(3) 59820

DDE Thins Eggshells and Lowers Reproductive Success of Captive Black Ducks

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Introduction

Population declines of certain raptorial and piscivorous birds have been correlated with organochlorine pesticide residues, primarily DDE [1,1-dichloro-2,2-bis(p-chlorophenyl) ethylene], a metabolite of DDT [1,1,1-trichloro-2,2-bis (p-chlorophenyl)ethane], found in bird tissues and eggs (1,2). In experimental studies, DDE has lowered reproductive success of mallards (Anas platyrhynchos) (3) by reducing eggshell thickness and increasing shell cracking and embryonic mortality; and it has significantly reduced eggshell thickness of American kestrels (Falco sparverius) (4).

The number of North American black ducks (Anas rubripes) along the Atlantic Coast has fluctuated downward since the mid-50's, and there has been a marked decrease in the percentage of immatures in the harvest (5). These declines cannot be attributed solely to hunting because more restrictive hunting regulations have resulted in reduced harvest. Breeding populations of black ducks in Eastern Canada have steadily declined since 1963 (6). A survey of organochlorine pesticide residues in wings of mallards and black ducks showed the highest DDE residues in black ducks from the Atlantic Coastal States (7).

Procedures

An experiment to determine if DDE would affect the reproduction of black ducks was started in 1969. Test ducks were obtained by collecting eggs from a captive black duck flock and allowing mallard hens to incubate the eggs and raise the ducklings in the test pens. Forty pairs of these ducks were randomly assigned to three experimental groups: (a) 14 pairs to receive dietary dosages of 10 ppm (dry weight) of DDE, (b) 12 pairs to receive 30 ppm, and (c) 14 pairs to receive untreated food. Individual pairs were assigned randomly to 15-by 30-foot pens each supplied with a 250-gallon water trough, a feeder, and a covered nest box. DDE-treated food was provided in mid-November and food and water were continuously available. The p,p'-DDE was dissolved in corn oil and mixed with commercial duck mash in the ratio of 1 part oil solution to 99 parts mash; an equal amount of clean oil was added to the diets of untreated birds.

OCT 13 1998
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Bulletin of Environmental Contamination & Toxicology,
Vol. 6, No. 6, 1971, published by Springer-Verlag New York Inc.

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Eggs were collected daily starting in April. They were marked, examined for fractures, reexamined for cracks with a candler and then stored for up to 10 days prior to incubation. Ten percent of the eggs were not incubated because they were selected for measurements or were cracked too severely. Embryonation and survival of embryos at weekly intervals were determined by candling. All hatchlings were web-tagged and fed untreated food for 3 weeks.

The third egg laid by each hen was selected for measurements of shell thickness and pesticide residues. Eggs were opened at the equator, the contents stored in jars, and the shells washed and air-dried. The thickness of the shell plus membrane was measured at the equator and at both poles with a micrometer calibrated in 0.01 mm units. Egg contents were analyzed by WARF Institute, Inc. Egg contents were dried and ground with sodium sulphate; extracted with a mixture of ethyl ether and petroleum ether (70:170) for 8 hrs. in Soxhlet apparatus; cleaned and separated by two elutions through a florisil column with ethyl ether and petroleum ether (5:95; 15:85). Analysis was by gas chromatography, using a Barber, Coleman Pesticide Analyzer Model 5360. Columns were glass, 4 ft x 4 mm. For the first elution, the column packing was 5 percent DC 200 on Cromport XXX (70/90 mesh); temperatures were: injector 235°C, column 190°C, and detector 240°C. For the second elution, packing was 5 percent Q-F 1 on Cromport XXX (60/70 mesh) and temperatures were: injector 220°C, column 195°C, and detector 240°C. Nitrogen flow rates were such that p,p'-DDT had retention of 8-10 min and dieldrin, 4-5 min.

Productivity data for test ducks and parameters for reproductive success are arranged sequentially in Tables 1a and 1b. Data were tested by analysis of variance with angular transformations applied to percentages before analysis (8). Methods of Cochran (9) were used to determine if weighting of data were necessary. Means were separated by methods of Duncan (10) and Kramer (11).

Results and Discussion

Diets containing DDE at both 10 and 30 ppm caused significant shell thinning ($P<0.01$) and shell cracking (Table 1b). Shells of third eggs from dosed ducks were: 18-24 percent thinner at the equator than shells from third eggs of undosed ducks; 28-31 percent thinner at the cap; and 29-38 percent thinner at the apex (Table 2). Extent of shell cracking of all eggs from 30 ppm dosed ducks averaged 21 percent, which significantly ($P<0.01$) exceeded the cracking of eggshells from undosed ducks or from 10 ppm dosed ducks. Incidence of cracked eggshells from 10 ppm dosed ducks was also higher than that of undosed birds ($P<0.05$) A comparison between the total cracked shells and uncracked shells of third eggs from both the two dosed groups revealed that cracked shells

TABLE 1a.

Reproductivity data of captive black ducks fed DDE in the food

	DDE added to food (ppm dry wt.)		
	None	10	30
Pairs of ducks	14	14	12
Eggs			
Laid	179	217	145
Cracked	3	21	31
Incubated*	160	182	104
Embryonated	85	107	44
Embryos alive:			
1 week	81	84	27
2 weeks	69	76	20
3 weeks	61	74	19
Ducklings hatched	35	39	8
Ducklings alive at 21 days	32	25	4

*Excludes cracked eggs and those removed for analysis.

TABLE 1b.

Progression of reproductive success among captive black ducks fed DDE in the food

	DDE added to food (ppm dry wt.)		
	None	10	30
Eggs laid per hen (average)	13	15	12
Percent			
Hens which laid	100	100	83
Cracked eggs	2	10*	21**
Embryonated (of eggs incubated)	53	59	42
Embryos alive:			
1 week	95	79**	61*
2 weeks	81	71**	45*
3 weeks	72	69	43
Ducklings hatched:			
of third week embryos	57	53	42
of eggs embryonated	41	36	18
Ducklings surviving:			
1 week	97	90	63
2 weeks	94	85	63
3 weeks	91	64**	50**
Ducklings alive at 21 days (of eggs embryonated)	38	23#	9*

*Difference from control significant ($P<0.05$).
**Difference from control highly significant ($P<0.01$).
#Difference from control approaches significance ($P=0.05$)

TABLE 2.

Shell thickness and residues of DDE in eggs laid by captive black ducks

Dose (ppm in diet, dry weight)	No. shells measured#	Eggshell thickness measurements: means, extremes (mm), and percentage difference between dosed and undosed groups			No. eggs analyzed for DDE#	DDE residue: mean and range (ppm wet weight)
		Equator	Cap	Apex		
None	13	0.34 (0.27-0.39)	0.29 (0.22-0.34)	0.24 (0.16-0.32)	13	0.28 (0.14-0.67)
10	14	0.28 (0.24-0.30) -17.6%*	0.21 (0.17-0.26) -27.6%*	0.17 (0.13-0.23) -29.2%*	14	46.3 (33.7-62.5)
30	10	0.26 (0.23-0.30) -23.5%*	0.20 (0.17-0.25) -31.0%*	0.15 (0.12-0.25) -37.5%*	10	144.1 (95.5-218.5)

*All differences from undosed group highly significant ($P<0.01$).
#Refers to measurement and analysis of the third eggs laid by hens.

from dosed birds were significantly thinner ($P<0.05$ and $P<0.01$) than uncracked third eggshells from the same dosage groups. Egg fractures were linear hairline cracks, indentations, and collapsed shells at egg poles. Twenty-five percent of the cracked eggshells from dosed hens were collapsed.

Productivity data are based on uncracked eggs from each treatment (Tables 1a, 1b). Egg production among treatment groups did not differ significantly. All undosed hens and all 10 ppm dosed hens laid and there was no apparent delay in the onset of laying. Two of 12 hens in the 30 ppm group did not lay. Embryonation of eggs from dosed hens equaled that of undosed hens. Embryonic mortality among eggs from dosed hens, in contrast to undosed hens, occurred early in incubation and was significantly greater in each of the first 2 weeks of incubation. The survival of ducklings to 21 days was significantly ($P<0.01$) lower for the dosed groups than for the control group. Survival of ducklings from dosed parents in terms of "percentage of 21-day ducklings of embryonated eggs" was 40-76 percent lower than survival of ducklings from undosed parents.

Average DDE residues (wet weight) in eggs from hens fed 10 and 30 ppm DDE were 46 ppm and 144 ppm (Table 2). Each egg from undosed hens had less than 0.7 ppm DDE. Residues of DDT, DDD, and dieldrin each averaged 0.05 ppm or less in all eggs regardless of treatment. Lipid weights averaged 12.7 percent of the fresh weight of egg contents.

Lamont *et al.* (12) report p,p'-DDE residues from brown pelican eggs (*Pelecanus occidentalis*) on Anacapa Island, California, that ranged from 39.5 to 135.0 ppm (wet weight). These DDE residues closely approximate the levels we found in our black duck eggs. This California pelican population has experienced a drastic, near total, nesting failure related to shell thinning and collapse of eggshells (13). Anderson *et al.* (14) have demonstrated significant correlations between DDE residues and shell thickness of field-collected eggs of double-crested cormorants (*Phalocrocorax auritus*) and white pelicans (*Pelecanus erythrorhynchos*). Krantz *et al.* (15) report that eggs from Maine bald eagles (*Haliaeetus leucocephalus*) contained DDE residues ranging from 13.2 to 27.6 ppm (wet weight). Maine bald eagle nesting has been a near failure for at least the past 4 years.

A continuous dietary concentration as low as 10 ppm DDE in dry mash, which approximates 3 ppm wet weight in natural foods, adversely affects black duck reproduction. DDE residues in aquatic invertebrates from black duck wintering areas (16) and in black duck eggs collected in 13 Atlantic Coastal States and Canada (17) suggest that wild black ducks may consume amounts of DDE equivalent to our lower dosage.

Summary

Eggs of captive black ducks fed diets containing DDE at 10 and 30 ppm (dry weight) experienced significant shell thinning and an increase in shell cracking when compared to eggs of untreated black ducks. Eggshells from dosed ducks were: 18-24 percent thinner at the equator than shells from undosed ducks; 28-31 percent thinner at the cap; and 29-38 percent thinner at the apex. Shell cracking averaged 21 percent among eggs from the 30 ppm DDE dosage and 10 percent among eggs from the 10 ppm dosage. Only 2 percent of the eggs from untreated black ducks were cracked. Survival of ducklings from dosed parents in terms of "percentage of 21-day ducklings of embryonated eggs" was 40-76 percent lower than survival of ducklings from undosed parents. Average DDE residues (wet weight) in eggs from hens fed 10 and 30 ppm DDE were 46 ppm and 144 ppm, respectively.

Acknowledgments

We thank R. G. Heath for statistical consultation; R. Andrews, L. Stickel, and E. H. Dustman for aid in experimental design and manuscript review; and E. Cromartie and R. M. Prouty for providing DDE.

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