Contaminant Report R6/515M/97
U.S. FISH AND WILDLIFE SERVICE

REGION 6

CONTAMINANTS PROGRAM

ARSENIC, MERCURY, SELENIUM, AND ORGANOCHLORINE COMPOUNDS IN INTERIOR LEAST TERN EGGS IN THE NORTHERN GREAT PLAINS STATES, 1992-1994

1995 Projects 64411-1261-6N29 and 60120-1261-6N29

U.S. FISH AND WILDLIFE SERVICE
Kansas Field Office
Manhattan, Kansas
1997

ARSENIC, MERCURY, SELENIUM, AND ORGANOCHLORINE COMPOUNDS IN INTERIOR LEAST TERN EGGS IN THE NORTHERN GREAT PLAINS STATES, 1992-1994

George T. Allen and Susan Humphreys Blackford

U. S. Fish and Wildlife Service
315E Houston Street
Manhattan, Kansas 66502-6172

OCTOBER 1997

EXECUTIVE SUMMARY

- The purpose of this study was to evaluate concentrations of arsenic, mercury, selenium, and chlorinated hydrocarbon compounds in interior least tern eggs from the northern Great Plains states from 1992 through 1994. The Environmental Contaminants Specialists in Kansas, Nebraska, South Dakota, North Dakota, and Montana agreed on a standard protocol for collection and analyses of eggs during the study period.

- Addled, flooded, or abandoned eggs collected during the study period were submitted for chemical analysis by the Environmental Contaminants Specialist in each state.

- A total of 104 eggs were analyzed for arsenic, mercury, and selenium; 78 of them also were analyzed for chlorinated hydrocarbons.

- Concentrations of some contaminants, particularly mercury, were difficult to interpret. Therefore, we also evaluated recent least tern productivity in the northern Great Plains states.

- Arsenic was detected in only 13 of the 104 eggs analyzed, and was unlikely to have detrimental effects on least tern reproduction.

- The geometric mean mercury concentrations for individual states each year were below 0.50 μg/g fresh weight (a concentration that is known to affect other species), but 11% of the eggs contained mercury at more than that concentration.

- Only 20 (19%) of the eggs contained selenium at less than the 3 μg/g dry weight concentration currently considered to be safe for avian reproductive success. Twenty-six percent of the eggs contained more than 5 μg/g dry weight. Thus, selenium likely is affecting least tern nesting success in the study area.

- Cyclodienes in 36 (46%) of the eggs analyzed for chlorinated hydrocarbons equaled or exceeded the concern level of 0.10 μg/g wet weight. The concentrations of oxychlordane and heptachlor epoxide, the most toxic components of technical chlordane were low in all eggs. Dieldrin and chlordane compounds and metabolites were ubiquitous in the tern eggs, and might be affecting least tern reproduction in the study area.

- DDT was detected at very low concentrations in some of the 1992 eggs, which shows that the terns had very recently been exposed to DDT. It was not detected in 1993 or 1994 eggs. DDT compound concentrations found are not likely to have detrimental effects on the population.

- PCB concentrations in eggs did not appear likely to affect reproductive success.

- Least tern nesting success in most locations in the study area was not sufficient to ensure survival of the interior population. Though nest flooding and predation likely are the major causes of the low recruitment, the results of this study indicate that selenium and mercury may be hampering reproduction.

- An analysis of least tern forage fish for contaminants in the study area should be undertaken to determine if there are locations where forage fish are high in selenium or mercury.

- Management of water in nesting areas to reduce selenium concentrations in least tern food sources should be considered.

ACKNOWLEDGMENTS

Denny Christopherson, Tom Custer, Katie Dugger, Brent Esmoil, Eileen Kirsch, Casey Kruse, Dan Mulhern, Greg Pavelka, and Rochelle Renken provided suggestions or data that helped in preparation of this report. Katie Dugger, Brent Esmoil, Kevin Johnson, Eileen Kirsch, John Malloy, Bill Olsen, Joe Skorupa, Patty Stevens, and Dan Welsh provided helpful reviews of the report draft.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The interior population of the least tern (*Sterna antillarum athalassos)* was listed as endangered in 1985 (50 Federal Register 21, 784-21, 792). Therefore, the U.S. Fish and Wildlife Service (Service) and other agencies are involved in efforts to increase the population of the interior least tern, as outlined by Sidle and Harrison (1990).

The major reason for listing the interior least tern as endangered was population reductions due to habitat losses caused by changes in the historic flow regimes along central U.S. rivers (Sidle and Harrison 1990:1). Contaminants may also play a role in the decline in numbers of the interior least tern, (U.S. Fish and Wildlife Service 1990). Terns acquire contaminants through the food chain, from drinking water, from preening feathers, and via inhalation. The pollutants may be derived from industrial effluents, agricultural runoff, air pollution fallout, natural erosion, and biogeochemical cycles.

Wintering areas of interior least terns include Central American and South American coastlines (Sidle and Harrison 1990). Though use of persistent chlorinated hydrocarbon pesticides continued in many areas outside the United States (Botero *et al.* 1996, Mora 1995, Mora *et al.* 1987, Ohlendorf *et al.* 1982,), not all DDT compound contamination is from other countries or from DDT use (Hunt *et al.* 1986, Risebrough *et al.* 1986). The persistence, bioaccumulation, and lipophilic characteristics of chlorinated hydrocarbons are special problems. Female birds eliminate organochlorines (and some metals) by sequestering them in their eggs, which may jeopardize developing embryos (Lamb *et al.* 1967, Bogan and Newton 1977).

This study was undertaken to determine concentrations of several inorganic contaminants of concern and of chlorinated hydrocarbons in least tern eggs in Region 6 of the Service. Environmental Contaminants Specialists in Montana, North Dakota, South Dakota, Nebraska, and Kansas had analyses of least tern eggs done when possible for several years prior to 1991. However, collection methods, preparation of the samples, analyses requested, and the analytical laboratory used for the analyses varied considerably. This report presents information from standardized sampling and analyses conducted from in 1992 through 1994.

Good least tern nesting success and recruitment would indicate that the contaminants found in least tern eggs would have minimal impacts on the population. Therefore, we also examined data on interior least tern reproduction in the northern Great Plains, to discover possible effects of contaminants on nesting success.

STUDY AREA

Eggs analyzed for this study were collected at Quivira National Wildlife Refuge (Quivira) in central Kansas, on or adjacent to the Platte River in Nebraska, on the Missouri River below Gavins Point Dam in South Dakota, on the Missouri River below Lake Sakakawea in North Dakota, and along the Missouri River below Fort Peck Dam in Montana (Figure 1).

METHODS

In 1991 the Kansas, Nebraska, South Dakota, North Dakota, and Montana Field Offices in Region 6 of the Service agreed to undertake analyses of least tern eggs; agreeing to use composite samples of three eggs from the same clutch from abandoned or flooded nests to analyze for arsenic, mercury, and selenium by atomic absorption spectrophotometry (AAS); for other metals by induction coupled plasma emission spectrophotometry (ICP); and on chlorinated hydrocarbons by electron capture gas chromatography (GC). The North Dakota office followed these protocols in 1991, except that individual eggs were analyzed.

The 1991 sampling showed that there was minimal concern over most metals analyzed by ICP; and we found that the analytical laboratories could analyze individual eggs even though the samples were small. From 1992 through 1994, Environmental Contaminants Specialists in the five states requested analyses of individual eggs, using AAS to test for arsenic, mercury, and selenium and GC for analyses of organochlorines. The Environmental Trace Substances Research Center (ETSRC) in Columbia, Missouri analyzed for inorganics, and the Mississippi State Chemical Laboratory (MSCL), Mississippi State University, analyzed chlorinated hydrocarbon concentrations. The samples were shipped to ETSRC; aliquots were sent to MSCL.

Because the interior least tern is a federally-listed species, collection of viable eggs was not permitted. Therefore only eggs that were flooded, addled, or abandoned were collected. The eggs were padded to prevent breakage, placed on ice, and transported to the Field Office in the state of collection. The eggs were either frozen whole in the shell or the shell was carefully broken and the contents of the egg were placed into a chemically-cleaned glass jar (polyethylene in North Dakota in 1993) and frozen. Damaged eggs were not analyzed.

Nominal wet weight detection limits at ETSRC were 0.05 μg/g for arsenic, 0.01 μg/g for mercury, and 0.1 μg/g for selenium; the actual detection limits varied slightly due to sample size. Dry weight concentrations were calculated from the wet weight concentrations, and

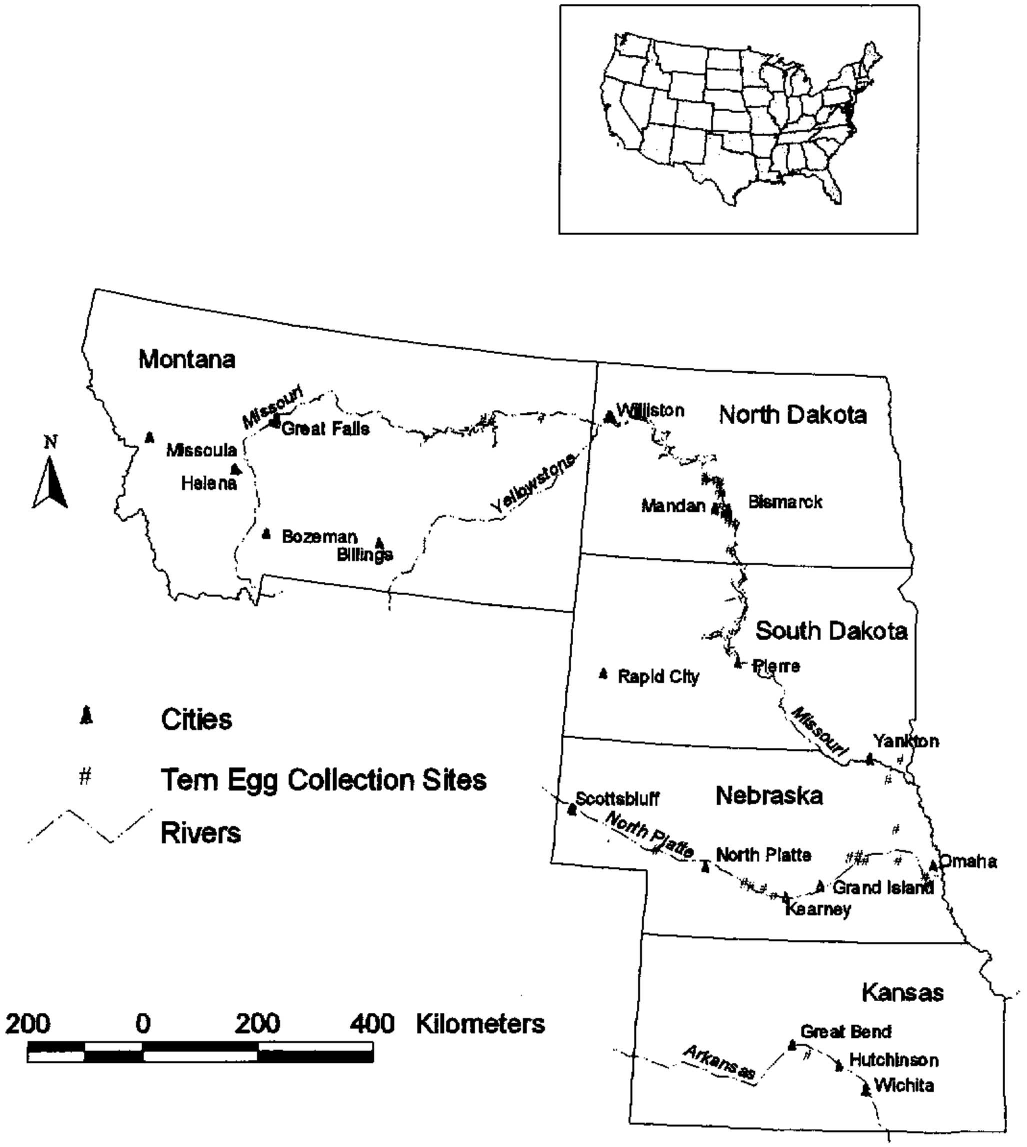

Figure 1. Least tern egg sampling locations in the northern Great Plains states, 1992-1994

ETSRC reported both. We report both fresh wet weight and dry weight concentrations for arsenic, mercury, and selenium. We report wet weight concentrations for chlorinated hydrocarbons, and all discussions of organics refer to wet weight values.

MSCL analyzed the aliquots for hexachlorobenzene (HCB); alpha-, beta-, gamma-, and delta-benzene hexachloride (BHC) (properly called hexachlorocyclohexane [HCH], which we use hereafter); oxychlordane, alpha- and gamma-chlordane; cis- and trans-nonachlor; heptachlor epoxide; the o,p' and p,p' forms of DDT, DDE, and DDD; endrin; dieldrin; mirex; toxaphene; and total polychlorinated biphenyls (PCBs). The detection limit for the compounds was 0.01 μg/g wet weight, except for toxaphene total PCBs, and for individual aroclors, for which the detection limit was 0.05 μg/g wet weight. Wet weight concentrations were reported by MSCL. Lipid-normalization does not improve data reporting (Huckins *et al.* 1988, Schmitt *et al.* 1990), so we report only wet weight concentrations. Some samples were too small for organics analyses or funding was not available for the analyses.

No anomalies were reported in the samples. Each sample was large enough for the laboratory to determine the concentration of each element or compound at the limit of the analytical equipment. Laboratory quality control was reviewed by the Patuxent Analytical Control Facility of the Service. Precision and accuracy of the laboratory analyses were confirmed with procedural blanks, duplicate analyses, test recoveries of spiked materials, and reference material analyses. Round-robin tests among Service contract analytical labs also were part of the quality control.

To standardize our samples and correct for weight loss after the eggs were laid, we followed the method of Hoyt (1979) to calculate the average fresh wet weight of least tern eggs. We used the mean length and breadth measurements for eggs collected at Quivira, in Nebraska, North Dakota, and the egg from Montana in 1994, to calculate a mean fresh wet weight of 9.10 g, using Hoyt's general K_W value of 0.548 (Table 1). We assumed that all weight loss in the eggs was due to loss of water, so the wet weight concentrations reported by ETSRC and MSCL were corrected to approximate fresh wet weight concentrations by multiplying the reported wet weight concentrations by the ratio of the sample weight divided by 9.01 g. The fresh wet weight concentrations are given in the tables of results, and discussions of wet weight values are based on corrected concentrations.

Geometric means were calculated for those cases in which at least half of the samples contained a detectable concentration of the particular contaminant. To calculate the mean we used a value of one-half of the detection limit for those samples in which the contaminant was not detected.

Table 1. Length and breadth measurements for least tern eggs from Kansas, Nebraska, North Dakota, and Montana. Measurements of eggs from Nebraska were converted from measurements in inches.

	Egg Measurements (mm)		
State	Length	Breadth	Fresh Egg Mass (g)[1]
Kansas	30.11	22.92	8.67
Kansas	31.82	23.02	9.24
Kansas	31.54	23.47	9.52
Kansas	32.87	22.78	9.35
Kansas	29.68	23.52	9.00
Kansas	30.81	23.63	9.43
Kansas	30.15	23.44	9.08
Nebraska	32.89	21.62	8.42
Nebraska	32.56	21.62	8.34
Nebraska	33.48	22.23	9.06
Nebraska	30.07	22.45	8.31
Nebraska	29.44	25.10	10.16
Nebraska	30.48	21.97	8.06
Nebraska	29.03	23.5	8.78
Nebraska	29.21	23.8	9.07
Nebraska	29.97	23.50	9.07
Nebraska	30.58	22.94	8.82
Nebraska	30.91	23.50	9.35
Nebraska	29.85	23.50	9.02
Nebraska	31.75	23.50	9.61
Nebraska	32.39	24.13	10.33

Table 1 (continued). Length and breadth measurements for least tern eggs from Kansas, Nebraska, North Dakota, and Montana. Measurements of eggs from Nebraska were converted from measurements in inches.

State	Egg Measurements (mm) Length	Egg Measurements (mm) Breadth	Fresh Egg Mass (g)[1]
Nebraska	30.48	23.50	9.22
Nebraska	29.21	23.50	8.84
Nebraska	27.94	22.86	8.00
Nebraska	27.94	22.86	8.00
Nebraska	30.12	23.11	8.82
Nebraska	30.20	22.23	8.18
Nebraska	31.42	23.62	9.61
Nebraska	32.00	22.45	8.84
Nebraska	30.94	23.60	9.44
Nebraska	31.47	22.61	8.81
North Dakota	32.25	22.45	8.91
North Dakota	32.40	24.25	10.44
North Dakota	28.65	23.85	8.93
North Dakota	31.15	23.10	9.11
North Dakota	30.10	24.05	9.54
North Dakota	30.90	22.70	8.73
North Dakota	30.85	23.15	9.06
North Dakota	30.80	23.40	9.24
North Dakota	30.85	22.95	8.90
North Dakota	31.70	22.80	9.03
North Dakota	30.60	23.40	8.79

Table 1 (concluded). Length and breadth measurements for least tern eggs from Kansas, Nebraska, North Dakota, and Montana. Measurements of eggs from Nebraska were converted from measurements in inches.

State	Egg Measurements (mm) Length	Egg Measurements (mm) Breadth	Fresh Egg Mass (g)[1]
North Dakota	29.30	23.40	8.79
Montana	30.12	23.39	9.03
			$\bar{x}=9.01$

[1] Calculated using Hoyt's (1979) general formula: (0.548 × length in cm × (breadth in cm)^2). Excludes shell.

In two instances, ICP analyses of eggs were requested in addition to the AAS analyses for arsenic, mercury, and selenium. The results of the ICP analyses and their implications are not discussed in this report.

In one case a Field Office also requested analysis of individual aroclors in the 1992 eggs in addition to an organochlorine scan. In another case, a Field Office requested a standard organochlorine scan, but a scan and an aroclor analysis were ordered by PACF. In those cases, MSCL did not report the total PCB concentration.

For most of the samples from South Dakota in 1993 and for a few other eggs, neither the submitter nor the analytical laboratory reported sample weights. Wet weight concentrations in those samples could not be corrected to fresh wet weight values; we report the uncorrected concentrations.

Because concentration data were not normally distributed for all contaminants in all years, we used a Kruskal-Wallis nonparametric test (Kruskal and Wallis 1952) run with SYSTAT (SYSTAT, Inc., Evanston, Illinois) to determine whether there were significant differences between mean concentrations of mercury, selenium, or cyclodienes between states in 1992 and 1993 (the 1994 samples sizes were too small for testing). The significance level for the tests was 0.05. We used the multiple comparison method of Siegel and Castellan (1988) to determine which states differed significantly. The overall significance level for the multiple comparisons was 0.05.

RESULTS AND DISCUSSION

The number of eggs from each state in each year is shown in Table 2. A total of 104 eggs were analyzed for arsenic, mercury, and selenium. In some cases organics analyses were not requested or the samples were too small for the analysis, so 78 eggs were analyzed for chlorinated hydrocarbons.

Table 2. Numbers of least tern eggs analyzed from each state, 1992-1994. Numbers in parentheses are the numbers analyzed for chlorinated hydrocarbons.

	Number of Eggs Analyzed			
State	1992	1993	1994	TOTAL
Kansas	4 (4)	3 (3)	0	7 (7)
Nebraska	20 (20)	6 (6)	1 (0)	27 (26)
South Dakota	10 (9)	19 (0)	5 (0)	34 (9)
North Dakota	16 (16)	16 (16)	0	32 (32)
Montana	0	3 (3)	1 (1)	4 (4)
TOTAL	52 (49)	47 (28)	7 (1)	104 (78)

ARSENIC, MERCURY, AND SELENIUM

Arsenic, mercury, and selenium concentrations in the eggs analyzed are shown in tables 3, 4, and 5.

Arsenic

Arsenic is a relatively common element present in air, water, soils and all living tissues. It is used in the production of herbicides, insecticides, desiccants, wood preservatives and growth stimulants for plants and animals (Eisler 1988). Large quantities of arsenicals are released into the environment as a result of industrial and agricultural activities. Although evidence is accumulating that arsenic is beneficial or even nutritionally essential, it is also a teratogen and carcinogen that can cross placental barriers and produce fetal death and malformations in

Table 3. Arsenic, mercury, and selenium concentrations in least tern eggs in 1992. Means are geometric means. NC = Not calculable. NA = Not analyzed. ND = Not detected.

Egg Mass (g)	Percent Moisture	Arsenic		Mercury		Selenium	
		Dry	Wet	Dry	Wet	Dry	Wet
Kansas							
7.5	74.4	ND	ND	0.99	0.21	4.60	0.99
8.2	77.6	ND	ND	4.70	0.99	3.80	0.77
8.2	70.4	ND	ND	4.40	1.17	2.60	0.69
8.1	74.0	ND	ND	0.69	0.16	4.20	0.98
				$\bar{x}$=1.94	$\bar{x}$=0.44	$\bar{x}$=3.72	$\bar{x}$=0.85
Nebraska							
7.6	76.5	ND	ND	1.40	0.27	3.70	0.73
6.7	75.7	ND	ND	1.50	0.27	3.80	0.68
6.5	79.2	ND	ND	1.40	0.21	5.60	0.86
6.5	78.1	ND	ND	1.00	0.16	5.90	0.93
4.0	NA	0.20	0.04	0.23	0.06	1.10	0.27
2.5	50.7	ND	ND	0.37	0.05	2.10	0.27
5.6	75.9	ND	ND	0.85	0.12	6.30	0.92
4.8	74.9	ND	ND	1.50	0.20	7.20	0.95
3.6	74.0	ND	ND	0.25	0.03	4.40	0.43
6.0	71.3	ND	ND	1.70	0.32	4.00	0.73
3.5	74.1	ND	ND	1.40	0.14	3.40	0.34
5.0	77.8	ND	ND	1.60	0.19	5.50	0.66
3.9	78.5	ND	ND	2.30	0.21	5.70	0.51
3.5	NA	ND	ND	1.40	0.16	5.00	0.54
3.2	77.0	ND	ND	2.30	0.19	5.80	0.46
3.6	77.3	ND	ND	1.80	0.16	5.40	0.48
2.4	73.3	ND	ND	3.40	0.24	3.60	0.26
6.0	75.7	ND	ND	1.20	0.19	5.30	0.86
2.2	72.9	ND	ND	1.20	0.08	3.60	0.24
3.5	76.0	ND	ND	1.70	0.16	5.10	0.47
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=1.19	$\bar{x}$=0.15	$\bar{x}$=4.32	$\bar{x}$=0.53

Table 3 (concluded). Arsenic, mercury, and selenium concentrations in least tern eggs in 1992. Means are geometric means. NC = Not calculable. NA = Not analyzed. ND = Not detected.

Egg Mass (g)	Percent Moisture	Arsenic		Mercury		Selenium	
		Dry	Wet	Dry	Wet	Dry	Wet
				South Dakota			
6.1	NA	ND	ND	1.80	0.26	4.70	0.68
NA	80.1	0.20	0.04[1]	0.40	0.08[1]	7.70	1.50[1]
NA	78.9	ND	ND	0.64	0.13[1]	7.00	1.50[1]
NA	84.8	ND	ND	0.46	0.07[1]	2.80	0.43[1]
NA	81.3	ND	ND	1.53	0.29[1]	4.00	0.75
NA	85.5	ND	ND	0.70	0.10[1]	4.40	0.64[1]
NA	84.3	ND	ND	1.35	0.21[1]	5.10	0.80[1]
NA	82.5	ND	ND	0.53	0.09[1]	4.20	0.74[1]
NA	82.4	ND	ND	0.20	0.04[1]	3.10	0.55[1]
NA	83.5	0.40	0.07	1.19	0.20[1]	4.10	0.68[1]
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=0.72	$\bar{x}$=0.13[1]	$\bar{x}$=4.50	$\bar{x}$=0.80[1]
				North Dakota			
5.1	77.5	ND	ND	1.88	0.24	4.98	0.63
4.4	78.2	ND	ND	3.10	0.33	5.20	0.55
4.9	77.6	ND	ND	2.29	0.28	5.00	0.60
4.6	80.4	ND	ND	1.42	0.14	5.41	0.54
4.7	80.2	ND	ND	1.69	0.17	4.32	0.45
2.8	78.6	ND	ND	1.52	0.10	4.74	0.31
5.0	80.9	ND	ND	0.83	0.09	2.91	0.30
2.6	77.6	ND	ND	1.94	0.12	3.65	0.23
2.5	80.6	ND	ND	1.57	0.08	3.88	0.20
4.2	74.8	ND	ND	3.08	0.36	4.09	0.48
4.8	79.6	ND	ND	2.77	0.30	4.21	0.45
3.9	71.1	ND	ND	1.23	0.15	3.65	0.46
5.6	78.3	ND	ND	0.41	0.05	7.20	0.97
5.1	73.2	ND	ND	0.41	0.06	6.87	1.03
5.3	81.7	ND	ND	1.64	0.18	5.48	0.58
4.0	78.3	ND	ND	1.36	0.13	3.94	0.38
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=1.47	$\bar{x}$=0.15	$\bar{x}$=4.60	$\bar{x}$=0.47

[1] Uncorrected wet weight concentrations. The analytical laboratory did not report sample masses.

Table 4. Arsenic, mercury, and selenium concentrations in least tern eggs in 1993. Means are geometric means. NC = Not calculable. NA = Not analyzed. ND = Not detected.

Egg Mass (g)	Percent Moisture	Arsenic		Mercury		Selenium	
		Dry	Wet	Dry	Wet	Dry	Wet
				Kansas			
8.9	74.6	ND	ND	1.80	0.45	2.30	0.57
9.1	76.3	ND	ND	2.90	0.59	1.90	0.45
6.3	69.9	ND	ND	1.90	0.40	1.80	0.38
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=2.15	$\bar{x}$=0.50	$\bar{x}$=1.99	$\bar{x}$=0.46
				Nebraska			
6.5	77.0	ND	ND	4.40	0.71	4.60	0.79
6.0	76.0	ND	ND	3.20	0.51	3.30	0.52
5.5	79.8	ND	ND	4.00	0.49	4.00	0.49
6.0	77.0	ND	ND	2.10	0.32	3.60	0.55
4.0	71.5	ND	ND	3.08	0.39	4.80	0.62
6.0	78.7	ND	ND	2.80	0.40	5.20	0.73
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=3.17	$\bar{x}$=0.45	$\bar{x}$=4.20	$\bar{x}$=0.60

mammals (Eisler 1988). Arsenic is bioconcentrated in organisms, but does not biomagnify in the food chain (Eisler 1994). Arsenic concentrations in mallard ducks (*Anas platyrhynchos*) quickly drop to normal upon return to a diet without added arsenic (Pendleton *et al.* 1995).

Eisler (1994) reported that arsenic concentrations in biota are usually less than 1 μg/g fresh weight. Eggs of mallard ducks fed a diet without added arsenic contained a mean arsenic concentration of 0.23 μg/g; eggs of those on a diet supplemented with 25 μg/g dry weight had a mean arsenic concentration of 0.46 μg/g (Stanley *et al.* 1994). Thus, if the differences between species are discounted, the detectable concentrations in the least tern eggs that contained arsenic would correspond to a diet with it added. However, there were no apparent effects on hatching success or deformities in mallards (Stanley *et al.* 1994), even at concentrations much higher than those found in this study. Arsenic was detected in only 13 of the eggs analyzed, and the maximum concentration found was only 0.40 μg/g dry weight. It was unlikely to have had detrimental effects, even on individual eggs.

Table 4 (continued). Arsenic, mercury, and selenium concentrations in least tern eggs in 1993. Means are geometric means. NC = Not calculable. NA = Not analyzed. ND = Not detected.

Egg Mass (g)	Percent Moisture	Arsenic		Mercury		Selenium	
		Dry	Wet	Dry	Wet	Dry	Wet
				South Dakota			
3.0	NA	0.05	0.01	1.80	0.21	5.50	0.63
4.6	NA	ND	ND	4.09	0.50	3.70	0.45
7.0	NA	ND	ND	1.50	0.25	4.60	0.75
4.6	NA	ND	ND	1.70	0.20	4.60	0.55
4.8	NA	ND	ND	0.93	0.11	3.80	0.43
6.9	NA	ND	ND	1.60	0.27	4.70	0.83
6.5	NA	ND	ND	1.20	0.21	3.90	0.68
3.6	NA	0.01	<0.01	0.67	0.06	8.00	0.70
5.4	NA	ND	ND	0.64	0.09	12.0	1.67
6.0	NA	ND	ND	0.82	0.12	3.70	0.55
4.0	NA	0.01	<0.01	1.30	0.14	3.30	0.35
5.2	NA	ND	ND	0.80	0.12	4.20	0.63
5.4	NA	ND	ND	1.30	0.17	4.30	0.57
5.1	NA	ND	ND	1.30	0.18	5.20	0.72
2.8	NA	ND	ND	1.90	0.17	5.20	0.46
3.4	NA	ND	ND	5.19	0.38	4.80	0.35
4.4	NA	ND	ND	2.56	0.28	4.50	0.48
4.4	NA	ND	ND	1.40	0.19	3.60	0.48
4.8	NA	ND	ND	1.30	0.17	3.60	0.48
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=1.44	$\bar{x}$=0.18	$\bar{x}$=4.65	$\bar{x}$=0.58

Table 4 (concluded). Arsenic, mercury, and selenium concentrations in least tern eggs in 1993. Means are geometric means. NC = Not calculable. NA = Not analyzed. ND = Not detected.

Egg Mass (g)	Percent Moisture	Arsenic		Mercury		Selenium	
		Dry	Wet	Dry	Wet	Dry	Wet
				North Dakota			
5.5	77.3	ND	ND	1.70	0.24	4.40	0.60
5.5	75.1	0.40	0.06	1.70	0.25	4.10	0.60
5.0	75.3	ND	ND	1.60	0.22	3.40	0.46
5.5	76.4	ND	ND	3.90	0.56	2.60	0.37
6.0	76.4	ND	ND	3.10	0.48	3.80	0.59
7.7	77.2	ND	ND	2.50	0.48	3.90	0.75
5.8	74.8	ND	ND	1.90	0.31	3.80	0.61
6.0	75.5	ND	ND	1.60	0.26	4.50	0.73
6.3	76.9	ND	ND	1.90	0.30	4.70	0.76
6.9	74.2	ND	ND	3.10	0.61	3.30	0.64
7.5	78.5	ND	ND	2.60	0.46	3.50	0.62
7.1	72.6	ND	ND	0.92	0.20	3.30	0.70
6.6	75.9	ND	ND	3.30	0.57	3.50	0.61
7.0	74.9	ND	ND	3.50	0.68	3.50	0.68
6.6	74.4	ND	ND	3.20	0.59	2.80	0.52
7.0	78.8	ND	ND	2.80	0.45	3.00	0.49
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=2.30	$\bar{x}$=0.39	$\bar{x}$=3.59	$\bar{x}$=0.60
				Montana			
5.0[1]	72.5	ND	ND	0.79	0.12	3.40	0.51
4.1	73.2	ND	ND	1.40	0.17	2.50	0.30
6.3	74.4	ND	ND	0.82	0.15	3.30	0.59
				$\bar{x}$=0.97	$\bar{x}$=0.14	$\bar{x}$=3.04	$\bar{x}$=0.45

---

[1] Mass reported by the submitter; value reported by the analytical lab was in error.

Table 5. Arsenic, mercury, and selenium concentrations in least tern eggs in 1994. Means are geometric means. NC = Not calculable. NA = Not analyzed. ND = Not detected.

Egg Mass (g)	Percent Moisture	Arsenic		Mercury		Selenium	
		Dry	Wet	Dry	Wet	Dry	Wet
				Nebraska			
4.0	73.9	ND	ND	0.95	0.11	4.60	0.53
				South Dakota			
3.1	NA	ND	ND	1.70	0.15	4.70	0.42
5.3	NA	ND	ND	0.31	0.06	4.60	0.81
6.0	NA	ND	ND	0.29	0.06	5.60	1.18
5.7	NA	0.06	0.01	1.20	0.18	5.80	0.82
5.1	NA	0.04	0.01	1.30	0.16	5.40	0.68
		$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=0.75	$\bar{x}$=0.11	$\bar{x}$=5.22	$\bar{x}$=0.74
				Montana			
7.3[1]	NA	ND	ND	2.04	0.41	3.90	0.79

[1] Mass reported by the submitter; analytical lab did not report mass.

Mercury

Mercury is a cumulative poison (Jenkins 1981) and is very toxic to fish (Eisler 1987). The potential for mercury bioaccumulation in birds and fish is high to very high (Jenkins 1981). Mercury is strongly bioconcentrated and biomagnified, has no useful physiological functions in fish and wildlife; is a carcinogen, mutagen, and teratogen; and in animals is easily transformed from an inorganic form to the more toxic methylated form (Eisler 1987).

It appears that the effects of mercury are more pronounced in some species of birds. Dietary mercury has been correlated with production of fewer eggs and increased duckling and embryonic mortality (Heinz 1974). Spann *et al.* (1972) reported that in pheasants (*Phasianus colchicus*) a concentration of 0.9 μg/g wet weight reduced hatching success. Heinz (1979) reported that mallard egg concentrations of 0.79 to 0.86 μg/g wet weight in eggs reduced neither hatching success nor duckling survival through three generations, though they may have reduced some other measures of nesting success. However, he did report aberrant behavior in hatchlings from eggs with wet weight concentrations of 0.80 μg/g or more. Herring gull (*Larus argentatus*) eggs from Alberta, Saskatchewan, and Manitoba that contained 0.5 to 2.0 μg/g wet weight hatched successfully (Vermeer 1971). Burger and Gochfeld (1995) reported annual geometric mean mercury concentrations in herring gull eggs of 0.172 to 0.458 μg/g wet weight at a nesting colony on Long Island in New York. Gulls nesting at that colony were exposed to mercury in their foods. The authors concluded that the concentrations found were "within the general range for mercury levels."

Concentrations up to 16 μg/g wet weight did not appear to affect herring gull hatching or fledging success in Ontario (Vermeer et al. 1973). Koster *et al.* (1996) determined that mercury levels up to 0.88 μg/g wet weight in herring gull eggs from the Great Lakes were not a factor in the poor reproduction of the species there.

In South Dakota, Greichus *et al.* (1973) found mean mercury concentrations in eggs of double-crested cormorants (*Phalacrocorax auritus*) and white pelicans (*Pelecanus erythrorhynchos*) of 0.29 and 0.22 μg/g wet weight, respectively. White and Cromartie (1977) reported average concentrations in hooded mergansers (*Lophodytes cucullatus*) eggs from the northeast in 1975 of 1.01 μg/g wet weight, of 0.64 μg/g in the midwest, and 0.62 μg/g in the south-central United States. Hooded mergansers eggs in Missouri in 1973 contained an average of 0.74 μg/g wet weight; in 1975 the mean was 0.92 μg/g. In 1975 in North Dakota, hooded merganser eggs contained an average of 0.73 μg/g wet weight (White and Cromartie 1977). Like least terns, those species feed largely on fish.

King *et al.* (1991) reported that mercury concentrations in eggs of Forster's (*Sterna forsteri*) and Caspian (*Sterna caspia*) terns from coastal Texas were 0.50 μg/g wet weight or less, and "were considerably lower than levels found in fish-eating waterbirds from mercury contaminated areas in [the] United States and Canada." They also concluded that the mean concentration of 0.46 μg/g wet weight had no effect on hatching success of black skimmers (*Rhyncops niger*). At two lakes in Ontario, Fimreite (1974) found that at a common tern (*Sterna hirundo*) nesting colony at which the mean mercury concentration in eggs was 3.65 μg/g wet weight, fledging success was only 10 to 12 percent. At a colony with what Fimreite believed to be normal fledging success, the mean was 1.00 μg/g wet weight. Common terns had lower nesting success and fledging rates when mercury concentrations in eggs were over 1.0 μg/g wet weight (Connors *et al.* 1975).

Wiemeyer *et al.* (1984) suggested that mercury concentrations in eggs of bald eagles (*Haliaeetus leucocephalus*) of more than 0.50 μg/g wet weight might adversely affect reproduction. The mean concentrations for successful and unsuccessful nests were 0.11 and 0.15 μg/g wet weight, which were not significantly different. Geometric means in bald eagle eggs from different states from 1980 to 1984 ranged from 0.06 to 0.41 μg/g wet weight (Wiemeyer *et al.* 1993). Concentrations in eggs in Arizona were 0.06 to 0.29 μg/g wet weight (Grubb *et al.* 1990). The maximum mean concentration in osprey (*Pandion haliaetus*) eggs from various U.S. locations from 1973 through 1978 was 0.22 μg/g wet weight

(Wiemeyer *et al.* 1988). Audet *et al.* (1992) reported median concentrations in osprey eggs from Massachusetts, Maryland, and Virginia of 0.05 to 0.11 μg/g wet weight, with a maximum concentration of 0.24 μg/g.

King *et al.* (1991) agreed with Faber and Hickey (1973) that residues less than 0.25 μg/g wet weight may represent background levels. Burger and Gochfeld (1995) reported that mercury concentrations in eggs generally range from 0.15 to 3.0 μg/g, dry weight. Thompson (1996) concluded that 0.50 μg/g wet weight in eggs would "have little detrimental effect on reproduction."

The maximum concentration in any egg collected for this study was 1.19 μg/g fresh weight, and the geometric means for all eggs for all years were 0.20 μg/g wet weight and 1.44 μg/g dry weight[1]. The geometric means for individual states each year were below 0.50 μg/g, 11 (11%) of the eggs contained more that concentration. Those eggs were from Kansas, Nebraska, and North Dakota. Some of the eggs had a mercury concentration that may have been detrimental to reproduction, but the information in the literature does not make that assessment certain.

Kruskal-Wallis analysis of the 1992 and 1993 mercury data showed that there was no significant difference between states in 1992 (P=0.209). However, in 1993 there were differences (P<0.001). Concentrations in the Nebraska eggs were significantly higher than those in South Dakota and Montana eggs. Concentrations in North Dakota eggs also were higher than those in eggs from South Dakota.

Selenium

Selenium is widely distributed in nature. It is an essential trace nutrient for terrestrial and aquatic organisms. However, the range between a dose that is nutritionally beneficial and one that is toxic is very narrow (Eisler 1985, Skorupa *et al.* 1996). In addition, the effect levels of the compounds of selenium also vary greatly (Heinz et al. 1989). Most authorities agree that selenium released as a result of human activities or found in naturally seleniferous areas poses the greatest threat to fish and wildlife (Eisler 1985).

The concern level for selenium in bird eggs is now much lower than it was just a decade ago. Heinz *et al.* (1987) and Lemly and Smith (1987) gave a concern level of 15 to 20 μg/g dry weight. Skorupa and Ohlendorf (1991) concluded that for black-necked stilts (*Himantopus mexicanus*) and American avocets (*Recurvirostra americana*), much lower hatching success was

---

[1] Includes uncorrected wet weight concentrations from South Dakota in 1993.

associated with a mean concentration of 2.4 μg/g wet weight, or about 8 μg/g dry weight. Lemly (1993) reported that mortality and deformities increase as concentrations rise, and may affect 50% or more of all birds when residues reach 10 μg/g in eggs, and recommended that 3 μg/g dry weight in eggs be taken as the threshold for selenium impacts on avian reproduction. Lemly (1995), in his protocol for evaluating selenium hazards to biota, considered concentrations of 5 to 12 μg/g dry weight to represent a low hazard, though he intended that egg concentrations to be added to other measures to evaluate the overall hazard to biota. Skorupa *et al.* (1996) stated that background means in bird eggs should be 3 μg/g or less, and the maximum concentration should be less than 5 μg/g dry weight. Heinz (1996) also considered 3 μg/g dry weight the threshold for reproductive impairment, though he warned that "setting the threshold at 3 [μg/g] leaves only a narrow margin of safety, especially because so few species have been tested under controlled laboratory conditions."

Differences in effects of selenium toxicity in different biota brought Lemly (1993) to recommend studies of reproductive performance to provide conclusive evidence of adverse effects. Skorupa *et al.* (1996) presented data to clearly point out different thresholds of selenium toxicity between different avian taxa.

Because the eggs were not randomly collected, the values from this study can not be considered representative of the population. Nevertheless, the geometric mean selenium concentrations exceeded 3 μg/g dry weight in every state and every year except in Kansas in 1993, as did the concentration in the egg from Montana in 1994. Only 20 of the eggs contained less than 3 μg/g dry weight. Some of the eggs clearly contained selenium concentrations of concern; 27 (26%) contained more than 5 μg/g dry weight. These selenium concentrations are similar to those measured in interior least terns eggs in the past (Allen 1992, Charbonneau 1993, Ruelle 1991, U.S. Fish and Wildlife Service 1990, Welsh and Mayer 1993).

Kruskal-Wallis analyses of selenium concentrations in 1992 and 1993 indicated that there were no significant differences between states in 1992 (P=0.609). In 1993 though, concentrations in eggs from Kansas were lower than those in eggs from Nebraska and South Dakota (P<0.001).

CHLORINATED HYDROCARBON COMPOUNDS

Delta HCH; gamma chlordane; endrin; o,p'-DDT; toxaphene; and mirex were not detected in any egg in 1992. In 1993, alpha HCH; beta HCH; delta HCH; gamma chlordane; endrin; p,p'-DDT; o,p'-DDT; o,p'-DDE, and mirex were not found in any egg. Not detected in the egg from Montana in 1994 were HCH; gamma chlordane; oxychlordane; endrin; DDT; o,p'-DDE; DDD; or mirex. The results of analyses of the eggs for chlorinated hydrocarbon compounds are shown in tables 6, 7, and 8.

Cyclodienes (chlordane compounds, heptachlor, aldrin, endrin, dieldrin, and endosulfan) are the most acutely toxic of the chlorinated hydrocarbons (Blus 1995). Some researchers have concluded that cyclodienes are less important in eggshell thinning than are DDT compounds. We suspect that is so largely because the cyclodienes are less common and because dieldrin residues often are highly correlated with those of DDT compounds. However, other cyclodienes have been shown to sometimes reduce reproductive success; like DDT compounds, dieldrin has been implicated in eggshell thinning (Lehner and Egbert 1969, Davison and Sell 1974). Wiemeyer *et al.* (1986) found that "dieldrin residues in eggs were more closely related to shell thickness than DDE", though they suspected that the result was due to lower than expected thinning from DDE. Atkins and Linder (1967) reported reduced fertility and hatchability in eggs from female pheasants fed dieldrin. In contrast, Mendenhall *et al.* (1983) provided evidence that in birds dieldrin is more a factor in direct mortality than in diminished reproduction.

Eisler (1990) suggested 0.1 μg/g as the no-observable-effect level for cyclodienes in fish. In 36 (46%) of the eggs the concentrations equaled or exceeded that level. In most of those cases the concentration was high enough for us to discount concerns about concentrations at the limits of the analytical methods. Concentrations of oxychlordane and heptachlor epoxide, the most toxic components of technical chlordane (Wiemeyer 1996), were low in all eggs, but dieldrin and chlordane compounds and metabolites were ubiquitous. However, Weseloh *et al.* (1989) concluded that similar concentrations in eggs of common terns in the Canadian Great Lakes were not high enough to be important in the population dynamics of the species there. Wiemeyer *et al.* (1988) and Audet *et al.* (1992) concluded that higher dieldrin concentrations in osprey eggs than we found in least tern eggs were not likely to affect productivity.

Analysis of the 1992 and 1993 data for cyclodienes showed that concentrations showed differences between states ($P<0.001$ in 1992; $P=0.002$ in 1993). Concentrations were significantly lower in North Dakota than in Nebraska in 1992. Concentrations were significantly higher in Nebraska than in North Dakota and Montana in 1993.

Among the chlorinated hydrocarbons, DDT compounds are best known for their effects on eggshell thinning and reproductive failure in birds. Brown pelicans (*Pelecanus occidentalis*) along the gulf coast in Louisiana were found to have been very seriously impacted by DDE. Blus (1982) determined that reproduction was affected at approximately 3 μg/g in eggs. Henny

Table 6. Wet weight chlorinated hydrocarbon compound concentrations in least tern eggs in 1992. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = Not detected.

Percent Moisture	Percent Lipid	HCB	alpha HCH	beta HCH	gamma HCH	alpha chlordane
			Kansas			
85.1	8.20	ND	ND	ND	ND	ND
86.1	7.40	ND	ND	ND	ND	ND
81.8	18.20	ND	ND	ND	ND	ND
82.8	6.90	ND	ND	ND	ND	0.027
						$\bar{x}$ =NC
			Nebraska			
NA	NA	ND	ND	ND	ND	0.008
NA	NA	ND	ND	ND	ND	0.007
NA	NA	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	0.007
NA	NA	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	0.005
NA	NA	ND	ND	ND	ND	0.006
NA	NA	ND	ND	ND	ND	0.005
75.0	11.60	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	0.013
76.0	10.40	ND	ND	ND	ND	0.008
NA	NA	0.005	ND	ND	ND	0.022
78.0	6.30	ND	ND	ND	ND	0.026
NA	NA	ND	ND	ND	ND	0.004
78.0	7.42	ND	ND	ND	ND	0.011
77.0	7.76	ND	ND	ND	ND	0.012
73.0	11.60	ND	ND	ND	ND	0.008
NA	NA	ND	ND	ND	ND	0.013
77.0	11.50	ND	ND	ND	ND	0.007
77.0	8.93	ND	ND	ND	ND	ND
		$\bar{x}$ =NC				$\bar{x}$ =0.011

Table 6 (continued). Wet weight chlorinated hydrocarbon compound concentrations in least tern eggs in 1992. Values in bold equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

Percent Moisture	Percent Lipid	HCB	alpha HCH	beta HCH	gamma HCH	alpha chlordane
South Dakota[1]						
70.0	12.70	0.01	0.01	0.01	0.01	0.05
72.0	12.30	0.01	ND	ND	ND	0.06
73.0	12.70	0.01	ND	ND	ND	0.02
76.8	10.90	ND	ND	ND	ND	0.06
NA	13.00	0.01	ND	0.01	ND	0.02
NA	8.47	ND	ND	ND	ND	ND
76.0	12.50	0.01	ND	ND	ND	ND
NA	27.00	0.01	0.01	ND	ND	0.04
67.0	4.42	ND	ND	ND	ND	0.02
		$\bar{x}$=0.01	$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=NC	$\bar{x}$=0.02
North Dakota						
NA	NA	0.006	ND	ND	ND	0.006
NA	NA	ND	ND	ND	ND	0.005
NA	NA	ND	ND	ND	ND	ND
NA	NA	0.005	ND	ND	ND	0.005
NA	NA	ND	ND	ND	ND	0.005
NA	NA	0.003	ND	ND	ND	0.003
NA	NA	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	0.003
NA	NA	ND	ND	ND	ND	0.003
NA	NA	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	ND
NA	NA	0.009	ND	ND	ND	0.004
NA	NA	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	ND
NA	NA	ND	ND	ND	ND	ND
		$\bar{x}$=NC				$\bar{x}$=0.003

---

[1] Uncorrected wet weight concentrations.

Table 6 (continued). Wet weight chlorinated hydrocarbon compound concentrations in least tern eggs in 1992. Values in bold equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

cis nonachlor	trans nonachlor	oxychlordane	heptachlor epoxide	dieldrin	cyclodiene total	p, p'-DDT	p, p'-DDE
Kansas							
ND	ND	ND	ND	ND	ND	ND	0.082
ND	ND	ND	ND	ND	ND	ND	0.117
ND	ND	ND	ND	0.018	0.018	0.018	0.144
0.027	0.062	0.018	0.045	0.018	**0.196**	0.009	0.134
x̄=NC	x̄=NC	x̄=NC	x̄=NC	x̄=0.009	x̄=0.017	x̄=0.008	x̄=0.118
Nebraska							
0.017	0.025	0.008	0.025	**0.100**	**0.184**	ND	0.384
0.015	0.037	0.007	0.022	0.074	**0.162**	ND	0.162
ND	0.007	0.007	0.004	0.014	0.068	ND	0.121
0.007	0.014	0.007	0.007	0.036	0.079	ND	0.193
ND	0.004	0.009	0.009	0.002	0.046	ND	0.123
ND	0.008	0.003	0.001	0.001	0.019	ND	0.330
0.006	0.018	0.006	0.006	0.012	0.055	ND	0.191
0.011	0.005	0.005	0.005	0.016	0.047	ND	0.121
ND	0.008	0.008	0.004	0.012	0.051	0.004	0.024
0.026	0.040	0.020	0.026	0.046	**0.171**	ND	0.112
ND	0.031	0.012	0.015	0.035	**0.101**	0.012	0.115
0.044	0.104	0.027	0.049	**0.132**	**0.379**	ND	0.253
ND	0.069	0.021	0.034	0.056	**0.206**	0.013	0.171
0.019	0.038	0.012	0.019	0.073	**0.165**	ND	0.181
ND	0.035	0.014	0.028	0.067	**0.155**	0.011	0.141
ND	0.036	0.012	0.028	0.067	**0.154**	0.008	0.131
ND	0.021	0.005	0.013	0.047	0.095	0.005	0.200
0.026	0.053	0.020	0.033	0.066	**0.211**	ND	0.171
ND	0.019	0.007	0.012	0.027	0.073	ND	0.075
ND	0.019	0.015	0.027	0.062	**0.142**	ND	0.092
x̄=NC	x̄=0.022	x̄=0.010	x̄=0.013	x̄=0.031	**x̄=0.104**	x̄=NC	x̄=0.144

Table 6 (continued). Wet weight chlorinated hydrocarbon compound concentrations in least tern eggs in 1992. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

cis nonachlor	trans nonachlor	oxychlordane	heptachlor epoxide	dieldrin	cyclodiene total	p, p'-DDT	p, p'-DDE
South Dakota[1]							
ND	0.18	0.04	0.07	0.06	0.44	0.04	0.38
ND	0.13	0.10	0.24	0.20	0.74	0.03	0.55
ND	0.03	0.01	0.03	0.05	0.15	ND	0.17
ND	0.05	0.03	0.04	ND	0.18	ND	0.54
ND	0.04	0.02	0.03	0.09	0.22	ND	0.77
ND	ND	ND	ND	0.05	0.05	ND	0.21
ND	ND	ND	ND	0.04	0.05	ND	0.25
ND	0.09	0.02	0.03	0.05	0.25	0.05	0.64
ND	0.05	0.01	0.03	0.02	0.13	ND	0.16
	$\bar{x}$=0.04	$\bar{x}$=0.02	$\bar{x}$=0.03	$\bar{x}$=0.04	$\bar{x}$=0.17	$\bar{x}$=NC	$\bar{x}$=0.32
North Dakota							
ND	0.017	0.006	0.011	0.011	0.050	ND	0.129
ND	0.010	0.005	0.005	0.005	0.029	ND	0.073
ND	0.016	0.005	0.005	0.005	0.035	ND	0.086
ND	0.010	0.005	0.010	0.010	0.040	ND	0.091
ND	0.010	ND	0.005	0.010	0.034	ND	0.114
ND	0.015	0.006	0.009	0.003	0.037	ND	0.089
ND	0.005	ND	ND	ND	0.016	ND	0.055
ND	0.003	ND	0.003	ND	0.011	ND	0.131
ND	0.003	ND	0.003	ND	0.011	ND	0.107
ND	ND	ND	ND	ND	ND	ND	0.152
ND	0.005	ND	0.005	ND	0.018	ND	0.063
ND	0.009	ND	0.004	0.004	0.024	ND	0.227
ND	ND	0.006	0.006	ND	0.022	ND	0.037
ND	ND	0.006	0.006	ND	0.020	ND	0.028
ND	0.006	ND	0.006	ND	0.020	ND	0.070
ND	0.004	0.004	0.004	0.004	0.020	ND	0.022
	$\bar{x}$=0.006	$\bar{x}$=0.003	$\bar{x}$=0.005	$\bar{x}$=0.004	$\bar{x}$=0.023		$\bar{x}$=0.078

---

[1] Uncorrected wet weight concentrations.

Table 6 (continued). Wet weight chlorinated hydrocarbon compound concentrations in least tern eggs in 1992. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

o, p'-DDE	p, p'-DDD	o, p'-DDD	Arochlor 1242	Arochlor 1248	Arochlor 1254	Arochlor 1260	total PCBs
Kansas							
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	0.018	NA	NA	NA	NA	ND
ND	ND	0.027	NA	NA	NA	NA	ND
		$\bar{x}$=0.010					
Nebraska							
ND	0.008	ND	NA	NA	NA	NA	0.359
ND	0.007	ND	NA	NA	NA	NA	0.442
ND	ND	ND	NA	NA	NA	NA	0.193
ND	0.007	ND	NA	NA	NA	NA	0.300
ND	ND	ND	NA	NA	NA	NA	0.431
ND	ND	ND	NA	NA	NA	NA	0.159
ND	0.006	ND	NA	NA	NA	NA	0.357
ND	0.005	ND	NA	NA	NA	NA	0.427
ND	ND	ND	NA	NA	NA	NA	0.010
ND	0.013	ND	NA	NA	NA	NA	0.336
ND	ND	ND	NA	NA	NA	NA	0.462
ND	0.016	ND	NA	NA	NA	NA	0.412
ND	ND	ND	NA	NA	NA	NA	0.514
ND	ND	ND	NA	NA	NA	NA	0.423
ND	ND	ND	NA	NA	NA	NA	0.457
ND	ND	ND	NA	NA	NA	NA	0.435
ND	ND	ND	NA	NA	NA	NA	0.198
ND	0.007	ND	NA	NA	NA	NA	0.323
ND	ND	ND	NA	NA	NA	NA	0.290
ND	ND	ND	NA	NA	NA	NA	0.242
	$\bar{x}$=NC						$\bar{x}$=0.284

Table 6 (concluded). Wet weight chlorinated hydrocarbon compound concentrations in least tern eggs in 1992. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

o, p'-DDE	p, p'-DDD	o, p'-DDD	Arochlor 1242	Arochlor 1248	Arochlor 1254	Arochlor 1260	total PCBs
South Dakota[1]							
0.11	ND	0.06	ND	ND	ND	ND	NA
ND	ND	ND	ND	ND	ND	ND	NA
ND	ND	0.02	ND	ND	ND	ND	NA
ND	ND	0.03	ND	ND	ND	ND	NA
ND	ND	0.03	ND	ND	ND	ND	NA
ND	ND	0.02	ND	ND	ND	ND	NA
ND	ND	0.02	ND	ND	ND	ND	NA
0.01	ND	0.04	ND	ND	ND	ND	NA
ND	ND	ND	ND	ND	ND	ND	NA
$\bar{x}$=NC		$\bar{x}$=0.02					
North Dakota							
ND	0.006	ND	NA	NA	NA	NA	0.319
ND	0.005	ND	NA	NA	NA	NA	0.218
ND	0.005	ND	NA	NA	NA	NA	0.232
ND	ND	ND	NA	NA	NA	NA	0.349
ND	ND	ND	NA	NA	NA	NA	0.310
ND	0.03	ND	NA	NA	NA	NA	0.246
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	ND	NA	NA	NA	NA	0.190
ND	ND	ND	NA	NA	NA	NA	0.210
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	ND	NA	NA	NA	NA	ND
ND	ND	ND	NA	NA	NA	NA	0.175
ND	ND	ND	NA	NA	NA	NA	0.180
	$\bar{x}$=NC						$\bar{x}$=0.075

[1] Uncorrected wet weight concentrations.

Table 7. Chlorinated hydrocarbon concentrations in least tern eggs in 1993. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

Mass (g)	Percent Moisture	Percent Lipid	HCB	alpha chlordane	cis nonachlor	trans nonachlor
Kansas						
NA	NA	11.40	ND	ND	0.010	0.020
NA	NA	10.40	ND	ND	ND	0.010
NA	NA	13.40	ND	ND	0.007	0.007
					$\bar{x}=0.007$	$\bar{x}=0.011$
Nebraska						
NA	NA	NA	ND	0.007	ND	0.014
NA	NA	NA	ND	ND	ND	0.013
NA	NA	NA	ND	ND	ND	0.024
NA	NA	NA	ND	0.007	ND	0.053
NA	NA	NA	ND	ND	0.009	0.026
NA	NA	NA	ND	0.007	0.013	0.033
				$\bar{x}=0.004$	$\bar{x}=$NC	$\bar{x}=0.024$
North Dakota						
NA	NA	NA	0.006	ND	ND	0.006
NA	NA	NA	ND	ND	ND	0.006
NA	NA	NA	ND	ND	ND	0.005
NA	NA	NA	ND	ND	ND	0.006
NA	NA	NA	0.007	ND	ND	0.013
NA	NA	NA	0.008	ND	ND	0.042
NA	NA	NA	ND	ND	ND	0.006
NA	NA	NA	ND	ND	ND	0.007
NA	NA	NA	ND	ND	ND	0.007
NA	NA	NA	ND	ND	ND	0.008
NA	NA	NA	0.008	ND	ND	0.016
NA	NA	NA	ND	ND	ND	0.007
NA	NA	NA	ND	ND	ND	0.007
NA	NA	NA	ND	ND	ND	0.008
NA	NA	NA	ND	ND	ND	0.007
NA	NA	NA	0.008	ND	ND	0.008
			$\bar{x}=$NC			$\bar{x}=0.008$

Table 7 (continued). Chlorinated hydrocarbon concentrations in least tern eggs in 1993. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means.
NC = Not calculable. NA = not analyzed. ND = not detected.

Mass (g)	Percent Moisture	Percent Lipid	HCB	alpha chlordane	cis nonachlor	trans nonachlor
			Montana			
10.6	72.5	NA	ND	ND	ND	0.005
4.1	73.2	NA	ND	ND	ND	0.005
6.3	74.4	NA	0.007	ND	ND	0.014
			$\bar{x}$=NC			$\bar{x}$=0.007

and Herron (1989) found that in white-faced ibis (*Plegadis chihi)* in Nevada, DDE was "significantly correlated with eggshell thinning and productivity decreased as DDE residues increased >4 ppm." Black-crowned night-herons (*Nycticorax nycticorax*) reproduction did not suffer until DDE concentrations in eggs of approximately 8 μg/g were reached (Henny *et al.* 1984). Eggs of black skimmers (*Rhynchops niger*) in south Texas that had an average DDE concentration of 1.9 μg/g hatched successfully (Custer and Mitchell 1987).

DDT was detected at very low concentrations in 11 (22%) of the 1992 eggs, which shows that the terns had recently been exposed to DDT (DDT is readily metabolized to DDE and DDD). It was not detected in 1993 or 1994 eggs. The geometric mean p,p'-DDE concentration in all eggs in 1992 was 0.138 μg/g; for all DDT compounds together it was 0.133 μg/g. In 1993 the geometric means were 0.086 μg/g for p,p'-DDE, and 0.087 μg/g for all DDT compounds. The highest value for p,p'-DDE in 1992 was 0.770 μg/g, and in 1993 it was 0.388 μg/g. These concentrations are not likely to have detrimental effects on the population.

In the United States, aquatic biota are often exposed to polychlorinated biphenyls (PCBs); the aquatic link is still important to fish-consuming birds (Rice and O'Keefe 1995). Effects of PCBs on eggs are difficult to assess because different PCB congeners have dramatically different toxicities to developing embryos (Brunström and Andersson 1988, Rice and O'Keefe 1995) and different genera have different tolerances of PCBs (Brunström 1989, Brunström and Reutergårdh 1986). In addition, growth reductions in embryos related to in-ovo PCB exposure are likely (Hoffman *et al.* 1986), but are not measurable in studies like ours.

Table 7 (continued). Chlorinated hydrocarbon concentrations in least tern eggs in 1993. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

oxychlordane	heptachlor epoxide	dieldrin	cyclodiene total	p, p'-DDE	p, p'-DDD
		Kansas			
ND	0.010	0.029	0.068	0.098	ND
ND	0.010	0.010	0.035	0.090	ND
ND	0.014	0.021	0.048	0.076	ND
	x̄=0.011	x̄=0.018	x̄=0.049	x̄=0.088	
		Nebraska			
0.007	0.014	0.064	0.107	0.121	ND
0.007	0.013	0.066	0.099	0.092	ND
0.006	0.018	0.042	0.091	0.145	ND
0.013	0.033	0.099	0.204	0.382	0.007
0.004	0.018	0.044	0.101	0.136	ND
0.007	0.026	0.092	0.178	0.185	0.007
x̄=0.007	x̄=0.019	x̄=0.064	x̄=0.123	x̄=0.158	x̄=NC
		North Dakota			
ND	0.006	0.036	0.051	0.115	ND
ND	0.006	0.018	0.033	0.030	ND
0.005	0.005	0.011	0.027	0.049	ND
0.006	0.006	0.006	0.024	0.060	ND
ND	0.020	0.059	0.096	0.086	ND
0.008	0.017	0.017	0.085	0.152	0.017
ND	ND	0.006	0.019	0.051	0.013
0.007	0.007	0.007	0.026	0.059	0.007
ND	ND	0.007	0.021	0.076	ND
ND	0.008	0.023	0.042	0.061	ND
0.008	0.016	0.058	0.099	0.124	ND
0.008	0.008	0.008	0.031	0.055	ND
0.007	0.007	0.015	0.036	0.080	ND
ND	0.008	0.008	0.027	0.069	ND
0.007	0.007	0.015	0.036	0.058	ND
0.008	0.015	0.015	0.046	0.123	ND
x̄=0.006	x̄=0.010	x̄=0.023	x̄=0.055	x̄=0.091	x̄=NC

Table 7 (continued). Chlorinated hydrocarbon concentrations in least tern eggs in 1993. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

oxychlordane	heptachlor epoxide	dieldrin	cyclodiene total	p, p'-DDE	p, p'-DDD
		Montana			
ND	0.005	0.011	0.025	0.060	ND
0.005	0.005	ND	0.016	0.036	ND
0.007	0.007	0.014	0.042	0.076	ND
$\bar{x}$=0.004	$\bar{x}$=0.006	$\bar{x}$=0.007	$\bar{x}$=0.025	$\bar{x}$=0.055	

Eisler (1986) suggested that total PCB concentrations in avian eggs should be less than 16 μg/g wet weight, based upon the research of Peakall *et al.* (1972) with Aroclor 1254. In chickens, one of the most PCB-sensitive bird species, Tumasonis *et al.* (1973) found that whole-egg Aroclor 1254 concentration of 4 μg/g or more reduced hatching success. Many other species are much more resistant to effects from PCBs (Custer and Heinz 1980, Harris and Osborn 1981, McLane and Hughes 1980).

Wiemeyer *et al.* (1978) found a mean PCB concentration of 1.2 μg/g and a much higher mean p,p'-DDE concentration in eggs from an osprey population with normal reproduction. Zicus *et al.* (1988) considered geometric mean PCB residues of 0.66 μg/g in hooded merganser eggs and 1.52 μg/g in goldeneye (*Bucephala clangula*) to be low.

The geometric mean PCB concentrations in eggs in this study also were low (0.63-0.288 μg/g wet weight). The concentrations were not at levels of concern for reproductive success.

The best known effect of chlorinated hydrocarbons is interference with calcium metabolism and associated thinning of eggshells. That does not appear to be a problem in least terns from the northern Great Plains. Custer *et al. (1983)* concluded that geometric mean DDE concentrations in roseate terns (*Sterna dougallii*) comparable to those we found in least terns had no effect on eggshell thickness. Least tern eggshells from Salt Plains National Wildlife in Oklahoma in 1993 and 1994 and Quivira from 1991 through 1993 were as thick as those from before the use of DDT (Koenen and Leslie 1996).

Table 7 (continued). Chlorinated hydrocarbon concentrations in least tern eggs in 1993. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

toxaphene	Arochlor 1242	Arochlor 1248	Arochlor 1254	Arochlor 1260	total PCBs
			Kansas		
0.049	NA	NA	NA	NA	0.225
0.050	NA	NA	NA	NA	0.130
0.035	NA	NA	NA	NA	0.138
$\bar{x}$=0.044					$\bar{x}$=0.159
			Nebraska		
ND	NA	NA	NA	NA	0.136
ND	NA	NA	NA	NA	0.112
ND	NA	NA	NA	NA	0.193
ND	NA	NA	NA	NA	0.574
ND	NA	NA	NA	NA	0.259
ND	NA	NA	NA	NA	0.270
					$\bar{x}$=0.222
			North Dakota		
ND	NA	NA	NA	NA	0.387
ND	NA	NA	NA	NA	0.157
ND	NA	NA	NA	NA	0.154
ND	NA	NA	NA	NA	0.187
ND	NA	NA	NA	NA	0.356
ND	NA	NA	NA	NA	0.660
ND	NA	NA	NA	NA	0.147
ND	NA	NA	NA	NA	0.211
ND	NA	NA	NA	NA	0.125
ND	NA	NA	NA	NA	0.190
ND	NA	NA	NA	NA	0.404
ND	NA	NA	NA	NA	0.148
ND	NA	NA	NA	NA	0.232
ND	NA	NA	NA	NA	0.231
ND	NA	NA	NA	NA	0.189
ND	NA	NA	NA	NA	0.231
					$\bar{x}$=0.224

Table 7 (concluded). Chlorinated hydrocarbon concentrations in least tern eggs in 1993. Shaded values equal or exceed the criterion for protection of biota. Means are geometric means. NC = Not calculable. NA = not analyzed. ND = not detected.

toxaphene	Arochlor 1242	Arochlor 1248	Arochlor 1254	Arochlor 1260	total PCBs
		Montana			
ND	NA	NA	NA	NA	0.143
ND	NA	NA	NA	NA	ND
ND	NA	NA	NA	NA	0.152
					x̄ =0.063

Table 8. Chlorinated hydrocarbon concentrations in a least t tern egg from Montana in 1994. Shaded values equal or exceed the criterion for protection of biota. NA = not analyzed. All concentrations are uncorrected wet weight values.

Mass (g)	Percent Moisture	Percent Lipid	HCB	cis nonachlor	trans nonachlor	heptachlor epoxide	dieldrin
NA	NA	14.70	<0.001	0.04	0.01	0.01	0.03

cyclodiene total	p, p'-DDE	toxaphene	Arochlor 1242	Arochlor 1248	Arochlor 1254	Arochlor 1260	total PCBs
0.10	0.20	0.05	0.05	0.05	0.23	0.32	NA

INTERIOR LEAST TERN REPRODUCTION

The general exceedance of the 3 μg/g dry weight criterion for selenium and the mercury and cyclodiene concentrations found are not conclusive as to their effects on interior least tern reproductive success. Intensive monitoring of interior least tern reproductive performance is needed to determine if recruitment has been negatively affected, but it appears to be low. Mayer and Dryer (1988) reported 62% hatching success for least terns along the Missouri River in North Dakota in 1988. In the 1980s, the number of young fledged per nesting pair in North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma ranged from 0.15 at Salt

Plains National Wildlife Refuge in Oklahoma to 1.09 on the Cimarron River in Kansas. Excluding the value from the Cimarron River, however, the highest recruitment found was 0.71 young per pair (Sidle and Harrison 1990).

Least terns are relatively long lived (some live over 20 years, Thompson 1982) so recruitment need not be very high to sustain a population if adult survival is 85%., and the Service established a goal of 0.70 fledglings produced per nesting pair for U.S. Army Corps of Engineers operations of the Missouri River mainstem (McPhillips 1993). However, Kirsch (1993) estimated that least terns along the lower Platte River in Nebraska produced only 0.50 young per pair from 1987 through 1990. Using a hypothetical annual post-fledging survival rate of 85% (also the value determined for Mississippi River adult terns in Missouri by Renken and Smith [1995]), Kirsch found that even with optimistic assumptions, the productivity estimated found in the field showed a decline in the model interior least tern population. K. Dugger (1997) studied least tern nesting on the lower Mississippi River from 1986 through 1992. Using a modified version of the deterministic model for piping plovers developed by Ryan *et al.* (1993), Dugger found that productivity of 1 chick per nesting pair per year would be necessary to maintain a stable least tern population.

Productivity in the Northern Great Plains States

Though Rattlesnake Creek (which flows through Quivira) typically has some of the highest selenium concentrations in surface waters in Kansas (Kansas Department of Health and Environment 1991), Allen and Wilson (1990) found that selenium concentrations in sediments, algae, and common carp (*Cyprinus carpio*) and biota at Quivira were not elevated. However, selenium could be affecting least terns there. Boyd (1991) reported that in 1991 fledging success (at least one fledging per pair of adults) was 71% at Quivira, and 73% for nests protected from predation, the highest success observed to date. In 1993 only 18% of all eggs hatched, though 47% of the nests were flooded or abandoned (Boyd 1993). Boyd's estimate of the overall least tern fledging rate for 13 years at Quivira (Figure 2) indicates generally poor recruitment, but the largest causes of nesting failure were predation and flooding, as was found in other studies (Mayer and Dryer 1988, Lingle 1993, Kirsch 1993). A detailed investigation of contaminants in water, sediments, invertebrates, forage fish, and large fish from a number of locations at Quivira by the Fish and Wildlife Service is ongoing.

Data from the Nebraska Public Power District (NPPD, 1996) showed that from 1991 through 1996 at islands and sand pits managed by NPPD on or adjacent to the central reach of the Platte River in Nebraska, least terns fledged 200 young from 199 nests, or 1.01 young per nest. Thirty-seven young fledged from 32 nesting attempts on islands (1.16 young per attempt), and 163 fledged from 167 nesting attempts in sand pits (0.98 young per attempt, Figure 2). NPPD data showed markedly better recruitment at managed sand pits than at

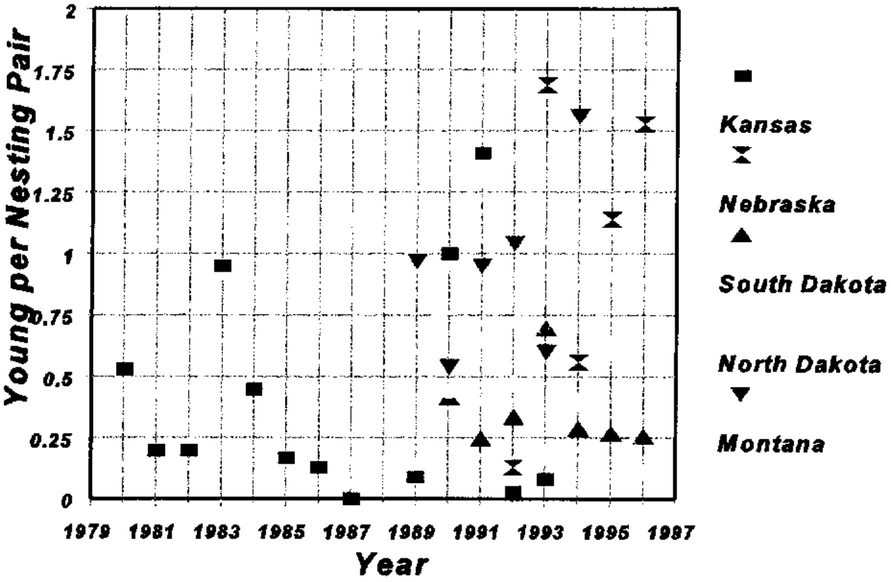

Figure 2. Young fledged per nesting pair of interior least terns in the northern Great Plains states, 1980-1996. Kansas data are for Quivira National Wildlife Refuge (Boyd 1993); Nebraska data are for sand pits along the North Platte River (Nebraska Public Power District 1996); South and North Dakota data are for the Missouri River (G. Pavelka, U.S. Army Corps of Engineers, personal communication); and Montana data are from the Montana Piping Plover Recovery Committee (1995).

unmanaged pits from 1994 through 1996. Presumably because of reduced human disturbance and measures to reduce predation at managed pits, terns at those locations fledged 1.06 young per nesting attempt, whereas terns at unmanaged pits fledged just 0.29 young per nesting attempt.

The U.S. Army Corps of Engineers summarized productivity data for least terns along the Missouri River in North Dakota and South Dakota from 1990 through 1996 (G. Pavelka, U.S.

Army Corps of Engineers, personal communication). Fledgling recruitment was generally poor; the number of young fledged per pair of adults ranged from 0.19 to 0.70 (Figure 2).

Nesting success and reproduction figures for Montana (Figure 2) are similar to those for the other states. The number of young produced per nesting pair on the Missouri River ranged from 0.2 to 1.1 from 1990 through 1994 , and at Fort Peck Reservoir it ranged from 0 to 3.0 (Montana Piping Plover Recovery Committee 1995).

Least terns in other areas suffer low recruitment in at least some years. García and Ceballos (1995) reported that California least terns (*Sterna antillarum browni*) nesting on the protected Cuixmal beach in Jalisco, Mexico produced 1.09 young per nesting pair in 1992, but only 0.44 per pair in 1993. The low success in 1993 was due largely to flooding of nests. K. Dugger (1997) found that productivity on the lower Mississippi River ranged from 0.2 to 1.4 fledglings per pair ($\bar{x}$ =0.66) from 1986 through 1992.

Least tern nesting success from 1992 through 1994 in most locations in the study area was not sufficient to ensure survival of the northern Great Plains interior population. Though flooding and predation likely are the major causes of the low recruitment, the results of this study indicate that selenium and mercury may contribute to low reproduction. An analysis of least tern forage fish for contaminants and management of water in nesting areas to reduce selenium concentrations in least tern food sources should be undertaken.

LITERATURE CITED

Allen, G.T. 1992. Contaminants in Interior Least Tern Eggs from Quivira National Wildlife Refuge in Kansas, in 1990 and 1991. R6/510M/92. U.S. Fish and Wildlife Service, Manhattan, Kansas.

Allen, G.T. and R.M. Wilson. 1990. Selenium in the aquatic environment of Quivira National Wildlife Refuge. Prairie Naturalist 22:129-135.

Atkins, T.D. and R.L. Linder. 1967. Effects of dieldrin on reproduction of penned hen pheasants. Journal of Wildlife Management 31:746-753.

Audet, D.J., D.S. Scott, and S.N. Wiemeyer. 1992. Organochlorines and mercury in osprey eggs from the eastern United States. Journal of Raptor Research 26:219-224.

Blus, L.J. 1982. Further interpretation of the relation of organochlorine residues in brown pelican eggs to reproductive success. Environmental Pollution 28A:15-33.

Blus, L.J. 1995. Organochlorine pesticides. Pages 275-300 *in* D. J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr., editors. Handbook of ecotoxicology. Lewis Publishers, Boca Raton, Florida.

Bogan, J.A. and I. Newton. 1977. Redistribution of DDE in sparrowhawks during starvation. Bulletin of Environmental Contamination and Toxicology 18:317-321.

Botero, J.E., M.W. Meyer, S.S. Hurley, and D.H. Rusch. 1996. Residues of organochlorines in mallards and blue-winged teal collected in Colombia and Wisconsin, 1984-1989. Archives of Environmental Contamination and Toxicology 31:225-231.

Boyd, R.L. 1991. Habitat management and population ecology studies of the least tern in Kansas, 1991. Unpublished report to the U.S. Fish and Wildlife Service, Manhattan, Kansas.

Boyd, R.L. 1993. Habitat management and population ecology studies of the least tern in Kansas and Oklahoma, 1993. Unpublished report to the U.S. Fish and Wildlife Service, Manhattan, Kansas.

Brunstrom, B. 1989. Toxicity of coplanar polychlorinated biphenyls in avian embryos. Chemosphere 19:765-768.

Brunström, B. and L. Andersson. 1988. Toxicity and 7-ethoxyresorufin O-deethylase-inducing potency of coplanar polychlorinated biphenyls (PCBs) in chick embryos. Archives of Environmental Contamination and Toxicology 62:263-266.

Brunström, B. and L. Reutergårdh. 1986. Differences in sensitivity of some avian species to the embryotoxicity of a PCB, 3,3',4,4'-tetrachlorobiphenyl injected into the eggs. Environmental Pollution (Series A) 42:37-45.

Burger, J. and M. Gochfeld. 1995. Heavy metal and selenium concentrations in eggs of herring gulls (*Larus argentatus*): temporal differences from 1989 to 1994. Archives of Environmental Contamination and Toxicology 29:192-197.

Charbonneau, C.S. 1993. Organochlorine and metal contaminant residue concentrations in interior least tern eggs collected in Mississippi County, Missouri. Contaminants Report.. U.S. Fish and Wildlife Service, Columbia, Missouri.

Connors, P.G., V.C. Anderlini, R.W. Risebrough, M.J. Gilbertson, and H. Hays. 1975. Investigations of heavy metals in common tern populations. Canadian Field-Naturalist 89:157-162.

Custer, T.W. and C.A. Mitchell. 1987. Organochlorine contaminants and reproductive success of black skimmers in south Texas, 1984. Journal of Field Ornithology 58:480-489.

Custer, T.W. and G.H. Heinz. 1980. Reproductive success and nest attentiveness of mallard ducks fed Aroclor 1254. Environmental Pollution 21:313-318.

Custer, T.W., I.C.T. Nisbet, and A.J. Krynitsky. 1983. Organochlorine residues and shell characteristics of roseate tern eggs, 1981. Journal of Field Ornithology 54:394-400.

Davison, K.L. and J.L. Sell. 1974. Dieldrin and DDT effects on reproduction and some hepatic mixed-function oxidases in the mallard duck. Archives of Environmental Contamination and Toxicology 2:302-314.

Dugger, K.M. 1997. The foraging ecology and reproductive success of least terns nesting on the lower Mississippi River. Ph.D. Disseration, University of Missouri, Columbia.

Eisler, R. 1985. Selenium hazards to fish, wildlife and invertebrates: a synoptic review. Contaminant Hazard Reviews Report Number 5. U.S. Fish and Wildlife Service, Washington, D.C.

Eisler, R. 1986. Polychlorinated biphenyl hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish and Wildlife Service, Washington, D.C.

Eisler, R. 1987. Mercury hazards to fish, wildlife and invertebrates: a synoptic review. Contaminant Hazard Reviews Report Number 10. U.S. Fish and Wildlife Service, Washington, D.C.

Eisler, R. 1988. Arsenic hazards to fish, wildlife, and invertebrates: A synoptic review. Contaminant Hazard Reviews Report Number 12. U.S. Fish and Wildlife Service, Washington, D.C.

Eisler, R. 1990. Chlordane hazards to fish, wildlife, and invertebrates: A synoptic review. Contaminant Hazard Reviews Report Number 21. U.S. Fish and Wildlife Service, Washington, D.C.

Eisler, R. 1994. A review of arsenic hazards to plants and animals with emphasis on fishery and wildlife resources. Pages 185-259 *in* J.O. Nriagu, editor. Arsenic in the environment, part II: human health and ecosystem effects. John Wiley and Sons, New York.

Faber, R.A. and J.J. Hickey. 1973. Eggshell thinning, chlorinated hydrocarbons, and mercury in inland aquatic bird eggs, 1969 and 1970. Pesticides Monitoring Journal 7:27-36.

Fimreite, N. 1974. Mercury contamination of aquatic birds in northwestern Ontario. Journal of Wildlife Management 38(1):120-131.

García, A. And G. Ceballos. 1995. Reproduction and breeding success of California least terns in Jalisco, Mexico. Condor 97:1084-1087.

Greichus, Y.A., A. Greichus, and R.J. Emerick. 1973. Insecticides, polychlorinated biphenyls and mercury in wild cormorants, pelicans, their eggs, food and environment. Bulletin of Environmental Contamination and Toxicology 9:321-328.

Grubb, T.G., S.N. Wiemeyer, and L.F. Kiff. 1990. Eggshell thinning and contaminant levels in bald eagle eggs from Arizona, 1977 to 1985. The Southwestern Naturalist 35:298-301.

Harris, M.D. and D. Osborn. 1981. Effect of a polychlorinated biphenyl on the survival and breeding of puffins. Journal of Applied Ecology 18:471- 479.

Heinz, G.H. 1974. Effects of low dietary levels of methyl mercury on mallard reproduction. Bulletin of Environmental Contamination and Toxicolgy 2:386-392.

Heinz, G. H. 1979. Methylmercury: reproductive and behavioral effects on three generations of mallard ducks. Journal of Wildlife Management 43:394-401.

Heinz, G.H. 1996. Selenium in birds. Pages 447-458 *in* Beyer, W.N., G.H. Heinz, and A.W. Redmon-Norwood, editors. Environmental contaminants in wildlife: interpreting tissue concentrations. Lewis Publishers, Boca Raton, Florida.

Heinz, G.H., D.J. Hoffman, A.J. Krynitsky, and D.M.G. Weller. 1987. Reproduction in mallards fed selenium. Environmental Toxicology and Chemistry 6:423-433.

Heinz, G.H., D.J. Hoffman, and L.G. Gold. 1989. Impaired reproduction of mallards fed an organic form of selenium. Journal of Wildlife Management 53:418-428.

Henny, C.J. and G.B. Herron. 1989. DDE, selenium, mercury, and white-faced ibis reproduction at Carson Lake, Nevada. Journal of Wildlife Management 53:1032-1045.

Henny, C.J., L.J. Blus, A.J. Krynitsky, and C.M. Bunck. 1984. Current impact of DDE on black-crowned night-herons in the intermountain west. Journal of Wildlife Management 48:1-13.

Hoffman, D.J., B.A. Rattner, C.M. Bunck, A. Krynitsky, H.M. Ohlendorf, and R.W. Lowe. 1986. Association between PCBs and low embryonic weight in black-crowned night herons in San Francisco Bay. Journal of Toxicology and Environmental Health 19:383-391.

Hoyt, D.F. 1979. Practical methods of estimating volume and fresh weight of bird eggs. Auk 96:73-77.

Huckins, J.N., T.R. Schwartz, J.D. Petty, and L.M. Smith. 1988. Determination, fate, and potential significance of PCBs in fish and sediment samples with emphasis on selected AHH-inducing congeners. Chemosphere 17:1995-2016.

Hunt, W.G., B.S. Johnson, C.G. Thelander, B.J. Walton, R.W. Risebrough, W.M. Jarman, A.M. Sprinter, J.G. Monk, and W. Walker, II. 1986. Environmental levels of p,p'-DDE indicate multiple sources. Environmental Toxicology and Chemistry 5:21-27.

Jenkins, D.W. 1981. Biological monitoring of toxic trace elements. Report 600/S3-80-090:1-9. U.S. Environmental Protection Agency, Washington, D.C.

Kansas Department of Health and Environment. 1991. A survey and assessment of selenium in the waters of Kansas. Kansas Department of Health and Environment, Bureau of Environmental Quality, Topeka.

King, K.A., T.W. Custer, and J.S. Quinn. 1991. Effects of mercury, selenium, and organochlorine contaminants on reproduction of Forster's terns and black skimmers nesting in a contaminated Texas bay. Archives of Environmental Contamination and Toxicology 20:32-40.

Kirsch, E.M. 1993. Productivity, causes of mortality, and projected population trends of least terns and piping plovers on the lower Platte River. Pages 137-138 *in* K.F. Higgins and M.R. Brashier, editors, Proceedings, the Missouri River and its tributaries piping plover and least tern symposium/workship. South Dakota State University, Brookings.

Koenen, M.T. and D.M. Leslie, Jr. 1996. Evaluation of interior least tern eggshell thickness. Colonial Waterbirds 19:143-146.

Koster, M.D., D.P. Ryckman, D.V.C. Weseloh, and J. Struger. 1996. Mercury levels in Great Lakes herring gull (*Larus argentatus*) eggs, 1972-1992. Environmental Pollution 93:261-270.

Kruskal, W.H. and W.A. Wallis. 1952. Use of ranks on one-criterion variance analysis. Journal of the American Stistical Association 47:583-621. Corrections in 48:907-911.

Lamb, D.W., R.L. Linder, and Y.A. Greichus. 1967. Dieldrin residues in eggs and fat of penned pheasant hens. Journal of Jwildlife Management 31:24-27.

Lehner, P.N. and A. Egbert. 1969. Dieldrin and eggshell thickness in ducks. Nature 224:1218-1219.

Lemly, A.D. 1993. Guidelines for evaluating selenium data from aquatic monitoring and assessment studies. Environmental Monitoring and Assessment 28:83-100.

Lemly, A.D. 1995. A protocol for aquatic hazard assessment of selenium. Ecotoxicology and

Environmental Safety 32:280-288.

Lemly, A.D. and G.J. Smith. 1987. Aquatic cycling of selenium: implications for fish and wildlife. Fish and Wildlife Leaflet 12. U.S. Fish and Wildlife Service, Washington, D.C.

Lingle, G.R. 1993. Causes of nest failure and mortality of least terns and piping plovers along the central Platte River. Pages 130-134 *in* K.F. Higgins and M.R. Brashier, editors, Proceedings, the Missouri River and its tributaries piping plover and least tern symposium/workship. South Dakota State University, Brookings.

Mayer, P.M. and M.P. Dryer. 1988. Population biology of piping plovers and least terns on the Missouri River in North Dakota and Montana: 1988 field season report. U.S. Fish and Wildlife Service, Bismarck, North Dakota.

McLane, M.A.R. and D.L. Hughes. 1980. Reproductive success of screech owls fed Aroclor 1248. Archives of Environmental Contamination and Toxicology 9:661-665.

McPhillips, N. 1993. Of birds and men: a tale of tern and plover management and the Endangered Species Act. Pages 7-9 *in* K.F. Higgins and M.R. Brashier, editors, Proceedings, the Missouri River and its tributaries piping plover and least tern symposium/workship. South Dakota State University, Brookings.

Mendenhall, V.M., E.E. Klaas, and M.A.R. McLane. 1983. Breeding success of barn owls (*Tyto alba*) fed low levels of DDE and dieldrin. Archives of Environmental Contamination and Toxicology 12:235-240.

Montana Piping Plover Recovery Committee. 1995. 1994 surveys for piping plover (*Charadrius melodus*) and least tern (*Sterna antillarum*) in Montana. Unpublished report, Montana Piping Plover Recovery Committee.

Mora, M.A. 1995. Residues and trends of organochlorine pesticide and polychlorinated biphenyls in birds from Texas, 1965-88. Fish and Wildlife Research 14. National Biological Service, Washington, D.C.

Mora, M.A., D.W. Anderson, and M.E. Mount. 1987. Seasonal variation of body condition and organochlorines in wild ducks from California and Mexico. Journal of Wildlife Management 51:132-141.

Nebraska Public Power District. 1996. Annual reports pursuant to paragraphs B and C of article 401, FERC Project 1835. Nebraska Public Power District , Columbus.

Ohlendorf, H.M., J.C. Bartonek, G.J. Divoky, E.E. Klaas, and A.J. Krynitsky. 1982. Organochlorine residues in eggs of Alaskan seabirds. Special Scientific Report - Wildlife Number 245. U.S. Fish and Wildlife Service, Washington, D.C.

Peakall, D.B., J.L. Lincer, and S.E. Bloom. 1972. Embryonic mortality and chromosomal alterations caused by Aroclor 1254 in ring doves. Environmental Health Perspectives 1:103-104.

Pendleton, G.W., M.R. Whitworth, and G.H. Olsen. 1995. Accumulation and loss of arsenic and boron, alone and in combination, in mallard ducks. Environmental Toxicology and Chemistry 14:1357-1364.

Renken, R.B. and J.W. Smith. 1995. Annual adult survival of interior least terns. Journal of Field Ornithology 66:112-116.

Rice, C.P. and P. O'Keefe. 1995. Sources, pathways, and effects of PCBs, dioxins, and dibenzofurans. Pages 424-468 *in* D. J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr., editors. Handbook of ecotoxicology. Lewis Publishers, Boca Raton, Florida.

Risebrough, R.W., W.M. Jarman, A.M. Sprinter, W. Walker II, and W.G. Hunt. 1986. A metabolic derivation of DDE from Kelthane. Environmental Toxicology and Chemistry 5:13-19.

Ryan, M.R. , B.G. Root, and P.M. Mayer. 1993. Status of piping plovers in the Great Plains of North America: a demographic simulation model. Conservation Biology 7:585-585.

Ruelle, R. 1991. A contaminant evaluation of interior least tern and piping plover eggs and chicks on the Missouri River, South Dakota. Contaminants Report. U.S. Fish and Wildlife Service, Pierre, South Dakota.

Schmitt, C. J., J. L. Zajicek, and P. H. Peterman. 1990. National Contaminant Biomonitoring Program: residues of organochlorine chemicals in U.S. freshwater fish, 1976-84. Archives of Environmental Contamination and Toxicology 19:748-782.

Sidle, J.G. and W.F. Harrison. 1990. Recovery plan for the interior population of the least tern (*Sterna antillarum*). U.S. Fish and Wildlife Service, Minneapolis, Minnesota.

Siegel, S. and N. J. Castellan, Jr. 1988. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Company, New York.

Skorupa, J.P. and H.M. Ohlendorf. 1991. Contaminants in drainage water and avian risks thresholds. Pages 345-368 *in* A. Dinar and D. Zilberman, editors. The economics and management of water and drainage in agriculture. Kluwer Academic Publishers, Norwell, Massachusetts.

Skorupa, J.P., S.P. Morman, and J.S. Sefchick-Edwards. 1996. Guidelines for interpreting selenium exposures of biota associated with nonmarine aquatic habitats. Unpublished report, U.S. Fish and Wildlife Service, Sacramento, California.

Spann, J.W., R.G. Heath, J.F. Kreitzer, and L.N. Locke. 1972. Ethyl mercury p-toluene sulfonanilide: lethal and reproductive effects on pheasants. Science 175:328-331.

Stanley, T.R., Jr., J.W. Spann, G.J. Smith, and R. Rosscoe. 1994. Main and interactive effecs of arsenic and selenium on mallard reproduction and duckling growth and survival. Archives of Environmental Contamination and Toxicology 26:444-451.

Thompson, B.C. 1982. Distribution, colony characteristics, and population status of least terns breeding on the Texas coast. Ph.D. dissertation, Texas A&M University. Cited by Sidle and Harrison (1990).

Thompson, D.R. 1996. Mercury in birds and terrestrial mammals. Pages 341-356 *in* W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, editors. Environmental contaminants in wildlife: interpreting tissue concentrations. Lewis Publishers, Boca Raton, Florida.

Tumasonis, C.F., B. Bush, and F.D. Baker. 1973. PCB levels in egg yolks associated with embryonic mortality and deformity of hatched chicks. Archives of Environmental Contamination and Toxicology 1:312- 324.

U.S. Fish and Wildlife Service. 1990. Selenium may be impacting endangered bird populations on the Missouri River in South Dakota. Unpublished contaminants survey report. U.S. Fish and Wildlife Service, Pierre, South Dakota.

Vermeer, K. 1971. A survey of mercury residues in aquatic bird eggs in the Canadian prairie provinces. Transactions of the North American Wildlife Conference 36:138-152.

Vermeeer, K., F.A.J. Armstrong, and D.R.M. Hatch. 1973. Mercury in aquatic birds at Clay Lake, western Ontario. Journal of Wildlife Management 37:58-61.

Welsh, D. and P.M. Mayer. 1993. Concentrations of elements in eggs of least terns and piping plovers from the Missouri River, North Dakota. Pages 172-180 *in* K.F. Higgins and M.R. Brashier, editors, Proceedings, the Missouri River and its tributaries piping plover and least tern symposium/workshop. South Dakota State University, Brookings.

Weseloh, D.V., T.W. Custer, and B.M. Braune. 1989. Organochlorine contaminants in eggs of common terns from the Canadian Great Lakes, 1981. Environmental Pollution 59:141-160.

White, D.H. and E. Cromartie. 1977. Residues of environmental pollutants and shell thinning in merganser eggs. Wilson Bulletin 89:532-542.

Wiemeyer, S.N. 1996. Other organochlorine pesticides in birds. Pages 99-115 *in* W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, editors. Environmental contaminants in wildlife: interpreting tissue concentrations. CRC Press (Lewis Publishers), Boca Raton, Florida.

Wiemeyer, S.N., C.M. Bunck, and A.J. Krynitsky. 1988. Organochlorine pesticides, polychlorinated biphenyls, and mercury in osprey eggs —1970-79— and their relationships to shell thinning and productivity. Archives of Environmental Contamination and Toxicology 17:767-787.

Wiemeyer, S.N., C.M. Bunck, and C.J. Stafford. 1993. Environmental contaminants in bald eagle eggs - 1980-84 - and further interpretations of relationships to productivity and shell thickness. Archives of Environmental Contamination and Toxicology 24:213-227.

Wiemeyer, S.N., D.M. Swineford, P.R. Spitzer, and P.D. McLain. 1978. Organochlorine residues in New Jersey osprey eggs. Bulletin of Environmental Contamination and Toxicology 19:56-63.

Wiemeyer, S.N., R.D. Porter, G.L. Hensler, and J.R. Maestrelli. 1986. DDE, DDT + dieldrin: residues in American kestrels and relations to reproduction. Fish and Wildlife Technical Report 6. U.S. Fish and Wildlife Service, Washington, D.C.

Wiemeyer, S.N., T.G. Lamont, C.M. Bunck, C.R. Sindelar, F.J. Gramlich, J.D. Fraser, and M.A. Byrd. 1984. Organochlorine pesticide, polychlorinated biphenyl, and mercury residues in bald eagle eggs - 1969-79 - and their relationships to shell thinning and reproduction. Archives of Environmental Contamination and Toxicology 13:529-549.

Zicus, M.C., M.A. Briggs, and R.M. Pace, III. 1988. DDE, PCB, and mercury residues in Minnesota common goldeneye and hooded merganser eggs, 1981. Canadian Journal of Zoology 66:1871-1876.