DDE-INDUCED EGGSHELL THINNING IN WHITE-FACED IBIS: A CONTINUING PROBLEM IN THE WESTERN UNITED STATES

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ABSTRACT—White-faced ibises (*Plegadis chihi*) nesting in Arizona in 2000 exhibited extreme eggshell thinning and possible reproductive failure associated with high egg residues of DDE. A small colony of approximately 75 pairs nested relatively late in the season, and egg laying occurred from about June 15 to June 29. Average clutch size in 19 marked nests was 2.5, which was low compared to that reported for most other ibis populations. Hatching success was 43% (13 of 30 eggs remaining in active nests). The geometric mean DDE egg residue (2.23 μg/g wet weight) was similar to those reported in other ibis populations where DDE-induced shell thinning adversely affected reproductive success. Two of 16 eggs collected from marked nests had a flexible shell that easily indented with slight finger pressure. Overall mean eggshell thickness of 23 eggs was 0.264 mm, 15% thinner than shells of museum eggs collected before the widespread use of DDT. Only 1 of 23 eggs contained mercury at potentially harmful concentrations (>2.5 μg/g dry weight). Selenium in 74% of the eggs exceeded background concentrations (<3.0 μg/g dry weight), but none exceeded the toxic threshold (>8.0 μg/g dry weight).

RESUMEN—Los ibis cariblancos (*Plegadis chihi*) anidando en Arizona en el año 2000 demostraron un adelgazamiento extremo del cascarón del huevo y posiblemente fracasaron en su reproducción debido a concentraciones elevadas de DDE en el huevo. Una colonia pequeña de aproximadamente 75 parejas anidó relativamente tarde en la temporada y la postura de huevos ocurrió aproximadamente del 15 al 29 de junio. El promedio de huevos por nido fue de 2.5 en 19 nidos marcados, lo cual fue bajo comparado con lo registrado en la mayoría de otras poblaciones de ibis. El exito de empollamento fue 43% (13 de 30 huevos que permanecieron en nidos activos). La concentración media geométrica de DDE en el huevo (2.23 μg/g peso húmedo) fue similar a las registradas en otras poblaciones de ibis en las que el adelgazamiento del cascarón inducido por DDE bajó el éxito reproductivo. Dos de 16 huevos colectados de los nidos marcados tuvieron un cascarón flexible que se hundía fácilmente con una ligera presión del dedo. En general, la media geométrica del espesor de la cáscara de 23 huevos fue 0.264 mm, 15% más delgada que cascarones de huevos en museos colectados antes del uso a gran escala de DDT. Sólo 1 de 23 huevos tuvo concentraciones de mercurio potencialmente dañinas (>2.5 μg/g peso seco). El selenio excedió concentraciones normales (<3.0 μg/g peso seco) en 79% de los huevos, pero ninguno excedió el límite de toxicidad (>8.0 μg/g peso seco).

Three decades after the suspension of most uses of the insecticide DDT in 1972, its metabolite DDE still is present at environmental concentrations great enough to cause severe reproductive problems in at least 1 species of waterbird. White-faced ibises (*Plegadis chihi*) nesting in Arizona in 2000 exhibited extreme eggshell thinning and possible reproductive failure associated with high egg residues of DDE. DDE-induced eggshell thinning has been recorded in numerous species of fish-eating and raptorial birds from the late 1960s through the 1980s (Blus, 1996; Keith, 1996). Because the use of most organochlorine insecticides was suspended in the early 1970s, there has been a general decline in residues of these compounds in wild birds and their eggs. One exception, however, is the continued high DDE contamination reported in eggs of white-faced ibises (Henny, 1997). Severe eggshell

thinning in white-faced ibis populations was documented in the 1970s and 1980s in Utah, Nevada, Oregon, and Texas (Capen, 1977; King et al., 1980; Henny and Herron, 1989) and more recently again in Nevada (Henny, 1997). We present information on eggshell thinning, insecticide residues, and mercury and selenium concentrations in white-faced ibis eggs collected in Arizona in 2000.

METHODS—*Study Area*—The study site consisted of a relatively small (0.4 ha) bulrush (*Scirpus*) island in Cibola Lake, Cibola National Wildlife Refuge (NWR), La Paz County, Arizona. The Cibola Lake study area was described by Zaun et al. (2003). Only nests located around the periphery of the island were accessible for close examination because the density of the bulrush precluded observations of nests located in the central portions of the colony. Field observations extended from 21 June through 20 July 2000. The colony was monitored for about 1 week after the last young hatched. We visited nests at sunrise to minimize potential heat stress to eggs and nestlings. Nests were individually marked with numbered strips of plastic ribbon tied to bulrush stems a known distance and direction from each nest. The colony was revisited every 4 to 8 days from the onset of egg laying through hatching, and the history of individual nests was recorded. New nests were marked as they were encountered. Because ibises as young as 4 to 7 days often leave the nest to hide in nearby vegetation when disturbed, we generally monitored the colony at 4-day intervals to obtain a relatively accurate count of nestlings hatched.

Sample Collection—Ibis eggs were collected using the "sample egg method" (Blus, 1984), in which 1 egg was collected per nest and the contaminants in each egg correlated with the success of eggs remaining in the nest. One egg was collected at random from 2-egg and 3-egg clutches. Generally, we waited until clutches were complete before collecting eggs. We also collected abandoned eggs and searched for dead nestlings in and below abandoned nests. Eggs were marked with the corresponding nest number using a waterproof felt-point pen. Hatching success of the remaining eggs was monitored. Eggs were placed in commercial egg cartons and stored on wet ice in coolers until they could be transferred to a commercial freezer.

We weighed and measured eggs, cut each egg around the girth, and placed its contents in chemically cleaned jars. Embryo development was assessed using methods described by Taber (1969) based on a 20-day incubation period for the white-faced ibis (Ryder and Manry, 1994). Jars with egg contents were frozen until analysis. Eggshells were gently washed and allowed to dry for several weeks. Thickness (shell plus shell membrane) was measured to the nearest 0.01 mm at 3 points around the equator using a Starrett Model 1010M dial micrometer, and a mean thickness was calculated for each egg. Because shell thickness of a single species can vary with latitude (Lack, 1954; Anderson and Hickey, 1972; Custer et al., 1983), we compared thickness measurements of eggs collected at Cibola Lake with measurements of 18 museum eggs (5 clutches) collected at a similar latitude in Texas (King et al., 1978) before the widespread agricultural use of DDT (pre-1945).

One 10-day-old nestling found dead was salvaged for residue analysis. The carcass was plucked, and bill, feet, wingtips, and gastrointestinal tract were removed and discarded. The liver was removed and saved for metals analysis. The whole body remainder was analyzed for organochlorine compounds.

Ibis eggs and the nestling were analyzed for organochlorine compounds, including o,p′-DDE and p,p′-DDE; o,p′-DDD and p,p′-DDD; o,p′-DDT and p,p′-DDT; dieldrin; heptachlor epoxide; hexachlorobenzene (HCB); alpha, beta, delta, and gamma BHC; alpha and gamma chlordane; oxychlordane; *trans*-nonachlor; *cis*-nonachlor; endrin; toxaphene; mirex; and total polychlorinated biphenyls (PCB) at Mississippi State Chemical Laboratory, Mississippi State, Mississippi, following methods described by Cromartie et al. (1975) and Kaiser et al. (1980). The lower limit of quantification was 0.01 μg/g (parts per million) for most organochlorine pesticides and 0.05 μg/g for toxaphene and PCBs. Recovery in spiked samples ranged from 84.5 to 101%. Organochlorine compounds are expressed in μg/g wet weight to facilitate comparison of residue levels with those reported in other studies.

Ibis eggs also were analyzed for mercury and selenium at Research Triangle Institute, Research Triangle Park, North Carolina, using methods described by Monk (1961). Mercury concentrations were quantified by cold-vapor atomic absorption spectrophotometry and selenium was analyzed by hydride-generation atomic absorption spectrophotometry. Results of mercury and selenium analyses are expressed on a dry-weight basis to avoid errors in interpretation associated with varying moisture levels (Stickel et al., 1973). The lower limits of quantification for mercury and selenium were 0.02 μg/g and 0.38 to 0.43 μg/g dry weight, respectively.

Statistical Analyses—Contaminant concentrations and shell thickness of eggs collected from marked nests were compared with those found abandoned. For organochlorine compounds, the data were log-transformed to common logarithms to improve homogeneity of variances, and geometric means (gmean) were calculated when residues were detected in more than 50% of the samples. Organochlorine residue concentrations were not adjusted for

moisture loss because most eggs were relatively fresh (≤4 days) when first collected. When means were calculated, a value equal to one-half the lower limit of detection was assigned to any non-detected value prior to log-transformation. Data were then analyzed using analysis of variance to determine statistical difference in residue levels between randomly collected and abandoned eggs. Retransformed gmeans are presented in the text and tables. Other comparisons of data were made with Student's *t*-test, correlation analyses, and Chi-square tests.

RESULTS—*Nesting Chronology*—When the ibis colony was first discovered on 21 June 2000, only 8 active nests with eggs were located, and the colony appeared to be in the egg laying and early incubation period. No nestlings were observed during our first visit to the colony, and we estimated the adult population to be about 50 pairs. Near the end of the incubation period, the total nesting population was estimated by visual counts and aerial photography at approximately 75 pairs (Zaun, 2000).

Nineteen nests with 48 eggs were marked, and 18 nests were monitored through hatching. The fate of the nineteenth marked nest and its 2 eggs was not determined. Although a small colony (ca. 15 pairs) of great-tailed grackles (*Quiscalus mexicanus*) was located in another bulrush island about 300 m from the ibis colony, we did not observe any grackle depredation on ibis eggs.

Assuming an average incubation period of 20 days (Ryder and Manry, 1994), we calculated that egg laying in the first nest occurred about 15 June and laying was initiated in the last nest about 29 June. Clutch size in completed nests ranged from 1 to 3 eggs (1 egg in 2 nests, 2 eggs in 5 nests, and 3 eggs in 12 nests). Average clutch size in all 19 nests was 2.5. Eggs were collected from the date of the first visit until 20 July, at which time the incubation period was mostly completed. We collected 23 eggs, 16 from marked nests and 7 found abandoned. Embryos in 13 of 16 eggs from marked nests were less than one-half developed.

Thirteen of the 30 eggs (43%) remaining on nests hatched in 8 of the 18 nests monitored through hatching. Hatching success was strongly associated with the timing of nest initiation. Eggs hatched in 6 of 7 nests (86%) initiated on or before 21 June, but eggs hatched in only 2 of 11 nests (18%) started after 21 June ($\chi^2 = 5.4029$, $P = 0.0201$).

Organochlorine Residues—Residues of 7 organochlorine insecticides and PCBs were detected in ibis eggs (Table 1). DDE was recovered in all eggs and individual residues ranged from 0.13 to 14 μg/g wet weight. There was no difference ($P = 0.8527$) in gmean DDE residues in eggs collected from marked nests (2.14 μg/g) and eggs found abandoned (2.46 μg/g). None of the remaining eggs hatched in nests where the sample egg contained >4.0 μg/g DDE, i.e., the "adverse effect zone" for DDE (Henny and Herron, 1989). The gmean chlordane residue in eggs from marked nests (0.01 μg/g) was identical to that in abandoned eggs. DDT was detected in 9 of 23 eggs (39%), and DDT residues generally were associated with eggs that contained higher DDE residues ($r = 0.60$, $P = 0.0090$). DDT was recovered in only 2 of 12 eggs (17%) that contained <4.0 μg/g DDE, but DDT was present in 7 of 11 (64%) eggs with >4.0 μg/g DDE. Low levels of PCBs, DDD, dieldrin, heptachlor epoxide, and HCB were present in 5 or fewer eggs. DDE was the only organochlorine compound recovered in the carcass of the dead nestling (0.26 μg/g wet weight).

Eggshell Thickness—Two of 16 eggs collected from marked nests were extremely thin-shelled, with a flexible shell that was easily indented with slight finger pressure. These 2 thin-shelled eggs measured 26 and 29% thinner than normal (pre-DDT). One of 7 abandoned eggs contained an embryo that appeared to have died as a result of the eggshell collapsing during pipping. The sample egg collected from the same nest 16 days earlier was 1 of the 2 visibly thin-shelled eggs. We did not, however, observe any other collapsed or cracked eggs in or below nests. Mean shell thickness of eggs collected from marked nests (0.264 mm) was identical to thickness of shells of abandoned eggs. Therefore, for additional statistical tests, we combined the data from eggs from marked nests with data from eggs found abandoned. Overall mean shell thickness of all 23 eggs was 0.264 mm, which was 15% thinner than shells of eggs collected before the widespread use of DDT ($P < 0.0001$) (Table 2). Individual eggshell thinning varied from 1 to 29%. Both log-DDE ($r = -0.51$, $P < 0.0001$) and log-chlordane ($r = -0.2028$, $P =$

TABLE 1—Organochlorine compounds, μg/g wet weight, in randomly collected and abandoned white-faced ibis eggs, Cibola Lake, Cibola National Wildlife Refuge, Arizona, 2000. ND = not detected.

	Number of eggs	Number of eggs with residues (geometric mean[1]) range							
		p,p'-DDE	Chlordane	p,p'-DDT	Total PCB	p,p'-DDD	Dieldrin	Heptachlor epoxide	HCB
Marked nests	16	16	10	8	3	4	2	2	1
		(2.14)[2]	(0.01)	—	—	—	—	—	—
		0.13 to 14.0	ND to 0.05	ND to 0.20	ND to 0.05	ND to 0.08	ND to 0.10	0.01 to 0.02	ND to 0.01
Abandoned nests	7	7	4	1	2	ND	ND	ND	ND
		(2.46)[2]	(0.01)	—	—				
		0.18 to 14.0	ND to 0.04	ND to 0.07	ND to 0.18				

[1] Means calculated only when more than 50% of the sample contained detectable residues.
[2] Mean concentrations of DDE in randomly collected and abandoned eggs were similar ($P = 0.8527$).

0.0310) were negatively correlated with eggshell thickness. Chlordane is not a primary shell thinning agent; therefore, the correlation between chlordane and shell thinning might have been spurious, because eggs with elevated residues of DDE also contained high residues of chlordane ($r = 0.24$, $P = 0.0172$). Because fewer than one-half of the eggs contained residues of other organochlorine compounds, we did not attempt to assess the statistical relationship of these compounds with shell thickness.

Mercury and Selenium—Mercury and selenium were recovered in all eggs (Table 3). The gmean mercury concentration in eggs collected from marked nests (0.42 μg/g dry weight) was similar ($P = 0.7830$) to that in abandoned eggs (0.38 μg/g). Concentrations of mercury in individual eggs ranged up to 2.72 μg/g. The gmean selenium concentration in ibis eggs from marked nests (3.17 μg/g) was similar ($P = 0.3033$) to selenium in abandoned eggs (3.38 μg/g). Selenium in individual eggs ranged from 2.44 to 4.16 μg/g. Both mercury and selenium were detected in the liver tissues of the dead nestling at 0.11 and 4.17 μg/g dry weight.

DISCUSSION—*Nesting Performance*—This colony represents the first documented nesting of white-faced ibises in Arizona (Zaun, 2000). Average clutch size (2.5) was lower than that reported in most other studies. Clutch size reported for ibises in Utah ranged from 2.8 to 3.5 (Kaneko, 1972; Capen, 1977; Steele, 1984). The mean clutch sizes for ibises nesting in Nevada and Texas were 2.9 to 3.6 (Henny and Herron, 1989) and 2.6 to 3.1, respectively (King et al., 1980; Custer and Mitchell, 1989).

The relatively small clutch size of the Cibola Lake colony might be related to natural latitude variation or to the late timing of the nesting effort. For species that nest over a broad geographic area, average clutch size usually is greater in populations nesting at northern latitudes than in those nesting at southern latitudes (Lack, 1954; Custer et al., 1983). Throughout most of North America, ibis egg laying and incubation extends from mid April to late May (Ryder and Manry, 1994). However, at southern latitudes, such as Texas and Louisiana, egg laying occurred from mid April through early July. Egg laying and incubation at the Cibola Lake colony occurred during the

TABLE 2—Comparison of shell thickness measurements of white-faced ibis eggs collected at Cibola Lake, Arizona, 2000, with those from museum collections (pre-DDT).

Area	Year	Number of eggs	Shell thickness (mm) range, mean ± *SE*	Percent difference
Texas[a]	Before 1945	18	0.26 to 0.37, 0.312 ± 0.006	
Arizona	2000	23	0.22 to 0.31, 0.264[b] ± 0.006	−15

[a] Data from King et al., 1980.

[b] Mean eggshell thickness was significantly different between samples ($P < 0.0001$, *t*-test).

latter portion of the time frame for other colonies located at similar southern latitudes. Late clutches of white-faced ibises are usually smaller than clutches initiated earlier in the season (Henny and Herron, 1989).

DDE/DDT—DDE residues in ibis eggs collected throughout western United States from 1968 through 2000 are presented in Table 4. As might be expected, highest gmean DDE residues (10.0 to 17.0 μg/g) were recorded in ibis eggs collected in the late 1960s and early 1970s before the suspension of urban and agricultural uses of DDT in 1972. From 1973 through 2000, annual gmean DDE residues in ibis eggs ranged from 0.14 to 6.0 μg/g, but there was no clear trend toward lower residues in later years.

As the concentration of DDE in ibis eggs increases to >4.0 μg/g wet weight, and especially >8.0 μg/g, productivity decreases and the incidence of cracked eggs increases (Henny, 1997). In our sample, 11 of 23 eggs (48%) exceeded 4.0 μg/g DDE, and 6 of 23 eggs (26%) exceeded the 8.0 μg/g threshold. In nests where the sample egg contained >4.0 μg/g DDE, none of the remaining eggs hatched.

TABLE 3—Mercury and selenium concentrations (μg/g dry weight) in white-faced ibis eggs, Cibola Lake, Cibola National Wildlife Refuge, Arizona, 2000.

Sample	Geometric mean (range) Mercury	Selenium
Marked nests (16 eggs)	0.42[a] (0.16 to 2.72)	3.17[b] (2.44 to 4.10)
Abandoned nests (7 eggs)	0.38[a] (0.21 to 0.95)	3.38[b] (2.70 to 4.16)

[a] Gmean concentrations were similar ($P = 0.7830$, *t*-test).

[b] Gmean concentrations were similar ($P = 0.3033$, *t*-test).

Gmean DDE egg residues were considerably higher in white-faced ibises (2.23 μg/g) than in eggs of other waterbirds collected along the lower Colorado River. Double-crested cormorant (*Phalacrocorax auritis*) eggs ($n = 21$) collected in 2000 from Havasu NWR averaged 1.45 μg/g DDE (King et al., 2003). A smaller sample ($n = 6$) of Clark's grebe (*Aechmophorus clarkii*) eggs contained a gmean of 0.12 μg/g DDE, and 2 least bittern (*Ixobrychus exilis*) eggs each contained 0.30 μg/g (King et al., 2003).

Eggshell Thinning—Within a given region, mean shell thinning of white-faced ibis eggs varied greatly from year to year (Table 4). Annual mean shell thinning ranged from 1 to 17% in ibis eggs collected intermittently in northern Utah from 1968 to 1979 (Capen, 1977; Steele, 1984). In Nevada, annual shell thinning ranged from 5 to 20% between 1980 and 1996. Mean shell thinning of Oregon ibis eggs collected from 1979 to 1983 ranged from 8 to 20% (Henny et al., 1985). Even within a single nesting season, mean shell thinning can vary by as much as 7% depending on when the sample was collected within the season, i.e., early or late (Henny and Herron, 1989).

What are the biological consequences of 15% shell thinning as observed in ibises nesting in Arizona? In most waterbird species, eggshell thinning of less than 10% seldom causes egg breakage (Hickey and Anderson, 1968). Egg loss usually becomes evident with decreases of 10 to 15%, and serious breakage, usually accompanied by population decline, occurs when average thinning exceeds 15% (Hickey and Anderson, 1968; Risebrough et al., 1970; Anderson and Hickey, 1972). It is now generally accepted that a long-term average of 18% eggshell thinning in most waterbird species will

TABLE 4—Changes in DDE residues (μg/g dry weight) and mean shell thinning in white-faced ibis eggs, 1968 through 2000.

State	Year	*n*	DDE		Mean shell thinning (%)	Author
			Gmean	Maximum		
Utah	1968	18	13.0	—	13	Capen, 1977
Utah	1969	80	17.0	—	17	Capen, 1977
Utah	1971	40	10.0	—	11	Capen, 1977
Utah	1974	56	1.0	—	1	Capen, 1977
Utah	1975	86	6.0	—	6	Capen, 1977
Utah	1976	99	5.0	—	5	Capen, 1977
Utah	1979	80	1.25	23.6	4	Steele, 1984
Texas	1970	86	0.94	2.2	4	King et al., 1978
Texas	1976	20	0.25	1.40	4	King et al., 1980
Texas	1985[a]	20	0.14, 0.27	—	2, 5	Custer and Mitchell, 1989
Nevada	1980	15	1.62	15	10	Henny and Herron, 1989
Nevada	1981	15	2.23	19	12	Henny and Herron, 1989
Nevada	1982	16	0.54	3	5	Henny and Herron, 1989
Nevada	1983	15	1.71	20	13	Henny and Herron, 1989
Nevada	1985[b]	60	1.87, 3.47	21	16, 20	Henny and Herron, 1989
Nevada	1986[c]	80	1.53 to 3.23	29	12 to 19	Henny and Herron, 1989
Nevada	1996	20	2.66	12	18	Henny, 1997
Oregon	1979	20	4.70	22	—	Henny et al., 1985
Oregon	1980	8	1.27	8	6	Henny et al., 1985
Oregon	1981	15	1.23	8	—	Henny et al., 1985
Oregon	1982	15	1.06	12	—	Henny et al., 1985
Arizona	2000	23	2.23	14.0	15	This study

[a] Two colonies monitored.

[b] Based on 2 collection periods in the same colony.

[c] Based on 4 collection periods in the same colony, early to late, Gmean DDE = 3.23, 1.70, 2.10, and 1.53 μg/g; shell thinning = 19, 14, 12, and 12%.

result in a population decline (Blus, 1996). In contrast to the above generalizations, average annual shell thinning of 4 to 14% in white-faced ibis eggs was associated with frequent eggshell breakage and reproductive failure (Capen, 1977; King et al., 1980; Henny and Herron, 1989). Based on whole egg analyses, limited data suggest that the white-faced ibis and the prairie falcon (*Falco mexicanus*) (Blus, 1996) are the 2 species most sensitive to DDE-induced eggshell thinning.

In addition to causing shell thinning, DDE can have other adverse impacts on bird physiology and reproduction. In extensive experimental trials using ringed turtle doves (*Streptopelia risoria*), overall productivity was reduced by 23% in pairs that had been fed DDE-treated food from 3 to 6 weeks prior to the reproductive cycle (Keith and Mitchell, 1993). The adverse effects of DDE on reproduction can be especially severe during periods of stress, such as food restriction. A 10% food restriction for birds that had been pre-exposed to a DDE-treated diet resulted in an 87% decrease in productivity. Although minor shell thinning was noted, reproductive failure was due primarily to low levels of hormones necessary to develop and maintain active gonads, adequate courtship and brooding behavior, and functional crop glands. Reproduction was depressed by both DDE and by food restriction, and the effects were synergistic (Keith and Mitchell, 1993).

DDT, DDE, and chlordane are known endocrine-disrupting compounds, and exposure to endocrine-disrupting chemicals has been associated with abnormal thyroid function, decreased fertility, decreased hatching success, altered immune function, and feminization of males (Colborn et al., 1993). In the lower Colorado River area, the adverse effects of endocrine-disrupting compounds have been docu-

mented in several species of fish (Goodbred et al., 1997), and it is likely that these compounds also are present in waterbirds in that area.

Sources of DDT/DDE—It is unlikely that ibises accumulated high DDT/DDE residues while feeding near the Cibola Lake colony. Studies conducted in that area (the lower Colorado River valley) documented relatively low residues of organochlorine compounds in resident fish and wildlife (Radtke et al., 1988; Schmitt et al., 1990). However, a potential source of high DDT/DDE residues is the lower Gila River and associated irrigated farmland located approximately 180 to 200 km east of the Cibola Lake colony. The lower Gila River riparian corridor, a natural flight path for waterbirds, links the irrigated farmlands with the Colorado River. Common carp (*Cyprinus carpio*) collected in 1994 from the Gila River contained the highest concentrations of DDE in the nation associated with agriculturally-applied DDT (King et al., 1997). European starlings (*Sturna vulgaris*) collected near the lower Gila River during a 1982 nationwide survey of 129 sites contained the highest (8.4 μg/g wet weight) DDE concentration in the United States (Bunck et al., 1987). Mallards (*Anas platyrhynchos*) taken in the same general area had the second-highest DDT residue in the nation (Cain, 1981). Earth Technology Corporation (1993: 2–71) concluded, "Based on TCLP analysis, fish and turtles (from the Painted Rock portion of the Gila River) could be considered a hazardous waste and would require treatment and disposal." White-faced ibises are regularly seen feeding in the lower Gila River riparian habitat and in agricultural fields irrigated with water from the lower Gila River. Ibises also might accumulate high DDE on wintering grounds in Mexico (Ryder and Manry, 1994) or in the Imperial Valley of California near the Salton Sea, where birds also contain high DDE residues (Ohlendorf and Miller, 1984; Mora et al., 1987).

Mercury and Selenium—Mercury concentrations in wild bird eggs of ≤0.5 μg/g wet weight (roughly 2.5 μg/g dry weight) seem to have little detrimental effect on reproduction (Thompson, 1996). Only 1 of 23 ibis eggs contained mercury at concentrations greater than 2.5 μg/g dry weight. There seemed to be little potential for adverse biological effects from mercury on the ibis population that nested in Arizona in 2000.

Background concentrations of selenium in eggs are usually less than 3.0 μg/g dry weight, and the lower limit of toxic concentrations is about 8.0 μg/g (Ohlendorf, 1993). Selenium in 74% of the ibis eggs (17 of 23) exceeded the 3.0 μg/g background concentration, but none exceeded the 8.0 μg/g toxic threshold.

In liver tissues, there is an overlap in mercury concentrations considered as background and those considered toxic. Background concentrations of mercury in the liver vary from <1 to 10 μg/g dry weight, but concentrations as low as 6 μg/g can be toxic to some species (Ohlendorf, 1993). The 0.11 μg/g mercury detected in the liver of the dead nestling was well within the normal or background range. The 4.17 μg/g dry weight selenium recovered in the dead nestling was well within the normal or background range (3 to 10 μg/g dry weight) previously reported for liver tissues of birds (Ohlendorf, 1993).

White-faced ibis populations declined throughout their range in the 1950s and 1960s (Ryder, 1967), probably as a result of reproductive failure due to eggshell thinning and loss. Since the mid 1970s, the Great Basin ibis population is thought to be increasing (Ryder and Manry, 1994), but the Texas Coast population has continued to decrease (United States Fish and Wildlife Service, www.TexasCoastalProgram.fws.gov). Our study documented continued high levels of DDE and biologically significant eggshell thinning in the white-faced ibis almost 3 decades after the national suspension of DDT. Further studies are needed to document areas where contaminant bioaccumulation is most likely. These studies should include assessments of both summer and winter range as well as migration stopover points. Studies using satellite telemetry are ongoing to locate wintering areas of the DDE-contaminated ibis from Carson Lake Nevada (C. J. Henny, pers. comm.).

We thank M. Hawkes, Manager, Cibola NWR, for logistical support throughout this study. We sincerely appreciate the hospitality extended by the Western Foundation of Vertebrate Zoology, Los Angeles, California, and the Welder Wildlife Foundation, Sinton, Texas for allowing us to measure eggshells collected before 1945. Appreciation is expressed to J. Goldberry and P. Keywood for aid in interpreting aerial photographs of the colony. We are especially grateful

to T. W. Custer, C. J. Henny, J. O. Keith, and A. L. Velasco for the numerous helpful and constructive comments on earlier drafts of this manuscript. We also thank M. Mora and M. Giggleman who translated the English abstract to Spanish.

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Submitted 12 February 2002. Accepted 2 August 2002. Associate Editor was Cheri A. Jones.