

## RECENT CHANGES IN CALIFORNIA CONDOR EGGSHELLS

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The entire population of the California Condor (*Gymnogyps californianus*) probably contains fewer than 50 individuals (Wilbur 1976, 1978). Within its recorded history the species has shown a continual decline in numbers. During the past decade there has been an especially alarming decrease in condor recruitment. Between 1968 and 1975 the entire population averaged only 1.5 young fledged per year with a maximum of two produced any single year (Wilbur 1978).

Mortality factors which historically have reduced the condor population (Koford 1953) cannot account for the observed recent decrease in productivity. Lowered reproductive success in numerous other bird species in recent years has been associated with eggshell thinning caused almost exclusively by p,p' DDE, the principal metabolite of DDT (Cooke 1973, Stickel 1975, Peakall 1975). In this paper we document thinning and other structural changes in California Condor eggshells, verify the presence of DDE in the thin eggs, and suggest that the "DDT syndrome" has contributed to lowered nesting success. Comparisons are made to the changes induced by the experimental feeding of DDE to the structure of eggshells of another falconiform species, the American Kestrel (*Falco sparverius*).

### MATERIALS AND METHODS

During the late 1960's, a former U.S. Fish and Wildlife Service biologist, Fred C. Sibley, regularly visited all condor nests thought to have been used recently in order to monitor reproductive activity. During his visit to each nest, Sibley strained the loose substrate from the floor of the cavity through a fine-meshed screen. Sharp rocks, bone fragments and other debris which might pose a danger to an egg were removed, and all eggshell fragments he found were collected. Between 1966 and 1969, he obtained at least eight samples of eggshell fragments of known year of origin from six different condor nest sites, and he made them available to us for study. In addition, Eben McMillan provided us with shell fragments of a broken condor egg that he found in a nest in 1964. Wilbur and John Borneman collected fragments from another nest in 1976, and a party directed by Wilbur secured four more samples in November 1977.

In order to detect changes in shell thickness, these fragments and intact California Condor eggshells in the Western Foundation of Vertebrate Zoology collection were measured with a model 35 PS Federal

bench comparator thickness gauge, or with a modified Starrett Model 1010 M micrometer. We attempted to measure only specimens that had intact shell membranes tightly affixed to the true shell. However, some samples of fragments totally lacked shell membranes. To the measured thickness of these we added 0.10 mm, the mean thickness of normal California Condor eggshell membranes, as compensation. Whole eggs were measured on the egg equator through the blow-hole near the middle of one side, whereas we couldn't tell what part of the eggshell the fragments came from.

Condor eggshell fragments taken in 1896, 1922, 1964, 1966, 1967 and 1969, and those of control and experimental kestrel eggshells were studied using scanning electron microscopy (SEM). Freshly broken fragments were mounted vertically on a stub, coated with gold and viewed with a Cambridge Stereoscan 4 scanning electron microscope. Thicknesses of the entire eggshells and of the principal component layers were determined from enlargements of photomicrographs taken at 100× magnification. The nomenclature of Schmidt (1957), as illustrated by Becking (1975), has been followed in describing structure (Fig. 1).

Eggshell fragments were immersed in hexane and gently agitated overnight at room temperature to extract the lipid soluble residues. Pre-1944 fragments submitted to the same process served as controls, and the extracts from these older eggs gave no peak that interfered with organochlorine analyses. Analyses for DDE were performed by gas-liquid chromatography, using an electron capture detector, without prior clean-up. Two columns (1.8 m long, 2 mm in diameter) with Supelcoport as support were used. One column had 1% SP 2100 as the liquid phase; the other was a mixed phase (1.68 m of 1% SP 2100 + 2% SP 2401; 0.15 m of 1% SP 2100 + 2% AN 600). Final confirmation of DDE was carried out by gas-liquid chromatography-mass spectrometry using a Varian MAT 311A mass spectrometer. Single ion monitoring on m/e 318 and scan integration from m/e 310 to m/e 322 was used. The amount of lipid extracted was determined by completely evaporating the hexane to dryness and weighing the resulting material on a microbalance with a precision of  $2 \times 10^{-5}$  g.

Eggshells of kestrels were those produced by control individuals and those dosed with 3 ppm and 6 ppm DDE during studies reported by Lincer (1975).

### RESULTS

#### EGGSHELL THICKNESS CHANGES

As shown in Table 1, eggshells collected between 1896 and 1943 averaged 0.79 mm thick, whereas fragments taken between 1964 and 1969 averaged only 0.54 mm thick, or 32% thinner. There was no overlap in the ranges of measurements of the 1896-1943 and 1964-1969 samples.

Mean shell thickness of fragments of six eggs

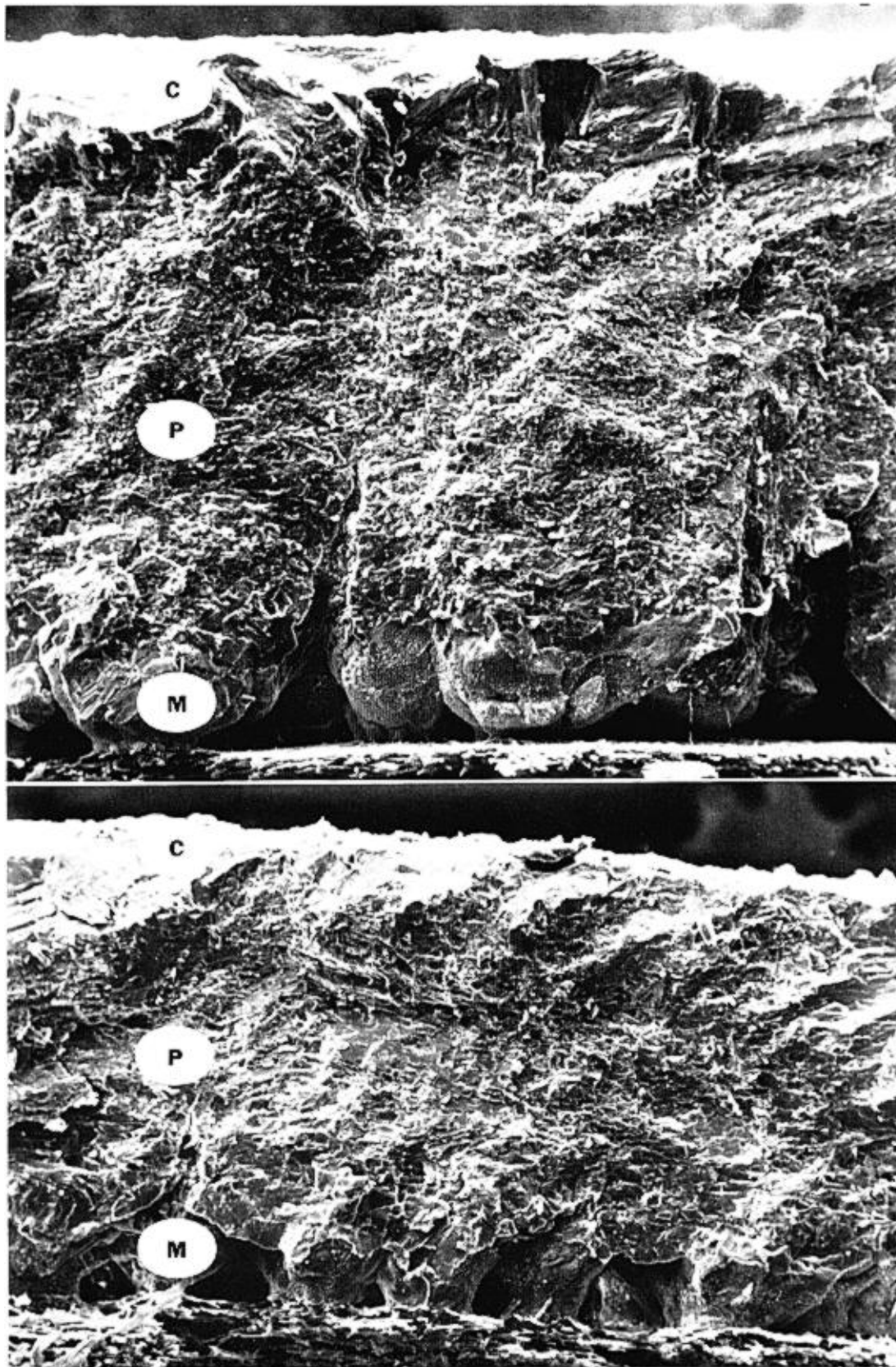


FIGURE 1. SEM micrographs of 1922 (upper) and 1969 (lower) California Condor eggshells showing principal layers. C = surface crystalline layer, P = palisade layer, and M = mammillary core layer. (100  $\times$  magnification.)

TABLE 1. Thickness measurements of California Condor eggs and eggshell fragments between 1896–1977.

Year <sup>a</sup>	Nest site <sup>b</sup>	Type <sup>c</sup>	Incubation stage or fate	N <sup>d</sup>	Total shell thickness <sup>e</sup>
1896	Monterey Co.	F	Hatched	12	0.78 ± .01 <sup>f</sup>
1898	San Luis Obispo Co.	I	Fresh	5	0.79 ± .02
1921	S-45	I	Fresh	5	0.71 ± .01
1922	S-44	F	Broken when fresh	10	0.80 ± .02
1928	Zoo	I	Infertile	5	0.86 ± .02
1939	S-23	I	Fresh	5	0.77 ± .01
1943	S-23	I	Small embryo	5	0.81 ± .01
1964	S-41	F	Found broken <sup>h</sup>	11	0.61 ± .02
1966	S-41	F	Found broken	10	0.48 ± .07 <sup>f</sup>
1966*	S-43	F	Unknown	19	0.56 (0.48–0.67) <sup>g</sup>
1967*	S-162	F	Addled	20	0.60 (0.52–0.63)
1967	S-231	F	Unknown	10	0.57 ± 0.03
1967*	S-41	F	Unknown	20	0.45 (0.39–0.51)
1967*	S-251	F	Found broken	20	0.45 (0.40–0.54)
1968*	S-15	F	Hatched	20	0.57 (0.52–0.63)
1969	S-231	F	Addled	10	0.59 ± .04
Assumed	S-41	F	Unknown and	11	(1) 0.45 ± .01 <sup>f</sup>
1970 & 1972			hatched	11	(2) 0.63 ± .04
1971 & 1973	S-231	F	Both hatched	20	0.57 ± .03 <sup>fx</sup>
Assumed 1972	S-313	F	Hatched	20	0.59 ± .03 <sup>f</sup>
1975	S-157	F	Hatched	20	0.76 ± .06 <sup>f</sup>
Assumed	S-135	F	Unknown and	11	(1) 0.52 ± .01 <sup>f</sup>
1976 & 1977			hatched	11	(2) 0.70 ± .03 <sup>f</sup>

<sup>a</sup> Year in which egg was believed to have been laid. Specimens marked with an asterisk were not preserved following measurements by John Azevedo, California Dept. of Fish and Game. All other specimens were measured at the Western Foundation of Vertebrate Zoology and are presently in the collection there.

<sup>b</sup> U.S. Fish and Wildlife Service designations. All numbered nest sites are in Ventura or Santa Barbara counties.

<sup>c</sup> F = Eggshell fragments; I = Intact museum egg.

<sup>d</sup> Number of fragments measured, or number of measurements taken on intact eggs.

<sup>e</sup> Measurements made at the WFVZ are followed by the standard error; those made by Azevedo are followed by the range. All measurements are in mm.

<sup>f</sup> 0.10 mm was added to thickness measurements to compensate for lack of shell membranes.

<sup>g</sup> Probably contain fragments of more than one egg; fragments of widely differing thickness were analyzed separately.

<sup>h</sup> Fate of eggs found broken was unknown.

thought to have been laid between 1971 and 1977 was 0.63 mm, or 20% thinner than the pre-1944 museum specimens. Fragments from two apparently recent nest sites (S-157 and S-135) were near historical thicknesses; the former, thought to have been laid in 1975, was only 4% thinner than the mean thickness of the pre-1944 eggs.

The thinnest post-1963 eggs known definitely to have hatched (sites S-15 in 1968, S-231 in 1971 and/or 1973) were 0.57 mm thick, or 28% thinner than the mean thickness of the pre-1944 eggs. It is not certain that fragments from site S-135 averaging 0.52 mm thick were from an egg that hatched. This nest site was not discovered until 1976, hence some fragments may have come from an earlier nesting attempt of unknown outcome.

Nest site S-231 yielded shell fragments of eggs thought to have been laid in 1967, 1969, 1971 and 1973. The consistency in thickness measurements of these samples (ranging from 0.57 to 0.59 mm) suggests that the same female laid all the eggs.

#### EGGSHELL STRUCTURE CHANGES

Mean thickness of 1964–1969 eggshell fragments, as determined from measurements of

enlarged SEM micrographs, was 33% less than the mean thickness of pre-1944 eggs, as determined by the same method. This is in close agreement with the difference in means (32%) obtained by direct measurements of the eggshells by mechanical devices.

In two presumably normal California Condor eggs laid in 1896 and 1922 the mammillary core layer composes approximately 23% of the true shell thickness, the palisade layer about 62%, and the surface crystalline layer, 15%. These layers are differentially thinner in the 1964–1969 samples, the surface crystalline layer being 62% less, the cone layer 32% less, and the palisade layer 25% less (Table 2; Fig. 2). The changes found in the eggshells of kestrels experimentally treated with DDE are very similar, although the decrease in the surface crystalline layer was not as marked (Table 2).

Normal hemispherically-shaped mammillary cores and aberrant forms are shown in Figures 1 and 2. Density of the mammillary cores in the two pre-1944 eggs was about 25/mm<sup>2</sup>, but only 17/mm<sup>2</sup> in the 1964–1969 eggs (R. Garrett, pers. comm.). Similar changes were noted in the kestrel (Table 2).

TABLE 2. Average thickness measurements of eggshell layers of California Condor and American Kestrel eggs determined from SEM micrographs (mm  $\pm$  standard error; 7 measurements per sample).

	Surface crystalline layer	Palisade layer	Cone layer	Total shell thickness	Mammillary cores/mm <sup>2</sup>
California Condor					
Pre-1944 (N = 2)	.112 $\pm$ .018	.443 $\pm$ .038	.162 $\pm$ .025	.717 $\pm$ .005	25
1964-1969 (N = 4)	.042 $\pm$ .013	.332 $\pm$ .012	.110 $\pm$ .021	.485 $\pm$ .002	17
Percent change	-62	-25	-32	-33	-32
American Kestrel*					
Control (N = 4)	.036 $\pm$ .006	.100 $\pm$ .008	.032 $\pm$ .007	.168 $\pm$ .008	84 $\pm$ 5
Fed 3 ppm DDE (N = 4)	.024 $\pm$ .006	.080 $\pm$ .010	.029 $\pm$ .006	.133 $\pm$ .015	68 $\pm$ 8
Percent change	-33	-20	-9	-21	-19

\* From experiments of Lincer (1975).

#### DDE RESIDUES

There were significant residues of DDE in seven of the eleven post-1963 condor eggshell fragment samples analyzed (Table 3). Virtually no lipid could be extracted from the four other samples; hence, it would not be expected that any lipophilic contaminants would be detected. Except for the 1922 sample, all eggshell fragments with extractable lipids did contain DDE residues.

Although the calculation of the residue level for each individual whole egg is subject to considerable error, due to the degree of extrapolation involved (Peakall 1974), the overall statistical correlation of DDE levels and eggshell thinning is high ( $r = -0.93$ ;  $P < 0.1$ ). Linear regression analysis indicated that 20% thinning is associated with approximately 100 ppm DDE (lipid weight basis on membrane), which can be calculated back to 5 ppm (wet weight) for the total egg contents.

#### DISCUSSION

The difference in mean thickness of pre-1944 and post-1963 California Condor eggshells was

unusually high. Despite the large number of species that have exhibited eggshell thinning in recent years, Stickel (1975) noted that thinning had reached 20% in only nine species at some time and place. This amount of thinning is generally accompanied by reproductive failure, primarily from egg breakage, and population decline (Hickey and Anderson 1968, Lincer 1975). Thus it would be expected that eggshell thinning contributed to some of the egg failures that occurred in the condor population in the 1960's (Table 1).

The structural abnormalities described here in condor eggs, including differential thinning of the eggshell layers and reduction of the density of mammillary cores, are paralleled by those found in the eggs of kestrels fed low dietary levels of DDE. McFarland et al. (1971) noted decreases in the spongy (palisade) layer and variable effects on the thickness of the surface crystalline layer in the eggshells of Common Coturnix (*Coturnix coturnix*) fed a diet containing DDT. Cooke (1975) found decreases in the palisade layer in eggshells of two ducks exposed to DDT. The cone layer was increased in eggshells from one

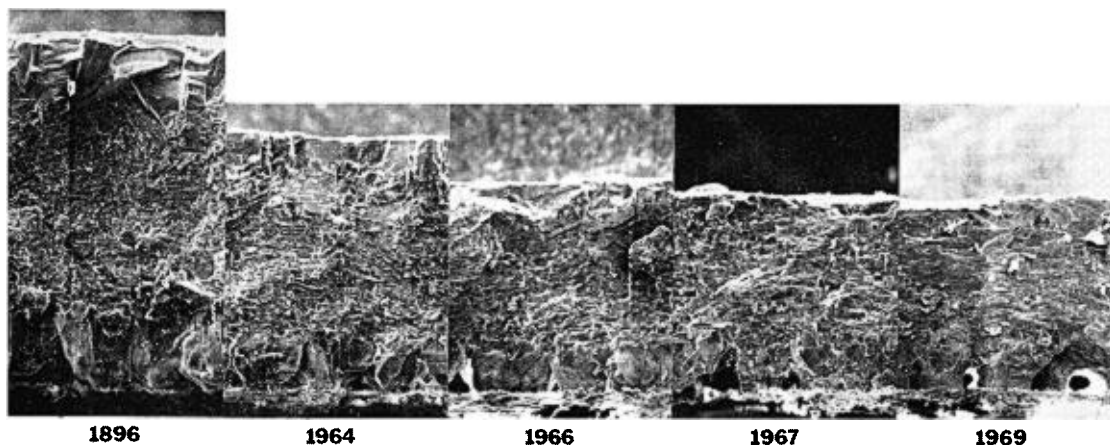


FIGURE 2. SEM micrographs of California Condor eggshells. (65  $\times$  magnification.)

TABLE 3. DDE residue levels in membranes of California Condor eggshell fragments.

Year	Nest site	Shell thickness (mm)	Weight of lipid (mg)	Weight DDE (mg)	Concentration of DDE in membrane (ppm, lipid)	Estimated DDE content in egg* (ppm, wet weight)
1922	S-44	0.80	1.45	n.d.	—	—
1922	S-44	0.80	2.03	n.d.	—	—
1964	S-41	0.61	0.02	n.d.	—	—
1966	S-43	0.56	0.03	n.d.	—	—
1967	S-231	0.57	0.59	64	110	5.5
1969	S-231	0.59	0.73	95	160	8
1971 & 1973	S-231	0.57	0.39	79	200	10
1970 & 1972	S-41**	(1) 0.45	0.10	38	380	17
		(2) 0.63	0.17	6.4	38	2
Assumed 1972	S-313	0.59	0.06	n.d.	—	—
		0.76	0.03	n.d.	—	—
1975	S-157	0.76	0.03	n.d.	—	—
1976 & 1977	S-135**	(1) 0.52	0.19	52	273	13.5
		(2) 0.72	0.15	3.0	20	1

n.d. Not detected.

\* Calculated assuming 5% lipid in total egg contents.

\*\* Probably contain fragments of more than one egg; fragments of widely differing thickness were analyzed separately.

bird and unaltered in eggshells from the other. No changes in the density of the mammillary cores were found. In the Grey Heron (*Ardea cinerea*), Cooke et al. (1976) found that the thicknesses of the cone layer and palisade layer were inversely related to egg residues of DDE. These workers did not distinguish the surface crystalline layer from the palisade layer.

Fox (1976) found that decreased numbers of mammillary cores correlated significantly with egg failure in the Common Tern (*Sterna hirundo*). Erben and Krampitz (1971) noted marked reductions in the palisade layer and external zone (surface crystalline layer), whereas the cone layer was not affected. In both studies, an increase of globular inclusions was noted, and DDE was suggested as the causative agent.

Eggshell thinning has been most severe in bird- and fish-eating birds (Hickey and Anderson 1968, Ratcliffe 1970, Anderson and Hickey 1972), presumably because of relatively high DDE residue levels in their diets. Condors feed primarily on carrion comprised of cattle, deer, sheep, and other herbivorous mammals (Wilbur 1972) in which organochlorine residues are generally low (Dustman and Stickel 1969). Virtually no data on organochlorine residues in large herbivorous mammals are available from the range of the condor, and specific information on the quantity of DDT used in the area is now largely unobtainable. However, in a single project to control the beet leafhopper (*Circulifer tenellus*) in the semi-arid foothills along the western edge of the San Joaquin Valley, the California Department of Agriculture applied DDT at the rate of one pound per acre over more than 190,000 acres annually

between 1950 to at least 1964 (Wilson 1960, S. G. Herman, pers. comm.).

Whatever the source, DDE has been found in the tissues of three California Condors. An immature killed accidentally in May 1965 "had 18 ppm DDT and 30 ppm DDE deposited in its fat" (Hunt 1969). An immature found dead in November 1974 contained approximately 50 ppm DDE, wet weight, in thigh muscle (Wilbur 1978). An adult found shot in October 1976 died in the Los Angeles Zoo two weeks later. A necropsy indicated that its adipose tissue contained 105 ppm DDE, wet weight (S. Wiemeyer, pers. comm.). Similarly, a sample of body fat from an Andean Condor (*Vultur gryphus*) obtained in January 1970 contained 320 ppm DDE, wet weight, by far the highest level recorded in any vertebrate species in a study of organochlorine contamination of the Peruvian coastal ecosystem (Risebrough et al., in press).

The calculated figure of 5 ppm DDE in egg contents associated with 20% thinning indicates that the California Condor is among the most sensitive of birds to DDE-induced eggshell thinning discovered to date. A dose-dependent relationship existed between kestrel eggshell thickness and dietary DDE intake with 15, 25, and 29% thinning accompanying dietary DDE levels of 3, 6, and 10 ppm, respectively (Lincer 1975). Keith and Gruchy (1972) reported that 12 ppm DDE was associated with 20% thinning for the Prairie Falcon (*Falco mexicanus*), whereas Peakall (1976) provided comparable figures of 15–20 ppm for the Peregrine Falcon (*Falco peregrinus*) and Blus et al. (1972) calculated 8 ppm for the Brown Pelican (*Pelecanus occidentalis*). The sensitivity of other New

World vultures to DDE-induced eggshell thinning has not been examined. However, significant eggshell thinning (>10%) has been demonstrated in Turkey Vulture (*Cathartes aura*) eggs from California, Texas, and Florida (Wilbur, in press) and in Black Vulture (*Coragyps atratus*) eggs from Florida and Texas (Kiff and Morrison, unpubl. data).

All known condor nesting attempts since 1971 have fledged young successfully (Wilbur 1978, and unpubl. data). During this period eggshells have averaged thinner than normal, yet were evidently strong enough to survive the long incubation period. Furthermore, it is encouraging to note that two of the three condor eggs believed to have been laid since 1975 had nearly normal shell thicknesses.

Wilbur (1976) believed that current low production of young in the condor population is not the result of egg breakage, but of the total failure of most adults to attempt nesting. However, if DDE has been the cause of eggshell thinning in the condor population, it might also be present in sufficient concentrations to inhibit nesting or cause aberrant breeding behavior as has been observed in the Prairie Falcon and Merlin (*Falco columbarius*; Fyfe and Fox, pers. comm.) and Herring Gull (*Larus argentatus*; Fox et al. 1978).

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## RECENT PUBLICATIONS

**Sounds of Florida's Birds.**—Compiled and narrated by John William Hardy. 1978. 33 $\frac{1}{2}$  rpm phonograph record, ARA-5. Published by John William and Carol K. Hardy. \$7.00. Available: ARA Records, 1615 N.W. 14th Ave., Gainesville, Florida 32605. This record gives the songs and calls of 86 species of birds that regularly occur in Florida. The cuts are in taxonomic order and are each briefly introduced by Hardy. The recordings, by several recordists, present not only easily-heard species but also some elusive ones, notably the Black Rail. While the record is intended for Florida school children, it can also serve more widely as an aid for learning the voices of many eastern North American birds.

**Rare and Endangered Biota of Florida. Volume Two. Birds.**—Edited by Herbert W. Kale II. 1979. University Presses of Florida, Gainesville. 121 p. Paper cover. \$7.00. Available: University Presses of Florida, 15 N.W. 15th St., Gainesville, Florida 32603. This is one of a series of volumes (under the general editorship of Peter C. H. Pritchard) that survey the rare and endangered plants and animals of the state. Over 70 species or subspecies are included, being grouped according to their status. The species accounts, prepared by several ornithologists, cover description, range, habitat, life history and ecology, specialized or unique characteristics, basis of status classification, and recommendations. They are each supplemented by range maps, and a short list of references. Although it is distressing to see such a large catalog of species in trouble, it is heartening to see them so well recognized at last. This is probably the most thorough report of its kind that has been compiled for any state; it should serve as a model for other such inventories.

**Revision of the *Myiarchus* flycatchers of South America.**—Wesley E. Lanyon. 1978. Bulletin of the American Museum of Natural History, Vol. 161, Art. 4. 201 p. Paper cover. \$12.70. Available: Amer. Mus. Nat. Hist., Central Park West and 79th Street, New York, N.Y. 10024. With this definitive mono-

graph, the systematics of the largest and one of the most difficult of tyrannid genera to study has largely been solved. Lanyon has used vocal characters in conjunction with more conventional morphological characters in his analysis. His report "(1) defines the limits of the South American species of *Myiarchus* and provides diagnoses and keys for their identification; (2) documents the known geographical and ecological distribution of these species; (3) analyzes geographical variation and provides a consistent basis for the recognition of subspecies where appropriate, and (4) summarizes data on breeding and the annual cycle." Maps, photographs, and sound spectrograms.

**Development of song in the Wood Thrush (*Hylocichla ustulata*), with notes on a technique for hand-rearing passerines from the egg.**—Wesley E. Lanyon. 1979. American Museum Novitates No. 2666. 27 p. Paper cover. \$2.10. Available: as above. This pamphlet reports an experiment in which "Two Wood Thrushes, reared from the egg in isolation from experienced conspecifics, developed song that is remarkably species-specific, but lacking in certain characteristics of the central phrases." It also updates the technique developed by the author and his wife for hand-rearing passerines, including simplification of equipment and diet. Photographs, sound spectrograms, and tables.

**The distribution of birds in Venezuelan Páramos.**—François Vuilleumier and David N. Ewert. 1978. Bulletin of the American Museum of Natural History, Vol. 162, Art. 2. 43 p. Paper cover. \$2.95. Available: as above. Páramos are islands with a characteristic low, open vegetation growing above the upper limit of continuous montane forest in the Andes of Venezuela, Colombia, Ecuador, and northern Peru. This report presents the results of six censuses in Venezuela and discusses the birds' use of the páramo habitat, geographical patchiness, and the origins of páramo birds in Venezuela. It will interest those who study the ecology and zoogeography of South American birds. Photographs and a chart.