Contaminants in Peregrine Falcon (Falco peregrinus) Eggs from Virginia, Maryland and West Virginia

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ABSTRACT

Title: **Contaminants in Peregrine Falcon (Falco peregrinus) Eggs from Virginia, Maryland, and West Virginia**

Abstract: Peregrine falcons were extirpated in the eastern United States in the 1960s principally due to the use of organochlorine pesticides, particularly DDT (Peakall et al., 1975). The reintroduction of peregrine falcons has successfully established breeding populations along the East Coast (Cade, 1985; Barclay, 1988). The possible impact of environmental contaminants on these newly established populations continues to be of concern.

Inviable peregrine eggs from 8 nests in Virginia, Maryland, and West Virginia were collected in 1992. All 11 egg samples contained measurable concentrations of DDE. DDE concentrations ranged from 0.97 parts per million (ppm) to 11.7 ppm (adjusted wet weight), with a geometric mean concentration of 3.2 ppm. Dieldrin was also found in all eggs, and displayed a geometric mean residue of 0.3 ppm, adjusted wet weight (range 0.09 to 1.1 ppm). DDE concentrations of 1.2 to 30 ppm wet weight and dieldrin concentrations of 1 ppm are associated with adverse effects on reproduction in peregrines (Fyfe et. al., 1988 and Wiemeyer et. al., 1986). Mercury residues were also elevated in one sample (0.61 ppm, wet weight). Egg shells were found to display thinning up to 26.9%, a level above the reported 14% to 17% range that results in egg failure (Fyfe et. al., 1988; Peakall and Kiff, 1988).

The results of this study indicate possible reproductive problems, which may be attributable to environmental contaminants. Most compounds of concern were present in concentrations just below the level thought to be critical in inducing adverse effects on avian health. The small sample size does not allow for a full assessment of the impacts of environmental contaminants on peregrine falcons of coastal Maryland and Virginia. Additional monitoring of peregrine eggs combined with the establishment of a database that compiles all contaminant and population information is recommended.

Key words: Environmental Contamination, Organochlorine Pesticides, Metals, Polychlorinated Biphenyls (PCB), Peregrine Falcon, (Falco peregrinus).

EXECUTIVE SUMMARY

Peregrine falcons were extirpated in the eastern United States in the 1960s principally through the use of organochlorine pesticides, particularly DDT in the 1940s and 1950s (Peakall et al., 1975). Cyclodienes such as dieldrin and chlordane may have also contributed to the decline. The reintroduction of peregrine falcons has successfully established breeding populations along the East Coast (Cade, 1985, Barclay, 1988). The possible impact of environmental contaminants on these newly established populations continues to be of concern.

Inviable peregrine eggs were collected from nests in Virginia, Maryland and West Virginia in 1992. Analysis of organochlorine pesticides, organophosphate pesticides, carbamates, and metals was conducted for each egg. Percent thinning of each egg shell was also established.

The results of this study indicate possible reproductive problems, which may be attributable to environmental contaminants. Most compounds of concern (DDE, dieldrin, and mercury) were present in concentrations just below the level thought to be critical in inducing adverse effects on avian health. All egg samples contained measurable concentrations of DDE. DDE concentrations ranged from 0.97 parts per million (ppm) to 11.7 ppm (adjusted wet weight), with a geometric mean concentration of 3.2 ppm. DDE concentrations in eggs of 1.2 to 30 ppm wet weight are associated with adverse effect to reproduction in peregrines (Fyfe et. al., 1988). Dieldrin was also found in all eggs, and displayed a geometric mean residue of 0.3 ppm, adjusted wet weight (range 0.09 to 1.1 ppm). With the exception of one egg, dieldrin levels were below the concentration of 1 ppm reported to be associated with reproductive failure in raptors (Wiemeyer et. al., 1986). In general, 0.5 ppm of mercury is considered the level which may result in adverse effects on reproduction in raptors (Wiemeyer, et. al., 1984). Since only one peregrine egg sampled displayed a concentration above 0.5 ppm, the impact of mercury may not be a major concern. Five of the 11 eggs showed a thinning index greater than 14%. Thinning indexes greater than a 14% to 17% have been reported to result in egg failure in peregrine falcons (Fyfe et. al.,1988; Peakall and Kiff, 1988).

There does not appear to be a correlation of these contaminant levels with egg shell thinning. This may be a result of small sample size. Additional monitoring of inviable peregrine eggs combined with the establishment of a database that compiles all contaminant and population information on eastern peregrines is recommended.

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INTRODUCTION

Although there were many causal factors involved in the decline of peregrine falcon (Falco pergrinus) populations in the eastern United States, peregrines were extirpated in the 1960s, principally through the use of organochlorine pesticides, particularly 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane (DDT) in the 1940s and 1950s (Peakall et al., 1975). Cyclodienes such as dieldrin and chlordane may have also contributed to the decline. It is generally accepted that two major mechanisms are responsible for the reduction in peregrine populations. Organochlorine compounds accumulated in peregrines and resulted in eggshell thinning. Thin eggshells led to cracked eggs and massive declines in reproduction. Studies have shown that lethal concentrations of cyclodiene compounds, primarily dieldrin, have contributed to increased mortality in adult peregrines (Nisbet, 1988). Therefore, direct toxicity of dieldrin to adults and reproductive impairment caused primarily by DDT have each contributed to the demise of the peregrine falcon. A ban was instituted in the United States for DDT in 1973 and EPA cancelled of most agricultural uses of cyclodienes between 1975 and 1980 (Ware, 1983). Many of these pesticides are still in use outside the United States. Peregrines may be exposed to these substances through their migrations, the migrations of their prey, or from local historical sources in the United States.

Peregrines in the mid-Atlantic region feed on small birds including pigeons, pelagic birds, songbirds and waterfowl but also will take mammals and insects (Byrd, 1991). Since peregrine falcons feed on species in high trophic levels, peregrines are subject to bioaccumulation and biomagnification of environmental contaminants in association with this feeding behavior. Raptors feeding on birds associated with contaminated aquatic environments are reported to be severely affected by bioaccumulation and biomagnification impacts (Lincer, 1975).

The reintroduction of peregrine falcons has successfully established breeding

populations along the East Coast of the United States (Cade, 1985; Barclay, 1988). The possible impact of environmental contaminants on these newly established populations continues to be of concern. Reduced productivity and eggshell thinning in Delaware Bay and River populations indicate that environmental contaminants still impact these birds (Augspurger, 1991). This study was initiated because low reproductive success of peregrine falcons has been observed in Virginia over the last several years (M. Byrd, College of William and Mary, Williamsburg, VA; pers. comm.).

The objective of this study was to determine if contaminants are present in high enough concentrations as to contribute to recruitment problems, reproductive dysfunction or declines in Virginia, Maryland, and West Virginia breeding populations of peregrine falcons.

MATERIALS AND METHODS

Peregrine falcon eggs were collected from 8 nests in Virginia, Maryland, and West Virginia during the summer of 1992 and immediately refrigerated. Exact sample locations will not be disclosed to protect each site; however, general locations are presented in Figure 1. Egg samples were made up of non-viable eggs. Eggs were candled to identify cracks present in the shell, then cleaned with Kimwipes to remove any soil or fecal material on the surface. The sample identification was written in pencil on the ends of the eggshell. The condition, coloration, and other unusual characteristics of the eggs were recorded. The mass, length, and breadth were then measured. Egg volume was determined for intact eggs by measuring water displacement using a volumeter. Cracked eggs were not immersed or rinsed in distilled water since this might have contaminated the sample. The volume of cracked or dented eggs was estimated using an equation based on length and breadth measurements (Stickel et al., 1973). Only one egg was cracked (WVGSC01). The results of the analysis of this egg are included in the tables of this report but contaminant residues were not used in the calculation of the geometric means or included

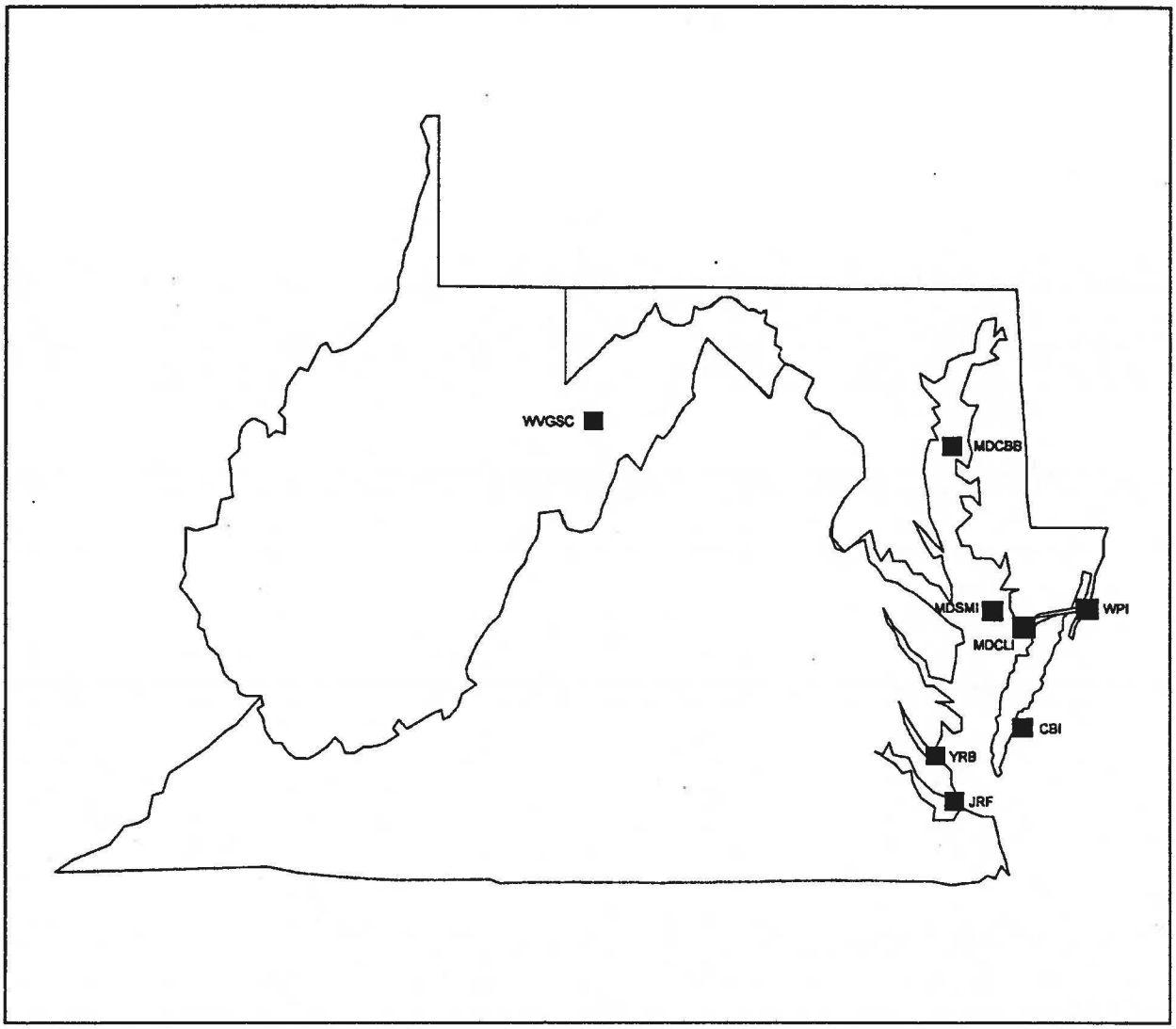
in the data interpretation.

Eggs that displayed signs of advanced decomposition were vented with a needle prior to opening. Eggs were opened by scoring the shell along the equator with a scalpel and gently inverting the halves over an open jar to collect the contents. The inside of each eggshell was scraped out with a chemically cleaned teflon spatula to remove all of the egg's contents. The mass of the egg's contents was then recorded for each sample. The contents were inspected for the presence of an embryo, estimated age of embryo, and any abnormalities. Each sample jar was labeled with sample identification information and mass and then stored in the freezer at -20° Centigrade.

Egg contents were split into equal aliquots and subsequently shipped to the contracted laboratories for metal, organophosphate/carbamate, and organochlorine/polychlorinated biphenyl (PCB) analyses. Analysis for organochlorine and PCB compounds was performed by Mississippi State University, Mississippi State, Mississippi. A Hewlett-Packard 5880A Gas Chromatograph (GC) equipped with a dual capillary column/dual electron capture detector (ECD) was used to conduct the organochlorine/PCB analysis. The lower limit of detection for residue concentrations was 0.01 ppm for organochlorine compounds and 0.05 ppm for toxaphene and PCBs. Residues in 20% of the samples were confirmed by GC/Mass Spectroscopy. Organochlorine and PCB concentrations were adjusted for moisture loss using calculated egg volume according to Stickel et al. (1973) and expressed as approximate adjusted fresh wet weight.

Metal analysis of egg contents was performed by Research Triangle Institute, Research Triangle Park, North Carolina. Inductively Coupled Plasma Emission (ICP) was used to conduct the metal analysis and ICP measurements were made using a Leeman Labs Plasma Spec. I sequential or an ES2000 simultaneous

Figure 1. Locations of peregrine falcon nests from which eggs were sampled in West Virginia, Maryland, and Virginia.



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spectrophotometer. Mercury measurements were conducted using $SnCl_4$ as the reducing agent and employing a Leeman PS2000 Mercury Analyzer. The detection limit ranged from 0.1 ppm to 13 ppm depending on the compound analyzed. The detection limit was reported as 0.1 ppm for mercury and 0.5 ppm for selenium. Metal residues are reported on a dry weight basis to avoid errors associated with moisture loss.

Organophosphate and carbamate pesticide analysis was performed by the Patuxent Wildlife Research Center, Laurel, Maryland. A gas chromatograph equipped with a flame ionization detector was used for organophosphate determinations, while a nitrogen phosphorus detector was used for carbamate determination. The detection limit for pesticide compounds was 1 ppm for carbamates and 0.5 ppm for organophosphates.

All compounds analyzed in this survey are listed in Appendix A. The geometric mean was calculated for compounds that received positive results in at least 50% of the samples analyzed. A value one half the detection limit was used in the calculation of the geometric mean for analytes reported as less than the lower detectable limit.

Eggshells were prepared for analysis by rinsing gently with tap water so not to tear the membrane. Shells were allowed to dry and then marked with the sample identification number with a technical pen. Eggshells were stored in a cool dry place for at least 30 days, or until they attained a constant mass. Eggshell mass and thickness were measured by the Western Vertebrate Association, Camerillo, CA. The mass of each eggshell was determined to the nearest 0.001 gram (g). Eggshell thickness was measured with a Federal model 35 bench comparator thickness gauge at ten equatorial locations along the shell of each half. The average of the ten measurements was then determined to be the final eggshell thickness. The Ratcliffe Index (a thickness index) of eggshell was then calculated based on length, breadth, and weight

measurements (Ratcliffe, 1967). Percentage thinning was calculated based on the pre-DDT (pre-1947) value as reported by Anderson and Hickey (1972).

RESULTS AND DISCUSSION

Organic Compounds

DDT and its metabolites, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane (DDD) and dichlorodiphenyldichloroethylene (DDE), have been conclusively shown to cause reproductive problems and eggshell thinning in raptor species (Wiemeyer et al., 1984). Reduced eggshell thickness and decreased productivity was reported in several falcon species in association with DDE concentrations (Fyfe et al., 1988). DDE concentrations of 15 to 20 ppm (wet weight) were found to be associated with an inability to maintain population levels of peregrine falcons and produced a 20% thinning in eggshell thickness (Peakall et al., 1975). Although the use of these compounds in the U.S. has been prohibited since the 1970s, these pesticides continue to persist in the environment and pose a risk to raptor populations.

At this time there is little information on the individual contribution of organochlorines to the extirpation of the peregrine falcon (Fyfe et al., 1988). Studies in the southwest United States indicate that high residues of DDE in unhatched peregrine eggs might be due to sources other than p,p' DDT (Hunt et al., 1986). Kelthane^{R}, a miticide, and other pesticides containing dicofol (4,4' dichloro-α-(trichloromethyl)benzhydrol) have been implicated in the production of DDE as a metabolite product (Risebrough et al., 1985). Dicofol-based pesticides are reported to be used extensively throughout the U.S. (Hunt et al., 1986). The use of these pesticides, along with the continued use of DDT and other organochlorines in countries in Central and South America, poses a continuing concern for the overall stability of North American raptor populations.

The results of the organochlorine analysis are presented in Tables 1 and 2. All egg samples contained measurable concentrations of DDE. DDE concentrations ranged from 0.97 ppm to 11.7 ppm (adjusted wet weight), with a geometric mean concentration of 3.2 ppm. DDE concentrations in eggs of 1.2 to 30 ppm wet weight are associated with adverse effects to reproduction in peregrines (Fyfe et. al., 1988). Since all but one sample fell with in this concentration range, the coastal peregrine population of Maryland and Virginia may still be experiencing reproductive problems in association with DDE. DDE concentrations were consistently lower among Virginia nests that were located further inland (sites JRF and YRB). The use of different prey bases between these two groups may explain these differences (M. Byrd, College of William and Mary, Williamsburg, VA; pers. comm.). DDE concentrations in eggs from Maryland and West Virginia nests were generally higher than Virginia nests.

Dieldrin was also found in all eggs, and displayed a geometric mean residue of 0.3 ppm, adjusted wet weight (range 0.09 to 1.1 ppm). With the exception of one egg, dieldrin levels were below the concentration of 1 ppm reported to be associated with reproductive failure in raptors (Wiemeyer et. al., 1986). The remaining organochlorine compounds were detected at concentrations below those considered to cause adverse effects on avian health (Olsen et. al., 1992). The maximum amount reported for each of these compounds follows: 0.02 ppm for HCB, 0.03 ppm for ß-BHC, 0.01 ppm for Γ-BHC, 0.01 ppm for δ-BHC, 0.01 ppm for endrin, 0.36 ppm for heptachlor epoxide, 0.56 ppm for trans-nonachlor, 0.25 ppm for mirex, and 0.6 for oxychlordane. The remaining compounds (dicofol, α-BHC, and toxaphene) were below detection.

The effects observed in birds exposed to PCB are difficult to differentiate from the effects of DDE. Typically, PCB and DDE concentrations in eggs are evaluated collectively (Hernandez et. al., 1988). However, it is believed that the effects of PCBs are analogous to the effects observed in DDE contaminated eggs (Risebrough et. al., 1968). Experimental data indicated

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Table 1. Pesticide and PCB concentrations in peregrine falcon eggs collected from Virginia, July 1992. Concentrations are expressed in parts-per-million, adjusted wet weight.

ID NUMBER	CBI01	CBI02	JRF01	JRF02	WPI01	YRB01	YRB01
MOISTURE (%)	84.0	80.5	82.5	82.0	78.5	81.5	81.5
LIPID (%)	3.66	4.35	7.24	6.39	5.34	5.80	5.54
COMPOUND							
HCB	0.01	0.01	ND	ND	0.02	0.01	0.01
α-BHC	ND	ND	ND	ND	ND	ND	ND
Γ-BHC	0.01	ND	ND	0.01	ND	ND	ND
ß-BHC	0.01	ND	ND	ND	0.03	0.01	0.01
δ-BHC	ND	ND	ND	ND	ND	ND	ND
OXYCHLORDANE	0.25	0.03	0.15	0.10	0.48	0.43	0.48
HEPTA EPOXIDE	0.15	0.03	0.10	0.07	0.30	0.30	0.36
Γ-CHLORDANE	0.01	ND	ND	ND	ND	ND	ND
t-NONACHLOR	0.17	0.03	0.04	0.02	0.56	0.37	0.46
TOXAPHENE	ND	ND	ND	ND	ND	ND	ND
AROCHLOR 1242	ND	ND	ND	ND	ND	ND	ND
AROCHLOR 1248	ND	ND	ND	ND	ND	ND	ND
AROCHLOR 1254	5.6	4.7	3.7	3.0	2.4	4.6	3.0
AROCHLOR 1260	4.4	4.1	5.4	5.7	9.6	4.6	4.1
o, p'-DDE	ND	ND	ND	ND	0.05	ND	ND
α-CHLORDANE	ND	ND	ND	ND	ND	ND	ND
p, p'-DDE	7.6	1.0	1.4	1.2	1.0	3.3	4.1
DIELDRIN	0.46	0.42	0.10	0.05	0.68	0.11	0.10
o, p'-DDD	ND	ND	ND	ND	ND	ND	ND
ENDRIN	0.01	0.01	ND	0.01	0.01	ND	ND
c-NONACHLOR	0.03	ND	ND	ND	0.14	0.12	0.08
o, p'-DDT	ND	ND	ND	ND	ND	ND	ND
p, p'-DDD	0.03	0.01	0.01	ND	0.10	0.12	0.14
p, p'-DDT	0.03	0.03	0.01	0.01	ND	0.18	0.18
MIREX	0.11	0.10	0.03	0.03	0.25	0.04	0.03
DICOFOL	ND	ND	ND	ND	ND	ND	ND

ND = no detection

Table 2. Pesticide and PCB concentrations in peregrine falcon eggs collected from Maryland and West Virginia, July 1992. Concentrations are expressed in parts-per-million, adjusted wet weight.

ID NUMBER	MDCBB01	MDCLI01	MDCLI02	MDSMI01	WVGCS01*
MOISTURE (%)	83.0	80.0	81.0	82.0	53.0
LIPID (%)	5.63	6.17	5.68	5.81	31.9
COMPOUND					
HCB	0.01	0.01	0.01	0.01	0.01
α-BHC	ND	ND	ND	ND	ND
Γ-BHC	ND	0.01	0.01	0.01	0.01
ß-BHC	ND	0.01	0.02	0.01	0.02
δ-BHC	ND	ND	0.01	ND	ND
OXYCHLORDANE	0.15	0.28	0.31	0.60	0.40
HEPTA EPOXIDE	0.09	0.18	0.20	0.32	0.28
Γ-CHLORDANE	ND	ND	ND	0.01	ND
t-NONACHLOR	0.07	0.20	0.23	0.42	0.34
TOXAPHENE	ND	ND	ND	ND	ND
AROCHLOR 1242	ND	ND	ND	ND	ND
AROCHLOR 1248	ND	ND	ND	ND	ND
AROCHLOR 1254	5.1	4.6	5.7	2.0	1.3
AROCHLOR 1260	6.7	5.4	5.6	10.9	1.4
o, p'-DDE	ND	ND	ND	ND	ND
α-CHLORDANE	ND	ND	ND	ND	ND
p, p'-DDE	2.0	7.1	8.0	11.7	6.0
DIELDRIN	0.9	0.59	0.63	0.74	1.1
o, p'-DDD	ND	ND	ND	ND	ND
ENDRIN	0.02	0.01	ND	ND	0.01
c-NONACLOR	ND	ND	0.05	0.08	0.04
o, p'-DDT	ND	ND	ND	ND	ND
p, p'-DDD	0.02	0.03	0.04	0.03	ND
p, p'-DDT	0.02	0.05	0.02	0.06	0.05
MIREX	0.08	0.09	0.10	0.21	0.14
DICOFOL	ND	ND	ND	ND	ND

ND = no detection
* = egg cracked, data suspect

that DDE-PCB mixtures fed to mallards and American kestrels resulted in an increased rate of egg breakage compared to birds fed DDE alone (Lincer, 1972). The formation of organic cores within eggshell material is a result of PCB contamination and thus contributes to a decrease in the strength of the shell (Greenburg et al., 1979). The geometric mean Arochlor 1260 concentration was found to be 5.2 ppm (adjusted wet weight), while Arochlor 1254 was found to be 3.5 ppm in this study. While these concentrations are not inordinately elevated, the PCB concentrations observed may contribute to the reproductive problems observed in eastern peregrines.

The use of organophosphate and carbamate pesticides has increased over recent years largely due to the bans and restrictions placed on organochlorine compounds. Organophosphate and carbamate pesticides are cholinesterase inhibitors, affecting the central nervous system and/or the neuromuscular junction (Ware, 1993). Various classes of cholinesterase inhibitors have been implicated in raptor mortality, including compounds such as parathion (Stone et. al., 1984), carbofuran (Balcomb, 1983), and fenthion (Henny et. al., 1987). Although many of these cholinesterase inhibitors are known to be toxic to many species of birds, little is known in regard to the toxicity of these compounds to Falconiformes (Wiemeyer, 1991). No carbamate or organophosphate compounds were detected in this survey. This result was expected since these compounds have a low environmental persistence. In addition, the high rate of avian metabolism makes the analysis of gut contents the most accepted method of documenting exposure to these compounds.

Inorganic Compounds

The data available concerning metals as contaminants in bird eggs is minimal. The bulk of the literature concerns birds other than raptors, therefore this information has limited applicability to peregrines. The results of the metal analysis for this study are presented in Tables 3 and 4.

Some studies have linked mercury and selenium contamination with adverse effects on avian health or reproduction (Ohlendorf and Fleming, 1988). Mercury residues were

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Table 3. Metal concentrations in peregrine falcon eggs collected from Virginia, July 1992. Concentrations are expressed in parts-per-million, dry weight.

ID NUMBER	CBI01	CBI02	JRF01	JRF02	WPI01	YRB01
STATE	VA	VA	VA	VA	VA	VA
MOISTURE (%)	84.13	79.74	81.4	81.35	75.39	81.56
Compound						
Al	10.6	8.13	6.74	8.43	17.4	17.2
As	ND	ND	ND	ND	ND	ND
B	ND	ND	ND	0.996	0.758	1.29
Ba	ND	ND	ND	ND	ND	ND
Be	ND	ND	ND	ND	ND	ND
Cd	ND	ND	ND	ND	ND	ND
Cr	ND	ND	ND	ND	3.08	1.48
Cu	2.35	2.36	2.92	0.933	4.48	3.82
Fe	53.8	52.3	63	25.3	129	98
Hg	2.547	2.99	ND	ND	1.968	0.2546
Mg	400	189	286	178	394	837
Mn	0.519	0.461	1.19	ND	1.69	1.39
Mo	ND	ND	ND	0.495	ND	ND
Ni	ND	ND	ND	ND	1.93	0.92
Pb	ND	ND	0.603	0.901	0.968	0.862
Se	2.36	2.46	1.15	1.25	2.93	2.19
Sr	0.562	0.371	1.81	0.645	1.35	1.08
V	ND	ND	ND	ND	ND	ND
Zn	25.2	17.5	44.7	16.2	61.8	53.5

ND = No detection

Table 4. Metal concentrations in peregrine falcon eggs collected from Maryland and West Virginia, July 1992. Concentrations are expressed in parts-per-million, dry weight.

ID NUMBER	CBB01	CLI01	CLI02	SMI01	GCS01*
STATE	MD	MD	MD	MD	WV
Moisture (%)	78.36	79.73	81.16	85.9	53.0
Compound					
Al	10.3	13.9	13.9	10.1	8.91
As	ND	ND	ND	ND	ND
B	ND	ND	ND	ND	ND
Ba	ND	ND	0.554	ND	ND
Be	ND	ND	ND	ND	ND
Cd	ND	ND	ND	ND	ND
Cr	ND	ND	2.62	ND	1.01
Cu	2.26	2.97	3.7	2.29	1.76
Fe	50.6	70.7	93.7	43.5	112
Hg	ND	0.7632	1.01	1.111	0.3142
Mg	424	533	548	28.7	166
Mn	0.524	0.486	1.1	0.521	1.72
Mo	ND	0.567	ND	ND	ND
Ni	ND	ND	1.12	ND	ND
Pb	ND	ND	ND	ND	1.03
Se	1.57	1.72	2.36	2.04	2.44
Sr	0.719	0.834	0.882	0.332	0.335
V	ND	ND	ND	ND	ND
Zn	37.9	31.3	35.8	47.3	54.3

ND = No detection
* = egg cracked, data suspect

slightly elevated in the three of the 11 eggs. The geometric mean mercury concentration for all of the coastal peregrine eggs was 0.14 ppm, wet weight. Eggs from the Eastern Shore of Virginia displayed the highest concentrations of mercury (maximum value of 0.61 ppm, wet weight). Eggshell thickness in American kestrels does not appear to be reduced by elevated mercury concentrations (Peakall and Lincer, 1972). However, Heinz (1979) found that mallards (Anas platyrhynchos) fed a diet containing 0.5 ppm of mercury produced eggs with concentrations of 0.79 to 0.86 ppm of mercury. These mallards also displayed lower rates of productivity. Similarly, pheasants (Phasianus colchicus) fed dietary mercury resulted in eggs with mercury concentrations of 0.9 to 3.1 ppm, and showed high embryo mortality, and produced fewer eggs than controls (Span et. al., 1972). Fimreite (1971) found significantly reduced hatchability in eggs containing mercury residues of 0.5 to 1.5 ppm. In general, 0.5 ppm of mercury is considered the level which may result in adverse effects on reproduction in raptors (Wiemeyer, et. al., 1984). Since only one peregrine egg sampled displayed a concentration above 0.5 ppm, the impact of mercury may not be a major concern. However, the concentrations observed in the Eastern Shore of Virginia peregrine eggs are sufficiently elevated to warrant additional monitoring.

Selenium is rapidly accumulated by birds but also quickly eliminated (Heinz, 1993). Selenium (as selenomethione) concentrations of 5 ppm wet weight in mallard eggs have reportedly resulted in harm to the embryo (Heinz et. al., 1989). Results of this survey found the geometric mean selenium concentration in the peregrine falcon eggs to be 0.29 ppm, adjusted wet weight. The largest residue concentration reported in this study was 0.5 ppm, adjusted wet weight. Since the values observed were well below those found to result in adverse effects to bird embryos, selenium does not appear to be a contaminant of concern to this population of peregrines.

Numerous studies have been conducted to investigate the effects of lead on waterfowl (Dieter, 1979; Di Giulio and Scanlon, 1984). Lead poisoning has been reported in raptors but is typically linked with ingestion of lead shot in food items (Custer

et. al., 1984). American kestrels (Falco sparverius) fed 50 mg/kg lead showed no adverse effects on survival, fertility, or eggshell thickness (Pattee, 1984). Little information is available on the egg concentrations associated with adverse effects on avian health. However, trialkylleads and dialkylleads cross biological membranes rapidly and have been found in developing embryos (Forsyth, et. al., 1985). The peregrine eggs in this study displayed a geometric mean concentration of 0.438 ppm, dry weight. Since there is no historical information available on lead concentrations in raptor eggs, there is no way to adequately evaluate this data.

The remaining metals analyzed appear to be present in low levels. Compounds detected in all samples included aluminum (range 6.74 to 17.4 ppm, dry weight), copper (0.933 to 4.48 ppm), iron (25.3 to 129 ppm), magnesium (28.7 to 837 ppm), strontium (0.332 to 1.81 ppm), and zinc (16.2 to 61.8 ppm). Again, there are no studies of metal concentrations in bird eggs to allow comparison with these results. However, most metals do not tend to biomagnify, therefore the impacts to developing embryos from these compounds should be minimal.

Eggshell thinning

The results of the egg shell thinning analysis are presented in Table 5. Egg shell thinning was found in the eggs sampled, ranging from 4.8 to 26.9 percent (%). Two eggs taken from nests on Eastern Shore of Virginia islands displayed the largest degree of thinning (22.9% and 26.9%). Failure of peregrine eggs has been reported to be associated with egg shell thinning of 17% or more (Peakall and Kiff, 1988), although Fyfe et. al. (1988) found thinning indexes as low as the 14% level resulted in zero productivity in peregrines. Five of the eleven eggs showed a thinning index greater than 14%. The remaining eggs displayed thinning similar to those rates observed in the eastern United States (range 10% to 20%, mean approximately 12%) (L. Kiff, Western Vertebrate Association, Camarillo, CA; pers. comm.). Eggs that displayed the greatest degree of thinning did not have the highest concentrations of DDE.

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Table 5. Egg shell thickness and percentage thinning of peregrine falcon eggs from Maryland, Virginia, and West Virginia, July 1992. Thickness is expressed in millimeters (mm), thickness index, and thinning as a percentage (%).

State	Site Id.	Thickness (mm)	Thickness Index	% Thinning
VA	JRF01	0.330	1.809	12.0
VA	JRF02	0.357	1.976	4.8
VA	CBI01	0.274	1.460	26.9
VA	CBI02	0.303	1.752	18.2
VA	WPI01	0.289	1.640	22.9
VA	YRB01	0.352	1.983	6.1
MD	CBB01	0.355	2.004	5.3
MD	CLI01	0.331	1.828	11.7
MD	CLI02	0.302	1.648	18.5
MD	SMI01	0.319	1.788	14.9
WV	GCS01	0.331	1.765	11.7

CONCLUSIONS AND RECOMMENDATIONS

It appears that environmental contaminants (DDE, dieldrin, and mercury) are present at slightly elevated concentrations in peregrine falcon eggs collected from coastal Virginia and Maryland. Reproductive problems have been associated with the levels observed in these eggs. Egg shell thinning was also observed in a number of eggs. However, there does not appear to be any correlation of these contaminant values with egg shell thinning. This effect may be a result of the small sample size. Whether the effects of the contaminants alone have contributed to the failure of Virginia and Maryland nests is not clear. Additional sampling and analysis of eggs from these and other locations is recommended to elucidate the processes contributing to reproductive problems in peregrines.

In addition, a database consisting of past and future contaminant surveys of peregrines should be established. This database should include information relating to the productivity of each population. Without this type of organization of data, the fate of the eastern U.S. peregrine populations can not clearly be assessed.

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APPENDIX A

COMPOUNDS ANALYZED

Metals

Aluminum (Al)
Arsenic (As)
Antimony (Sb)
Barium (Ba)
Beryllium (Be)
Boron (B)
Cadmium (Cd)
Chromium (Cr)
Copper (Cu)
Iron (Fe)
Lead (Pb)
Magnesium (Mg)
Manganese (Mn)
Mercury (Hg)
Molybdenum (Mo)
Nickel (Ni)
Selenium (Se)
Silver (Ag)
Strontium (Sr)
Thallium (Tl)
Tin (Sn)
Vanadium (V)
Zinc (Zn)

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Organochlorine Compounds Analyzed

HCB (Hexachlorobenzene)
α-BHC (benzene hexachloride)
Γ-BHC (benzene hexachloride)
β-BHC (benzene hexachloride)
BHC (benzene hexachloride)
Oxychlordane
Heptachlor
Heptachlor Epoxide
Methoxychlor
c-Chlordane
t-Nonachlor
Toxaphene
PCBs (Polychlorinated biphenyls (Arochlors))
o, p'-DDE (dichlorodiphenyldichloroethylene)
t-Chlordane
p, p'-DDE (dichlorodiphenyldichloroethylene)
Dieldrin
Aldrin
o, p'-DDD (1,1-dichloro-2,2-bis(p-chlorophenyl) ethanex)
Endrin
c-nonachlor
o, p'-DDT (dichlorodiphenyltrichloroethane)
p, p'-DDD (1,1-dichloro-2,2-bis(p-chlorophenyl) ethanex)
p, p'-DDT (dichlorodiphenyltrichloroethane)
Mirex

Organophosphates and Carbamates

EPN (O-ethyl O-(4-nitrophenyl) phenylphosphonothionate)
Acephate
Aldicarb
Azinphos-methyl
Carbaryl
Carbofuran
Chlorpyrifos
Coumaphos
Demeton
Diazinon
Dichlovos
Dichrotophos
Dimethoate
Disulfoton
Ethoprop
Famphur
Fensulfothion
Fenthion
Malathion
Methamidophos
Methiocarb
Methomyl
Methyl parathion
Mevinphos
Monocrotophos
Oxamyl
Parathion
Phorate
Terbufos
Trichlorfon

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