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DDE and the California Condor *Gymnogyps californianus:* the End of a Story?

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On 9 March 1986 an egg laid by the last female California Condor (*Gymnogyps californianus*) to attempt breeding in the wild was discovered broken under a nest in the Sespe Condor Refuge (Clendenen 1986). It appeared to have been crushed almost immediately after it was laid, probably by the weight of the incubating bird. The egg was visibly very thin-shelled, and it had a highly abnormal, coarse, granular surface. It appeared to represent a classic example of the "DDE thin eggshell syndrome", even though 14 years had elapsed since the parent compound, DDT, was banned for domestic use in the United States (Ruckelshaus 1972).

When the associations were first made between organochlorines and eggshell thinning (Ratcliffe 1967) and specifically with DDE (Hickey & Anderson 1968), the early finds indicated that bird- and fish-eating birds were at the greatest risk from this problem. Birds and fish generally had higher levels of contamination than did herbivorous mammals (Cooke 1973; Stickel 1975). There was less concern for raptors or avian scavengers which feed mainly on mammals, since it was presumed that they would not accumulate as high a body burden of organochlorines, except for the Golden Eagles of West Scotland (Lockie *et al.* 1969). Early investigations on mammal-feeding birds of prey indicated relatively low DDE burdens and little eggshell thinning (Lincer *et al.* 1970; Anderson & Hickey 1972). Consequently, there was no formal effort to investigate possible organochlorine contamination in Condors or other cathartid species in the late 1960s and early 1970s.

During his tenure with the Condor Recovery Program between 1966-69, the first U.S. Fish and Wildlife Service Condor biologist, Fred C. Sibley, visited a number of currently active Condor nests to sift their substrates in an effort to remove rocks, bones and other sharp objects which might pose a danger to a Condor egg. He routinely saved the eggshell fragments, some obviously from recently broken eggs, which he found in the nest cavities. He did not analyse the eggshell samples himself, but turned most of them over to the Pesticides Laboratory of the California Department of Fish and Game (CDFG). There they were measured by CDFG toxicologist John Azevedo in about 1969, but the resulting data were not reported at that time, at least in published form. The samples themselves were thought to have been discarded until 1983, when they were rediscovered at the CDFG offices by biologist Ronald Jurek, who immediately provided them to Condor biologists for analytical purposes.

A few samples of Condor eggshell fragments were retained by Sibley and subsequently passed along to his successor, Sanford Wilbur. Given the low priority still assigned to this line of research at the time, it was not until 1975 that these samples were measured by the author and Clark Sumida at the Western Foundation of Vertebrate Zoology. A preliminary comparison with the figure for California Condor eggshell thickness, 0.92mm, given by Schönwetter (1961) indicated that the recent Condor eggshells were over 40% thinner than the historical mean! Similar measurements had been obtained from the misplaced samples by Azevedo, whose data were then made available to Wilbur.

In order to expand upon this alarming finding, additional Condor eggshell samples were obtained from recently active Condor nests in 1976 and 1977 by field teams led by Wilbur and John Borneman, of the National Audubon Society. These samples also included some very thin eggshells, as well as some which proved to be of near historical thickness. The latter were from the eggs apparently laid most recently, i.e., in the mid-1970s. Some of the thin eggshells, as well as two samples from 1896 and 1922 respectively, were examined with a scanning electron microscope (SEM). In addition, organochlorine residues were extracted from the eggshell membranes of the post-DDT eggshell samples and subjected to gas chromatographic analyses by David B. Peakall.

The results of the Condor eggshell studies were reported in (appropriately) the ornithological journal named after the species (Kiff *et al.* 1979). The sample of eggshells from 1964-69 averaged 32% thinner than the historical (pre-1944) mean, which was determined to be 0.78mm from a larger sample than that available to Schönwetter. Samples from eggs laid between 1971-77 averaged 20% thinner than the historical mean. There was no overlap between the thickness measurements of the pre-1944 museum eggs and the recent eggshell fragments. A significant negative correlation was found between DDE levels in eggshell membranes and the eggshell thickness. The 1960s eggshells examined with the SEM showed ultrastructural disruptions of the type associated with DDE-induced eggshell thinning in both laboratory and field studies (Garrett 1973; Fox 1974). Clearly, the California Condor was yet another species affected by DDE contamination.

Sibley documented several cases of outright egg breakage by Condors in the later 1960s and suspected others (F. Sibley field notes; Snyder 1983). At that time, critics of the Condor management programme attributed such failures to Sibley's nest inspection (C. Koford, pers. comm.), evidently being unaware that in all instances his entry into the nests occurred well after the eggs had actually been broken, as indicated by their condition and by the behaviour of the birds (F. Sibley field notes). It now seems likely that severe eggshell thinning was responsible for some or even all of the Condor egg breakage documented by Sibley.

Snyder (1983), however, compared the documented frequencies of egg failures from all causes in the Koford era (1940s), Sibley era (1960s) and the recent era (1980s), and essentially found no differences among the periods. This has already led some to question whether DDE was as serious as certain natural factors in contributing to eggshell breakage (Mundy & Ledger 1986). Snyder pointed out, however, that it is awkward to compare the respective data sets because of the different objectives and techniques of the principal investigators. For example, only in the most recent era were the actual causes of egg failure well documented. Furthermore, there was little attempt by Koford or Sibley to monitor all Condor breeding attempts, and the chances of overlooking early egg breakage was great, a point most pertinent to the latter researcher's era.

Several recent egg losses have been due to Common Raven (*Corvus corax*) predation (Snyder *op. cit.*), a mortality factor unreported by Koford and Sibley. Whether this is a source of egg loss overlooked by the earlier researchers, or a new phenomenon, is unclear. Snyder (*op. cit.*) correctly pointed out that egg breakage has probably always been one of the few significant natural causes of Condor mortality. For example, approximately 10% of the eggs known to have been taken by collectors were found already punctured or otherwise damaged in the nests (S. Wilbur & L. Kiff unpubl.), and there are several reports of Condors kicking their egg out of the nest cavities upon being flushed precipitately by human intruders (Koford 1953). The ability of Condors to re-nest after an initial failure has only recently been demonstrated (Snyder & Hamber 1985; Harrison & Kiff 1980).

Based on more detailed studies on other bird populations affected by eggshell thinning, as well as the structural degradation of the 1960s eggshell fragments, it seems reasonable to suspect that the severe eggshell thinning experienced by Condors during the "DDT era" further exacerbated their existing tendency to break eggs, resulting in an increased rate of egg failure. We suggested earlier that this could have resulted in the loss of an age cohort or more of Condors (Kiff *et al.* 1979). In fact, an observed decline in the ratio of dark-headed juvenile birds to adults was observed in the 1970s (Wilbur 1978), indicating that breeding success in the 1960s and early 1970s was depressed. Although observations were not made at all active Condor nest sites between 1966-71, only 8 Condor young were known to have successfully fledged over this period; the observed age ratios among free-flying birds indicated that average annual productivity was probably less than two young (Wilbur *et al.* 1972).

Since 1980, Noel Snyder, former U.S. Fish and Wildlife Service Condor biologist, has been coordinating a comprehensive study on Condor eggshells, including Pleistocene, historical and all recent samples. Assisted by Rob Roy Ramey II and others, he made a determined effort to enter all known historical Condor nest sites to obtain eggshell samples. Shells of the eggs hatched in the wild or at the San Diego Zoo between 1983-86 were also obtained. Eggshell thickness and other parameters have been analysed over the last few years at the Western Foundation of Vertebrate Zoology with the author and Clark Sumida. Over 50 samples have been examined with SEM techniques by Karl Hirsch of the University of Colorado. David Peakall, of the Canadian Wildlife Service, and Wally Jarman and Robert Risebrough, of the University of California, Santa Cruz, have been involved in analysing the organochlorine content of the eggshell membrane lipids. A report on these joint investigations is near completion (Snyder *et al.* unpubl.).

Given our assumption that DDE-induced eggshell thinning was a problem of the past for the California Condor, the striking pathological condition of the 1986 Sespe egg came as a shock to all of the researchers associated with the recovery effort. The egg measured 56% thinner than normal (Snyder *et al.* unpubl.). Aside from some Brown Pelican eggshells found on Anacapa Island, California in 1969 that were of the order of 95% thin, this is the thinnest wild bird egg ever reported. An analysis of the lipids contained in the associated eggshell membranes indicated that the egg had contained 130ppm DDE lipid wt. (Jarman & Risebrough 1986), and D. Peakall's independent analysis on another eggshell fragment yielded a figure of 180ppm DDE lipid wt. (*in litt.*). Although the extrapolations yielded by this methodology are necessarily imprecise (Peakall *et al.* 1983), these figures are approximately equivalent to 6.5 and 9ppm DDE wet wt., respectively, both above the 5ppm wet wt. estimated to be associated with 20% eggshell thinning in California Condors (Kiff *et al.* 1979).

The decline of the California Condor has occurred from a frustrating variety of causes, all of them man-induced (Wilbur 1978; U.S. Fish and Wildlife Service 1984; Snyder 1986), and I do not suggest that the desperate plight of the species can be blamed solely on DDT use. However, it is clear that severe eggshell thinning and correspondingly high DDE residue levels from some still unspecified source did still occur in at least one Condor egg right up until the last year that the species attempted to breed in the wild. Furthermore, DDE contamination probably had a very serious impact on the breeding success of the remnant population of the species in the 1960s, leading to a subsequent decline in the number of individuals added to the pool of breeding adults in the 1970s. Had DDT use in California continued at pre-1972 levels, it is quite possible "that the California Condor would have been the first species to become extinct as a result of DDT use" (Risebrough 1986).

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