Monitoring distribution and abundance of nesting Swainson's hawks in the Sacramento Valley and Sacramento River Delta, California

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We surveyed for nesting Swainson's hawks (*Buteo swainsoni*) using a stratified random sample design during the years 2002, 2003, and 2009 in portions of the Sacramento Valley and Sacramento-San Joaquin River Delta, California, USA. We estimated the number of active nests in the study area to be 593, 1008, and 941 in each of those years, respectively. We found the number of nests per survey block to be significantly higher in 2003 than 2002, while 2003 and 2009 did not differ statistically. Significant concentration of nests was found on the flat valley floor, notably in Yolo, Sacramento, San Joaquin, and Solano counties, and fewer nests were found toward the valley margins. We intend that monitoring of this population be continued in the future and that methods described herein provide a repeatable approach to investigating Swainson's hawk population trends in the Sacramento Valley. The results of surveys will be used to update nest records for the Swainson's hawk in the California Natural Diversity Data Base.

Key words: Aves, Swainson's hawk, *Buteo swainsoni*, nesting pairs, active nests, monitoring, trend, distribution, spatial analysis

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The Swainson's hawk (*Buteo swainsoni*) is a Neotropical migrant, breeding in North America and Canada, and wintering in Mexico, Central and South America (England et al. 1997, Howell and Webb 1995, M. Bradbury [California Department of Water Resources, personal communication]). The majority of California's breeding Swainson's hawks nest within the Sacramento Valley and Sacramento/San Joaquin Delta. Records contained in the

California Natural Diversity Data Base (CNDDB) as of 2002 indicated that approximately 72% of California's Swainson's hawk records occurred within the Great Valley ecoregion north of the southern San Joaquin County line.   Bloom (1979) surveyed California and described the distribution of Swainson's hawk "nest territories". He speculated that the, "…Central Valley probably supported the highest nest densities of Swainson's hawks." Subsequent surveys (Estep 2007a, b, 2008, 2009; Anderson et al. 2007) have established the Central Valley's significance to the species and established its importance to the conservation of Swainson's hawk in California.

        During the spring and summer of 2002, 2003, and 2009, the California Department of Fish and Game (CDFG) surveyed a portion of the Sacramento Valley and Sacramento-San Joaquin Delta of California for nests of Swainson's hawks. The goals of our survey were to (1) detect changes in the number of nesting pairs within the study area; (2) monitor changes over the long term; and, (3) gather information about the location and spatial distribution of nests. We anticipate this information will provide baseline information and help inform comparative analyses to gauge effectiveness of Habitat Conservation Plans on multiple spatial scales within the Sacramento Valley and Delta regions. We also intended to use the results of the survey to refresh the occurrence database of active Swainson's hawk nests recorded in CNDDB. The database information is useful in making informed recommendations to land use agencies.

STUDY AREA

        Our study area includes those portions of the Sacramento Valley and the Sacramento-San Joaquin River Delta that fall within Administrative Region 2 of the California Department of Fish and Game. We maintained our study area along the regional boundary line in place in 2001, which was used in the 2002 and 2003 surveys, although the boundary has since been revised. This is roughly an area of the Central Valley that extends from Chico, Butte County in the north to Tracy, San Joaquin County in the south. We examined the likely breeding range of the Swainson's hawk by plotting records of that species in the January 4, 2002 CNDDB over a Digital Elevation Model. All of the CNDDB Swainson's hawk nests were below 152 meters (500 feet) above sea level. However, in order to avoid overlooking nests along the margins of the valley we extended the maximum elevation to 305 meters in the study area for the years 2002 and 2003 (Figure 1).

METHODS

        Sampling design.—To increase uniformity of search effort, the study area was subdivided using a grid. Each 5-km x 5-km cell in the grid (survey block) was given a unique identifying number. In all years, individual survey blocks were included in the sample regardless of vegetation, land use, or habitat characteristics. In some instances this resulted in selection of sample blocks that contained urban environments.

        The sampling area initially included the valley and foothill margin up to 305 m in elevation. This produced a sample frame that included 1074 survey blocks, which was sampled during the 2002 and 2003 surveys. Analysis of the 2002-2003 data indicated that we found only a single Swainson's hawk nest above 152 meters in elevation; therefore we revised our 2009 study area to contain only blocks with 50% or more of their area below 152 meters in elevation (Figure 2). This reduction permitted a refinement of the sample frame,
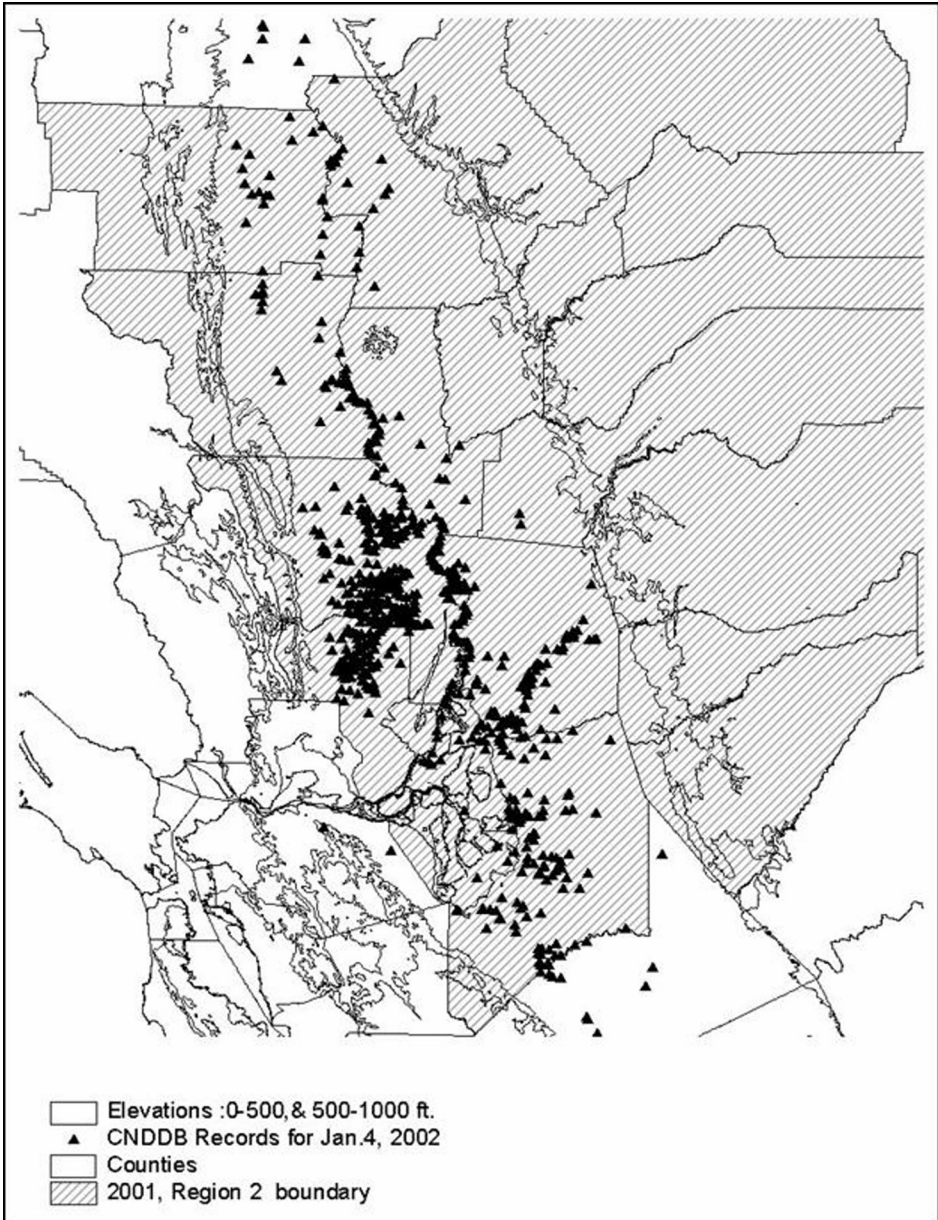
Figure 1.—Swainson's Hawk records in the California Natural Diversity Data Base as of 2002, showing the importance of the Sacramento-San Joaquin River Delta and Sacramento Valley, California. County boundaries, elevation contours at 0, 152, and 305 meters, and the boundary of the California Department of Fish and Game's North Central Region as of 2001 also are shown.
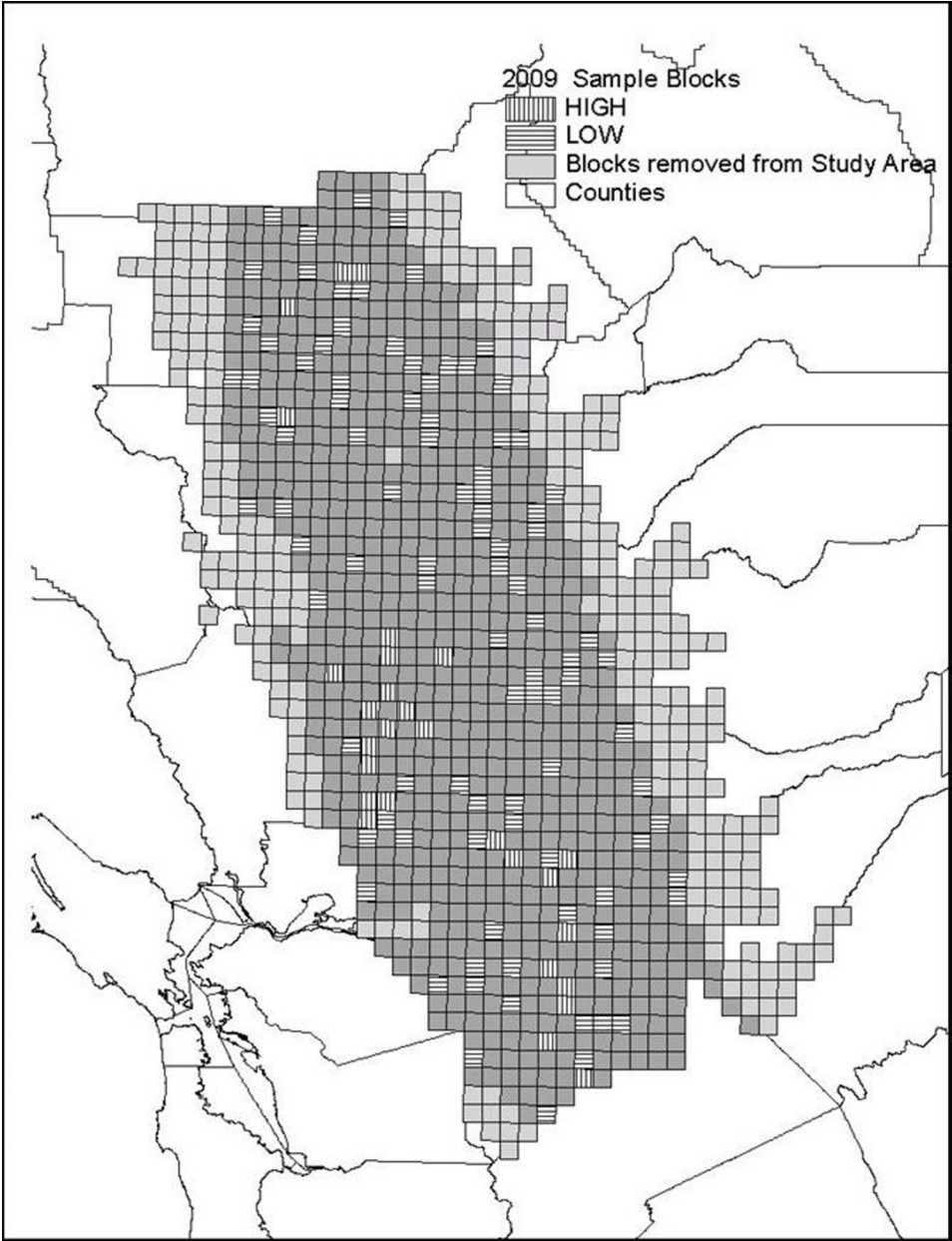
Figure 2.—Study area for the Swainson's hawk survey showing higher-elevation blocks removed from the 2009 sample frame (light gray), and blocks randomly selected for survey from high and low density strata during 2009 in the Sacramento-San Joaquin River Delta and Sacramento Valley, California.

and a reduction from 1074 to 781 survey blocks. We address the altered 2009 sampling frame in our results analysis.

We used a stratified sample design, with two strata based on 2002 Swainson's hawk CNDDB records. Survey blocks that had one or more records were included in the high density stratum; those with no record were included in the low density stratum. Within each stratum we drew a simple random sample. During 2002 and 2003, there were 225 high density and 849 low density blocks in the strata, respectively (Table 1). In 2009 we stratified the sample in a slightly different manner. Based on analyses of the 2002-2003 data, we determined that ≥ 2 CNDDB records was a good break point for defining the strata (instead of ≥ 1), and we used power analysis to determine optimal sampling allocation between the strata (Cochran 1977:98). Thus, during 2009 we defined the high stratum as any survey

TABLE 1.—Number of 5-km by 5-km survey blocks, Sacramento Valley and Sacramento-San Joaquin River Delta, California, showing number available by year over the entire study area (sample frame, N) and throughout two strata (high, low); and number of blocks actually sampled, total (n) and per stratum.

Year	Sample Frame: N	High Stratum N_H	Low Stratum N_L	Sample: n	High Stratum n_H	Low Stratum n_L
2002	1074	225	849	120	80	40
2003	1074	225	849	120	60	60
2009	781	118	663	125	28	97

block that had 2 or more records of Swainson's hawks (using 2002 CNDDB), low stratum as blocks with 1 or 0 records, which yielded a sampling space containing 118 high stratum blocks and 663 low stratum blocks (Table 1). We randomly selected blocks for sampling during 2003 and 2009 without regard for whether they had been surveyed in an earlier year.

Survey protocol.—We adapted our protocol from the Swainson's Hawk Technical Advisory Committee's (2000) recommended survey protocol. The protocol required that surveyors drive all of the public roads, or other public access routes, in the survey block and methodically search for active Swainson's hawk nests during the breeding season using binoculars and spotting scopes (it is possible nests in the Delta visible only from the water were undercounted). Surveyors were required to completely search each survey block at least once during each of three survey phases (March-April, May-June, and July) to increase the likelihood of detecting the greatest number of nests in the survey block, as well as to gain information about the rate of nest success and the number of chicks produced.

The surveyors consisted of 20 or more DFG employees (biologists, seasonal aides, and research assistants), and each year included a mix of neophytes and veterans of raptor nest surveys. To help reduce the potential for bias, all were required to attend two training sessions during which they were introduced to the survey protocol, data sheet, and survey equipment, which included a Geographic Positioning System (GPS) unit, compass, and laser range finder. Most surveyors were assigned 4 or 5 survey blocks.

Each surveyor received a 22x30 cm map of each their assigned survey blocks. The maps showed the boundaries of the block overlaid on aerial imagery, which helped to identify public roads and other land features. Surveyors were instructed that the objective of the survey was to locate every Swainson's hawk nest within each assigned survey block. In instances where access or visibility prohibited full coverage, the surveyor was instructed to draw a line around any un-surveyable area and label it "un-surveyed" on the block map to allow later calculation of the un-surveyed area.

Only occupied, active Swainson's hawk nests were recorded. Confirmation of an occupied nest consisted of observation of the nest itself in one or more of the following contexts: (1) an adult in the nest; (2) an adult defending the nest; (3) an adult carrying food to the nest; or, (4) young in and around the nest (identification verified by the presence of an adult).

When a Swainson's hawk nest was detected, the observer recorded the coordinates using a GPS unit, a compass bearing to the nest tree (declination-corrected), and the distance of the observer to the nest tree. These measures were later entered into a calculation that determined the nest tree coordinates based on the input data. To verify the accuracy of nest locations, each calculated nest coordinate was mapped over current aerial imagery and reviewed by the original surveyor. The surveyor made corrections to the nest location if necessary, and any needed corrections were recorded in the data base.

Analyses.— We tested the null hypothesis that numbers of nests per survey block (nest densities) were the same for all years by substituting the stratified means ($\bar{y}_{st}$) and their standard errors (*SE*) for each of the survey years into (Gonick and Smith 1993)

$$Z_{obs} = \frac{\bar{y}st_1 - \bar{y}st_2}{SE(\bar{y}st_1 - \bar{y}st_2)} \qquad [1]$$

Since sample size was large enough each year for the mean to approximate normality ($n \geq 120$), we compared Z_{obs} to the standard normal distribution to derive the associated probability.

Estimates of the total number of actively nesting pairs of Swainson's hawks within the study area were obtained for each survey by summing each stratum's estimated number (mean nest density [$\bar{y}_{st}$] multiplied by the total number of blocks in the stratum) (Thompson 1992). The 95% confidence interval was calculated as

$$T_{st} \pm t\sqrt{\text{var } T_{st}} \qquad [2]$$

where T_{st} is the total population (number of nesting pairs) and *t* is Student's *t* statistic for $\alpha/2 = 0.025$.

To assess the data for patterns of spatial distribution, the three survey periods were analyzed using Moran's *I* index of spatial autocorrelation. This statistic is available as a tool within Environmental Systems Research Institute, Inc., ArcMap GIS software, and was selected because it is a "global" statistic, useful in addressing whether there is a spatial pattern present, and because it can be applied to a set of discontinuous subsamples of the study area (Scott 2008, deSmith et al. 2009). The Moran *I* tool calculates the value of Moran's index and associated *Z*-score for a given input feature class. In our analysis, the input feature class was the individual survey blocks sampled during each survey, and the input field was the number of nests recorded for each survey block. The *Z*-score, which is distributed approximately as a standard normal distribution, was used to determine whether

to accept or reject the null hypothesis that there is no spatial pattern (i.e., the spatial pattern is random). The higher the positive *Z*-score the greater the significance of clustering; a *Z*-score near zero indicates no apparent clustering.

<div style="text-align:center">

RESULTS

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During 2002-2009 we recorded 707 active Swainson's hawk nests and added their locations to the CNDDB. This value includes "incidental finds," which were nests outside assigned survey blocks, usually located by the surveyor when traveling to or from an assigned block. A total of 478 recorded nests fell within the assigned sample blocks, especially high-stratum blocks (Table 2). Roughly 5% of high stratum block area and 10% of low stratum block area could not be accessed.

Change in the number of nests per survey block.—Detecting a change in the number of pairs nesting over time was a primary goal of the study. We tested for change in the number of nests detected, and rejected the null hypothesis of no change (Z_{obs}=2.45, $P_{(2\text{-tailed})}$<0.05) between 2002 and 2003, when overall mean nest densities of 0.55 and 0.94 per survey block were recorded.

TABLE 2.—Number of active Swainson's hawk nests recorded, by year and stratum. Sample size (number of blocks: n_H or n_L) in parentheses is adjusted for unsurveyable area. Mean is the average number of nests per sample block calculated using adjusted sample size. Sampling frame and stratum definitions changed between 2003 and 2009; in 2002 and 2003 the low stratum included blocks with no CNDDB nest records; in 2009 the low stratum was changed to remove blocks having >50% of their area greater than 152 meters above sea level, and formerly high stratum blocks with only 1 CNDDB record were transferred to the low stratum.

Year		High Stratum Sample				Low Stratum Sample		
	Nests	n_H (adj.)	Mean	Var.	Nests	n_L (adj.)	Mean	Var.
2002	130	80 (77.5)	1.7	3.40	9	40 (35.5)	0.25	0.487
2003	152	60 (58.6)	2.6	12.02	25	60 (50.1)	0.50	1.027
2009	*84*	*28 (25.9)*	*3.2*	*9.56*	*78*	*97 (92.6)*	*0.84*	*2.972*

To compare 2009 to earlier years, we examined results from all years solely within the smaller 2009 sampling frame. All 293 blocks outside the 2009 frame were low stratum blocks. Due to the exclusion of mostly empty blocks sampled outside the smaller frame, mean densities for 2002 and 2003 were greater within the more focused frame. Compared on this basis, mean nest densities per survey block (and standard deviations) were 0.76 (0.13) in 2002, 1.40 (0.19) in 2003, and 1.21 (0.16) in 2009. Mean nest densities were not distinguishable between 2003 and 2009 (Z_{obs}=-0.82, $P_{(2\text{-tailed})}$>0.40) , but the difference between 2002 and 2003 remained significant (Z_{obs}=2.83, $P_{(2\text{-tailed})}$<0.01); nest density in 2009 also was significantly different from that in 2002 (Z_{obs}=2.17, $P_{(2\text{-tailed})}$<0.05).

The 2002 to 2003 difference remained significant (P<0.05) when the multiple comparisons were taken into account (Dunn-Bonferroni corrected significance threshold under multiple comparisons; Dunn 1961), while the 2002 to 2009 difference was not significant (P~0.10). Also, within the smaller sample frame, numbers of blocks sampled per stratum fell slightly below the minimum sample size of 30 recommended by Thompson (1992:106) in certain instances (2002 n_L = 25; 2009 n_H = 28). A *t*-test approximation for

sample sizes under 30 (Thompson 1992) yielded the same significance presented herein.

Survey-wide nesting pairs.—Our calculations for total actively nesting pairs suggested larger numbers in 2003 and 2009, relative to 2002 (Figure 3). Although the 2009 survey covered a smaller sampling frame, we believe relatively few pairs were left out by excluding the higher-elevation blocks that were included during 2002 and 2003.
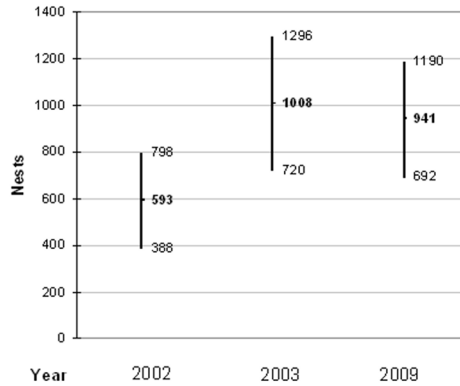
Figure 3.—Estimated number of active Swainson's hawk nests in the study area, 2002, 2003, and 2009 (with 95% confidence intervals), Sacramento Valley and Sacramento-San Joaquin River Delta, California.

Nest Density and Distribution.—Most nests were recorded on the flat valley floor, with fewer nests located along its margins. Survey blocks containing ≥2 nests — perhaps implying higher quality or greater availability of breeding habitat — were concentrated in the four counties surrounding the Sacramento-San Joaquin River Delta (San Joaquin, Sacramento, Solano, and Yolo counties; Table 3, Figure 4). The same four counties contained >60% of recorded nests, and this pattern of nest distribution was consistent during all three years.

We found support for spatial clumping of active nests found per block, suggesting spatial differences in Swainson's hawk habitat or preferences (Moran's I: 0.1 in 2002, 0.12 in 2003, and 0.04 in 2009; $I > 0$ indicates positive spatial autocorrelation). Using the associated Z-scores for each year (2002: 9.0; 2003: 10.7; 2009: 4.5), we concluded that the clustering of Swainson's hawk nests was significant, and that there was a less than 1% chance that the spatial distribution of nest counts per block as shown in Figure 4 was due to chance alone.

TABLE 3.—Number of survey blocks, by county, containing two or more Swainson's hawk nests as determined by ground surveys during 2002, 2003, and 2009.

County	2002	2003	2009	Total
Yolo	13	8	9	30
Sacramento	9	11	5	25
San Joaquin	9	6	9	24
Solano	6	3	6	15
Colusa	4	6	2	12
Sutter	5	6	0	11
Glenn	3	1	4	8
Butte	2	0	3	5
Yuba	0	2	0	2
Placer	0	1	0	1
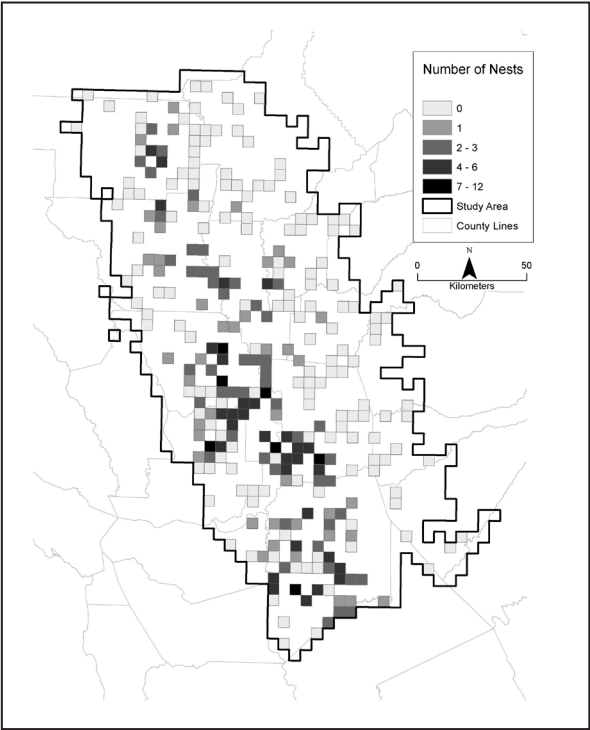
FIGURE 4.—Swainson's hawk nest counts per sample block within the study area in the Sacramento Valley and Sacramento-San Joaquin River Delta, California. All three years of survey data are illustrated. For blocks that were surveyed in more than one year, average nest count is shown (55 of 289 blocks were surveyed in two years; 10 were surveyed in all three years).

Discussion

The survey protocol we have presented here proved to be repeatable and usable in comparative analyses. The ability to detect change is related to sampling design, sample size, sample allocation, and observer bias. We chose a stratified sample design employing a simple random sample with replacement. We sampled 120-125 survey blocks, which resulted in an initial sample effort of 11% of the sample space, but which was increased to 16% after reduction in the study area and an increase in sample size. To help address the potential for observer bias we standardized the survey methods through the use of a survey protocol, standard recording form, and mandatory surveyor training.

One of the goals of our surveys was the collection of accurate nest locations. Through the use of the verification process described herein we were successful in recording the locations of active nest trees with an accuracy of ≤10 m. Although the survey results are limited to the blocks sampled and do not provide a full picture of the distribution of active nests, their timeliness and accuracy make them a valuable tool for use in land use planning or impact analysis.

Our results suggesting an increase in Swainson's hawk nests are consistent with the North American Breeding Bird Survey (BBS), which reported a 1999-2009 increase in the species both throughout California and in a region including coastal central and southern California and the Great Central Valley (Sauer et al. 2011), with 4 statewide surveys summarized by Anderson et al. (2007), and with increased nest-finding success reported by Briggs et al. (2011) in far northern California. The California data on Swainson's hawks is considered deficient by the BBS (Sauer et al. 2011) however, and we did not make quantitative comparisons with BBS results. Anderson et al. (2007) reported a combined 2005 and 2006 estimate of 1548 territorial pairs for our study area (summed Sacramento Valley and San Joaquin County estimates; summed 95% confidence interval 1207-1889 pairs). Given methodological differences between projects we believe their finding and ours are of a similar magnitude. Our result suggesting an increase in nesting pairs between 2002 and 2003 must, nonetheless, be regarded with healthy caution since it is based on only 3 years of survey results. There are a number of confounding factors (weather, flooding, prey availability, etc.) that may have affected the number of Swainson's hawks that initiated nests within our study area. Monitoring over a longer time period will be needed to confirm a population increase.

Spatial analysis of the data indicated that Swainson's hawk nests were neither randomly nor evenly distributed. While an analysis of nest distribution would best be conducted with data from a complete survey of all blocks, the data from our survey are the result of three random selections of sampling blocks over a period of seven years. For the purpose of spatial analysis the data may be considered the results of replicate surveys. Analysis of each replicate produced a similar result: high-value survey blocks (those with the most nests) were clustered, and the pattern of distribution was consistent over the period of observation. The data indicate that greater numbers of nests are located in the central portion of the study area — specifically, in the Central Valley on the low-lying bottom of the valley and, to a much lesser extent, along its margins. Searches of survey blocks at or above 152 meters in elevation located only a single Swainson's hawk nest. This pattern of nest distribution could change with changing abundance of the species if the observed pattern results from filling in "preferred" sites first and, as a result, additional pairs must spread to less desirable locations.

A follow-up study has found that our accuracy of Swainson's hawk nests located and identified was high (T. Gardner [CDFG] and D. Gifford [CDFG, retired] personal communications). Nonetheless, some constraints of our data bear noting. We know from a small pilot study using duplicate independent block surveys that not all Swainson's hawk nests present were found during our surveys. We cannot accurately estimate detectability at this time, but this implies there were likely more Swainson's hawk nests and nesting pairs in the Sacramento Valley and the Delta than we have calculated here.

Future survey refinements should include quantifying detectability — perhaps in relation to observer skills, effort, and habitat sampled — in order to refine population estimates and survey methods. A habitat model would be valuable in explaining the non-random Swainson's hawk nesting distribution and prioritizing areas that, as yet, remain unsurveyed. With such refinements, monitoring the population of Swainson's hawks in the Sacramento Valley at regular intervals will yield meaningful results useful in planning and conservation.

ACKNOWLEDGMENTS

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