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INVESTIGATIONS OF THE DECLINE OF SWAINSON'S HAWK POPULATIONS IN CALIFORNIA

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ABSTRACT.—Previous studies have shown that habitat loss is not the principal factor accounting for >90% decline in California populations of the Swainson's Hawk (*Buteo swainsoni*) over the past 80 yr. Swainson's Hawks no longer breed in the southern half of the state, where high levels of DDE contamination may have contributed to, or caused, the extirpation of the species in that area; this hypothesis, however, can no longer be tested. Organochlorine contamination in eggs from central and northern California does not suggest a significant contribution from residues accumulated in South American wintering grounds, nor do present levels of organochlorine contaminants indicate a threat to the surviving California population. Although local population declines continue to occur in California and have also been reported in Oregon and Nevada, other North American populations remain viable. Therefore, mortality during migration, uses of toxic chemicals in South America, or habitat loss on the wintering grounds are not plausible causes of disappearance of the species from southern California. A local factor, or factors, as yet uncharacterized, is indicated.

The Swainson's Hawk (*Buteo swainsoni*), now rare, once occupied a breeding range in California that covered most of the non-forested lowland regions of the state (Bloom 1980). Unfortunately, no quantitative data exist on historical population sizes, but early accounts indicate the species was once very common locally (Sharp 1902). Qualitative information and descriptive generalizations indicate that Swainson's Hawks were so common that most naturalists of the late-ninteenth and early-twentieth century felt the species unworthy of special mention (see Bloom 1980). By the early 1940s, the population was declining (Grinnell and Miller 1944) and by 1978 the species was a scarce breeding bird in California. Bloom (1980) found that the population had fallen from a conservative estimate of 4300 pairs at the beginning of the century to <400 pairs in 1979, a loss exceeding 90%. Breeding distribution also had been greatly reduced and the species has disappeared from the southern part of the state (Fig. 1). The last recorded nestings were in the Mojave Desert in San Bernardino and Los Angeles counties in 1979 and 1980, respectively (P. Bloom, unpubl.). Between 1980 and 1988, 3–8 breeding territories have been active in Inyo and Mono counties (P. Bloom, unpubl.; Fig. 1). In this paper we address the hypothesis that exposure to persistent organic contaminants, either in California or in South America, has adversely affected the population of Swainson's Hawks in California, and we review other possible causes of the population decline.

STUDY AREA AND METHODS

In July 1979 we collected 1 addled egg from each of 3 nests that contained 1–3 young, and 3 eggs with dead embryos from 1 nest in the Great Basin in northern California (Siskiyou and Modoc counties). Habitat in this area is characterized by juniper (*Juniperus occidentalis*) and big sagebrush (*Artemisia tridentata*). An additional addled egg was obtained in 1979 in the Mojave Desert, San Bernardino County, in Joshua tree (*Yucca brevifolia*) habitat, one of the 2 last known nestings of the species in California south of the San Joaquin Valley (P. Bloom, unpubl.). In April and May of 1982 and 1983, 1 fresh egg was taken from each of 8 Swainson's Hawk nests in the Central Valley (Yolo, Sacramento, Sutter, and San Joaquin counties). Collection sites were in agricultural areas interspersed with riparian and oak woodland habitat containing cottonwood (*Populus fremontii*), valley oak (*Quercus lobata*) and willow (*Salix* sp.). Fresh eggs were collected from each nest as rapidly as possible to ensure that the remainder of the clutch would not suffer lethal chilling or heating. The resulting 15 egg sample was therefore representative of greatest Swainson's Hawk nesting density in California

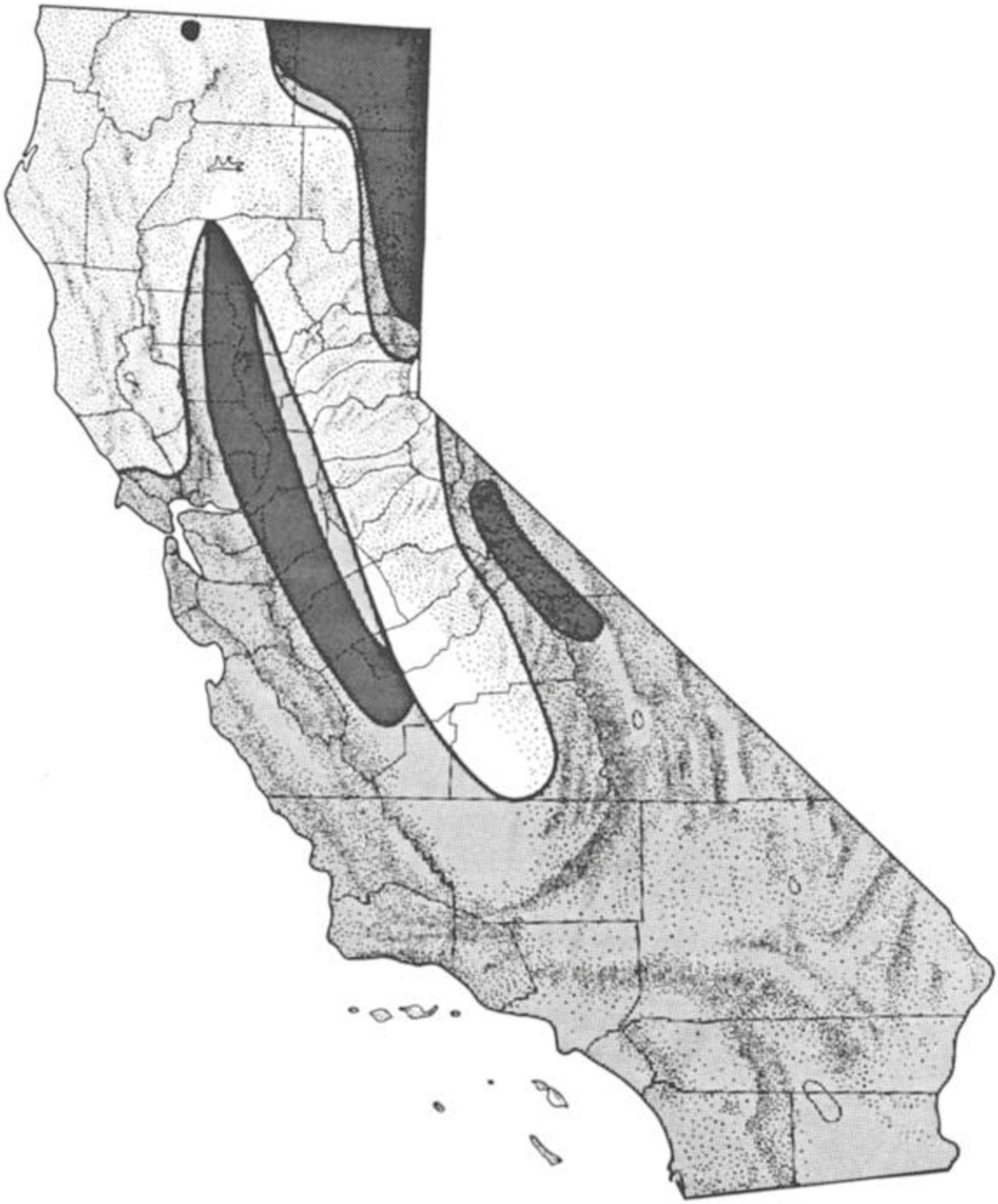

Figure 1. Breeding range of the Swainson's Hawk in California during the late nineteenth and early twentieth centuries (stipled area) and in the 1980s (shaded area). From Schlorff and Bloom (1983).

Since no statistical tests were performed with an assumption that residue composition is affected by the state of the egg, whether addled or fresh, all data are considered together; moreover, Ambrose et al. (1988) recorded no difference in residue composition between addled and fresh eggs within Peregrine Falcon (*Falco peregrinus*) clutches.

Analytical Methods. Eggs obtained in 1979 were analyzed at the University of California. Egg contents were mixed with anhydrous sodium sulfate and soxhlet-extracted with methylene chloride. After removal of methylene chloride by rotary evaporation, lipids were dissolved in hexane. For clean-up, up to 0.5 g lipid was placed on a florisil column that had been pre-rinsed with hexane (florisil activated overnight at 165°, cooled, deactivated with 0 5% H_2O, 33 g florisil, column ID 20 mm). Three fractions were collected, eluting with hexane (F1), 30% methylene chloride in hexane (F2), and 50% methylene chloride in hexane (F3). Volumes were adjusted such that DDE but not DDT eluted in F1, DDT but not dieldrin eluted in the F2, and dieldrin eluted in the F3.

Extracts were analyzed with Carlo Erba 2350 and 4160 gas chromatographs equipped with Carlo Erba and Brechbuhler electron capture detectors. Two columns, 30 m fused silica DB1 and DB5 (J&W Scientific), were used in the course of the study. Injections were on-column. After an initial hold for 3 min at 45°, runs were programmed at 10°/min to 140°, and at 4°/min to 290°. Carrier gas was helium. Compounds reported were quantified initially on the basis of electron capture response of decachlorobiphenyl (DCB), which was added as an internal standard, then by applying a factor based upon electron capture response of authentic standards supplied by the U.S. Environmental Protection Agency. Extract volumes were reduced to 100 microliters or less to increase analytical sensitivity which ranged from 0.1–0.5 ng/g (ppb) of individual compounds except when interfering compounds co-eluted on both column types employed.

Samples obtained in 1982–1983 were analyzed at the California Department of Fish and Game Fish and Wildlife Water Pollution Control Laboratory, Rancho Cordova. Five-g subsamples of egg contents were ground with anhydrous sodium sulfate and blended with two 150 ml portions of petroleum ether. After vacuum filtration, volumes were adjusted to 250 ml. A 200 ml aliquot was evaporated to dryness to determine lipid content. The remaining 50 ml aliquot was passed through a florisil column and eluted with 200 ml petroleum ether, 200 ml 6% ethyl ether in petroleum ether, and 200 ml 15% ethyl ether in petroleum ether. Eluates were concentrated to 10 ml, and analyzed with a Varian Aerograph 370 gas chromatograph equipped with a Ni^{63}-electron capture detector. Lower limit of detection was 10 ppb for individual compounds.

A calculation of approximate fresh weight (Stickel et al 1973) was made for the 1982 and 1983 samples. No reduction in weight due to moisture loss was noted and no conversion was made.

An intercalibration carried out between the 2 laboratories over approximately the same time period revealed satisfactory agreement in measurements of DDE and PCB in a series of Peregrine Falcon eggs (Peakall et al. 1983). Shell thicknesses were measured at the Western Foundation of Vertebrate Zoology, Los Angeles, to the nearest 0.001 mm with a Federal bench comparator thickness gauge.

RESULTS AND DISCUSSION

Population Decline and Productivity. Swainson's Hawk populations in Wyoming and Alberta do not appear to have undergone a decline comparable to that which has occurred in California (Dunkle 1977; Fyfe 1977; Schmutz 1984). Similar declines, however, have been reported from Nevada (Oakleaf 1975; Oakleaf and Klenbenow 1975; Oakleaf and Lucas 1976; Herron and Lucas 1978) and in southeast Oregon (Littlefield et al. 1984). In the latter area Swainson's Hawks had formerly been the most common nesting buteo in the Malheur-Harney Lakes Basin, but became uncommon after the 1950s. In the 1960s the number of breeding pairs ranged between zero and 5 in the Malheur National Wildlife Refuge, and in the 1970s there were no nesting pairs in most years (Littlefield et al. 1984).

No reduction in productivity has been recorded in Oregon (Henny et al. 1984; Janes 1987), but in the Klamath Basin in northern California fewer than 50% of the active territories produce young and fewer than 50% of territories previously known to be active were active in the mid 1980s (P. Bloom and S. J. Hawks, unpubl.).

Shell Thinning. Using an estimate of 0.402 (S.D. = .032) mm for the pre-1947 thickness of Swainson's Hawk eggshells from California, a mean reduction of 4% in shell thickness among the sample of 14 eggs (Table 1) was not significant ($P > 0.05$; Student's *t*-Test). Henny and Kaiser (1979) estimated a pre-1947 thickness from measurements of 31 eggs from Oregon, Washington, and Idaho of 0.428 (S.D. = 0.028) mm, 6.5% higher than our estimate for eggs from California. Three eggs collected in 1976 near a DDT spray area in northeast Oregon showed a mean reduction in shell thickness of 11% and contained 4–7 ppm DDE (Henny and Kaiser 1979). In a study undertaken in the Columbia Basin in Oregon in 1978–1980 to assess the extent of heptachlor epoxide contamination, 25 eggs, each obtained from separate nests, averaged 9.6% reduction in shell thickness from the estimated pre-1947 mean of 0.428 (Henny et al. 1984).

Since both estimates of pre-1947 thicknesses were derived from measurements made at the Western Foundation of Vertebrate Zoology using a bench comparator thickness gauge, the difference between pre-1947 estimates does not derive from differences

Table 1. Shell thickness of Swainson's Hawk eggs from California.

LOCALITY	YEAR	N	MEAN THICKNESS (S.D.)
California	pre-1945	40*	0.402 (0.032)
Klamath Basin	1979	5	0.399 (0.028)
San Bernardino Co.	1979	1	0.378
Central Valley	1982	3	0.400 (0.033)
Central Valley	1983	5	0.363 (0.013)
California	1979–83	14	0.385 (0.028)

* Data provided by Western Foundation of Vertebrate Zoology.

in measuring techniques and most likely derives from geographical differences in pre-1947 thickness over California, Oregon, Washington and Idaho. Using the pre-1947 estimate of Henny and Kaiser (1979) would increase the mean level of thinning in the California sample to about 10%, comparable to that reported by Henny et al. (1984) in eggs from the Columbia Basin.

A review of eggshell thinning and population status has shown that thinning above 18% is invariably associated with population decline (Anderson and Hickey 1972; Lincer 1975). Productivity of Prairie Falcons (*Falco mexicanus*) in Alberta, however, declined to zero over a range of 8–14% reduction in Ratcliffe thickness index (see Ratcliffe 1967; Fyfe et al. 1988); reduced productivity of Golden Eagles (*Aquila chrysaetos*) in western Scotland was associated with a 10% reduction in thickness index (Lockie and Ratcliffe 1964; Lockie et al. 1969; Ratcliffe 1970). A 10% reduction of mean thickness does not therefore indicate normal productivity. As noted above, no reduction in productivity has been recorded in Oregon.

Organochlorine Residues. Geometric mean DDE levels in eggs from the Great Basin and the Central Valley were <1 part per million (ppm) (Table 2), lower than geometric means of 1.2 ppm in 6 eggs from southeast Washington in 1976 and 2.3 ppm in 4 eggs from northeast Oregon in the same year (Henny and Kaiser 1979). Three of the latter eggs ($\bar{x}$ = 5.4 ppm) were from an area adjacent to forests treated with DDT 2 yrs previously, and elevated residues were attributed to that source. The 25 eggs obtained in Oregon in 1978–1980 contained a (geometric) mean level of 0.98 ppm DDE (Henny et al. 1984). A sample of 5 addled eggs obtained in southeastern Washington in 1977 and 1978 contained a mean DDE level of 0.92 ppm (Bechard 1981). Four eggs from 3 nests at the Hanford Site in Washington in 1976 contained substantially higher levels (range = 4–17 ppm; Fitzner 1980). Sixteen eggs (1/clutch) from North and South Dakota over 1974–1979 all contained <1 ppm DDE (Stendell et al. 1988). Except for higher values at the Hanford site and the site adjacent to DDT spraying operations in Oregon, DDE levels were therefore com-

Table 2. Organochlorines (ppb of wet weight) in eggs of Swainson's Hawks from California. Values are geometric means of clutch arithmetic means, with an interval of 1 standard deviation.

LOCALITY	N	% H_2O	% LIPID	p,p'-DDE	p,p'-DDD	p,p'-DDT	DIEL-DRIN	HCB	PCB	HEPT. EPOX
Klamath Basin	4	78	6.0	780	18	27	100	11	45	51
		75–81	4.7–7.7	320–1900	7–48	2–100	55–180	5–25	30–68	31–82
San Bernardino County	1	76	4.7	7900	34	24	75	13	67	16
Central Valley	8	nm*	3.8	910	<10	<10	57	3	<100	17
			3.0–4.8	460–1800			32–100	1–11		4–76

LOCALITY	t-NONA-CHLOR	OXYCHLOR-DANE	γ-CHLOR-DANE	α-CHLOR-DANE	ENDRIN	α-HCH	β-HCH	γ-HCH
Klamath Basin	27	37	3	4	33	<2	12	<1
	9–77	7–200	1–7	1–10	22–59		3–50	
San Bernardino	11	12	0.9	<4	20	0.7	12	0.6
Central Valley	12	18	nm	nm	nm	nm	nm	nm
	7–19	7–36						

* nm = not measured.

parable over Washington, Oregon, and northern and central California over 1976–1983.

A single egg from southern California from one of the 2 last known nestings in the area contained 7.9 ppm DDE and had a thickness reduction of 6% (Tables 1 and 2). The DDE level is within range of DDE concentrations associated with reproductive failures of Prairie Falcons (Fyfe et al. 1988), Bald Eagles (*Haliaeetus leucocephalus*; Wiemeyer et al. 1984), and higher than the 5 ppm level associated with 20% thinning of California Condor (*Gymnogyps californianus*) eggs (Kiff et al. 1979). Henny et al (1984) found, however, that productivity was high in 5 Swainson's Hawk nests from which single eggs taken for analysis contained between 5 and 10 ppm DDE. The threshold of sensitivity to DDE (see Fyfe et al. 1988) appears therefore to be higher for Swainson's Hawks than for these species.

The contaminant profile in the single egg mentioned above was similar to that recorded in several other recent studies of organochlorine contamination in the Southwest that have been characterized by high levels of DDE and high ratios of DDE to all other compounds, including the parent compound, p,p′-DDT (Cain and Bunck 1983; Clark and Krynitsky 1983; White and Krynitsky 1986; Hunt et al. 1986). DDE levels in both terrestrial and marine environments of southern California have remained high throughout the 1980s (Hunt et al. 1986; Risebrough 1987; Kiff 1989; Garcelon et al. 1989; R. W. Risebrough and P. H. Bloom, unpubl.), a legacy of past disposal of wastes from a DDT factory in Los Angeles (Risebrough 1987; Young et al. 1976).

A South American "Signature"? Comparison of contamination patterns, characterized as the ratio of DDE to other organochlorines, with those in eggs of Peregrine Falcons from California and Alaska over the same period (Table 3) suggest but do not conclusively indicate a South American component in the profile. Peregrines breeding in Alaska, which migrate to South America and take among their prey many species which also migrate to South America, contained significantly higher ratios of dieldrin, DDT+DDD, endrin, heptachlor epoxide, trans-nonachlor, mirex, and beta-HCH to DDE than the resident birds of California (Springer et al. 1984). Relatively high amounts of dieldrin were recorded in Swainson's Hawk eggs examined, at levels 8–16 times below those of DDE (Table 3). Dieldrin is no longer used in California; nor is aldrin, which converts to dieldrin in the environment. Aldrin is used in South America to control species of leaf-cutting ants which are destructive to many crops (Risebrough and Springer 1983; Burton and Philogene 1986), and the presence of relatively high levels of dieldrin could indicate a South American source. Relative amounts of DDT+DDD, PCBs, heptachlor epoxide, endrin, and beta-HCH are also typical of a South American profile. Relative levels of mirex, however, are low. Mirex is also extensively used in South America to control leaf-cutting ants. Levels of mirex in species such as American Kestrels (*Falco sparverius*) in southern Brazil may be equivalent to those of DDE (A. M. Springer and R. W. Risebrough, unpubl.). Concentrations of mirex were higher in eggs of Peregrine Falcons that had migrated to South America than in eggs of peregrines resident in California where mirex is not used (Springer et al. 1984). Western Sandpipers (*Calidris mauri*) collected at 2 sites in California in 1980 during spring migration contained mirex at levels in the order of 15% of DDE (Risebrough, unpubl.).

Mirex is therefore a potential "marker" compound for South America origins of organochlorine mixtures. Like the DDE : PCB ratio, which tends to be conservative within an ecosystem when the PCB consists primarily of the penta-, hexa-, and heptachloro compounds (Risebrough et al. 1968; Norstrom et al. 1978), the DDE : mirex ratio is

Table 3. Ratios of DDE to other organochlorines in eggs of Peregrine Falcons from California, 1975–1980,* Alaska, 1977–1980* and in eggs of Swainson's Hawks analyzed in this study.

	Peregrine Falcon		Swainson's Hawk	
Compound(s)	Alaska	California	Klamath Basin	Central Valley
N	8	12	4	8
DDD + DDT	150	350	17	>45
Dieldrin	19	180	8	16
HCB	570	380	71	300
PCB	3.9	3.2	17	>9
Hept. Epox.	36	300	15	54
t-nonachlor	510	1900	29	76
Oxychlordane	72	87	21	51
Endrin	780	1900	24	—
beta-HCH	93	520	65	—
mirex	90	1000	800	—

* Data from Springer et al. (1984).

also relatively conservative in ecosystems (Norstrom et al. 1978). Mirex was detected at low concentrations (in the order of 1 ppb) in 2 eggs from the Klamath Basin. The DDE : mirex ratio would be in the order of 800, closer to the ratio of 1000 found in the eggs of California Peregrine Falcons than ratios of 28–110 found in eggs of Peregrine Falcons in Alaska and Greenland (Springer et al. 1984).

We find therefore suggestions but no convincing evidence for a South American "signature" of organochlorine residues in California Swainson's Hawk eggs. Such a signature may, however, be partially obscured by the contaminant profile of local prey. Nor is there evidence for excessive exposure to aldrin/dieldrin or heptachlor/heptachlor epoxide that might suggest mortalities on wintering grounds caused by these biocides. Argentina, where many Swainson's Hawks winter (Brown and Amadon 1968; Houston 1968; White et al. 1989), has adopted controls on the use of most organochlorine insecticides similar to those of North America; comparable restrictions have been adopted in the neighboring Brazilian state of Rio Grande do Sul (Risebrough and Springer 1983).

Other Potential Causes in South America of Population Decline. Shooting during migration can be devastating to roosting flocks (Bloom 1980). Loss of wintering habitat is poorly studied; in southeastern Brazil large areas of grassland have recently been converted to soya bean cultivation (Albuquerque 1978), a change likely to have affected available habitat. Several of the newer-generation organophosphates and carbamates that are highly toxic to birds include famphur (Franson et al. 1985; Henny et al. 1985; Henny et al. 1987), carbofuran (Balcomb 1983) and fenthion (Henny et al. 1987). Documentation is lacking, however, on possible effects in Latin America.

There is no evidence for regional partitioning of wintering range that might account for local population declines in North America. Among 23 band returns from Argentina, 3 were from Colorado, 1 from Wyoming, 7 from Alberta, and 8 from Saskatchewan (White et al. 1989).

Interspecific Interactions. Among possible causes for the decline in southeast Oregon proposed by Littlefield et al. (1984) was a local abundance of Great Horned Owls (*Bubo virginianus*). Fitzner (1978) has reported a low tolerance of Swainson's Hawks for Great Horned Owls. In Oregon, Janes (1987) has documented intense interspecific territorial encounters between Swainson's Hawks and Red-tailed Hawks (*Buteo jamaicensis*). In these Swainson's Hawks were frequently dominant in spite of their smaller size and would displace Red-tails from territories with a low density of perches and outcrops. Red-tails successfully defended, however, territories with a higher density of perches and outcrops. Human settlement has increased the numbers of available perches in trees and on utility poles, thereby favoring Red-tails over Swainson's Hawks (long-term) in habitat suitable for both species (Janes 1987).

We consider it unlikely that interspecific competition would result in the disappearance of the Swainson's over all of southern California. Nor does predation by a high density of Great Horned Owls in southern California appear plausible. Of more than 1000 nests of Red-tailed and Red-shouldered Hawks (*B. lineatus*) examined in the region, only 1 failure could be attributed to Great Horned Owl predation (P. Bloom, unpubl.).

Habitat Loss and Modification. In southeast Oregon native grasses have disappeared because of overgrazing; sagebrush has become the dominant plant, forming large monotypic stands in some areas and reducing the number of foraging sites (Littlefield et al. 1984). Prey vulnerability is reduced; Bechard (1982) has reported that hunting sites of Swainson's Hawks in Washington were determined more on vulnerability of prey to predation than on prey density.

Breeding habitat in the Central Valley of California and elsewhere has been lost due to agricultural conversions. Some 1,400,000 acres of riparian habitat in the Central Valley have been destroyed since pre-settlement times, an 85% loss (Smith 1977). Elsewhere, however, breeding populations have disappeared in the absence of environmental changes, and large areas of formerly occupied breeding habitat in the Central Coast Ranges, the Mojave Desert, the Great Basin, Owens Valley and the Southern California coastal area still exist (Bloom 1980, Schlorff and Bloom 1983). Thus, although a contributing factor, particularly in the Central Valley, habitat destruction on breeding grounds is probably not the principal reason for extirpation of the species in the southern half of the state.

Impact of Oganochlorines on Other *Buteo* Species. Generally, raptorial species that feed like the Swainson's Hawk on small mammals, reptiles and invertebrates (Bloom 1980; White et al. 1989) have shown only a relatively small degree of shell thinning (Anderson and Hickey 1972); non-bird-eating species generally accumulate lower residues of organochlorines than bird-eating species (Gilbertson and Reynolds 1974). Common Buzzards, (*B. buteo*), however, suffered severe population declines in the Netherlands in the 1960s that were attributed to dieldrin (Fuchs et al. 1972).

Low-to-moderate shell thinning has been reported in apparently only 2 other species of the genus *Buteo*, the Red-shouldered Hawk (Anderson and Hickey 1972; Wiley 1975) and the Red-tailed Hawk (Anderson and Hickey 1972). Analysis of banding records of Red-shouldered Hawks has indicated lower recruitment during the years of heavy DDT use in North America (Henny 1972). Counts during migration indicated population declines in eastern North America at that time (Hackman and Henny 1971; Brown 1971). This is apparently the only documented decline of a species of *Buteo* during the DDT era in North America that can plausibly be attributed to DDE.

Summary. In California, only the Least Bell's Vireo (*Vireo bellii pusillus*) (Remsen 1978) and the California Condor (Wilbur 1980; Kiff 1989) have experienced more severe population reductions. After a severe reduction in the 1960s (Herman et al. 1970), Peregrine Falcons are now rapidly recovering (Walton et al. 1988). The hypothesis that high levels of environmental DDE were the major cause of disappearance of the Swainson's Hawk in southern California remains plausible. In the current absence of any breeding Swainson's Hawks in the area, it is no longer subject to testing. It is likely, however, that the cause of the extirpation in southern California is related to the decline in Nevada and southeast Oregon, and most likely to the report of depressed productivity in the Klamath Basin area of Northern California (P. Bloom and S. J. Hawks, unpubl.).

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