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ASSESSING CHANGES IN THE DISTRIBUTION AND ABUNDANCE OF BURROWING OWLS IN CALIFORNIA, 1993-2007[1]

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Abstract. The Western Burrowing Owl (*Athene cunicularia hypugaea*) has declined in recent decades across much of its range, including California, where it is classified as a Species of Special Concern. During 2006-2007, we surveyed the entire breeding range of the species in California, except the Channel Islands. Relying largely on volunteers, we surveyed 860 5km x 5km blocks, and documented exact locations of 1,758 pairs. Using data from randomly-selected blocks, we extrapolated a statewide, breeding-season population of 9,187 (SE = 2,346) pairs. For all of the species' California range, except the Modoc Plateau and the Mojave and Sonoran deserts, we compared results with those of DeSante et al. (2007) using identical methods and study area boundaries during 1991-1993. Our 2006-2007 estimate of 8,128 (SE = 2,391) pairs was 10.9% lower than the previous estimate, but the difference was not statistically significant. The major patterns of Burrowing Owl occurrence across California appeared to be relatively unchanged since 1993, although non-significant declines were apparent in numerous regions. Burrowing Owls appear to have declined particularly sharply in two urban areas: the San Francisco Bay Area and Bakersfield. Our surveys of previously unsurveyed portions of the species' California range yielded few or no owls in the Modoc Plateau/Great Basin, Northern Mojave/eastern Sierra Nevada, eastern Mojave, and Sonoran Desert regions (excluding the Palo Verde Valley) but detected large aggregations in the Palo Verde Valley and the western Mojave Desert region.

Key words: Burrowing Owl, California, Athene cunicularia, *citizen science*

EVALUAR LOS CAMBIOS EN LA DISTRIBUCIÓN Y ABUNDANCIA DEL BÚHO LLANERO EN CALIFORNIA, 1993-2007

Resumen. El Búho Llanero (*Athene cunicularia hypugaea*) ha disminuido en las últimas décadas en gran parte de su distribución, incluyendo a California, donde está clasificado como una especie de interés especial. Durante el periodo 2006-2007, encuestamos a todo el rango reproductivo de la especie en California, con la excepción de las Channel Islands.

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Dependimos en gran medida de voluntarios para contar búhos en 860 bloques de 5 km x 5 km, y para documentar la ubicación exacta de 1,758 parejas. Usando datos de los bloques seleccionados al azar, extrapolamos una población para la temporada de reproducción en todo el estado de 9,187 (SE = 2,346) pares. En toda la distribución de la especie de California, con excepción de la Modoc Plateau y los Mojave y Sonoran Deserts, se compararon los resultados con los de DeSante et al. (2007) utilizando métodos idénticos y los límites del área de estudio durante 1991-1993. Nuestra 2006-2007 estimación de 8,128 (SE = 2,391) pares fue 10.9% inferior a la estimación anterior, pero la diferencia no fue estadísticamente significativa. Los principales patrones de ocurrencia del Búho Llanero a través de California parece no haberse cambiado desde 1993. Aunque hubo disminuciones evidentes en numerosas regiones, éstas no fueron estadisticamente significativas. La disminución del Búho Llanero fue especialmente marcada en dos áreas urbanas: el San Francisco Bay Area y Bakersfield. Nuestro estudio de las regiones préviamente no investigadas de distribución de la especie de California dio pocos o ningunos búhos en la Modoc Plateau/Great Basin, el norte de Mojave/este de Sierra Nevada, el este de Mojave, y regiones del Sonoran Desert (excluyendo el Palo Verde Valley), pero detectó grande agregaciones en el Palo Verde Valley y la región occidental del Mojave Desert.

Palabras clave: Búho Llanero, California, *Athene cunicularia*, ciencia ciudadana

INTRODUCTION

Burrowing Owls (*Athene cunicularia hypugaea*) in California breed in natural grasslands and a variety of human-modified habitats, including areas of intense agriculture (Cuolombe 1971, DeSante et al. 2004), as well as airports (Thomsen 1971, Barclay 2007b) and other open areas in urban environments (Trulio 1997, Trulio and Chromczak 2007). Once considered "abundant" and "common" throughout California (Baird 1870, Keeler 1891, Grinnell 1915, Dawson 1923), the species has been declining since at least the 1940s (Grinnell and Miller 1944, Remsen 1978, James and Ethier 1989, DeSante et al. 2007) and is now classified as a Species of Special Concern (Gervais et al. 2008, Shuford and Gardali 2008). The species has declined throughout much of its range (Wedgwood 1978, James and Ethier 1989, Sheffield 1997a, Holroyd et al. 2001, Wellicome and Holroyd 2001) with suggested causes including conversion of grassland habitats to urbanization and inhospitable forms of agriculture (DeSante et al. 2007, Gervais et al. 2008), eradication of fossorial mammals (Zarn 1974, Remsen 1978, Holroyd et al. 2001) and perhaps exposure to pesticides and other contaminants (James and Fox 1987, Haug et al. 1993, Sheffield 1997b; but see also Gervais and Anthony 2003).

In the early 1990s, DeSante et al. (2007) coordinated a survey of the species' entire California breeding range, except for the Modoc Plateau/Great Basin region and the Mojave and Sonoran deserts. At that time Burrowing Owl populations in the southern San Francisco Bay region and in the northern and central portions of the Central Valley appeared to have been declining rapidly, and populations elsewhere in the census area, including the coastal slope of central and southern California, had virtually disappeared. DeSante et al. (2007) estimated that the entire survey area contained >9,000 pairs, with 71% of the estimated population occupying the Imperial Valley south of the Salton Sea (an area comprising just 2.5% of the state) and 24% occupying the Central Valley, primarily in the southern portion of the San Joaquin Valley. Prior to the present study, adequate information to assess Burrowing Owl population trends since 1993 was not available, and in the Great Basin and Mojave and Sonoran desert regions no systematic assessment of population size had ever been made.

Local-scale demographic studies of four focal populations (Imperial Valley, Carrizo Plain, Naval Air Station Lemoore, and the San Jose area) suggest highly variable demographic rates (Gervais 2002, Ronan 2002, Gervais and Anthony 2003, Rosenberg and Haley 2004). Breeding Bird Survey (Sauer et al. 2008) trend results for California exist but are difficult to interpret, because the great majority of detections are clustered on a small number of routes in the Imperial Valley, home to one of the largest concentrations of the species anywhere (DeSante et al. 2007).

We undertook the present study to assess how Burrowing Owl distribution and abundance in California may have changed since 1993, and to determine the status of Burrowing Owl populations in the previously unsurveyed Modoc Plateau and desert regions of the state.

METHODS

STUDY AREA

For their 1991-1993 study, DeSante et al. (2007) defined and surveyed 11 distinct geographic regions, comprising the entire California breeding range, except for the Sonoran and Mojave deserts and the Modoc Plateau. To maximize comparability, we retained all of the region boundaries established by DeSante et al. (2007; Fig. 1).

We re-surveyed 8 of the 11 regions defined for the early 1990s survey (Table 1); because populations in the San Francisco Bay Area Coast, Central-western Coast, and Southwestern Coast regions were well studied and known to be very small or extirpated entirely, we opted not to devote volunteer resources to surveying those, but instead to rely on published literature and/or local experts for population estimates.

In addition to resurveying most of the DeSante et al. (2007) regions, we also targeted the state's Modoc/Great Basin and desert, in order to assess the species' heretofore largely unknown abundance and distribution within these areas, and to better understand their relative importance to the state's overall Burrowing Owl population. DeSante et al. (2007) omitted these areas from the 1991-1993 survey because adequate numbers of local volunteer surveyors were not available. We were able to include these regions in the 2006-2007 effort by surveying them with a crew of full-time field technicians, rather than relying on local volunteers.

We divided the previously unsurveyed portions of the California breeding range into five new regions, four of which are described in greater detail in Wilkerson and Siegel (*in press*; Fig. 1): Northern Mojave Desert/Eastern Sierra Nevada, Western Mojave Desert, Eastern Mojave Desert, Sonoran Desert. The fifth, the Modoc Plateau/Great Basin region (Fig. 1), matches the geographic boundaries of the "Jepson area" mapped as "Modoc Plateau" by Hickman (1993) and the California Gap Analysis Project (1998). The region lies entirely above the 610m elevation contour, which was used as the upper limit for high elevation subregions in ten of the 12 regions defined by DeSante et al. (2007). We therefore did not stratify our sampling within this region by elevation. Rather, we classified the entire region as "upland". Because of the presence of large tracts of forested areas that are not suitable Burrowing Owl habitat, we used the Forest Multi-source Landcover Data (California Department of Forestry and Fire Protection 2002) in conjunction with Burrowing Owl habitat characterizations produced for the region by Cull and Hall (2007) to assess the extent of potential habitat within each survey block. All land area above 1,830m was excluded from the sample frame because it consists of mountainous and forested habitat. We classified the remaining survey blocks as having either greater than or less than 50% suitable Burrowing Owl habitat, and then drew our random sample of blocks such that 2/3 had >50% suitable habitat cover and 1/3 had <50% suitable habitat cover. Survey blocks with <5% suitable habitat cover were not included.

SURVEY DESIGN

Within each region previously surveyed by DeSante et al. (2007), we used the grid defined for their 1991-1993 survey, which divides all the land in the study area into 5-km by 5-km blocks, oriented and referenced according to the Universal Transverse Mercator (UTM) system. Each block was classified as belonging primarily to the lowland subregion or the upland subregion, using a set of classification rules that varied slightly by region (see details in DeSante et al. 2007). Survey effort was stratified by elevational subregion because Burrowing Owl densities are generally much higher in lowland areas throughout California than in upland areas (DeSante et al. 2007). For logistical reasons, we discarded the small number of blocks that could not be accessed anywhere by roads, and then stratified sampling effort among the remaining blocks by region and subregion, randomly selecting as many blocks as we

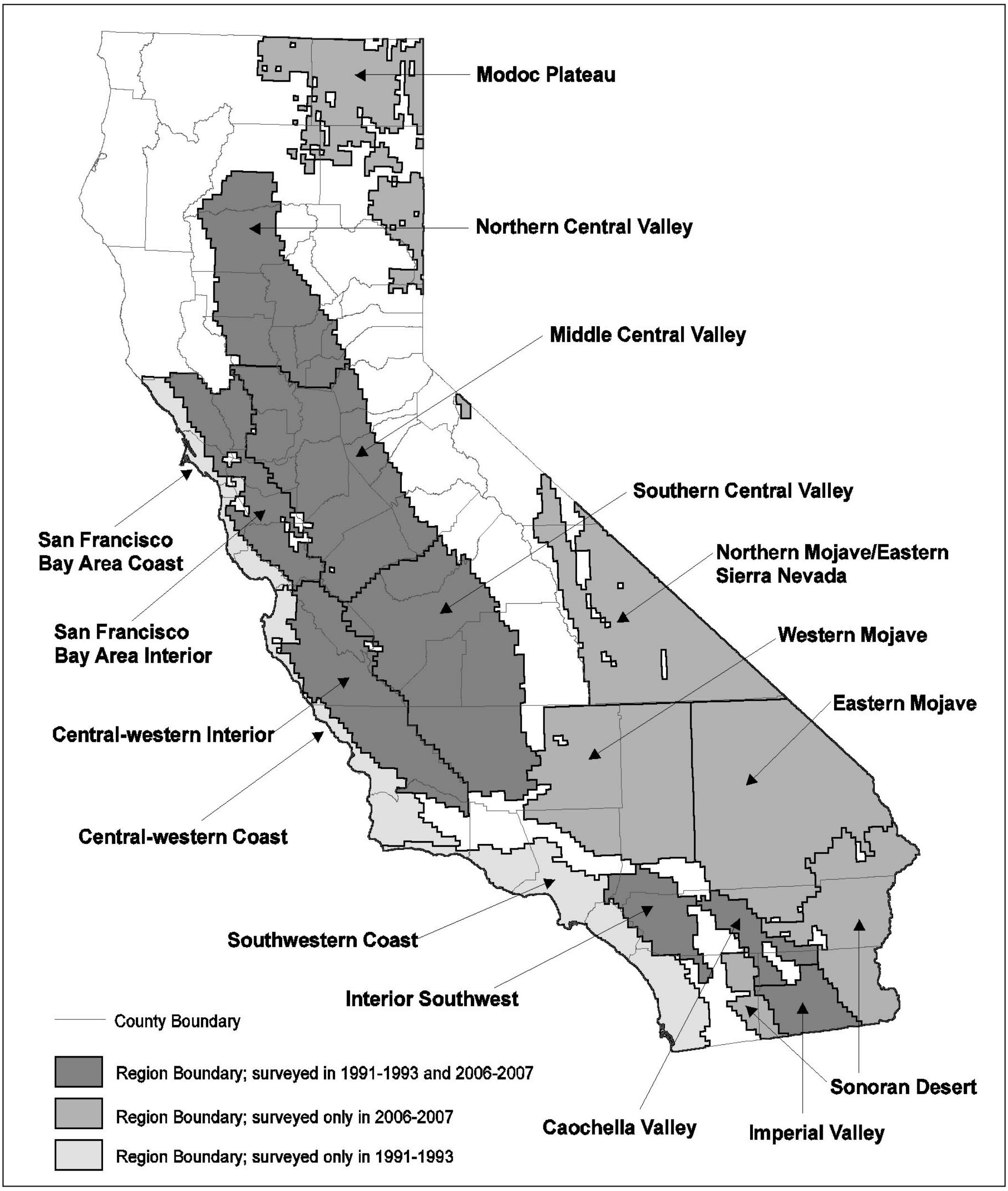

FIGURE 1. Burrowing Owl regions delineated and surveyed for The Institute for Bird Populations' 1991-1993 and/or 2006-2007 statewide Burrowing Owl surveys.

thought we would have the manpower to survey. Blocks in each region were then assigned to be surveyed in a randomly determined order to avoid bias if our volunteers and field crew were unable to survey all of the selected blocks.

We used Geographic Information System (GIS) software to define grids of 5-km by 5-km blocks covering each of the four new regions in a manner consistent with the previously established grid. The 1991-1993 survey drew from a sampling frame of 5,990 blocks (DeSante et al. 2007). The five new survey regions

TABLE 1. Regions of California defined and surveyed for The Institute for Bird Populations' California Burrowing Owl surveys during 1991-1993 and/or 2006-2007.

Region	Status during 2006-2007 survey
Regions surveyed during the 1991-1993 survey	
Northern Central Valley	Resurveyed
Middle Central Valley	Resurveyed
Southern Central Valley	Resurveyed
San Francisco Bay Area Interior	Resurveyed
San Francisco Bay Area Coast	Not resurveyed – population extirpated
Central-western Interior	Resurveyed
Central-western Coast	Not resurveyed – population likely extirpated
Southwestern Coast	Not resurveyed – small, well-known population
Southwestern Interior	Resurveyed
Coachella Valley	Resurveyed
Imperial Valley	Resurveyed
Regions not previously surveyed	
Modoc Plateau/Great Basin	Surveyed for the first time
Northern Mojave Desert/Eastern Sierra Nevada	Surveyed for the first time
Western Mojave Desert	Surveyed for the first time
Eastern Mojave Desert	Surveyed for the first time
Sonoran Desert	Surveyed for the first time

contained an additional 4,991 blocks. After removing those regions from the 1991-1993 survey we decided not to survey, our sampling frame contained a total of 9,823 blocks.

Random sample blocks were selected separately by region and elevation stratum. The selected number of blocks to be visited in each subregion was proportional to its size and amount of estimated surveyor effort available over the two-year survey period. Because Burrowing Owls are known to be more abundant in the lower elevation strata throughout our sample area (DeSante et al. 2007), low elevation blocks comprised 2/3 of the random sample selected to be visited while high elevation substrata blocks comprised 1/3 of selected random sample blocks in all survey regions.

We also identified additional blocks (hereafter, "historic breeding blocks") where Burrowing Owls were known to have been detected during the breeding season in any year since 1981. Historic breeding blocks were identified by querying or consulting the following sources for historical detections: the database compiled by DeSante et al. (2007), which includes Burrowing Owls detected during the 1991-1993 survey as well as historical detections gathered from multiple sources from the decade prior to that survey; the California Natural Diversity Database (CNDDB; California Dept. Fish and Game 2006); and knowledgeable researchers and birders with local expertise throughout the state.

Based on previous knowledge from the 1991-1993 survey, we estimated that it was feasible to visit approximately 670 blocks in the eight regions being resurveyed, and 230 blocks in the five new survey regions, for a total of 900 blocks. Prior to the 2006 field season, we identified 500 historic breeding blocks (459 historic breeding blocks in the eight regions surveyed in 1991-1993 and 41 historic breeding blocks in the five new survey regions); a few additional historic blocks were identified during the course of our two-year survey. We also selected 520 random blocks to be surveyed: 340 in regions scheduled to be resurveyed and 180 in the new regions, of which 47 also happened to be historic breeding blocks in which Burrowing Owls had been detected during the 1991-1993 survey. The total number of blocks drawn for surveying during 2006-2007 was 973 (slightly more than we thought we could survey, in case some selected blocks proved to be inaccessible or we were able to sample more blocks than we anticipated).

All selected blocks were assigned to a randomly generated order. In each subregion, half of all blocks in each elevation stratum and each category (random or historic) were

TABLE 2. Number of blocks surveyed, Burrowing Owl pairs found, and population estimate for each geographic region surveyed during 2006-2007 that was also surveyed in 1991-1993 by DeSante et al. (2007). For each region and elevational subregion, we considered our "best estimate" of the number of pairs in 2006-2007 to be the larger of a) the extrapolated estimate of pairs, based only on results from randomly-selected blocks, or b) the actual number of pairs counted, pooling data from randomly-selected blocks and historic breeding blocks.

		All blocks			Random blocks only				
Region	Total area of region (km2)	Random & historic breeding blocks surveyed	Square km surveyed	No of pairs found	Random blocks surveyed	Square km surveyed	No. of pairs found	Estimated no. of pairs (SE)	"Best estimate" of no. of pairs (SE)[a]
Northern Central Valley									
Lowland	10,900	37	822	12	22	497	0	0	12
Upland	8,975	11	252	0	11	252	0	0	0
All	19,875	48	1,074	12	33	749	0	0	12
Middle Central Valley									
Lowland	16,400	174	3,903	339	59	1,265	34	502 (209)	502 (209)
Upland	10,858	25	433	43	12	236	0	0	43
All	27,258	199	4,336	382	71	1,501	34	502 (209)	545 (209)
Southern Central Valley									
Lowland	18,650	121	2,902	204	63	1,544	72	968 (342)	968 (342)
Upland	13,025	43	714	32	18	323	3	145 (118)	145 (118)
All	31,675	164	3,616	236	81	1,867	75	1,113 (460)	1,113 (460)
San Francisco Bay Area Interior									
Lowland	4,903	69	1,592	98	20	447	0	0	98
Upland	6,275	21	515	14	12	290	1	21 (21)	21 (21)
All	11,178	90	2,107	112	32	737	1	21 (21)	119
Central-western Interior									
Lowland	5,325	20	308	8	17	276	0	0	8
Upland	11,225	24	477	13	13	233	2	76 (51)	76 (51)
All	16,550	44	785	21	30	509	2	76 (51)	84
Southwestern Interior									
Lowland	1,250	12	301	37	3	75	1	17 (17)	37
Upland	5,050	56	1,265	113	8	173	0	0	113
All	6,300	68	1,566	150	11	248	1	17 (17)	150
Coachella Valley									
Lowland	1,615	10	245	12	4	100	1	16 (16)	16 (16)
Upland	2,350	10	251	37	4	100	0	0	37
All	3,965	20	496	49	8	200	1	16 (16)	53

TABLE 2. Continued.

		All blocks			Random blocks only				
Region	Total area of region (km2)	Random & historic breed-ing blocks surveyed	Square km surveyed	No of pairs found	Random blocks surveyed	Square km surveyed	No. of pairs found	Estimated no. of pairs (SE)	"Best estimate" of no. of pairs (SE)[a]
Imperial Valley									
Lowland	2,810	12	301	499	5	126	254	5,701 (2,244)	5,701 (2,244)
Upland	1,780	3	53	22	2	50	17	707 (140)	707 (140)
All	4,590	15	354	521	7	176	271	6,408 (2,384)	6,408 (2,384)

[a] For each subregion we considered our "best estimate" of the number of Burrowing Owl pairs to be the larger of a) the extrapolated estimate of pairs, based only on results from randomly-selected blocks, or b) the actual number of pairs counted, pooling data from randomly-selected blocks and historic breeding blocks. We then summed the "best estimate" for each subregion to obtain "best estimates" for each region.

assigned to observers for sampling in year one (2006) based on the firing order. All random and historic blocks not sampled in 2006 were assigned to be surveyed in 2007. Most blocks were sampled during one of the two years in our survey period. In the few instances that a block was surveyed during both years (generally because volunteer observers became interested in "their" blocks during 2006 and independently chose to resurvey them in 2007), we used data from the first survey year (2006) in our analysis.

DATA COLLECTION

Adhering to the strategy developed by DeSante et al. (2007), we relied largely upon volunteer observers, many associated with local California Audubon Society chapters, to collect our field data in the regions that were surveyed during 1991-1993. We also deployed a crew of full-time field biologist technicians to a) survey some of the blocks in regions where the number of volunteer observers was inadequate to reasonably survey all the selected blocks, and b) survey all of the selected blocks in the Sonoran, Mojave, and Great Basin regions, where potential volunteers were very scarce.

Volunteer surveyors and IBP field crews surveyed blocks using the field methodology developed for the 1991-1993 survey (DeSante et al. 2007). For most regions, surveyors were instructed to visually scan all of the area in their blocks at least once during morning (dawn to 10:00 AM) or late-afternoon (4:00 PM to dusk) during the two-month period between May 15 and July 15, when breeding Burrowing Owls are likely to be feeding nestlings or recently-fledged young. The survey season was shifted two weeks earlier in the Western and Eastern Mojave Desert, Sonoran Desert, Southwestern Interior, and the Coachella and Imperial Valley regions to account for phenological differences among areas.

We provided surveyors with 1:24,000 scale topographic maps with survey block boundaries and clearly marked locations of any owls known or suspected to have bred anytime since 1981. Surveyors delineated the extent of appropriate habitat in their block, visually scanned all areas of appropriate habitat for owls, and plotted the locations of any detections on their maps. For each detection location, observers provided a count of all owls seen (identified to age and sex, if possible), an estimate of the number of breeding pairs present, and standardized habitat information. The latter included information on vegetation community type and structure, land use, distance to irrigation canals, local abundance of ground squirrels, and other variables. Finally, observers provided a detailed assessment of how much of their block they were actually able to survey adequately. In some cases this was <100%, due to private property restrictions or physiographic barriers.

For each region (except for the Modoc Plateau and desert regions where we relied strictly on IBP field crews) we recruited one or more local area coordinators, who helped recruit volunteers and coordinate their efforts. Prior to the start of the first field season, we developed a training presentation to explain the rationale and goals of the survey, provide tips for identifying Burrowing Owls and determining their age and sex, and teach volunteers how to conduct the survey and complete data forms in a standardized manner. We gave the presentation at eight live meetings and workshops, and also posted it as an online presentation on our website so that it was available to volunteers who could not attend a local training session. We also prepared a detailed data collection protocol which was provided to all observers prior to data collection.

STATISTICAL ANALYSES

We estimated the number of breeding pairs in each subregion and region surveyed. First we calculated the density of breeding pairs on each randomly-selected surveyed block, as the quotient of the number of pairs observed divided by the area of the block that was adequately surveyed. Densities were then averaged across all randomly-selected blocks surveyed in each subregion. Estimates are presented with standard errors, except in cases where the estimate was zero pairs and the SE could not be calculated.

For each subregion and region, we also totaled the actual number of pairs detected, as the sum of all pairs found on randomly-selected blocks plus all pairs found on historic breeding blocks. We present these totals without standard errors, since they are minimum counts rather than statistical estimates.

For each subregion, we considered our "best estimate" of the number of Burrowing Owl pairs to be the larger of a) the extrapolated estimate of pairs, based only on results from randomly-selected blocks, or b) the minimum number of pairs counted, pooling data from randomly-selected blocks and historic breeding blocks (in other words, we only used the minimum count as our "best estimate" if it was larger than the extrapolated estimate). We then summed the "best estimate" for each subregion to obtain "best estimates" of the number of pairs in each region, and across the state.

For subregions and regions surveyed in the 1990s, we compared the 2006-2007 population estimate (no. of pairs) with the estimate obtained for 1991-1993 by a) using Levene's Test to determine whether variances for the two estimates were similar, and then b) using F-tests to assess statistical significance of differences between the estimates (Zar 1984). Such comparisons were only possible when our best estimate for the number of pairs in a region was derived from randomly-selected sample blocks; in cases where our "best estimate" was the actual number of pairs counted (aggregating results from randomly-selected blocks and historic breeding blocks) there was no variance associated with the estimate, so we provide only qualitative, rather than statistical, assessments of population change since the early 1990s.

We used ArcMap to determine land ownership (public versus private) or land managing agency (various federal agencies, state government, local government, tribal areas) at all occupied sites, based on the California Department of Fish and Game Region 6 Spatial Data Framework's Public and Conservation Lands shapefile ("govconfee_1").

We used a paired t-test to assess whether owl abundance changed between the 1991-1993 and 2006-2007 surveys for historic breeding blocks where owls were detected during 1991-1993. We used logistic regression to assess whether the probability of detecting owls on these blocks during 2006-2007 was related to the number of owl pairs detected on them during 1991-1993.

RESULTS

With the help of 21 local coordinators, we recruited 394 volunteers to participate in surveying one or more blocks during the 2006 or 2007 field season. These volunteers spent over 6,400 hr surveying blocks and completing data forms. Their efforts were augmented by our full-time crews of field biologist technicians, who largely focused their efforts in the new survey regions, where few volunteers were available, and in the southern Central Valley, where the large number of historic breeding blocks surpassed the survey capacity of the local pool of volunteers.

During our 2006-2007 efforts we were able to complete surveys at 453 of the 500 historic breeding owl blocks identified prior to the start of the 2006 field season; 47 historic breeding blocks thus went unsurveyed. However, 24 of those unsurveyed historic breeding blocks were surveyed but yielded no owl detections during the 1991-1993 survey. In other words, the occupancy records were from before 1991-1993, and occupancy could not be confirmed during the 1991-1993 survey. Thus, only 26 historic blocks known to have owls during the 1991-1993 survey went unsurveyed during 2006-2007.

We completed surveys of 860 blocks during 2006-2007. Of these, 444 were randomly selected, and 453 were historic breeding blocks (37 of which were also randomly selected and were treated as random blocks in our analysis). During the course of this survey, we documented the exact locations of 1,758 Burrowing Owl pairs, and have provided this information to the California Department of Fish and Game for their conservation planning purposes.

INDIVIDUAL REGIONS

NORTHERN CENTRAL VALLEY

We surveyed 33 randomly-selected and 15 historic breeding blocks in this region (Fig. 2). We detected no burrowing owls in the random blocks and 10 pairs in the historic breeding blocks; 2 pairs were incidentally detected outside our targeted blocks. All pairs were detected on lowland blocks in Tehama and Yuba counties.

Our random-sample based population estimate for this region is zero. Using our criteria stated earlier, the "best estimate" is 12 pairs for the lowland subregion and zero for upland subregion. The number of Burrowing Owl pairs detected in the region declined only moderately, from 18 pairs to 12 pairs between the 1991-1993 and 2006-2007 surveys, but because 11 pairs were found on randomly-selected blocks during 1991-1993 (compared to no owls detected on randomly-selected blocks during 2006-2007), DeSante et al. (2007) extrapolated their early 1990s findings to estimate that 231 pairs were present in the region, a number greatly in excess of both our estimate of zero pairs extrapolated from random blocks only ($\chi^2_1 = 4.274$, $P = 0.039$; Table 3) and our "best estimate" of 12 pairs, reflecting the actual number of pairs we detected on all blocks surveyed (Table 4).

MIDDLE CENTRAL VALLEY

We surveyed 71 randomly-selected blocks and 128 historic breeding blocks in this region (Fig. 3). Surveys of random blocks yielded 34 Burrowing Owl pairs, and surveys of historic breeding blocks yielded 348 pairs, for a total of 382 pairs. Substantial concentrations of owls were located in lowland areas of Yolo, Solano, Sacramento, Contra Costa, and San Joaquin counties. However we found only two pairs in all of Stanislaus County, and detected only one pair incidentally in Merced County. We found no Burrowing Owls in the upland (foothill) blocks of western El Dorado, Amador, Calaveras, Tuolumne, and Merced counties.

In the 59 randomly-selected lowland blocks surveyed, we found 34 owl pairs, yielding a random-sample based estimate of 502 ± 209 pairs. This estimate was greater than the total number of pairs we actually found in the lowland subregion (34 pairs on randomly-selected blocks plus 305 pairs on historic breeding blocks), so it serves as our "best estimate" for the upland subregion. No owls were detected on randomly-selected upland blocks anywhere in the region, so our random-sample based estimate for the upland subregion is zero pairs. However, we found 43 pairs on upland historic breeding blocks, so our "best estimate" for the upland subregion is the actual number of pairs we found in upland blocks: 43 pairs. Summing our estimate of 502 ± 209 pairs in the lowland subregion and our count of 43 pairs on the upland blocks surveyed, our estimate for the Middle Central Valley region is 545 pairs, 8.2% fewer than the 594 pairs DeSante et al. (2007) estimated to be present in the early 1990s (Table 4).

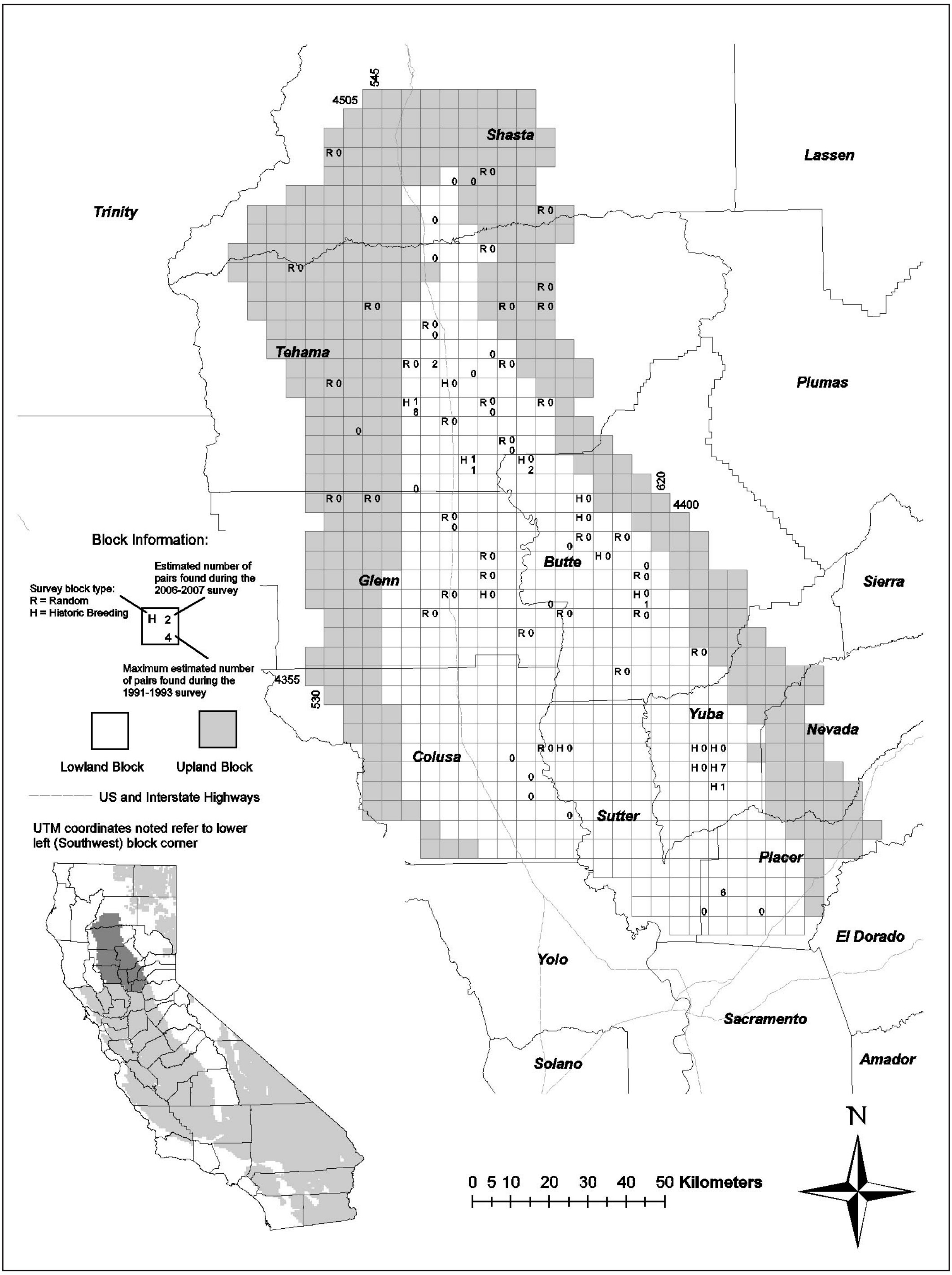

FIGURE 2. Results from the Northern Central Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Northern Central Valley region are shown in the inset.

TABLE 3. Comparison of Burrowing Owl regional population estimates extrapolated from randomly-selected blocks for regions that were surveyed during both the 1991-1993 and 2006-2007 surveys. Although we present extrapolated population estimates for all regions here, in many cases the extrapolated number of pairs based on random blocks only was not judged to be the "best estimate" of the regional population.

	1991-1993 survey		2006-2007 survey			
Region	No. of random blocks surveyed	Extrapolated no. of pairs (SE)	No. of random blocks surveyed	Extrapolated no. of pairs (SE)	Change in estimated no. of pairs	Percent change in estimated no. of pairs
Northern Central Valley						
Lowland	22	231 (153)	22	0	-231	-100%
Upland	2	0	11	0	0	n/a
All	24	231 (153)	33	0	-231	-100%
Middle Central Valley						
Lowland	163	577 (122)	59	502 (209)	-75	-13.0%
Upland	28	17 (17)	12	0	-17	-100%
All	191	594 (139)	71	502 (209)	-92	-15.5%
Southern Central Valley						
Lowland	41	1,000 (410)	63	968 (342)	-32	-3.2%
Upland	11	396 (182)	18	145 (118)	-251	-61.4%
All	52	1,396 (592)	81	1,113 (460)	-283	-20.3%
Entire Central Valley	267	2,221 (884)	185	1,615 (669)	-606	-27.3%
San Francisco Bay Area Interior						
Lowland	86	41 (20)	20	0	-41	-100%
Upland	25	0	12	21 (21)	+21	n/a
All	111	41 (20)	32	21 (21)	-20	-51.2%
Central-western Interior						
Lowland	14	0	17	0	0	n/a
Upland	16	31 (27)	13	76 (51)	+45	+145.2%
All	30	31 (27)	30	76 (51)	+45	+145.2%
Southwestern Interior						
Lowland	4	100 (100)	3	17 (17)	-83	-83%
Upland	10	127 (81)	8	0	-127	-100%
All	14	227 (181)	11	17 (17)	-210	-95.2%
Coachella Valley						
Lowland	5	0	4	16 (16)	+16	n/a
Upland	6	0	4	0	0	n/a
All	11	0	8	16 (16)	+16	n/a
Imperial Valley						
Lowland	15	6,429 (1,135)	5	5,701 (2,244)	-728	-11.32%
Upland	1	142	2	707 (140)	+565	+397.9%
All	16	6,577	7	6,408 (2,384)	-163	-2.6%

SOUTHERN CENTRAL VALLEY

We surveyed 81 randomly-selected blocks and 83 historic breeding blocks in this region (Fig. 4). Surveys of random blocks yielded 75 Burrowing Owl pairs, and surveys of historic breeding blocks yielded 161 pairs, for a total of 236 pairs.

Owls were considerably more abundant in the southern portion of this region than in the northern portion. We found Burrowing Owls in only one survey block in Madera County (though it had 12 pairs), and our detections were nearly as sparsely distributed in Fresno and Kings counties. We found substantial concentrations only in Tulare and Kern counties. As in the other Central Valley regions, the great majority of owls we found were in lowland blocks; in the upland blocks covering the Sierra foothills we found owls in just one block in each

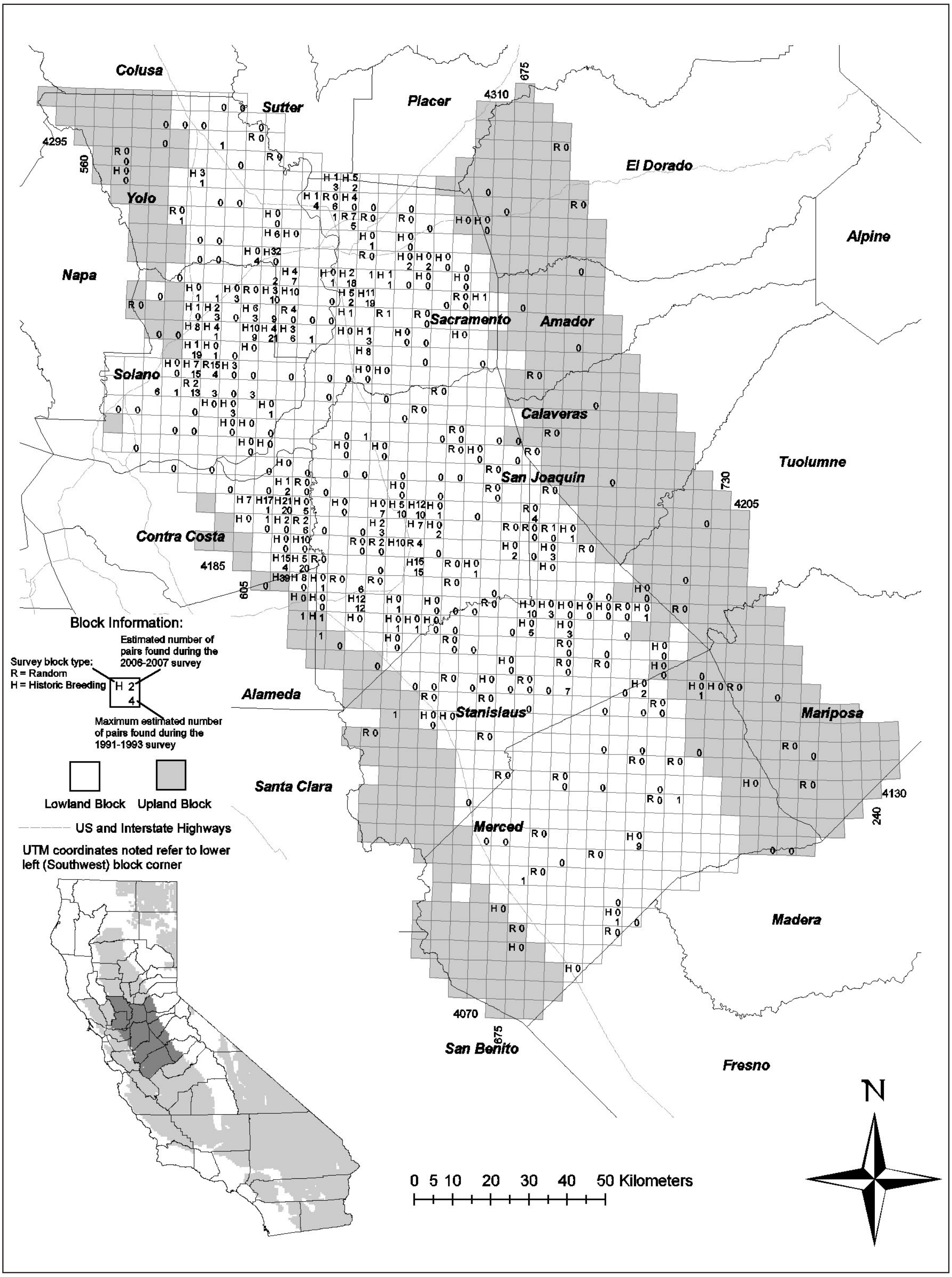

FIGURE 3. Results from the Middle Central Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Middle Central Valley region are shown in the inset.

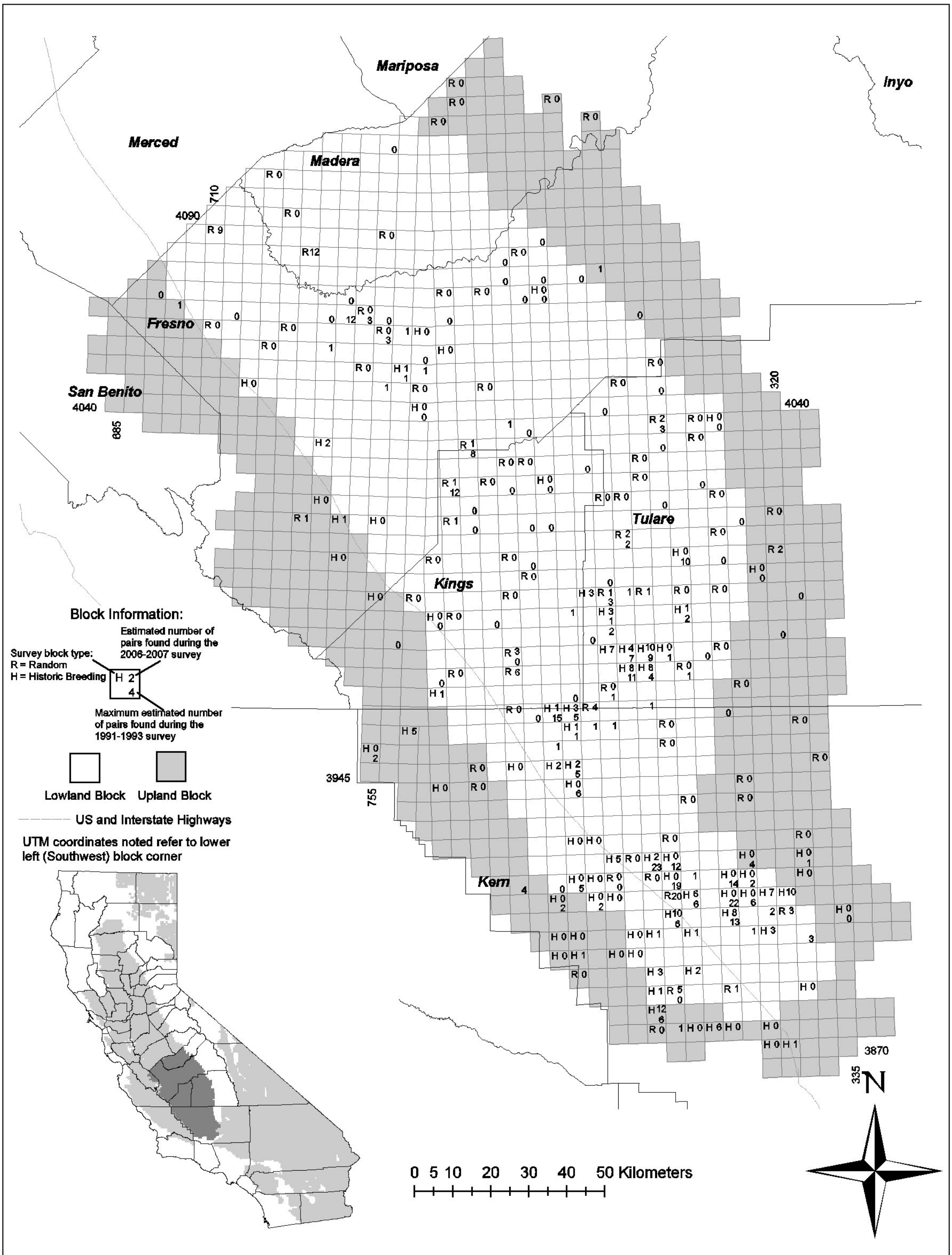

FIGURE 4. Results from the Southern Central Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Southern Central Valley region are shown in the inset.

TABLE 4. Comparison of regional and statewide "best estimates" of population size from the 1991-1993 and 2006-2007 Burrowing Owl surveys.

	1991-1993 survey		2006-2007 survey			
Region	No. of pairs found	"Best estimate" of pairs in region[a]	No. of pairs found	"Best estimate" of pairs in region[a]	Change in estimated no. of pairs	Percent change in estimated no. of pairs
Northern Central Valley						
Lowland	18	231 (153)	12	12	-219	-94.8%
Upland	0	0	0	0	0	n/a
All	18	231 (153)	12	12	-219	-94.8%
Middle Central Valley						
Lowland	404	577 (112)	339	502 (209)	-75	-13.0%
Upland	1	17 (17)	43	43	+26	+152.9%
All	405	594 (129)	382	545	-49	-8.2%
Southern Central Valley						
Lowland	259	1,000 (410)	204	968 (342)	-32	-3.2%
Upland	19	396 (182)	32	145 (118)	-251	-63.4%
All	278	1,396 (592)	236	1,113 (460)	-283	-20.3%
San Francisco Bay Area Interior						
Lowland	154	154	98	98	-56	-36.4%
Upland	11	11	21	21	+10	+90.9%
All	165	165	119	119	-46	-27.9%
San Francisco Bay Area Coast[b]						
Lowland	0	0	0	0	0	n/a
Upland	0	0	0	0	0	n/a
All	0	0	0	0	0	n/a
Central-western Interior						
Lowland	7	7	8	8	+1	+14.3%
Upland	3	31 (27)	13	76 (51)	+45	+145.2%
All	10	38	21	84	+46	+121.1%
Central-western Coast[c]						
Lowland	8	8	0	0	-8	-100%
Upland	0	0	0	0	0	n/a
All	8	8	0	0	-8	-100%
Southwestern Coast[d]						
Lowland	8	36 (36)	16	16	-20	-55.6%
Upland	0	0	26	26	+26	n/a
All	8	36 (36)	42	42	+6	+16.7%
Southwestern Interior						
Lowland	12	100 (100)	37	37	-63	-63%
Upland	6	127 (81)	113	113	-14	-11.0%
All	18	227 (181)	150	150	-77	-33.9%
Coachella Valley						
Lowland	0	0	12	16 (16)	+16	n/a
Upland	0	0	37	37	+37	n/a
All	0	0	49	53	+53	n/a
Imperial Valley						
Lowland	1,041	6,429 (1,135)	499	5,701 (2,244)	-728	-11.3%
Upland	4	142	22	707 (140)	+565	+397.9%
All	1,045	6,571	521	6,408 (2,384)	-163	-2.5%
Modoc Plateau/Great Basin						
All	Not surveyed		0	0	n/a	n/a
Northern Mojave/Eastern Sierra Nevada[e]						
Lowland	Not surveyed		1	1	n/a	n/a
Upland	Not surveyed		0	0	n/a	n/a
All	Not surveyed		1	1	n/a	n/a

TABLE 4. Continued.

Region	1991-1993 survey: No. of pairs found	1991-1993 survey: "Best estimate" of pairs in region[a]	2006-2007 survey: No. of pairs found	2006-2007 survey: "Best estimate" of pairs in region[a]	Change in estimated no. of pairs	Percent change in estimated no. of pairs
Western Mojave Desert[e]						
Lowland	Not surveyed		94	560 (268)	n/a	n/a
Upland	Not surveyed		0	0	n/a	n/a
All	Not surveyed		94	560 (268)	n/a	n/a
Eastern Mojave Desert[e]						
Lowland	Not surveyed		1	32 (32)	n/a	n/a
Upland	Not surveyed		0	0	n/a	n/a
All	Not surveyed		1	32 (32)	n/a	n/a
Sonoran Desert[e]						
All	Not surveyed		179	179	n/a	n/a
Statewide, excluding "new" regions						
Number of pairs found	1,955		1,532		-423	-21.6%
Extrapolated no. of pairs		9,127 (1,243)		8,128 (2,391)	-999	-10.9%
"Best estimate" of no. of pairs		9,266		8,526	-740	-8.0%
Statewide, including "new" regions						
Number of pairs found			1,758			
Extrapolated no. of pairs				9,187 (2,346)		
"Best estimate"				9,298		

[a] Numbers in parenthesis indicate the standard error of the estimate. Estimates lacking a standard error indicate the actual count of breeding pairs detected in a subregion and are presented as the "best estimate" in cases where the count is higher than the region's calculated population estimate, which is based on randomly-selected blocks only and excludes data from historic breeding blocks that were not randomly selected

[b] The San Francisco Bay Area Coast region was not surveyed as part of this study in 2006-2007. Our "best estimate" of zero pairs in both the lowland and upland subregions is based on local knowledge (D. DeSante, *pers. comm.*) and information in Townsend and Lenihan (2007).

[c] The Central-western Coast region was not surveyed as part of this study in 2006-2007. Our "best estimate" of zero pairs in both the lowland and upland subregions is based on local knowledge (D. Roberson, *pers. comm.*).

[d] The Southwestern Coast region was not surveyed as part of this study in 2006-2007. Our "best estimates" of 16 pairs in the lowland subregion and 26 pairs in the upland subregion are based on information in Lincer and Bloom (2007) and Kidd et al. (2007).

[e] Reported in Wilkerson and Siegel (*in press*).

of Fresno, Tulare, and Kern counties.

In the 63 randomly-selected lowland blocks surveyed, we found 72 pairs of owls, yielding a random-sample based estimate of 968 ± 342 pairs. This estimate was greater than the total number of pairs found in the lowland subregion (72 pairs on randomly-selected blocks plus 132 pairs on historic breeding blocks), so it serves as our "best estimate" for the lowland subregion. In the 18 randomly-selected upland blocks surveyed, we found three pairs of owls, yielding a random-sample based estimate of 145 ± 118 pairs in the upland subregion. This estimate is greater than the total number of pairs found in the upland subregion (three pairs on randomly-selected blocks plus 32 pairs on historic breeding blocks), so it serves as our "best estimate" for the upland subregion. Summing our extrapolated estimates for the lowland and upland subregions, our estimate for the Southern Central Valley region is 1,113 ± 460 pairs (Table 3), 20.3 % fewer than the 1,396 pairs DeSante et al. (2007) estimated in the early 1990s (Table 4), but not a statistically significant difference ($F_{1,131}$ = 0419, P = 0.838).

Examining blocks that contained Burrowing Owls in the early 1990s and were resurveyed during 2006-2007 indicates two areas in the region where substantial, concentrated losses appear to have occurred: six blocks in western

Bakersfield lost a total of 53 breeding pairs, and further west, in agricultural land located west of Rosedale and south of Shafter, 42 fewer pairs were detected on three survey blocks (Fig. 5). Concentrated losses of Burrowing Owls on the western edge of Bakersfield occurred in blocks where substantial urban land conversion occurred between 1992 and 2001 (Multi-resolution Land Characteristics Consortium 2001).

SAN FRANCISCO BAY AREA INTERIOR

We surveyed 32 randomly-selected blocks and 58 historic breeding blocks in this region (Fig. 6). The relatively large proportion of historic breeding blocks reflects the excellent pre-survey information available about the region's Burrowing Owls. Surveys of random blocks yielded only a single pair, located on an upland block in northeastern Alameda County, north of Livermore. Pooling data from random and historic breeding blocks, we found 119 pairs.

All of the Burrowing Owls detected in the region were in Alameda or Santa Clara counties. During the 1990s survey small numbers of Burrowing Owl pairs were also detected in San Mateo County (one pair) and Sonoma County (two pairs), but our surveyors were unable to find owls in these or other locations throughout those counties.

In Alameda County, we detected no Burrowing Owls in the western, lowland portion adjacent to San Francisco Bay, where 34 pairs were found distributed across nine blocks in the early 1990s (Fig. 7). In contrast, we found 14 pairs of owls in the upland blocks of the eastern half of the county (compared with 11 pairs found in the early 1990s) along the Highway 580 corridor between Dublin and Livermore and in the Altamont Hills northeast of Livermore, an area where relatively large numbers of breeding Burrowing Owls have recently been observed (Barclay and Harman 2007). The richest area in Alameda County was the south-central lowland portion; we observed 25 pairs on a single block at Don Edwards San Francisco Bay National Wildlife Refuge. Two pairs were detected on the same block during the 1991-1993 survey. Nine additional pairs were distributed across two historic breeding blocks to the north of this area, apparently in urban park or industrial yard settings in the cities of Fremont and Newark.

In Santa Clara County, detections were restricted to the lowland area in the northwestern corner, as they were during the early 1990s. We detected 56 pairs on two blocks in San Jose and two blocks in Mountain View (Fig. 7), reduced from 97 pairs in the early 1990s.

We detected no pairs on randomly-selected lowland blocks anywhere in the San Francisco Bay Area Interior region, resulting in a zero population estimate for the lowland subregion. We detected 98 pairs on lowland historic breeding blocks, resulting in our "best estimate" of 98 pairs for the lowland subregion. On the 12 randomly-selected upland blocks surveyed, we found one owl pair, yielding a random-sample based estimate of 21 ± 21 pairs throughout the upland subregion. This estimate was greater than the total number of pairs we found on surveyed blocks in the upland subregion (one pair on randomly-selected blocks plus 13 pairs on historic breeding blocks), so it serves as our best estimate for owl pairs in the upland subregion. Summing our count from the lowland blocks and our estimate in the upland subregion, our "best estimate" for the number of Burrowing Owl pairs in the San Francisco Bay Area Interior region is 119. This estimate represents a nearly 28% reduction from the 165 pairs estimated from the 1991-1993 survey (Table 4). Like our estimate, the early 1990s estimate was also an actual count of all pairs found, rather than an extrapolated estimate based on randomly-selected blocks only, so the statistical significance of the apparent decline cannot be tested. However, because the region is very well known by the local birding community (which helped us identify historical breeding blocks), it seems unlikely that there could be more than a few pairs that went undetected during either survey.

SAN FRANCISCO AREA COAST

DeSante et al. (2007) were unable to find any Burrowing Owls in this region during the 1990s survey (Table 4). This relatively small region is well-monitored and well-known by the local birding community. We did not resurvey the region for the 2006-2007 study, as consultation with local experts as well as information in Townsend and Lenihan (2007) strongly indicates that the species remains extirpated from the region.

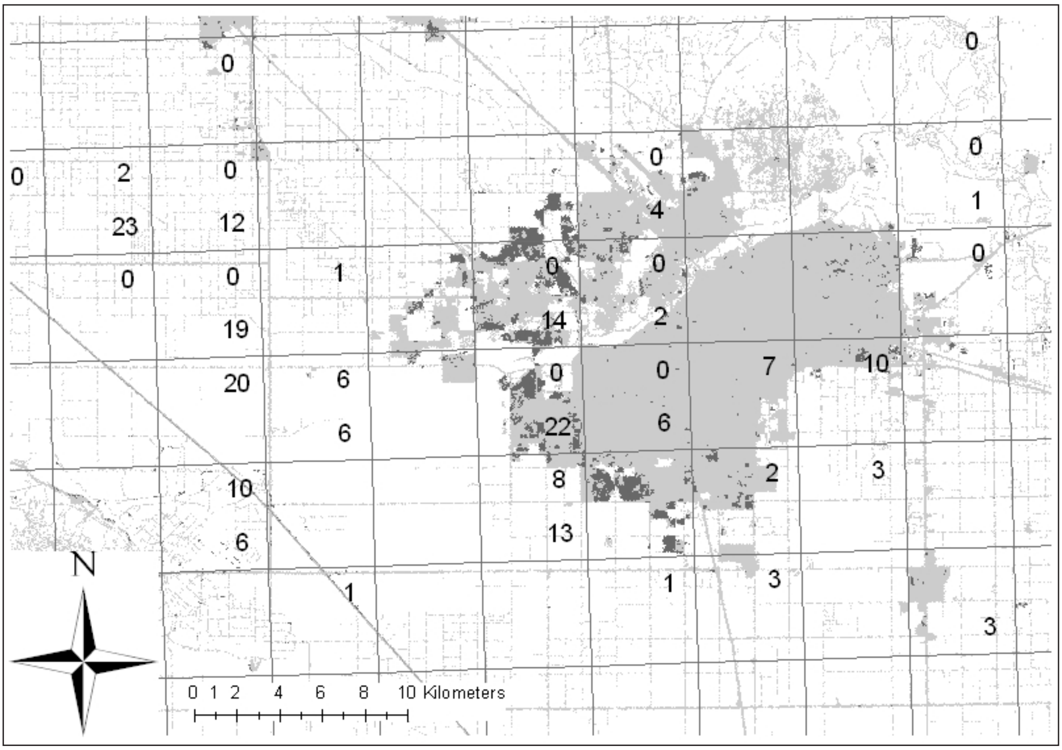

FIGURE 5. The number of Burrowing Owl pairs detected in the Bakersfield area during IBP's 1991-1993 survey (indicated in lower right corner of each block) and 2006-2007 survey (indicated in upper right corner of survey block). The large shaded area represents metropolitan Bakersfield; light gray shading indicates urban land cover as of 1992; dark gray shading indicates areas that were not mapped as urban in 1992, but were converted to urban use between 1992 and 2001 (Multi-resolution Land Characteristics Consortium 2001). Note the concentrated losses of Burrowing Owls in blocks on the western edge of Bakersfield, where substantial urban land conversion occurred between 1992 and 2001.

CENTRAL-WESTERN INTERIOR

We surveyed 30 randomly-selected blocks and 14 historic breeding blocks in this region (Fig. 8). Surveys of random blocks yielded just two Burrowing Owl pairs, both located on upland blocks of San Luis Obispo County. Pooling data from random and historic breeding blocks, we found 21 pairs in the region. Small clusters of owls were found in four areas: Bolsa Valley northwest of Hollister, San Benito County; low foothills of the Coast Range east of King City, Monterey County; northeast corner of San Luis Obispo County; and the Carrizo Plain, southeastern San Luis Obispo County (Fig. 8).

Since no Burrowing owls were detected on randomly-selected lowland blocks anywhere in this region, our random-sample based population estimate for the lowland subregion is zero pairs. However, we found 8 pairs on lowland historic breeding blocks, so our "best estimate" for the lowland subregion is the actual number of pairs we found: eight. On the 13 randomly-selected upland blocks we surveyed, we found two pairs, yielding a random-sample based estimate of 76 ± 51 pairs throughout the upland subregion. This estimate was greater than the total number of pairs we found in the upland subregion (two pairs on randomly-selected blocks plus 11 pairs on historic breeding blocks), so it serves as our best estimate for owl pairs in the upland subregion. Summing our count on the lowland blocks and our estimate in the upland subregion, our estimate for the Central-western Interior region is 84 pairs, a 121% increase from the estimate of 38 pairs during the 1991-1993 survey (Table 4).

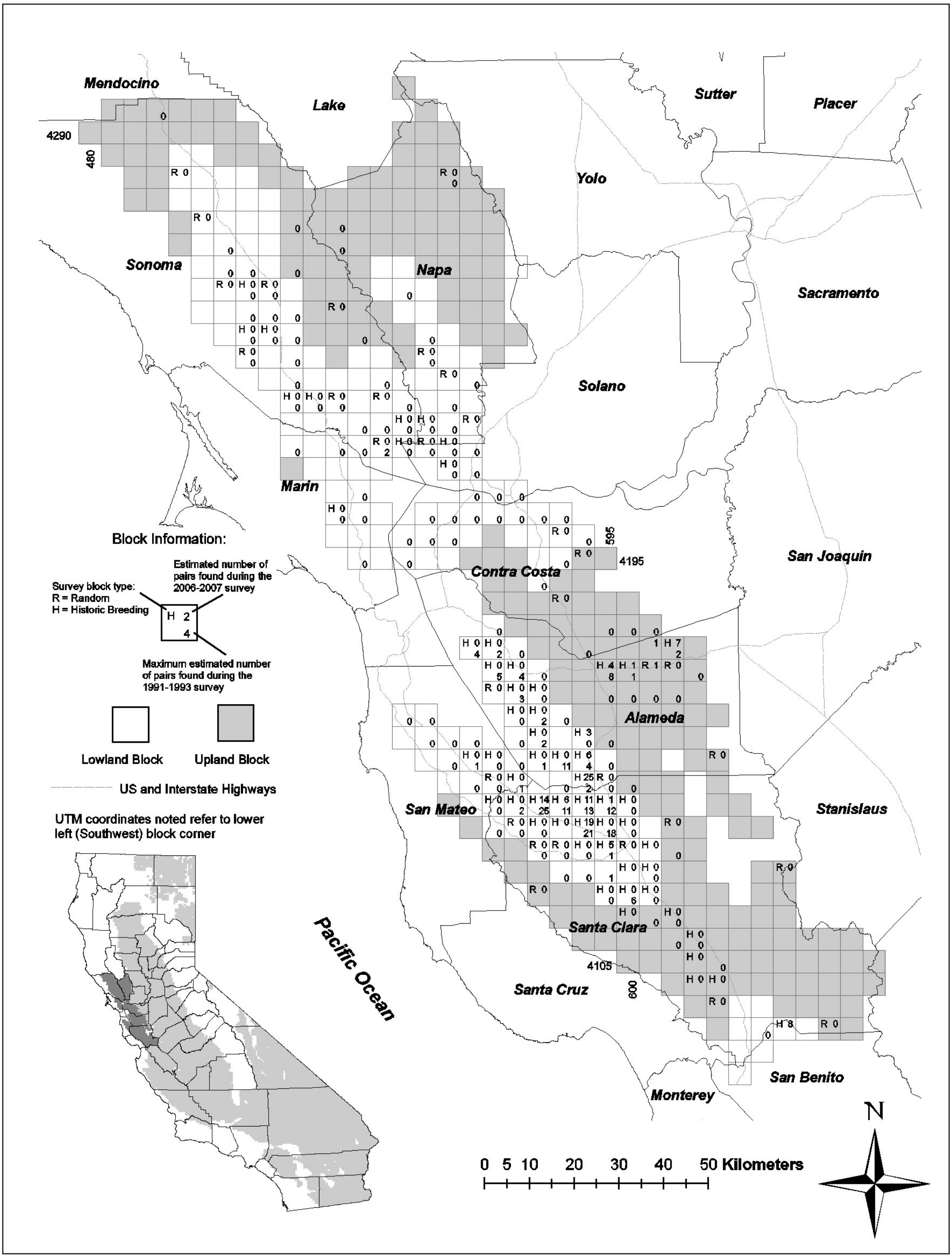

FIGURE 6. Results from the San Francisco Bay Area Interior region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the San Francisco Bay Area Interior region are shown in the inset.

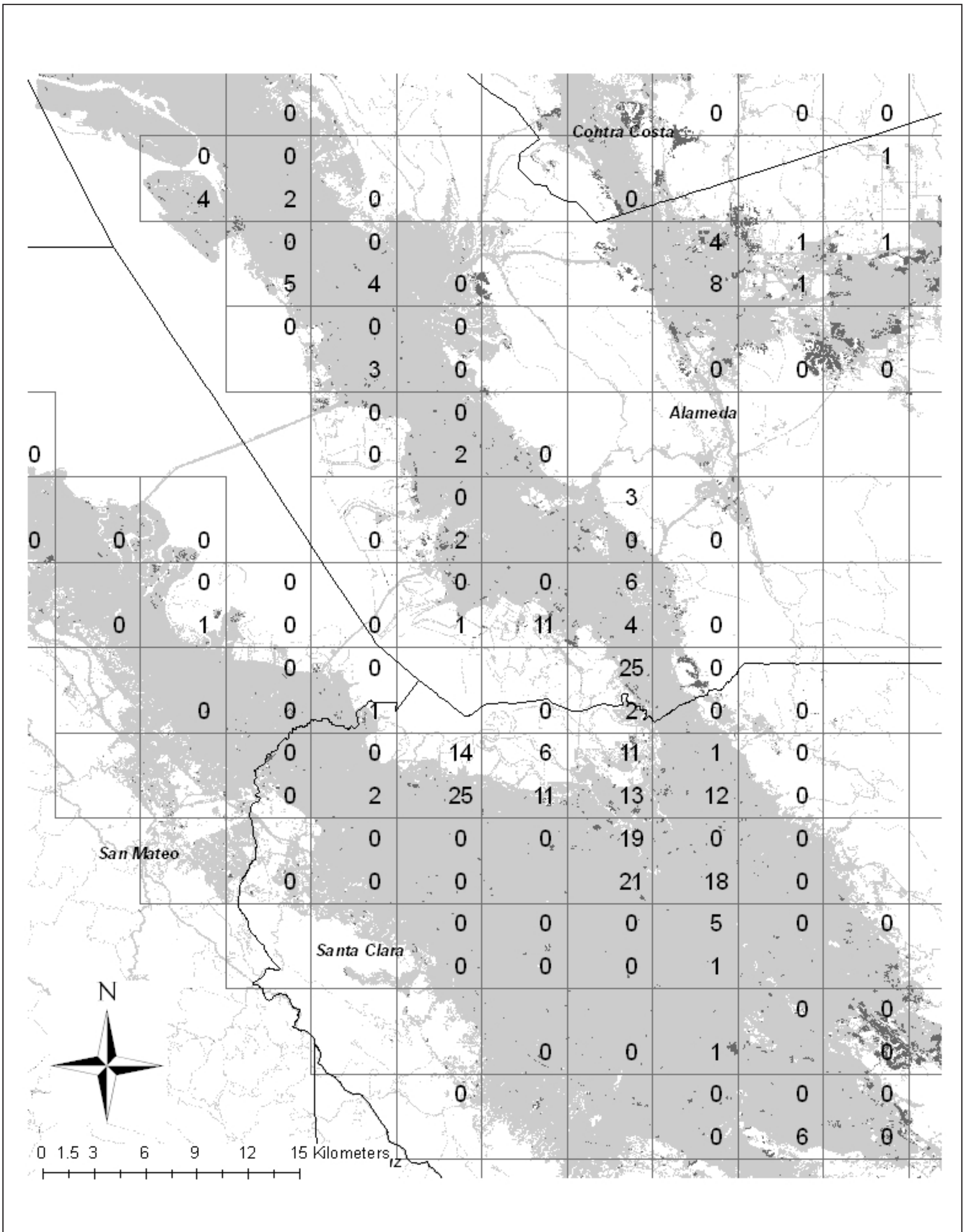

FIGURE 7. The number of Burrowing Owl pairs detected on survey blocks in the southern and eastern San Francisco Bay Area during IBP's 1991-1993 survey (indicated in lower right corner of each block) and 2006-2007 survey (indicated in upper right corner of survey block). Light gray shading indicates urban land cover as of 1992; dark gray shading indicates areas that were not mapped as urban in 1992, but were converted to urban use between 1992 and 2001 (Multi-resolution Land Characteristics Consortium 2001).

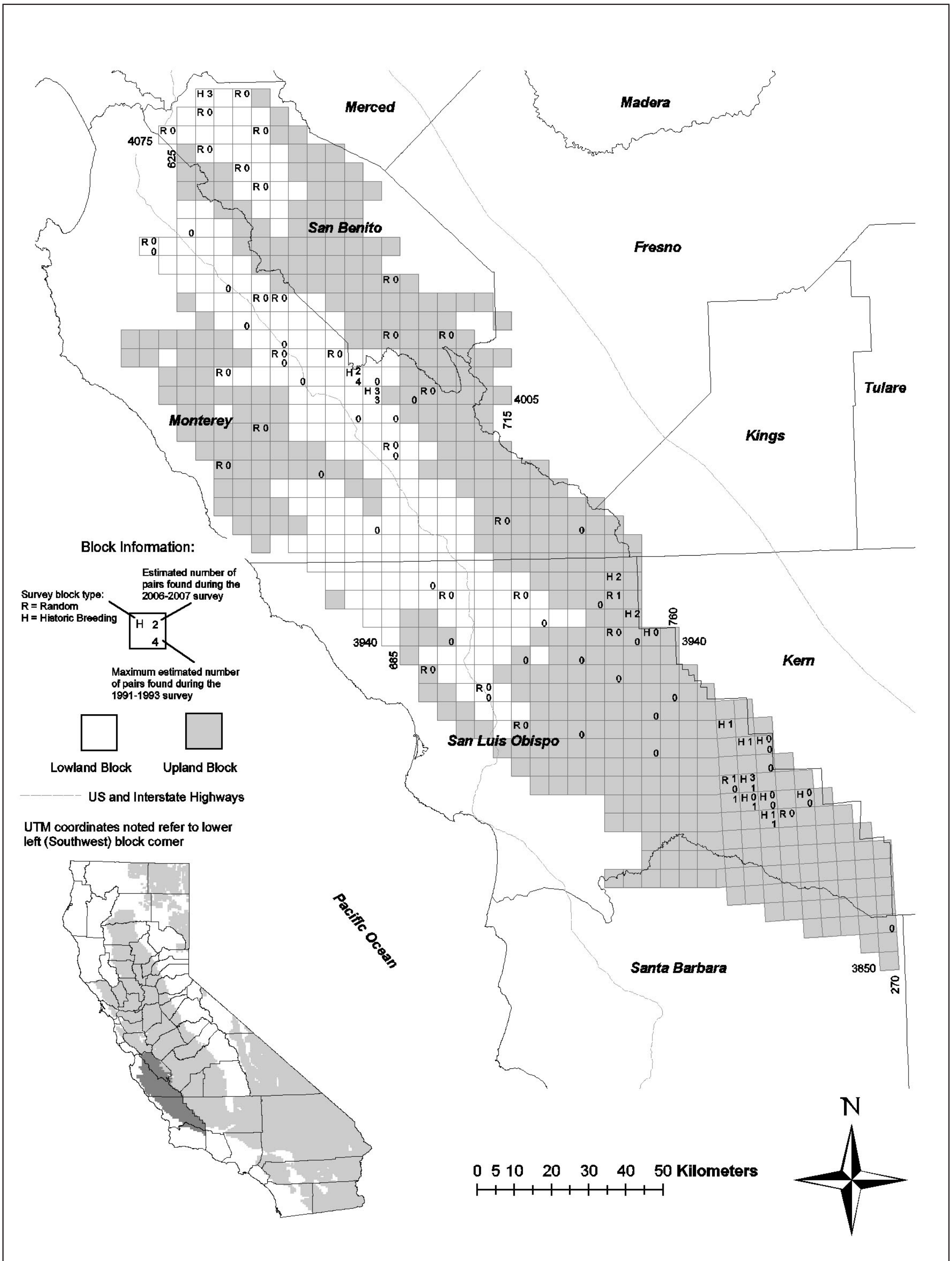

FIGURE 8. Results from the Central-western Interior region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Central-western Interior region are shown in the inset

CENTRAL-WESTERN COAST

This is one of the three coastal regions we did not survey during 2006-2007. In the 1991-1993 survey, eight pairs of Burrowing Owls were detected in the region; seven pairs were near Salinas, Monterey County, and a single pair was in northern Santa Barbara County (DeSante et al. 2007). The Salinas owls were distributed between two areas; five pairs were at the Salinas Airport and two pairs were near the town of Boronda. Visits to both of those sites by local birders in the last decade have yielded no detections, and foraging habitat adjacent to the airport colony has been developed (D. Roberson, *pers. comm.*). The single pair from northern Santa Barbara County was present in 1992, but could not be relocated when the same survey block was revisited in 1993 (DeSante et al. 2007). Consequently Burrowing Owls are likely extirpated from the region (Table 4).

SOUTHWESTERN COAST

Because the few breeding owls present in this region are already well monitored, we did not survey the region. Kidd et al. (2007) determined that Burrowing Owl populations in western Santa Barbara, Ventura, and Los Angeles counties had been extirpated; however, they documented three breeding pairs in Orange County as recently as 2005. In a thorough assessment of the species' status in San Diego County, Lincer and Bloom (2007) determined there were between 41 and 46 pairs present; all but two were within our region boundaries, allowing for a count of between 39 and 44 pairs. The lower count of 39 plus the three pairs from Orange County yields an estimate of 42 pairs for the Southwestern Coast region (Table 4). The 1991-1993 "best estimate" for this region was 36 pairs, although only eight pairs were actually detected (DeSante et al. 2007). The apparent increase could be from the more thorough coverage provided by Lincer and Bloom (2007) or a slight but real increase in the region's owl population.

SOUTHWESTERN INTERIOR

We surveyed 11 randomly-selected blocks and 57 historic breeding blocks in this interior region (Fig. 9). The relatively large proportion of historic breeding blocks reflects the excellent pre-survey information we received from a UC Riverside graduate student studying the local Burrowing Owl population (Ginny Short, *pers. comm.*). Our surveys of random blocks yielded only a single pair, located in a lowland block at Ontario International Airport, San Bernardino County. However, we found 149 pairs utilizing diverse habitats on historic breeding blocks, yielding a total of 150 pairs of owls detected in the region.

The one pair of owls found on the three randomly-selected lowland blocks yielded a random-sample based estimate of 17 ±17 pairs throughout the lowland subregion. Since this estimate was lower than the total number of pairs found in the lowland subregion (pooling data detections from random and historic breeding blocks) our "best estimate" for the number of owl pairs in the lowland subregion is the actual number of pairs counted: 37. Since no Burrowing Owls were detected on any of the eight randomly-selected upland blocks, our random-sample based estimate for the upland subregion is zero pairs. However, we found 113 pairs on upland historic breeding blocks, so our best estimate for the upland subregion is the actual number of pairs found: 113. Summing our counts from lowland and upland blocks, our estimate for the Southwestern Interior region is 150 pairs, 33.9% fewer than were estimated to be present during the 1991-1993 survey (Table 4). We note, however, that the 1990s estimate was extrapolated from surveys of random blocks while our estimate is our actual count of all owls on random and historic breeding blocks, and was based on more extensive pre-survey information. Thus, comparing these "best estimates" may be somewhat problematic.

COACHELLA VALLEY

We surveyed eight randomly-selected blocks and 12 historic breeding blocks in this region (Fig. 10). Surveys of random blocks yielded just one pair of Burrowing Owls, while surveys of historic breeding blocks yielded 48 pairs, for a total of 49 pairs detected in the region. The highest densities of detections were clustered at the northern end of the region around the town of Desert Hot Springs and south to Interstate 10. Smaller numbers of owls (1-4 pairs per block) were detected along the Interstate 10 corridor as far south as the town of Mecca. A single pair was located on a randomly-selected block along

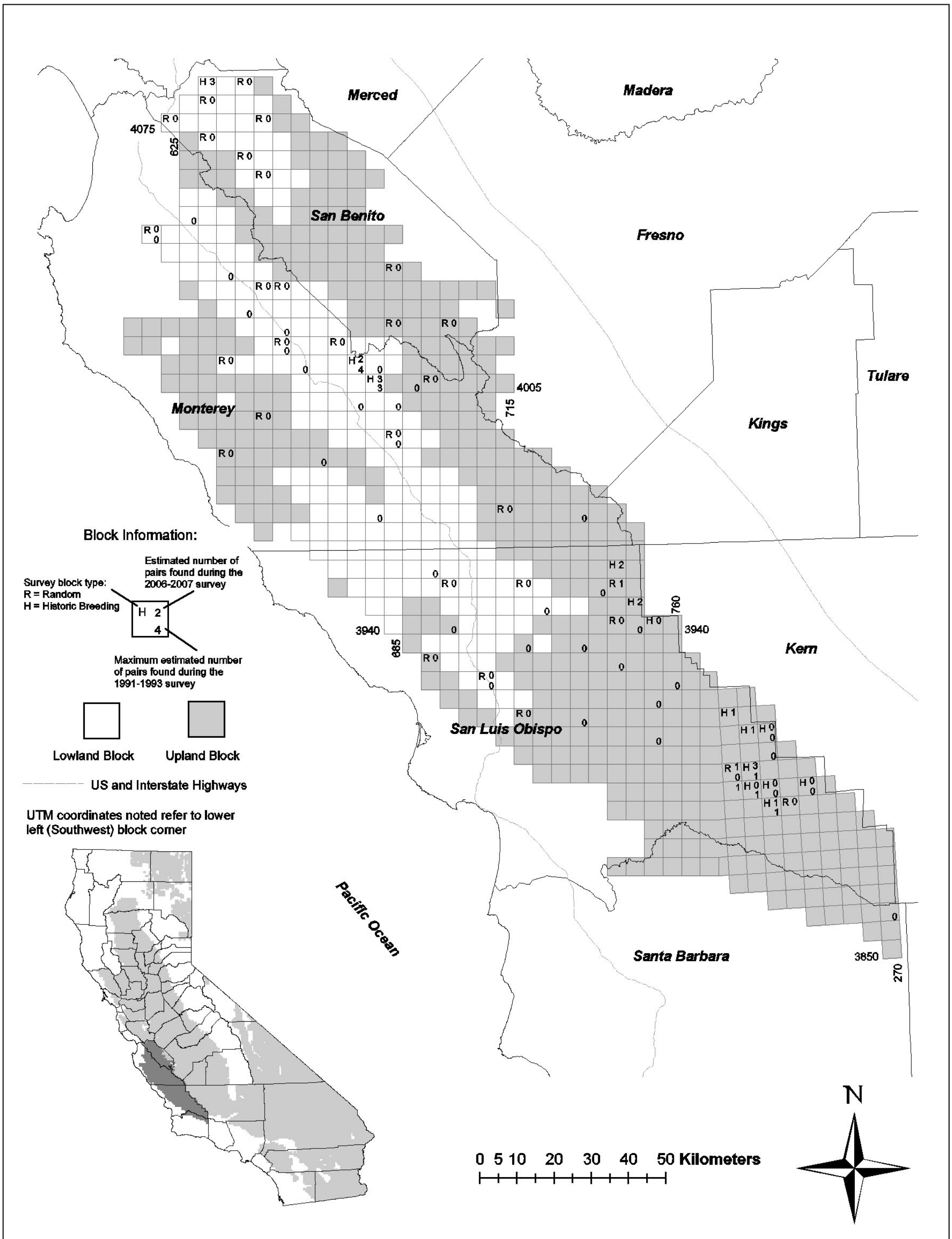

FIGURE 9. Results from the Southwestern Interior region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Southwestern Interior region are shown in the inset.

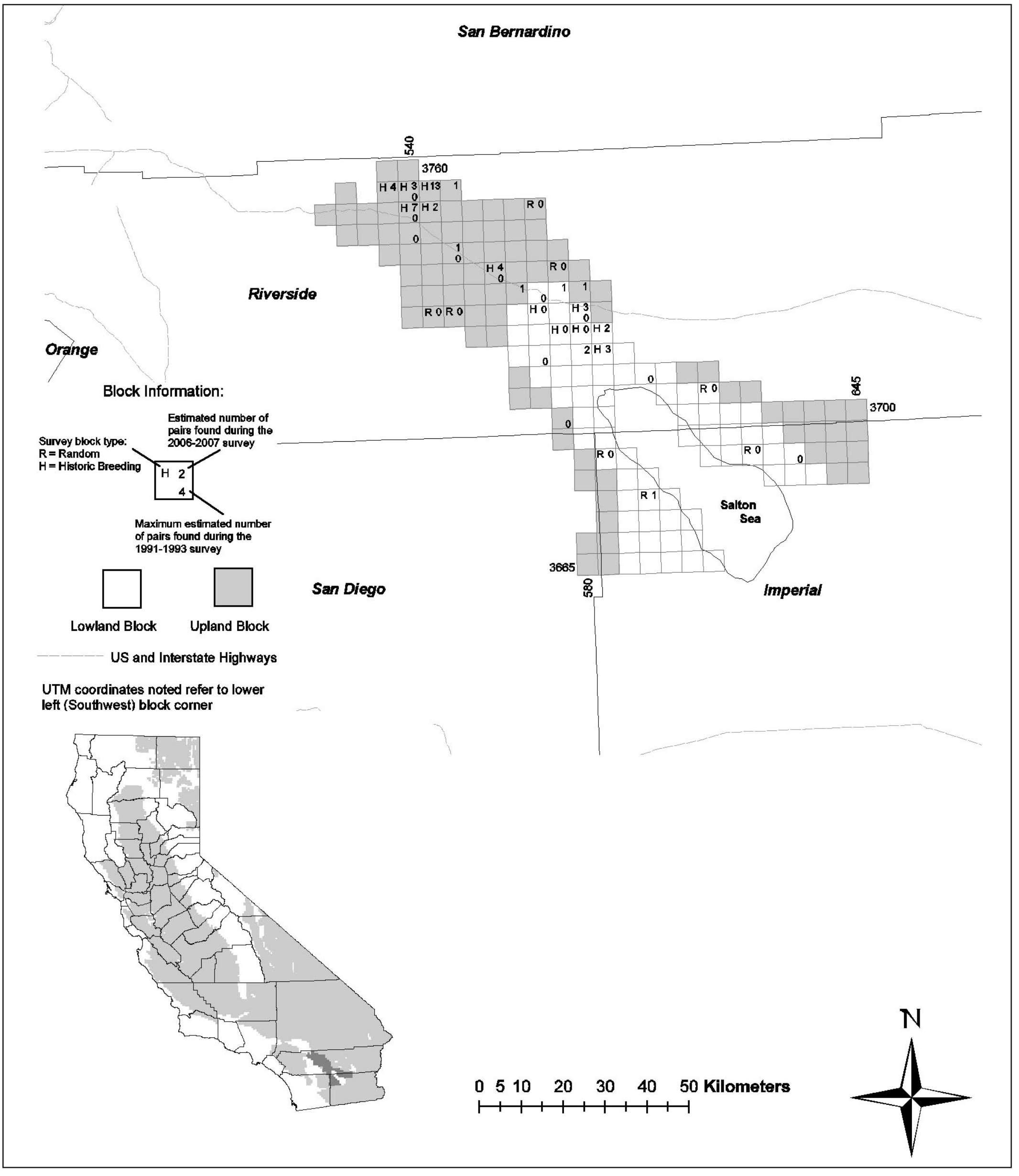

FIGURE 10. Results from the Coachella Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Coachella Valley region are shown in the inset.

the west side of the Salton Sea, at the southern end of Salton City.

In the four randomly-selected lowland blocks surveyed, we found one pair of owls, yielding a random-sample based estimate of 16 ± 16 pairs throughout the lowland subregion. This estimate was slightly greater than the total number of pairs found in the lowland subregion (one pair on randomly-selected blocks plus 11 pairs on historic breeding blocks), so it serves as our "best estimate" for owl pairs in the lowland subregion. No Burrowing Owls were detected on the four randomly-selected upland blocks, so our random-sample based population estimate for the upland subregion is zero pairs. However, we found 37 pairs on upland historic breeding blocks, so our "best estimate" for the upland subregion is the actual number of pairs we found: 37. Summing our estimate from the lowland subregion and our count on the upland blocks surveyed, our estimate for the Coachella Valley region is 53 pairs, a remarkable change from the 1991-1993 estimate of zero pairs (Table 4). Four historic breeding blocks (two upland blocks at the northern end of the region plus an additional upland and lowland block further south), in which we found multiple pairs, were also surveyed in the early 1990s (then also selected as random blocks), when no owls were detected. These results suggest the blocks may have been colonized since the 1991-1993 survey.

IMPERIAL VALLEY

We surveyed seven randomly-selected blocks and eight historic breeding blocks in this region (Fig. 11). Surveys of random blocks yielded 271 Burrowing Owl pairs, and surveys of historic breeding blocks yielded 250 pairs, for a total of 521 pairs detected.

In the five randomly-selected lowland blocks surveyed, we found 254 pairs, yielding a random-sample based estimate of 5,701 ± 2,244 pairs throughout the lowland subregion. This estimate was greater than the total number of pairs found in the lowland subregion (254 pairs on randomly-selected blocks plus 245 pairs on historic breeding blocks), so it serves as our "best estimate" for pairs in the lowland subregion. In the two randomly-selected upland blocks surveyed, we found 17 pairs of owls, yielding a random-sample based estimate of 707 ± 140 pairs throughout the upland subregion. This estimate was greater than the number of pairs we found in the upland subregion (17 pairs in randomly-selected blocks plus five pairs in historic breeding blocks), so it serves as our "best estimate" in the upland subregion. Summing our estimates for the lowland and upland subregions, our estimate for the Imperial Valley region is 6,408 ± 2,384 pairs, 2.5% fewer than the 6,571 pairs estimated during the 1991-1993 survey (Table 4), a statistically insignificant decline ($F_{1,12} = 0.3163$, $P = 0.584$).

MODOC PLATEAU/GREAT BASIN

We surveyed 13 randomly-selected blocks, and two historic breeding blocks in this region (Fig. 12). All blocks surveyed were classified as upland blocks, because the entire bioregion lies well above the upper bound of the lower elevation zones for all of our other survey regions.

We detected no Burrowing Owls on random blocks or historic breeding blocks, so our "best estimate" for the number of pairs in the region is zero pairs. Subsequent to our survey, breeding has been observed in Sierra Valley as recently as 2009 (Richard Carlson, *pers. comm.*), although information is lacking to determine whether this breeding location was active during 2006-2007 when we conducted our field work.

NORTHERN MOJAVE DESERT/EASTERN SIERRA NEVADA

We surveyed 36 randomly-selected blocks and two historic breeding blocks in this region; none of them yielded Burrowing Owl detections. However, one pair was detected incidentally on an otherwise unsurveyed block (see Wilkerson and Siegel, *in press*, for additional details).

WESTERN MOJAVE DESERT

We surveyed 48 randomly-selected blocks and 19 historic breeding blocks in this region. Our "best estimate", based on 25 pairs of owls detected on 42 pairs of owls detected on the random blocks, is 560 ± 268 pairs (see Wilkerson and Siegel, *in press*, for additional details).

EASTERN MOJAVE DESERT

We surveyed 43 randomly-selected blocks and two historic breeding blocks in the Eastern Mojave Desert region. Our "best estimate" for the region, based on one pair of owls detected on the randomly-selected blocks, is 32 ± 32 pairs (see Wilkerson and Siegel, *in press*, for additional details).

SONORAN DESERT

We surveyed 31 randomly-selected blocks, and 16 historic breeding blocks in the Sonoran Desert region. Our "best estimate" for the region, based on 179 pairs of owls detected

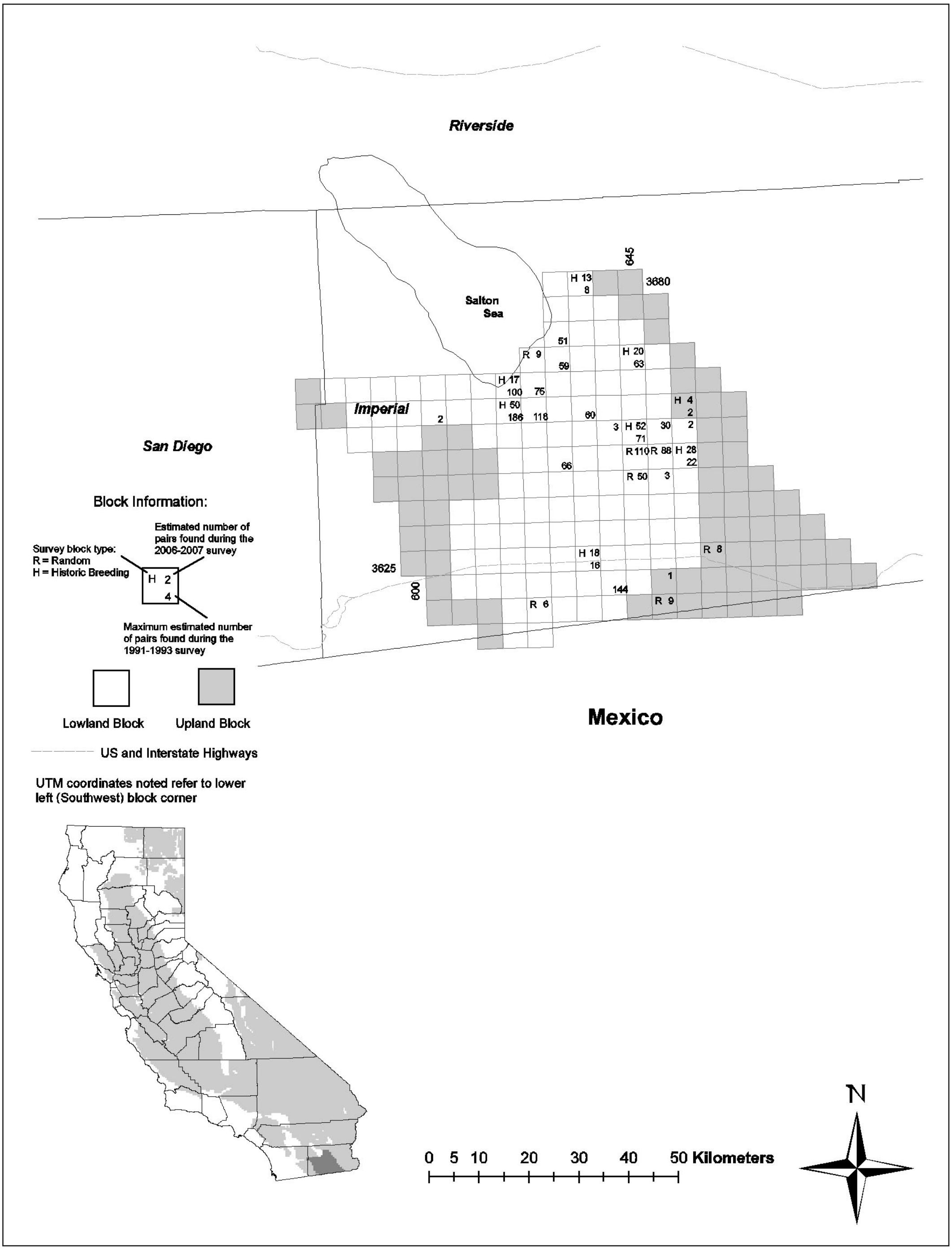

FIGURE 11. Results from the Imperial Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Imperial Valley region are shown in the inset.

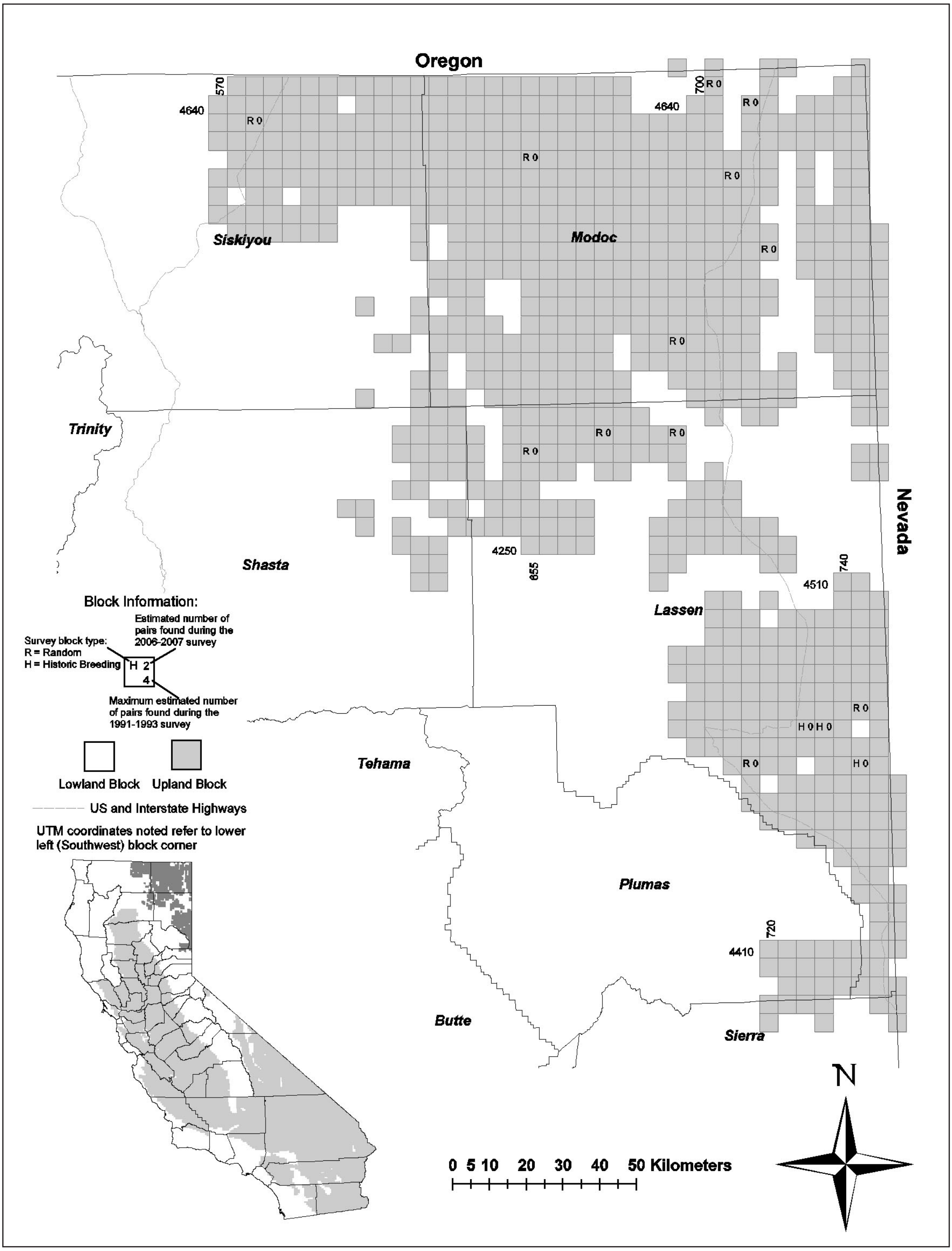

FIGURE 12. Results from the Modoc Plateau/Great Basin region of the 2006-2007 California Burrowing Owl survey. Shown are all 5-km x 5-km assigned to the region; in the case of this region, all blocks were classified as upland. The entire 2006-2007 survey area and the location of the Modoc Plateau/Great Basin region are shown in the inset.

exclusively within the Palo Verde Valley, and no owls detected elsewhere in the region, is our actual pair count in the Palo Verde Valley: 179 pairs (see Wilkerson and Siegel, *in press*, for additional details).

AGGREGATED STATEWIDE RESULTS

Aggregating results across all 2006-2007 survey regions yields a "best estimate" of 9,298 pairs of Burrowing Owls (Table 4). The population is highly concentrated in the Imperial Valley (68.9% of the California population) and to a lesser extent, the Southern Central Valley (12.0% of the statewide population) (Fig. 13). DeSante et al. (2007) reported very similar proportions of the estimated statewide population in 1991-1993 in these two regions.

Omitting the "new" survey regions (Modoc Plateau/Great Basin , Northern Mojave/Eastern Sierra Nevada, Western Mojave, Eastern Mojave, and Sonoran Desert), the aggregated "best estimate" for all regions that were previously surveyed in 1991-1993 is 8,526 pairs, 8% lower than the corresponding estimate generated from 1991-1993 (Table 4). Much of the apparent decline appears to be concentrated in two regions: the Northern Central Valley (231 pairs in 1991-1993 to 12 pairs in 2006-2007), and the Southern Central Valley (1,396 pairs in 1991-1993 to 1,113 pairs in 2006-2007). Other regions with reduced "best estimates" between 1991-1993 and 2006-2007 include the Middle Central Valley (-49 pairs), San Francisco Bay Interior (-46 pairs), Southwestern Interior (-77 pairs), and the Imperial Valley (-163 pairs, but the relatively high absolute numbers make this unlikely to be a meaningful change). In contrast to the overall pattern of declines, our 2006-2007 "best estimates" were higher than the corresponding 1991-1993 estimates for three regions: Central-western Interior (+46 pairs), Southwestern Coast (+6 pairs), and Coachella Valley (+53 pairs).

Because the statewide "best estimate" of the number of pairs is an aggregate of regional extrapolated population estimates and regional minimum counts there is no way to test the statistical significance of the apparent decline between 1991-1993 and 2006-2007. However, we can test for statistically significant change in our population estimates extrapolated only from surveys of randomly-selected blocks. DeSante et al. (2007) provided an extrapolated estimate of 9,127 ± 1,243 pairs for their entire study area; our 2006-2007 estimate extrapolated from randomly-selected blocks across the same survey regions is 8,128 ± 2,391 pairs (Table 4), a non-significant ($F_{1,710}$ = 0.0533, P = 0.817) reduction of 10.9%.

Including the "new" survey regions, our 2006-2007 estimate extrapolated from randomly-selected blocks is 9,187 ± 2,346 pairs (Table 4). Our "best estimate" for the same comprehensive area is a very similar 9,298 pairs (Table 4).

LAND OWNERSHIP AND HABITATS.

Similar to the findings reported by DeSante et al. (2007), we found that the vast majority of California's breeding Burrowing Owls occur on private lands (Table 5). Small numbers were also found on lands managed by four federal agencies, California state government, and local municipalities (Table 5).

The Burrowing Owls detected during our survey occupied a wide range of habitats, including natural grasslands, agricultural lands, and other human-modified areas (Table 6). Nearly one third of breeding sites were located on the banks of irrigation canals or other concrete or earthen water conveyance structures (Table 6).

DeSante et al. (2007) reported a strong association between Burrowing Owl breeding sites and the presence of ground squirrels. Our results corroborated this finding, but also revealed that association to be far weaker for owls nesting along irrigation canals and other water conveyance structures (Table 6). This weaker association presumably stems from owls not having to depend on ground squirrels for burrow excavation along canal banks, where earthen banks may be particularly easy to excavate, and concrete-lined banks often provide attractive nesting spaces between the concrete lining and the underlying soil.

OWL PERSISTENCE ON SURVEY BLOCKS OCCUPIED DURING THE 1991-1993 SURVEY

Considering blocks surveyed during both 1991-1993 and 2006-2007, in which owls were detected during the first (1991-1993) survey (N = 149), we found that abundance significantly declined (mean difference = -2.68 ± 0.50; t = -5.37; df = 148; P < 0.0001). The probability of detecting

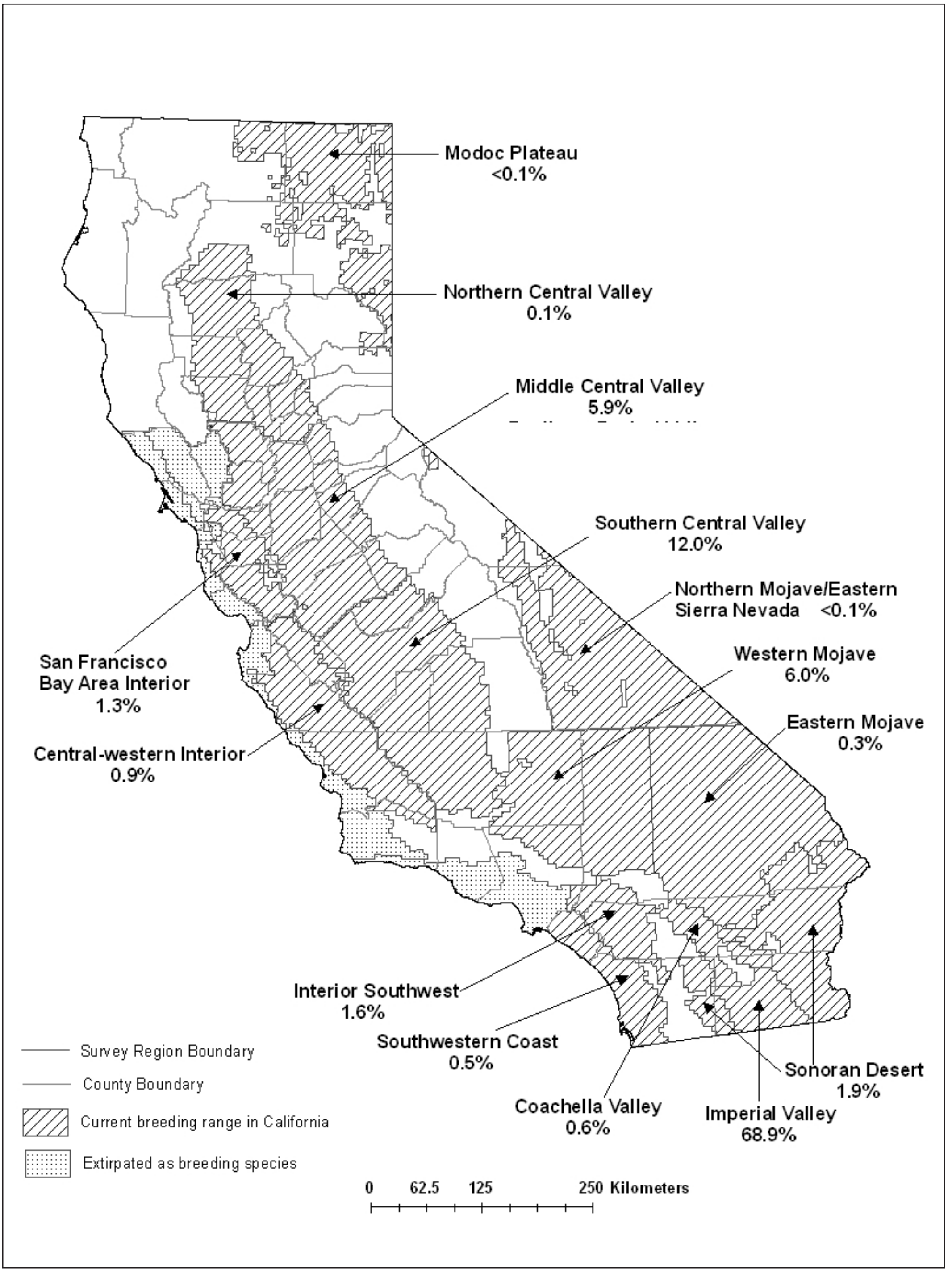

FIGURE 13. Current and former breeding range of Burrowing Owl in California, and percent of the 2006-2007 statewide breeding population estimated to occur in each region based on "best' estimates" (see Methods for explanation of "best" estimates) during the 2006-2007 survey.

TABLE 5. Number and percent of owl pairs detected during the 2006 and 2007 statewide Burrowing Owl survey, classified by land ownership or jurisdiction.

	Number of Burrowing Owl pairs detected	
Land ownership or jurisdiction	Randomly-selected blocks only	Randomly-selected blocks and historic breeding blocks
Private	415 (96.7%)	1,592 (90.6%)
Federal		
Bureau of Land Management	2 (0.5%)	18 (1.0%)
Department of Defense	12 (2.7%)	50 (2.8%)
NASA	0	11 (0.6%)
National Wildlife Refuge System	0	38 (2.2%)
Local government	0	26 (1.5%)
State government	0	22 (1.3%)
Tribal	0	1 (0.1%)
Total	429	1,758

TABLE 6. Primary habitats indicated by field observers at sites where Burrowing Owl pairs were found, and prevalence of ground squirrels at those sites.

Primary habitat	No. of breeding sites[a]	No. of sites where ground squirrel presence was assessed	Percentage of assessed sites with ground squirrels present
Irrigation canal[b]	383	285	19
Natural grassland	211	211	92
Idle or fallow field	121	103	76
Field crop	114	10	60
Pasture	100	100	87
Brushland	75	75	67
Airport	45	45	91
Golf course	30	30	100
Levee	27	26	92
Railroad	26	26	85
Grain or hayfield	25	21	57
Row crop	14	6	43
Other	116	107	48
Total	1,287	1,045	64

[a]In many cases breeding sites encompassed multiple Burrowing Owl pairs.
[b]Here the term "irrigation canal" is used broadly to indicate any man-made concrete or earthen water conveyance structure.

owls on those blocks during the 2006-2007 survey increased as a function of the number of owls detected during the 1991-1993 survey (Fig. 14; $\chi^2_1 = 12.41$; $P = 0.0004$). For example, the predicted probability of detecting owls during the 2006-2007 survey in blocks where just one pair was detected during the 1991-1993 survey was about 0.36, compared to 0.93 in blocks where 25 pairs of owls were detected during the 1991-1993 survey.

DISCUSSION

Our survey method likely contains some systematic sources of error. As DeSante et al. (2007) pointed out, the inability of observers to

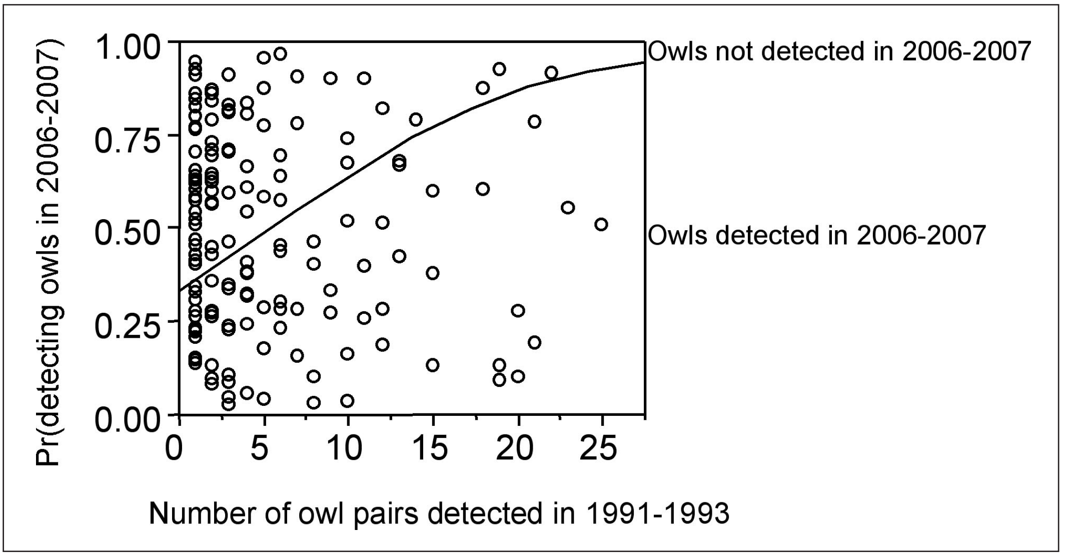

FIGURE 14. Probability of detecting owls during the 2006-2007 survey in blocks where owls were detected in 1991-1993 as a function of the number of owl pairs detected on the block in 1991-1993. The predicted probability of detection in 2006-2007 is shown by the curve. Data points below the curve are blocks on which owls were detected during both surveys; data points above the curve represent blocks where owls were detected in 1991-1993 but not detected in 2006-2007. Data points are plotted at their 1991-1993 owl pair (x-axis) values and randomly jittered in the probability (y-axis) space (below or above the curve, depending on whether owls were present in 2006-2007) to show the distribution of the data.

reliably detect all owls in sampled areas (Conway and Simon 2003, Conway et al. 2008), particularly in areas with limited or no road access may tend to bias our estimates low. Additionally, observers generally assumed that whenever they detected a single adult Burrowing Owl, it represented a breeding pair. To the extent that unmated adult birds may have been detected, this could result in an upward bias in our estimate of breeding pairs. Another potentially confounding factor was that surveyors were unable to gain access to some military installations and private landholdings; if such areas were more or less likely to be occupied by owls than other areas, bias in one direction or the other could have been introduced into our estimates. Finally, our survey methodology incorporated no means for assessing detection probability, which in some environments (such as desert areas with very low road density) may have been quite low. Perhaps of even greater concern than detection probability being low is that it could have varied substantially across survey blocks or survey regions with different physiographic characteristics.

Nevertheless, we believe the sheer volume of data collected counterbalances some of the methodological limitations described above, and ensures that the broader patterns in distribution and abundance are meaningful. Additionally, because our methods adhered to those established by DeSante et al. (2007), any biases affecting our results likely affected the 1991-1993 study, too, so that comparisons between the two surveys are appropriate. Finally, our survey documented the exact locations of 1,758 Burrowing Owl pairs (18.9% of the estimated total) across California, information that should be of great use for ongoing and future conservation efforts.

The generally large variances associated with our regional and statewide population estimates extrapolated from randomly-selected blocks indicate that our statistical power to detect changes in abundance was rather weak. Indeed, the Northern Central Valley was the only region for which our 2006-2007 population estimate differed significantly from the 1991-1993 estimate of DeSante et al. (2007). Moreover, many of our regional "best estimates" were not obtained by extrapolating data from the randomly-selected blocks, but rather by simply counting all of the owl pairs that could be found in either randomly-selected or historical breeding blocks. We had no means for assessing statistical significance of such estimates from the corresponding 1991-1993 "best estimates", many of which were generated in the same manner. Nevertheless, inspection of our results, and qualitative comparisons with results from the 1991-1993 survey, still yield some important conclusions.

The major patterns in Burrowing Owl distribution and abundance across California described by DeSante et al. (2007) have not changed dramatically since 1991-1993, when the species was already extirpated or nearly extirpated from the San Francisco Bay Area Coast, Central-western Coast, and Southwestern Coast regions. The Imperial Valley still accounts for slightly more than two-thirds of the estimated statewide population, and the Southern Central Valley remains the second largest Burrowing Owl population center. Populations in other regions of the state that were surveyed in 1991-1933 all remain much smaller than those in the two most heavily populated regions.

While not statistically significant, we observed apparent declines in two urban areas: San Francisco Bay Area Interior Region and the Bakersfield area in the Southern Central Valley region. The San Francisco Bay Area Interior region's breeding owl population is both small and well-known by local birders and researchers, making it very likely that the "best estimates" from both the 1991-1993 and 2006-2007 surveys reflect very nearly all the owl pairs actually present. Consequently, the apparent loss of 27.9% of the population, from 165 to 119 pairs since the early 1990s survey, is somewhat alarming. This loss includes the last known pairs of owls in both Sonoma and San Mateo counties, and suggests that Burrowing Owls have now been extirpated as a breeding species in the entire San Francisco Bay Area, except for Alameda and Santa Clara counties, where populations have also declined. It should be noted that Burrowing Owl populations can fluctuate annually, so our lower count of owls in the region does not necessarily indicate a deterministic decline. However, the increasingly restricted distribution of the species throughout the region would seem to indicate that such a trend is real.

In the greater Bakersfield area, heavy losses (nine blocks lost a total of 96 pairs) appear to be associated with recent land conversion from agriculture to urban, though a finer resolution spatial assessment would be helpful to determine whether such land conversion really has driven the losses. In any case, it seems that like the San Francisco Bay Area, the greater Bakersfield area is in danger of losing most if not all of its once substantial Burrowing Owl population. This is particularly unfortunate because the species exhibits a remarkable degree of tolerance for human alteration of natural habitats (Klute et al. 2003, Chipman et al. 2008), often nesting within landfills, golf courses, airports, and vacant lots within urban areas (Haug et al. 1993, Trulio 1997). This tolerance of humans and their activities would seem to provide ample opportunity for successful conservation efforts, even in the context of urban areas with growing human populations. One result, showing that the likelihood of Burrowing Owls persisting through 2006-2007 on survey blocks where they were present in 1991-1993 was strongly and positively related to the number of owls that were present on the blocks in 1991-1993, underscores the precariousness of dwindling urban-area populations, and the need for rapid action to prevent local extirpation.

In contrast to areas where we noted declines, we also noted areas where Burrowing Owls may have increased since the 1991-1993 survey: the Central-Western Interior region and the Coachella Valley. However, we surveyed a much greater number of upland blocks in contrast to the earlier survey in the Central-Western Interior region, so the apparent increase could be an artifact due to increased surveys effort. In contrast, the apparent increase (from zero to 53 owl pairs) in the Coachella Valley seems more likely to indicate a real increase in owl presence, especially because we found multiple Burrowing Owl pairs on four blocks in the region that were also surveyed in the early 1990s, but yielded no detections at that time. Interestingly, none of the pairs we found in Coachella Valley appeared to be associated with agriculture or water conveyance structures;

rather they occupied a variety of relatively arid habitats including brushland, desert scrub, and natural grasslands, and appear to be clustered on the outskirts of urban development.

Large confidence intervals make comparing our statewide population estimate with that of DeSante et al. (2007) during 1991-1993 difficult, especially since the difference in the estimates is relatively small. Three quarters of owl pairs in our aggregated population estimate reside in the densely occupied Imperial Valley, where the standard error associated with our regional estimate is well over 2,000 pairs. Thus, the lack of precision in this single regional estimate could easily mask a real statewide decline, or for that matter, potentially even obscure a statewide increase. Future survey efforts could perhaps minimize the problem of low statistical power by focusing monitoring efforts on smaller areas selected for high owl population density or other factors, and sustaining those efforts for multiple successive breeding seasons.

Our survey of the "new" survey regions covering the Modoc Plateau/Great Basin, Mojave Desert, and Sonoran Deserts represents the first systematic survey of Burrowing Owls across vast portions of California. We found Burrowing Owls to be distributed heterogeneously among these regions, with few or no owls in the Modoc Plateau/Great Basin, Northern Mojave/Eastern Sierra Nevada, Eastern Mojave, or Sonoran Desert regions (excluding the Palo Verde Valley). However, we found much larger aggregations of burrowing Owls in the Western Mojave region, and in one small area of the Sonoran Desert—the Palo Verde Valley.

CONSERVATION IMPLICATIONS

A comprehensive conservation strategy for Burrowing Owl in California is under development by California Department of Fish and Game and its partners (Burkett and Johnson, 2008). Here we provide a few conservation-related conclusions and recommendations that stem directly from our results:

1) Despite the apparent robustness of the population in the Imperial Valley, smaller populations elsewhere in the state, particularly in and near urban areas, appear to have continued to decline since the 1991-1993 survey.

2) The vast majority of the state's breeding Burrowing Owls continue to nest on private lands; any meaningful conservation efforts must therefore engage private stakeholders.

3) Across much of California, Burrowing Owl nesting remains closely associated with the presence of ground squirrels, another factor that must be considered in developing successful conservation measures.

4) In a few key areas, particularly the Imperial Valley and the Palo Verde Valley, Burrowing Owls are not closely associated with ground squirrels, and instead rely heavily on the banks of concrete and earthen water conveyance structures for nesting sites. Comprehensive conservation planning for Burrowing Owl in California must take into consideration the importance of these artificial structures.

5) Although Burrowing Owl detections were scarce across most of the land area of the newly surveyed Modoc Plateau/Great Basin and southern California desert regions, substantial populations persist in the Sonoran Desert (Palo Verde Valley) and the western Mojave Desert regions (particularly in and around the Antelope, Apple, and Lucerne valleys). We estimate the western Mojave Desert region to contain ~6% of California's breeding Burrowing Owls, superseded in numerical importance to the statewide population only by the Imperial Valley and the Southern Central Valley regions. Successful conservation planning for this species must address the particular needs of these substantial desert populations (Wilkerson and Siegel, *in press*).

6) A statewide conservation strategy will likely need to incorporate a statewide monitoring program to assess the effectiveness of conservation measures. Our study demonstrates the potential value of citizen-science participation in single-species studies, particularly of raptors or other highly charismatic species like Burrowing Owls that are relatively easy to find and identify. While many of our volunteer observers were highly skilled birders, and in some cases, even wildlife professionals, others had little or no birding experience. With a fairly modest investment of time and money for recruiting, training, and supporting volunteer surveyors, we were able to extend our survey across a vast area. Engaging citizen-scientists in monitoring could reduce the cost and extend the scope of any owl monitoring project, and may also yield less tangible benefits — participants in

citizen science monitoring programs can reap an increased awareness and appreciation of study organisms and their habitats, which may then translate into tangible actions on their behalf (Evans et al. 2005).

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