these areas also results in increased use by waterbirds (Remsen *et al.* 1991; Fasola & Ruíz 1996, 1997). Bird communities seem to differ little between these studies and ours. Consequently, our results may be applicable to other temperate rice-growing regions. If this is the case, improved management of rice paddies for aquatic birds may provide a partial solution to the loss of natural wetland habitats worldwide.

### Management recommendations

1. Increasing the area of winter flooded rice fields is likely to benefit a wide variety of waterbirds. Some species, however, occur at higher densities in fields that are not flooded by farmers. This group is primarily made up of common species of little conservation concern, although it does include greater sandhill crane *Grus canadensis tabida* which is considered threatened in California. How much unflooded rice is necessary to support the crane population is unknown, but is likely to be small relative to the amount of unflooded rice currently available.

2. The method of flooding has little effect on the abundance of most species, and there is no single straw management method that can be recommended for birds in general. There is some evidence that incorporating straw into the soil (e.g. by disking) leads to increased use by shorebirds; however, this may be due to shallower water in incorporated fields.

3 Water depth affected the occurrence of species, but was not a major factor determining the abundance of individual species. Depths of 15–20 cm appear to maximize the variety of species that will occur in a flooded field. Reducing depths during the early part of the winter will therefore lead to use by a wider variety of species while also lowering water costs.

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