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HEPTACHLOR SEED TREATMENT CONTAMINATES HAWKS, OWLS, AND EAGLES OF COLUMBIA BASIN, OREGON

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ABSTRACT - We evaluated organochlorine residues in 12 species of hawks, owls, and eagles from the Columbia Basin of Oregon between 1978 and 1981. Companion studies showed that heptachlor epoxide (HE) induced adult mortality and reduced productivity of the Canada Goose (*Branta canadensis*) and American Kestrel (*Falco sparverius*). In this study, brain tissue from raptors found dead and sample eggs from 90 nests were analyzed for organochlorines. The primary concern was HE that entered raptor food chains through the ingestion of heptachlor-treated seed by their prey. HE residues were detected in eggs from 9 of 10 species and ranged as high as 4.75 ppm (wet wt), but no definite effects of HE on productivity were readily apparent from the limited series of nests. However, the hazard of heptachlor seed treatments to birds of prey was demonstrated by the occurrence of lethal residues of HE in brain tissue of 3 Golden Eagles (*Aquila chrysaetos*) and 1 Rough-legged Hawk (*Buteo lagopus*). Other organochlorine pesticides were present in the eggs and significant relationships were found between DDE and eggshell thickness for the Swainson's Hawk (*Buteo swainsoni*) and Western Screech-Owl (*Otus kennicotti*), although shell thinning (9.6% and 7.4%) was below the generally accepted range where reproductive problems have been known to occur.

The history of heptachlor as a wheat seed treatment to control wireworms in Umatilla and Morrow counties, Oregon, is poorly understood. Through 1970, it was listed in the *Pacific Northwest Insect Control Handbook* (Anon., various dates) after aldrin and dieldrin, with an application rate on seed of 1 oz/bu (about 1,000 ppm). It was not listed in 1971, 1972, and 1973. Then from 1974, heptachlor was listed at 2 oz/bu (about 2,000 ppm). In 1979, heptachlor seed treatments were banned in a 1700 km² area near the Umatilla National Wildlife Refuge (NWR), and by 1981, there appeared to be a nearly complete changeover from heptachlor to lindane as a seed treatment in our study area. As of September 1982, production of heptachlor for use as a seed treatment in the United States was prohibited; however, there was a provision for using up existing stocks.

In 1976 and 1977, die-offs of several species of birds occurred in Umatilla and Morrow counties, Oregon. Residues of HE that are considered lethal (Stickel et al. 1979) were found in brain tissue of the Ring-necked Pheasant (*Phasianus colchicus*), California Quail (*Callipepla californica*), Canada Goose, Black-billed Magpie (*Pica pica*), and Golden Eagle (Blus et al. 1979). This history of wildlife mortality associated with heptachlor seed treatment of wheat prompted a detailed study of Canada

Geese nesting at Umatilla NWR (Blus et al. 1979), and a study of American Kestrels nesting throughout the region (Henny et al. 1983). Both studies showed heptachlor-induced adult mortality. Furthermore, although HE did not thin eggshells, reduced nesting success was correlated with increased HE residues in eggs of both species. The kestrel was more sensitive to HE residues in eggs than was the Canada Goose (i.e., reduced productivity occurred at > 1.5 ppm [wet wt] in kestrel eggs vs. > 10 ppm in Canada Goose eggs).

We reasoned that Canada Geese were obtaining heptachlor directly from the ingestion of treated seeds; however, the diet of American Kestrels is mainly insects (especially grasshoppers) but includes mice, small birds and some lizards and amphibians (Fisher 1893). Therefore, the presence of HE in kestrel eggs indicated contamination of the food chain of at least one species of hawk.

This study was designed (1) to determine if HE entered food chains of other species of hawks and owls nesting in the region, and (2) to evaluate the success or failure of each nesting attempt in relationship to organochlorine residues in the sample egg collected. The egg data provides insight into residue concentrations that affect reproductive success of the various species although more information of this type is needed. Also, brain tissue of

birds of prey found dead were analyzed to determine if mortality was related to organochlorine contaminants.

METHODS

We collected a sample egg from 90 raptor nests located in Umatilla and Morrow counties, Oregon in 1978-81. The remainder of the eggs were monitored for hatchability and fledging rates. Since a sample egg was collected from each nest for organochlorine analysis, some productivity values were not directly comparable to other published studies. Nest boxes were placed in the region to attract American Kestrels, but Western Screech-Owls and the Northern Saw-whet Owl (*Aegolius acadicus*) also used them. The Burrowing Owl (*Athene cunicularia*) used artificial burrows (Henny and Blus 1981).

The sample eggs were refrigerated until opened. Contents were placed in a chemically cleaned jar and frozen for later analysis. Shell thickness (shell and shell membranes) was measured at 3 sites on each egg equator with a micrometer graduated in units of 0.01 mm. Historical eggshells (pre-1947) were measured at 3 museums in Oregon and Washington. One randomly selected egg from each clutch was measured.

Samples were homogenized and subsamples extracted by a Soxhlet apparatus and cleaned by Florisil-column chromatography. Polychlorinated biphenyls (PCB's) were separated from pesticides by silicic acid column chromatography (Cromartie et al. 1975 and Kaiser et al. 1980). All samples were analyzed for DDE, DDD, DDT, dieldrin, heptachlor epoxide, mirex, oxychlordane, *cis*-chlordane, *cis*-nonachlor, *trans*-nonachlor, endrin, toxaphene, hexachlorobenzene, and PCB's. Additionally, samples in 1978, 1980 and 1981 were analyzed for lindane, samples in 1978 and 1981 for β -BHC, and samples in 1978 for pentachloronitrobenzene (it was not detected).

Residues were quantitated by electron-capture gas-liquid chromatography using either a 1.5/1.95% OV-17/QF-1 or a 1.5/1.95% SP-2250/2401 column. Recoveries from fortified chicken eggs ranged from 83-104%. Residue levels were not corrected for recovery. A few samples from 1978 were analyzed at the Denver Wildlife Research Center (Peterson et al. 1976). Residues in 8% of the samples were confirmed on a Finnigan 4000 series gas chromatograph/mass spectrometer (Kaiser et al. 1980). The lower limit of residue quantification was 0.1 ppm for pesticides and 0.5 ppm for PCB's. For statistical purposes, the lower limit of quantification was divided in half and that value assigned to samples in which the contaminant was not detected. Statistical calculations were not performed unless 75% of the samples contained detectable residues. Contents of eggs were converted to an approximate fresh wet wt by use of egg volume (Stickel et al. 1973); residue concentrations were then expressed on an estimated fresh wet wt basis. A t-test was used to determine significant ($P \leq 0.05$) changes in eggshell thickness. The mean clutch size and mean number of young fledged was not calculated unless ≥ 6 nest records were available.

RESULTS AND DISCUSSION

The largest series of eggs was obtained from the Swainson's Hawk (25 nests) and Long-eared Owl (*Asio otus*) (21 nests), but because the preponderance of data pertain to either 1978 or 1979, a statis-

tical analysis of the residue changes over time was not advisable. A ban on heptachlor seed treatments near the Umatilla NWR in 1979 resulted in an immediate lowering of HE concentrations in kestrel eggs the following year (Henny et al. 1983).

Hawk Eggs. — Heptachlor epoxide was detected in the majority of eggs sampled among the buteos, i.e., Swainson's Hawk (21 of 25, 84%), Ferruginous Hawk (*Buteo regalis*) (9 of 10, 90%), and Red-tailed Hawk (*B. jamaicensis*) (5 of 6, 83%) (Table 1). DDE was detected at about the same frequency as HE in all 3 species: Swainson's Hawk (23 of 25, 92%), Ferruginous Hawk (8 of 10, 80%), and Red-tailed Hawk (5 of 6, 83%). Dieldrin was frequently detected in Swainson's Hawk eggs (13 of 25, 52%), but was virtually absent from the Ferruginous Hawk (0 of 10) and Red-tailed Hawk (1 of 6) eggs.

Residues in sample eggs were tabulated from the highest to the lowest to ascertain if residues influenced nesting success. Although sensitivity to contaminants varies from species to species, we know American Kestrel nesting success declined when HE egg residues increased above 1.5 ppm (Henny et al. 1983). With the Swainson's Hawk, 15 of 21 nests (71%) with < 1.5 ppm HE were successful with 26 young fledged (1.24 per nesting attempt) which was judged good to excellent. (Note: 1 egg was collected which reduced the number fledged). Only 4 nests contained ≥ 1.5 ppm HE (2 were successful and fledged 4 young or 1.00 per nesting attempt). Four of 5 Swainson's Hawk nests with the highest DDE residues (5 to 10 ppm) in eggs were successful and produced 10 young (2.00 young/nest). Two successful Swainson's Hawk nests in 1976 contained DDE residues of 4.35 and 7.13 ppm and produced 3 young and 1 young, respectively (Henny and Kaiser 1979). When the 10 nest records from 1976 were combined with 25 nests in this study, regression analysis indicated a significant logarithmic relationship between DDE and eggshell thickness ($Y = 0.393 - 0.022 \log_{10} X$, $r = -0.40$, $P < 0.02$). The same method showed no significant relationship between HE and eggshell thickness ($Y = 0.393 + 0.002 \log_{10} X$, $r = 0.04$, $P > 0.05$). Eggshell thickness ($\bar{x} \pm SE$) during this study was 0.387 ± 0.007 mm which was 9.6% thinner ($P < 0.01$) than the pre-DDT era (before 1947) mean of 0.428 ± 0.005 mm in the Pacific Northwest (Henny and Kaiser 1979). This amount of thinning was less than the generally accepted 18-22% range where reproductive problems occur (Lincer 1975).

Bechard (1981) collected a sample egg from 6 Swainson's Hawk nests in nearby southeastern Washington in 1977 and 1978. At least 1 young was fledged from each nest. Low DDE residues (ppm wet wt) were reported in 5 eggs (0.20, 0.68, 1.2, 1.4, 2.9) and low HE residues in 2 eggs (0.11, 0.35).

Neither the Ferruginous nor the Red-tailed Hawk eggs contained HE above 1.5 ppm (the effect zone observed for the American Kestrel), and DDE residues were generally low. Shell thickness for the Red-tailed Hawk was identical (0.420 ± 0.017 mm) to pre-1947 thickness from the northern prairies (Anderson and Hickey 1972); whereas, the small series of Ferruginous Hawk eggs showed a significant ($P < 0.01$) shell thickness increase

(0.485 ± 0.006 mm, $n = 10$ vs. 0.451 ± 0.008 mm, $n = 14$) in comparison to eggs collected in Oregon and Washington before 1947. Ferruginous Hawk eggs collected from 6 nests in southcentral Idaho in 1979 contained low residues (ppm wet wt) of DDT and its metabolites (highest value 0.65) and low residues of HE (highest value 0.10) (Thurow et al. 1980). HE residues in Swainson's and Ferruginous Hawk eggs from this study were higher than reported from eggs collected in adjacent states during the same time period.

Four Northern Harrier (*Circus cyaneus*) eggs and 2 Prairie Falcon (*Falco mexicanus*) eggs all contained HE and DDE (Table 1).

Owl Eggs. — Heptachlor epoxide was detected

Table 1. Clutch size, fledging success, eggshell thickness, and organochlorine residues (ppm wet wt) in eggs of hawks nesting in Umatilla and Morrow counties, Oregon, 1978-80.

Year	Clutch size ^a	Fledged	Shell Thickness (mm)	HE	OXY	DDE	Dieldrin	HCB	TRNO
Swainson's Hawk									
1979	4	1	0.480	2.95	0.31	0.76	0.49	0.19	0.10
1978 ^b	4	3	0.383	2.93		2.16			
1979	2	0	0.372	2.82	0.23	10.34			1.03
1979	3	0	0.360	2.52	0.28	1.15	0.52	2.62	0.58
1979	2	0	0.418	1.42		0.21			
1979	2	1	0.391	1.31	0.14	1.87			0.14
1979 ^c	4	3	0.365	1.20	0.11	10.41	0.11		
1979	4	3	0.430	0.93		0.66	0.14		
1979	3	0	0.417	0.67		0.21	0.45		
1980	?	1	0.429	0.64	0.13		0.10		
1979	3	0	0.353	0.50		0.45			
1979 ^c	4	3	0.335	0.36		8.74	1.34		
1979 ^d	3	0	0.378	0.35	0.13	1.28	0.33		
1979	3	0	0.398	0.26			0.10		
1980	2	0	0.351	0.25		0.28	0.17		
1979 ^e	4	3	0.370	0.23		7.50	0.10		
1979	3	1	0.359	0.23		1.41			
1979	3	1	0.388	0.19		2.66	0.15		
1979	4	2	0.377	0.14		2.96			
1979	3	1	0.430	0.13		0.56			
1978 ^b	?	1	0.371	0.10		0.15			
1978 ^b	3	1	0.346			5.00			
1979	4	2	0.381			1.56			
1979	3	1	0.404			1.32	0.13		
1979 ^f	4	2	0.397			0.23			
	3.22 ^g	1.20 ^g	0.387 ^g	0.38 ^h		0.98 ^h			

(Table 1 Continued)

(Table 1 Concluded)

Year	Clutch size ^a	Fledged	Shell Thickness (mm)	HE	OXY	DDE	Dieldrin	HCB	TRNO
Ferruginous Hawk									
1978 ^b	4	3	0.475	1.32		3.88			
1979	2	0	0.493	1.08	0.12	2.25			
1979	2	0	0.509	0.56	0.11			0.28	
1978 ^b	2	1	0.457	0.49		1.05			
1979	4	2	0.455	0.40		0.65			
1979	4	2	0.512	0.38					
1978 ^b	4	3	0.497	0.17		0.29			
1978 ^b	4	0	0.477	0.14		0.10			
1978 ^b	5	0	0.496	0.10		0.32			
1980	4	2	0.475			1.31		0.30	
	3.50 ^g	1.30 ^g	.485 ^g	0.31 ^h		0.42 ^h			
Red-tailed Hawk									
1979	4	0	0.353	1.44	0.17	0.20			
1980	?	2	0.477	1.34	0.14	0.15			
1978 ^b	3	?	0.417	1.22		3.58			
1979	3	2	0.441	0.87	0.22	0.24	0.43		
1978 ^b	?	2	0.407	0.14		0.32			
1979	3	2	0.424						
				0.420 ^g	0.49 ^h		0.27 ^h		
Northern Harrier									
1979	6	0 ⁱ	0.315	1.90	0.18	3.61	0.22		
1978 ^b	?	0 ⁱ	0.317	1.06		5.24			
1978	?	0 ⁱ	0.55	0.55	0.14	4.15	0.13		
1979	?	0 ⁱ	0.289	0.25		0.61			
			0.307 ^g	0.73 ^h		2.63 ^h			
Prairie Falcon									
1979	5	3	0.372	4.75	0.33	0.86		0.21	0.22
1978 ^b	4	?	0.319	1.84		1.11			
			0.346 ^g	2.96 ^h		0.98 ^h			

Note: HE = heptachlor epoxide, OXY = oxychlordane, HCB = hexachlorobenzene, and TRNO = *trans*-nonachlor.

^aBefore sample egg removed. ^bAnalyzed at Denver Wildlife Research Center. ^cAlso, 0.36 or 0.66 ppm toxaphene. ^dAlso, 0.13 ppm DDD. ^eAlso, 1.0 ppm PCB's. ^fRecycled after first nest abandoned. ^gArithmetic mean. ^hGeometric mean. ⁱNests destroyed by farm mowing operations.

less frequently in eggs of the 5 species of owls (Table 2) than in hawk eggs: Western Screech-Owl (5 of 7, 71%), Short-eared Owl (*Asio flammeus*) (3 of 5, 60%), Long-eared Owl (7 of 21, 33%), Burrowing Owl (2

of 6, 33%), and Northern Saw-whet Owl (0 of 4). Our criteria for calculating geometric means (75% of samples with detectable amounts) was not met for HE in any of the owl species. DDE occurred in

eggs at greater frequencies than HE: Western Screech-Owl (6 of 7, 86%), Burrowing Owl (5 of 6, 83%), Long-eared Owl (17 of 21, 81%), Short-eared Owl (4 of 5, 80%), and Northern Saw-whet Owl (1 of 4, 25%). However, the DDE concentrations in owls were low.

Long-eared Owls experienced excellent reproductive success; 16 of 19 nests (84%) were successful. The 3 nests that failed did not contain higher residue concentrations than the successful nests. A test for the logarithmic relationship between DDE and eggshell thickness was not statistically significant ($P > 0.05$). The mean eggshell thickness (0.237 ± 0.003 mm, $n = 21$) was similar to the pre-1947 mean (0.238 ± 0.002 mm, $n = 11$) from Oregon and Washington.

Western Screech-Owl eggs contained some of the higher DDE residues among the owls (Table 2). Although only 7 Western Screech-Owl eggs were collected, a highly significant logarithmic relationship existed between DDE and eggshell thickness ($Y = 0.211 - 0.025 \log_{10} X$, $r = -0.92$, $P < 0.01$). There was no significant relationship ($P > 0.05$) between HE and eggshell thickness. Mean Western Screech-Owl eggshell thickness of 0.212 ± 0.007 mm was 7.4% thinner ($P < 0.01$) than the pre-1947 mean (0.229 ± 0.004 mm, $n = 11$) from Oregon and Washington. Laboratory studies showed that 2.8 ppm (wet wt) of DDE in the diet reduced Eastern Screech-Owl (*Otus asio*) eggshell thickness by an average of 12% (McLane and Hall 1972). Residues of DDE in Eastern Screech-Owl eggs from Ohio in

Table 2. Clutch size, fledging success, eggshell thickness, and organochlorine residues (ppm wet wt) in eggs of owls nesting in Umatilla and Morrow counties, Oregon, 1978-81.

Year	Clutch size ^a	Fledged	Shell Thickness (mm)	HE	OXY	DDE	Dieldrin	HCB	PCB's
Long-eared Owl									
1979	5	4	0.237	1.92	0.25	0.14		0.10	
1979	5	3	0.250	0.65	0.11	0.16			
1079	6	5	0.236	0.61		0.45		1.49	
1979	6	5	0.242	0.49		0.15			
1980	5	?	0.243	0.45	0.19	1.04		0.22	
1980	5	4	0.240	0.15		0.16		0.39	
1978	5	0	0.265	0.14					
1980	5	4	0.218			3.32			
1979	7	5	0.221			1.58			
1979	8	0	0.228			0.90			
1980	5	3	0.250			0.56		0.18	
1980	6	4	0.218			0.44			
1978 ^b	7	2+	0.247			0.42			0.78
1980	5	?	0.236			0.26		0.48	
1980	6	0	0.234			0.25			
1979	6	5	0.208			0.16			
1980	4	3	0.264			0.12			
1980	7	6	0.254			0.10			
1980	5	4	0.231						
1980	5	4	0.231						
1980	5	4	0.218						
						0.24 ^d			
5.62 ^c		3.42 ^c		0.237 ^c					

(Table 2 Continued)

(Table 2 Concluded)

Year	Clutch size ^a	Fledged	Shell Thickness (mm)	HE	OXY	DDE	Dieldrin	HCB	PCB's
Western Screech-Owl									
1979	5	4	0.225	3.15	0.39	0.55		0.39	2.76
1979	1 ^e	X	0.189	2.57	0.73	3.94	0.15	0.11	1.01
1980	4	0	0.204	1.03	0.13	0.60			
1978 ^b	?	2	0.206	0.46		1.98			
1979 ^f	3	0	0.201	0.30	0.28	3.43	0.50	0.10	
1980	5	4	0.215			1.06			
1981	4	3	0.243						
	4.20 ^c	2.17 ^c	0.212 ^c			0.90 ^d			
Burrowing Owl									
1981	6	0	0.178	0.19		0.66			
1981	5	0 ^g	0.182	0.16		0.24			
1979	10	7	0.172			0.18			
1980	8	7	0.174			0.14			
1980	10	?	0.180			0.11			
1980	12	10	0.192						
	8.50 ^c		0.180 ^c			0.17 ^d			
Short-eared Owl									
1979	6+	3	0.246	1.70	0.33	0.20		0.51	
1980	4	?	0.277	0.99	0.35	0.29	0.24		
1978 ^b	?	0 ^h	0.216	0.61		1.08			
1979	8	5+	0.235			0.74		0.26	
1979	9	3+	0.258				0.85		
			0.246 ^c			0.30 ^d			
Northern Saw-whet Owl									
1978	5+	3	0.185			0.11			
1979	6	5	0.197						
1981	7	3	0.192						
1981	6	2	0.191						
			0.191 ^c						

Note: HE = heptachlor epoxide, OXY = oxychlorane, HCB = hexachlorobenzene, PCB's = polychlorinated biphenyls.

^aBefore sample egg removed. ^bAnalyzed at Denver Wildlife Research Center. ^cArithmetic mean. ^dGeometric mean. ^eLone egg found in nest box. ^fAlso, 0.96 ppm *cis*-chlordane. ^gFour hatched but depredated by a Badger (*Taxidea taxus*). ^hNest destroyed by farm mowing operation.

1973 were generally low (arithmetic \bar{x} 1.29 ppm wet wt, range 0.33-2.8) and no relationship was found between hatching failure and presence of organochlorine residues (Klaas and Swineford 1976). For comparison, the arithmetic mean for DDE in this study was 1.65 ppm.

The shell thickness of 6 Burrowing Owl eggs averaged 0.180 ± 0.003 mm which was not significantly different from 6 eggs collected in Oregon and Washington before 1947 (0.191 ± 0.009 mm). Short-eared Owl eggs showed a mean shell thickness of 0.246 ± 0.010 mm which was nearly identical to the 0.245 ± 0.006 mm from 3 eggs collected in Oregon and Washington prior to 1947. Northern Saw-whet Owl eggs had a mean shell thickness of 0.191 ± 0.003 mm; however, no historical eggs were available from the region for comparison. DDE residues were generally < 1 ppm in eggs of these 3 species of owls.

Eagles and Hawks Found Dead. — Although eggs from Golden Eagle nests in the region were not collected, 8 eagles found dead were analyzed (Table 3). Residues of HE in brain tissue of 3 Golden Eagles (7.9, 10, and 13 ppm) were diagnostic of HE poisoning (i.e., > 8 ppm established for experimental birds [Stickel et al. 1979]). The eagle with 4.7 ppm HE died under suspicious cir-

cumstances; it was observed gliding and then fatally diving straight into the ground! Rough-legged Hawks nest in the Arctic and winter in the region, but 1 bird accumulated lethal residues of HE. A nesting American Kestrel died in its nest box with 28 ppm HE in her brain; an egg she laid contained the highest HE concentration among the 261 kestrel eggs collected during a 4-year study (Henny et al. 1983). The birds with lethal HE residues died in March, April, May, and June which is considerably after the fall planting time for heptachlor-treated wheat seeds.

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ADDENDA

A Barn Owl (*Tyto alba*) found dead in the study area on 1 January 1984 had the following residues (ppm wet wt) in its

Table 3. Organochlorine residues (ppm wet wt) in brain tissue of eagles and hawks found dead in Umatilla and Morrow counties, Oregon, 1977-80.

Species	Wt (g)	Age	Sex	Date	HE	OXY	DDE	Dieldrin	TRNO	HCB	PCB's
Golden Eagle ^a	2640	Adult	M	30 April 1977	10	0.62	1.1	0.75	0.40	0.29	0.61
Golden Eagle ^b	3600	Adult	M	May-June 1978	13	0.69	0.49		0.43	0.21	
Golden Eagle	4825	Adult	F	Winter 78-79							
Golden Eagle	4500	S Ad	F	Winter 78-79			0.11				
Golden Eagle	3350	S Ad	M	Winter 78-79	0.10						
Golden Eagle	3225	Adult	M	Early 1979	1.5	0.12					
Golden Eagle	4025	Adult	F	3 May 1980	4.7	0.30	1.8		0.12		0.89
Golden Eagle	2900	S Ad	M	17 June 1980	7.9	0.67	1.5	0.26	0.31		1.6
Red-tailed Hawk	1050	Juv	M	10 Feb 1980							
Rough-legged Hawk	728	Juv	F	20 March 1980	20	2.4	0.42		0.34	7.4	
American Kestrel ^c		Adult	F	11 June 1979	28	2.5	0.35		0.95	0.21	

Note: SAd = subadult (has white on tail or wings; see Steenhof et al. 1983), Juv (in second calendar year of life; juvenal plumage); HE = heptachlor epoxide, OXY = oxychlorodane, TRNO = *trans*-nonachlor, HCB = hexachlorobenzene, PCB's = polychlorinated biphenyls.

^aFell from sky, hit ground and began convulsing. ^bFound alive; no coordination and some muscle twitching. ^cSee Henny et al. (1983) for details.

brain: heptachlor epoxide 1.1, oxychlordane 0.31, trans-nonachlor 0.10, and DDE 0.18. Thus, another raptor species in the area accumulated residues of heptachlor epoxide.

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