

Organochlorine Residues in Great Blue Herons from the Northwestern United States

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Abstract.—We collected eggs or young Great Blue Herons (*Ardea herodias*) from eight nesting colonies in the northwestern United States from 1977 through 1982. Subadults were collected at three estuarine areas in Puget Sound in 1981 and dead young or adults were collected at various localities. Nearly all samples analyzed contained residues of DDE and polychlorinated biphenyls (PCBs); small residues of 10 other organic contaminants were detected infrequently. Maximum residues (wet weight) in eggs were 26 µg/g DDE and 13 µg/g PCBs. Livers of adults from Puget Sound contained up to 5 µg/g PCBs. Maximum residues of DDE and PCBs in livers of pre fledgling Great Blue Herons from three colonies were only 0.45 and 1.20 µg/g, respectively. Maximum residues in whole bodies of hatchlings found dead at Lake Chatcolet, Idaho were 21 µg/g DDE and 11 µg/g PCBs. On a colony basis, eggshell thinning averaged from 4 to 13%. Multiple regression analysis indicated that DDE and PCBs accounted for 26 and 3%, respectively, of the variability in eggshell thickness. There was no evidence that any of the organochlorines detected were related to lethal or serious sublethal effects.

Key words.—*Ardea herodias*, DDE, eggshell thinning, Great Blue Heron, Idaho, Nevada, Oregon, organochlorine residues, Washington.

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The Great Blue Heron (*Ardea herodias*) commonly occurs in a variety of habitat types throughout much of the United States. It is exposed to an array of environmental contaminants, including organochlorines (Blus et al. 1980, Faber et al. 1972, Fitzner et al. 1982, Ohlendorf et al. 1979, Vermeer and Reynolds 1970); therefore, it is useful for monitoring residues of contaminant for trends and effects on mortality and reproductive success. The objectives of this paper are 1) to report concentrations of organic contaminants in tissues and eggs of Great Blue Herons from Idaho, Nevada, Oregon, and Washington, and 2) to interpret their impact on this species.

METHODS

From 1977 through 1982, Great Blue Heron eggs were collected at three colonies in Washington, one colony lying in both Oregon and Washington on several islands and channel markers in the Columbia River, two in Oregon and one in Nevada (Fig. 1). Three of the colonies were located along the Columbia River system, three were in interior marshes, and one was in an estuarine area. We collected eggs from heronries in Washington, including the U.S. Department of Energy Hanford Reservation (Hanford Res-

ervation), McNary Recreation Area (Foundation Island) on the Columbia River, and the Fort Lewis Military Reservation (Fort Lewis) near Puget Sound. Egg collections were also made at the Umatilla National Wildlife Refuge (NWR) on the Columbia River in both Washington and Oregon, two Oregon colonies

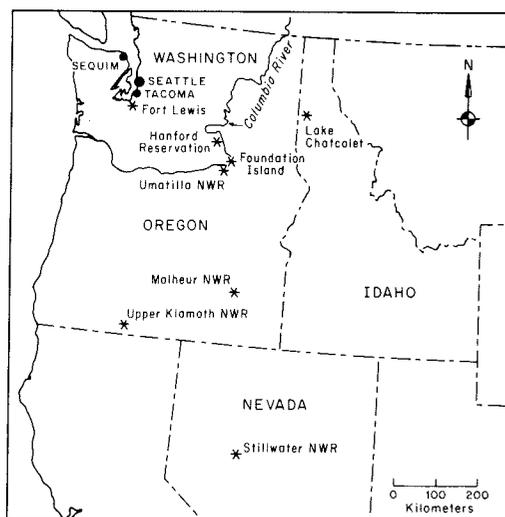


Figure 1. Great Blue Heron collection sites in the northwestern United States; stars indicate nesting colonies, 1977-82.

situated at interior marshes on the Malheur NWR and the Upper Klamath NWR, and the Nevada colony located on the Stillwater NWR. The eggs were stored in a refrigerator until they were weighed, volumed, and measured. Each egg was opened at the equator and its contents placed in a chemically-cleaned jar. The samples were stored in a freezer until they were analyzed. Shells of all eggs were rinsed in tap water and dried. Eggshell thickness (including membranes) was measured at three sites on the equator with a micrometer graduated in units of 0.01 mm; an average of three measurements represented shell thickness. Seven hatchlings and four prefledglings were collected at a heronry at Lake Chatcolet, Idaho. One hatchling and four prefledglings (one found dead) were collected at Fort Lewis, and six prefledglings were collected at the Hanford Reservation. Liver samples were taken from the 13 prefledglings that were shot and the brain of one found dead. Five subadult herons were trapped and collected in Puget Sound—two from Elliott Bay near Seattle, two from Commencement Bay near Tacoma, and one from Sequim Bay near Sequim. These birds were dissected and liver samples taken. Whole bodies of hatchlings and other tissues were placed in chemically-cleaned jars and frozen for subsequent analysis.

All tissue and egg samples were analyzed for organochlorine pesticides, their metabolites, and polychlorinated biphenyls (PCBs). The Pacific Northwest Laboratory of Battelle Northwest (PNL) provided analysis of the five subadult herons collected in Puget Sound (Riley et al. 1983). The Patuxent Wildlife Research Center (PWRC), Laurel, Maryland, provided all other residue analyses (Cromartie et al. 1975). All analyses were performed using a gas-liquid chromatograph with an electron capture detector. Residues in 10% of the samples analyzed by PWRC and all the samples analyzed by PNL were confirmed with a mass spectrometer. Recoveries of DDE and PCBs from spiked eggs ranged from 83% to 104%. Residues were not adjusted on the basis of these recoveries. The lower limit of detection was 0.5 µg/g for PCBs and 0.1 µg/g for all other pollutants. Residues are expressed on a wet weight basis; contents weight was adjusted to volume of the intact egg (Stichel et al. 1973).

Five Great Blue Herons found dead were sent to the U.S. Fish and Wildlife Service National Wildlife

Health Center (NWHC), Madison, Wisconsin where necropsies were performed. The relationship between eggshell thickness and residues of DDE and PCBs in eggs was investigated using linear and multiple regression. Residues showed a skewed distribution; therefore, these data were transformed (\log_{10}) for use in statistical testing. A geometric mean was calculated for each contaminant detected in $\geq 50\%$ of the samples in each group. The lower limit of quantification was halved in samples where a contaminant was not detected in order to calculate geometric means. Eggshell thickness as well as residues of DDE and PCBs in heron eggs from each of the seven colonies were compared using one-way analysis of variance (ANOVA). When significant differences ($P \leq 0.05$) were found using ANOVA, means were separated using a multiple range test (Kramer 1956).

RESULTS

Eggshell Thickness

Mean eggshell thickness in the seven colonies ranged from 4 to 13% less than the pre-1947 museum norm (Anderson and Hickey 1972); thickness of individual eggs ranged from 0.30 to 0.41 mm (Table 1). Maximum thinning of a shell was 23%; however, this represented a sample egg taken from a nest that fledged two young. The three colonies on the Columbia River had the greatest amount of shell thinning with the extreme at Foundation Island. No obvious cracked or crushed eggs were observed during this study.

Reproductive Success

We obtained extensive data on reproductive success at only two colonies including Umatilla NWR and the Hanford Reservation. These data indicated a high rate of productivity and were summarized pre-

Table 1. Eggshell thickness of Great Blue Heron eggs collected in seven northwestern colonies compared to the pre-1947 museum norm.

Area	Date Collected	N	Eggshell Thickness (mm)	
			Mean \pm se ¹	Range
Foundation Island	1978	8	0.338 \pm 0.011A	0.34-0.40
Umatilla NWR	1978-80	17	0.350 \pm 0.007AB	0.30-0.40
Hanford Reservation	1981-82	13	0.360 \pm 0.007ABC	0.32-0.40
Fort Lewis	1982	3	0.362 \pm 0.013ABCD	0.34-0.38
Malheur NWR	1980	10	0.372 \pm 0.010 BCD	0.32-0.41
Upper Klamath NWR	1977	4	0.374 \pm 0.016 CD	0.34-0.40
Stillwater NWR	1981	5	0.375 \pm 0.007 CD	0.35-0.39
Pacific Northwest	Pre-1947	64 ²	0.389 \pm 0.003 D	—

¹Arithmetic means compared by a multiple range test (Kramer 1956). Means sharing a common letter are not significantly different ($p > 0.05$) from one another.

²Data from Anderson and Hickey (1972), range not listed.

viously (Blus et al. 1980, Blus et al. 1985). Inaccessibility of nests and infrequent visits prevented quantification of these data at the other colonies. A previous intensive study at the Lake Chatcolet colony in 1977 and 1978 indicated excellent reproductive success both years (Collazo 1981). The only indication of a problem occurred in the Fort Lewis colony in 1981 when 30 to 40 dead nestlings (all around 4 weeks of age) were found on the forest floor under the heronry. Possible reasons for this die-off are discussed later.

Residues

Eggs.—All 60 eggs were analyzed for PCBs, DDE, (Table 2) and other organochlorine contaminants (Table 3). Only *p,p'*-isomers of DDT and metabolites were detected; PCBs detected resembled Aroclorr 1260. DDE was detected in all eggs while PCBs were detected in 52 eggs. Residues of organochlorines in samples from 1978 (Umatilla NWR and Foundation Island) were reported previously (Blus et al. 1980) as were concentrations of heavy metals in some of the samples collected in 1981-82 (Blus et al. 1985).

The highest mean value of DDE (4.71 $\mu\text{g/g}$) occurred at Foundation Island in 1978, while the highest mean for PCBs oc-

curred at Fort Lewis (3.35 $\mu\text{g/g}$) in 1982 and Upper Klamath NWR (3.34 $\mu\text{g/g}$) in 1977. Highest residues in individual eggs were 26.2 $\mu\text{g/g}$ for DDE (Malheur NWR) and 13.2 $\mu\text{g/g}$ for PCBs (Hanford Reservation). Stillwater NWR contained the lowest mean residues of both DDE (0.44 $\mu\text{g/g}$) and PCBs (0.36 mg/g). The DDE:PCBs ratio ranged from 0.44 at Fort Lewis to 9.5 at Malheur NWR. Although residues of DDE and PCBs were significantly intercorrelated [$p < 0.0001$] overall, this relationship did not hold for each individual colony as at Malheur NWR. The 5-year interval between sampling may have influenced relationships of some organochlorines as the general tendency is for a decline in residues of certain organochlorines, such as DDT and metabolites and dieldrin, after they were banned in the early 1970's (Blus 1982).

Residues of 10 other organochlorines were found in eggs of Great Blue Herons (Table 3). Incidences of detection of these contaminants were too low for statistical comparisons. In general, these contaminants were found most frequently and at the highest levels at Umatilla NWR. Residues of the chlordane group and particularly heptachlor epoxide (HE) at Umatilla NWR may have been related to use of heptachlor treated cereal grains in the area at

Table 2. Concentrations ($\mu\text{g/g}$, wet weight) of DDE and PCBs in eggs of Great Blue Herons, collected in seven northwestern colonies, 1977-82.

Location	Year(s)	N	Geometric Mean ¹ and Range	
			DDE	PCBs
<u>Columbia River System</u>				
Foundation Island	1978	8	4.71 B (1.39-15.4)	2.24 B (0.82-9.24)
Umatilla NWR	1978-80	17	3.51 B (0.86-16.0)	1.94 B (ND-9.34)
Hanford Reservation	1981-82	13	3.12 B (1.08-7.18)	1.56 B (ND-13.2)
<u>Interior Marshes</u>				
Malheur NWR	1980	10	3.61 B (0.80-26.2)	0.38 A (ND-2.68)
Stillwater NWR	1981	5	0.44 A (ND-3.67)	0.36 A (ND-0.67)
Upper Klamath NWR	1977	4	2.06 B (0.82-8.90)	3.34 B (1.70-7.00)
<u>Estuarine—Puget Sound</u>				
Fort Lewis	1982	3	1.47 AB (0.76-2.40)	3.35 B (1.61-7.33)

¹Means for DDE or PCBs were compared using a separation test (Kramer 1956). Means sharing a common letter in each column are not significantly different ($p > 0.05$).

Table 3. Residues ($\mu\text{g/g}$, wet weight) of other organochlorine pollutants in eggs of Great Blue Herons collected in seven northwestern colonies, 1977-82.

Location	Year	No. of Eggs	Pollutant ¹						
			DDD	Dieldrin	HE	OXY	CCH	TNCH	CNCH
<u>Columbia River System</u>									
Umatilla NWR	1978-80	17 ²	(5) ND-0.49	(8) ND-0.29	0.13(11) ND-0.46	0.14(12) ND-0.57	0.23(13) ND-1.36	0.14(16) ND-2.25	0.12(9) ND-0.69
Hanford Reservation	1981-82	13	(3) ND-0.10	(5) ND-0.37	(1) 0.08	— ND	0.09(9) ND-0.28	(3) ND-0.20	— ND
<u>Interior Marshes</u>									
Malheur NWR	1980	10 ³	(2) ND-0.32	(1) ND-0.14	— ND	(1) ND-0.17	(2) ND-0.47	0.09(5) ND-0.70	(1) ND-0.10
Stillwater NWR	1981	5	— ND	— ND	— ND	(1) ND-0.12	(1) ND-0.12	(1) ND-0.38	— ND
Upper Klamath NWR	1977	4	— ND	0.28(4) 0.15-0.78	— ND	— ND	0.09(2) ND-0.19	— ND	— ND
Foundation Island	1978	8 ⁴	(3) ND-1.00	0.39(4) ND-1.16	(1) ND-0.25	0.07(4) ND-0.19	0.25(7) ND-0.63	0.30(8) 0.10-0.73	0.09(4) ND-0.20
<u>Estuarine—Puget Sound</u>									
Fort Lewis	1982	3	ND	ND	ND	ND	ND	ND	ND

¹Geometric mean, number of positive samples in parenthesis, and range listed where appropriate. HE = heptachlor epoxide, OXY = oxychlorodane, CCH = *cis*-chlorodane, TNCH = *trans*-nonachlor, CNCH = *cis*-nonachlor; ND = not detected.

²DDT (0.18 $\mu\text{g/g}$) detected in two eggs and 0.11 $\mu\text{g/g}$ hexachlorobenzene (HCB) in another.

³Toxaphene (0.13 mg/g) detected in one egg.

⁴DDT (0.52 $\mu\text{g/g}$) and HCB (0.13 $\mu\text{g/g}$) also detected in one egg.

the time samples were taken (Blus et al. 1984). The three eggs from Fort Lewis contained no detectable residues other than DDE and PCBs. Hexachlorobenzene (HCB), DDT, and toxaphene were rarely detected; endrin was not detected in eggs; and mirex and lindane were not detected in any samples during this study.

Livers.—Residues of organochlorines in livers of 13 prefledglings shot at three colonies in Washington and Idaho and in livers of 5 subadults trapped and sacrificed at several sites in Puget Sound were relatively low with DDE and PCBs detected in seven and two prefledglings, respectively (Table 4). DDE residues were not detected in subadult livers, but PCBs were present in four of five samples. Maximum residues in livers were 0.65 $\mu\text{g/g}$ DDE in a prefledgling and 5.09 $\mu\text{g/g}$ PCBs in a subadult. Only DDE and PCBs were detected in livers of prefledglings; whereas, only PCBs and HCB were detected in the subadults. No residues were detected in the four liver samples from Lake Chatcolet. Livers of five subadults were the only samples analyzed for chlorinated butadiene (CB) and trichlorobenzene (TCB); low residues of these organics were detected.

Brains.—Brains of six Great Blue Herons found dead in Oregon and Washington were analyzed for residues of organochlorines (Table 4). Residues of DDE (0.10 to 25.0 $\mu\text{g/g}$) and PCBs (0.10 to 12.0 $\mu\text{g/g}$) were detected in all six brains. Residues of nine other organochlorines were detected infrequently and at low levels.

The brain of the prefledgling found dead at Fort Lewis contained low residues of organochlorines (Table 4), and the necropsy indicated no signs of disease. Military aircraft frequently make low-level flights in the area, but there was no evidence of their involvement in the die-off of young. Endrin was detected in the brain of one bird from Wenatchee; this was the only detection of this insecticide during this study. None of the residues in brains of the six herons were near levels considered diagnostic of lethality in experimental birds given contaminated diets (Stickel et al. 1970, Stickel et al. 1979).

Whole Bodies.—Residues of DDE and PCBs were detected in all samples of whole bodies of hatchlings found on the ground at Fort Lewis (one bird) and Lake Chatcolet (seven birds). Several of the young at

Table 4. Residues ($\mu\text{g/g}$, wet weight) of organic pollutants in tissues and whole bodies of Great Blue Herons, Pacific Northwest, 1980-83.

Area (Year)	Method of Col- lection	Age ¹	Sample (N) ²	Pollutant ³						
				DDE	Dieldrin	OXY	PCBs	HCB	TCB	CB
Fort Lewis, WA										
(1981)	Shot	P	L(3)	0.22(2)	—	—	0.59(2)	—	—	—
				ND-0.65	ND	ND	ND-1.20	ND	NA	NA
(1981)	Found	P	B(1)	0.48	ND	ND	0.93	ND	NA	NA
(1982)	Found Dead	H ⁴	WB(1)	3.30	0.48	0.16	6.20	ND	NA	NA
Lake Chatcolet, ID										
(1981)	Shot	P	L(4)	ND	ND	ND	ND	ND	NA	NA
(1982)	Found Dead	H ⁵	WB(7)	3.20(7)	(3)	(2)	5.63(7)	—	—	—
				0.58-21.0	ND-0.13	ND-0.48	2.20-11.0	ND	NA	NA
Hanford Reservation, WA										
(1981)	Shot	P	L(6)	0.26(5)	—	—	—	—	—	—
				0.18-0.45	ND	ND	ND	ND	NA	NA
Umatilla, OR										
(1980)	Found Dead	A ⁶	B(2)	14.5(2)	(1)	(1)	9.42(2)	0.45(2)	—	—
				14.0-15.0	ND-0.31	ND-0.23	7.40-12.0	0.23-0.87	NA	NA
Wenatchee, WA										
(1982)	Found Dead	A ⁷	B(1)	25.0	ND	ND	2.50	ND	NA	NA
(1983)	Found Dead	A	B(1)	0.10	ND	ND	0.10	ND	NA	NA
Aeneas, WA										
(1982)	Found Dead	S ⁸	B(1)	5.30	0.10	0.10	4.70	ND	NA	NA
Tacoma, WA										
(1981)	Trapped	S	L(2)	—	—	—	1.40(2)	(1)	(1)	0.45(2)
				ND	ND	ND	1.03-1.90	ND-0.40	ND-0.50	0.40-0.50
Seattle, WA										
(1981)	Trapped	S	L(2)	—	—	—	2.57(2)	0.45(2)	(1)	0.45(2)
				ND	ND	ND	1.30-5.09	0.40-0.50	ND-0.50	0.40-0.50
Sequim, WA										
(1981)	Trapped	S	L(1)	ND	ND	ND	0.75	0.70	0.80	0.70

¹P = prefledging, H = hatchling, A = adult, S = subadult.

²L = liver, B = brain, WB = whole body.

³TCB = trichlorobenzene, CB = chlorinated butadiene; other acronyms defined in previous tables. Geometric mean, number of positive samples (parenthesized), and range listed where appropriate; NA = no analysis for pollutant.

⁴DDD (0.15 $\mu\text{g/g}$), CCH (0.33 $\mu\text{g/g}$), TNCH (0.48 $\mu\text{g/g}$), and CNCH (0.15 $\mu\text{g/g}$) also detected.

⁵Some (no. positive samples and maximum residues) contained DDD (3, 0.30 $\mu\text{g/g}$), CCH (2, 0.98 $\mu\text{g/g}$), TNCH (3, 1.00 $\mu\text{g/g}$), and CNCH (2, 0.48 $\mu\text{g/g}$).

⁶One sample contained 0.19 $\mu\text{g/g}$ HE and 0.10 $\mu\text{g/g}$ CCH.

⁷DDT (0.35 $\mu\text{g/g}$) and endrin (0.14 $\mu\text{g/g}$) also detected.

⁸Also contained 0.17 $\mu\text{g/g}$ TNCH.

the Lake Chatcolet colony still retained the egg tooth. Geometric means and maximum residues of DDE (3.20 and 21.0 $\mu\text{g/g}$) and PCBs (5.63 and 11.0 $\mu\text{g/g}$) were relatively high, especially considering that no residues were detected from livers of prefledglings collected at Lake Chatcolet, and only low residues of PCBs and DDE were found in livers of Fort Lewis prefledglings. There were no residues in eggs available at Lake Chatcolet because of inaccessibility of nests, but residues in hatchlings probably approximated most of the organochlorine residues in fresh eggs.

Relationships of Residues to Sublethal Effects

Eggshell Thickness.—The 60 eggs collected from the seven heronries were used to determine the statistical relationship between eggshell thickness and residues of DDE and PCBs. Regression analysis indicated that both of these pollutants were significantly correlated with eggshell thickness; DDE and PCBs accounted for 26 and 14%, respectively, of the variation in eggshell thickness when separate regression analyses were conducted (Fig. 2). When both DDE and PCBs were included in a multiple regression analysis, DDE was selected first and accounted for 26% of the variability ($p < 0.001$) in eggshell thickness; the PCBs were then selected and accounted for only 3% ($p > 0.05$) of the variability.

Reproductive Success.—Organochlorine residues detected in this study seemed to exert little influence on reproductive success of the Great Blue Heron even

though DDE and PCB residues in eggs were as high as 26 and 13 $\mu\text{g/g}$, respectively. A sample egg collected from a nest at Umatilla NWR that contained 16 $\mu\text{g/g}$ DDE produced two fledged young. Reproductive success was considered satisfactory with about two young fledged per active nest at the Umatilla NWR, Hanford Reservation, and Lake Chatcolet colonies. This level of recruitment was considered adequate to maintain a stable population based on a recruitment standard of 1.9 that was calculated from age-specific mortality rates derived from banding data (Henny 1972).

Necropsy Findings

Five of the six Great Blue Herons found dead (Table 4) were necropsied at the NWHC. No definite causes of death were determined; but enteritis was found in one bird and two emaciated herons found dead near Umatilla, Oregon in February 1980 probably died from exposure to severe winter weather.

DISCUSSION

The range of eggshell thinning detected in our Great Blue Heron colonies was similar to that reported in other studies conducted after 1946. Shell thinning averaged 5.2% in Florida and Tennessee and 7.9% in Minnesota, Michigan, and Ohio (Ohlendorf et al. 1979); 16% in Wisconsin (Faber and Hickey 1973); 8% in Alberta (Vermeer and Reynolds 1970); 13% in Texas (King et al. 1978) and 10% in intact eggs and 17% in broken eggs in central California (Faber et al. 1972). None of these studies related eggshell thinning or organochlorine residues to reproductive problems or population declines.

The residues of DDE and PCBs detected in egg, tissue, and whole body samples in this study were considerably below levels associated with mortality or reproductive problems in Ardeids (Ohlendorf et al. 1979, Blus et al. 1980). Residues in livers of prefledglings were low in the three colonies where they were collected, particularly in view of the fact that eggs or hatchlings from these colonies contained higher residues and a wider variety of contaminants. One explanation for this may be that residues are diluted during growth

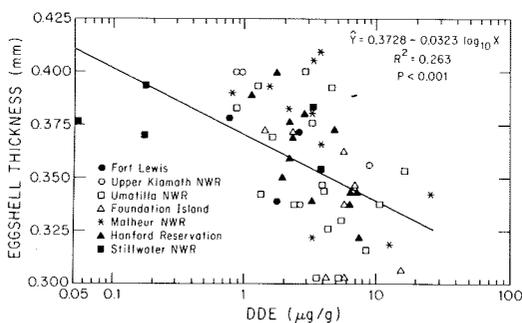


Figure 2. Regression analysis showing the relationship of DDE residues to eggshell thickness in 60 eggs of Great Blue Herons, seven colonies in the northwestern United States, 1977-82.

of young (Charnetski 1976) unless their food source is heavily contaminated (Flickinger and Meeker 1972).

The Great Blue Heron is not considered a sensitive species to effects of DDT and metabolites; no serious problems were documented from this source even during the height of DDT use (Henny 1972). The critical level of DDT and metabolites or other organochlorines in eggs that adversely impact reproductive success have not been established; but they are probably relatively high in view of the fact that a viable, pipped egg contained 78 $\mu\text{g/g}$ DDE and an egg with 234 $\mu\text{g/g}$ DDE contained a small dead embryo (Vermeer and Reynolds 1970). The other organochlorine residues in eggs and tissues of Great Blue Herons were primarily low and below levels usually associated with lethal or sublethal effects in experimental birds.

Some of the geographic differences in residues may also be related to degree of contamination of wintering or breeding areas. Some Great Blue Herons may winter in localities as far north as the Hanford Reservation, but there is a positive correlation between tendency to migrate south as latitude of the nesting colony increases (Henny 1972). The Fort Lewis colony is located near sea level and has a relatively mild winter climate and aquatic feeding sites are open during the winter when some herons roost in nest trees. Organochlorines in our Great Blue Herons were probably obtained primarily on the wintering grounds south of our colony sites, but at the time most of our samples were taken, residues of DDE and PCBs were locally high in the northwestern U.S., particularly along the Columbia River where several of our colonies were located (Blus et al. 1980).

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