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ORGANOCHLORINE AND METAL RESIDUES IN ROYAL TERNS NESTING ON THE CENTRAL TEXAS COAST

BY KIRKE A. KING, CATHY A. LEFEVER, AND BERNARD M. MULHERN

In 1976, about 2000 pairs of Royal Terns (*Sterna maxima*) nested on islands in Corpus Christi and Nueces bays (Mullins et al. 1982), bays that are contaminated with heavy metals and organochlorine pollutants (Holmes et al. 1976, Pulich 1980, White et al. 1980). The city of Corpus Christi is the petro-chemical and industrial center for the central coast of Texas, and its 7 major oil refineries are refining West Texas and Mexican crude oil which has a high sulfur, selenium, and cadmium content. A zinc refinery located on Nueces Bay may have been a possible contributor to high metal residues in bay sediments and sea grasses (*Halodule wrightii*) (Pulich 1980). Cotton and grain sorghum are the major agricultural crops grown in the Corpus Christi area. Both crops receive repeated applications of insecticides and herbicides throughout the growing season and much of the runoff ultimately reaches local rivers, bays, and estuaries. The combined chemical input from these industrial and agricultural sources has resulted in a contaminated environment that could have harmful effects on resident and migratory bird populations.

Numbers of Royal Terns nesting at Pelican Island in Corpus Christi Bay declined from 3500 pairs in 1973 to 2000 pairs in 1976 (Mullins et al. 1982). In 1976, a few Royal Tern chicks were observed with deformed bills, spines, and feathers (E. Payne, National Audubon Society, Corpus Christi, Texas); conditions similar to those reported by other investigators (Gochfeld 1975, Hays and Risebrough 1972) in Common Terns (*Sterna hirundo*) and Roseate Terns (*Sterna dougallii*). Mercury residues were about 2.5 times greater in the blood of deformed chicks than in normal chicks (Gochfeld 1975). These findings indicated a need for further assessments of the impact of metals and organochlorine pollutants on Royal Terns and other bird species that nested in the Corpus Christi—Nueces Bay area. Our objectives were to compare organochlorine and metal residues in Royal Tern eggs from the Corpus Christi Bay area with levels in eggs from a relatively unpolluted area and to correlate pollutant levels with eggshell thinning and the incidence of abnormal young.

METHODS

Pelican Island was our study area in Corpus Christi Bay, and Sundown Island was a control area in Matagorda Bay (Fig. 1). Although none of the Texas bays is completely free from agricultural runoff, the land around Matagorda Bay is less intensively cultivated than that near Corpus Christi Bay. Also, because there is little urban and industrial de-

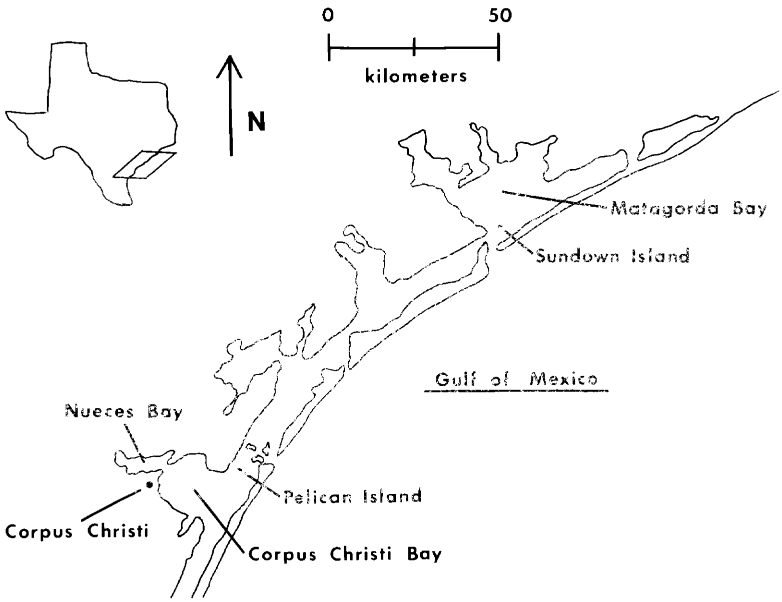

FIGURE 1. Location of Pelican Island and Sundown Island Royal Tern colonies on the Texas coast.

velopment near Matagorda Bay, organochlorine and heavy metal residues were expected to be lower there than at Corpus Christi Bay.

We made 18 trips to the Royal Tern colonies during the 1978 nesting season (March to August) to collect eggs for shell thickness measurements and chemical residue analyses, and to determine the incidence of deformed young. Both colonies were visited every 2 weeks from the onset of the nesting season until the first eggs hatched. Thereafter, weekly observations were made at each colony. Observation and data collection were confined largely to the periphery of each colony until most of the eggs had hatched. We then entered the colonies and examined unhatched eggs to assess viability. Since Royal Terns seldom lay more than one egg per nest, the possibility of collecting more than one egg from a single female was unlikely. Whole eggs were weighed and measured. The contents were removed and stored frozen in chemically cleaned jars until analysis.

Shell thicknesses of eggs collected in 1978 were compared both with those of museum eggs collected before the widespread use of DDT (pre-1947) and also with measurements of eggs collected in 1970 (King et al. 1978). Measurements of eggshells collected before 1947 were obtained from the Western Foundation of Vertebrate Zoology, Los Angeles, California. Eggshell thickness for a particular species varies significantly over broad geographic areas, particularly with latitude. In this study, only eggs from Texas were used for shell thickness comparisons.

Since only addled eggs were collected for residue analyses and shell thickness measurements, ours was not a random collection. Pesticide residues may have been biased towards higher levels and shell thickness values may have been lower than those of a random collection of viable eggs.

At the same time we entered the colonies to collect eggs, we assessed the frequency of abnormalities among chicks. Thereafter, weekly observations of tern chicks continued until most of the young had fledged. Royal Tern chicks are precocial and remain at or [illegible]ly 1 to 3 days after hatching. During the first week, [illegible] together in groups (pods), and remain in these pods [illegible]e formation of pods facilitated our observations for some typ[illegible] abnormalities such as debilitating leg or wing conditions. However, since the pods constantly moved about the island, we found it difficult to handle large numbers of young to assess the frequency of the more subtle deformities such as feather and bill aberrations. On each of our weekly trips to the study areas from late June to August, at least 1000 nestlings were closely studied with the aid of binoculars. About 60 young at each island also were captured and examined. All abnormal young were collected for necropsy.

Residue analyses were conducted at the Patuxent Wildlife Research Center, Laurel, Maryland. For organochlorine analysis, the egg contents were homogenized and a 10-g portion was mixed with anhydrous sodium sulfate and extracted with hexane in a Soxhlet apparatus and cleaned up with a Florisil column (Cromartie et al. 1975). The organochlorine compounds were separated into 4 fractions on a SilicAR® column (rather than 3 fractions) to ensure the separation of dieldrin or endrin into an individual fraction (Kaiser et al. 1980). The individual fractions were analyzed by a gas-liquid chromatograph equipped with an electron-capture detector and a 1.5% OV-17/1.95% QF-1 column at 190°C. Toxaphene was quantified as described by Prouty et al. (1977). Residues in 10% of the samples were confirmed by a gas-liquid chromatograph/mass spectrometer. Residue levels were not corrected for recovery, which ranged from 75 to 101%. The lower limit for quantification was 0.1 ppm for all organochlorine pesticides and 0.5 ppm for polychlorinated biphenyls (PCBs). All residues are expressed on a wet weight basis.

For arsenic and selenium analysis, a 2-g portion of sample homogenate was dissolved in 20 ml of concentrated HNO_3 and boiled down to 1 ml of acid. The concentrate was then diluted to 50 ml with distilled, deionized water. Arsenic and selenium levels were determined by methods of additions, by using heated quartz tube atomization following hydride generation with the Perkin-Elmer MHS-1 accessory to the Perkin-Elmer model 403 AAS. For arsenic analysis, 5 ml of a 50% HCl solution and 2.5 ml of 5% $NaBH_4$ in 2.5% NaOH were added to a 5-ml portion of sample homogenate. Additions of 0.02, 0.05, and 0.10 μg of arsenic or selenium were made. The analyses were performed at 193.7 nm with an electrodeless discharge lamp. The quartz tube was heated to 900°C and purged with argon. Analysis for selenium was similar to that for arsenic except that 5 ml of 10% HCl solution was added to 5 ml of sample digestate. A 10% $NaBH_4$ in 2.5% NaOH solution was used to make the hydride, and the analyses were determined at 196.0 nm wave length. The lower limit of reportable residues was 0.05 ppm for arsenic and 0.10 ppm for selenium.

The 5-g sample for mercury analysis was digested by methods described by Monk (1961). Total mercury was determined by cold vapor atomic absorption spectrophotometry (Hatch and Ott 1968) with a Coleman model MAS-50 mercury analyzer. The lower limit of reportable mercury residues was 0.02 ppm.

The sample portion for copper and zinc analysis was first dried in an oven, then charred in a muffle furnace. The temperature was raised to 500°C at a rate of 100°C/h and left to ash overnight. The ash was cooled, dissolved over a hot plate in about 2 ml of concentrated HNO_3 and 1 ml of concentrated HCl, transferred to a 12-ml polypropylene centrifuge tube, and diluted to 10 ml with distilled deionized water. Analysis was completed by flame atomic absorption spectrophotometry with a Perkin-Elmer model 703 AAS equipped with a deuterium arc background corrector, an AS-50 autosampler, and a PRS-10 printer. The lower limit of quantification for copper and zinc was 0.1 ppm. Metal residues were not corrected for recovery which ranged from 81 to 110%.

Statistical comparisons of shell thicknesses of pre-1947, 1970, and 1978 eggs were made using a Students *t*-test. Since arithmetic and geometric means were nearly equal, arithmetic means rather than geometric means were compared. Regression analysis was used to determine the relationship of shell thickness with residue levels.

RESULTS AND DISCUSSION

Reproduction in 1978.—An estimated 5900 pairs of Royal Terns nested on Pelican Island and 4500 pairs nested on Sundown Island in 1978. Eggs were first observed in nests at the Pelican Island colony on 25 April; nesting activities at Sundown Island began about 1 week later. Most eggs were hatched in both areas by the first week in June and almost all young had fledged from both colonies by 1 August.

Organochlorine residues.—Residues of DDE, the only metabolite of DDT detected, were recovered in all eggs in 1978 (Table 1). The average level of DDE in eggs from Pelican Island was similar ($t = 0.170$, $P > 0.05$) to that for Sundown Island. DDE residues in individual eggs ranged up to 6.3 ppm, but only 5 of 40 eggs contained levels greater than 2.0 ppm. PCBs were found in 35 of 40 eggs with no significant difference in mean levels between the study areas ($t = 1.985$, $P > 0.05$). PCBs in individual eggs ranged up to 2.2 ppm at Pelican Island and 5.3 ppm at Sundown Island. Few other organochlorine compounds were found.

TABLE 1. Insecticide and PCB residues in Royal Tern eggs in Texas, 1970 and 1978.

Year and location	No. eggs	Mean residue ± SE[1] and range	
		DDE	PCB
1970			
Pelican Island	5	4.28 ± 0.88 (3.1–7.8)	11.60 ± 2.84 (3.0–20)
1978			
Pelican Island[2]	20	1.13 ± 0.29 (0.25–6.3)	0.75 ± 0.12 (ND–2.2)
Sundown Island[3]	20	1.20 ± 0.29 (0.28–5.8)	1.34 ± 0.27 (ND–5.3)

[1] DDE residues were found in all eggs analyzed. PCBs (Aroclor 1260) were found in all eggs in 1970 and in 17 eggs from Pelican Island and in 18 eggs from Sundown Island in 1978. ND = not detected.
[2] One egg contained 0.14 ppm dieldrin.
[3] Two eggs contained toxaphene at 1.0 and 0.25 ppm. Two eggs contained HCB at 0.12 and 0.10 ppm. One egg contained 0.11 ppm chlordane.

Residues of 1.0 ppm or less of toxaphene and hexachlorobenzene (HCB) each were recovered in two eggs; chlordane and dieldrin were found at low levels (0.11 and 0.14 ppm) in one egg each. DDE and PCB residues were generally below levels associated with chronic poisoning and reproductive problems in most species of birds (Ohlendorf et al. 1978, Stickel 1973).

Metal residues.—Detectable levels of zinc, mercury, copper, and selenium were found in all eggs from both colonies (Table 2). There were no significant differences in residue levels between the colonies ($t \leqq 1.126$, $P > 0.05$). Low residues of arsenic (<0.3 ppm) were found in 7 eggs from Pelican Island and in 5 eggs from Sundown Island ($t = 0.977$, $P < 0.05$).

Species of birds differ greatly in their sensitivity to mercury. Mercury

TABLE 2. Heavy metal and selenium residues in Royal Tern eggs collected from Pelican and Sundown islands, Texas, 1978.

Location	No. eggs	Mean residue ppm ± SE[1] and range				
		Zinc	Mercury	Copper	Selenium	Arsenic
Pelican Island	15	12.32 ± 0.38 (8.8–14)	1.11 ± 0.10 (0.73–2.2)	1.22 ± 0.10 (0.78–2.1)	1.06 ± 0.10 (0.49–2.1)	0.13 ± 0.03 (ND–0.26)
Sundown Island	15	11.72 ± 0.41 (9.0–14)	1.27 ± 0.11 (0.86–2.2)	1.09 ± 0.06 (0.6–1.5)	0.94 ± 0.06 (0.43–1.3)	0.18 ± 0.04 (ND–0.29)

[1] All eggs analyzed contained residues of zinc, mercury, copper, and selenium. Seven eggs from Pelican Island and 5 eggs from Sundown Island contained arsenic. ND = not detected.

TABLE 3. Eggshell thickness of Royal Tern eggs collected in Texas, pre-1943, 1970, and 1978.

Location[1]	Period	No.	Mean ± SE	Change %
Texas Coast	pre-1947	18	0.358 ± 0.004	—
Texas Coast	1970	12	0.330 ± 0.007	−8[2]
Pelican Island	1978	40	0.367 ± 0.004	+2[3]
Sundown Island	1978	37	0.347 ± 0.004	−3[3]

[1] Pre-1943 eggs were collected from 6 locations on the central and south Texas coast. Eggs collected in 1970 were from Pelican Island and one other island near Corpus Christi, Texas (King et al. 1978).
[2] $P < 0.001$ (Student's t-test).
[3] $P > 0.05$.

residues as low as 0.5 to 1.5 ppm (Fimreite 1971), and 0.9 to 3.1 ppm (Spann et al. 1972) in the eggs of Ring-necked Pheasant (*Phasianus colchicus*) were associated with reproductive failure. Mean levels of mercury in eggs that ranged from 0.79 to 0.86 ppm had no reproductive effects on first- and third-generation Mallards (*Anas platyrhynchos*), but these residues were associated with lowered reproductive success of second-generation hens (Heinz 1979). Lowered hatching success and a reduced fledging rate in Common Terns was associated with mercury levels in eggs between 1.0 and 3.6 ppm (Connors et al. 1975). Conversely, mercury residues from 2 to 16 ppm in eggs of Herring Gulls (*Larus argentatus*) did not appear to affect hatching or fledging success (Vermeer et al. 1973). The levels of mercury in Texas Royal Tern eggs averaged almost 1.2 ppm. Although not alarmingly high, this level is within the range associated with toxic effects in Pheasants, Mallards, and the closely related Common Tern.

Average zinc and copper levels (12.0 and 1.2 ppm) were similar to those found in Common Tern eggs from Great Gull Island, N.Y. (13.7 and 1.0 ppm, converted to wet weight) and may represent background levels (Connors et al. 1975). Selenium and arsenic residues (1.0 and <0.16 ppm) in Royal Tern eggs are similar to residues in Texas White-faced Ibis (*Pelegadis chihi*) eggs (King et al. 1980), and these amounts also may represent background levels. The biological significance of these residue levels of zinc, copper, selenium, and arsenic is unknown.

Residues and eggshell thickness.—The mean thicknesses of Royal Tern eggshells collected in 1978 were 0.367 mm at Pelican Island and 0.347 mm at Sundown Island (Table 3). The pre-1947 average of Texas eggs was 0.358 mm. While the mean thickness of eggs from Pelican Island was significantly greater (t = 3.547, $P < 0.001$) than the Sundown Island mean, neither was significantly different from the pre-1947 average (t = 1.642, $P > 0.05$). In contrast, tern eggs collected from Pelican Island in 1970 (mean thickness = 0.330 mm) were significantly thinner than pre-1947 eggs; thus, there has been a significant increase (t = 4.674,

$P < 0.001$) in the thickness of Royal Tern eggshells from 1970 to 1978. Although eggshell thinning ranged up to 18% (one egg), we found no cracked or crushed eggs in the colony.

Shell thinning in many species of birds has been associated primarily with residues of DDE (Ohlendorf et al. 1978, Stickel 1973). However, DDE was not correlated ($P > 0.05$, regression analysis) with shell thinning of tern eggs collected from Pelican Island ($r = +0.14$) and Sundown Island ($r = -0.41$) in 1978. DDE levels almost 3 times greater (3.12 ppm) than those in Texas tern eggs did not result in significant thinning of Royal Tern eggshells in South Carolina (Blus et al. 1979). In one of the most pollution-sensitive wildlife species, the Brown Pelican (*Pelecanus occidentalis*), a geometric mean of 1.77 ppm DDE did not adversely affect reproduction (Blus et al. 1974). Levels of DDE in Texas tern eggs averaged 1.13 ppm and may have been below the minimum threshold level responsible for eggshell thinning. DDE in tern eggs declined significantly ($t = 4.356$, $P < 0.001$) from 1970 to 1978 (Table 1), and lowered DDE levels were associated with an increase in average shell thickness. No significant correlation ($r = +0.03$ and $+0.02$, $P < 0.05$) was found between PCB and eggshell thinning. There was positive correlation ($r = +0.61$, $P < 0.05$) between copper residues and eggshell thickness of Pelican Island eggs, but not in eggs from Sundown Island ($r = +0.02$, $P > 0.05$). No significant correlations were found between other metals and eggshell thickness.

Incidence of abnormal young.—The incidence of tern chicks with disabilities was much lower than expected. We found only two debilitated terns at Sundown Island and one at Pelican Island. In each bird the condition was attributed to perosis or slipped tendons as described by Gilbertson et al. (1976). We saw no terns with deformed bills or spines as observed by cooperators in past years. Also, we found no chicks with feather anomalies like those described for other tern species on the East Coast (Gochfeld 1975, Hays and Risebrough 1972). The frequency of occurrence of abnormal young in 1976 was not quantified, but was probably fewer than 10 individuals. We have no explanation for the presence of abnormal young in 1976 but not in 1978.

SUMMARY

Royal Tern eggs collected from Pelican and Sundown islands on the central Texas coast in 1978 contained relatively low levels of organochlorine and metal pollutants. DDE and PCBs were found most frequently, but levels were below those known to have an adverse effect on avian reproduction and survival. Average metal residues did not vary significantly between study areas, and with the possible exception of mercury, were present only at background levels. Shells of eggs collected in 1978 were no thinner than eggshells collected before 1947. There was a significant improvement in mean eggshell thickness from 1970 to 1978 and a corresponding decline in DDE and PCB residues. No deformed or abnormal young were observed. Although elevated levels of industrial contaminants were reported in sediments and sea grasses of Corpus Christi Bay, little of those contaminants appear to have accumulated in the Royal Tern.

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U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Gulf Coast Field Station, P.O. Box 2506, Victoria, Texas 77902 (K.A.K.); *U.S. Fish and Wildlife Service, 6924 Tremont Road, Dixon, California 95620* (C.A.L.); *Patuxent Wildlife Research Center, Laurel, Maryland 20708* (B.M.M.). Received 1 Nov. 1982; accepted 20 May 1983.

NOTES AND NEWS

North American Bluebird Society Research Grants. The North American Bluebird Society provides grants in aid for ornithological research directed toward cavity nesting species of North America with emphasis on the genus *Sialia.* Presently 3 annual grants totalling $3000 are available consisting of varying amounts, generally stipends of $1000 are awarded and include:

Student Research Grant—Available to full-time college or university students for a suitable research project focused on a North American cavity nesting species.

Bluebird Research Grant—Available to student professional or individual researchers for a suitable research project focused on any of the three species of bluebird from the genus *Sialia.*

General Research Grant—Available to student, professional, and individual researchers for a suitable research project focused on a North American cavity nesting species.

Further guidelines and application forms are available upon request from Theodore W. Gutzke, Research Committee Chairman, P.O. Box 66, Upham, North Dakota 58789. Completed applications must be received by 31 January 1984; decisions will be announced by 15 March 1984.