U.S. FISH AND WILDLIFE SERVICE
MAINE FIELD OFFICE
SPECIAL PROJECT REPORT: FY96-MEFO-6-EC

ENVIRONMENTAL CONTAMINANTS IN ARCTIC TERN EGGS FROM PETIT MANAN ISLAND

Petit Manan National Wildlife Refuge
Milbridge, Maine

May 2001

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U.S. Fish and Wildlife Service

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EXECUTIVE SUMMARY

Petit Manan Island is a 3.5-hectare (-9 acre) island that lies approximately 4-kilometers (2.5-miles) from the coastline of Petit Manan Point, Steuben, Washington County, Maine. It is one of nearly 40 coastal islands within the Petit Manan National Wildlife Refuge. The treeless, rocky island is the site of an automated U.S. Coast Guard light station, Petit Manan Light. Prior to automation, the lighthouse was staffed by lightkeepers from 1817 to 1972. During that period, the island was used by nesting Arctic, common and roseate terns (*Sterna paradisea*, *S. hirundo*, and *S. dougallii*). After the lighthouse was automated, and USCG personnel had left the island, gulls began nesting on the island. By 1980, nesting herring gulls (*Larus argentatus*) and great black-backed gulls (*Larus marinus*) had displaced all nesting terns.

A gull control program was initiated in 1983 by refuge personnel. Within 2 weeks of gull removal, several pairs of terns began recolonizing the island. By 1992, over 1,800 pairs of terns were nesting on Petit Manan Island, including over 60 pairs of the federally-endangered roseate tern. Also nesting on the island were approximately 500 pairs of laughing gulls (*Larus atricilla*), 10 pairs of Atlantic puffin (*Fratercula arctica*) and several hundred pairs of black guillemots (*Cepphus grylle*). Because the island became one of the most diverse seabird nesting colonies in the Gulf of Maine, and the most important nesting island for roseate terns in Maine, a baseline study of contaminants was initiated for nesting terns. Being a relatively abundant nesting tern species on Petit Manan Island, and easily accessible for scientific collection, the Arctic tern was selected as the indicator species for this contaminant survey.

The purposes of the survey were:

< To determine the baseline levels of trace element and organochlorine contaminants in Arctic tern eggs on Petit Manan Island.

< To evaluate the potential contaminant threat within breeding terns of Petit Manan Island.

Eleven Arctic tern eggs were collected in 1993 and submitted to the USFWS Patuxent Analytical Control Facility (PACF) for contaminant analysis. All eggs were analyzed for organochlorines and five eggs were also examined for trace elements. Both analyses were performed by Hazelton Environmental Services, a laboratory under contract to PACF. Organochlorine contaminant analyses found hexachlorobenzene (HCB) and the DDT metabolite, DDE, in tern eggs. Seventeen other organochlorine compounds (e.g., PCBs, chlordane, endrin, etc.) were not detected in egg samples. Mean HCB (0.015 ppm, fresh weight weight) and DDE (0.039 ppm) levels in Arctic tern eggs were not elevated compared to other tern studies and to avian effect threshold concentrations.

Ten of 19 trace elements in the analytical scan were detected in tern eggs. The trace elements and their mean concentrations in tern eggs were arsenic (0.18 ppm, fresh wet weight), chromium (0.11 ppm),

copper (0.76 ppm), iron (28.31 ppm), magnesium (106.68 ppm), manganese (0.49 ppm), mercury (0.10 ppm), selenium (1.89 ppm), strontium (2.14 ppm), and zinc (17.46 ppm). Trace element concentrations in Arctic tern eggs were not highly elevated compared to other tern studies. One egg, however, had a selenium concentration (2.93 ppm) that was slightly less than the suggested threshold level for reproductive impairment (3 ppm).

PREFACE

This report describes the results of a screening level survey of Arctic tern eggs collected from Petit Manan Island within the Petit Manan National Wildlife Refuge. Analytical work for this survey was completed under Patuxent Analytical Control Facility Catalog Number 5030029 - Purchase Orders No. 85830-3-4026 (trace elements) and No. 85830-3-4027 (organochlorines).

Questions, comments, and suggestions related to this report are encouraged. Written inquiries should refer to Report Number FY96-MEFO-6-EC and be directed to:

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ACKNOWLEDGMENTS

D. Major submitted the tern egg catalog to the Service's Patuxent Analytical Control Facility. L. Welch and M. Langlois provided tern nesting data for Petit Manan Island. G. Allen, S. Schwarzbach, and K. Dickerson provided reprints of tern papers and contaminants reports. L. Munroe provided the photo for Figure 3. J. Moore rechecked the analytical data package for errors associated with dry weight values.

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1. INTRODUCTION

Petit Manan Island (PMI) is one of nearly 40 coastal islands that comprise the Petit Manan National Wildlife Refuge (PMNWR) in Downeast Maine. Petit Manan Island lies at 44º 22' 01"N/067º 51' 57"W approximately 4-km (2.5 mi) from the coastline of Petit Manan Point, Steuben, Washington County, Maine (Figure 1). The 3.5-ha (-9 ac) island is the site of an automated U.S. Coast Guard light station, Petit Manan Light. Prior to automation, the lighthouse was staffed by lightkeepers from 1817 to 1972. During that period, the island was used by nesting Arctic, common and roseate terns (*Sterna paradisea*, *S. hirundo*, and *S. dougallii*). After the lighthouse was automated, and USCG personnel had left the island, gulls began nesting on the island. By 1980, nesting herring gulls (*Larus argentatus*) and great black-backed gulls (*Larus marinus*) had displaced all nesting terns.

A gull control program was initiated in 1983 by refuge personnel. Within 2 weeks of gull removal, several pairs of terns began recolonizing the island. By 1992, over 1,800 pairs of terns were nesting on Petit Manan Island, including over 60 pairs of the federally-endangered roseate tern. Also nesting on the island were approximately 500 pairs of laughing gulls (*Larus atricilla*), 10 pairs of Atlantic puffin (*Fratercula arctica*) and several hundred pairs of black guillemots (*Cepphus grylle*). Annually, refuge personnel measure tern populations on the island (Figure 2). In 2000, estimates of Arctic tern and common tern nests on PMI were 469 and 951, respectively, while a direct count of roseate terns revealed 16 nests. Because the island became one of the most diverse seabird nesting colonies in the Gulf of Maine, and the most important nesting island for roseate terns in Maine, a baseline study of contaminants was initiated for nesting terns. Being a relatively abundant nesting tern species on the island, and easily accessible for scientific collection, the Arctic tern was selected as the indicator species for this 1993 survey.

2. SURVEY PURPOSES

The purposes of the survey were:

< To determine the baseline levels of trace element and organochlorine contaminants in Arctic tern eggs on Petit Manan Island and,

< To evaluate the potential contaminant threat within breeding terns of Petit Manan Island.

3. STUDY AREA

Petit Manan Island is a low, treeless, rocky island off the coast of Maine (Figure 3). The shallow rocky soils of the island support grasses and forbs. Immediately north of PMI, connected by a cobble bar, is an important eider nesting area known as Green Island (Figure 1).

Figure 1. Petit Manan Island (USGS Quadrangle: Bois Bubert)

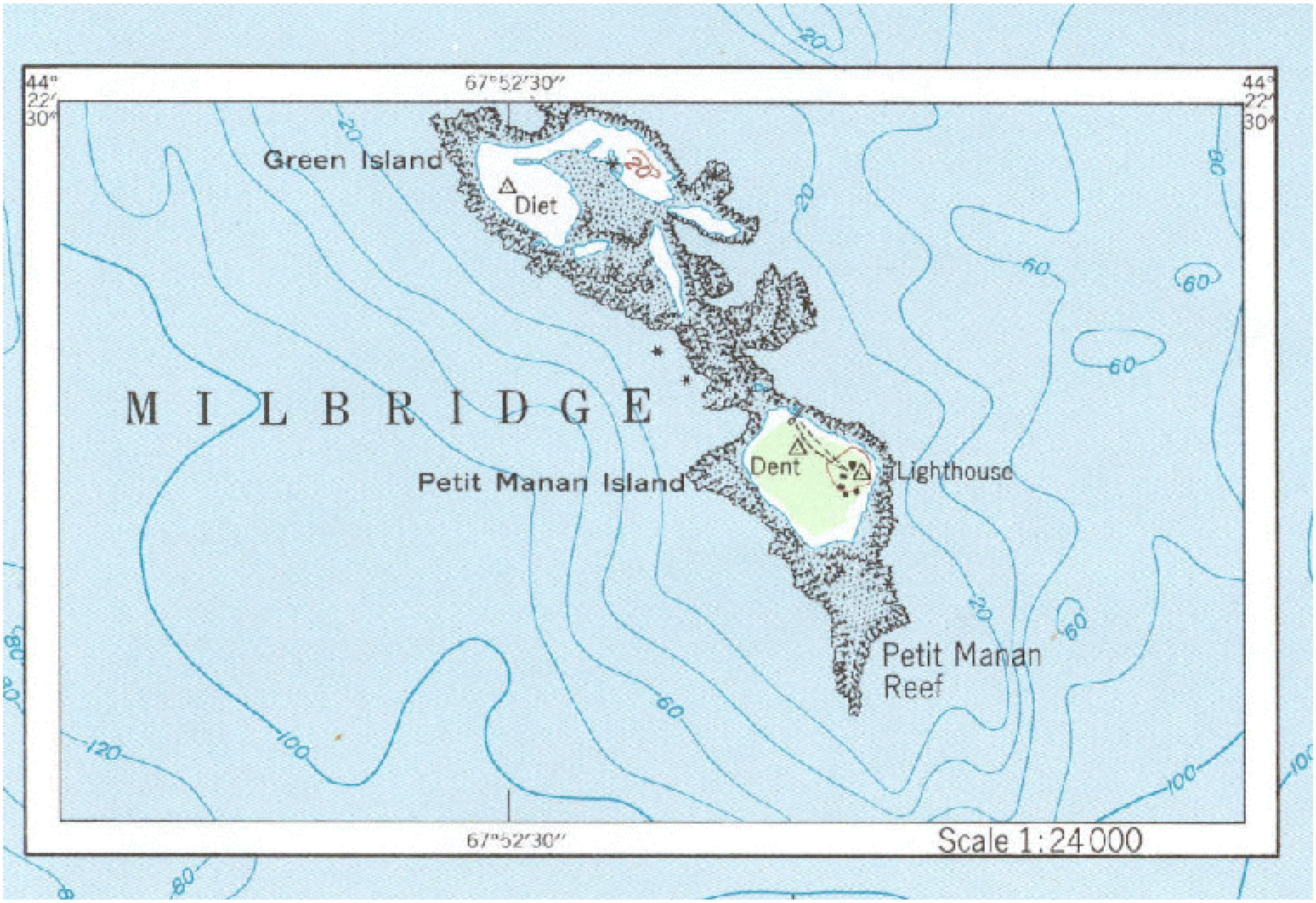

Figure 2. Nesting pairs of terns on Petit Manan Island, 1984 - 2000

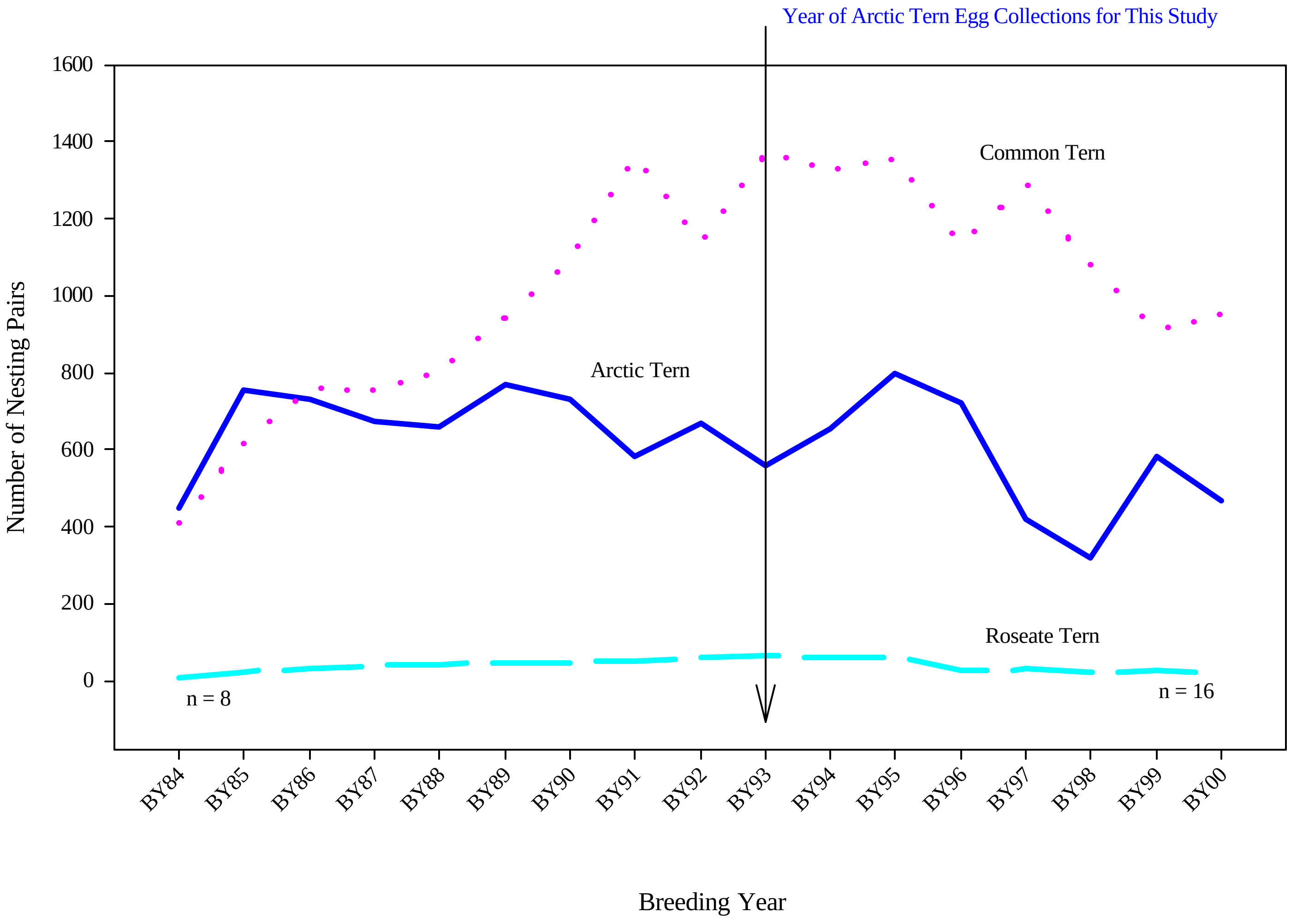

Figure 3. Petit Manan Island

4. METHODS

In early June 1993, eleven nests, each containing two eggs, were randomly selected on Petit Manan Island within three Arctic tern nesting areas. Between June 11 and 13, 1993, one of the two eggs from each nest was randomly selected and collected for contaminant analysis. Egg length and breadth were measured with vernier calipers to the nearest 0.1 millimeter. Each egg was then opened at the equator, the contents placed in chemically-clean jars, and frozen. All eggs appeared viable, and in most, embryos were partially developed.

Eleven eggs were submitted to the USFWS Patuxent Analytical Control Facility for contaminant analysis. All eggs were analyzed for organochlorines. Five eggs were also examined for trace elements. Both analyses were performed by Hazelton Environmental Services, Incorporated of Madison, Wisconsin. The organochlorine scan included the following compounds: HCB, total PCBs, *alpha* BHC, *alpha* chlordane, *beta* BHC, dieldrin, endrin, *gamma* BHC, *gamma* chlordane, heptachlor epoxide, mirex, *o*,*p*'-DDD, *o*,*p*'-DDE, *o*,*p*'-DDT, oxychlordane, *p*,*p*'-DDD, *p*,*p*'-DDE, *p*,*p*'-DDT, toxaphene, and *trans*-nonachlor. Organochlorine extraction, cleanup, and separation methods used by Hazelton are described on pages 19 through 25 of Appendix A. The trace element scan included the following elements: aluminum, arsenic, boron, barium, beryllium, cadmium, chromium, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, lead, selenium, strontium, vanadium, and zinc. Inductively coupled plasma spectroscopy, cold vapor atomic absorption, and graphite furnace analytical methods used by Hazelton are described on pages 16 through 22 of Appendix B. Lipid content was measured in all egg samples, while moisture content was determined in 9 samples.

Table 1. Sample metrics, percent moisture, and percent lipids

Sample Number	Sample Weight (g)	Egg Length (mm)	Egg Breadth (mm)	Percent Moisture	Percent Lipid
ATN0001	16.6	41.90	28.40	73.90	9.9
ATN0006	16.6	39.66	29.14	74.54	7.7
ATN0007	16.5	39.80	28.98	69.60	9.4
ATN0009	16.5	41.80	28.90	73.81	10.3
ATN0406	15.0	38.92	27.57	nm	8.5
ATN0407	15.5	40.10	27.58	70.87	10.1
ATN0408	18.5	43.09	30.49	nm	10.1
ATN0411	16.5	40.42	28.63	69.96	8.3
ATN1050	16.5	39.80	30.76	74.40	10.8
ATN1052	16.5	40.28	30.47	77.14	10.6
ATN1054	19.0	41.30	30.67	75.53	11.9
Mean	16.7	40.64	29.24	nc	9.8
SD	1.144	1.232	1.194		1.225

nm = not measured, nc = not calculated

5. ANALYTICAL RESULTS

Analytical results are summarized below. Laboratory results are reported in the appendices in micrograms per gram (: g/g = parts per million) dry weight and wet weight. The results in the text and tables of this report are presented on a **fresh wet weight basis**. Wet weight concentrations in Arctic tern eggs were adjusted to account for moisture loss after egg laying (Stickel *et al.* 1973, Hoyt 1979).

5.1 Trace elements - Five eggs were analyzed for 19 trace elements. Aluminum, barium, beryllium, boron, cadmium, lead, molybdenum, nickel and vanadium were not detected in eggs at the analytical limits of detection (LOD). The arithmetic mean concentration as fresh wet weight, standard deviation, and ranges of the elements that were detected in eggs follow: **arsenic** 0.18 : g/g ± 0.023 (range: 0.14 - 0.19 : g/g), **chromium** 0.11 : g/g ± 0.046 (range: nondetect - 0.18 : g/g), **copper** 0.76 : g/g ± 0.063 (range: 0.70 - 0.86 : g/g), **iron** 28.31 : g/g ± 3.235 (range: 24.22 - 32.04 : g/g), **magnesium** 106.68 : g/g ± 15.855 (range: 94.22 - 115.97 : g/g), **manganese** 0.49 : g/g ± 0.093 (range: 0.34 - 0.58 : g/g), **mercury** 0.10 : g/g ± 0.022 (range: 0.08 - 0.14 : g/g), **selenium** 1.89 : g/g ± 0.758 (range: 1.04 - 2.93 : g/g), **strontium** 2.14 : g/g ± 0.570 (range: 1.50 - 2.77 : g/g) and **zinc** 17.46 : g/g ± 3.369 (range: 13.92 - 21.47 : g/g).

5.2 Organochlorines - Eleven eggs were analyzed for 18 organochlorine pesticides and PCBs. Only two organochlorine compounds were detected in egg samples - hexachlorobenzene (HCB) and DDE. **HCB** concentrations ranged from non-detect to 0.021 : g/g (mean 0.015 : g/g ± 0.0039). The DDT metabolite, **DDE**, was found in all samples with a mean concentration of 0.039 : g/g ± 0.0135 (range: 0.017 - 0.058 : g/g).

5.3 Quality Assurance/Quality Control

The Service's Patuxent Analytical Control Facility reviewed the data package provided by the contract laboratory. QA/QC procedures for the tern egg catalog were approved with comment. Individual tern eggs for this survey were analyzed for trace elements and organochlorines. With two exceptions, percent moisture and percent lipid were also determined. In egg samples ATN0406 and ATN0408 percent moisture was not determined.

Detection limits are directly affected by sample amount and samples smaller than the minimum weight for analysis result in elevated Levels of Detection (USFWS 1990). The amount of material in each Arctic tern egg did not always contain sufficient mass for proper organochlorine analysis. Small sample amount was a problem in the Petit Manan Island tern egg analyses; too little material resulted in slightly elevated detection limits. The PACF Limits of Detection (LOD) for pesticides and PCBs are 0.01 : g/g and 0.05 : g/g, respectively. In some Arctic tern egg samples, pesticide LODs increased from 0.010 : g/g to 0.014 : g/g, while the LOD for PCBs increased from 0.05 : g/g to 0.07 : g/g. Because of small sample amounts, spike or duplicate analyses for QA/QC were not performed in the organochlorine analyses of tern eggs. The Patuxent Analytical Control Facility approved the tern egg organochlorine analyses based on the labs demonstrated acceptable accuracy and precision in previous catalogs, and the acceptable recoveries of control spikes.

In the QA/QC review of trace element analyses, there was only one abnormality. The spike recovery of Hg was less than 75%. The accuracy of the trace element analyses of all other elements was acceptable based on spike recovery and reference material analysis. In Appendix A - Trace Elements, the dry weight values for samples that were not analyzed for percent moisture (ATN0406, ATN0408) should be ignored (J. Moore. 2001. Personal communication). Overall, the precision of the trace element analyses was acceptable to PACF based on the results of the duplicate sample analyses.

Table 2. Trace elements in Arctic tern eggs, Petit Manan Island. ug/g, fresh wet weight*

Sample No.	As	Cr	Cu	Fe	Mg	Mn	Hg	Se	Sr	Zn
ATN0001	0.18	0.12	0.75	27.54	95.24	0.34	0.10	1.04	2.77	15.99
ATN0007	0.19	0.13	0.70	32.04	97.77	0.50	0.08	1.43	2.30	20.62
ATN0406	0.19	0.18	0.79	31.11	130.21	0.50	0.14	1.66	2.52	21.47
ATN0408	0.19	0.05	0.72	26.64	94.22	0.58	0.11	2.37	1.58	15.31
ATN1050	0.14	0.09	0.86	24.22	115.97	0.54	0.10	2.93	1.50	13.92
Mean	0.18	0.11	0.76	28.31	106.68	0.49	0.10	1.89	2.14	17.46
SD	0.023	0.046	0.063	3.235	15.855	0.093	0.022	0.758	0.570	3.369

* Adjusted for moisture loss
Shaded cell was non-detect. Value listed is one-half the sample detection limit.
Trace elements not detected: aluminum, barium, beryllium, boron, cadmium, lead, molybdenum, nickel, vanadium

Table 3. Organochlorines in Arctic tern eggs, Petit Manan Island. ug/g, fresh wet weight*

Sample Number	HCB	p,p'-DDE
ATN0001	0.017	0.017
ATN0006	0.016	0.051
ATN0007	0.007	0.020
ATN0009	0.012	0.030
ATN0406	0.016	0.032
ATN0407	0.018	0.051
ATN0408	0.012	0.030
ATN0411	0.015	0.044
ATN1050	0.017	0.046
ATN1052	0.018	0.045
ATN1054	0.021	0.058
Mean	0.015	0.039
SD	0.0039	0.0135

* Adjusted for moisture loss
Shaded cell was non-detect. Value listed is one-half the sample detection limit.
Organochlorines not detected: total PCBs, alpha-BHC, alpha-chlordane, beta-BHC, dieldrin, endrin, gamma-BHC, gamma-chlordane, heptachlore epoxide, mirex, o,p'-DDD, o,p'-DDE, oxychlordane, p,p'-DDD, p,p'-DDT, toxaphene, trans-nonachlor

6. DISCUSSION

In this contaminant study, the Arctic tern was selected as a surrogate species for other tern species using Petit Manan Island, including a federally-listed endangered species, the roseate tern. Ecologically, the Arctic tern is similar in some ways to the other terns inhabiting Petit Manan Island, but differences do exist among the tern species using the island. These ecological differences may play a role in contaminant exposure and uptake.

Arctic, common, and roseate terns have similar foraging strategies. The birds obtain prey by making dives into the water from heights of 9 to 12-m. (30 to 40 ft; Bent 1921, Ehrlich *et al.* 1988). Prey selection among terns species can differ (Safina *et al.* 1990). However, Hopkins and Wiley (1972) reported that common terns and Arctic terns at Petit Manan Island fed on similar prey, particularly herring. More recent foraging studies by PMNWR staff indicate that Atlantic herring (*Clupea harengus*) and hake (*Urophycis* sp.) are principal prey species of terns foraging at Petit Manan Island (USFWS. unpublished data). Besides fish, earthworms, several orders of insects, and a few pelagic mollusks may be consumed by Arctic terns (Ehrlich *et al.* 1988, Lemmetyinen 1976, Hawksley 1957). Prey size may also differ among terns with Arctic terns taking smaller fish than common terns (Cramp 1985). Due to differences in prey species or prey size, contaminant residues found in Arctic tern eggs may not mirror uptake in roseate or common terns.

As migratory species, terns have the ability to come into contact with a variety of environmental contaminants. The Arctic tern is unique among birds in its length of migration, traveling over 17,700-km (11,000 mi) from the breeding range in the northern part of the northern hemisphere to the wintering areas in the seas of the Antarctic (Bent 1921, Cramp 1985). Arctic terns, like all other migrants, may be exposed to a variety of contaminants while foraging along coastlines and in offshore marine environments between their breeding and wintering areas. During breeding season, Arctic terns typically forage within 3-km (- 1.75 mi) of the colony (Cramp 1985). Compared to other birds, the Arctic tern appears to be a long-lived species. An Arctic tern trapped on Petit Manan Island in 1970 had been banded 35 years earlier in the same colony (Hatch 1974). Longevity may also play a role in contaminant uptake by Arctic terns. Certain contaminants such as DDE and Hg accumulate over time in fat, muscle, or organ tissue. Longer-lived species of fish and wildlife tend to have higher body burdens of these contaminants than short-lived species.

Arctic terns are colonial nesters. Breeding pairs produce a typical clutch of two eggs; on occasion three are laid (Bent 1921, Pettingill 1939, Cramp 1985). Although nestling birds would likely have provided better data that would reflect local contaminant conditions, we collected eggs. We chose eggs over nestlings to minimize disruption of breeding and the colony. Removal of a single egg from a nest typically does not cause the breeding pair to abandon the nest. In many situations, egg removal may cause the female to lay another egg to complete the clutch. In contrast, the collection of nestlings can much more disruptive to the colony. Neighboring adult terns may temporarily abandon young during collections leaving their nestlings available to gulls and other predators. Consequently, eggs are often use as substitutes for chicks in contaminant investigations.

Metal concentrations in eggs represent metals sequestered in the egg by females at the time of egg formation (Burger and Gochfeld 1996). These egg contaminants can be derived from recent exposure or from mobilization from other tissues in the female (Burger *et al*. 1999). The contaminant levels in Arctic tern eggs from PMI may reflect local contaminant conditions or reflect a contaminant burden accumulated by the female during migration.

In the following pages, contaminant concentrations in Arctic tern eggs from Petit Manan Island are compared with levels in tern or other bird studies reported in the scientific literature. Comparisons of egg data are made on a wet weight basis. If contaminant levels in eggs in other reports were reported on a dry weight basis, the egg concentrations were adjusted to wet weight based on 75% moisture. Arctic tern egg data from PMI are presented as fresh wet weight. The contaminant concentrations were adjusted for moisture loss following egg laying. Fresh wet weight concentrations in bird eggs are typically 10 to 15% lower than wet weight concentrations (Valoppi *et al*. 1999). Birds may respond differently to to certain contaminants and doses. Species-specific differences among birds to contaminants are often reported in the scientific literature. Thus, our review of avian contaminant effect studies should be viewed with caution. Contaminant-related effects reported in other bird species may not necessarily be exhibited by Arctic terns.

6.1 Trace Elements. Ten trace elements were found above detection limits in Arctic tern eggs - arsenic, chromium, copper, iron, magnesium, manganese, mercury, selenium, strontium, and zinc. Typically, iron, magnesium, manganese, and strontium are not ecological contaminants of concern and they will not be discussed in this report. Aluminum, barium, beryllium, boron, cadmium, lead, molybdenum, nickel and vanadium were not detected in tern eggs.

Brief notes on the hazards posed by arsenic, chromium, copper, mercury, selenium, and zinc follow along with concentrations found in Arctic tern eggs from Petit Manan Island, and potential effects associated with exposure to these elements. Trace element egg exposure and effect data for other tern species and, if necessary, other birds (e.g., waterfowl, wading birds) are presented for comparative purposes. As noted earlier, the Arctic tern data in this report are presented in :g/g (parts-per-million), fresh wet weight.

6.1.1 Arsenic (As) - Arsenic is a teratogen and carcinogen, which bioconcentrates in organisms, but does not biomagnify in food chains (Eisler 1994). In mallard dietary studies, As exposure did not affect hatching success and was not teratogenic, but did delay egg laying, reduced egg weight, and caused eggshell thinning (Stanley *et al.* 1994). In some bird studies, adverse reproductive effects were not expected when As residues in eggs were below 9 :g/g (Hothem and Welsh 1994). Arsenic levels in Arctic tern eggs from PMI were less than 0.25 :g/g, the As effect level reported for waterfowl by Hothem and Welsh (1994). The mean and range of As found in Arctic terns at PMI were similar to the levels reported in tern studies by Allen *et al.* (1998) and King *et al.* (1983).

Table 4. As concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	As Conc. :g/g fww Mean (Range)	Reference
Arctic Tern	0.18 (0.14 - 0.19)	This study
Least Tern	(nondetect - 0.10)	Allen *et al*. 1998
Royal Tern	0.13 (nondetect - 0.26)	King *et al*. 1983
Royal Tern	0.18 (nondetect - 0.29)	King *et al*. 1983

6.1.2 Chromium (Cr) - Trivalent Cr is an essential trace element for vertebrates. The hexavalent form of Cr, however, may cause adverse effects in the liver and kidney, and could also be a carcinogen (FDA 1993, Environment Canada and Health Canada 1994). In the laboratory, Cr is a mutagen, carcinogen, and teratogen to several organisms (Eisler 1986). Little information is available describing the potential effects of Cr on birds. Heinz and Haseltine (1981) fed Cr-contaminated feed to American black ducks *Anas rubripes* and tested avoidance response to a fright stimulus. No significant effect on avoidance behavior was detected in ducks with diets as high as 200 ppm chromium.

Information on Cr exposure levels in tern eggs is limited. Eisler (1986) suggested that tissue concentrations greater than 1 :g/g are generally indicative of Cr contamination. Burger *et al.* (1999) summarized the results of 20 studies that included raptors, seabirds, and other fish-eating birds and reported a median Cr egg level of 0.21 :g/g with a range between 0.01 :g/g and 1.01 :g/g. In New York and Newark Bays, herring gull eggs collected near Cr-contaminated sites had a mean Cr concentration of 0.75 :g/g (Gochfeld 1997). In Wyoming, American avocet *Haematopus palliatus* eggs contained a mean Cr concentration of 0.36 :g/g (range: 0.06 - 14.22 :g/g; Dickerson and Ramirez 1998). Pectoral sandpiper *Calidris melanotos* eggs from Arctic NWR had a Cr range of < 0.12 :g/g to 0.42 :g/g (USFWS, unpublished data).

Compared to other bird studies (Burger *et al.* 1999, Dickerson and Ramirez 1998, Gochfeld 1997), a common tern study by Connors *et al.* (1975) and to Eisler's (1986) recommended toxicological benchmark, the Cr levels found in Arctic tern eggs from PMI do not appear elevated.

Table 5. Cr concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	Cr Conc. :g/g fww Mean (Range)	Reference
Arctic Tern	0.11 (nondetect - 0.18)	This study
Common Tern	0.65 (0.28 - 1.28)	Connors *et al*. 1975

6.1.3 Copper (Cu) - Copper is an essential element for vertebrates. At environmentally realisitic concentrations, Cu is not carcinogenic, mutagenic or teratogenic (Eisler 1997). No data are available on Cu toxicity to avian wildlife, but at elevated dietary concentrations Cu accumulated in poultry liver, inhibited growth, and caused gizzard erosion (Eisler 1997, Hui *et al.* 1998).

Four tern studies were found that listed Cu concentrations in eggs (Table 6). The mean Cu levels in these studies were higher than the mean concentration found in Arctic terns from PMI. In other bird studies, Cu concentrations similar to the levels found at PMI have been reported. Hui *et al.* (1998) found Cu concentrations of 0.76 :g/g in snow geese *Anser caerulescens* eggs from Wrangel Island, Russia. Kelp gulls from the Antarctic Peninsula had Cu egg levels of 0.75 :g/g (de Moreno *et al.* 1997). In the Mediterranean, Audouin's gull *Larus audouinii* eggs from the Ebro Delta of Spain contained a mean Cu concentration of 0.64 :g/g (Morera *et al.* 1997).

Copper criteria for the protection of avian wildlife are not available (Eisler 1997), but the levels found in Arctic tern eggs from PMI do not appear elevated compared to other tern and bird studies.

Table 6. Cu concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	Cu Conc. :g/g fww Mean (Range)	Reference
Arctic Tern	0.76 (0.70 - 0.86)	This study
Common Tern	1.47 (1.02 - 1.64)	Connors *et al*. 1975
Royal Tern	1.22 (0.78 - 2.10)	King *et al*. 1983
Royal Tern	1.09 (0.60 - 1.50)	King *et al*. 1983
Antarctic Tern	1.0	de Moreno *et al*. 1997

6.1.4 Mercury (Hg) - Mercury is a mutagen, teratogen, and carcinogen which bioconcentrates in organisms and biomagnifies through food chains (Eisler 1987). Mercury concentrations in eggs of 0.5 to 2.0 : g/g are sufficient to reduce egg viability, hatchability, embryo survival and chick survival in nonmarine birds (Thompson 1996). In a generational study, hen mallards fed a diet containing 0.5 : g/g mercury laid fewer sound eggs than controls (Heinz 1979). Residues of mercury in duck eggs in the Heinz study (1979) were approximately 0.8 : g/g.

In birds, Hg is deposited into feathers with molting being an efficient mechanism for reducing Hg body burdens (Burger *et al*. 1994). Piscivorous birds are at risk from Hg in fish tissue. Barr (1986) reported that loons feeding on fish with Hg concentrations of 0.30 to 0.40 : g/g appeared to have impaired reproduction. King *et al*. (1991) found no effect on hatching success when mercury egg levels were less than 0.9 : g/g in Caspian and least terns, and at 0.4 : g/g in Forster's terns. The mercury levels detected in Arctic terns from Petit Manan island (mean 0.10 : g/g, range: 0.08 - 0.14 : g/g; qualified data - spike recoveries were below 75%) were well below the avian effect ranges reported by King *et al.* (1991), Heinz (1979) and Barr (1986).

Table 7. Hg concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	Hg Conc.:g/g fww Mean (Range)	Reference
Arctic Tern	0.10 (0.08 - 0.14)	This study
Common Tern	0.09 (0.02 - 0.27)	Connors *et al*. 1975
Common Tern	0.41	Becker *et al.* 1994
Caspian Tern	(0.62 - 2.10)	Blus *et al*. 1998
Caspian Tern	0.20 (nondetect - 0.50)	King *et al*. 1991
Caspian Tern	1.25	Ohlendorf *et al*. 1988
Forster's Tern	0.22 (nondetect - 0.84)	King *et al*. 1991
Forster's Tern	0.40 (0.05 - 0.91)	King *et al*. 1991
Forster's Tern	0.09	Ohlendorf *et al*. 1988
Least Tern	0.34 (nondetect - 0.82	King *et al*. 1991
Least Tern	0.20	Allen *et al*. 1998
Royal Tern	1.11 (0.73 - 2.20)	King *et al*. 1983
Royal Tern	1.27 (0.86 - 2.20)	King *et al*. 1983
Sooty Tern	0.172	Ohlendorf & Harrison 1986
Sooty Tern	0.127	Ohlendorf & Harrison 1986
Sooty Tern	7.93	Stoneburner *et al*. 1980
Antarctic Tern	0.10	de Moreno *et al*. 1997

6.1.5 Selenium (Se) - Selenium contamination in irrigation drainwater and surface water is a serious problem to fish and wildlife resources in the western United States, a region with seleniferous soils. In the eastern United States seleniferous soils are less common, but Se has been identified in the Northeast as an environmental contaminant in fish collected from rivers in industrialized areas. Selenium is an essential trace element for vertebrates. Selenium deficiency may cause death (Eisler 1985b). Heinz (1996) reviewed several Se studies and concluded that a Se level of about 3 : g/g in bird eggs should be considered the threshold of reproductive impairment. One of 5 Arctic tern eggs from Petit Manan Island had a Se concentration slightly below the suggested effects threshold.

Table 8. Se concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	Se Conc. : g/g fww Mean (Range)	Reference
Arctic Tern	1.89 (1.04 - 2.93)	This study
Forster's Tern	0.68 (0.42 - 0.87)	King *et al*. 1991
Forster's Tern	0.71 (0.55 - 1.30)	King *et al*. 1991
Caspian Tern	0.31 (0.22 - 0.42)	King *et al*. 1991
Least Tern	0.73 (0.54 - 0.87)	King *et al*. 1991
Least Tern	(0.27 - 3.00)	Allen *et al*. 1998
Royal Tern	0.94 (0.43 - 1.30)	King *et al*. 1983
Royal Tern	1.06 (0.49 - 2.10)	King *et al*. 1983
Sooty Tern	1.38	Ohlendorf & Harrison 1986
Sooty Tern	1.09	Ohlendorf & Harrison 1986
Sooty Tern	3.78	Stoneburner *et al*. 1980

6.1.6 Zinc (Zn) - Zinc is an essential element for vertebrates. Generally, Zn is efficiently regulated by wildlife and tissue concentrations are not reliable indicators of exposure except in extreme cases (Beyer and Storm 1995). Elevated Zn levels in bird tissue are typically greater than 52 :g/g with Zn poisoning occurring in birds with liver or kidney levels greater than 525 :g/g (Eisler 1993). Zinc toxicosis in mallards *Anas platyrhynchos* was characterized by leg paralysis, high concentrations in the pancreas and kidneys, and yellowish-red kidneys (Gasaway and Buss 1972).

The mean Zinc concentration in Arctic tern eggs from PMI was higher than mean levels reported in other tern studies (Table 9). The range of Zn concentrations in Arctic tern eggs, however, was similar to the ranges reported in other tern studies.

Table 9. Zn concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	Zn Conc. :g/g fww Mean (Range)	Reference
Arctic Tern	17.5 (13.9 - 21.5)	This study
Common Tern	21.1 (16.2 - 26.9)	Connors *et al*. 1975
Royal Tern	12.32 (8.80 - 14.00)	King *et al*. 1983
Royal Tern	11.72 (9.00 - 14.00)	King *et al*. 1983
Antarctic Tern	15.5	de Moreno *et al*. 1997

6.2 Organochlorines. Only two of 19 organochlorine compounds were detected in Arctic tern eggs - HCB and *p,p*'-DDE. Total PCBs, *alpha* BHC, *alpha* chlordane, *beta* BHC, dieldrin, endrin, *gamma* BHC, *gamma* chlordane, heptachlor epoxide, mirex, *o,p*'-DDD, *o,p*'-DDE, *o,p*'-DDT, oxychlordane, *p,p*'-DDD, *p,p*'-DDT, toxaphene, and *trans*-nonachlor were not detected in tern eggs.

6.2.1 Hexachlorobenzene (HCB) - HCB, or hexachlorobenzene, is a fungicide and starting material for the wood preservative, pentachlorophenol (Gilbertson and Reynolds 1972). It is a contaminant in the herbicide Dacthal, and is persistent in the environment (Wiemeyer 1996). Based on its ability to bind to the aryl hydrocarbon (Ah) receptor, its dioxin-like effects, and ability to bioaccumulate, it has been suggested that HCB be classified as a dioxin-like compound (van Birgelen 1998). HCB is often released to the atmosphere from the same sources that are releasing polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (e.g., chloralkali and wood-preserving plants, municipal and hazardous waste incinerators; ATSDR 1997, Environment Canada 1999). Dietary exposure in animals to HCB damaged the liver, thyroid, nervous system, bones, kidney, blood, and immune and endocrine systems (ATSDR 1997).

Wiemeyer (1996) reviewed several studies and reported that the effects of HCB on reproduction of birds was variable among species. In one exposure study, Japanese quail eggs with an estimated HCB burden of 35 :g/g were not affected, while in another study, hatchability of chicken eggs containing 100 :g/g was normal (Wiemeyer 1996). Compared to Wiemeyer's review and to other tern studies reported in the scientific literature, Arctic terns from PMI did not contain elevated levels of HCB.

Table 10. HCB concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	HCB Conc. :g/g fww Mean (Range)	Reference
Arctic Tern	0.015 (nondetect - 0.021)	This study
Common Tern	0.08	Weseloh *et al*. 1989
Common Tern	2.30	Gilbertson & Reynolds 1972
Common Tern	0.06 (0.02 - 0.37)	Niemi *et al*. 1986
Common Tern	0.018 (0.012 - 0.028)	Nisbet 1982
Caspian Tern	0.009, 0.014, 0.020	Ewins *et al*. 1994
Caspian Tern	(0.018 - 0.026)	Yamashita *et al*. 1993
Least Tern	(nondetect - 0.01)	Allen *et al*. 1998
Forster's Tern	(0.01 - 0.02)	Blus *et al*. 1998

6.2.2 DDE - DDE, dichlorodiphenyl-dichloroethylene, is a metabolite of the pesticide DDT. Although the use of DDT in the United States was essentially discontinued in 1972 (EPA 1990), the compound and its metabolites continue to be detected in wildlife tissues. DDT metabolites are lipophilic and accumulate in lipid deposits and other fatty tissues (Blus 1995). In raptors and piscivorous birds, DDT metabolites cause eggshell thinning (Hickey and Anderson 1968). Eggs of piscivorous birds with DDE residues of 1 :g/g have a 5% to 10% reduction in eggshell thickness, and eggshells with 18% thinning are associated with declining populations (Blus 1996). In general, DDE residues in wildlife tissues have declined substantially since the DDT ban.

In a San Diego Bay (CA) study, hatching success of Caspian tern (*Hydroprogne caspia*) and elegant terns (*Sterna elegans*) was not affected by DDE egg levels as high as 9.3 :g/g and 3.8 :g/g, respectively (Ohlendorf *et al.* 1985). In Alberta, common tern eggs with a total DDT level of 4.5 :g/g did not have any evidence of reproductive failure (Switzer *et al.* 1973). DDE levels in Arctic tern eggs from PMI at 0.058 :g/g (max.) were orders of magnitude less than the levels found in San Diego Bay or Alberta. Consequently, reproductive effects from residual DDE contamination in eggs are not expected in Arctic terns from PMI.

Table 11. DDE concentrations in Arctic tern eggs from PMI compared to other tern studies.

Species	DDE Conc. :g/g fww Mean (Range)	Reference
Arctic Tern	0.039 (0.017 - 0.058)	This study
Common Tern	0.016 (0.007 - 0.040)	Castillo *et al*. 1994
Common Tern	0.119 (0.060 - 0.230)	Medvedev & Markova 1995
Common Tern	6.38 (1.20 - 33.30)	Vermeer & Reynolds 1970
Common Tern	2.5 (0.08 - 6.80)	Niemi *et al*. 1986
Common Tern	(1.40 - 1.70)	Hoffman *et al*. 1993
Common Tern	0.43	Custer *et al*. 1985
Common Tern	7.57 (0.64 - 104.0)	Switzer *et al*. 1971
Roseate Tern	(nondetect - 0.90)	Custer *et al*. 1983
Caspian Tern	2.20 (0.70 - 4.70)	King *et al*. 1991
Caspian Tern	2.86 (1.47 - 4.23)	Ewins *et al*. 1994
Caspian Tern	(1.9 - 7.2)	Blus *et al*. 1998
Caspian Tern	(2.30 - 6.30)	Yamashita *et al*. 1993
Caspian Tern	6.93	Ohlendorf *et al*. 1988
Forster’s Tern	(0.72 - 1.20)	Blus *et al*. 1998
Forster’s Tern	1.60 (0.70 - 9.00)	King *et al*. 1991
Forster’s Tern	0.80 (0.10 - 5.90)	King *et al*. 1991
Forster’s Tern	1.92	Ohlendorf *et al*. 1988
Royal Tern	1.13 (0.25 - 6.30)	King *et al*. 1983
Royal Tern	1.20 (0.28 - 5.8)	King *et al*. 1983
Least Tern	(0.022 - 0.77)	Allen *et al*. 1998
Little Tern	2.79 (nondetect - 22.3)	Goutner *et al*. 1997
Elegant Tern	3.79	Ohlendorf *et al*. 1988

7. SUMMARY

Organochlorine contaminant analyses found hexachlorobenzene (HCB) and the DDT metabolite, DDE, in Arctic tern eggs from Petit Manan Island. Seventeen other organochlorine compounds (e.g., PCBs, chlordane, endrin, etc.) were not detected in egg samples. Mean HCB (0.015 µg/g, fresh weight weight) and *p,p*'-DDE (0.039 µg/g, fww) levels in Arctic tern eggs were not elevated compared to other tern studies and to avian effect threshold concentrations.

Ten of 19 trace elements in the analytical scan were detected in Arctic tern eggs. Trace element concentrations in Arctic tern eggs were not highly elevated compared to other tern studies. One Arctic tern egg, however, had a selenium concentration (2.93 µg/g, fww) that was slightly less than the suggested threshold level for reproductive impairment (3 µg/g).

8. LITERATURE CITED

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APPENDICES

Appendices A and B provided upon request.

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APPENDIX A

ORGANOCHLORINES

Analytical Laboratory:
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APPENDIX B

TRACE ELEMENTS

Analytical Laboratory:
Hazelton Laboratories America, Inc.