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FORAGING BY SWAINSON'S HAWKS IN A VINEYARD-DOMINATED LANDSCAPE

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Abstract.—We studied habitat use for foraging by Swainson's Hawks (*Buteo swainsoni*) within a complex agricultural crop matrix in California's Central Valley to ascertain if vineyards were used for foraging. Central Valley vineyard agriculture has increased recently, especially in areas supporting the highest regional numbers of Swainson's Hawks. There is concern that increased vineyard coverage may reduce the amount of foraging habitat available for Swainson's Hawks, because vineyards have been considered poor foraging habitat for this species, due to the height and density of the vines. In 2002 and 2003, we conducted road surveys to record observations of foraging Swainson's Hawks in relation to agricultural habitats. Using chi-square tests and 95% CIs, we assessed habitat selection for foraging Swainson's Hawks and determined whether habitat use varied throughout the breeding season. Swainson's Hawks used 10 unique habitat types for foraging during the breeding season. Swainson's Hawks used vineyards less than expected and irrigated hay and dryland grain habitats more than expected, with some variation in habitat use as the season progressed. The variety of habitats that Swainson's Hawks used for foraging in our study area suggests that maintenance of large heterogeneous areas of agricultural habitats that include crops such as alfalfa, as well as large tracts of grazed grasslands, should be one of the priorities for conservation of this species in this region.

Key Words: *Swainson's Hawk*; Buteo swainsoni; *agriculture*; *foraging*; *habitat selection*; *vineyards.*

FORRAJEO POR PARTE DE *BUTEO SWAINSONI* EN UN PAISAJE DOMINADO POR VIÑEDOS

Resumen.—Estudiamos el uso del hábitat para alimentación por parte de *Buteo swainsoni* dentro de una matriz compleja de cultivos agrícolas en el valle central de California, para determinar si los viñedos son utilizados por esta especie para forrajear. La agricultura de viñedos en este valle se ha incrementado recientemente, especialmente en áreas que sustentan las mayores cantidades de individuos de esta especie a nivel regional. Existe preocupación en cuanto a que el incremento en la cobertura de viñedos podría reducir la cantidad de hábitat que *B. swainsoni* tiene disponible para forrajear, pues los viñedos se han considerado un ambiente de alimentación pobre para esta especie debido a la altura y la densidad de las viñas. En 2002 y 2003, realizamos censos desde carreteras para registrar observaciones de forrajeo por parte de individuos de esta especie en relación con ambientes agrícolas. Usando pruebas de chi-cuadrado e intervalos de confianza del 95%, evaluamos la selección de hábitat para forrajeo, y determinamos si el uso del hábitat variaba a través de la época reproductiva. Las aves utilizaron 10 tipos de hábitat únicos para forrajear durante la época reproductiva. Éstas utilizaron los viñedos menos de lo esperado, y ambientes de heno irrigados y áreas de cultivos de granos no irrigados más de lo esperado, con algo de variación en el uso de hábitat a medida que pasó la temporada. La variedad de hábitats que *B. swainsoni* utilizó para el forrajeo

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en nuestra área de estudio sugiere que el mantenimiento de áreas grandes y heterogéneas de ambientes agrícolas, incluyendo cultivos como alfalfa y áreas amplias de pastizales ramoneados, debería ser una prioridad para la conservación de esta especie en esta región.

[Traducción del equipo editorial]

Prey availability, combined with prey abundance, determines which areas are used by raptors for foraging (Baker and Brooks 1981, Bechard 1982, Preston 1990). An important factor affecting prey availability is vegetative structure (Craighead and Craighead 1956, Bechard 1982, Janes 1985). For example, plants that offer cover for prey may be too tall or too dense for raptors to hunt successfully, and thus might be avoided by foraging raptors. In agricultural areas, where a variety of vegetative structures may exist, foraging raptors might be expected to congregate in areas that offer a combination of prey abundance and availability, to maximize energy gain per unit hunting effort (MacArthur and Pianka 1966).

In the Central Valley of California, Swainson's Hawks foraged more often in agricultural areas that support irrigated hay crops (e.g., alfalfa), as well as dryland pastures, grassy ruderal lots, and some irrigated crops due to a higher relative abundance of prey and better accessibility (Bloom 1980, Estep 1989, Babcock 1995, Smallwood 1995). Vineyards are considered to be unsuitable foraging habitat for Swainson's Hawks because of low prey density and inaccessible vegetative structure (Estep 1989, Smallwood 1995). Replacing more open agricultural lands with vineyards may remove Swainson's Hawk foraging habitat from the Central Valley because vineyards typically represent long-term plantings covering large areas.

The recent increase in vineyard acreage in the Central Valley may negatively impact Swainson's Hawks (Estep 1989). For example, between 1987 and 2002, there was a substantial increase in the amount of land planted as vineyards in areas that support the highest numbers of Swainson's Hawk breeding pairs in California (Bureau of the Census 1989, National Agricultural Statistics Service 2004, Anderson et al. 2007). During this period, increases in the vineyard area of 509%, 595% and 53% were recorded in Sacramento, Yolo, and San Joaquin counties, respectively. These increases reflect an addition of >21 700 ha of vineyards within these three counties. Over the same time period (1987–2002), vineyard area also increased substantially in Colusa (163%), Solano (65%), and Merced (69%) counties, all of which support substantial populations of Swainson's Hawks (Anderson et al. 2007). Although vineyards have been considered unsuitable foraging habitat for Swainson's Hawks (Estep 1989, Smallwood 1995), to our knowledge no studies have described or quantified Swainson's Hawk foraging in vineyards relative to other habitats. We here report habitat use by foraging Swainson's Hawks in a vineyard-dominated landscape during the 2002 and 2003 breeding seasons.

METHODS

Study Area. The study area was in northern San Joaquin County, California, near the Sacramento River delta (Fig. 1), including the watershed of the lower Mokelumne River, which originates in the Sierra Nevada range and flows into the delta. The elevation ranged from 1 m above sea level (ASL) in the west to 115 m ASL in the Sierra foothills in the east. Dominant native tree species included valley oak (*Quercus lobata*), blue oak (*Q. douglasii*), Fremont cottonwood (*Populus fremontii*), and live oak (*Q. wislizenii*).

Habitat Mapping. We used the California Wildlife-Habitat Relationships system (CWHR) to classify 13 of the 15 native and agricultural habitats that occurred in the surveyed area (Mayer and Laudenslayer 1988). We also defined two additional habitat types to classify agricultural lands not described by the CWHR (Reeves and Smith 2004): ag-urban (rural residences and adjacent ruderal lots, farm operations, roads, and corridors between agricultural fields) and idle farmland (all agricultural fields unused during a growing season).

We measured habitat availability, quantified as a proportion of total surveyed area, using ArcView 3.2 GIS software® (ESRI 1999). We pooled data for both years in our analyses. Habitat layers were based on digitized 1996 California Department of Water Resources aerial photos and land-use maps.

Surveys. We used the strip transect road survey method for surveying all hawk species encountered (Fuller and Mosher 1987, Bibby et al. 1992). All observations of Swainson's Hawks within a 600-m wide strip (300 m on each side of the road) were recorded during surveys, but only foraging use was considered for data analysis (Kimsey and Conley 1988, Millsap and LeFranc 1988). In late April

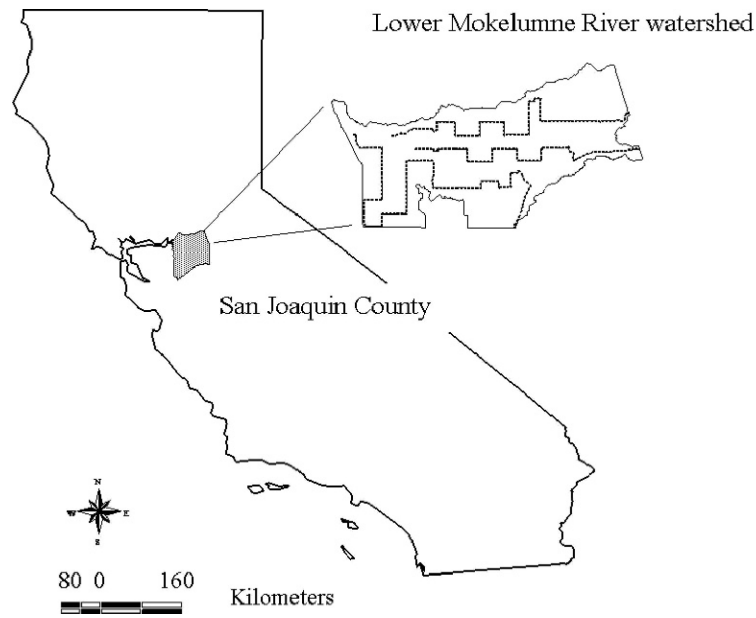

Figure 1. The lower Mokelumne River watershed (inset) in the northeastern corner of San Joaquin County (gray area), California, U.S.A. In the inset are the three routes (dashed lines) that were surveyed for Swainson's Hawks.

2002 and mid-March 2003, we began systematic road surveys on three established routes. We conducted 65 surveys on two of the driving routes and 64 surveys on the third route. The total length of the three transects was 135 km and we surveyed 8725 km during the two study seasons. Our surveys required 192 hr and each survey included an area of 8985 ha.

We selected the route sequence and direction of the initial survey randomly each year. Subsequent surveys were completed in numeric order to assure that each route would be driven at different times and directions throughout the season. All routes were driven twice per week by the same observer (CAS) during good weather (excluding days of steady rain, sustained winds over 32 kph, or temperatures over 38°C) between 0630 H and 1530 H at an average speed of 55 km/h (35 mph). When a raptor was spotted, the observer stopped the vehicle briefly and recorded the raptor species, its distance from the road, activity, the estimated height above ground, vehicle odometer reading, habitat association, land use, and notes on farming practices. Notes included plant height categories for alfalfa fields after they had been mowed. We categorized raptor activities as follows: foraging, perching on objects, flying, agonistic behavior, breeding behavior, present at nest, and perching on the ground. Swainson's Hawks are considered to be primarily aerial hunters (Janes 1985) and we considered them to be foraging if we observed them coursing, circling, kiting, or hovering $\leq$100 m above a field (Janes 1985, Estep 1989). We used 9 $\times$ 25 binoculars to identify hawks from a distance.

Habitat Analysis. We developed Geographic Information System (GIS) themes in Arcview from digitized maps and verified theme accuracy on the ground each year. The minimum mapping unit was 1 hectare. The individual habitat proportions were calculated for the 600-m-wide strips surrounding the survey routes. We accounted for differences in total coverage of individual routes (Haney and Solow 1992). For some fields that underwent crop rotations, habitat categories changed in midseason (e.g., dryland grain fields harvested and replaced with irrigated field crops). To satisfy the assumption that habitat availability is constant throughout the study (Manly et al. 2002), we made adjustments in the final proportion of these habitats by tallying the areas of all fields that changed crops midseason, dividing the values in half, and assigning those values to each habitat.

Data Analysis. We quantified foraging counts as discrete field observations, rather than tallies of hawks observed, to avoid violating the assumption of independence of resource selection (Manly et al.

2002); therefore, clusters of foraging hawks in a line of sight were counted as one observation. We evaluated trends in foraging habitat use throughout each season to determine the habitat use over time. In 2002, surveys were conducted from May through August. In 2003, surveys spanned the entire Swainson's Hawk breeding season from mid-March through August.

Hypothesis testing for selection of foraging habitat consisted of a multinomial chi-square test for goodness of fit, followed by calculation of 95% confidence intervals (Neu et al. 1974, Haney and Solow 1992). Significance levels were set at $\alpha \leq 0.05$. Selective habitat use is defined as any habitat used disproportionately, relative to its availability (Manly et al. 2002). Our null hypothesis stated that Swainson's Hawks used each habitat for foraging in proportion to habitat availability (occurrence) in the surveyed area. Foraging observation counts of Swainson's Hawks, pooled from both seasons, were used in the chi-square tests.

In order to determine which individual habitats were used more or less than expected, 95% CIs were calculated using the formula:

$$P_i - Z_{(\alpha/2k)}\sqrt{P_i(1-P_i)/n} \leq P_i \leq P_i + Z_{(\alpha/2k)}\sqrt{P_i(1-P_i)/n}$$

presented by Haney and Solow (1992), where "P_i" is the proportion of the ith resource, "Z" is the upper standard normal table value corresponding to a probability tail area of $\alpha/2k$ (2-tailed $\alpha = 0.05$), "k" represents the number of habitat categories, and "n" is the total number of observations. These ranges were compared with expected proportion values. If the expected value fell either above or below the 95% C.I., then a significant difference was recorded for that category.

To test whether differences in habitat use remained consistent throughout the breeding season, we divided observation counts into time blocks of equivalent surveys. Time segments in 2002 were divided into blocks of five surveys each between early May and mid-August. In 2003, the time segments were divided into blocks of six surveys each between mid-March and late August. We measured confidence intervals for individual time blocks per year and for the entire survey period per year. Analysis was only performed on habitat or time block categories that satisfied the assumptions for sample size as described by Haney and Solow (1992). Habitat categories which contained an insufficient number of observations were pooled together into one category for the purpose of analysis. We also recorded the foraging effort of Swainson's Hawks in alfalfa crops from the time of mowing through increasing plant heights.

RESULTS

The five most dominant habitat types in the survey area were vineyards (41%), annual grasslands (16%), ag-urban (11%), blue oak woodlands (6%), and irrigated pasture (5%). Both trellised and free-standing vineyard types were present throughout the study area, but most of the vineyards were trellised. The use of plant cover between rows of vines was commonly practiced in the study area, but the relative frequency of this practice was not quantified. Other habitats in the study area included deciduous orchard, dryland grain, irrigated hay, irrigated field crops, idle farmland, valley-foothill riparian, and urban. Three habitats (valley oak woodland, freshwater emergent wetland, and lacustrine) each represented <1% of the surveyed area. The largest concentration of vineyards was located to the west and north of the city of Lodi, and east along the Mokelumne River, where viticulture has been practiced for the past 100 yr.

We made 1331 hawk observations in 2002 and 2003 on the three survey routes. Of these, we observed 578 Swainson's Hawks (43.4% of all hawk species) including 266 foraging observations (46% of all Swainson's Hawk observations). Swainson's Hawks were observed foraging in 10 of the 15 available habitats (Table 1). The highest percentage of all foraging observations (26.3%) was associated with irrigated hay (Table 1). These observations were unique in that a number of observations in the irrigated hay included groups of hawks rather than a single hawk, especially during or immediately after mowing of the crop. No foraging observations were associated with deciduous orchard, valley oak woodland, valley-foothill riparian, fresh emergent wetland, or lacustrine habitats. Of all foraging observations, 40.2% were made in agricultural habitat types that were often used by local dairy operations in San Joaquin County.

Habitat Selection. Results of the multinomial chi-square goodness of fit test (Table 1) did not support the null hypothesis that habitats were being used for foraging in proportion to their availability ($P < 0.0001$). Irrigated hay accounted for the largest contribution (88.3%) of the overall chi-square.

Table 1. Results of multinomial chi-square analysis, testing the hypothesis that habitats are used by Swainson's Hawks in proportion to their availability. Observations pooled from two seasons, 2002 and 2003, San Joaquin County, California. All unused habitats (deciduous orchard, valley-foothill riparian, valley oak woodland, freshwater emergent wetland, and lacustrine) were here combined into one category (unused habitats).

HABITAT NAME	AVAILABLE HABITAT (%)	OBSERVED USE OF HABITAT (FREQUENCY)	EXPECTED USE OF HABITAT (FREQUENCY)	CHI-SQUARE CONTRIBUTION
Annual grassland	16.20%	46	43.09	0.2
Ag-urban	10.90%	29	28.99	0
Blue oak woodland	6.00%	5	15.96	7.53
Dryland grain	3.30%	22	8.78	19.92
Idle farmland	2.60%	16	6.92	11.93
Irrigated field crops	1.70%	3	4.52	0.51
Irrigated hay	2.20%	70	5.85	703.17
Irrigated pasture	4.80%	12	12.77	0.05
Urban	2.10%	8	5.59	1.04
Vineyard	40.80%	55	108.5	26.4
Unused habitats	9.40%	0	25	25
TOTAL	100%	266	266	795.75[a]

[a] $P < 0.0001$.

Ninety-five percent CIs, calculated for habitat use proportions of pooled data of both years, showed lower foraging use of vineyard habitats than expected, and higher use of irrigated hay habitat and dryland grain (Table 2). For 2002, similar results were found for both vineyard and irrigated hay use. For 2003, results were similar to 2002; however, dryland grain also was used for foraging more than was expected.

Analysis of time blocks in both years showed that habitat foraging use varied throughout the season. The 2002 season was problematic due to low sample sizes for certain habitats (<4 observations per habitat in each time block); however, a few results were notable. The period from June to early July showed no difference between expected and observed use of vineyards. In 2003, the period of mid-March to early May showed no difference in foraging use of vineyards, while later time periods showed a lower use. The pattern of use in irrigated hay in 2003 was consistent throughout the season until late July and early August when no difference was found. In 2003, no difference between observed and expected use for dryland grain was found in mid-March to early May, but use was higher than expected in mid- to late May. No difference in use of annual grassland was found in any time segment in either year.

Agricultural Habitat Use. Six of the ten habitats used (annual grassland, ag-urban, idle farmland, irrigated pasture, blue oak woodland, and urban) consisted of short vegetation (grasses or pasture); these habitats composed 43.6% of the foraging observations. Two of the habitats consisted of short vegetation and crops (irrigated hay and dryland grain) that were harvested at least once during the season; these habitats made up 34.6% of all foraging observations.

Observations in irrigated hay habitat (N = 70) comprised 79% in alfalfa, 14% in ryegrass hay, and 7% clover. Numbers of Swainson's Hawk observations increased after mowing of alfalfa crops and decreased as the crop grew higher (Fig. 2). Nearly half (46%) of the observations in alfalfa were made immediately after the fields were mowed while the crop was shortest. We also observed Swainson's Hawks following tractors during disking or mowing in vineyards, dryland grain, and in road medians.

In ag-urban habitat, 41.4% of the foraging observations were along roadsides or other grassy corridors. In irrigated pastures, five of the eight observations (62.5%) were in shorter grasses (0–15 cm in height). For idle farmland, 78.6% of the observations were in disked and bare fields and 21.4% were in fields that had a cover of weeds. In annual grassland, 87.2% of foraging observations were over grazing land and the remainder was over large ruderal lots. We noted a peak in the number of observations of Swainson's Hawks foraging in alfalfa fields following mowing (Fig. 2).

Table 2. Ninety-five percent CIs (Haney and Solow 1992) of observed proportions of used habitats, completed for each year, and for pooled data of combined years, for foraging Swainson's Hawks in San Joaquin County, California. CIs are compared with proportions expected to be used in each habitat. The category ''other used habitats'' include categories which did not satisfy sample size requirements for the test, so were pooled. In 2002, habitats included ag-urban, blue oak woodland, dryland grain, irrigated field crops, and urban habitats. In 2003, they include blue oak woodland, idle farmland, irrigated pasture, and urban habitats.

YEAR	DATES	ANNUAL GRASSLAND	IDLE FARMLAND	AG-URBAN	DRYLAND GRAIN	IRRIGATED PASTURE	IRRIGATED HAY	VINEYARD	OTHER USED HABITATS
2002	5/24–6/14	0.018–0.444	N/A[a]			N/A	0.105–0.587	N/A	N/A
	6/18–7/10	N/A	N/A			N/A	0.099–0.629	0–0.457	N/A
	7/12–7/29	N/A	N/A			N/A	0.054–0.652	N/A	N/A
	2002 season	0–0.402	0–0.402			0–0.133	0.253–0.463	0.100–0.344	0.035–0.237
	Expected proportion	**0.158**	**0.034**			**0.046**	**0.02**	**0.402**	**0.34**
2003	3/19–5/5	0.028–0.335		N/A	0–0.272		0.028–0.335	0.173–0.555	N/A
	5/12–5/26	N/A		N/A	0.118–0.382		0.118–0.382	N/A	N/A
	6/2–6/27	N/A		0–0.317	N/A		0.092–0.514	0–0.317	0.005–0.359
	7/2–7/16	0.049–0.391		0.049–0.392	N/A		0.049–0.392	0.032–0.358	0–0.255
	7/21–8/6	0.112–0.578		N/A	N/A		0–0.357	N/A	0.009–0.406
	2003 season	0.122–0.278		0.082–0.220	0.048–0.168		0.141–0.303	0.122–0.278	0.056–0.182
	Expected proportion	**0.166**		**0.114**	**0.041**		**0.023**	**0.413**	**0.243**
2002–2003	Both seasons	0.112–0.234		0.059–0.159	0.038–0.128		0.192–0.334	0.141–0.273	0.105–0.225
	Expected proportion	**0.162**		**0.109**	**0.033**		**0.022**	**0.408**	**0.266**

[a] N/A = Insufficient data for analysis.

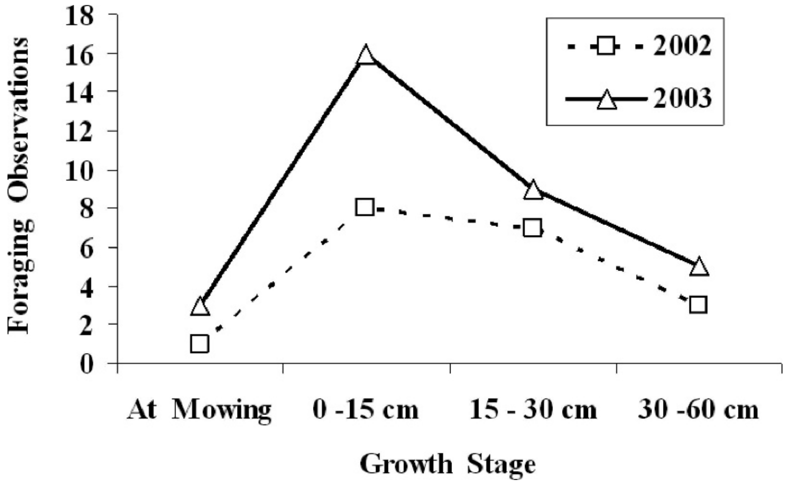

Figure 2. Foraging effort of Swainson's Hawks in alfalfa crops from the time of mowing through increasing plant heights, San Joaquin County, California, for 2002 and 2003 seasons.

DISCUSSION

In general, Swainson's Hawks in the study area demonstrated similar partialities for foraging habitat as in other Central Valley studies (Estep 1989, Babcock 1995, Smallwood 1995); Swainson's Hawks used irrigated hay (alfalfa) and dryland grain more than expected and vineyards less than expected. We hypothesize that the relatively high frequency of foraging in vineyards by Swainson's Hawks may be a reflection of the high local nesting density of Swainson's Hawks in a study area where dominant land use is viticulture. Being an opportunistic species (England et al. 1997), Swainson's Hawks may be expected to utilize sub-optimal foraging habitats based on availability and proximity to established nest sites (Newton 1979, Manly et al. 2002).

Our results support Janes's (1985) model that indicated that vegetative structure, including plant height, density, and cover can alter foraging behavior of aerial hunters including the Swainson's Hawk. We hypothesize that the higher frequency of hawks foraging in alfalfa after mowing was most likely due to temporal increases in prey availability and also may explain Swainson's Hawks' apparent preference for hay crops in the Central Valley over their more traditional preference of grassland habitats (Estep 1989, England et al. 1997). Further, although annual grassland ranked third in absolute number of foraging observations, it was not used more than expected, given its availability. It is notable that the majority of observations in annual grassland habitat were in grazed parcels. Though the difference in grass height and density between grazed grassland and unmanaged grassy fields was not measured in the study area, grazed grassland was observably shorter in height and less dense in cover.

The variety of habitats that Swainson's Hawks used for foraging in our study area suggests that maintenance of large heterogeneous areas of agricultural habitats that include crops such as alfalfa, as well as large tracts of grazed grasslands, should be one of the priorities for conservation of this species in this region. Further, we suggest that large, contiguous areas of vineyards are likely unsuitable for foraging by Swainson's Hawks at a population level. A land-use model created by Hilty et al. (2006) predicted that the probability of native mammalian predator occurrence in large blocks of vineyards decreased, but increased as the vineyard blocks became more isolated. Thus, we recommend some agricultural practices including the maintenance of between-row cover crops, midseason vine-trimming, and the establishment of buffer areas of native grasses and shrubs between fields in areas with larger tracts of vineyards. These measures are currently being practiced by grape growers in our study area in the lower Mokelumne River watershed, and may increase prey accessibility for raptors (K. Reeves unpubl. data). In addition to planting cover crops in vineyards, we recommend maintaining such crops for multiple years, as gopher (*Thomomys* sp.) density in vineyards increases with cover crop persistence (Smallwood 1996). Additionally, selection of cover plant types should optimize both prey cover and accessibility. By boosting prey populations, viticulturists may help offset possible decrease in foraging habitat for Swainson's Hawks created by large-scale vineyard development.

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LITERATURE CITED

ANDERSON, R.L., J.L. DINSDALE, AND R. SCHLORFF. 2007. California Swainson's Hawk Inventory: 2005–2007. Final Report. Department of Fish and Game Resource Assessment Program, California Department of Fish and Game, Sacramento, CA U.S.A.

BABCOCK, K.W. 1995. Home range and habitat use of breeding Swainson's Hawks in the Sacramento Valley of California. *J. Raptor Res.* 29:193–197.

BAKER, J.A. AND R.J. BROOKS. 1981. Distribution patterns of raptors in relation to density of meadow voles. *Condor* 83:42–47.

BECHARD, M.J. 1982. Effect of vegetative cover on foraging site selection by Swainson's Hawk. *Condor* 84:153–159.

BIBBY, C.J., N.D. BURGESS, AND D.A. HILL. 1992. Bird census techniques. Academic Press, New York, NY U.S.A.

BLOOM, P.H. 1980. The status of the Swainson's Hawk in California, 1979. Final Report II-8.0, USDI Bureau of Land Management and Federal Aid in Restoration, Project W-54-R-12, California Department of Fish and Game, Sacramento, CA U.S.A.

BUREAU OF THE CENSUS. 1989. 1987 census of agriculture, Vol. 1, geographic area series. U.S. Department of Commerce, Washington, DC U.S.A.

CRAIGHEAD, J.J. AND F.C. CRAIGHEAD. 1956. Hawks, owls and wildlife. Dover Publications, Inc., New York, NY U.S.A.

ENGLAND, A.S., M.J. BECHARD, AND C.S. HOUSTON. 1997. Swainson's Hawk (*Buteo swainsoni*). *In* A. Poole and F. Gill [EDS.], The birds of North America, No. 265. The Academy of Natural Sciences, Philadelphia, PA and The American Ornithologists' Union, Washington, DC U.S.A.

ESRI (ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE, INC.). 1999. ArcView 3.2 GIS. Environmental Systems Research Institute, Inc., Redlands, CA U.S.A.

ESTEP, J.A. 1989. Biology, movements and habitat relationships of the Swainson's Hawk in the Central Valley of California, 1986–87. California Department of Fish and Game, Nongame Bird and Mammal Sec. Rep., Sacramento, CA U.S.A.

FULLER, M.R. AND J.A. MOSHER. 1987. Raptor survey techniques. Pages 37–66 *in* B.A. Giron Pendleton, B.A. Millsap, K.W. Cline, and D.M. Bird [EDS.], Raptor management techniques manual. Natl. Wildl. Fed., Washington, DC U.S.A.

HANEY, J.C. AND A.R. SOLOW. 1992. Testing for resource use and selection by marine birds. *J. Field Ornithol.* 63:43–52.

HILTY, J.A., C. BROOKS, E. HEATON, AND A.M. MERENLENDER. 2006. Forecasting the effects of land-use change on native and non-native mammalian predator distributions. *Biodivers. Conserv.* 15:2853–2871.

JANES, S.W. 1985. Habitat selection in raptorial birds. Pages 159–188 *in* M.L. Cody [ED.], Habitat selection in birds. Academic Press, San Diego, CA U.S.A.

KIMSEY, B. AND M.R. CONLEY. 1988. Habitat use by raptors in south-central New Mexico. Pages 197–203 *in* R.L. Glinski, B.G. Pendleton, M.B. Moss, M.N. LeFranc, Jr., B.A. Millsap, and S.W. Hoffman [EDS.], Proceedings of the southwest raptor management symposium and workshop. Institute for Wildlife Research Scientific and Technical series #11. Natl. Wildl. Fed., Washington, DC U.S.A.

MACARTHUR, R.H. AND E.R. PIANKA. 1966. On optimal use of a patchy environment. *Am. Nat.* 100:603–610.

MANLY, B.F.J., L. MCDONALD, D.L. THOMAS, T.L. MCDONALD, AND W.P. ERICKSON. 2002. Resource selection by animals: statistical design and analysis for field studies, Second Ed. Kluwer Academic Publishers, Boston, MA U.S.A.

MAYER, K.E., and W.F. LAUDENSLAYER. [EDS.]. 1988. A guide to wildlife habitats of California. California Department of Fish and Game, Sacramento, CA U.S.A.

MILLSAP, B.A. AND M.N. LEFRANC, JR. 1988. Road transect counts for raptors: how reliable are they? *J. Raptor Res.* 22:8–16.

NATIONAL AGRICULTURAL STATISTICS SERVICE. 2004. 2002 census of agriculture, Vol. 1, geographic area series. USDA, Washington, DC U.S.A.

NEU, C.W., C.R. BYERS, AND J.M. PEEK. 1974. A technique for analysis of utilization-availability data. *J. Wildl. Manage.* 38:541–545.

NEWTON, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, SD U.S.A.

PRESTON, C.R. 1990. Distribution of raptor foraging in relation to prey biomass and habitat structure. *Condor* 92:107–112.

REEVES, K.A. AND J.R. SMITH. 2004. Survey of falcons, kites, hawks, and owls in the lower Mokelumne River watershed, Sacramento and San Joaquin counties. Report to Federal Energy Regulatory Commission by East Bay Municipal Utility District, 1 Winemasters Way, Suite K, Lodi, CA U.S.A.

SMALLWOOD, K.S. 1995. Scaling Swainson's Hawk population density for assessing habitat use across an agricultural landscape. *J. Raptor Res.* 29:172–178.

———. 1996. Managing vertebrates in cover crops: a first study. *Am. J. Altern. Agric.* 11:155–159.

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