Organochlorine Residues in Aquatic Birds in the Canadian Prairie Provinces

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Abstract. A survey was conducted of organochlorine residues in 21 aquatic bird species at 31 locations in Alberta, Saskatchewan and Manitoba. As DDT and DDD residue levels from analyses without PCB separation proved to be unreliable, they were omitted from the results. DDE and dieldrin levels were higher in eggs of larids and fish-eating birds than in those of geese and ducks, presumably reflecting different trophic levels between those two groups of birds. Interspecific differences of DDE, dieldrin, HE and β BHC residues observed in larids and fish-eating birds at the same breeding localities may reflect interspecific differences of feeding habits. DDE, dieldrin and PCB levels may be predicted in tissues of California Gull females when known in their eggs. Residue levels in eggs closely resembled those in the livers of females at the time of laying. Shell thickness was significantly and inversely correlated with the concentration of DDE in 40 Great Blue Heron eggs from Alberta, but no significant correlation was found between the concentration of PCBs and shell thickness in those eggs.

Introduction

It has been shown that fish-eating birds in England contained greater average organochlorine residues than any other group of birds examined (Moore and Walker, 1964). J. O. Keith (1966) found that fish-eating birds in California accumulated large residues of insecticides in their body tissues. The results of a study on reproductive success in a Wisconsin population of Herring Gulls, *Larus argentatus*, contaminated with DDT suggested that DDT residues were responsible for the low hatching success of eggs (J. A. Keith, 1966). Reduced shell thickness has been found to be correlated with the amount of DDE in the egg contents of raptors (Hickey and Anderson, 1968; Fyfe *et al.*, 1969) and fish-eating birds (Hickey and Anderson, 1968; Anderson *et al.*, 1969). Experimental studies with Mallards, *Anas platyrhynchos*, showed that DDE can reduce thickness and cause cracking of eggshells (Heath *et al.*, 1969). For these reasons, and as little is known about the extent of organochlorine residues present in aquatic birds of the Canadian prairie provinces, a survey was conducted to determine the type and quantity of organochlorine residues present in aquatic birds, particularly larids and fish-eating birds, in Alberta, Saskatchewan, and Manitoba. Eggs were chosen as samples to be analyzed for organochlorine residues as they are easy to collect and constitute distinct units of comparison between species.

Methods

Seventy composite samples of eggs were collected during egg-laying and incubation from aquatic birds in Alberta and Saskatchewan in 1968 and thirty composite samples of eggs were collected in Saskatchewan and Manitoba in 1969. Each composite sample consisted of 10 eggs, representing one egg from each of 10 nests of the same species. Composite rather than individual samples were collected to reduce costs of analyses. Additionally, in 1969 ten individual egg samples were taken from Common Terns, *Sterna hirundo*, and Double-crested Cormorants, *Phalacrocorax auritus*, and 40 individual egg samples were taken from Great Blue Herons, *Ardea herodias*, to assess variations of pesticide residue levels within nesting colonies. The egg shells of the Great Blue Herons were dried at room temperature for 4½ months before their thickness was measured in order to relate shell thickness to DDE levels in those eggs. Thickness in each case represents the shell itself plus the dried egg membranes. Ten adult California Gulls, *Larus californicus*, were also collected on an Edmonton garbage dump upon arrival during the second week of April, 1969. Ten females of that species and their eggs were taken from their nests at Joseph and Miquelon lakes, 20 and 27 miles respectively from the first collection site, during egg-laying and their first week of incu-

TABLE 1.—DDT and DDD residue levels in ppm wet weight before and after PCB separation in tissues and eggs of female California Gulls.

Tissue sample	No. Sam.	Mean DDT			Mean DDD		
		Before	After	%	Before	After	%
Abdom. fat	10	2.099	0.577	28	1.891	0.064	3
Ovary	10	0.156	0.025	16	0.157	0.025	16
Liver	10	0.066	0.002	3	0.072	0.009	13
Brain	10	0.022	0.001	5	0.023	0.001	4
Eggs	10	0.090	0.028	31	0.073	ND	0

ND = none detected = < 0.0001 ppm

bation in the first week of May, 1969. Gull tissues and eggs were analyzed for the purpose of comparing pesticide residue levels between arriving and incubating gulls as well as between incubating females and their own eggs. One type of tissue analysed was fat, taken from the abdominal cavities of the gulls.

The contents of eggs and bird tissues were stored in glass jars and preserved by freezing.

Laboratory Analysis

For extraction of the organochlorine residues, the frozen egg sample was thawed out and homogenized in a Waring Blender.

An aliquot (2-5 g) of the blend was weighed into a 50 ml beaker to the nearest milligram and dried in a vacuum oven at 45°C with slight vacuum to constant weight (approximately 36 hours needed). The per cent moisture was then calculated from the difference in weights.

After constant weight was obtained, the dried sample was broken up by adding 5-10 g anhydrous Na_2SO_4 and grinding with a flattened glass rod. The dried material was removed from the sides and bottom of the beakers by grinding and scraping. The mixture was poured into a Soxhlet thimble and the beaker rinsed several times with ether : n-hexane (1:1). A glass wool plug was used to cover the sample in the thimble which was then extracted in a Soxhlet apparatus for 2 hours, using about 150 ml of 1:1 ether-hexane mixture at a rate of 10 siphonings per hour.

After extraction, the solvent was removed in a flash evaporator and the dried flask was weighed. The per cent fat was calculated from the difference in weights.

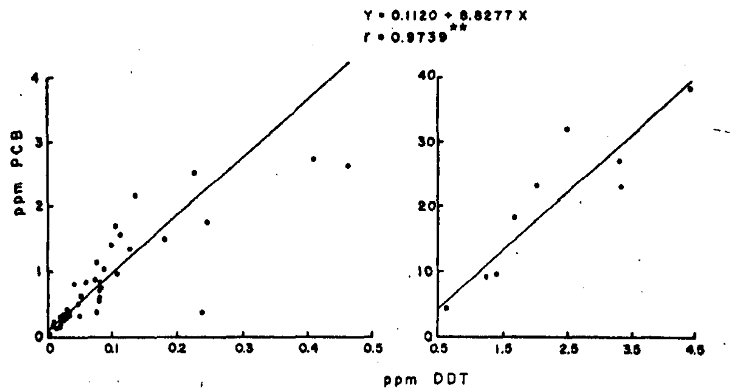

FIGURE 1. Relationship between DDT, before PCB separation, and PCB levels in ppm wet weight (** $p < 0.01$).

TABLE 2.—Mean wet-weight ppm residues of DDE in composite samples of 10 aquatic bird eggs in the prairie provinces.

Sample location	California Gull	Ring-billed Gull	Franklin's Gull	Herring Gull	Common Tern	Double-crested Cormorant	White Pelican
1. Nemur Lake	7.69			2.67			1.45
3. L. Therien Lake	6.80	2.48			3.29	8.43 (3.57)*	
4. Chip Lake	9.12	3.63			25.2 (6.38)*		
5. Miquelon Lake	21.6 (7.51)*	2.99					
8. Dowling Lake	9.53	3.95					
10. Lake Newell	10.2	4.82	0.335		11.1	4.58	
11. Murray Lake	6.17	5.06					
13. Kazan Lake	11.3					5.00	2.98
14. Primrose Lake	11.2	5.98			2.04	6.36	1.97
15. Doré Lake	9.77	9.84					
16. Lavallee Lake					13.5	5.55	2.56
17. Montreal Lake					15.9		
18. Suggi Lake		3.31		11.9		4.15	1.46
19. Jackfish Lake		12.3	0.447				
21. Redberry Lake	5.38	5.52				4.22	2.04
22. Old Wives Lake	6.81	1.63				3.47	1.85
23. Cypress Lake	7.86	2.88				5.88	1.76
24. Talbot Lake				17.2		3.88	1.36
25. Moose Lake				14.2		6.13	0.957
26. Lake Winnipegosis		4.18		13.3		3.74	1.17
27. Kawinaw Lake		3.59					1.47
28. Pelican Lake	4.07	2.24		15.5		3.43	0.830
29. Lake Winnipeg (St. Martin Is.)				15.2		5.57	1.37
30. Dog Lake						8.41	1.00
31. Lake Manitoba		1.26				9.00	4.76
	Great Blue Heron	**Black-crowned Night Heron**	**Western Grebe**	**Horned Grebe**	**Eared Grebe**	**American Avocet**	**Coot**
2. Cold Lake			7.76				
4. Chip Lake	37.01						
6. Battle River (Wetaskiwin)	5.71						
7. Jamieson Lake	11.90 (6.61)*						
8. Dowling Lake	6.71						
9. Stobart Lake						3.32	
10. Lake Newell						3.16	0.41
11. Murray Lake		0.90					
12. Belly River (Glenwoodville)	9.95						
19. Jackfish Lake			3.94				
20. Battleford				5.13			
22. Old Wives Lake		2.93			0.55		
27. Kawinaw Lake			3.46				
	Canada Goose	**Mallard**	**Pintail**	**Gadwall**	**American Widgeon**	**Blue-winged Teal**	**Lesser Scaup**
3. L. Therien Lake							0.33
4. Chip Lake				0.23			1.02
5. Miquelon Lake		0.14					
8. Dowling Lake	0.04						
10. Lake Newell	0.03	0.37		0.16	0.09	0.81	0.36
19. Jackfish Lake		0.24					
22. Old Wives Lake		0.24	0.92				
23. Cypress Lake	0.02	1.07					

*Collected in 1969.

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TABLE 3.—Mean wet-weight ppm residues of dieldrin in composite samples of 10 aquatic bird eggs in the prairie provinces

Sample location	California Gull	Ring-billed Gull	Franklin's Gull	Herring Gull	Common Tern	Double-crested Cormorant	White Pelican
1. Namur Lake	ND			0.012			0.113
3. L. Therien Lake	0.030	0.331			0.063	0.414 (0.112)*	
4. Chip Lake	0.039	0.364			0.075 (0.038)*		
5. Miquelon Lake	ND (0.059)*	0.284					
8. Dowling Lake	0.048	0.415					
10. Lake Newell	ND	0.260	0.314		0.396	0.172	
11. Murray Lake	1.52	0.320					
13. Kazan Lake	0.051					0.652	0.131
14. Primrose Lake	0.048	0.788			0.017	0.360	0.383
15. Doré Lake	1.38	0.425					
16. Lavallee Lake					0.144	0.266	0.133
17. Montreal Lake					0.130		
18. Suggi Lake		0.453		0.318		0.270	0.184
19. Jackfish Lake		0.913	0.284				
21. Redberry Lake	0.034	0.726				0.498	0.082
22. Old Wives Lake	0.044	0.288				0.205	0.087
23. Cypress Lake	0.057	0.409				0.068	0.054
24. Talbot Lake				0.478		0.366	0.127
25. Moose Lake				0.438		0.642	0.096
26. Lake Winnipegosis		0.614		0.442		0.380	0.103
27. Kawinaw Lake		1.27					0.176
28. Pelican Lake	0.065	1.11		0.514		0.305	0.087
29. Lake Winnipeg (St. Martin Is.)				0.496		0.681	0.099
30. Dog Lake						0.542	0.084
31. Lake Manitoba		0.442				0.330	0.179

Sample location	Great Blue Heron	Black-crowned Night Heron	Western Grebe	Horned Grebe	Eared Grebe	American Avocet	Coot
2. Cold Lake			ND				
4. Chip Lake	0.111						
6. Battle River (Wetaskiwing)	0.077						
7. Jamieson Lake	0.344 (0.119)*						
8. Dowling Lake	0.056						
9. Stobart Lake						0.171	
10. Lake Newell						0.252	
11. Murray Lake		0.026					0.004
12. Belly River (Glenwoodville)	0.236						
19. Jackfish Lake			ND				
20. Battleford				ND			
22. Old Wives Lake		0.139			0.002		
27. Kawinaw Lake			0.128				

Sample location	Canada Goose	Mallard	Pintail	Gadwall	American Widgeon	Blue-winged Teal	Lesser Scaup
3. L. Therien Lake							0.030
4. Chip Lake				0.027			0.169
5. Miquelon Lake		0.038					
8. Dowling Lake	0.012						
10. Lake Newell	0.022	0.020		0.025	0.032	0.027	0.022
19. Jackfish Lake		0.063					
22. Old Wives Lake		0.080	0.050				
23. Cypress Lake	0.012	0.050					

*Collected in 1969.

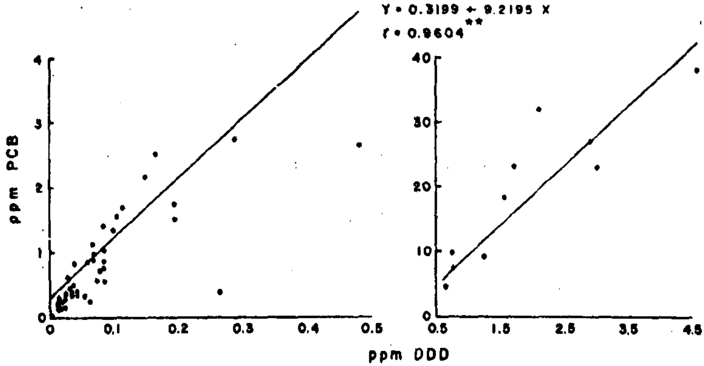


FIGURE 2. Relationship between DDD, before PCB separation, and PCB levels in ppm wet weight.

TABLE 4. — Mean wet-weight ppm residues of HE in composite samples of 10 aquatic bird eggs in the prairie provinces

Sample location	California Gull	Ring-billed Gull	Herring Gull	Double-crested Cormor.	White Pelican	Great Blue Heron	Mallard
3. L. Therien Lake				0.016			
4. Chip Lake						0.071	
5. Miquelon Lake	0.015						
6. Battle Riv. (Wetaskiwin)						0.007	
7. Jamieson Lake						0.015	
12. Belly Riv. (Glenwoodville)						0.040	
22. Old Wives Lake	0.020	0.043		0.033	ND		0.009
23. Cypress L.	0.027	0.246 (0.008)*		0.015	0.018		0.902 (0.067)*
24. Talbot L.			0.167	0.032	0.015		
25. Moose L.			0.146	0.075	0.010		
26. Lake Winnipegosis		0.045	0.043	0.022	0.022		
27. Kawinaw Lake		0.127			0.022		
28. Pelican L.	0.009	0.142	0.134	0.022	0.023		
29. Lake Winnipeg (St. Martin Is.)			0.114	0.074	0.018		
30. Dog Lake				0.028	0.011		
31. Lake Manitoba		0.035		0.044	0.017		

*Heptachlor.

TABLE 5.—Mean wet-weight ppm residues of β-BHC in composite samples of 10 aquatic bird eggs in the prairie provinces

Sample location	California Gull	Ring-billed Gull	Herring Gull	Double-crested Cormor.	White Pelican	Great Blue Heron	Mallard
3. L. Therien				0.065			
4. Chip Lake						0.082	
5. Miquelon Lake	ND						
6. Battle Riv. (Wetaskiwin)						0.008	
7. Jamieson Lake						0.020	
12. Belly Riv. (Glenwoodville)						0.028	
22. Old Wives Lake	ND	ND		ND	ND		ND
23. Cypress L.	ND	ND		ND	ND		ND
24. Talbot L.			ND	0.230	ND		
25. Moose L.			ND	0.176	ND		
26. Lake Winnipegosis		ND	ND	0.167	ND		
27. Kawinaw Lake		0.040			0.032		
28. Pelican L.	ND	0.028	ND	0.170	ND		
29. Lake Winnipeg (St. Martin Is.)			0.035	0.280	ND		
30. Dog Lake				0.208	ND		
31. Lake Man.		ND		0.200	ND		

The fat residue was dissolved in 150 ml of 5% benzene in acetone and the solution was cleaned-up by cold precipitation, essentially according to the method of McCully and McKinley (1964). The solution was chilled to —70°C and stirred for 35 minutes in a dry ice-methanol cold bath. The mixture was then filtered through a carbon-celite (2 g: 10 g) pad at —70°C dried with Na_2SO_4, concentrated and made to a volume of 5 ml with hexane. Additional cleanup was effected by use of a Florisil column and the cleaned-up extract was analysed for pesticide residues by gas liquid chromatography-electron capture (GLC-EC) technique with parameters as described by Reynolds (1969).

FIGURE 3. Sample locations of aquatic bird eggs in Alberta, Saskatchewan and Manitoba.

The compounds screened for were lindane, heptachlor, aldrin, kelthane, DDE, dieldrin, DDD, o,p′-DDT, p,p′-DDT, methoxychlor, endrin and tedion in 1968 and in addition heptachlor epoxide (HE) and benzene hexachloride (α-, β-, and γ-BHC) in 1969.

No corrections were made for pesticide losses during the extraction and cleanup processes, although recovery studies for 8 of the more common pesticides showed an average loss of about 10%. Confirmation of specific residues was made by use of more polar phase GLC columns, derivatization and use of characteristic

GLC retention times of the derivatives, and by thin layer chromatography where possible.

A number of samples were analysed for polychlorobiphenyls (PCBs) as these compounds interfere with the organochlorine pesticide analyses. The PCBs were separated from the organochlorine pesticides by differential elution from a Florisil column and estimated by the methed of Reynolds (in press). The PCB values reported are based on Aroclor 1254 and are the averages of the calculation for peaks No. 8 and 10, two of the major peaks in the PCB commercial mixture. It can be seen that DDT and DDD residue levels obtained in 50 California Gull tissues without prior PCB separation are unreliable (Table 1). An increase in those levels can be significantly correlated with a greater PCB contamination (Figures 1 and 2). As the DDT and DDD levels obtained without PCB separation are unreliable and as they constituted only a small fraction of the total DDT plus metabolite contamination, they have been omitted from the results.

The DDE values presented may include small contributions from PCBs since DDE is not separated from a minor PCB interfering peak. However, if the GLC pattern of a sample extract (prior to PCB separation on Florisil) shows high "apparent" DDE with little or no DDD and DDT present, then all or most of the apparent DDE is probably "true" DDE. It should be noted that almost all the samples, with the exception of the fat tissues, showed less than one ppm DDT or DDD prior to PCB separation, thus indicating that PCB contributions to the DDE values are likely to be small.

No standard method was found in the literature to represent quantities of organochlorine residues in tissues. In this paper, the pesticide residues are shown in ppm wet weight as most articles relating to pesticides appear to follow this procedure. As loss of moisture from eggs during incubation tends to concentrate organochlorine residues in the growing embryo, and as there are interspecific differences in the moisture percentage of eggs it may be more accurate to present residues on a dry-weight basis. For those who want to convert the residues from wet to dry or lipid weight in ppm, the percentage moisture and fat of each pooled egg sample is shown in the appendix.

Results and Discussion

Survey of Pooled Egg Samples

The numbers in Figure 3 denote the locations where the egg samples were collected and relate to those in Tables 2, 3, 4, and 5. Samples were taken in Alberta and Saskatchewan in 1968, except for Cypress and Old Wives Lakes, and at those two lakes and in Manitoba in 1969. Collections were made at certain locations in Alberta in both years. Table 2 shows the DDE residue levels present in aquatic bird eggs. The eggs of larids (except Franklin's Gull, *Larus pipixcan*) and those of fish-eating birds such as the Double-crested Cormorant, White Pelican, *Pelecanus erythrorhynchos*, Great Blue Heron, and Western Grebe, *Aechmophorus occidentalis*, contained the highest DDE levels, while waterfowl egg levels were generally the lowest. This difference may simply reflect feeding habits and biological magnification of DDE, for the plant and small animal food of the waterfowl can be reliably expected to contain lower concentrations of DDE than the larger animal food of the larids and fish-eating birds.

Within larids, the generally higher DDE residue levels in the eggs of California Gulls than in those of Ring-billed Gulls, *Larus delawarensis*, may also result from a difference in diet, since California Gulls eat on the average larger rodents and are greater scavengers than Ring-billed Gulls (Vermeer, 1967).

For Franklin's Gulls, the average DDE residue level found in the present study is similar to the 0.462 ppm wet weight reported for 30 eggs of Franklin's Gulls at Hay Lakes, Alberta, in 1966 (Guay, 1968). The relatively low residue levels in the eggs of Franklin's Gulls may be related to their dominantly insectivorous diet. Guay (1968) found that the Franklin's Gull diet consisted of 88% insects. No vertebrates were present in the stomachs of the 27 Franklin's Gulls examined by him. The diet of California and Ring-billed Gulls in contrast includes large quantities of rodents (Vermeer, 1967).

TABLE 6.—Means and 95% confidence intervals of organochlorine insecticide residues in tissues of California Gulls collected in the vicinity of Edmonton; 10 during spring arrival and 10 during egg-laying in 1969

Tissue analized	Time collected	% Fat in tissue	Residues in ppm wet weight		
			DDE	Dieldrin	HE
Abdominal fat	Arrival	67.8±7.4	211.62±141.53	1.01±0.43	0.68±1.31
	Egg-laying	68.6±8.8	134.11± 91.20	1.16±0.40	0.31±0.25
Liver	Arrival	4.1±1.0	7.73± 6.53	0.09±0.05	0.02±0.02
	Egg-laying	4.0±0.6	5.37± 3.29	0.08±0.04	0.01±0.01
Brain	Arrival	7.3±0.4	2.14± 1.43	0.02±0.01	0.0007*
	Egg-laying	6.9±0.5	1.31± 0.74	0.02±0.01	0.0011*

*HE observed in < 3 samples.

The Herring Gull, like the California Gull, is a scavenger, but the former appears to eat more fish in its inland habitat (Mendall, 1939; Ludwig, 1962). The DDE residue levels observed in the eggs of this species at the large Manitoba lakes may be a reflection of its diet. J. A. Keith (1966) associated Herring Gull egg levels averaging 202 ppm wet-weight DDE with exceptionally low hatching success in northern Lake Michigan, and the lower 95% confidence limit of this average was 122 ppm, seven times higher than the highest Herring Gull level reported here.

No quantitative data on the food habits of Common Terns, in the prairie provinces are available. The diet of this species on the Maine coast chiefly consists of fish and crustaceans (Mendall, 1935). The DDE levels in the eggs of this species at different breeding locations appear to vary more than in the other larids.

The higher residue levels found in the eggs of Double-crested Cormorants than in those of White Pelicans may be related to their different feeding habits. White Pelicans scoop fish from the water surface (Hall, 1925) while Double-crested Cormorants obtain fish by diving (Bartholomew, 1942). Anderson *et al.* (1969) found similar differences in DDE residues between those two species in Minnesota, Wisconsin, North Dakota, Manitoba and Saskatchewan. They explain them as being a result of dissimilar non-breeding area exposures. According to their calculations, based on information from Bent (1922), Lewis (1929), Mendall (1936), and refuge personnel, pelicans arrive on the average on April 10 and cormorants on May 3. However, Lewis (1929: 14) states that

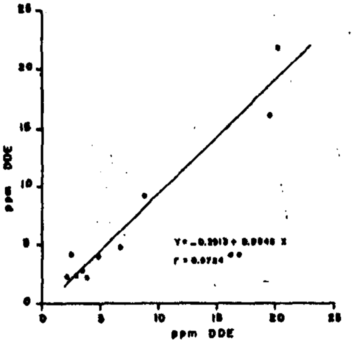
TABLE 7.—Variation of DDE residues in ppm wet weight in individual samples of 10 aquatic bird eggs in Alberta in 1969.

Species	Where Collected	Mean	Range	Coefficient of Variation
Great Blue Heron	Belly River (Glenwoodville)	9.95	1.5 - 24.0	61.83
Great Blue Heron	Battle River (Wetaskiwin)	5.71	1.4 - 13.5	69.96
Great Blue Heron	Jamieson Lake	6.61	1.0 - 31.8	138.68
Great Blue Heron	Chip Lake	37.01	0.7 - 234.4	197.73
Common Tern	Chip Lake	6.38	1.2 - 33.3	151.93
California Gull	Miquelon and Joseph Lakes	7.51	2.1 - 20.2	91.09
Double-crested Cormorant	L. Therien Lake	3.57	1.5 - 6.4	41.65

cormorants in Manitoba may arrive at the end of March or early April. From eight average arrival dates each (Lewis 1929: 16), we calculate that cormorants arrive on average in Minnesota, Wisconsin and North Dakota on April 17 and in Manitoba on April 24. One of us (KV) watched the spring arrival of cormorants at Cypress Lake, Saskatchewan, in 1969 and at Lake Newell, Alberta, in 1968 and 1969. Cormorants occupied their nesting grounds by mid-April, even before ice disappeared from those lakes, and initiated egg-laying during the last week of April (Vermeer, 1970; in press). KV also observed little or no interspecific difference in hatching dates where the two species nested together in large numbers in the Canadian prairie provinces. Hence it appears that the interspecific differences in DDE residues cannot be explained on the basis of dissimilar spring arrival dates. Different food habits on the breeding and/or non-breeding grounds is a more likely explanation for dissimilar DDE contamination of the two species.

The dieldrin residue levels in the aquatic bird eggs are shown in Table 3. Although the dieldrin levels are not as high as those of DDT compounds, their effects are not less serious. DeWitt *et al.* (1960) tested the toxicity of 21 insecticides to Bobwhite Quail, *Colinus virginianus*, and found dieldrin to be 14 times more toxic than DDT. As has been observed for the DDE residues, the eggs of larids and fish-eating birds contain more dieldrin than those of waterfowl, while cormorants appear to be more contaminated than pelicans.

HE is of similar toxicity as dieldrin to birds (Moore, 1965). HE is rapidly metabolized from heptachlor and hence the latter is rarely



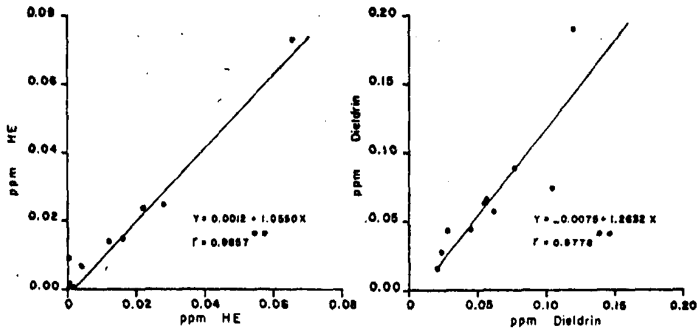


FIGURE 4. Relationships of organochlorine residue levels within pairs of eggs from 10 California Gull clutches; points being intersections of pair values.

TABLE 8. Means and 95% confidence intervals of organochlorine insecticide residues in tissues and single eggs of 10 California Gull females at Miquelon and Joseph Lakes, Alberta in 1969.

Tissues	Per cent		ppm wet weight		
	Fat	Non-fat (water excl.)	DDE	Dieldrin	HE
Abdominal fat	68.6±8.8	7.4±3.2	134.11±91.20	1.16±0.40	0.31 ±0.25
Ovary	11.4±3.6	17.7±1.1	12.56± 9.33	0.15±0.12	0.019±0.016
Egg	7.8±1.0	16.1±0.5	7.26± 4.84	0.06±0.03	0.016±0.015
Liver	4.0±0.6	26.3±0.8	5.37± 3.29	0.08±0.04	0.009±0.008
Brain	6.9±0.5	13.9±1.1	1.31± 0.74	0.02±0.01	0.001

detected as a residue. But heptachlor was still present where high HE residue levels were found in Ring-billed Gull and Mallard eggs at Cypress Lake (Table 4). It can be seen in Table 5 that Herring and Ring-billed Gulls are more contaminated with HE than cormorants and pelicans, while cormorants in turn have higher average HE levels than pelicans.

Table 5 shows that the cormorants at the lakes in Manitoba are most contaminated with β BHC residues. Eggs of White Pelicans, Herring and Ring-billed Gulls contained lower β BHC residues at the same locations. Perhaps β BHC is associated with the fish on which cormorants feed.

Nothing is known concerning the source of the organochlorine residues in the aquatic birds. We compared residue levels from tissues of 10 California Gulls collected near Edmonton at spring arrival with those of 10 birds of that species taken at Joseph and Miquelon Lakes during egg-laying and the first few days of incubation in 1969 (Table 6). Although there are no statistically significant changes in residue levels between gulls from those two time periods, a trend indicates a residue decline of DDE in gulls with the advancing season. This suggests that food taken during spring migration or during the winter contained higher levels of DDT or DDE than food taken during the early breeding season.

In order to reduce costs of residue analyses, composite egg samples were usually analyzed. However, ten individual eggs, of various species from several localities in Alberta in 1969, were also analyzed to determine DDE residue variation within local populations (Table 7). It can be seen that the DDE levels vary considerably within eggs of local breeding populations of Great Blue Herons, California Gulls and Com-

TABLE 9.—DDE and dieldrin residue ratios in tissues and single eggs of 10 California Gull females at Joseph and Miquelon Lakes, Alberta in 1969.

Tissue comparisons	DDE		Dieldrin	
	Mean ratios ± SE	Coefficient of correlation	Mean ratios ± SE	Coefficient of correlation
Fat/egg	19.6±3.3	0.9506**	20.3±2.8	0.8073*
Liver/egg	0.81±0.12	0.9242**	1.48±0.29	0.3612
Brain/egg	0.20±0.03	0.9283**	0.27±0.04	0.9366**
Ovary/egg	1.76±0.20	0.8539**	2.21±0.05	0.4327

*$p < 0.05$
**$p < 0.01$

TABLE 10.—DDE and dieldrin residue ratios in tissues of 20 California Gulls from Edmonton and Joseph and Miquelon Lakes, Alberta in 1969.

Tissue comparisons	DDE		Dieldrin	
	Mean ratios ± SE	Coefficient of correlation	Mean ratios ± SE	Coefficient of correlation
Fat/liver	30.8±3.8	0.9553**	16.4±2.1	0.4760*
Fat/brain	107.5±9.4	0.9172**	73.3±9.8	0.8570**
Liver/brain	5.78±0.24	0.9286**	5.78±0.81	0.7284**

mon Terns. Although one highly contaminated gull, heron or tern may bias a mean composite sample, nevertheless a pooled sample is better than a single sample as an indicator of the degree of organochlorine contamination of a population. Two Great Blue Heron eggs with 78.0 and 234.4 DDE residue levels at Chip Lake, for example, had the highest DDE levels of all aquatic bird eggs collected. If one egg, low in DDE residues, had been sampled, there would be no indication that some herons at that locality were highly contaminated.

The variation in individual DDE residue levels was smaller in Double-crested Cormorants than in Great Blue Herons, California Gulls and Common Terns (Table 7). Intraspecific variation in mean DDE residues between different localities was also smaller in cormorants, as well as in pelicans, than in California Gulls, Ring-billed Gulls, Common Terns, Herring

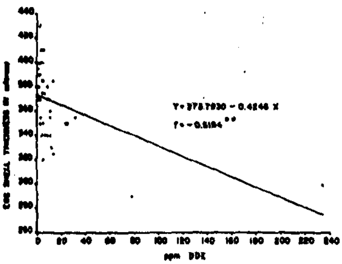


FIGURE 5. Relation between DDE concentrations and shell thickness in forty Great Blue Heron eggs from four Albertan heronries in 1969.

Gulls and Great Blue Herons (Table 2). This may be related to the almost exclusively fish diet of cormorants as compared to the only partly fish diet of the gulls and herons. Cormorants probably are more restricted to feeding in deeper waters than terns, which have been observed feeding in very shallow bays as well as in ponds adjacent to the lakes where they nest.

Eggs as Indicators

Two eggs of each of 10 clutches of California Gulls at Joseph and Miquelon Lakes were taken in 1969 to determine if organochlorine residue levels in one egg were representative of those in other eggs laid by the same female. It can be seen that they were representative as there are highly significant correlations of residue levels between eggs of the same clutch (Figure 4). A comparison is also made between the organochlorine insecticide residue levels in tissues and in single eggs of 10 California Gull females during the egg-laying period (Table 8). As residue levels of eggs and livers were the most alike of all the tissues examined, those in eggs are approximate indicators of those in livers of females at the time of egg-laying. It can be seen that the residue levels in the abdominal fat are significantly higher than those in the ovary, egg, and liver, and that the levels of those tissues in turn are significantly higher than in the brain of the same birds. As organochlorine residues tend to dissolve and concentrate in fat, the tissues with most fat generally have the highest residue levels. There are exceptions, however, for while the brain contains a significantly higher percentage of fat than the liver, nevertheless the liver has a significantly higher DDE and dield-

TABLE 11.—Means and 95% confidence intervals of PCB residues in tissues and single eggs of 10 California Gull females at Joseph and Miquelon Lakes, Alberta in 1969.

Tissues	Per cent		PCB in ppm wet weight
	Fat	Non fat (water excluded)	
Abdominal fat	68.6±8.8	7.4±3.2	18.87±8.57
Ovary	11.4±3.6	17.7±1.1	1.22±0.65
Egg	7.8±1.0	16.1±0.5	0.87±0.39
Liver	4.0±0.6	26.3±0.8	0.79±0.36
Brain	6.9±0.5	13.9±1.1	0.29±0.16

rin level than the brain (Table 8). Hence residue comparisons between different tissues on a lipid basis may be sometimes misleading.

Residue levels in tissues of California Gull females are compared with those in their eggs (Table 9). As HE residues were not observed in many samples, they have been excluded from the table. Highly significant correlations can be observed in DDE levels between tissues and eggs. Dieldrin levels in the fat and brain also relate significantly to those in eggs. DDE and dieldrin ratios appear to be of similar magnitude for the same tissue comparisons. Hence, as the correlations are generally significant, DDE and dieldrin residue levels in tissues of California Gulls at the time of egg-laying may be predicted when known in their eggs. They may also be predicted when known in another tissue than eggs (Table 10).

PCB residue levels in tissues of California Gull females are also compared with those in their eggs (Tables 11 and 12). It can be seen that the distribution of PCB residues in tissues follows the same trend as those for DDE, dieldrin and HE (Tables 8), and that the pattern of PCB residue ratios also follows the same trend as those for DDE and dieldrin (Table 9). Hence PCB residue levels in egg-laying California Gulls may be predicted when known in their eggs, and for birds generally, PCB residues may prove to have a tissue distribution pattern similar to the patterns of DDE, dieldrin, and HE.

TABLE 12.—PCB residue ratios in tissues of 10 California Gull females and their eggs at Joseph and Miquelon Lakes, Alberta in 1969.

Tissue comparisons	Mean ratio ± SE	Coefficient of correlation
Fat/egg	25.45±6.32	0.7558*
Liver/egg	1.11±0.27	0.6159*
Brain/egg	0.38±0.09	0.6274*
Ovary/egg	1.67±0.38	0.7127*

Figure 5 shows a highly significant inverse correlation between shell thickness and DDE residues in 40 Great Blue Heron eggs from heronries at the Battle River near Wetaskiwin, the Belly River near Glenwoodville, Chip Lake, and Jamieson Lake in Alberta. The DDE residues are shown in ppm wet weight to maintain uniform presentation of results. Somewhat better correlations between DDE residues in eggs and egg shell thickness of herons were observed on a dry-weight ($r = -0.5741^{**}$) and a lipid-weight basis ($r = -0.5958^{**}$). Hence more significant correlations may be obtained by means of the latter methods when comparing organochlorine residues within the same tissues. Although a linear regression is shown in Figure 5, the relation between DDE residues in eggs and egg shell thickness was

TABLE 13.—Relation between DDE residue levels and embryonic development in Great Blue Heron eggs collected at Chip Lake on May 28, 1969

ppm DDE in wet wt.	% water in eggs	Condition of embryo in collected egg	No. eggs and/or young per nest
0.713	84	Embryo alive	5
2.17	83	Embryo alive	4
2.74	84	Embryo alive	5
4.00	80	No development (infertile?)	4
4.62	84	Embryo alive	5
6.59	82	Embryo alive	4
11.1	83	Embryo alive	4
25.8	83	Embryo alive (pipping)	5
78.0	82	Embryo alive (pipping)	4
234.4	73	Embryo died at early stage	1

slightly curvilinear, fitting an exponential curve $y = (374.081)\ (0.9987)^x$. However, more egg samples with high DDE residue contents are needed to determine whether the actual relationship between DDE residues in eggs and shell thickness is a curvilinear or a linear one.

In contrast with DDE, no significant correlation ($r = -0.1692$) was found between shell thickness and PCB residues in the contents of the 40 Great Blue Heron eggs.

The heron eggs most contaminated with DDE were found at Chip Lake. It can be seen than an embryo from an egg with 78.0 ppm DDE shows development at least until hatching (Table 13). The embryo from an egg with 234.4 ppm DDE died at an early stage, perhaps as a result of the DDE concentration.

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APPENDIX.—Percentage moisture (percentage fat in parenthesis) in composite samples of 10 aquatic bird eggs in the prairie provinces

Sample location	California Gull	Ring-billed Gull	Franklin's Gull	Herring Gull	Common Tern	Double-crested Cormorant	White Pelican
1. Namur Lake	77.2 (7.9)			76.8 (7.5)			81.9 (4.9)
3. L. Therien Lake	77.3 (8.6)	75.6 (9.1)			76.3 (10.0)	85.3 (3.0)	
4. Chip Lake	76.7 (8.0)	75.8 (9.8)			77.2 (8.7)		
5. Miquelon Lake	76.5 (10.0)	75.9 (9.6)					
8. Dowling Lake	75.6 (9.6)	75.7 (9.6)					
10. Lake Newell	76.1 (8.9)	76.0 (9.8)	75.0 (8.7)		75.9 (10.0)	83.9 (4.1)	
11. Murray Lake	76.4 (9.3)	74.8 (9.5)					
13. Kazan Lake	76.1 (8.8)					84.3 (4.0)	81.6 (4.0)
14. Primrose Lake	76.0 (8.4)	75.1 (8.0)			75.9 (10.1)	84.2 (3.9)	81.9 (4.9)
15. Doré Lake	77.0 (8.3)	75.2 (9.2)					
16. Lavallee Lake					76.2 (8.8)	83.8 (4.6)	83.7 (5.4)
17. Montreal Lake					77.8 (8.7)		
18. Suggi Lake		76.0 (9.1)		76.4 (7.9)		84.9 (2.9)	82.7 (4.9)
19. Jackfish Lake		76.9 (7.9)	76.9 (8.1)				
21. Redberry Lake	76.8 (8.4)	75.3 (9.6)				84.8 (3.8)	82.9 (3.9)
22. Old Wives Lake	75.0 (7.7)	75.3 (9.0)				84.4 (3.3)	83.0 (3.3)
23. Cypress Lake	75.3 (8.0)	74.4 (8.3)				84.7 (4.0)	83.0 (4.7)
24. Talbot Lake				77.9 (8.4)		84.0 (4.3)	80.7 (2.7)
25. Moose Lake				75.0 (8.8)		84.3 (3.7)	81.7 (4.3)
26. Lake Winnipegosis		75.7 (9.0)		75.7 (8.0)		84.7 (4.0)	81.7 (5.0)
27. Kawinaw Lake		74.3 (9.3)					82.3 (4.7)
28. Pelican Lake	76.0 (8.0)	77.0 (8.7)		75.7 (8.7)		84.0 (3.3)	82.7 (4.7)
29. Lake Winnipeg (St. Martin Is.)				75.7 (8.3)		83.3 (3.7)	82.3 (5.0)
30. Dog Lake						84.3 (3.0)	80.7 (5.3)
31. Lake Manitoba		75.0 (9.3)				84.0 (4.0)	82.7 (5.0)

Sample location	Great Blue Heron	Black-crowned Night Heron	Western Grebe	Horned Grebe	Eared Grebe	American Avocet	Coot
2. Cold Lake			77.8 (8.9)				
4. Chip Lake	81.9 (4.8)						
6. Battle River (Wetaskiwin)	82.1 (5.1)						
7. Jamieson Lake	81.7 (5.8)						
8. Dowling Lake	82.6 (4.9)						
9. Stobart Lake						74.0 (10.9)	
10. Lake Newell						73.6 (11.3)	66.0 (8.8)
11. Murray Lake		81.1 (5.1)					
12. Belly River (Glenwoodville)	81.8 (5.2)						
19. Jackfish Lake			78.5 (6.8)				
20. Battleford				80.1 (5.8)			
22. Old Wives Lake		81.3 (5.0)			78.8 (8.0)		
27. Kawinaw Lake			78.0 (7.7)				

Sample location	Canada Goose	Mallard	Pintail	Gadwall	American Widgeon	Blue-winged Teal	Lesser Scaup
3. L. Therien Lake							67.4 (16.1)
4. Chip Lake				66.9 (16.0)			65.5 (15.2)
5. Miquelon Lake		68.1 (14.8)					
8. Dowling Lake	68.6 (15.6)						
10. Lake Newell	69.1 (15.8)	68.0 (15.9)		67.9 (16.0)	68.2 (16.4)	66.9 (14.8)	68.1 (14.9)
19. Jackfish Lake		68.6 (14.3)					
22. Old Wives Lake		68.3 (12.7)	69.7 (12.7)				
23. Cypress Lake	66.4 (15.7)	68.6 (14.7)					

NB The decrease in the % moisture and the increase in the % fat in eggs in the order cormorants - pelicans - herons - grebes - larids - shorebirds (avocets) - ducks and geese may reflect interspecific relations within and differences between avian orders.