

DISTRIBUTION, ABUNDANCE, AND MIGRATION TIMING OF GREATER AND LESSER SANDHILL CRANES WINTERING IN THE SACRAMENTO-SAN JOAQUIN RIVER DELTA REGION OF CALIFORNIA

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Abstract: The Sacramento-San Joaquin River Delta region of California (hereafter, Delta region) is an important wintering region for the Central Valley Population of greater sandhill cranes (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*), but basic information about the ecology of these birds is lacking to design a biologically sound conservation strategy. During the winters of 2007-08 and 2008-09, we conducted roost counts, roadside surveys, aerial surveys, and tracked radio-marked birds to define the geographic area used by sandhill cranes in the Delta region, document migration chronology, and estimate subspecies-specific abundance. Radio-marked sandhill cranes arrived in our study area beginning 3 October, most arrived in mid-October, and the last radio-marked sandhill crane arrived on 10 December. Departure dates ranged from 15 January to 13 March. Mean arrival and departure dates were similar between subspecies. From mid-December through early-February in 2007-2008, the Delta population ranged from 20,000 to 27,000 sandhill cranes. Abundance varied at the main roost sites during winter because sandhill cranes responded to changes in water conditions. Sandhill cranes used an area of approximately 1,500 km² for foraging. Estimated peak abundance in the Delta region was more than half the total number counted on recent Pacific Flyway midwinter surveys, indicating the Delta region is a key area for efforts in conservation and recovery of wintering sandhill cranes in California. Based on arrival dates, flooding of sandhill crane roost sites should be staggered with some sites flooded in early September and most sites flooded by early October. Maintained flooding through mid-March would provide essential roosting habitat until most birds have departed the Delta region on spring migration.

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Key words: abundance, California, *Grus canadensis*, migration chronology, Sacramento Delta, sandhill cranes, San Joaquin Delta.

California's Central Valley is an important wintering region for sandhill cranes (*Grus canadensis*), both for the Central Valley Population of greater sandhill crane (*G. c. tabida*, hereafter referred to as greater) and the Pacific Flyway Population of lesser sandhill crane (*G. c. canadensis*, hereafter referred to as lesser) (Pacific Flyway Council 1983, 1997). Sandhill cranes are patchily distributed in the Central Valley using areas where agricultural practices appear to meet their ecological needs and undisturbed roost sites are available (e.g., Pogson and Lindstedt 1991). The Sacramento-San Joaquin Delta region of California (hereafter Delta region) is a major wintering site for sandhill cranes in the Central Valley, and is particularly important for greater (Pogson and Lindstedt 1991),

listed as threatened in California (CDFW 2013).

Because of the importance of the Delta region for wintering sandhill cranes, agencies and conservation groups have acquired, enhanced, and managed lands for use by sandhill cranes. Most of this activity has centered on 5 major roost complexes in the Delta region; the Isenberg Sandhill Crane Reserve owned by California Department of Fish and Wildlife (CDFW), Stone Lakes National Wildlife Refuge (NWR) and San Joaquin River NWR owned by U.S. Fish and Wildlife Service (USFWS), Cosumnes River Preserve, established by The Nature Conservancy (TNC) in partnership with the Bureau of Land Management (BLM) and with multiple agency ownerships, and the more recent acquisition of Staten Island by TNC. All these properties include a portion of habitat managed to provide winter roost sites for sandhill cranes.

Periodic monitoring has confirmed sandhill cranes

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are using all areas currently managed for roost habitat (Pogson and Lindstedt 1991, Ivey and Herziger 2003), but basic information about the timing of use and subspecies composition are lacking. Moreover, no annual surveys are conducted to estimate crane abundance and define their distribution in the Delta region. Such basic information is necessary for proper sandhill crane management in the face of new environmental threats. For example, the recent spread of West Nile virus into California has caused landowners and managers to reduce the amount of shallow, standing water that might support mosquitoes during summer and early fall (e.g., CDFW 2007). Data on the timing of arrival and expected abundance over time at key roost sites in fall will provide the information needed to justify the timing and size of flooded roost sites to maintain sandhill crane use on traditional sites.

Our study addresses key questions about the abundance and distribution of sandhill cranes that winter in the California's Sacramento-San Joaquin Delta. Specifically, we quantify the timing of arrival, residence time, and timing of departure at major roost sites, track changes in roost use from fall through winter, estimate subspecies specific sandhill crane abundance, and define the distribution of sandhill crane occurrence in the Delta region during winter. When combined with information on habitat use and individual movements, this information will be critical for the development of biologically sound conservation plans for sandhill cranes wintering in the Delta region.

STUDY AREA

Our study focused on the Delta region but we also collected some information on sandhill crane abundance in the San Joaquin NWR region (Fig. 1). Our study concentrated specifically on several properties managed to provide night roost sites for sandhill cranes that subsequently support most of the sandhill cranes that winter in the Delta region (Pogson and Lindstedt 1991, Ivey and Herziger 2003), including Staten Island, Canal Ranch, Cosumnes River Preserve, Brack Tract, and Stone Lakes NWR. The study area was primarily rural agricultural landscapes bordered by urban communities. Agricultural land uses included field and silage corn, fall-planted (winter) wheat, rice, alfalfa, irrigated pasture, dairies, vineyards and orchards. The area also contained tracts of oak savannah and floodplain wetlands along the Cosumnes and Mokelumne rivers.

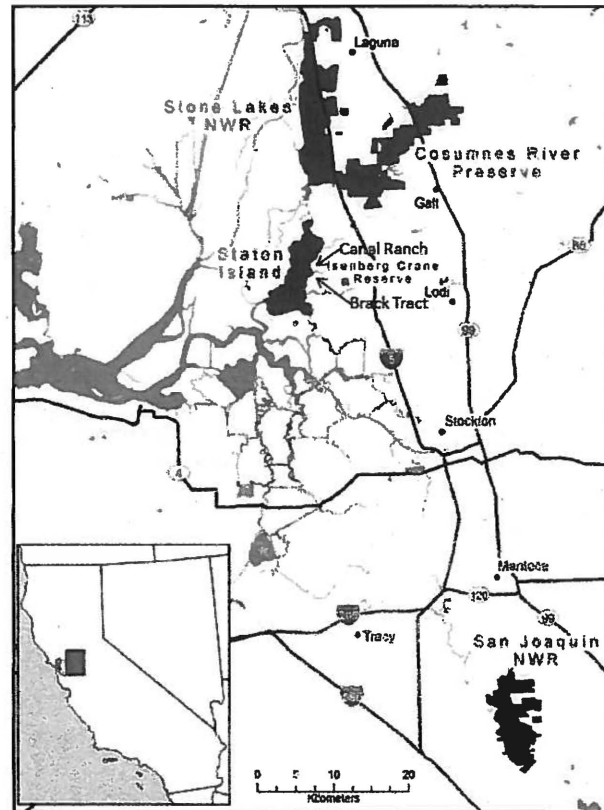


Figure 1. Map of the Sacramento-San Joaquin Delta and the San Joaquin River National Wildlife Refuge where distribution, abundance, and arrival and departure dates of greater and lesser sandhill cranes were studied, 2007-2009. Grey areas are waterways.

The San Joaquin NWR region (located in Stanislaus County, approximately 12 km west of Modesto) includes the refuge and private croplands similar to the Delta region.

METHODS

Capture, Radio-marking, and Tracking

We captured and radio-marked a total of 33 greaters, 44 lessers, and 1 Canadian sandhill crane (*G. c. rowani*; identified morphologically, hereafter referred to as Canadian) on wintering, spring staging, and breeding areas. We captured 33 greaters and 28 lessers using rocket nets baited with corn (Urbanek et al. 1991) and noose lines (Hereford et al. 2000) at Staten Island or Cosumnes Preserve between 17 October 2007 and 27

February 2008. Additionally, to increase our sample of marked birds, we used rocket nets to capture 6 lessers on a spring staging site (Ladd Marsh Wildlife Management Area) near LaGrande, Oregon, in April 2008 and used noose lines to capture 10 lessers on their breeding grounds near Homer, Alaska, in August 2008.

For each sandhill crane captured, we determined subspecies based on morphological differences (Johnson and Stewart 1973). We marked each individual with a U.S. Geological Survey aluminum leg band and a unique combination of color bands. Finally, we radio-marked each sandhill crane with a VHF transmitter (Sirtrack, Hawkes Bay, New Zealand, Model AVL6171) that was mounted to a tarsal band (Krapu and Brandt 2001). Transmitters weighed approximately 30 g (<1% of body mass), had a life expectancy of 730 days, and were equipped with a mortality sensor. The 10 birds captured in Alaska were marked with platform terminal (satellite) transmitters mounted to a tarsal band. All birds were released at their capture site within an hour after capture.

We attempted to locate each radio-marked sandhill crane daily, from October through mid-March, using hand-held 3-element Yagi antennas and a truck-mounted null-peak antenna system (Balkenbush and Hallett 1988, Samuel and Fuller 1996); however, our relocation rate averaged every 2 days, varied by individual, and primarily depended on sandhill crane movement within our study area. We used a Global Positioning System (GPS) linked to a computer system to enter bird identification number, local site name, truck location, date, time, and bird bearings from multiple locations. We used Program Locate III (Pacer Computing, Tatamagouche, NS, Canada) to triangulate locations (Nams 2005). We conducted 7 aerial searches (Gilmer et al. 1981) over the 2 winters of our study of areas throughout central California to locate sandhill cranes that left the Delta region. During aerial surveys, we also mapped locations that looked suitable as sandhill crane night roosts.

Our handling of sandhill cranes was conducted under the guidelines of the Oregon State University Animal Care and Use Committee (project #3605) to ensure methods were in compliance with the Animal Welfare Act and United States Government Principles for the Utilization and Care of Vertebrate Animals Used in Testing, Research, and Training policies. Sandhill cranes were captured under CDFW permit SC-803070-02 and U.S. Geological Survey federal banding permit MB#21142.

Migration Chronology

We used telemetry information from our radio-marked sandhill cranes to characterize fall migration arrival and spring migration departure dates relative to our study area during fall 2008 and spring 2009. We defined arrival date as the first date each sandhill crane was found during fall in the study area and departure date as the last date they were detected in late winter. We calculated the number of days our marked sandhill cranes were at our study sites in the Delta region (i.e., winter residency period) from our telemetry records by totaling days that individuals were found at our study sites in the Delta region. We used the Student's *t*-test to assess if either mean arrival date in fall of 2008 or departure date in spring of 2009 differed by subspecies.

Sandhill Crane Abundance

Roost counts.—We conducted biweekly counts of sandhill cranes at the 5 major night roost complexes in the our study area (Staten Island, Brack Tract, Canal Ranch Tract, Cosumnes River Preserve, and Stone Lakes NWR) between 5 October 2007 and 27 February 2008 to document seasonal patterns of abundance and estimate peak sandhill crane population size in the Delta region. We also conducted roost counts at the San Joaquin River NWR monthly during October 2007 through February 2008. We conducted each count over a period of 2 or 3 days but all sites within each roost complex were counted on the same night or morning. We conducted surveys by stationing observers with binoculars at key locations around a roost complex to count all sandhill cranes as they flew into a roost site at sunset or during early morning before they left their roost. We did not have permission to survey the Canal Ranch roost complex on 3 December, so we report estimates only for 3 dates with complete roost count data.

Aerial surveys.—To generate an unbiased estimate of abundance that included a measure of precision, we conducted aerial surveys (e.g., Caughley 1977, Dugger et al. 2005) on 14 and 28 January and 5 February 2008. We first partitioned the study area into high and low density survey blocks based on our understanding of roost site distribution and relative sandhill crane abundance (Ivey and Herziger 2003). In the Delta region, we created 3 high density survey blocks centered on the major roost complexes at Stone Lakes

NWR, Staten Island and adjacent Brack Tract and Canal Ranch, and the Cosumnes River Preserve. The remainder of the Delta region was classified as a low density survey block. In the San Joaquin NWR region, we identified 1 high density block associated with San Joaquin NWR that was imbedded in a larger, low density, block. We partitioned each survey block into a series of 1-km-wide survey strips oriented north-south. We stratified our sample effort by survey block size and randomly selected (without replacement) a sample of transects to survey within each block, adding transects until the total transect area equaled or exceeded 10% of the total block area. We used the same set of transects for each survey.

We conducted surveys from a fixed-wing aircraft flying 300 m above the ground and at a speed of 160 km/hr. We used markers on the aircraft window to identify transect boundaries, and 2 observers counted sandhill cranes out each side of the aircraft while the pilot flew a line down the middle of each survey strip.

For each survey, we estimated sandhill crane abundance as (Caughley 1977):

$$\hat{Y} = RZ$$

where Z = area of total census

$$R = \text{average density per unit area} = \Sigma y_j / \Sigma z_i$$

where y_j = total sandhill cranes j counted on transect i

$$z_i = \text{area of transect } i$$

variance was calculated as:

$$[N(N-n)/n(n-1)]/(\Sigma y^2 + R^2 \Sigma z^2 - 2R \Sigma yz)$$

We estimated abundance separately for high and low density survey blocks then combined the 2 estimates for an estimate of total population size for each survey. We estimated abundance for the Delta and San Joaquin River NWR regions separately, and provide totals for these 2 regions.

Abundance by subspecies.—Because we could not identify sandhill cranes to subspecies during roost counts or aerial surveys, we conducted roadside surveys at the Cosumnes River Preserve, Staten Island, and Brack Tract to differentiate the subspecies and estimate the relative abundance of greater and lesser in the Delta region. Counts by roadside surveys were conducted biweekly by 2 experienced observers during morning feeding periods (0700-1000 hr) from early October through mid-February in 2007-08 and 2008-09. We counted all flocks from vehicles using binoculars

and spotting scopes and assigned all sandhill cranes observed as greater or lesser using morphological characteristics described by Drewien and Bizeau (1974): 1) greater are approximately 25-33% taller and more massive; 2) greater are lighter gray in late fall and winter; 3) greater have longer and more massive bills in relation to head length; and, 4) greater have sloping foreheads in comparison to lesser which have rounded foreheads. A few sandhill cranes appeared intermediate in size and were likely Canadians. Our abundance estimates for greater probably included a few Canadians, but because only 1 of the 60 sandhill cranes that we captured had the morphological measurements of a Canadian (see Johnson and Stewart 1973), this source of bias is likely very low.

We used the estimate of the ratio of greater to lesser derived from roadside surveys to calculate subspecies-specific abundance for 4 roost count dates (3, 17, 31 December 2007 and 14 January 2008). We could not conduct a roadside survey at the Cosumnes River Preserve on 17 December because of poor road conditions; therefore, we took the mean proportion of the roadside surveys for dates immediately before and after 17 December as our estimate to estimate subspecies proportions for that roost count data. Based on the arrival and departure dates of our radio-marked sandhill cranes, our 3 December to 14 January survey interval occurred after all sandhill cranes had arrived and ended before any birds had departed for spring migration. This interval included the period previously known to support peak numbers of greater in the Delta region (Pogson and Lindstedt 1991). To adjust the total roost count data, we used the proportion estimate generated from the roadside survey that was closest to the roost count date. Finally, because sandhill crane abundance varied by roost complex, we generated proportion estimates (of greater to lesser) separately for each roost complex and applied that ratio to estimate the number of greater and lesser at each roost. To derive relative abundances for roosts where we did not have roadside surveys we used proportions from the next nearest roost area: for Stone Lakes NWR we applied the estimate from the Cosumnes River Preserve; and for Canal Ranch we applied the estimate averaged from Staten Island and Brack Tract. We then summed estimates from each roost to arrive at the total. We did not have data on subspecies proportions for the San Joaquin NWR region because no roadside surveys were conducted there. We report values as mean \pm SE.

Sandhill Crane Distribution

We plotted all locations for radio-marked sandhill cranes on a map of the study area. We supplemented that data with observations of flocks seen from the ground and air during our searches for radio-marked birds. We combined these data sets to generate a map of sandhill crane distribution as well as roost locations in the Delta region.

RESULTS

Migration Chronology

Sandhill cranes were reported arriving in our study area as early as 6 September 2007 (M. Ackerman, personal communication), and 9 September 2008 (B. Tadman, personal communication). In 2008 we detected the first radio-marked lesser on 3 October, and the first radio-marked greater on 4 October. Peak arrival occurred slightly earlier for greater than lessers in 2008 (Fig. 2); however, the average arrival date was similar ($t = 1.22$, $P = 0.23$) between radio-marked greater (13 Oct ± 2 days) and radio-marked lessers (17 Oct ± 3 days). The average departure date was also similar ($t = 1.03$; $P = 0.30$), for greater (25 Feb ± 1 days) and lessers (22 Feb ± 2 days) (Fig. 2). Lessers began departing the study area earlier yet some lingered longer in the Delta region than the greater (latest departure 13 March versus 7 March, respectively). Winter residency was 22% longer for greater (130 ± 7 days) than for lessers (107 ± 4 days; $t = 2.78$, $P < 0.01$).

Abundance

Roost counts.—The total number of roosting sandhill cranes in the Delta region increased from a low of 6,421 (5 Nov 2007) to a high of 27,213 (11 Feb 2008, Fig. 3). The season mean was 15,037 \pm 4,529. Table 1 shows the largest average abundance was recorded at Brack Tract roost complex (7,423 \pm 2,129) followed by Staten Island (4,898 \pm 1,045), Canal Ranch (4,095 \pm 1,425), Cosumnes River Preserve (1,539 \pm 339), and Stone Lakes NWR (345 \pm 40). Early in the season, most sandhill cranes roosted at Staten Island, however as winter progressed sandhill cranes shifted to Brack Tract and by end of winter most sandhill cranes were roosting in the Brack Tract roost complex. Peak counts recorded at each site included 24,487 at Brack Tract, 10,995 at

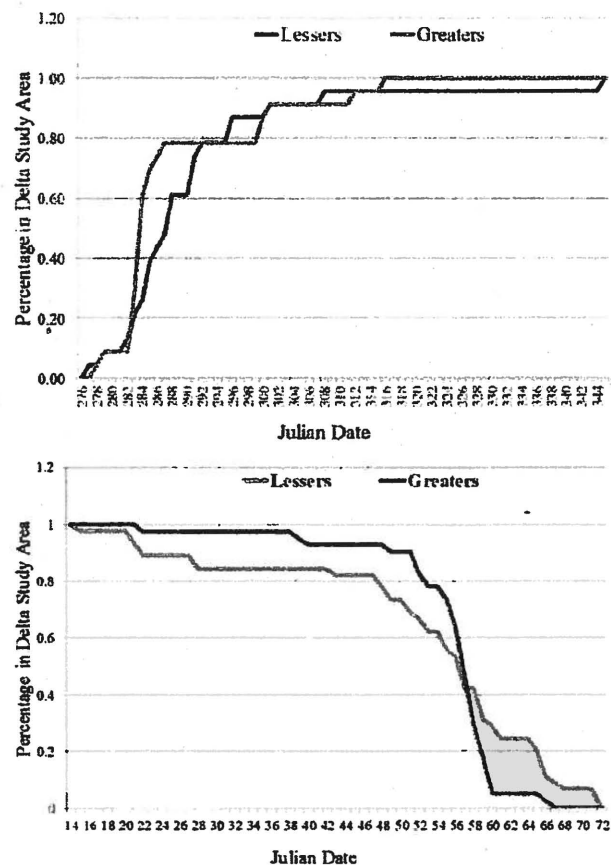


Figure 2. Chronology of arrival in fall 2008 (top) and departure in spring 2009 (bottom) of radio-marked greater and lesser sandhill cranes to the Sacramento-San Joaquin Delta, 2008. The lines represent the proportion of radio-marked birds on the study area at each date. Julian date 276 is 2 October, date 344 is 10 December, date 14 is 14 January, date 66 is 7 March, and date 72 is 12 March.

Staten Island, 7,215 at Canal Ranch, 4,347 at Cosumnes River Preserve, and 598 at Stone Lakes NWR (Table 1). Counts for San Joaquin River NWR averaged 2,310 (± 132), and peaked at 2,895 in February (Table 1).

Aerial surveys.—Based on aerial surveys conducted in 2008, we estimated 19,183 \pm 1,500 (95% CI: 16,243–22,123; Coefficient of Variation [CV]: 0.07) sandhill cranes in the combined Delta and San Joaquin NWR regions on 14 January, 9,028 \pm 769 (95% CI: 7,520–10,535; CV: 0.01) on 28 January and 21,125 \pm 1,903 (95% CI: 17,395–24,855; CV: 0.09) on 5 February. Estimates for the Delta region during those same 3 surveys were 15,687 \pm 843 (95% CI: 14,214–17,519; CV: 0.05), 8,086 \pm 724 (95% CI: 7,362–8,810; CV:

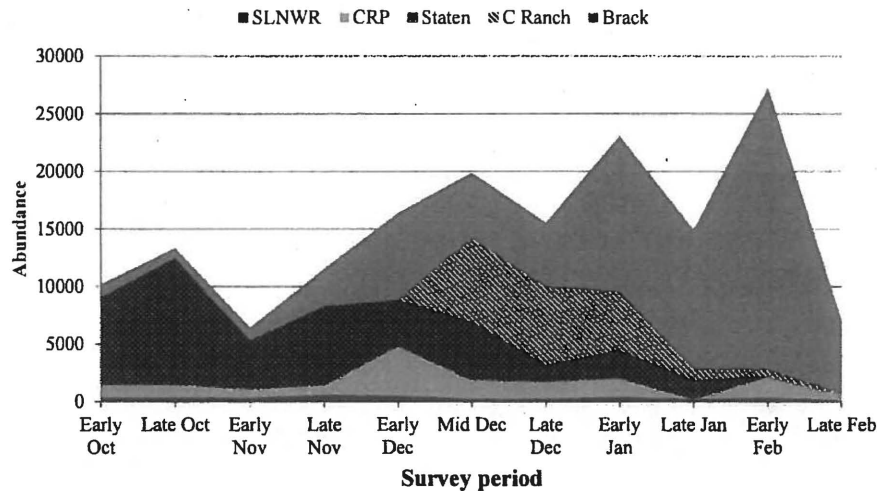


Figure 3. Counts of sandhill cranes (all subspecies combined) at all major roost sites (Brack Tract, Canal [C] Ranch, Staten Island, Cosumnes River Preserve [CRP], and Stone Lakes National Wildlife Refuge [SLNWR]) in the Sacramento-San Joaquin Delta, California, as determined from evening roost counts conducted every 2 weeks during the winter 2007-08.

0.09), and $18,405 \pm 1,795$ (95% CI:14,886-21,923; CV: 0.10), while estimates for the San Joaquin River NWR region during those 3 surveys were $3,496 \pm 657$ (95% CI: 2,208-4,783; CV: 0.18), 942 ± 45 (95% CI: 853-1,030; CV: 0.05), and $2,720 \pm 108$ (95% CI: 2,508-2,932; CV: 0.04), respectively. In the Delta region, only

a few sandhill cranes were observed south of Highway 12 or west of Isleton where we did not conduct roost count surveys, therefore our roost counts included a high percentage of the total Delta region population.

Abundance by subspecies.—The proportion of sandhill cranes that we identified as greater during roadside surveys varied from 1.0% to 80.4% with higher proportions of greater generally observed at the Cosumnes River Preserve than other areas (Table 2). We estimated that the number of greater roosting in the Delta Region ranged from 2,166 to 6,866, while the number of lessers ranged from 12,867 to 17,690 (Table 3).

Table 1. Roost count comparisons of sandhill cranes at all major roost sites (Brack Tract [BT], Canal Ranch [CR], Cosumnes River Preserve [CRP], Staten Island [SI], and Stone Lakes National Wildlife Refuge [SLNWR]) in the Sacramento-San Joaquin Delta region and the San Joaquin National Wildlife Refuge, (SJNWR) California, fall-winter 2007-08.

Week	BT	CR	CRP	SI	SLNWR	SJNWR
08 Oct	1,132	- ^a	1,105	7,565	362	- ^d
22 Oct	852	- ^a	1,137	10,995	358	- ^d
05 Nov	1,083	- ^a	775	4,230	333	- ^d
19 Nov	3,255	- ^a	850	6,846	598	2,537
03 Dec	7,540	- ^b	4,347	3,986	506	- ^d
17 Dec	5,706	7,215	1,650	5,041	251	2,264
31 Dec	5,605	6,758	1,504	1,397	261	- ^d
14 Jan	13,551	5,064	1,621	2,403	417	- ^d
28 Jan	12,140	915	- ^c	1,622	230	2,895
11 Feb	24,487	525	1,834	- ^a	367	- ^d
25 Feb	6,306	- ^a	564	- ^a	113	2,484
Average	7,423	4,095	1,539	4,898	345	

^a Roost site was dry.

^b Did not have permission to survey.

^c Roads were too wet to survey.

^d Did not survey on these dates.

Distribution

Sandhill cranes were found primarily in Sacramento and San Joaquin counties, but also in east Yolo, Solano, and Contra Costa counties (Fig. 4). This area includes both the Central Delta and Cosumnes and Stone Lakes areas, and is approximately 1,500 km², bounded on the west by the Sacramento River and the Deep Water Ship Channel, on the north by Elk Grove and South Sacramento, on the south by Highway 4 to Stockton and on the east by Lodi, Galt, and rural communities of Herald and Wilton. This area includes the Cosumnes River floodplain (below Wilton), the Mokelumne River floodplain (below Galt), the Sacramento River floodplain (below Freeport), and the Delta tracts and islands which lie east of the Deep Water Ship Channel, east of the Sacramento River channel

Table 2. Proportion of greater (G) and lesser (L) sandhill cranes observed during 4 roadside surveys of feeding fields around 3 major roost complexes in the Sacramento-San Joaquin Delta, California, during winter 2007-08. "n" indicates the total number of cranes observed during surveys at all 3 sites.

Week	n	Roost complex					
		Brack		Cosumnes		Staten Island	
		G	L	G	L	G	L
3 Dec 2007	5,180	0.014	0.986	0.182	0.818	0.083	0.917
17 Dec 2007	3,788	0.074	0.926			0.065	0.935
31 Dec 2007	5,416	0.093	0.907	0.783	0.217	0.093	0.917
14 Jan 2008	8,152	0.678	0.322	0.804	0.196	0.014	0.986

between Rio Vista and Antioch, north of Highway 4, and west of Interstate Highway 5.

DISCUSSION

Migration Chronology

Sandhill cranes first arrived in our Delta region study area during the first week of September, earlier than the third week of September as reported by Pogson and Lindstedt (1991) in the mid-1980s. The difference may be due to changes in cropping practices that have benefited sandhill cranes. For example, at Staten Island before the mid-1980s, corn harvest was not begun until mid-September and continued to November. With more corn planted due to the falling price of wheat, the start date for harvest was moved up in order to harvest the entire crop early. Earlier crop harvesting has permitted earlier flooding of harvested fields to serve as roost sites on the island (J. Shanks, personal communication). Possibly some sandhill cranes learned that resources are

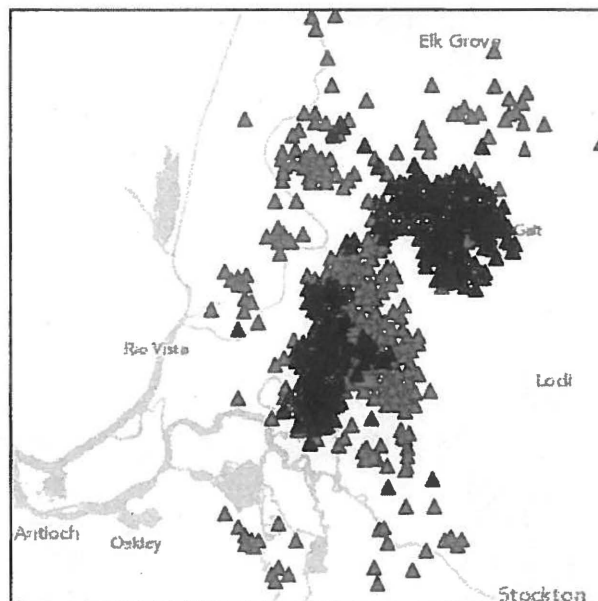


Figure 4. Distribution of greater (black triangles) and lesser sandhill crane (grey triangles) winter foraging locations in the Sacramento-San Joaquin Delta, California, winters 2007-08 and 2008-09, as determined by locations of radio-marked cranes from ground and air surveys.

available earlier in the Delta region and therefore arrived from migration earlier than they had in the past. Also, the earlier arrival might be attributed to an increasing population of greater sandhill cranes since the mid-1980s (see Littlefield 2002) or because the breeding population has expanded southward in the Sierra Nevada to locations that are shorter migration distances from the Delta region (see Ivey and Herziger 2001).

Despite the earlier initial arrival dates of some birds, only a small number of sandhill cranes were present

Table 3. Abundance of greater (G) and lesser (L) sandhill cranes at 5 roost complexes (Brack Tract, Cosumnes River, Staten Island, Canal Ranch, and Stone Lakes NWR) in Sacramento-San Joaquin Delta, California, on 3 dates during winter 2007-08.

Roost	Date					
	17 Dec		31 Dec		14 Jan	
	G	L	G	L	G	L
Brack Tract	422	5,284	521	5,084	3,444	10,107
Cosumnes River	792	858	1,173	331	1,297	324
Staten Island	328	4,713	130	1,267	34	2,369
Canal Ranch	503	6,712	630	6,128	1,757	3,307
Stone Lakes NWR	121	130	204	57	335	83
Total	2,166	17,697	2,658	12,867	6,867	16,190

in September. Our radio-marked birds arrived about 1 month later in October coincident with the arrival of large numbers of sandhill cranes into the region. Despite the considerable difference in the length of migration between subspecies (see Pacific Flyway Council 1983, 1997), the arrival chronology of our radio-marked lessers and greater was similar. These subspecies flocks occasionally share fall staging areas and their movements south may be synchronized by favorable weather conditions for migration to the Central Valley. Arrival dates for lessers to the Delta region were very similar to mean arrival times for lessers to wintering areas in Texas (Krapu *et al.* 2011), despite the fact that lessers wintering in California use different migration routes and staging areas than birds wintering in Texas (Petrula and Rothe 2005, Krapu *et al.* 2011).

During our study, sandhill cranes used roosts throughout our study area into early March, much later than reported by Pogson and Lindstedt (1991), who noted sandhill cranes departed Brack Tract, Staten Island, and Canal Ranch in late January. We attribute this difference to changes in management that currently maintains roosts for sandhill cranes later during winter. The general chronology of spring departure was similar for both subspecies. However, lessers tended to begin their departure earlier than greater but finished departing after the all greater had left.

Abundance

During mid-winter surveys in the Pacific Flyway in 2008 and 2009, 51,981 and 49,238 sandhill cranes were counted, respectively (Collins and Trost 2010). A comparison of our results with previous work in the Delta region suggests the total abundance of sandhill cranes in the Delta region has increased since the 1980s. Previous aerial counts ranged from 3,380 during 1983-1989 (CDFW, unpublished data) to 17,030 in the late 1990s (Ducks Unlimited, unpublished data) and 11,625 in 2000-2001 (CDFW, unpublished data). Roost count and aerial survey data are not directly comparable, but it is likely that the sandhill crane population in the Delta region is higher today than in the 1980s. The highest estimate from our aerial surveys was similar to the estimate from the air in the late 1990s; however, our methods differed because previous surveys were assumed to be complete counts while our estimates were generated using sampling statistics.

Our population estimates from aerial surveys were

relatively precise, with coefficients of variation ranging from 5 to 10% during all but 1 survey. This precision indicates that an aerial-based survey for sandhill cranes in the Delta may be a valid method to estimate their population size or at least derive an index of population size. Such a survey would have to be coupled with ground surveys to derive the percentage of the total population comprised of greater and lessers. The aerial survey estimates were consistently smaller than the abundance estimates from roost counts (on average 37% less), and the roost count estimates were well above the 95% confidence limits for the aerial survey. Given the large discrepancy, additional work is needed to determine the more accurate method of surveying cranes, but aerial surveys may provide a precise index of crane abundance.

The increase in sandhill crane numbers in the Delta region since the 1980s reflects an overall increase in sandhill cranes in the Pacific Flyway from counts of 10,000 in the 1980s to counts of over 50,000 in recent years (Collins and Trost 2010). A comparison of peak counts for the Delta region relative to the total sandhill crane population in the Pacific Flyway indicates about one-third of all sandhill cranes that wintered in the Pacific Flyway used the Delta region during the 1980s. Our peak roost count of >27,000 sandhill cranes in mid-February indicates that more than half of all sandhill cranes in the Pacific Flyway may currently use the Delta region, so both the absolute and relative importance of this region for wintering sandhill cranes has increased since the 1980s. The increase of sandhill cranes in the Delta region could reflect improved roosting and foraging conditions in the Delta region from the conservation efforts of the past 3 decades or could be the result of habitat loss and degradation elsewhere which would force the sandhill cranes to increase their presence in the Delta region.

Roost count data indicate that the population of sandhill cranes using the Delta region increased from October through mid-February. Pogson and Lindstedt (1991) noted a similar pattern for greater during the 1980s. However, our radio-marked greater had all arrived in the Delta region by the end of November and lessers had all arrived by early December. Furthermore, movement data indicate that once greater arrived in the Delta region they were relatively sedentary (Ivey *et al.* 2011). This discrepancy between increases in roost counts and movement data may be because our telemetry results were based on a relatively few

individuals and may not have encompassed movement trends of the population.

Previous to this study only a few population estimates were made of greater and lesser wintering in the Central Valley or the Delta region. Pogson and Lindstedt (1991) estimated 6,800 “large cranes” wintered in the Central Valley in 1983 and 1984, while Littlefield (2002) estimated that 6,000 greater wintered in the Sacramento Valley during the early 1990s. Both estimates apparently combined greater with the Canadian subspecies which are more common in the Sacramento Valley (G. Ivey, personal observation) so their counts are likely biased high. Using roost counts and roadside surveys to allocate total count data to subspecies, our estimate for the number of greater using the Delta region ranged from 2,166 to 6,800. The maximum number of greater counted during a single set of roadside surveys in the Delta region was 1,786. Our estimate of 6,800 is likely biased high because in January large flocks of lesser were using Brack Tract for roosting while foraging to the south in areas not covered by our roadside surveys; therefore greater were over-estimated in our roadside survey proportions. The number of sandhill crane using Brack Tract during the feeding count in January 2008 was less than 3% of the number roosting, further suggesting our estimates of proportions might be biased. In comparison, our roadside surveys counted 24% and 41% of birds roosting at Brack Tract in mid and late December. Therefore, we think that the true number of greater in the Delta region was between 2,000 and 3,000 birds, which is a significant portion of the Central Valley Population. Additional work to develop a more precise survey methodology, including using random sampling of subspecies composition of foraging flocks from ground surveys to assess subspecies composition, and possibly including distance sampling with aerial surveys (see Ridgway 2010), is needed to accurately estimate the population size of each subspecies of sandhill crane wintering in California’s Central Valley.

The changing distribution of sandhill crane among roost complexes in the Delta region was likely in response to changes in roost site conditions. Managers at Staten Island began flooding roost sites relatively early in fall during both years of our study, which attracted early arriving sandhill crane. As winter proceeded additional roost sites at Brack Tract and Canal Ranch were flooded both years, and sandhill crane spread out to take advantage of these sites. By mid-winter during

both years, managers at Staten Island began drying several large roosts which likely induced birds to shift their roosting to nearby Brack Tract. At the Cosumnes River Preserve, roost sites remained available throughout winter and sandhill crane numbers were relatively stable there the entire season. This pattern of habitat use suggests the abundance and distribution of sandhill crane in the Delta region can be influenced by changing the distribution of their roosts.

In addition to responding to habitat changes, the proportion of greater to lesser differed by habitat areas. Greater were proportionately more abundant in the Cosumnes River Preserve and Stone Lakes NWR and lesser dominated in the Central Delta. Reasons for this pattern are not clear but may be related to a preference by lesser for alfalfa (see Ivey *et al.* 2011) which is widely grown in the Central Delta and rarer near the Cosumnes River Preserve and Stone Lakes Refuge. Differences in proportions of the subspecies may have been due to difference in physical characteristics of roosts that favored or constrained use by 1 subspecies compared to the other. Greater are also socially dominant over lesser (G. Ivey, unpublished data), which may have allowed them to dominate proportional use of the Cosumnes River preserve which grew rice, a food resource preferred by both subspecies (Ivey *et al.* 2011).

Distribution

In comparing our data to that from a 1980s study reported in Pogson and Lindstedt (1991), the winter range for sandhill crane in the Delta region has decreased. While development of conservation areas such as Cosumnes River Preserve and Stone Lakes NWR has improved habitat conditions for wintering sandhill crane, significant loss of foraging habitat has occurred over the past 3 decades on private lands in the region (primarily from conversion to vineyards) and such losses are continuing (see Littlefield and Ivey 2000). Within their Delta region winter range, large areas of habitat have been lost primarily due to conversions to incompatible crops (e.g., vineyards and orchards) and to the expansion of the cities of Elk Grove and Galt. Most noticeable has been the increase in grape vineyards, but in more recent years other incompatible crops such as turf farms, olives, and blueberries have further reduced compatible foraging area (Littlefield and Ivey 2000). For example, between 2003 and 2007, approximately

335 ha of cropland used regularly by sandhill cranes at Canal Ranch was converted to olive trees (G. Ivey, personal observation). If such habitat losses continue, this could further influence sandhill crane use of the Delta region and possibly limit the regional carrying capacity for sandhill crane populations in the future.

MANAGEMENT IMPLICATIONS

Based on arrival dates, flooding of some sites managed for crane roosting should begin slowly in early September and managers should provide larger areas for roosting cranes by early October. Maintaining flooded roosts until mid-March when most birds leave the Delta region for spring migration would provide roosting habitat throughout their wintering period. For areas specifically managed for the welfare of greater (e.g., Staten Island) our data suggests that maintenance of roost sites through the first week of March would be beneficial, based on departure times for greater. Our estimates for the population of greater using the Delta region represent a significant percentage of the total population. Therefore, this region should be considered a key area for efforts in conservation and recovery of this listed subspecies.

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