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PATTERNS AND DYNAMICS OF SHOREBIRD USE OF CALIFORNIA'S CENTRAL VALLEY[1]

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Abstract. Surveys of California's Central Valley between 1992–1995 document it as one of the most important regions in western North America to migratory and wintering shorebirds. Populations averaged 134,000 individuals in August, 211,000 in November, 303,000 in January, and 335,000 in April. Of 33 species, the 10 or 11 that averaged over 1,000 individuals each season accounted for 99% of total numbers. Managed wetlands, agricultural fields (especially rice), and agricultural evaporation ponds held the most shorebirds. Species varied their seasonal, geographic, and habitat use of the Central Valley, primarily in response to changes in water availability from rainfall or management practices and latitudinal variation in habitat availability mediated, in part, by climate. In the record rainfall year of 1994–1995, shorebird numbers increased 74% between November and January, primarily from coast-to-interior movements of the Dunlin (*Calidris alpina*) and Long-billed Dowitcher (*Limnodromus scolopaceus*) and local habitat shifts of Killdeer (*Charadrius vociferus*). Although the Valley's shorebirds face threats from poor or toxic water quality, changing agricultural practices, and habitat loss to urbanization, they should benefit from current efforts to increase flooding of rice fields and to secure a stable high quality water supply for wetlands. Development of a sound conservation strategy is crucial for the preservation of shorebird populations in the Central Valley, as this agriculturally-dominated landscape is among the most altered in North America and remains vulnerable to strong economic and population growth pressures that may impact shorebird habitats in the future.

Key words: conservation, distribution, habitat use, Pacific Flyway, ricelands, seasonal abundance, wetlands.

INTRODUCTION

North American shorebirds are primarily wetland-dependent species, many of which migrate long distances between breeding and wintering areas. Although massive habitat alteration in this century has undoubtedly reduced many shorebird populations, information indicating population declines is largely anecdotal (Page and Gill 1994) or limited to the past 25 years (Howe et al. 1989, Morrison et al. 1994).

Concern over the effects of continued habitat loss on migrating and wintering shorebirds (Myers 1983, Senner and Howe 1984) led to the creation of a system of voluntary reserves in North and South America known as the Western Hemisphere Shorebird Reserve Network (Myers et al. 1987, Harrington and Perry 1995). Still, much basic information critical for guiding the selection of sites for inclusion in this reserve system is lacking. Key information needed for western North America are an overview of the relative importance of specific wetlands and geographic regions as migration-staging and wintering areas for various species, and knowledge of species' population sizes, seasonal abundance patterns, and habitat needs.

From 1988 to 1995, Point Reyes Bird Observatory (PRBO) conducted a large-scale censusing program to document the number of shorebirds in specific wetlands in the western United States. Expanding geographically, by 1992 this effort included California's entire Central Valley, which historically hosted one of the world's largest concentrations of wintering waterfowl and other aquatic birds (Banks and Springer 1994). During the past 150 years, the Valley has been converted into one of the most productive agricultural areas in the world. Although over 90% of its historic wetlands have been lost (Frayer et al. 1989, Kempka et al. 1991), it still supports about 60% of the waterfowl wintering in the Pacific Flyway and 20% of those in the United States (Heitmeyer et al. 1989). Current efforts to increase wetland habitat in the Central Valley in response to continent-wide declines of waterfowl also aim to benefit other wetland-dependent birds, including shorebirds (U.S. Fish and Wildlife Service 1990, Streeter et al. 1993),

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but are hampered by a paucity of biological data on most of these species.

Prior information on shorebird occurrence in the Central Valley consists primarily of surveys of small isolated sites (Jurek 1973, 1974), coarse descriptions of seasonal abundance patterns and habitat selection in the northern drainage of the Valley (Manolis and Tangren 1975), and studies of single species (e.g., Pitelka 1950). Our surveys of most wetland and other shallow-water habitat in the Central Valley from 1992 to 1995 provide an overview of the overall abundance, geographic distribution, and habitat use of shorebirds throughout this region and document its continent-wide importance to migrating and wintering shorebirds. We also examine future threats to shorebird habitat to evaluate the potential of the Central Valley to remain a key staging and wintering area for shorebirds.

METHODS

STUDY AREA

The Central Valley, surrounded by mountains except for its western drainage into San Francisco Bay, averages about 644 km long and 64 km wide (Fig. 1). It is divided into the Sacramento Valley, draining southward, the San Joaquin Valley, draining northward, and the Sacramento-San Joaquin River Delta (hereafter Delta) where these rivers converge. The Sacramento Valley is further divided into the Colusa, Butte, Sutter, American, and Yolo drainage basins, and the San Joaquin Valley is divided into the San Joaquin Basin and, the usually closed, Tulare Basin. Heitmeyer et al. (1989) described the physiography and extent of historical and recent wetlands and croplands by subregion of the Valley, and Moore et al. (1990) and Chilcott and Johnson (1991), respectively, provided information on agricultural evaporation ponds and sewage ponds, two other shorebird habitats. Precipitation in the watershed falls primarily from October through April, as rain on the valley floor and foothills and snow in the higher mountains. Chico, in the northern Sacramento Valley, has average temperatures of 24.7°C in August and 7.1°C in January and an average annual rainfall of 65.9 cm, whereas Bakersfield, in the southern San Joaquin Valley, has average temperatures of 28.0°C in August and 9.0°C in January and an average rainfall of 14.5 cm (National Oceanic and Atmospheric Administration 1982).

DATA COLLECTION

Our primary shorebird surveys of the Central Valley occurred from 1992 to 1995 after 6 years of drought (1986–1987 to 1991–1992) and encompassed one dry (1993–1994) and two wet winters, including the wettest on record (67% above average) in 1994–1995. We tried to survey all shallow-water habitat in the entire Valley in August 1992, 1993, and 1994; November 1993 and 1994; late January to mid-February (hereafter January) 1993, 1994, 1995; and April 1992, 1993, and 1994. We also made supplemental surveys of selected subregions of the Valley that documented (1) high shorebird numbers in the Grasslands wetlands of the San Joaquin Basin in April 1991 during a period of delayed draw-down of water in duck clubs, (2) high shorebird numbers in the Tulare Basin in April 1995 after an unusually wet winter, and (3) numbers of Wilson's Phalaropes (*Phalaropus tricolor*) in the Tulare Basin in late July 1990, 1993, 1994, and 1995, during the peak period of their migration (Jehl 1988).

Reliance on aerial versus ground surveys varied by region and habitat to obtain the most accurate counts while accommodating logistical restraints. Aerial counts were the primary method used for large expanses of flooded agricultural lands, which varied greatly in size seasonally and annually, and for other areas inaccessible on the ground. They were the primary census method for the Sacramento Valley and Delta, although we regularly undertook ground counts on all federal and state wildlife areas and a few private wetlands and sewage ponds. We relied on ground counts for all wetlands in the San Joaquin Valley, except for the southern Tulare Basin, where we used aerial surveys for private wetlands and flooded agricultural fields.

Ground counts were conducted by skilled volunteers, agency personnel, and project staff and were timed to coincide closely with aerial counts. Aerial counts were conducted by G. Page and D. Shuford, primarily from a Cessna 172 flown at about 130 km hr^{-1} mostly from 15 to 60 m above the ground. Counts made from opposite sides of the plane were summed to obtain totals. We used maps of the entire survey region divided into many small subareas and worked opportunistically back and forth between known landmarks to cover all habitat in each subarea before moving to the next. We flew

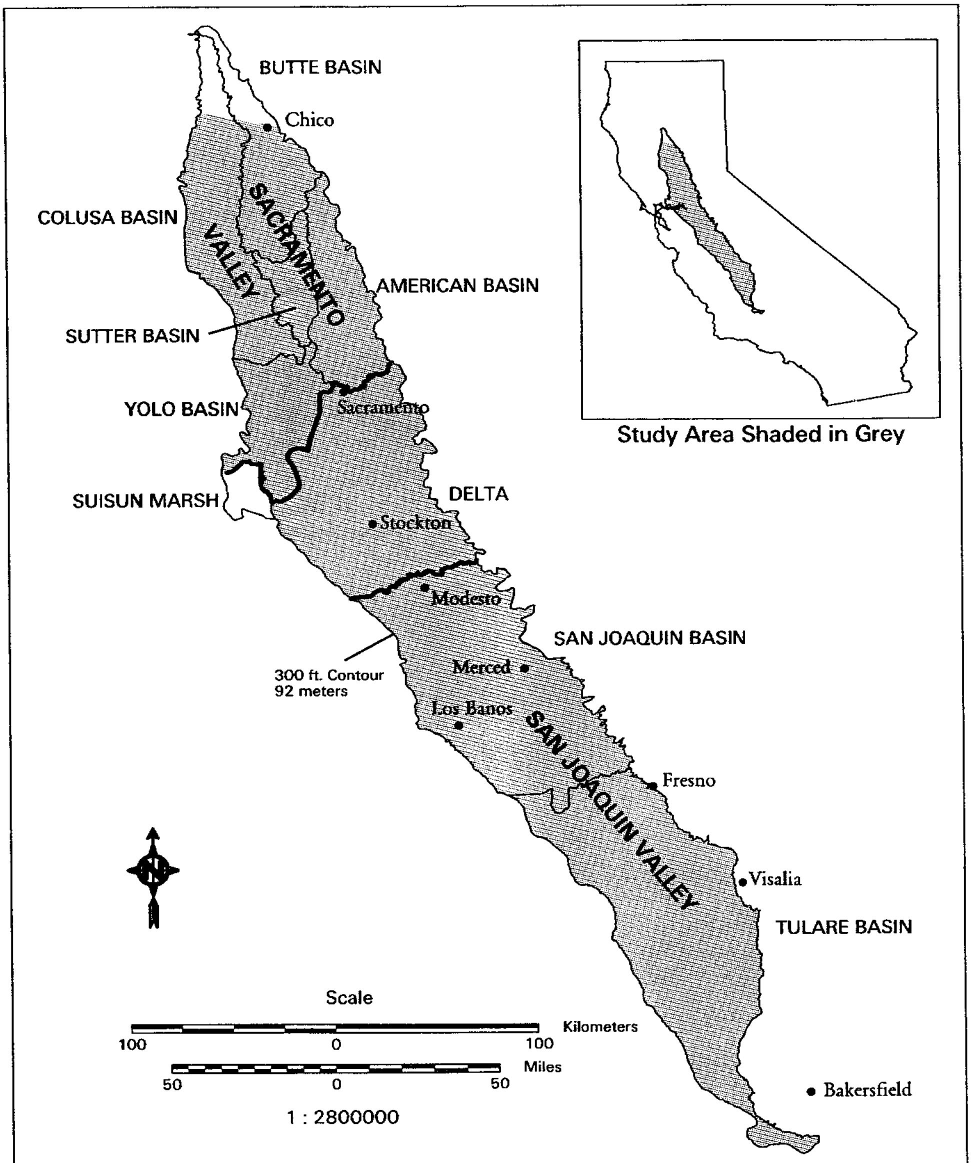

FIGURE 1. Map of the drainage basins of California's Central Valley.

multiple parallel abutting transects over larger bodies of water and single passes over small wetlands and sewage ponds. Occasionally we made repeat passes to obtain better counts or confirm species identifications. An important supplement to the aerial counts, particularly in the Sacramento Valley and Delta, were ground counts at sites, varying from census to census, where large concentrations of shorebirds were located from the air. These were taken by 1–2 project staff within a day of aerial counts to refine aerial numbers, particularly by providing ratios for species of small sandpipers (Western Sandpiper, Least Sandpiper, and Dunlin; see Table 2 for scientific names) not distinguishable from the air.

Extensive discussions with numerous field biologists, coupled with overflights of most of the Valley, convinced us that our surveys covered almost all habitat likely to support large numbers of shorebirds. We were unable to cover relatively small proportions of some habitats on each census. Coverage of shallow-water habitat was very complete in the Sacramento Valley and Delta. At most, we probably missed a few sites that likely held only a few hundred birds. In the San Joaquin Basin, the principal area covered was the 720 km^2 Grasslands wetlands complex near Los Banos, Merced County (two-thirds private, one-third public lands), and nearby Mendota Wildlife Area, Fresno County. We covered nearly all public lands and 75–85% of private lands, except in April 1993 when none of the San Joaquin Basin state wildlife areas were covered. For that season, we estimated numbers for each area as the sum of the median numbers of those species present on at least four of five other April censuses from 1990 to 1995. Coverage of sewage ponds in the San Joaquin Basin was not consistent, although these ponds generally held only hundreds of shorebirds. We covered variable proportions of flooded cropland in the San Joaquin Basin, but knew of no cropland where large numbers of shorebirds regularly concentrated. In the Tulare Basin, we regularly covered most managed wetlands, agricultural evaporation ponds, and flooded agricultural lands; coverage of sewage ponds was less consistent, possibly causing us sometimes to miss low thousands of shorebirds. In April 1993, we did not conduct an aerial survey of the southern Tulare Basin and likely missed low thousands of shorebirds in the selected habitats usually covered by this method. We also did not cover agricultural habitats in the northern Tulare Basin where we knew of no consistent occurrence of thousands of shorebirds.

On each survey, shorebirds not identified to species were apportioned into species according to ratios of identified birds as described by Stenzel and Page (1988). Numbers of small sandpipers so estimated are reported in Table 2, but most analyses were for all small sandpipers combined. To estimate the population sizes of each species of small sandpiper, we made further final allocations by region and season in the following ways. In all regions in August and April, and most in November and January, when $\leq$ 20% of all sandpipers remained unidentified, we allocated by the ratios of identified/allocated sandpipers summed over all censuses for each season. In the Sacramento Valley for January (33.5% unidentified) and November (49% unidentified), we apportioned sandpipers according to ratios provided by C. Elphick (83.3% Dunlin, 11.5% Least Sandpiper, 0.2% Western Sandpiper; n = 14,700 sandpipers) from ground counts in rice fields from mid-November through March in 1993–1994 and 1994–1995. In the Tulare Basin in January (34.7% unidentified), lacking ratios from independent surveys, we allocated by the ratios of identified sandpipers in two main habitats (saline evaporation ponds and all other freshwater habitats) summed over all January censuses. We also apportioned small sandpipers separately by each basin for November 1994 and January 1995 to allow comparisons between these seasons in this very wet winter.

In most instances dowitchers could not be identified to species. In the Valley, only the Long-billed Dowitcher has been recorded in winter and only very small numbers of the Short-billed Dowitcher occur during spring and fall (Pitelka 1950, Manolis and Tangren 1975, McCaskie et al. 1979). Hence, we generally refer only to the Long-billed Dowitcher, because the vast majority of dowitchers recorded were of this species. Similarly, fairly large numbers of yellowlegs were not identified to species, particularly on aerial surveys. These undoubtedly were mostly Greater Yellowlegs (Table 2).

Intrinsic to a study designed to document shorebird use of shallow-water habitats and to cover a broad region, we underestimated the numbers of species that use both wetland and upland habitats and species inherently difficult to survey. Thus we did not account for the proportion of the populations of the Black-bellied Plover, Killdeer, Whimbrel, and Long-billed Curlew using upland habitats. The Mountain Plover went almost unrecorded on our surveys because it almost exclusively prefers relatively dry uplands. We had further problems estimating curlew numbers because they tended to fly long before the approach of a plane. Of wetland-dependent species, we had difficulty surveying the Common Snipe (even on ground counts) because of its cryptic coloration and secretive behavior, uncommon-to-rare small shorebirds because on aerial surveys they were indistinguishable from small sandpipers, and yellowlegs because they were distributed widely as single individuals or in small loose flocks, some of which we probably missed on aerial surveys while estimating species composition of large flocks. Still, our methods seemed adequate for most of the common species of shorebirds using the Valley's shallow-water habitats.

DATA ANALYSIS

We summarized our survey data by the five basins of the Sacramento Valley, the Delta, and the two basins of the San Joaquin Valley following a GIS map prepared by Ducks Unlimited/Pacific Meridian Resources (Rancho Cordova, CA) modified to include Mendota Wildlife Area in the San Joaquin rather than the Tulare Basin (Fig. 1). Most data, however, are presented by four areas: the Sacramento Valley, Delta, San Joaquin Basin, and Tulare Basin. For habitat comparisons, data were grouped into: (1) flooded agricultural croplands (ricelands tallied separately), (2) managed wetlands—largely seasonally flooded or semipermanent wetlands on wildlife refuges and private duck clubs, (3) agricultural evaporation ponds holding hypersaline agricultural drain waters in the Tulare Basin, (4) sewage ponds—typical diked sewage ponds and wetlands or agricultural lands flooded with treated sewage effluent, and (5) miscellaneous—including pastures, ditches, sloughs, streams, farm ponds, and reservoirs.

We compared shorebird densities in managed wetlands and agricultural lands in the Sacramento Valley and Delta, using estimates of the area of all flooded agricultural land and managed wetlands in January 1993 and all flooded ricelands in January 1994 (Table 1). We assumed that the extent of flooded managed wetlands was roughly the same in January 1993 and 1994 as management practices varied little between these years (F. Reid, pers. comm.). We also assumed that flooded agricultural lands were mostly ricelands in 1993, as 80.7% of all shorebirds recorded on agricultural lands in the Sacramento Valley in January 1993 were in ricelands (92.4% north of the Yolo Basin). We were unable to make density comparisons for the Sacramento Valley at other seasons or for the San Joaquin Valley at any season because of a lack of habitat data for the periods of our surveys. For the Killdeer, yellowlegs, small sandpipers (mostly Dunlin), and Long-billed Dowitcher, we used 12 density comparisons (two years for the five basins and the Delta), but because of very low numbers of the Black-necked Stilt in some basins its densities were compared over the two years only for the Colusa, Butte, and Yolo basins and the Delta. For each species we ranked the difference in densities between the two habitats and performed two-tailed Wilcoxon matched-pairs signed-ranks tests. Means are reported ± SE (min.–max.).

TABLE 1. Extent (ha) of key shorebird habitats in the Central Valley, 1992 to 1995.

	Habitats[a]				
Basin	MGWE[b]	AGLA[b]	AGRI[c]	EVAP[d]	SEPO[e]
Colusa	9,862	81,330	13,680	0	55
Butte	9,407	63,255	24,728	0	47
Sutter	2,062	37,635	5,446	0	32
American	2,970	47,318	12,163	0	111
Yolo	4,172	20,863	1,590	0	251
Delta	7,040	14,895	118	0	418
San Joaquin	?[f]	?	?	0	1,015
Tulare	6,178	53,623	0	2,536	1,477
Total	—	—	57,725	2,536	3,406

[a] MGWE = managed wetlands: palustrine habitat of permanent and seasonal marshes; AGLA = all agricultural lands (including ricelands) in winter with standing water or moist soil; AGRI = ricelands intentionally flooded in winter; EVAP = agricultural evaporation ponds; SEPO = sewage ponds.

[b] Data derived from GIS mapping of satellite images from 3 January 1993, except that images from 20 December 1992 used for the Tulare Basin (D. Kempka, in litt.); ? = no data available for San Joaquin Basin in winter 1992–1993.

[c] Data for 6 January 1994 from Spell et al. (1995); ? = no data available for San Joaquin Basin.

[d] The 2,536 ha of ponds active in 1992 had been reduced to 2,190 in 1995 (Moore et al. 1990; A. Toto, pers. comm.), and structural changes were made at some remaining ponds to limit bird use. Creation of mitigation wetlands may have compensated for some of these habitat losses.

[e] Data from Chilcott and Johnson (1991) and R. Diekstra (pers. comm.). Figures are minimums; throughout the Central Valley some small sewage ponds not reported and none north of Chico in Butte Basin reported.

[f] GIS data from 13 November 1990 (in dry winter) estimated 24,052 ha of wetlands (R. Spell, in litt.); recent Central Valley Habitat Joint Venture figures estimated 54,907 ha (D. Paullin, in litt.).

RESULTS

SEASONAL AND ANNUAL VARIATION

Our surveys of the Central Valley found a total of 33 species of shorebirds, of which 32 occurred in August, 29 in April, 25 in November, and 22 in January. In all seasons, 10 or 11 species averaged over 1,000 individuals, and combined accounted for at least 99% of total numbers (Table 2). Of these, 3 species were most numerous in August, 4 in January, and 2 in April; 2 species were equally numerous in November and January, and 1 in January and April. The Wilson's Phalarope attained highest numbers outside the main survey periods, as four supplemental surveys in late July at Tulare Basin evaporation ponds averaged 14,832 ± 1,096 (11,739–15,868) individuals (cf. Table 2).

Total shorebird numbers in the Central Valley averaged 133,671 ± 23,045 birds in August, 211,140 ± 4,058 in November, 302,851 ±

TABLE 2. Numbers of shorebirds in the Central Valley, 1992 to 1995.

Species	Season										
	Fall			Early winter		Mid winter			Spring		
	AUG 92	AUG 93	AUG 94	NOV 93	NOV 94	JAN 93	JAN 94	JAN 95	APR 92	APR 93	APR 94
Black-bellied Plover											
Pluvialis squatarola	5,146	3,632	3,944	6,795	6,292	6,098	10,205	9,653	3,520	8,600	11,465
Snowy Plover[a]											
Charadrius alexandrinus	172	297	250	192	150	174	138	91	168	231	170
Semipalmated Plover											
Charadrius semipalmatus	111	47	27	4	8	2	1	1	792	597	497
Killdeer[b]											
Charadrius vociferus	3,062	7,136	5,879	4,735	5,606	11,201	11,696	17,202	698	1,218	1,636
Black-necked Stilt[b]											
Himantopus mexicanus	11,334	23,844	17,158	12,114	13,450	7,056	10,393	11,287	7,710	9,350	8,316
American Avocet[b]											
Recurvirostra americana	7,516	13,816	8,375	4,037	2,548	2,273	3,409	3,428	4,756	5,646	6,204
Greater Yellowlegs											
Tringa melanoleuca	1,059	1,812	1,246	2,202	1,724	1,537	2,000	1,333	313	1,130	764
Lesser Yellowlegs											
Tringa flavipes	99	117	42	54	18	16	32	40	34	14	66
Yellowlegs spp.											
Tringa spp.	212	1,173	1,224	2,399	2,286	1,878	2,191	4,414	166	1,288	746
Willet											
Catoptrophorus semipalmatus	18	74	14	5	58	40	108	26	11	15	28
Whimbrel											
Numenius phaeopus	3	3	8	0	0	0	0	0	9,337	6,196	9,216
Long-billed Curlew											
Numenius americanus	1,321	1,146	6,595	2,198	2,920	3,801	5,602	4,955	538	548	516
Marbled Godwit											
Limosa fedoa	97	116	31	99	59	121	43	135	23	1	55
Western Sandpiper											
Calidris mauri	14,284	24,977	11,216	2,736	3,779	8,751	5,486	6,920	52,878	146,980	128,077
Least Sandpiper											
Calidris minutilla	3,255	16,485	9,886	21,382	11,942	10,256	13,712	12,682	5,697	7,032	9,567
Western/Least Sandpiper											
C. mauri/C. minutilla	7,223	4,917	6,031	257	920	2,821	1,476	431	25,610	11,295	13,492
Dunlin											
Calidris alpina	1	15	0	44,731	58,231	87,820	81,829	134,942	20,256	72,786	55,391
Western/Least/Dunlin											
C. mauri/C. minutilla/C. alpina	0	0	0	24,337	25,011	48,070	34,725	47,527	18,121	28,326	26,581
Dowitcher spp.											
Limnodromus spp.	37,010	71,678	47,217	77,692	79,331	69,120	89,216	118,349	68,341	92,516	117,876

TABLE 2. Continued.

Species	Fall			Early winter		Mid winter			Spring		
	AUG 92	AUG 93	AUG 94	NOV 93	NOV 94	JAN 93	JAN 94	JAN 95	APR 92	APR 93	APR 94
Common Snipe[a]											
Gallinago gallinago	5	9	34	1,100	829	312	742	637	10	45	104
Wilson's Phalarope[c]											
Phalaropus tricolor	4,902	4,026	1,151	0	2	1	1	0	13	5	15
Red-necked Phalarope											
Phalaropus lobatus	2,908	2,412	2,597	1	0	0	0	0	98	0	15
Phalarope spp.											
Phalaropus spp.	312	11	173	0	0	0	0	0	23	0	0
Other species[d]	34	55	34	12	34	17	111	19	51	16	16
Total shorebirds	100,084	177,798	123,132	207,082	215,198	261,365	273,116	374,072	219,164	393,835	390,813

[a] Breeds very locally in the Central Valley.
[b] A year-round resident and breeder in the Central Valley.
[c] May occasionally breed in the Central Valley.
[d] Includes a total of 13 additional species (12 August, 7 November, 5 January, 9 April): American Golden-Plover (*Pluvialis dominica*), Pacific Golden-Plover (*P. fulva*), Mountain Plover (*Charadrius montanus*), Solitary Sandpiper (*Tringa solitaria*), Spotted Sandpiper[b] (*Actitis macularia*), Ruddy Turnstone (*Arenaria interpres*), Red Knot (*Calidris canutus*), Sanderling (*C. alba*), Semipalmated Sandpiper (*C. pusilla*), Baird's Sandpiper (*C. bairdii*), Pectoral Sandpiper (*C. melanotos*), Stilt Sandpiper (*C. himantopus*), and Ruff (*Philomachus pugnax*).

35,772 in January, and 334,604 ± 57,727 in April (Table 2). Numbers also varied annually with coefficients of variation of 29.9% for August, 2.7% for November, 20.5% for January, and 29.9% for April. For the two winters with comparable data, Valley totals increased 32% between November 1993 and January 1994 and 74% between November 1994 and January 1995, largely from gains in the Dunlin, Long-billed Dowitcher, and Killdeer. In 1994–1995, these species increased by 93,000 (220%), 39,000 (49%), and 12,000 (207%), respectively. Although of smaller magnitude, November-to-January increases of the Western Sandpiper in the Sacramento Valley and Delta also were greatest in 1994–1995, when proportions of valleywide totals found in those regions increased from 3% to 17%, and 1% to 34%, respectively.

Supplemental surveys provided additional information on variation in shorebird numbers. An April 1991 census of the Grasslands wetlands in the San Joaquin Basin tallied 216,625 shorebirds. Of these, the 121,161 Western Sandpipers equalled 89% of the 1992 to 1994 average for the species in the entire valley. April 1992 to 1994 counts of the San Joaquin Basin averaged only 146,234 ± 33,677 (90,232–206,643) shorebirds, of which 65,826 were Western Sandpipers. In the Tulare Basin, an April 1995 survey, after record winter rainfall, produced 102,009 shorebirds (67,003 small sandpipers) versus a mean of 51,042 ± 11,274 (30,019–68,613) from April 1992 to 1994.

GEOGRAPHIC DISTRIBUTION

The distribution of shorebirds varied seasonally among regions of the Central Valley. Species richness at all seasons, but especially in winter, was higher in the San Joaquin Valley than in the Sacramento Valley or Delta (Fig. 2). Total shorebird numbers averaged higher in the San Joaquin Valley than in the Sacramento Valley and Delta, except in January (Fig. 3A–D). Specifically, totals were highest in the Tulare Basin in August, the Sacramento Valley in January, and the San Joaquin Basin and Sacramento Valley in November and April. The increased proportion of total shorebirds in the Sacramento Valley from November to January, primarily reflected an increase in the proportion of Dunlin in that region over that period (Figs. 3B, 3C, and 4A).

In August, the American Avocet, Wilson's Phalarope, Red-necked Phalarope, small sand-

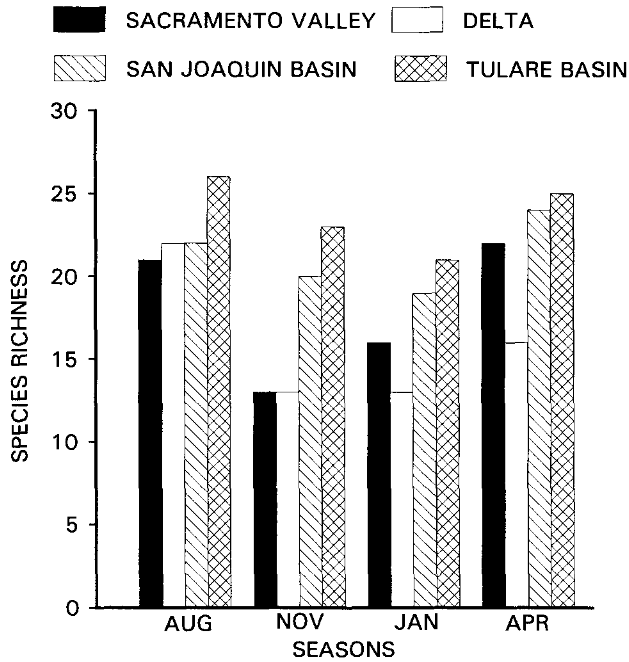

FIGURE 2. Species richness in four subregions of the Central Valley over four seasons.

pipers (Western and Least Sandpipers combined), and Black-necked Stilt were concentrated in the Tulare Basin, and the Killdeer and Long-billed Dowitcher in the Sacramento Valley (Fig. 3A).

In both November and January, the Dunlin was concentrated in the Sacramento Valley, the American Avocet in the Tulare Basin, the Black-necked Stilt in the San Joaquin Basin, and the Western Sandpiper in the San Joaquin Valley (Figs. 3B, 3C, and 4A). Unlike the north-to-south variation in abundance of other species of small sandpipers in winter, the Least Sandpiper was relatively evenly distributed throughout the Central Valley. The high proportion in the Tulare Basin in November resulted from an anomalous local concentration in 1993 of over 10,000 birds; the regularity of such occurrence needs further verification. Although about one-third of the Black-bellied Plovers in winter were in the Sacramento Valley (Fig. 3B and 3C), almost all of these were in the extreme southern basin. Hence, valleywide, 99% and 97% of all Black-bellied Plovers in November and January, respectively, were found from the Yolo Basin southward.

In April, the Whimbrel concentrated in the Tulare Basin and yellowlegs in the Sacramento Valley (Fig. 3D). Three uncommon species of regular occurrence—Snowy Plover, Willet, and Marbled Godwit—were always concentrated in the San Joaquin Valley. At all seasons, over 87% of all Snowy Plovers and Willets were found in the Tulare Basin.

HABITAT USE

Habitat use by shorebirds varied seasonally (Fig. 5A–D). In August, shorebird totals were highest in evaporation ponds, where the Wilson's Phalarope, American Avocet, Red-necked Phalarope, small sandpipers, and Black-necked Stilt all concentrated (Fig. 5A). Concurrently, the Killdeer concentrated in agricultural fields and miscellaneous habitats, and the Black-bellied Plover on evaporation ponds and sewage ponds.

In winter, shorebird numbers were highest in managed wetlands and agricultural fields. Use of agricultural lands (including rice fields) increased from November to January (Fig. 5B and 5C). Of agricultural lands, rice fields held the most shorebirds: 23% of valleywide totals in November and 30% in January. Killdeers, yellowlegs, small sandpipers, and Long-billed Dowitchers all used mainly agricultural fields and managed wetlands in winter (Fig. 5B and 5C). The Western Sandpiper, although using managed wetlands extensively, differed from the

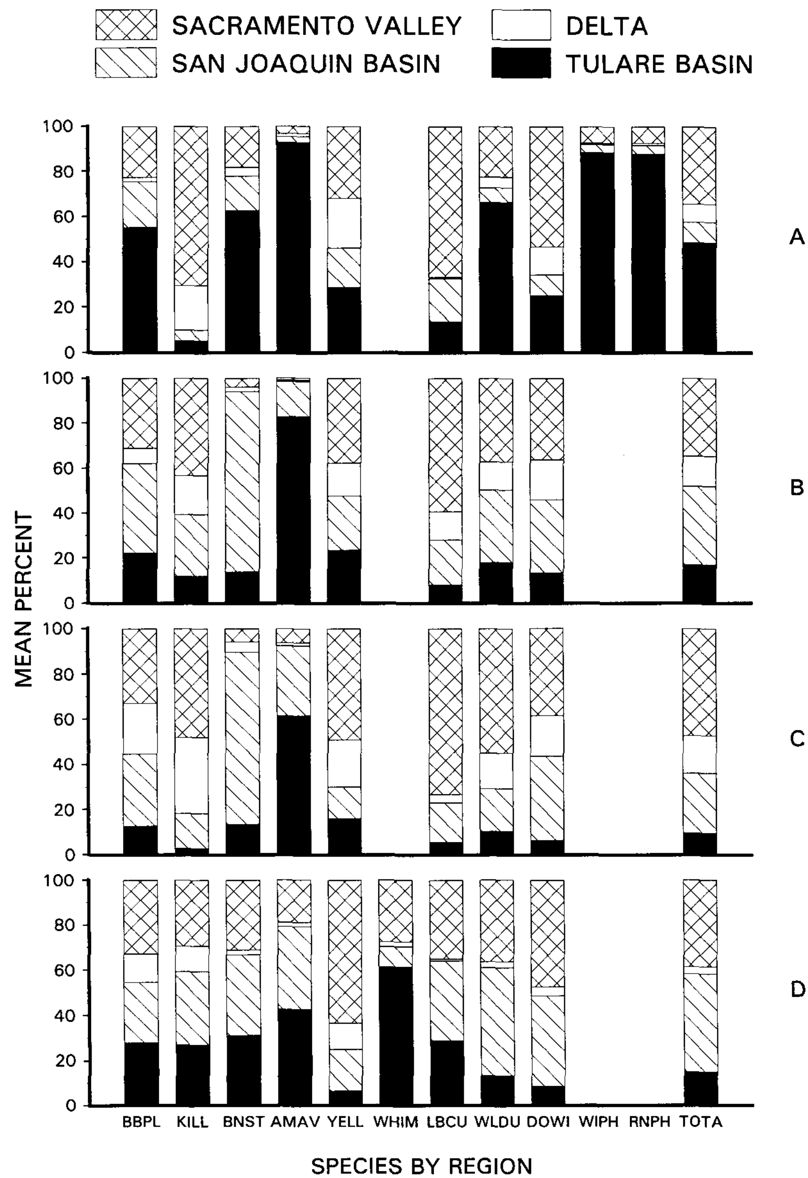

FIGURE 3. Geographic distribution of key shorebird taxa by the major subdivisions of the Central Valley in (A) August, (B) November, (C) January, and (D) April. Data plotted as mean percentage of shorebirds per subdivision of valley by season. BBPL = Black-bellied Plover, KILL = Killdeer, BNST = Black-necked Stilt, AMAV = American Avocet, YELL = yellowlegs spp., WHIM = Whimbrel, LBCU = Long-billed Curlew, WLDU = Western Sandpiper/Least Sandpiper/Dunlin, DOWI = dowitcher spp. (mostly Long-billed Dowitcher), WIPH = Wilson's Phalarope, RNPH = Red-necked Phalarope, TOTA = total shorebirds.

Least Sandpiper and Dunlin in using saline evaporation ponds to a greater and agricultural fields to a lesser degree (Fig. 4B). Use of evaporation ponds by American Avocets decreased from November to January while their use of managed wetlands increased (Fig. 5B and 5C). In both months, the Black-necked Stilt concentrated heavily in managed wetlands (Fig. 5B and 5C), primarily in the San Joaquin Basin (Fig. 3B and 3C).

In January 1993 and 1994, densities of some species varied greatly between habitats in the

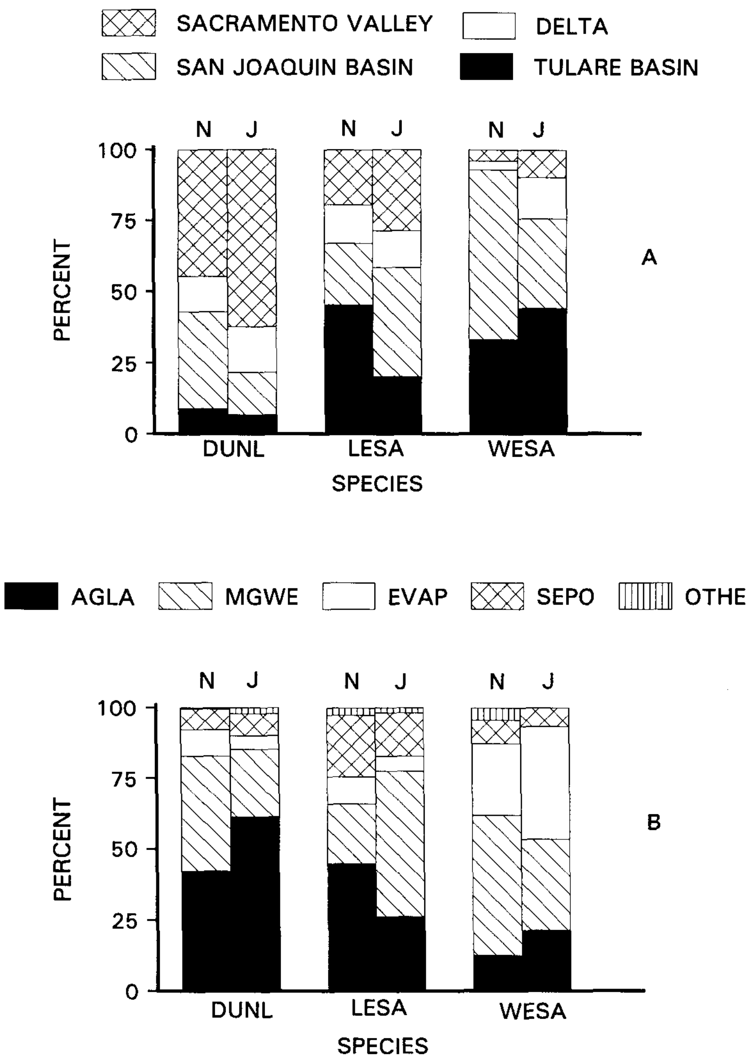

FIGURE 4. Proportions of small sandpipers in November and January in the Central Valley by (A) species by region and (B) species by habitat. DUNL = Dunlin, LESA = Least Sandpiper, WESA = Western Sandpiper; AGLA = agricultural croplands, MGWE = managed wetlands, EVAP = agricultural evaporation ponds, SEPO = sewage ponds, OTHE = miscellaneous other habitats (see Methods).

Sacramento Valley and Delta. Black-necked Stilt densities were significantly higher in managed wetlands than in agricultural fields ($n = 8$, $v = 2$, $P < 0.03$), whereas the reverse was true for the Killdeer ($n = 12$, $v = 6$, $P < 0.01$), yellowlegs ($n = 12$, $v = 11$, $P < 0.03$), and small sandpipers (mostly Dunlin; $n = 12$, $v = 10$, $P < 0.03$). Densities were similar in agricultural fields and managed wetlands for the Long-billed Dowitcher ($n = 12$, $v = 27$, $P > 0.05$). Habitat (Table 1) and abundance (Table 2) data also indicate that Black-necked Stilt densities in managed wetlands were about 9 to 20 times greater in winter in the San Joaquin Basin than in the Sacramento Valley.

In April, most species concentrated in managed wetlands, except for the Black-bellied Plover and Whimbrel, which concentrated in agricultural fields (Fig. 5D).

DISCUSSION

IMPORTANCE OF THE CENTRAL VALLEY

Our surveys show the Central Valley to be one of the most important regions in western North

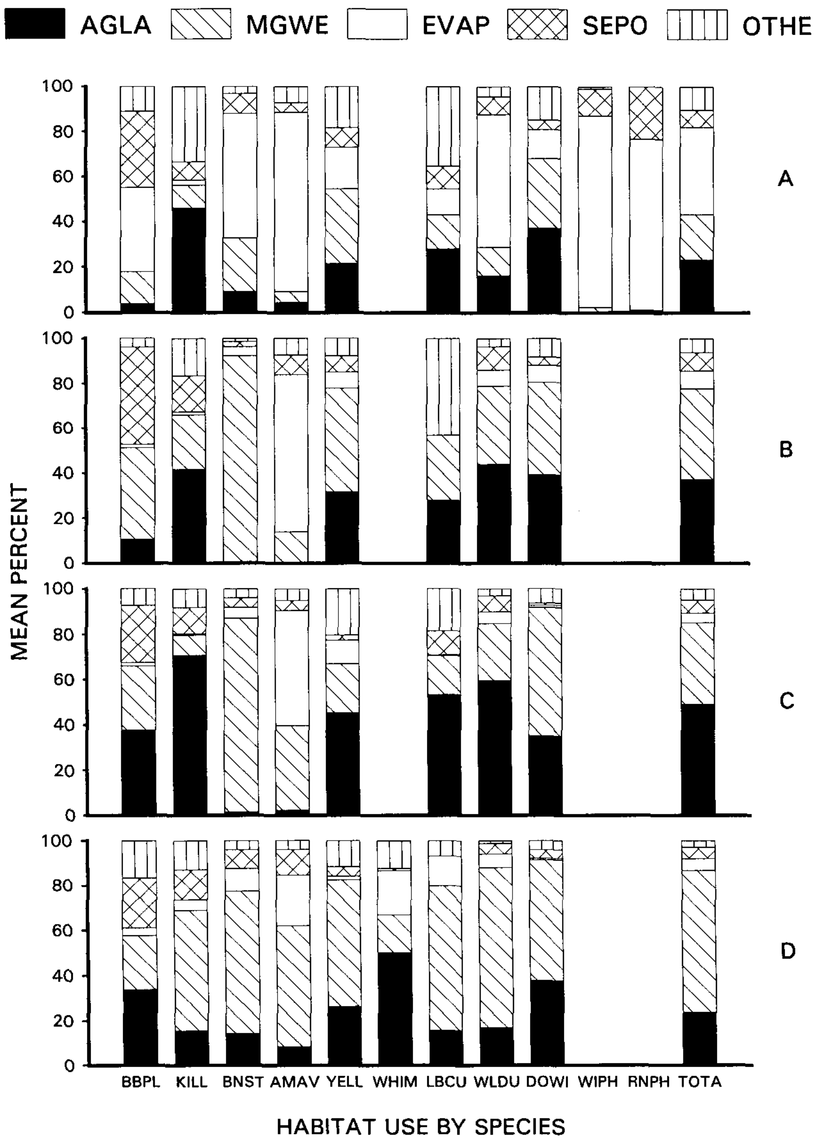

FIGURE 5. Habitat use of key shorebird taxa in the Central Valley in (A) August, (B) November, (C) January, and (D) April. Data plotted as mean percentage of shorebirds per key habitat type by season. AGLA = agricultural croplands, MGWE = managed wetlands, EVAP = agricultural evaporation ponds, SEPO = sewage ponds, OTHE = miscellaneous other habitats (see Methods). See caption for Figure 4 for four-letter species codes.

America for migrating and wintering shorebirds. In winter and spring, the Valley supports more shorebirds than any other inland site, and in winter is the only inland area, other than the Salton Sea in southern California, that supports tens of thousands of shorebirds (PRBO, unpubl. data). Remsen et al. (1991) estimated the rice-growing region of south-central Louisiana may support 225,000 wintering shorebirds and might support the most wintering shorebirds of any area in the interior of North America. By comparison, the Central Valley, which encompasses a larger area, held 261,000 to 374,000 shorebirds during three January surveys. In fall, Great Salt Lake is the only inland site in western North America consistently surpassing the Central Valley in shorebird numbers (PRBO, unpubl. data).

Central Valley shorebird totals equal 22% of those in all wetlands along the California coast in fall, 39% in spring, and 39% in early winter (November) (PRBO, unpubl. data). There were no January surveys of coastal wetlands, but our data indicate November-to-January increases of shorebirds in the Valley, which probably represent a movement of birds inland from the coast (Shuford et al. 1989, Warnock et al. 1995). If the mid-winter increase of shorebirds in the Valley were attributable solely to such movement, the January total for the Valley would equal about 67% of the corresponding coastal total (estimated by reducing the November coastal total by the November-to-January increase in the Valley). Of 12 numerous species with comparable data, 7 had Valley populations exceeding those on the California coast in at least one season: Killdeer (all seasons), Black-necked Stilt (all seasons), American Avocet (April), Greater Yellowlegs (all seasons), Whimbrel (April), Long-billed Curlew (August and winter), and Long-billed Dowitcher (all seasons). Three other species—Black-bellied Plover, Least Sandpiper, and Dunlin—had Valley totals exceeding 50% of their coastal totals in at least one season. At all seasons, except perhaps mid-winter, San Francisco Bay is the only coastal California site with shorebird numbers exceeding those in the Valley (PRBO, unpubl. data).

SEASONAL OCCURRENCE AND STATEWIDE MIGRATION PATTERNS

Occurrence patterns of shorebirds on our Central Valley surveys often conformed closely with patterns in the rest of California. Species richness was highest during migration but was slightly higher in August than April because of the addition in fall of juveniles of some species that are rare to absent in the state in spring (Page et al. 1979, Shuford et al. 1989). A slightly higher number of species in November than January reflected the occurrence of a few late migrants in early November. The Whimbrel was most abundant in the Valley in April and does not occur anywhere in California in large numbers except in spring (PRBO, unpubl. data). The peak occurrence of the Western Sandpiper in April reflected the passage of the most numerous shorebird migrant throughout California in spring (Page et al. 1979, Shuford et al. 1989). Conversely, low numbers of the Long-billed Curlew, Common Snipe, Killdeer, and Greater Yellowlegs in April reflected the early departure of these species to breeding grounds (Nehls 1994). The Dunlin did not occur in large numbers in August because most birds are still staging in Alaska and do not depart in numbers until October (Warnock and Gill 1996). Wilson's and Red-necked Phalaropes were most numerous in July and August, respectively; they stage in large numbers inland in western North America only during fall migration (Jehl 1986, 1988). The staging of the Black-necked Stilt and American Avocet at Tulare Basin evaporation ponds in August paralleled the pattern typical of saline playa lakes in the Great Basin (PRBO, unpubl. data.).

SEASONAL ABUNDANCE, GEOGRAPHIC DISTRIBUTION, AND HABITAT USE

Shorebird distribution and abundance in the Central Valley is influenced simultaneously by species' habitat preferences, seasonal and geographic variation in habitat availability, and north-to-south variation in climatic conditions. Low shorebird numbers in August coincided with the yearly low point in acreage of flooded managed wetlands ($\leq$ 5% flooded; F. Reid, pers. comm.) and non-rice agricultural habitat in the Central Valley. Although rice is still flooded in August, the crop is too mature to leave much open water suitable for shorebirds, and the fall flooding of managed wetlands in September and October is too late for many autumn migrants. The concentration of shorebirds in the Tulare Basin in August reflected mainly an attraction of abundant fall-migrating avocets, stilts, phalaropes, and small sandpipers (Fig. 5A) to the basin's highly productive evaporation ponds (Roster et al. 1992).

The August-to-November increase in shorebird numbers valleywide coincided with extensive fall flooding of managed wetlands throughout the Central Valley, but especially in the San Joaquin Basin and Sacramento Valley, for waterfowl hunting, and the postharvest flooding of Sacramento Valley rice fields for hunting and stubble decomposition. Similarly, a change in the concentration of shorebirds during this period from the Tulare Basin to the San Joaquin Basin and Sacramento Valley also corresponded with these habitat changes and the southward departure of many avocets and stilts and most phalaropes, the species that swelled shorebird numbers at Tulare Basin evaporation ponds in fall. The arrival of large numbers of the late-migrating Dunlin in October also swelled valleywide shorebird populations. The further increase in shorebird numbers by January corresponded with increased shorebird use of agricultural lands (including rice fields) and likely reflected an increase in habitat from winter rains. The increased importance of the Sacramento Valley, in particular, to shorebirds in January (Fig. 3B and 3C), reflected movements of Dunlins and probably Long-billed Dowitchers from coastal estuaries. This was probably related to the greater likelihood of flooding in the Sacramento Valley, where runoff is over three times greater than in the San Joaquin Basin (Kahrl 1979), and the direct linkage of shorebird habitats in the Sacramento Valley and Delta to San Francisco Bay and neighboring coastal wetlands holding large numbers of shorebirds in early winter.

The occurrence of the highest annual shorebird numbers in mid-April corresponded with natural and managed water draw-downs creating shallow-water habitat in ponds and fields during a period of vigorous invertebrate growth. These habitats were used by large numbers of Western Sandpipers and other species (Table 2, Fig. 5D) during the peak of their spring migration. Reduced use of rice fields and increased use of managed wetlands by shorebirds from winter to spring (Fig. 5B–D) corresponded with seasonal water management practices that reduced the extent of shallow water on ricelands and increased it on managed wetlands. Cultivation of rice necessitates draining fields in early spring to prepare for planting, and reflooding of fields too late to be useful to most migrant shorebirds or too deep to be suitable for small shorebirds. Concurrently, much managed wetland habitat is actively drawn down, exposing extensive shallow-water and mudflat habitat during the peak of shorebird migration, a practice which mimics the seasonal evaporation of water in areas flooded naturally by winter rains.

North-south patterns of habitat use by a few species may reflect clines in climatic variables. The negative effect of cooler temperatures on prey availability (Pienkowski 1981) may explain the high proportion of Black-necked Stilts that winter in managed wetlands in the San Joaquin Basin versus the Sacramento Valley and the Black-bellied Plover's avoidance in winter of extensive agricultural fields in the northern Central Valley. At all seasons, the Snowy Plover concentrated primarily at saline evaporation ponds in the Tulare Basin, the most xeric region in the Valley, reflecting the adaptation of inland plover populations to arid climates and, in winter, mild temperatures (Shuford et al. 1995).

YEAR-TO-YEAR VARIATION

Year-to-year variation in shorebird numbers appeared related to water availability, particularly via rainfall. The largest November-to-January increase in shorebird totals was in 1994–1995 when precipitation was 67% above average and extensive flooding occurred in the Valley starting in January. The Dunlin, the species most responsible for this increase, is known to move from the central California coast to the Delta and Sacramento Valley in winter following periods of heavy rain (Warnock et al. 1995). Our surveys further suggest some coast-to-inland movement may occur even in relatively dry years, such as 1993–1994. The Western Sandpiper's similar pattern of increasing winter numbers in the Delta and Sacramento Valley suggests the species makes coast-to-interior movements, but to a much smaller degree than the Dunlin, and primarily in very wet years. The Long-billed Dowitcher also may make such movements. Dowitcher numbers, which increased in the Central Valley, particularly in wet winters (Table 2), sometimes drop dramatically in coastal estuaries after periods of heavy winter rain (Shuford et al. 1989). The Killdeer is not numerous enough in coastal estuaries (PRBO, unpubl. data) to account for its mid-winter increases in the Central Valley (Table 2). The Killdeer's increase may reflect local movements of birds from drier upland sites to flooded fields where prey is probably more available or movement of birds from the north or east in response to cold weather; numbers wintering in Oregon are reduced in severe winters (Nehls 1994).

Low numbers of shorebirds in the Central Valley in April 1992 versus 1993 and 1994 likely reflected, in part, limited habitat after six years of drought. Particularly high numbers of shorebirds in the Grasslands in April 1991 may have been a response to the unusually favorable habitat conditions created by landowners who held water on duck clubs later than normal in a cooperative effort to increase San Joaquin River flows for migrating salmon (Salmonidae; T. Poole, pers. comm.). The highest shorebird numbers recorded in the Tulare Basin in spring coincided with more extensive areas of shallow water on agricultural lands than usual in 1995 after record rainfall the prior winter.

HISTORICAL PERSPECTIVE

Because early descriptions of the Valley's ecosystem and its birdlife are so limited, we will never fully appreciate the former importance of the region's wetlands to shorebirds. Information on historical trends of shorebirds in the Central Valley and California as a whole is almost entirely anecdotal (Grinnell et al. 1918, Grinnell and Miller 1944, Page and Gill 1994). By the early 1900s, shorebird populations in California had declined mostly from market hunting, with large desirable species, such as the Long-billed Curlew, suffering the greatest reduction (Grinnell et al. 1918). Other factors contributing to these declines were habitat loss from land reclamation and cultivation (both locally and at distant breeding grounds), mortality from collisions with telegraph lines and entrapment in oil pools, and nest losses from trampling by cattle. By the 1940s, some species had recovered from market hunting, whereas others, such as the Black-necked Stilt and American Avocet, had declined greatly from reduction of interior marshlands (Grinnell and Miller 1944).

Despite the paucity of historical data on shorebird abundance in the Central Valley, the replacement of over 90% of the Valley's wetlands (Frayer et al. 1989), largely with agricultural habitats, must have had a profound effect on shorebird numbers and distribution in that region. Among the greatest losses was that in the southern San Joaquin Valley of Tulare Lake, formerly the largest freshwater lake and marsh system west of the Mississippi River (Johnson et al. 1993, Thelander and Crabtree 1994). In most years this wetland system, swelled by peak runoff from snowmelt in May and June (Katibah 1984), must have provided very extensive shallow water and mudflat habitat during autumn migration, a period today when, valleywide, shorebird habitat is extremely limited.

Wetland reclamation was abetted by a total alteration of the natural hydrologic regime of the Valley via construction of a vast network of water storage, irrigation, and flood control structures (Kahrl 1979). Formerly, almost annual flooding in winter and spring of the Sacramento Valley's major rivers formed vast flood basins and huge, shallow seasonal lakes, which occurred in a diverse mosaic with permanent wetlands, vernal pools, and an array of upland habitats (Thompson 1961, Katibah 1984, Scott and Marquiss 1984). In normal or wet years, the flood basins of the Sacramento Valley gradually drained in late spring and early summer (California Department of Fish and Game 1983), thus undoubtedly providing extensive shallow water habitat during the peak of spring shorebird migration. By contrast, today in spring most agricultural fields are drained rapidly and early for planting, leaving very limited shorebird habitat in the Sacramento Valley at that season except in managed wetlands. Originally, almost three-fifths of the Delta's 2,000 km^2 was subject to daily inundation by ordinary tides and almost the entire Delta to periodic inundation by winter floodwaters or high tides in spring (Kahrl 1979). It is unclear whether shorebird habitat in the Delta was more suitable under the extremes of original conditions or now when most wetlands have been lost but levees keep out tidal and most flood waters while retaining shallow waters on agricultural fields from intentional flooding or local runoff. The great uncertainties in the historical record underscore the continuing need to study broadscale use of the Valley's wetlands by shorebirds to document changes that will accompany the inevitable future modifications in land use.

THREATS TO SHOREBIRDS

Currently, the main threats to shorebirds in the Central Valley are poor and sometimes toxic water quality, habitat loss or degradation to urbanization, and changing agricultural practices. However, shorebirds should benefit from the sizeable acreage of wetland habitat recently created or enhanced for waterfowl (U.S. Fish and Wildlife Service 1990; D. Paullin, pers. comm.) and the dependable supply of high quality water for many wetlands secured via the 1992 Central Valley Project Improvement Act (Title 34 of Public Law 102-575). Still, the wetlands shorebirds depend upon received only 1% of the states' water supply in 1990 (T. Cervantes, pers. comm.), and future legislation potentially could reverse past gains. Given California's expanding population, arid climate, and water delivery system already operating at capacity (D. Denton, pers. comm.), wildlife will continue to face difficulty in competing with other interests for increasingly expensive water.

As recently as the early 1980s, agricultural drain water used to flood wetlands in the Grasslands resulted in biological accumulation of selenium sufficient to harm reproduction of shorebirds and other wildlife (Ohlendorf et al. 1987). After replacement with uncontaminated water in 1985, selenium levels declined steadily, although concentrations in some species still exceed those known to impair reproduction (Paveglio et al. 1992, 1997, Hothem and Welsh 1994a, 1994b). Concentrations of salts and trace elements, particularly selenium, at evaporation ponds in the Tulare Basin, have impaired reproductive success of Black-necked Stilts and American Avocets (Skorupa and Ohlendorf 1991, Ohlendorf et al. 1993). Shorebirds now face habitat loss as pond owners seek ways to reduce the risk to wildlife by hazing, physically altering ponds to make them less attractive, and creating nearby uncontaminated wetlands as alternative habitat (Moore et al. 1990, Steele and Bradford 1991, Bradford 1992). These efforts have begun without an overall plan for the extent or nature of alternative habitat (C. Taylor, pers. comm.). The evaporation ponds, although artificial, mimic the vast historic playa lakes of the Tulare Basin. Playa lakes provided habitat not only for shorebirds using shallow water habitats but also for the Mountain Plover which used upland alkali flats (Knopf and Rupert 1995). Because it would be most valuable to replace wetlands with hydrologic or ecologic equivalents based on a landscape, rather than an individual project, scale (Bedford 1996), preservation of wetlands in the Tulare Basin should include replacement of saline evaporation ponds with playa lake habitat. Otherwise, creation solely of alternative freshwater habitat could greatly change the composition of the shorebird community.

Use of pesticides in rice fields has caused periodic mortality in waterfowl, raptors, and, rarely, shorebirds, but no chronic problem has been documented (Littrell 1988). Dormant spray pesticides, transported by runoff from Central Valley orchards and fields, however, cause mortality to invertebrates (Kuivila and Foe 1995), and may have detrimental effects on shorebirds by reducing their invertebrate prey in winter.

Urban encroachment also directly threatens wetlands, most notably at the Grasslands wetlands complex (D. Widell, pers. comm.). Urbanization continues to reduce agricultural lands in the Central Valley at a rate among the highest of any region in North America (American Farmland Trust 1995, Sorensen et al. 1997), although the effect on shorebirds remains undocumented.

A $14 billion agriculture industry (California Agricultural Statistics Service 1995) dominates land use in the Central Valley, and its future could tremendously influence shorebird habitat. In addition to urbanization, some Sacramento Valley riceland could be lost to the current expansion of cotton, a less friendly crop to shorebirds, although 80% of this riceland is incapable of supporting other economically viable crops (J. Roberts, pers. comm.). In the Tulare Basin, changing irrigation practices during the past two decades have reduced the amount of shallow-water agricultural habitat available to ducks and shorebirds (Barnum and Euliss 1991, D. Barnum, pers. comm.). Conversely, to meet a legislative mandate to reduce air pollution in the Sacramento Valley (California Rice Straw Reduction Act of 1991, AB-1378), farmers have begun winter flooding of fields as an alternative to burning to dispose of rice stubble. Although the increase in winter-flooded habitat so far has been modest (Spell et al. 1995), it is expected to expand from the current level of 58,000 ha to 77,000–81,000 ha annually (F. Reid, pers. comm.). Intentionally flooded rice fields receive significantly greater use by most waterbirds, including shorebirds, than nonflooded fields (Elphick and Oring, in press).

A FRAMEWORK FOR MANAGEMENT

Compared to the long history of wetland management for waterfowl in the Central Valley (Heitmeyer et al. 1989) and North America (Nichols et al. 1995), management for shorebirds is in its infancy. Although general guidelines are available for managing wetlands for shorebirds in North America (Helmers 1992), they could be made more effective with more accurate information on shorebirds' seasonal and regional distribution patterns, habitat preferences, susceptibility to threats, and responses to particular management practices.

Our study suggests the Western Sandpiper would benefit in winter from enhancement of shallow saline wetlands in the San Joaquin Valley but in spring, when the species is most numerous, it would benefit more from enhancement of wetland and agricultural habitats throughout the Central Valley. Efforts to increase the winter Black-necked Stilt population most profitably would be spent enhancing or restoring managed wetlands in the San Joaquin Valley. Similarly, management for Snowy Plovers at any season should focus on saline wetlands in the San Joaquin Valley, especially in the Tulare Basin. Wintering Dunlin would benefit most from additional freshwater wetlands and agricultural habitats in the Sacramento Valley. Also, the mid-winter movement of large numbers of Dunlin from the coast to the Central Valley highlights the need to integrate management efforts between these two regions. Other species, such as the Black-bellied Plover, Whimbrel, and Long-billed Curlew, will benefit less from enhancement of wetlands than agricultural fields, where they appear to be more numerous. Perhaps the most threatened shorebird in the Central Valley, the Mountain Plover forages almost exclusively in upland habitats, preferring alkali flats, heavily grazed grasslands, and recently cultivated fields (Knopf and Rupert 1995). Whereas factors on the breeding grounds may limit the species' abundance, the scarcity of remaining alkali flats and secondary use of extensive agricultural fields has prompted management of grazing and burning in the Carrizo Plain to enhance the species' wintering habitat (S. Fitton, pers. comm.). Finally, further research is needed to determine the best water levels, drawdown regimes, and levels of invertebrate production for shorebirds that are compatible with other land use priorities, because in the future it may be important to intensively manage remaining habitats to maintain large shorebird populations in the Central Valley.

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