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High Levels of HCB and DDE Associated with Reproductive Failure in Prairie Falcons *(Falco mexicanus)* from California

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Organochlorine compounds, particularly DDE [1,l'-(dichloroethenylidene)bis(4-chlorobenzene)] and polychlorinated biphenyls (PCBs), have been linked to reproductive failure in birds (Risebrough 1986). Hexachlorobenzene (HCB), a pesticide and industrial by-product, has been detected in many wild bird populations (e.g., Vos et al. 1969; Noble and Elliott 1990; Jarman et al. 1993). In laboratory studies HCB has been shown to decrease the survivability and hatchability of birds (Schwetz et al. 1974; Reed et al. 1977) and has been associated with reproductive problems in wild populations (Vos et al. 1969; Gilbertson and Reynolds 1972). HCB toxicosis in humans has been reported to cause porphyria cutanea tarda (Morgan 1989) which is one of the symptoms of Great Lakes embryo mortality, edema, and deformities syndrome seen in piscivorous birds (Gilbertson et al. 1991).

As part of a long-term falcon monitoring program in California and as part of a raptor monitoring program in Pinnacles National Monument (PNM), prairie falcon *(Falco mexicanus)* nesting success was monitored in the PNM and throughout the state beginning in about 1984 (Linthicum and Walton 1991). The goals of this monitoring were to assess the prairie falcon population, breeding success, and to cross-foster peregrine falcons *(Falco peregrinus)* into historical eyries now used by prairie falcons (Linthicum and Walton 1991). Prairie falcons have been documented to be more sensitive to the effects of DDE than peregrine falcons; estimates of threshold levels (the levels at which a population may be impacted) of DDE on prairie falcons are 2,000 $ugkg^{-1}$ (wet weight), and 15,000-20,000 $ugkg^{-1}$ for peregrines (Fyfe et al. 1976, 1988).

In general, prairie falcons throughout California did not experience the catastrophic decline in numbers that the peregrine falcons experienced (Fyfe et al. 1988). Although more sensitive to DDE than peregrines, their population stability can probably be attributed to their lower trophic position relative to peregrines; prairie falcons feed on mammals, reptiles, and insects in addition to birds (Fyfe et al. 1976).

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However, in the 1980s monitoring of prairie falcons within PNM detected nesting failures which were reminiscent of peregrine falcons impacted by DDE, i.e., whole clutches of eggs did not hatch *(Rectin, unpublished manuscript).*

This study examines the relationship between productivity and organochlorine levels, focusing on DDE, PCBs, and HCB, in prairie falcon eggs collected in California between 1989 and 1991.

MATERIALS AND METHODS

The falcon eggs were collected by biologists working for the SCPBRG or volunteer climbers working with biologists at PNM from eyries in northern and central California between 1989 and 1991. Addled eggs and eggs which did not hatch were transferred to organic free jars and frozen until chemical analysis.

The samples were extracted with CH_2Cl_2:hexane (1:1), fractionated by Florisil chromatography, and analyzed by dual column (DB-5 and DB-17) high resolution gas chromatography. A standard reference material (NIST SRM 1974) was analyzed with each batch of samples; the precision of the analytical batch was determined acceptable if the values for the SRM were within 20% of the validated values. Concentrations were not recovery corrected. A detailed description of the method can be found in (Jarman et al. 1993). Levels are reported in $\mu g kg^{-1}$ wet weight (ppb), as geometric means.

The data were considered to be significantly different if $p < 0.05$.

RESULTS AND DISCUSSION

The levels of DDT, HCH, HCB, Mirex, chlordane, and PCB compounds are presented in Table 1. The highest levels of DDE were found in the Frog/Hand nest (these eyries were combined because field and laboratory observations suggested that this was a single female who was using two nesting locations in different years) (9700 $\mu g kg^{-1}$) and the Pig Canyon eyrie (8200 $\mu g kg^{-1}$); their levels were not statistically different *(t= 0.57, df = 6, p= 0.59)* (Table 1). These levels are more than an order of magnitude higher than those reported for Canadian prairie falcons between 1980 and 1988 (384 $\mu g kg^{-1}$) (Noble and Elliott 1990). The levels of DDE for the other eyries in California ranged from 1000 to 4200 $\mu g kg^{-1}$ at Mount Dome and Goat Rock, respectively.

(Fyfe et al. 1976) determined the critical concentration level (the level at which the population might be impacted) of DDE for prairie falcon eggs at 2000 $\mu g kg^{-1}$ (wet weight). This threshold value makes the prairie falcon one of the most sensitive falcons to the effect of DDE (Fyfe et al. 1988). At the Frog/Hand nest, Pig Canyon, and Goat Rock eyries there were no young

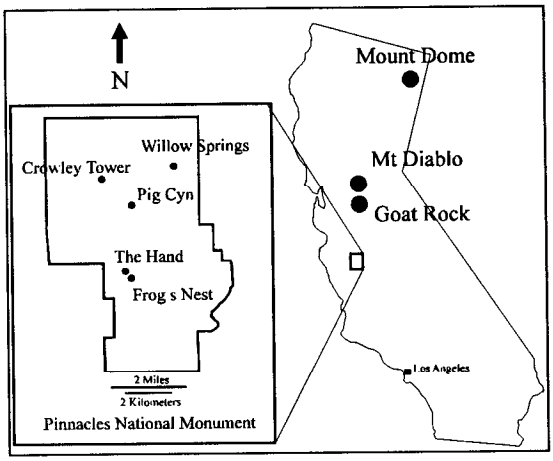

Figure 1. Prairie falcon egg sampling locations in California

produced. Willow Springs and Mount Dome had better productivity, and DDE levels of 2800 and 1000 $\mu g kg^{-1}$, respectively (Table 1). In general our data set agrees with Fyfe et al. (1976) conclusions, although our data indicate that threshold DDE values in California prairie's might be slightly higher than 2000 $\mu g kg^{-1}$

The highest levels of CPCB found in the California samples was 600 $\mu g kg^{-1}$ (Table 1). There was no significant difference between the regions, Frog/Hand nest, other Pinnacles eyries, and the rest of the California eyries ($F = 0.82$, $df = 15$, $p = 0.462$). Fyfe et al. (1976) found no evidence of reproductive impairment of prairie falcons at PCB levels of 580 $\mu g kg^{-1}$ (assuming 80% water in the eggs). The levels of PCBs in the samples are probably not toxicologically important.

Of particular interest was the high relative levels of HCB detected in the Frog/Hand eyrie (Table 1). Chromatograms of eggs from the two eyries located within PNM show the difference in relative HCB levels (Figure 2); although DDE and PCB levels are similar, HCB levels are dramatically different. The levels of HCB in the Frog/Hand eyrie are significantly different (from either the other Pinnacles eyries, or from the other California eyries ($F = 82.04$, $df = 15$, $p < 0.001$). The levels in the Frog/Hand eyrie are over 15 times higher than those levels reported for Canadian prairie falcons (48 $\mu g kg^{-1}$) (Noble and Elliott 1990).

The first report of HCB in birds was in raptors and raptor eggs from the Netherlands. (Vos et al. 1969). Gilbertson and Reynolds (1972) reported levels of HCB in common terns *(Sterna hirundo)* from Lake Ontario collected in 1970

Table 1. Levels of organochlorine compounds in prairie falcon eggs collected in California between 1989 and 1991.
Levels are reported as mgkg-1 of the wet weight

	Pinnacles National Monument													
	Frog/Hand Nest			Pig Cyn			Crowley Tower	Willow Sp.	Goat Rock			Mt. Dome			Mt. Diablo
Fate of eggs	11 eggs, none hatched			4 eggs, none hatched			4 eggs, 3 hatched	5 eggs, 3 hatched	2 eggs, failed nest			5 eggs, 3 hatched			5 eggs, 4 hatched
	GM ± 1 sd		n[@#]	GM ± 1 sd		n[@#]	n=1	n=1	GM ± 1 sd		n[#]	GM ± 1 sd		n[@#]	n=1
p,p'-DDE	9700	5700-17000	6	8200	5800-12000	3	1900	2800	4200	4200-4300	2	1000	1000-1500	2	2000
p,p'-DDD	65	(36-120)	6	16	(10-24)	3	8.4	2.4	7.8	(0.69-90)	2	2.5	(2.5-12)	2	<0.5
p,p'-DDT	66	(11-400)	6	64	(27-150)	3	8.7	1.1	63	(9.9-390)	2	5.1	(5.1-38)	2	6.8
HCB	800	(570-1100)	6	17	(11-28)	3	11	8.0	10	(7.5-14)	2	20	(20-20)	2	81
Mirex	1.3	(0.73-2.4)	5	3.1	(1.1-8.5)	3	4.2	4.6	3.7	(1-13)	2	1.1	(1.1-1.3)	2	3.8
α-HCH	0.4	(0.25-0.66)	5	0.49	(0.45-0.53)	2	0.16	0.16	0.49	(0.44-0.55)	2	0.44	(0.44-0.52)	2	<0.5
β-HCH	7.9	(5.9-11)	6	9.1	(6.5-13)	3	2.0	1.3	3.2	(1.4-7.1)	2	1.1	(1.1-1.6)	2	5.0
γ-HCH	0.66	(0.25-1.7)	2	0.38	(0.36-0.42)	2	<0.5	<0.5	0.43	(0.31-0.6)	2	0.39	(0.39-0.41)	2	<0.5
δ-HCH	0.6		1	<0.5		0	<0.5	<0.5			0	<0.5		0	<0.5
Oxychlr.	17	(13-23)	6	50	(37-68)	3	13	12	66	(51-86)	2	45	(45-57)	2	23
trans-nona.	12	(7.7-20)	6	21	(12-37)	3	6.8	16	42	(26-69)	2	14	(14-21)	2	26
cis-nona.	3.2	(0.89-12)	6	3.4	(2-5.6)	3	2.1	NA	5.6	(4.5-7)	2	1.5	(1.5-3.5)	2	3.2
cis-chlor.	2.6	(1.2-5.6)	5	1.1	(0.71-1.8)	3	<0.5	<0.5	1	(0.93-1.2)	2	0.23	(0.23-0.52)	2	<0.5
trans-chlor.	4	(1.9-8.2)	5	2.4	(1.3-4.4)	3	<0.5	<0.5	2.8	(1.3-6)	2	0.3	(0.3-0.56)	2	<0.5

Table 1. Cont.

	Pinnacles National Monument														
	Frog/Hand Nest			Pig Cyn			Crowley Tower	Willow Sp.	Goat Rock			Mt. Dome			Mt. Diablo
PCBs:															
99	11	(7.9-14)	6	17	(10-29)	3	1.9	7.5	24	(14-43)	2	4.1	(4.1-6.7)	2	4.9
118	45	(31-66)	5	<0.5		0	4.6	19	36		1			0	9.8
138	44	(33-60)	6	46	(23-90)	3	16	38	75	(44-130)	2	0.09	(0.09-16)	2	34
49 & 123	4.6	(2.1-10)	5	<0.5		0	1.4	<0.5	9.4		1	<0.5		0	2.9
153	120	(88-170)	6	180	(110-320)	3	31	63	200	(73-570)	2	24	(24-29)	2	63
170	21	(16-27)	6	28	(15-52)	3	7.1	14.5	49	(16-150)	2	5.1	(5.1-9.3)	2	15.2
180	40	(31-53)	6	58	(31-110)	3	21	42	110	(44-260)	2	13	(13-22)	2	40
187	24	(19-30)	6	23	(13-42)	3	6.9	23	48	(24-97)	2	2.7	(2.7-3.5)	2	18.8
195	3.6	(2.6-5)	5	4.3	(2-9.2)	3	0.46	3.0	9.7	(2.8-34)	2	1	(1-1.1)	2	1.7
96 & 203	8.1	(5.8-11)	6	13	(7.5-22)	3	3.9	7.6	15	(6.8-32)	2	2.5	(2.5-3.2)	2	8.0
201	6.1	(4.4-8.5)	6	7.5	(3.9-14)	3	4.6	NA	13	(5.2-34)	2	1.6	(1.6-2)	2	8.5
206	3.1	(2-4.8)	6	5.6	(3.1-10)	3	1.7	3.5	9.5	(2.6-34)	2	1.5	(1.5-2.1)	2	2.4
ΣPCB	330	(270-410)	6	390	(220-690)	3	100	221	600	(270-1300)	2	64	(64-77)	2	210

@ = Not all eggs were analyzed

= Number of eggs in which the compound was detected (detection limit approx.0.5 µgkg-1)

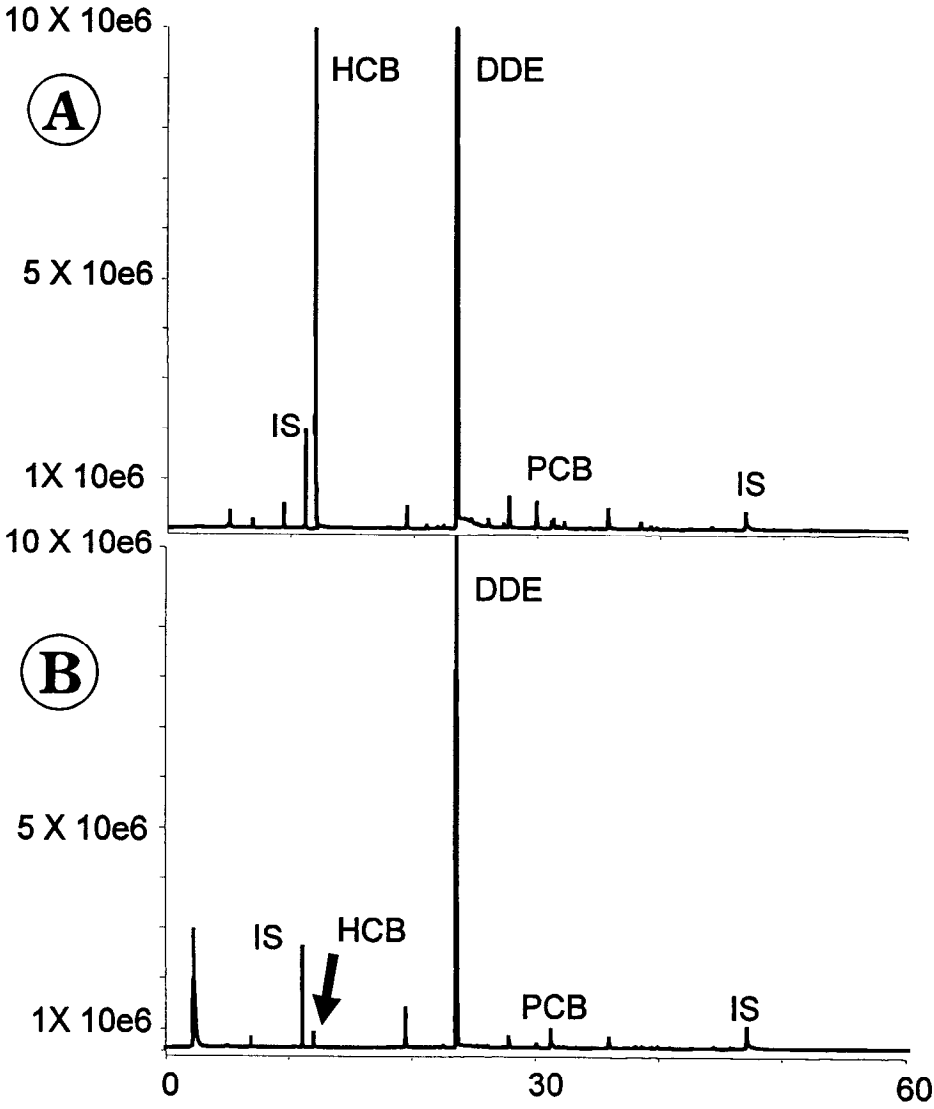

Figure 2. HRGC/ECD chromatograms (DB-5 column) of extracts of prairie falcon eggs collected at Pinnacles National Monument (California) in 1990. A- Egg from Frog/Hand eyrie; B- Egg from Crowley Tower.

at 1500 μgkg^{-1} (assuming 80% water in the eggs). Boersma et al. (1986) in an egg injection study found a dramatic increase of embryo mortality with increasing dose of HCB in herring gulls *(Larus argentatus)*, and calculated the LD50 to be 4300 μgkg^{-1}. At a concentration of 1500 μgkg^{-1} (twice that of the mean value found in this study), Boersma et al. (1986) found a mortality rate in the herring gull embryos of 21% . Given the known sensitivity of prairie falcons to DDE, the known toxicity of HCB to birds, and the possible additive effect of DDE and HCB, the high levels of HCB in this study may have had deleterious effect on the hatching success at the Frog/Hand nest.

The continuing high levels of both DDE and HCB in the falcons from PNM suggest a point source. The PNM is located between two areas of intensive farming, the Salinas (directly west of PNM) and Central Valleys (east of PNM). The different residues levels of HCB and DDE in falcons that are nesting within several miles of each other in the PNM suggest different foraging locations or behavior.

The prairie falcons within the PNM do not appear to forage in the park; the Frog/Hand falcons foraged west (into the Salinas Valley), Crowley falcons north or northwest, and Pig Canyon falcons east. The falcons have never been followed using radio telemetry studies, therefore we do not know exactly where they forage nor where they winter. However, these differences in foraging direction (i.e., into known agricultural areas) may explain the continuing high levels of pesticides in the falcons.

A point source is also suggested by the successful fledging of young at the Frog/Hand territory in 1991-95 *(Rectin, unpublished manuscript).* A slight change in foraging location could allow the prairies at that territory to avoid contaminated prey.

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