AVAILABILITY OF CONTAMINANTS TO MIGRATORY SHOREBIRDS CONSUMING HORSESHOE CRAB EGGS ON DELAWARE BAY BEACHES

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Title: Availability of Contaminants to Migrating Shorebirds Consuming Horseshoe Crab Eggs on Delaware Bay Beaches

Abstract: A perceived decline in the shorebird population has raised concern regarding contamination at shorebird breeding, staging, and wintering grounds. Thousands of shorebirds utilize Delaware Bay as the final staging ground during their migration to breeding areas in northern Canada. The abundance of horseshoe crab eggs on the beaches of Delaware Bay provides a plentiful food source for shorebirds. Shorebirds consume enough horseshoe crab eggs to double or triple their weight during the two to three weeks stopover at Delaware Bay. Horseshoe crab eggs, sand, and ruddy turnstones were collected at two beaches on the Delaware shore of Delaware Bay and analyzed for organochlorines and trace metals to determine whether the horseshoe crab eggs are a potential source of contamination to the shorebirds. Sand, eggs, and bird tissues contained background to moderately elevated levels of contaminants. This limited study indicates that contamination of the shorebirds at Delaware Bay is probably not responsible for any decline in the population. However, a more extensive survey of horseshoe crab eggs throughout Delaware Bay would provide a more reliable assessment.

Acknowledgments

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INTRODUCTION

The largest population of horseshoe crabs (*Limulus polyphemus*) in North America spawns in Delaware Bay. An estimated 1,240,700 horseshoe crabs spawned on the beaches in Delaware Bay during the peak of the 1991 spawning season (U.S. Fish and Wildlife Service 1991). Because the eggs provide an abundant, protein rich, food source, the Bay is also the staging area of the largest population of shorebirds in North America. Shorebirds obtain from the eggs the fat reserves necessary for completing the spring migration, and the birds can double or triple their weight in a few weeks from feeding on the eggs (Hall 1991). Some birds eat as many as 9,000 eggs per day.

No studies have documented the potential contaminants contribution to migratory shorebirds from horseshoe crab eggs. Because of the quantity of eggs consumed, even low levels of contaminants in the eggs may cause toxic effects in the birds during migration or impair reproduction at the breeding ground. The potential impact from contaminants in horseshoe crab eggs could be greater if the birds are already burdened with contaminants from their wintering grounds. The objective of the study is to determine the potential contribution of contaminants to migratory shorebirds from horseshoe crab eggs (the primary food source) in Delaware Bay.

Horseshoe crabs can pick up contaminants from several sources. Juvenile horseshoe crabs live in the Delaware Bay for at least two years, and a population of adults is believed to reside in the Bay year-round (Dr. Carl Schuster, VA Inst. Mar. Sci., pers. comm.). The majority of adult horseshoe crabs migrate to the Atlantic Ocean as far east as the continental shelf, and spend only two to three months in the Delaware Bay during spawning.

Polychlorinated biphenyls (PCBs) are the primary contaminants of concern in Delaware Bay. PCBs are lipophilic compounds, and therefore accumulate in fatty tissue (Eisler 1986). While at Delaware Bay, the shorebirds are producing fat stores for the migration north (Hall 1991). Any PCBs consumed are stored in the newly developed fat, producing a toxic risk to birds during migration or egg production, when the fatty tissue is metabolized (Lemmetyinen et al. 1982, Ohlendorf et al. 1978). This same phenomena has been documented in bats suffering from organochlorine toxicity (Clark 1988).

Offshore dumping of industrial and municipal waste provides a potential source of inorganic and organic contamination to horseshoe crabs. An accidental spill of arsenic trioxide off the coast of Cape May, New Jersey, is a recent contaminant concern. The spill occurred in an area where horseshoe crabs reside or potentially migrate, and may be a source of contamination to crabs and subsequently to the birds through consumption of the horseshoe crab eggs.

METHODS

Sample Collection and Preparation

The study consists of two sampling locations: a site in the upper Delaware Bay at Port Mahon and a site in the lower Delaware Bay at South Bower Beach (Figure 1). Schuster (pers. comm.) suspects resident horseshoe crabs spawn in the upper reaches of the Bay and migratory horseshoe crabs spawn in the lower reaches of the Bay. The study design incorporates the two potential pathways of exposure to contaminants by sampling at the sites where populations of resident and migratory crabs are most likely to spawn.

Ruddy turnstones are migrating shorebirds, fairly representative of the migrating shorebird population, readily identifiable, and of adequate body size for contaminant sampling (Red knots were eliminated from the original study design because they were at Delaware Bay in small numbers, for only a short period of time, and were not observed feeding at the sample locations). CBFO sampled ruddy turnstones to identify their contaminant loads at the end of the staging period and for comparison with contaminants in the horseshoe crabs.

The sample collection took place during the peak of the horseshoe crab spawning in 1982. The peak spawning typically occurs during the full moon in May, with smaller peaks during the following new and full moons during June. Migrating shorebirds are attracted by the abundant food source and will feed on crab eggs for approximately two weeks before continuing their northward migration. Spawning did not peak during the May full moon in 1992 and the migrating species of interest (red knots and turnstones) were not at Delaware Bay for extended periods until the new moon in June (Didyk, pers. comm.). Therefore, sampling took place June 1 through June 4 at the next new moon when the horseshoe crab spawning peaked and after birds were at Delaware Bay for a week or more. Unfortunately, because of irregularities in the weather and the late spawning of the horseshoe crabs, many of the shorebirds migrated through Delaware Bay prior to the peak spawning period.

A field team of six from the Chesapeake Bay Field Office (CBFO) conducted the sampling. CBFO sampled beach sediment (sand) and horseshoe crab eggs at each site and ruddy turnstones (*Arenaria interpres*) at Port Mahon. CBFO sampled sand because birds consume a considerable amount of sand while feeding, and the sand may contain local contaminants. Eggs are the primary food source for the migrating birds and greatest potential contributor of contaminants. Andy Didyk, a researcher from University of New Brunswick, Canada who was doing a study on parasites in shorebirds migrating through Delaware Bay, observed arrival times of the birds, length of stay, and feeding habits. CBFO determined when to sample based on information from Mr. Didyk and other sources.

CBFO sampled sand along ten transects per site using a 2.54 cm (1") diameter, stainless steel, soil probe. The transects extended from the low tide to high tide line. The transects were nine meters (30 ft) apart. Approximately ten subsamples of the top ten inches of sand were

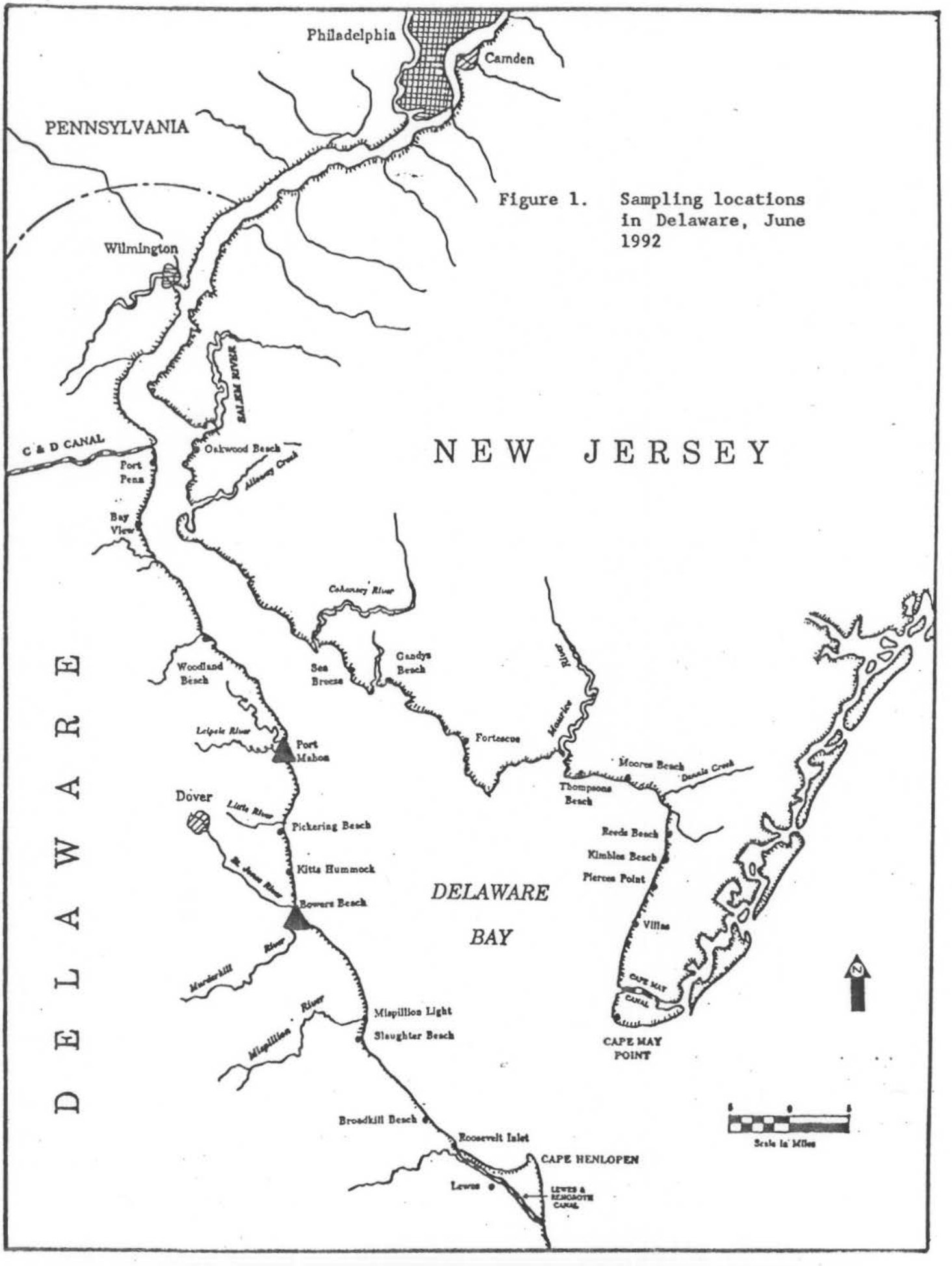

Figure 1. Sampling locations in Delaware, June 1992

taken along each transect. The subsamples for each transect were mixed 100 times by hand and split into three subsamples: inorganics, organics, and reserve. The samples were placed in chemically clean, I-Chem jars, labeled, and frozen.

CBFO excavated egg masses with a stainless steel spoon or collected eggs from the beach surface. As much sand as possible was removed from the eggs by placing the eggs in a stainless steel sieve or aquarium net, and washing the eggs with Bay water. CBFO collected the eggs along the transects used for sand collection. The eggs for each transect were mixed and split into three subsamples: inorganics, organics, and reserve. The samples were placed in chemically clean, I-Chem jars, labeled, and frozen.

CBFO collected all of the birds using a shotgun and the smallest steel shot available (size 6). Although mist netting was attempted at South Bower Beach, the technique proved unsuccessful in capturing the shorebirds. The extensive riprap at Port Mahon made mist netting impractical. Twenty-two ruddy turnstones were collected at Port Mahon. Each bird was weighed and measured, plucked, and the wings, legs, and beaks were removed. The livers were removed for inorganic analyses and the carcasses preserved for organics analysis. The livers were placed in individual Whirlpak bags, labeled, and frozen. The carcasses were placed in chemically cleaned jars, labeled, and frozen.

Chemical Analyses

Geochemical Environmental Research Group (GERG) at Texas A&M University conducted the analyses for inorganic and organic residues, percent moisture and percent lipid of tissues, total organic carbon of sediments, and grain size of sediments.

Samples for organic residue analyses were extracted by the NOAA Status and Trends Method (MacLeod et al. 1985) with minor revisions (Brooks et al. 1989; Wade et al. 1988). Briefly, the samples were homogenized with a Teckmar tissumizer by adding surrogate standards, anhydrous Na_2SO_4, and methylene chloride in a centrifuge tube. The tissue extracts were purified by silica/alumina column chromatography to isolate the aliphatic and PAH/pesticide/PCB fractions. The PAH/pesticides/PCB fraction was further purified by HPLC in order to remove interfering lipids. The quantitative analyses were performed by capillary gas chromatography (CGC) with electron capture detection for pesticides and PCBs (Wade et al. 1988). The limits of detection (LOD) for the different media were 0.07-0.20 ppm, wet weight for horseshoe crab eggs; 0.04-0.20 ppm, wet weight for ruddy turnstone carcasses; and 0.01 ppm, wet weight for sand.

Sample digestion for mercury analysis was performed by EPA method 245.5 with minor revisions. Mercury was determined by a modification of the method of Hatch and Ott (1968). A portion of the digest solution was placed in a sealed container, and 0.4 ml of 10% stannous chloride solution was added. Mercury was reduced to the elemental state and

aerated from solution into an atomic absorption spectrophotometer where its concentration was measured.

For determination of the remaining trace elements in sediment, the sediments were digested with aqua regia (3:1) $HCl:HNO_3$ in glass beakers on a hotplate and diluted to volume with distilled water. Tissues were either digested with nitric acid or dry ashed in a muffle furnace. Metals in the digestate were determined by graphite furnace atomic absorption spectrometry, in which electrical heating is used to produce an atomic cloud.

Each sample was also analyzed for percent moisture. Approximately one gram of wet sample was weighed into a clean, labeled, pre-weighed 10 ml beaker. The beaker was placed in a forced air oven at approximately 75 degrees Celsius for 24 hours. The beaker with the dry sample was then weighed and the percent dry weight was calculated by the formula:

$$\frac{\text{(wt. dry sample and beaker) - (wt. beaker)(100)}}{\text{(wt. wet sample and beaker) - (wt. beaker)}}$$

To determine grain size, a small aliquot of sediment was treated with 30% hydrogen peroxide to remove any organic coating from the grains. A dispersing agent was then added to the sample. The sand/mud fractions were separated using a 63 micron sieve. The sand fraction (>63 microns) was retained on the screen and the mud fraction (silt and clay <63 microns) was washed into a one-liter volumetric cylinder. The sand fraction was dried, sieved on a 63 micron screen and weighed. The sediment which passes through the screen a second time was added to the one-liter cylinder. The mud fraction was analyzed by stirring the cylinder and sampling 20 ml aliquots at four and eight phi intervals. The four and eight phi samples were dried and weighed. The percent sand, silt, and clay fractions were determined on a dry weight basis.

Total organic carbon was measured by coulometrics. Coulometrics burns sediment under an oxygen atmosphere to produce carbon dioxide gas. The gas was bubbled through an electrochemical cell, where a reaction between the CO_2 and the cell solution produced a color change. This solution was then electrically back-titrated to the endpoint. The amount of electricity (coulombs) used to reach the endpoint was directly proportional to the amount of organic carbon in the sample. The concentration of inorganic carbon was determined using the same detector, but the CO_2 was produced by acidifying the sample in a closed environment.

Quality Assurance

GERG tested the methods for accuracy and precision. Accuracy of the analytical methods was measured by spike recoveries: the ability to recover a known quantity of compound added to a sample. Spike recoveries ranging 80-120% are generally acceptable for organochlorine analyses, and recoveries ranging 85-115% are generally acceptable for atomic absorption analyses. GERG spiked one crab egg sample, one bird carcass sample, and four laboratory reference samples for the organochlorine analysis; and two egg samples and one sand sample for trace metal analysis. Procedural blanks verified minimal contamination during the analyses. GERG analyzed six procedural blanks for organics and four for trace metals.

Precision was measured by duplicating analyses of samples. Relative percent differences of 17.3% for organochlorine and 11.5% for trace metals are generally acceptable if the concentrations are within 10-times the limit of detection. Relative percent differences of 8.64% and 5.75%, respectively, are generally acceptable if the concentrations are greater than 10-times the limit of detection. GERG duplicated the organochlorine analyses for two egg, two carcass, and one sand sample and duplicated the trace metal analyses for three egg and one sand sample.

PACF considered the results of analyses for organic and trace metals as acceptable based on the results of the quality assurance (QA) report. Reagent blanks and duplicate analyses were within the acceptable range of performance. Although percent recoveries for HCB, heptachlor, alpha BHC, delta BHC, endrin, and gamma BHC in some of the spiked samples were lower than the generally acceptable range, PACF considered the results adequate based on the type of media and performance of the laboratory over time.

RESULTS

Organics

Almost all of the samples had concentrations of organic compounds less than the LOD. One horseshoe crab egg sample and four birds had detectable levels of total PCBs; one bird had a detectable level of dieldrin; 16 birds had detectable levels of 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene (p,p'-DDE); and two birds had detectable levels of 1,1,1-trichloro-2,2-bis(p-chlorodiphenyl)ethane (p,p'-DDT) (Appendix A).

Trace Metals

All of the ruddy turnstones had measurable concentrations of arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), and selenium (Se) (with the exception of one bird that did not have a measurable concentration of lead) (Appendix B). All of the egg samples contained measurable concentrations of As, Pb, and Se. Concentrations of Hg and Cd were found at

levels above the LOD in 70% and 35% of samples, respectively (Appendix C). All of the sand samples contained measurable concentrations of As, Cd, and Pb, however, only two sand samples contained measurable concentrations of Hg, and none had a measurable concentration of Se (Appendix D).

Statistical analysis was conducted to evaluate the relationship in concentration of trace metals between locations for crab eggs and sand, and between male and female birds. An Analysis of Variance with Tukey test was conducted on SAS for the analyses. The data was $\log_{10}$ transformed before analysis because several data sets were not normal. The only statistically significant difference ($\alpha < 0.05$) was between Pb concentrations in sand collected at Port Mahon and sand collected at South Bower Beach. Geometric mean concentrations of trace metals are listed in Table 1.

DISCUSSION

The results of the organic analyses indicate that organochlorine contamination is not a significant threat to the crabs or the birds. The levels of PCBs and DDE in the ruddy turnstones are well within background levels (Frenzel and Anthony 1989, Wiemeyer et al. 1988, Eisler 1986, Blus and Stafford 1980, Ohlendorf et al. 1978). However, the presence of p,p'-DDT in two of the carcasses suggests that these birds may have been exposed recently to DDT.

Results of the inorganic analyses indicate that the concentrations of cadmium, lead, and mercury are within background levels for all the media sampled, and that these trace metals are not contaminants of concern for either horseshoe crabs or ruddy turnstones (Eriksson et al. 1989, Henny and Heron 1989, Eisler 1988a, 1985a, Scheuhammer 1987, Ohlendorf et al. 1986, Ohlendorf et al. 1985, White and Cromartie 1985, Custer and Mulhern 1983, Hutton 1981, Ohlendorf et al. 1978). The significantly higher levels of lead in sand collected at Port Mahon are likely due to the presence of a boat dock and commercial fishing traffic. Although significantly higher than the concentrations reported at South Bowers, the concentrations of lead (5.79-10.8 ppm, dry weight) in sand at Port Mahon are still within background concentrations for sediments and soils of the Delmarva Peninsula (Maghini 1992).

The concentration of arsenic in the bird livers (3.01-10.1 ppm, dry weight) appears quite elevated when compared to background levels for all bird species (Eisler 1988b). However, the levels reported in this study are only slightly elevated compared with birds which feed on marine crustaceans and other marine organisms. Goede (1985) reported a range of

Table 1. Geometric means (ppm, dry weight) and ranges of trace metal residues in ruddy turnstone livers, horseshoe crab eggs, and sand collected from Port Mahon and South Bower Beach, Summer 1992.

Matrix	Location	No. of Samples	Geometric mean[1] and range (ppm, dry weight) As	Cd	Pb	Hg	Se
Bird Livers	Port Mahon	22	6.27 (3.01-10.1)	0.848 (0.277-3.008)	0.26 (<0.12-0.93)	1.237 (0.612-3.103)	24.43 (12.52-39.98)
Crab Eggs	Port Mahon	10	7.16 (4.13-61.9)	0.009 (<0.008-0.019)	0.67 (0.37-2.06)	n/a (<0.034-0.071)	2.93 (2.08-3.68)
	South Bower	10	6.47 (5.46-7.81)	0.009 (<0.008-0.023)	0.59 (0.24-2.04)	n/a (<0.034-0.071)	3.23 (2.19-4.53)
Sand	Port Mahon	10	0.68 (0.49-0.95)	0.026 (0.019-0.035)	7.01 (5.79-10.8)	n/a (<0.008)	n/a (<0.17)
	South Bower	10	0.63 (0.30-1.10)	0.023 (0.021-0.025)	3.30 (2.09-5.11)	n/a (<0.008-0.019)	n/a (<0.17)

[1]1/2 the LOD was used for values < LOD
no geometric mean was calculated if more than 1/2 of the samples had concentrations < LOD

concentrations of arsenic in livers of bar-tailed godwit, knot, and Icelandic redshank from 3 to 15 ppm. Other concentrations of arsenic reported for marine species that feed on fish and shellfish range from approximately 0.06 to 8 ppm, dry weight in liver tissue (Eisler 1988b, Goede 1985).

As with many other compounds, the concentration of arsenic in tissues is dependent on the concentration of arsenic in prey consumed. Although no correlation could be conducted in this study between trace metal residues in the ruddy turnstone livers compared with the horseshoe crab eggs, the high arsenic content of the crab eggs is likely responsible for the elevated levels reported in the birds. Unfortunately, the significance of the elevated arsenic concentrations cannot be determined without knowing the form of arsenic in the crab eggs (aquatic marine species have a high percentage of nontoxic arsenic compounds) (Eisler 1988b).

Like the concentrations of arsenic, the concentrations of selenium in ruddy turnstone livers appear high when compared to background levels for all bird species (Eisler 1985b, Ohlendorf 1989). However, marine species appear to accumulate and probably tolerate higher levels of selenium than freshwater species, and the levels reported in this study are within the range reported for other marine species (Ohlendorf et al. 1986, Goede 1985, Hutton 1981). A more diagnostic measure in adult birds of potential toxicity is the ratio of selenium in the liver compared with the kidney. Higher concentrations of selenium in a bird's liver than in its kidneys indicates probable reproductive impairment (teratogenic effects in developing embryos) (Ohlendorf 1989, Rusk 1991). Without knowing the concentrations of selenium in the turnstone kidneys, it is difficult to evaluate the degree of potential toxicity.

It is probable, as discussed for arsenic, that the concentrations of selenium in the birds are the result of their feeding on the horseshoe crab eggs. Selenium is quickly absorbed in birds and generally correlates to dietary concentrations within a few weeks. The normal ratio of selenium in liver tissue to diet concentrations is approximately 3-7:1 (Lemly 1989, Rusk 1991), similar to that observed in this study.

There was no significant difference in concentrations of contaminants between horseshoe crab eggs collected at South Bowers Beach and Port Mahon. This suggests either that resident and non-resident horseshoe crabs accumulate similar levels of contaminants, or that the two locations were not far enough apart to accurately reflect different populations of crabs. Based on the close proximity of the beaches to each other, it is most likely that the beaches are utilized by the same population of crabs. Current tagging studies should clarify the migratory patterns of the crabs, and whether location of spawning can be predicted for different horseshoe crab populations.

Overall, the concentrations of trace metals and organochlorines appear to be relatively low in all the media sampled and of low toxicological concern. However, the samples taken reflect

only a small portion of Delaware Bay beaches, the horseshoe crab population, and the migrating shorebird population utilizing Delaware Bay. A similar study conducted at several other beaches in both Delaware and New Jersey would provide a more accurate representation of contaminant levels in the horseshoe crab population and potential contribution to migrating shorebirds utilizing this resource. The Canadian Wildlife Service is conducting contaminant investigations of various staging areas as well as breeding and wintering grounds of migrating shorebirds. Their results should further elucidate whether additional contaminant investigations of shorebird staging areas are warranted.

MANAGEMENT RECOMMENDATIONS

If further study is undertaken, more sampling sites should be positioned around the Delaware Bay to differentiate between contaminant levels in resident and migratory crab populations and acquire results that are more representative of contaminant exposures to the entire staging population of migratory shore birds. Sampling should occur when the peak of the horseshoe crab spawning period coincides with the greatest concentration of shore birds in the Bay and the primary food source for the birds is crab eggs. If possible, at least two bird species should be collected at each sampling site. Studies have found that different avian species and different populations of similar species contain different tissue levels of some contaminants due to differences in metabolism and geographic location of wintering and breeding grounds (Lemmetyinen 1982). Shore bird kidneys should be analyzed for selenium in addition to livers to determine whether reproductive impairment is occurring. Arsenic levels in horseshoe crab eggs should be broken down into toxic and nontoxic components to determine whether the high total arsenic results witnessed in this study may be adversely affecting the birds. Once completed, the results of the Canadian Wildlife Service contaminants study in shore bird staging areas should be obtained to determine the possible sources of contaminants like DDT that were found in this study.

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APPENDICES

Appendix A. Organic residues (ppm, wet wt.) in horseshoe crab eggs and ruddy turnstones collected from Port Mahon and South Bower Beach, Delaware, Summer 1992.

Sample	Percent Moisture	Percent Lipid	Total PCBs[3]	p,p'-DDE[3]	p,p'-DDT[3]	Dieldrin[3]
92FBEO05[1]	61.06	3.36	0.12	<0.09	<0.09	<0.09
92PMTO01[2]	33.8	45.06	3.65	0.57	<0.17	<0.17
92PMTO02	63.68	9.96	0.86	0.35	<0.19	<0.19
92PMTO04	35.41	12.25	<0.19	0.23	<0.19	<0.19
92PMTO05	39.19	37.50	<0.19	0.22	<0.19	<0.19
92PMTO11	41.84	39.35	<0.17	0.22	<0.17	<0.17
92PMTO12	37.26	43.86	<0.05	0.15	<0.05	<0.05
92PMTO13	44.10	44.06	0.05	0.08	<0.04	<0.04
92PMTO14	51.32	32.98	<0.04	0.05	<0.04	<0.04
92PMTO15	42.40	45.49	<0.04	0.10	<0.04	<0.04
92PMTO16	56.44	52.14	0.07	1.01	<0.05	<0.05
92PMTO17	49.33	41.34	<0.05	0.08	<0.05	<0.05
92PMTO18	45.31	31.07	<0.04	0.10	<0.04	<0.04
92PMTO19	35.28	49.18	<0.05	0.07	<0.05	<0.05
92PMTO20	39.56	38.65	<0.05	0.09	<0.05	<0.05
92PMTO21	52.02	36.13	<0.04	0.40	0.28	0.48
92PMTO22	45.45	49.96	<0.05	1.69	0.10	<0.05

[1] Horseshoe crab egg sample from South Bower Beach
[2] Ruddy Turnstone carcass sample from Port Mahon (all PMTO samples)
[3] Concentration in ppm, wet weight

Appendix B. Trace metal residues (ppm, dry weight) in livers of ruddy turnstones collected from Port Mahon, Delaware, Summer 1992.

Sample #	Percent Moisture	Concentration in, ppm, dry weight				
		As	Cd	Pb	Hg	Se
92PMTM01	67.1	3.01	3.008	0.15	1.105	39.98
92PMTM02	61.5	7.41	0.701	<0.12	3.103	12.52
92PMTM03	68.0	9.88	0.448	0.21	1.052	13.32
92PMTM04	67.4	6.54	0.337	0.22	1.024	21.59
92PMTM05	66.7	5.63	0.413	0.31	0.776	34.04
92PMTM06	67.0	5.06	0.467	0.41	1.473	14.48
92PMTM07	65.8	6.71	2.218	0.49	0.876	22.06
92PMTM08	66.6	8.07	2.868	0.49	0.821	32.29
92PMTM09	65.8	5.59	1.131	0.93	1.731	34.56
92PMTM10	67.3	10.1	0.508	0.16	1.171	15.82
92PMTM11	68.5	5.06	0.547	0.62	0.833	29.15
92PMTM12	68.8	4.38	1.209	0.37	1.401	34.59
92PMTM13	68.8	5.94	1.723	0.18	1.323	26.80
92PMTM14	66.5	8.88	1.840	0.33	1.558	20.23
92PMTM15	67.0	6.62	0.508	0.16	0.612	24.83
92PMTM16	67.9	5.77	0.214	0.20	0.654	25.17
92PMTM17	67.1	9.94	0.541	0.17	1.126	27.19
92PMTM18	63.5	4.83	0.726	0.19	3.438	18.86
92PMTM19	65.1	6.65	2.380	0.17	1.172	26.22
92PMTM20	67.2	5.15	1.824	0.74	2.463	26.26
92PMTM21	68.3	7.26	1.111	0.19	1.015	32.43
92PMTM22	70.0	5.13	0.277	0.28	1.594	31.70

Appendix C. Trace metal residues (ppm, dry weight) in horseshoe crab eggs collected from Port Mahon and South Bower Beach, Delaware, Summer 1992.

Sample No. [1]	Percent Moisture	Concentration in ppm, dry weight				
		As	Cd	Pb	Hg	Se
92FBEI01	53.7	5.64	0.017	0.93	0.055	3.24
92FBEI02	51.7	7.81	0.023	2.04	<0.034	3.94
92FBEI03	53.7	5.46	<0.008	0.55	0.040	3.59
92FBEI04	50.4	6.89	<0.008	0.30	<0.034	3.31
92FBEI05	51.1	6.15	0.009	0.52	<0.034	2.81
92FBEI06	49.2	7.14	0.017	1.12	0.071	2.19
92FBEI07	49.7	7.01	0.013	0.49	<0.034	3.24
92FBEI08	52.8	6.65	0.011	0.44	<0.034	3.39
92FBEI09	52.4	6.76	<0.008	0.24	<0.034	4.53
92FBEI10	44.5	5.58	<0.008	0.52	<0.034	2.63
92LCEI01	53.1	6.96	<0.008	0.53	<0.034	3.68
92LCEI02	40.2	4.13	0.008	0.58	<0.034	2.29
92LCEI03	50.0	6.81	<0.008	0.37	<0.034	3.41
92LCEI04	56.3	6.05	0.017	0.51	0.034	3.31
92LCEI05	44.8	5.33	0.019	2.06	0.071	2.08
92LCEI06	58.2	5.83	<0.008	0.57	<0.034	3.09
92LCEI07	52.1	4.61	0.011	0.45	<0.034	2.50
92LCEI08	43.9	61.9	0.009	0.66	<0.034	3.29
92LCEI09	52.2	6.71	0.014	1.20	0.051	3.62
92LCEI10	42.5	5.05	0.010	0.79	<0.034	2.53

[1]FBEI samples collected from South Bower Beach
LCEI samples collected from Port Mahon

Appendix D. Trace metal residues (ppm, dry weight) in sand collected from Port Mahon and South Bower Beach, Delaware, Summer 1992.

Sample No. [1]	Percent Fines	Percent Moisture	Concentration in ppm, dry weight				
			As	Cd	Pb	Hg	Se
92FBSI01	1.01	16.0	0.95	0.024	5.79	<0.008	<0.17
92FBSI03	0.62	17.8	0.72	0.019	6.55	<0.008	<0.17
92FBSI05	0.48	16.6	0.49	0.035	10.8	<0.008	<0.17
92FBSI07	0.50	16.8	0.63	0.024	5.97	<0.008	<0.17
92FBSI09	0.44	13.8	0.30	0.021	2.09	0.019	<0.17
92LCSI01	0.74	13.9	0.63	0.024	5.11	<0.008	<0.17
92LCSI03	0.57	18.7	0.89	0.025	3.44	<0.008	<0.17
92LCSI05	0.80	16.1	1.10	0.023	3.07	<0.008	<0.17
92LCSI07	0.92	15.7	0.52	0.023	3.48	0.016	<0.17
92LCSI09	0.72	17.0	0.69	0.029	6.90	<0.008	<0.17

[1]Samples FBSI01, 03, 05, 07 and LCSI09 collected at Port Mahon
Samples LCSI01, 03, 05, 07 and FBSI09 collected at South Bower Beach