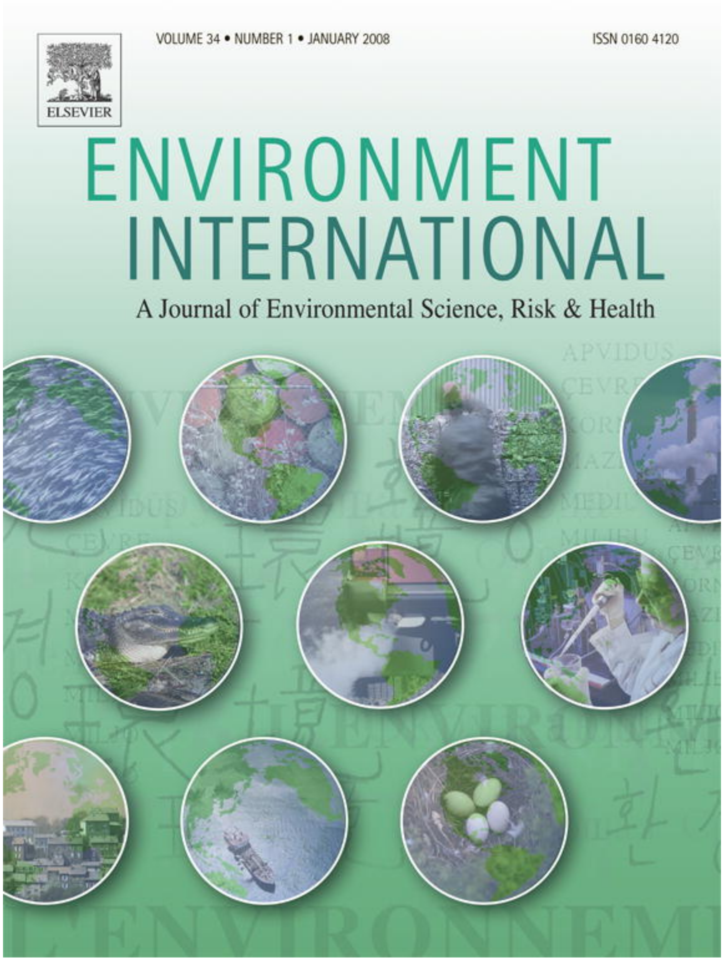
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Persistent environmental pollutants in eggs of aplomado falcons from Northern Chihuahua, Mexico, and South Texas, USA

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Abstract

The northern aplomado falcon (*Falco femoralis septentrionalis*) disappeared from south Texas in the 1940s. Due to great success in the release of captive-reared aplomado falcons in south Texas, there are currently more than 40 established nesting pairs in the region. Addled eggs from aplomado falcons nesting in northern Chihuahua and south Texas were analyzed to determine organochlorine (OC) and inorganic element contaminant burdens and their potential association with egg failures and effects on reproduction. Among the OCs, DDE [1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene] was present at the highest concentrations (range 262–21487 ng/g wet weight) followed by polychlorinated biphenyls (PCBs, range 88–3274 ng/g ww). DDE was greater ($P=0.03$) in eggs from El Sueco (Chihuahua, Mexico) than in those from Matagorda Island (Texas, USA). DDE concentrations in eggs of aplomado falcons from El Sueco were elevated; however, reproductive success in the two Chihuahuan populations did not seem to be affected by DDE. DDE and metals in potential avian prey of the aplomado falcon from Matagorda Island were very low and below levels in the diet at which some negative effects might be expected. Except for mercury (Hg), metal concentrations in eggs were fairly low and were not different among locations in Chihuahua and south Texas. Hg was somewhat elevated and was greater ($P<0.001$) in Texas than in the Chihuahua locations. Periodic monitoring of Hg concentrations in addled eggs of aplomado falcons in south Texas is recommended to continue evaluating potential negative effects on their recovery.

Keywords: Aplomado falcon; Endangered species; Contaminants; DDE; Hg; Northern Mexico; South Texas

1. Introduction

The historical range of the northern aplomado falcon (*Falco femoralis septentrionalis*) included desert grassland and coastal prairie habitat in Arizona, New Mexico, and Texas; however, by the 1940s, the species had disappeared from most of its U.S. range, probably due to the conversion of grasslands to farmland, encroachment of woody vegetation, and pesticide contamination in both the U.S. and eastern Mexico (Kiff et al., 1980; Keddy-Hector, 2000). In 1986, the aplomado falcon was listed as endangered in the United States (U.S. Fish and Wildlife Service, 1990).

A captive breeding program for the northern aplomado falcon was initiated in 1977 by the Chihuahuan Desert Research Institute (Cade et al., 1991) and has been continued to the present date by The Peregrine Fund (2005). This recovery program has resulted in the release of 1268 captive-bred falcons in Texas by 2006 (The Peregrine Fund, unpubl. data). Aplomado falcons have been released primarily at the Laguna Atascosa and Matagorda Island National Wildlife Refuges (LANWR and MINWR), and most recently on several private ranches in west Texas and New Mexico. In 1995, a nesting pair of aplomado falcons was observed in Texas for the first time in over fifty years

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(Jenny et al., 2004). By 2006 there were 40 occupied territories (The Peregrine Fund, unpubl. data).

In the early 1990s, an aplomado falcon population was discovered in the desert grasslands of northern Chihuahua, Mexico (Montoya et al., 1997). This population was considered independent of any other populations in eastern Mexico and south Texas, and has been monitored since then in order to understand the ecology of aplomado falcons in desert grasslands of Mexico (Macias-Duarte et al., 2004). Aplomado falcons were first released on private ranches in west Texas in 2002 (The Peregrine Fund, unpubl. data). During that year, an un-banded juvenile falcon which may have dispersed from the Chihuahua population was seen in the area. The Chihuahuan and west Texas populations are as close as 100 km; thus, it is likely that future exchange will occur between the two populations.

The Lower Rio Grande Valley (LRGV) is one of the most intensively farmed areas in south Texas (U.S. Fish and Wildlife Service, 1986). Since the early 1900s, 95% of the native habitat has been cleared, with the majority of land under agricultural production (Jahrsdoerfer and Leslie, 1988). Also, the LRGV has seen a recent dramatic increase in urban and industrial growth. Although concentrations of persistent organochlorine (OC) pollutants have declined significantly in the last decade, recent studies suggest that DDE [1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene] a metabolite of DDT [1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane] is still prevalent in wildlife (Mora et al., 2006; Wainwright et al., 2001). Mercury (Hg) and selenium (Se) are two other persistent contaminants that are widely observed in wildlife on the U.S. side of the Rio Grande/Rio Bravo (Mora and Wainwright, 1998).

Potential prey of the aplomado falcon was collected from LANWR in 1994. Analytical results showed that while OCs were low in most prey items, some meadowlarks (*Sturnella magna*) had elevated levels of Hg (Mora et al., 1997). Addled eggs collected from the first pairs of aplomado falcons nesting near Brownsville, TX in 1995 and 1996 had Hg levels of 1.5 and 4.1 µg/g dry weight (dw) respectively (Mora et al., 1997). Mercury concentrations that affect reproduction vary among raptors; however, concentrations greater than 3 µg/g dw have been reported to affect some species (Newton and Haas, 1988).

Recovery plan objectives for the aplomado falcon include monitoring contaminant residues in typical falcon prey and identifying sources of contaminants and their related effects (U.S. Fish and Wildlife Service, 1990). This study is a follow-up to a previous study (Mora et al., 1997) and the objective is to determine if aplomado falcons released in south Texas are accumulating contaminants to potentially hazardous levels that may pose a risk to their reproductive success. We provide contaminant residues in potential prey of the aplomado falcon in Matagorda Island and compare contaminant residues in eggs of aplomado falcons from south Texas with those observed in a population in northern Chihuahua, Mexico. The objective was to determine if persistent OC pollutants were greater in an established population in Mexico than in those in newly established pairs in south Texas. It should be emphasized that contaminant levels may be higher in addled than in viable eggs, thus, the data could be biased; however, such data are still useful for assessing potential associations with egg failures and effects on reproduction.

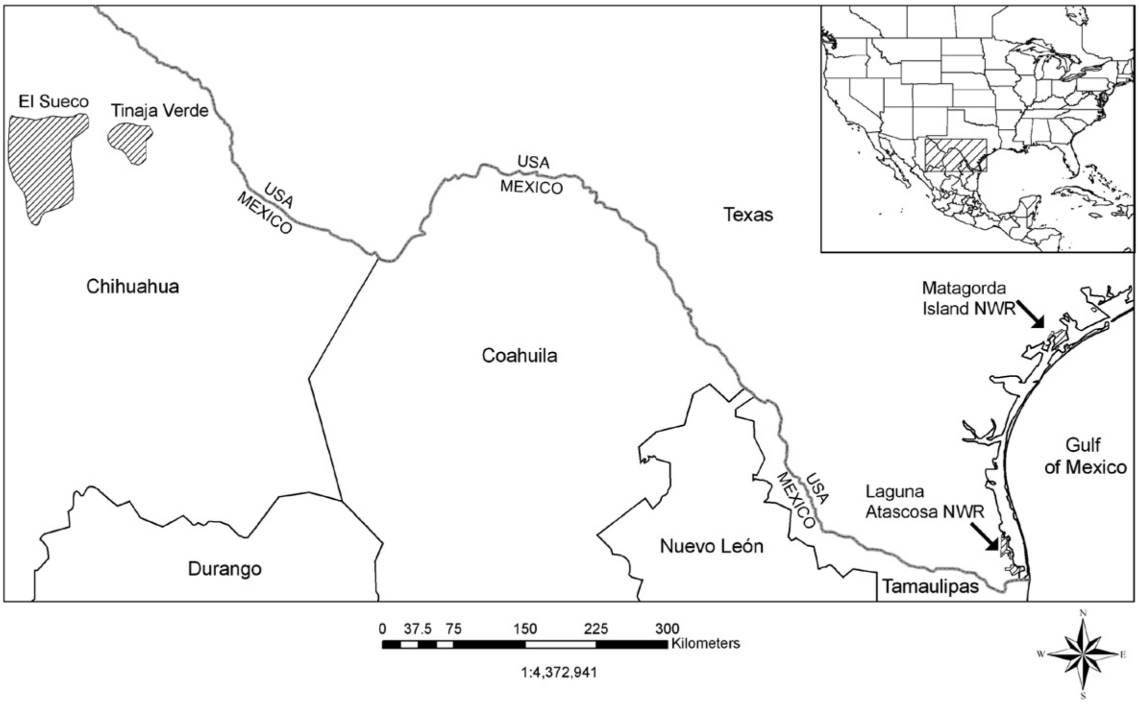

Fig. 1. Map of south Texas and northern Mexico showing the locations where eggs were collected, Matagorda Island NWR and Laguna Atascosa NWR in the USA, and El Sueco and Tinaja Verde in Mexico.

2. Materials and methods

2.1. Study area

The study area included the desert grasslands of north-central Chihuahua, Mexico and coastal prairies in southern Texas, USA. The nesting sites in Chihuahua were located in El Sueco and Tinaja Verde in the municipalities of Ahumada and Coyame (Fig. 1). Climate is temperate semiarid and temperate arid in this region. The nesting sites in Chihuahua were dominated by open grasslands and open halophyte grasslands interspersed with Chihuahuan desert scrublands. The land use practice at the Chihuahuan nest sites was predominantly ranching, although, some farming occurred in the vicinity of nest sites. The south Texas area encompassed coastal savannah in the vicinity of Laguna Atascosa National Wildlife Refuge in Cameron and Willacy Counties and Matagorda Island National Wildlife Refuges in Calhoun County. Land use practices near nests were predominantly ranching with farming also occurring near some nest sites.

2.2. Sample collection

We collected addled aplomado falcon eggs from 1997 to 2003 at El Sueco and Tinaja Verde in northern Chihuahua, Mexico, and from 1999 to 2003 at Laguna Atascosa and Matagorda Island National Wildlife Refuges in south Texas (Fig. 1). All eggs were collected during the breeding season from April to July. We analyzed 29 individual and 4 pooled sample eggs from Chihuahua and 4 individual and 3 pooled sample eggs from south Texas for OC contaminants and inorganic elements. The pooled samples consisted of eggs from the same clutch (2–3 eggs) and were from MINWR (3), Sueco (3), and Tinaja (1). The eggs were placed in egg cartons or in glass jars and stored temporarily at −20 °C. In the laboratory, the egg contents were placed on chemically cleaned glass jars and stored at −80 °C until chemical analysis. The egg volume was not determined because of the advanced stage of decomposition and minor cracks in some eggs. We washed the eggshells with distilled water and acetone to remove leftover egg residues and dried them at room temperature. We measured eggshell thickness (including the membrane) around the equator with the use of a micrometer (Starrett®, Athol, MA) and recorded the average of three measurements.

During 2004, we collected selected avian prey of the aplomado falcon on Matagorda Island. Four to five individuals of each of the following species were collected with stainless steel shot: mourning dove (*Zenaida macroura*), common nighthawk (*Chordeiles minor*), northern mockingbird (*Mymus polyglottos*), red-winged blackbird (*Agelaius phoeniceus*), eastern meadowlark (*S. magna*), and great-tailed grackle (*Quiscalus mexicanus*). Aplomado falcons also prey occasionally on insects; thus, we used sweep nets to collect four 5–10 g samples of insect biomass, mainly dragonflies and cicadas. The insect samples were placed directly into chemically cleaned glass jars and stored at −20 °C. The bird carcasses and insect biomass were stored on ice in Whirl-pak bags and were processed within 8 h of collection. We weighed and plucked the whole bodies and removed the bill, feet, wing tips and gastrointestinal tract. The remaining sample was placed in a chemically cleaned glass jar and stored at −20 °C until chemical analysis. We also analyzed one aplomado falcon carcass which was collected during 1997 at the LANWR.

2.3. Organochlorine analysis

The egg contents, bird carcasses, and invertebrate samples were analyzed for organochlorines, including PCBs, by TDI Brooks International, College Station, Texas, USA, according to methods previously described (Lauenstein and Cantillo, 1993; U.S. Environmental Protection Agency, 1997, 2001). Bird carcasses were ground and homogeneized with a Hobhart meat grinder. Egg contents were homogeneized with a Waring Blender. Approximately 1 g of homogenate was taken for moisture determination by drying in an oven at 105 °C until constant weight. A portion of the remaining egg and carcass homogenate was dried with sodium sulfate and then extracted with dichloromethane. The extract was concentrated to approximately 3 mL and then a 100 μL aliquot was used for lipid determination. The extract was then cleaned-up with a silica gel/alumina chromatography column and high performance liquid chromatography (HPLC). The cleaned up extract was analyzed for selected OCs and PCBs by gas chromatography/electron capture detection (GC/ECD), with a HewletPackard (HP), Model 5890 GC (Palo Alto, CA). Relative percent difference between duplicates was less than 10%, and spike recoveries of all OCs averaged 94±10%. Detection limits varied with each sample, but were approximately 1 ng/g wet weight (ww). On average, water content in eggs was approximately 70%; however, eggs from Laguna Atascosa were fresher and had approximately 80% moisture; thus, there was some water loss in addled and broken eggs. Total PCBs were calculated as the sum of 18 PCB congeners, IUPAC numbers 8, 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, 206, and 209. The organochlorine data in eggs are reported on a wet weight basis and were not adjusted for water loss.

2.4. Metals and metalloids

The egg contents, bird carcasses, and invertebrate samples were analyzed for heavy metals and metalloids by the Trace Element Research Laboratory, Texas A&M University, College Station, Texas, USA. The homogenates were freeze dried in order to minimize loss of analytes, to facilitate subsequent sample preparation, and to determine moisture content. Dried samples were homogenized to a fine powder by cryomilling. Approximately 0.20 g of powdered tissue was weighed into a reaction vessel and 3 mL of HNO_3 was added. The closed reaction vessel was heated to approximately 100 °C until digestion was nearly complete. One to 2 mL 30% H_2O_2 was added and the sample was heated to 80 °C to complete digestion. One mL HCl was added and the sample heated to 80 °C to complex certain analytes, and samples were then diluted to a final volume of 20 mL with deionized distilled water and stored in

Table 1
Organochlorines (geometric means and ranges, ng/g wet weight) and moisture and lipid content (arithmetic means±SD, percent) in eggs of aplomado falcons from El Sueco and Tinaja Verde in northern Chihuahua, Mexico (1997–2003), and Laguna Atascosa (LANWR) and Matagorda Island (MINWR) in southern Texas, United States (1999–2003)

Location	*n*	% Moisture	% Lipid	HCB	HCH	Heptachlor epoxide	Oxychlordane	Mirex	*p,p*'-DDE	PCBs
LANWR	3	81.1±1.8	6.8±0.8	1.7 (1–3) B	1.6 (1–5) A	1.9 (1–3) B	8.1 (5–13) AB	21.1 (10–38) AB	1242 (924–1544) AB	869 (431–3274) A
MINWR	4	65.9±29.7	14.0±9.8	6.0 (21–83) AB	2.2 (1–10) A	23.9 (4–1347) A	64.7 (18–1627) A	100 (59–290) A	821 (262–6131) B	1228 (564–2780) A
Sueco	26	65.6±19.0	18.0±11.9	7.7 (2–48) A	7.1 (2–43) A	10.3 (2–44) AB	14.4 (2–67) B	15.4 (12–74) B	3487 (648–21487) A	323 (104–1550) B
Tinaja	7	63.9±26.0	15.2±11.4	8.8 (5–16) A	5.9 (1–40) A	5.6 (3–12) AB	8.6 (3–59) B	13.1 (6–32) B	2055 (753–8005) AB	221 (88–618) B

Within columns, values not sharing the same letter are significantly different.

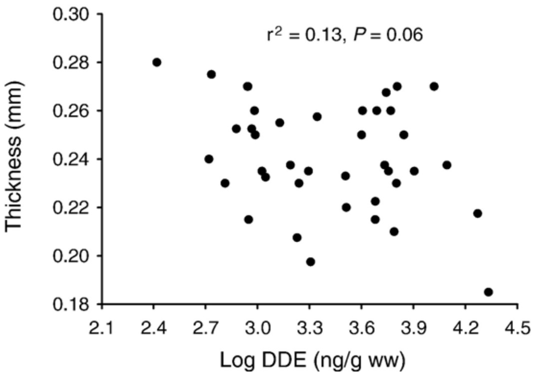

Fig. 2. Relationship between eggshell thickness and DDE concentrations in eggs of aplomado falcons from southern Texas and northern Chihuahua.

1 oz. polyethylene bottles for analysis by instrumental techniques. With the exception of Hg, most analyte levels were determined by more than one technique. Most elements (Al, B, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, S, Sr, Ti, Zn) were analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES). Additional elements (Ag, As, Cd, Pb, V) were analyzed by inductively coupled plasma mass spectroscopy (ICP-MS). Selenium was analyzed by atomic fluorescence spectroscopy (AFS). Mercury was analyzed by cold-vapor atomic absorption spectroscopy (CVAAS). Moisture content was determined by weight loss upon freeze-drying, and is expressed as weight percent of the original wet sample. Approximately 1 g of homogenate was frozen and then dried under vacuum until a constant weight was attained.

2.5. Statistical analysis

The OC data for eggs were log transformed to meet the assumptions of normality and homogeneity of variance. The inorganic element data were normally distributed. The composite samples were treated like one single sample since they consisted of eggs from the same clutch. We used a general linear model (GLM) analysis of variance (ANOVA) of log transformed data to determine differences in concentrations of OCs among years within El Sueco region, among the four main regions, and among potential avian prey of the aplomado falcon from Matagorda Island. We used simple linear regression to determine the relationship between concentrations of DDE and eggshell thickness, and analysis of covariance (ANCOVA) to determine the effect of year on location differences in concentrations of OCs. Within El Sueco, data for DDE were grouped by years (1997–1999, $n=13$ and 2000–2003, $n=13$) to determine potential differences between early and late years (t test, log transformed data) in relation to cotton production. We determined differences in concentrations of metals and metalloids in eggs, among locations, and among potential avian prey from Matagorda Island with the GLM method. Since most eggs from aplomado falcons in the USA were collected during 2002–2003, we also compared (t-test) the USA data set with the data from eggs that were collected in Mexico during the same years. We used SAS® software (ver 9.1, SAS Institute, Cary NC, USA) for all the statistical analyses. Statistical significance was set at $P \leq 0.05$.

3. Results

3.1. Contaminants in eggs

Hexachlorobenzene (HCB), hexachlorocyclohexane (HCH), heptachlor epoxide, oxychlordane, mirex, *p,p*'-DDE and PCBs were all measured at above detection limits in 100% of the samples (Table 1). *p,p*'-DDT was below the method detection limit in 73% of the samples and it was below 4 ng/g ww in the rest of the samples, except for one composite egg sample from Matagorda which had 59 ng/g ww. HCB concentrations were greater ($F_{3,36}=2.9$, $P<0.05$) in aplomado falcon eggs from the Chihuahua locations than in those from Laguna Atascosa, but were similar to those from Matagorda. Concentrations of heptachlor epoxide were greater ($F_{3,36}=3.0$, $P=0.02$) in eggs from Matagorda Island than in those from Laguna Atascosa, but were similar to those from the Chihuahua locations. Oxychlordane and mirex also were greater ($F_{3,36}=5.8$, 12.9, $P<0.001$) in eggs from Matagorda Island than in those from the two Chihuahua locations. DDE and PCBs were present at greater concentrations than all other OCs analyzed. There were no significant differences among years in concentrations of DDE or PCBs in eggs of aplomado falcons from El Sueco, which was the only region from which enough eggs were available for comparisons among years. Also, when DDE concentrations were grouped by early vs late years of collection, DDE concentrations were 1.5 times greater in eggs from 1997–1999 (geometric mean=4467 ng/g ww) than in those from 2000–2003 (geometric mean=2722 ng/g ww) but were not significantly different. Among regions, DDE concentrations were greater ($F_{3,36}=3.3$, $P=0.03$) in eggs from El Sueco than in those from Matagorda Island, but were similar to those of Tinaja Verde in Chihuahua and Laguna Atascosa in Texas (Table 1). Maximum DDE concentrations in eggs from Texas were 6131 ng/g ww, whereas those from El Sueco in Chihuahua reached 21,487 ng/g ww. At El Sueco, approximately 65% (17 of 26) of the eggs contained DDE residues greater than 2000 ng/g ww. DDE residues in eggs of falcons from the Tinaja region were more similar to those of both regions in south Texas. Concentrations of PCBs showed an opposite pattern and were higher ($F=5.0$, $P=0.005$) in eggs from Matagorda Island and Laguna Atascosa in the U.S. than in those from El Sueco and Tinaja Verde in Chihuahua.

Eggshell thickness tended to decrease slightly with increased concentrations of DDE but not significantly ($R^2=0.13$, $P=0.06$, Fig. 2). We estimated percent eggshell thinning in relation to concentrations of DDE by considering 0.279 mm as the normal thickness of an egg laid prior

Table 2
Metals and metalloids (arithmetic means±SD, μg/g dw) in eggs of aplomado falcons from El Sueco and Tinaja Verde in northern Chihuahua, Mexico (1997–2003), and Laguna Atascosa (LANWR) and Matagorda Island (MINWR) in southern Texas, United States (1999–2003)

Location	n	As	Ba	Cu	Hg	Mn	Pb	Se	Sr	Zn
LANWR	3	0.85±0.6	0.17±0.14	2.48±0.08	1.47±1.2 A	1.21±1.17	0.04±0.05	3.04±0.52	3.72±3.1	38.1±14.5
MINWR	4	0.74±0.58	0.35±0.07	2.46±0.51	1.33±0.09 A	1.2±0.49	0.03±0.02	2.51±0.15	1.57±1.51	40±7.3
Sueco	18	0.63±0.39	0.38±0.26	3.1±0.54	0.46±0.24 B	2.0±1.4	0.02±0.02	2.87±0.69	2.12±1.36	42.8±12.6
Tinaja	6	0.69±0.37	0.40±0.40	2.78±0.33	0.74±0.31 AB	2.04±1.45	0.04±0.03	3.02±0.67	2.43±2.53	41.4±9.4

Except for Hg, concentrations were not significantly different among locations. For Hg, concentrations for locations that do not share the same letter are significantly different.

Table 3
Body mass (g), lipid and moisture percent (arithmetic mean±SD) and organochlorine content (geometric mean+range, ng/g wet weight) in potential avian and invertebrate prey of the aplomado falcon in Matagorda Island NWR, Texas

Species	*n*	Body mass (g)	Moisture (%)	Lipid (%)	*p,p*'-DDE	PCBs
Mourning Dove	5	85.2± 6.1	70.7±0.7	3.6±0.7	0.4 (0.1–1.1) CD	7.0 (6.8–7.3) C
Common Night Hawk	5	47.8± 4.1	66.6±2.3	11.6±3.7	1.1 (0.5–2.2) BCD	23.4 (17.7–34.9) A
Northern Mockingbird	4	37.6± 2.7	68.9±1.7	5.6±0.8	24.1 (3.0–828) A	21.7 (9.6–94.2) AB
Red-winged Blackbird	5	45.2± 1.0	70.8±0.8	3.2±0.8	5.0 (1.6–54.5) AB	12.8 (8.6–19.2) ABC
Eastern Meadowlark	5	83.0± 11.6	71.1±0.4	3.9±0.8	4.0 (1.9–6.4) ABC	16.2 (12.3–23.3) ABC
Great-Tailed Grackle	5	92.6± 16.3	71.1±0.9	4.0±0.8	2.7 (0.6–6.8) ABCD	13.1 (6.8–23.9) ABC
Invertebrates	4	ND	67.8±2.3	5.2±5.7	0.3 (0.1–0.5) D	8.7 (6.8–12.3) BC

to the use of DDT (Kiff et al., 1980). The eggs from Texas and Chihuahua ranged in thickness from 0.185 mm to 0.280 mm, equivalent to 33.7% and 0% thinning compared with pre-DDT eggs. One egg from El Sueco in Chihuahua contained 21487 ng/g ww DDE and was 33.7% thinner than the reference egg.

Arsenic (As), Barium (Ba), Copper (Cu), Hg, manganese (Mn), lead (Pb), Se, strontium (Sr), and Zinc (Zn) were detected in 100% of the eggs from the four locations (Table 2). Concentrations of inorganic elements in eggs were not significantly different among locations, except for Hg, which was higher ($F_{3,27}=9.6$, $P<0.001$) in eggs of aplomado falcons from Matagorda and Laguna Atascosa in the U.S. than in those from El Sueco in Chihuahua, Mexico (Table 2). Mercury concentrations in eggs from the U.S. locations were also nearly two times greater than those from Tinaja Verde, but were not significantly different.

3.2. Contaminants in Carcass

One female aplomado falcon released at the LANWR in August 1997 was found dead under the hack tower at the refuge on March 28, 2000 and contained 6.5 µg/g ww of DDE in carcass.

3.3. Contaminants in prey

Concentrations of all OCs, including *p,p*'-DDE and PCBs in potential invertebrate and avian prey of the aplomado falcon from Matagorda Island were rather low (Table 3). Northern mockingbirds had significantly higher concentrations of DDE ($F_{6,26}=7.51$, $P<0.0001$) than common nighthawks and mourning doves. Common nighthawks had significantly higher concentrations of PCBs ($F_{6,26}=4.6$, $P=0.003$) than mourning doves. There were no significant differences in concentrations of Cr and Mn among the six bird species (Table 4). Great-tailed grackles had significantly greater concentrations of As ($F_{5,23}=3.7$, $P=0.013$) than common nighthawks, greater concentrations of Hg ($F_{5,23}=10.7$, $P<0.0001$) than nighthawks, mockingbirds, and mourning doves, Sr ($F_{5,23}=10.9$, $P<0.0001$) than all other species, and greater concentrations of Zn ($F_{5,23}=19.8$, $P<0.0001$) than nighthawks and mourning doves. Northern mockingbirds also had higher concentrations of Ba ($F_{5,23}=8.03$, $P=0.0002$) than most other species, and Pb ($F_{5,23}=2.72$, $P=0.045$) than nighthawks and grackles. Common nighthawks had greater concentrations of Cd ($F_{5,23}=21.4$, $P<0.0001$) than most other species; and red-winged blackbirds had greater concentrations of Cu ($F_{5,23}=7.75$, $P=0.0002$) than nighthawks, mourning doves, and grackles, and greater concentrations of Se ($F_{5,23}=6.2$, $P=0.0009$) than doves and nighthawks. In general, concentrations of DDE and PCBs (Table 3), and As, Hg, Se, and Sr (Table 4) tended to be greater in birds than in invertebrates; however, Cu, Mn, and Zn were higher in invertebrates than in birds (Table 4).

4. Discussion

Our results indicate that most OCs are near detection limit levels in eggs of aplomado falcons in the Lower Rio Grande Valley, except for DDE and PCBs. Two aplomado falcon eggs collected during 1995 and 1996 at Laguna Atascosa had mean DDE concentrations of 1.6 µg/g ww (Mora et al., 1997), which is within the range of those detected in eggs collected during 1999–2003 in the same area. DDE concentrations in eggs of

Table 4
Metals and metalloids (arithmetic means±SD, µg/g dw) in potential avian and invertebrate prey of the aplomado falcon in Matagorda Island NWR, Texas

Species	As	Ba	Cd	Cr	Cu	Hg	Mn	Pb	Se	Sr	Zn
Mourning Dove	2.4±0.3 AB	1.2±0.5 B	0.1±0.1 C	0.5±0.1 A	6.8±0.7 BC	0.02±0 C	3.1±0.4 A	0.6±0.5 AB	0.7±0.2 C	15.2±3.0 B	67.2±5.6 B
Common Night Hawk	2.2±0.2 B	2.0±0.5 B	0.7±0.1 A	0.5±0.1 A	5.9±0.7 C	0.4±0.1 BC	3.0±0.4 A	0.1±0.1 B	0.9±0.1 BC	17.7±6.4 B	54.8±5.9 B
Northern Mockingbird	2.8±0.1 AB	9.8±5.1 A	0.4±0.2 B	0.7±0.2 A	7.8±0.7 AB	0.2±0.1 C	3.2±0.8 A	1.8±2.1 A	1.0±0.1 ABC	16.5±3.8 B	82.7±11.3 A
Red-winged Blackbird	2.8±0.3 AB	2.9±0.7 B	0.1±0.03 BC	0.5±0.01 A	8.2±0.4 A	0.8±0.3 AB	6.8±4.0 A	0.7±0.6 AB	1.4±0.1 A	16.3±4.4 B	88.5±1.5 A
Eastern Meadowlark	2.6±0.5 AB	4.4±1.4 B	0.07±0.03 C	0.6±0.1 A	7.0±0.6 ABC	0.8±0.2 AB	5.1±1.9 A	0.2±0.1 AB	1.0±0.1 ABC	21.9±4.4 B	85.9±8.9 A
Great-Tailed Grackle	3.1±0.5 A	5.7±2.9 AB	0.08±0.08 C	0.5±0.1 A	6.9±0.7 BC	0.9±0.4 A	4.1±2.3 A	0.1±0.08 B	1.2±0.3 AB	39.8±11.4 A	89.3±6.3 A
Invertebrates	0.6±0.2	1.4±0.7	0.3±0.03	0.9±0.4	32.4±12.7	0.1±0.1	65.2±65	0.1±0.02	0.6±0.4	2.2±1.2	123.6±22.2

Within columns (for birds only), values that do not share the same letter are significantly different.

aplomado falcons from Laguna Atascosa were higher, although not significantly, than those in eggs from Matagorda Island in the United States reflecting perhaps differences in agricultural practices between the two regions. Concentrations of DDE in potential prey of the aplomado falcon in Matagorda Island also were very low. Among potential prey, northern mockingbirds had the highest levels of DDE, although they still were lower than those observed in other species in the region (Mora and Wainwright, 1998; Mora et al., 2006). During 1994, DDE levels in potential avian prey from the Laguna Atascosa were lower than 0.25 μg/g ww (Mora et al., 1997). Henry (1992) reported higher concentrations of DDE (mean of 2.8 μg/g ww) in carcasses of great-tailed grackles collected during 1991 both in the LRGV and throughout the habitat of the aplomado falcon in eastern Mexico.

Although DDE residues in eggs of aplomado falcons from south Texas were not significantly different from those in the Tinaja region in Chihuahua; they were much lower than those in eggs from El Sueco. The differences in DDE residues between eggs of aplomado falcons from south Texas and those from El Sueco could be explained perhaps because of more recent use of DDT and dicofol in Chihuahua than in south Texas. Agricultural use of DDT in Mexico was discontinued around 1978 (Fertilizantes Mexicanos, 1981); however, until recently, the use of DDT was still permitted for malaria control and other public health campaigns (Chanon et al., 2003, Catalogo de Plaguicidas 2004, CICLOPLAFEST, http://cofepris.gob.mx/bv/libros.htm, consulted December 4, 2006). Additionally, dicofol is still approved for agricultural use and has been used in Chihuahua over the last few years (Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca y Alimentación, SAGARPA unpubl. data). In the past, dicofol was reported to contain as much as 15% DDT (Clark, 1990); however, new dicofol formulations contain less than 0.1% DDT (http://extoxnet.orst.edu/pips/dicofol.htm, consulted December 5, 2006).

The higher DDE concentrations in aplomado falcon eggs from El Sueco than at Tinaja Verde can be explained perhaps because there is more agriculture near El Sueco than in Tinaja Verde. During 1998, an estimated 19,614 ha of cotton were planted in Ahumada County in the vicinity of El Sueco, whereas in 1999 only 3249 ha were planted (SAGARPA unpubl. data). This reduction in cotton crops in El Sueco could help explain the minor decrease in DDE residues between eggs collected during 1997–1999 and those collected from 2000 to 2003. Despite the higher concentrations of DDE at El Sueco than at Tinaja Verde productivity of young was better at El Sueco during most of the years studied (Macias-Duarte et al., 2004). Also, productivity at El Sueco was greater during 1997–1998 when DDE concentrations in eggs were greater and lower during 2001–2003 when DDE diminished (Macias-Duarte et al., 2004). Macias-Duarte et al. (2004) reported a mean productivity of 0.53 and 0.94 young fledged per occupied territory for Tinaja Verde and El Sueco over the period 1996 to 2002. The differences in productivity between the two regions were attributed to low brood survival; however, hatching success was similar. Macias-Duarte et al. (2004) suggested that drought was probably the major factor affecting reproduction of falcons in northern Chihuahua, since drought may have affected the relative abundance of potential avian prey.

The main known effects of DDE in birds are eggshell thinning and increased egg breakage (Hickey and Anderson, 1968). DDE concentrations in eggshell fragments of aplomado falcons collected in the state of Tamaulipas, Mexico and the LRGV during 1977, averaged 297 μg/g on a lipid basis (Kiff et al., 1980). Two eggs collected in the state of Veracruz, Mexico, during the same year had eggshell thicknesses of 0.197 and 0.227 mm, equivalent to 29.4% and 18.6% reduction in thickness compared with eggshells collected prior to the use of DDT (Kiff et al., 1980). We found that eggs with concentrations of DDE as low as 886 ng/g ww had eggshells 20% thinner than pre-DDT eggshells. Except for one egg from Matagorda, all of the eggs that exceeded 20% thinning (9 of 40 or 22.5%) were from El Sueco. Fyfe et al. (1988) suggested that the bat falcon (*Falco rufigularis*) was more sensitive to eggshell thinning by DDE than other species of the Genus Falco. Fyfe et al. (1988) further speculated that the aplomado falcon was probably as sensitive to DDE as the bat falcon. Thus, it is possible that lower levels of DDE in eggs of aplomado falcons could still result in significant eggshell thinning. Holm et al. (2006) suggested that eggshell thinning could result from a developmental effect of embryonic exposure to estrogen-like contaminants.

PCBs were low in aplomado falcon eggs from the LRGV and Chihuahua and were not different from those observed in eggs collected in 1995 and 1996 (Mora et al., 1997). Also, PCBs in eggs were much lower than those observed in eggs of screech owls (*Otus asio*, 4–18 μg/g ww) at which there were no adverse effects (McLane and Hughes, 1980). PCBs in potential avian prey of the aplomado falcon also were much lower than dietary levels (3 μg/g as Aroclor® 1248) administered to screech owls with no negative effects on reproduction (McLane and Hughes, 1980). Sensitivity to PCBs varies among species and birds of prey are not the most sensitive (Rice et al., 2003). In general, PCB concentrations reported in various other aquatic and terrestrial bird species of the LRGV have been below levels of concern (Mora, 1996; Wainwright et al., 2001; Mora et al., 2006).

Most trace elements were higher in eggs of falcons nesting in Texas than in those nesting at the El Sueco but not at Tinaja Verde in Chihuahua. Concentrations of Hg in eggs from Matagorda and Laguna Atascosa were similar to those reported in two of the first eggs collected in the region during the mid-1990s; however, one of these two early eggs contained Hg residues nearing 4 μg/g dw (Mora et al., 1997). Concentrations of Hg in eggs were below the generally accepted threshold level for negative impacts on raptors (Koivusaari et al., 1980; Helander et al., 1982; Newton and Haas, 1988). Nonetheless, some species could be affected by lower Hg levels (Wiemeyer et al., 1984).

Our results indicate that DDE, PCBs, and other OCs as well as metals and metalloids are currently not a threat to aplomado falcon reproduction in south Texas; however, DDE still may be having some negative effects on the Chihuahuan populations. Mercury, however, did not appear to decline during this study and continues to be elevated in eggs but below levels known to affect other raptors. There is a continued need to monitor Hg changes in aplomado falcon prey and eggs to document any potential negative impact. Monitoring of both populations for contaminants should continue until the species fully recovers to its former range in the southwestern United States and northern Mexico.

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