Environ. Sci. Technol. **2004**, *38,* 1305−1312

Persistent Organic Pollutants in Alaskan Murre (*Uria* spp.) Eggs: Geographical, Species, and Temporal Comparisons

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Concentrations of persistent organic pollutants (POPs) in eggs of common and thick-billed murres (*Uria aalge* and *U. lomvia*) from five Alaskan nesting colonies were dominated by 4,4′-DDE, total polychlorinated biphenyls (ΣPCBs; 46 congeners comprised mainly of PCB congeners 153, 118, 138, 99, and 151), hexachlorobenzene (HCB), β-hexachlorocyclohexane (β-HCH), and chlordane compounds (ΣCHL). Concentrations of 4,4′-DDE, *cis*-nonachlor, and heptachlor epoxide were lower than those reported for some of the same colonies in the 1970s, while HCB concentrations were similar. In general, significantly higher concentrations were found in eggs from Gulf of Alaska colonies compared to those from Bering Sea colonies except for HCB (higher in the Bering Sea) and β-HCH (no significant difference between the two regions). Thick-billed murre eggs contained higher concentrations of 4,4′-DDE and ΣPCBs, whereas common murre eggs had higher HCB concentrations. Possible factors contributing to the POPs patterns found in eggs from these murre colonies are discussed.

Introduction

Persistent organic pollutants (POPs) were reported in Alaskan birds as early as the 1960s (*1*−*4*). Although few POPs have been used in northern environments (i.e., arctic and subarctic regions), characteristics of these compounds, such as low water solubility and long atmospheric residence time, facilitate long-range atmospheric and oceanic transport (*5*). Therefore, the upper latitudes become a sink for some POPs because cold temperatures favor condensation over evaporation and slow natural decomposition (*6*). Because of human health concerns and stable or increasing POP levels in some wildlife species, monitoring contaminants in the Arctic has received international support (*7*).

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This paper reports work conducted by the recently initiated multi-agency Seabird Tissue Archival and Monitoring Project (STAMP). STAMP was implemented in 1999 as a long-term collaborative Alaska-wide effort by the U.S. Fish and Wildlife Service's Alaska Maritime National Wildlife Refuge (USFWS/AMNWR), the U.S. Geological Survey's Biological Resources Division (USGS/BRD), and the National Institute of Standards and Technology (NIST) to monitor long-term trends in environmental quality by banking the contents of colonial seabird eggs and analyzing them for contaminants (e.g., chlorinated pesticides, PCBs, and mercury).

Common (*Uria aalge*) and thick-billed murre (*U. lomvia*) eggs were selected for the long-term STAMP program for several reasons. Murres feed at the upper trophic levels and have the potential to accumulate and store contaminants at relatively high levels, similar to many marine mammals (*8*−*11*). Also, murre eggs are harvested by residents of many rural Alaskan coastal communities and play a role in local subsistence diets (*12*).

Murres have several attributes that make them desirable species for tracking changes in POP levels in northern environments. Unlike many species of birds, murres stay at northern latitudes throughout the year. Alaskan murres winter in the Gulf of Alaska and Bering Sea (*8*, *9*, *13*) and, as a result, reflect accumulations of POPs from relatively small regions. Also, murres lay single eggs, limiting the effect of laying order on variability in contaminant loads (*14*). Murres arrive on their breeding grounds several weeks before egg laying begins (*15*−*16*). Because they are capable of laying replacement eggs about 15 days after losing eggs (*8*), there is little doubt that eggs develop after the birds arrive on their breeding grounds and are representative of these areas. Because murres are abundant and about 80% of the pairs that lose eggs early in the breeding season re-lay eggs (*17*), collecting small numbers of eggs for contaminant analyses will not detrimentally affect nesting populations. Also, POP concentrations in the eggs are representative of the adult female at the time of laying (*18*−*19*). Because of these factors, the International Arctic Monitoring and Assessment Programme chose alcid eggs as key tissues for long-term monitoring of POPs in northern environments (AMAP; *7*).

Study objectives were to (1) analyze murre eggs from several different Alaskan colonies for POPs and compare the results within and among regions, (2) determine if contaminant levels differed between common and thick-billed murres, and (3) determine if POP levels have changed since the mid-1970s.

Materials and Methods

In 1999−2000, 67 eggs were collected from five Alaskan murre colonies following STAMP protocols (*20*). USFWS personnel collected the eggs at four of the study locations and subsistence harvesters obtained them at the fifth sampling site (Little Diomede Island; see Table 1 and Figure 1). Egg contents were removed from the shells at the Alaska Science Center in Anchorage, AK and shipped frozen (−150 °C) to the NIST Laboratory in Charleston, SC. There they were broken into manageable pieces by striking them with a Teflon-wrapped mallet and then cryogenically homogenized according to the techniques described by Zeisler et al. (*21*). The individually homogenized samples (~88 g) were divided into 5-g aliquots and stored in labeled Teflon jars at −150 °C in liquid N_2 vapor freezers for later analysis. Subsamples of the egg contents are cryogenically stored by NIST at the

10.1021/es034987r Not subject to U.S. Copyright. Publ. 2004 Am. Chem. Soc.
Published on Web 01/17/2004

TABLE 1. Murre Egg Sample Information (Letters in Parentheses are the Same Abbreviations Used in the Other Figures and Tables)

colony	species	year collected	egg content mass (g)[a]	eggshell thickness (mm)[a]	*N*
Little Diomede (LD)	*Uria* spp. (SP)	1999	90.7 ± 8.7	0.27 ± 0.1	9
St. George (SG)	*U. aalge* (CO)	1999	90.2 ± 9.9	0.26 ± 0.01	11
St. George (SG)	*U. lomvia* (TB)	2000	87.6 ± 8.4	0.50 ± 0.02	7
Bogoslof (BO)	*U. aalge* (CO)	2000	84.2 ± 15	0.26 ± 0.02	9
Bogoslof (BO)	*U. lomvia* (TB)	2000	86.9 ± 8.1	0.24 ± 0.01	10
East Amatuli (EA)	*U. aalge* (CO)	1999	88.0 ± 7.4	0.26 ± 0.02	11
St. Lazaria (SL)	*U. aalge* (CO)	1999	85.8 ± 5.9	0.26 ± 0.01	10

[a] Mean ± 1 SD.

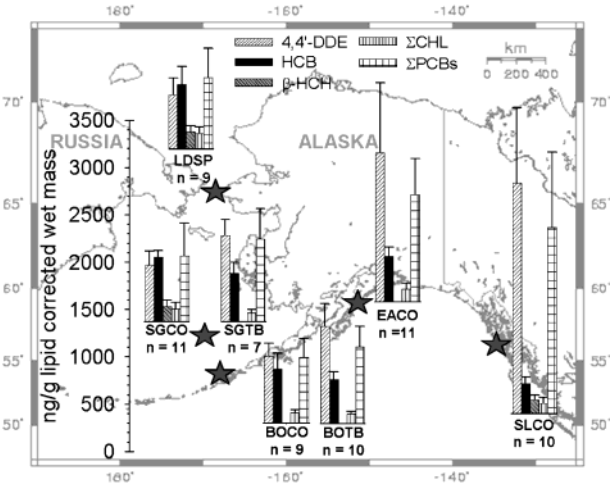

FIGURE 1. Mean values (± 1 SD error bars) of primary POPs in murre (*Uria* spp.) eggs collected by STAMP in 1999 and 2000 (BO = Bogoslof Island, EA = East Amatuli Island, LD = Little Diomede Island, SG = St. George Island, and SL = St. Lazaria Island; CO = common murres, TB = thick-billed murres, and SP = murre species).

National Biomonitoring Specimen Bank (NBSB) in Charleston, SC for retrospective analysis.

Techniques for organochlorine analyses were similar to those published by Kucklick et al. (*22*). Additional details are available in Vander Pol (*23*). Approximately 3 g of material from each sample was extracted by pressurized fluid extraction (PFE), cleaned up by using size exclusion and aminopropylsilane liquid chromatography (LC), and analyzed by gas chromatography with dual micro-electron capture detectors (GC-ECD; Hewlett-Packard 6890, Palo Alto, CA). POPs were measured after separation on a 60-m DB-5 with 0.25-mm i.d. and 0.25-μm film thickness (J&W Scientific, Folsom, CA) and a 60-m DB-XLB with 0.25-mm i.d. and 0.25-μm film thickness (J&W Scientific). Standard reference material (SRM) 1946 Lake Superior Fish Tissue, six calibration solutions, and a blank were run with each batch for quality assurance and control. Herring gull egg reference material from the Canadian Wildlife Service (CWS) was also analyzed with the last two batches. One sample from a St. George Island thick-billed murre egg was run three separate times to check homogeneity and reproducibility of the analysis. The means of these results were used in all subsequent comparisons. A mixed internal standard solution containing 4,4′-DDT-d_8, 4,4′-DDE-d_8, 4,4′-DDD-d_8, endosulfan I-d_4, PCB 103, and PCB 198 was added to the samples, calibration solutions, and blanks prior to extraction. GC/mass spectrometry (MS; Hewlett-Packard 6890/5973, Palo Alto, CA) was used to verify oxychlordane concentrations in selected samples (*23*).

POPs measurements included hexachlorobenzene (HCB), α-, β-, and γ- hexachlorocyclohexanes (HCH), chlordane-related compounds (ΣCHL; oxychlordane, *trans*-chlordane, *cis*-chlordane, *trans*-nonachlor, *cis*-nonachlor, and heptachlor epoxide), 4,4′-DDE, mirex, dieldrin, and 46 PCB congeners or congener groups identified according to the IUPAC system (8, 18, 29, 31, 28, 45, 52, 49, 44, 74, 63, 70 + 76, 95, 66, 56 + 60, 92 + 84 + 89, 101 + 90, 99, 87, 110, 82, 151, 107, 149, 118, 146, 132, 153, 105, 138, 163, 158, 187, 183, 128, 174, 201, 156 + 202 + 171, 157, 180, 193, 170, 195, 194, 206, and 209; congeners joined by a plus sign coeluted and were reported together).

Statistical analyses were conducted on lipid-corrected wet masses because there were significant differences in lipid percentages among the colonies as reported by Vander Pol (*23*). Multivariate analysis of variances (MANOVAs) followed by post-hoc analysis of variances (ANOVAs) with Tukey−Kramer honestly significant difference (HSD) tests were used to examine geographical differences. Species differences were tested with MANOVAs with post-hoc 2-factor ANOVAs, and 2-tailed *t* tests were used to examine temporal differences. Only compounds that had fewer than half of the values below the detectable limit (<0.1 ng/g) were included in tests for geographic differences. Values below the detectable limit were assigned half the detection value. Only compounds without values below the detectable limit were used to compare species because of degree-of-freedom problems caused by small sample sizes. Principal components analyses (PCAs) were conducted to help visualize geographical and species differences in three dimensions (*24*−*25*). PCAs were run on the fractions of PCBs and organochlorine pesticides relative to total POPs for each egg. Compounds with values below the detectable limit were removed from the PCAs. All statistical tests were conducted using JMP (SAS Institute, Cary, NC) software and plotted using SigmaPlot (SPSS Inc., Chicago, IL) software.

Results and Discussion

Quality Control. SRM 1946 and the CWS herring gull egg homogenate reference material values were within the limits of uncertainty of the mean reported values for most compounds. The exceptions were slightly higher values (within 10%) in SRM 1946 for PCB congeners 105, 118, and 195 and slightly lower values (within 10%) for *cis*- and *trans*-chlordane compared to the certified and reference values reported by Poster et al. (*26*). In the herring gull egg homogenate, variances for PCB congeners 44, 95, 66, 87, 149, 158, 157, and heptachlor, oxychlordane, mirex, *cis*-nonachlor, and 4,4′-DDT ranged from 6% to 69% compared to the reference values. β-HCH was not quantified in the East Amatuli Island eggs and eggs collected in 2000. Results for the three aliquots from the St. George Island thick-billed murre egg varied by less than 12% for all compounds (see *23*).

Concentrations of Persistent Organic Pollutants. Primary POPs in Alaskan murre eggs were 4,4′-DDE, ΣPCB (sum of

TABLE 2. Organochlorine Values from the 1999−2000 STAMP Murre Eggs[a]

	lipid-corrected wet mass means ± SD (ng/g)							geographic	species
compound	LDSP	SGCO	BOCO	EACO	SLCO	SGTB	BOTB	$F_{4,45}$	$F_{3,33}$
% lipid[b]	12.8 ± 2.3^{A}	12.3 ± 1.6^{A}	10.9 ± 1.5^{AB}	8.97 ± 1.4^{B}	12.3 ± 0.87^{A}	10.5 ± 1.4	11.0 ± 1.4	10.6[d]	2.73
4,4′-DDE	572 ± 180^{C}	594 ± 150^{C}	712 ± 140^{C}	1570 ± 740^{B}	2440 ± 800^{A}	914 ± 170	1030 ± 240	38.0[d]	13.1[d]
dieldrin	40.2 ± 17^{A}	32.6 ± 26^{A}	21.5 ± 6.0^{A}	21.6 ± 12^{A}	35.7 ± 31^{A}	23.3 ± 18	38.3 ± 27	21.9[c,d]	
HCB	685 ± 190^{A}	679 ± 68^{A}	576 ± 170^{AB}	478 ± 98^{B}	316 ± 72^{C}	510 ± 120	466 ± 84	20.7[d]	6.80[d]
α-HCH	10.0 ± 5.5^{B}	11.0 ± 4.5^{B}	22.3 ± 7.2^{A}	16.2 ± 7.5^{AB}	9.51 ± 4.0^{B}	17.4 ± 9.1	17.3 ± 4.0	6.71[d]	3.95[d]
β-HCH[b]	183 ± 63	161 ± 64			143 ± 50			0.885	
γ-HCH	3.74 ± 3.1^{AB}	3.10 ± 2.5^{AB}	6.27 ± 1.3^{A}	15.9 ± 2.5^{B}	3.00 ± 1.3^{B}	5.9 ± 1.7	6.0 ± 1.6	19.7[c,d]	
mirex	22.6 ± 14^{A}	14.5 ± 6.0^{A}	6.30 ± 3.4^{B}	20.6 ± 11^{A}	25.2 ± 14^{A}	6.3 ± 2.9	8.5 ± 5.1	21.6[c,d]	
ΣCHL	165 ± 67	133 ± 66	113 ± 30	132 ± 64	106 ± 65	93.7 ± 36	102 ± 28	1.97	1.56
ΣPCBs	758 ± 310^{BC}	695 ± 340^{C}	699 ± 200^{BC}	1130 ± 380^{B}	1970 ± 800^{A}	876 ± 320	811 ± 220	12.3[d]	1.26
DDE/PCB[b]	0.783 ± 0.14^{B}	0.937 ± 0.25^{B}	1.08 ± 0.34^{AB}	1.38 ± 0.42^{A}	1.33 ± 0.30^{A}	1.11 ± 0.26	1.30 ± 0.20	8.35[d]	3.77[d]
β-HCH/ΣHCH[b]	0.928 ± 0.053	0.910 ± 0.068			0.919 ± 0.049			0.743	

[a] Values are means ± 1 SD in ng/g lipid corrected wet mass, except where noted. ANOVAs with Tukey-Kramer HSD post-hoc tests were conducted to determine geographical differences. Colonies that did not share a common letter were significantly different ($P < 0.05$). Post-hoc 2-factor ANOVAs were conducted to compare species differences. Statistical tests were conducted on log + 1 transformed values to meet parametric assumptions. Abbreviations are the same as those used in Figure 1. [b] Compound not included in MANOVAs. [c] Welch ANOVA used due to unequal variances. [d] $p < 0.05$.

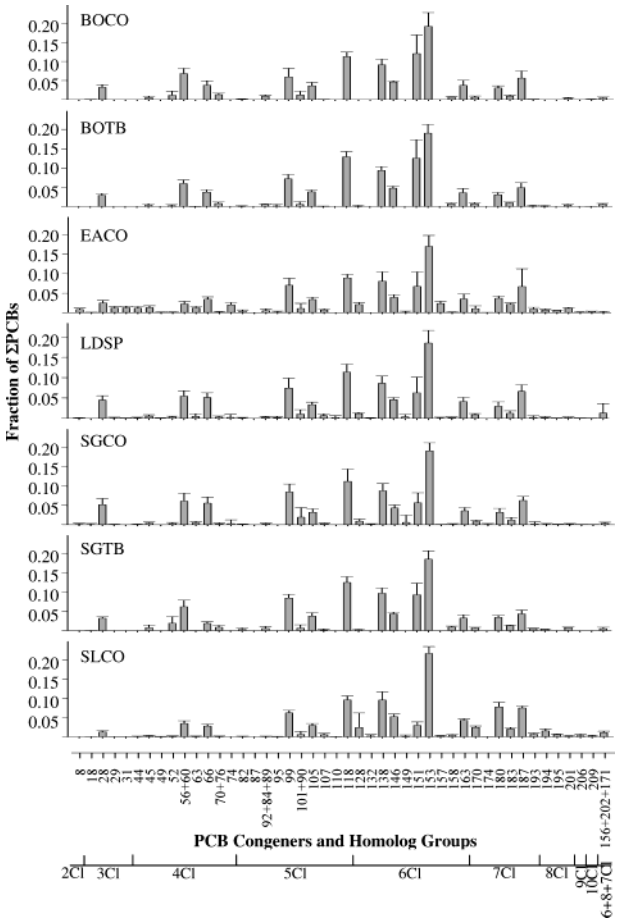

FIGURE 2. Fraction of PCB congeners to ΣPCBs separated by homologue group (congener numbers are based on the IUPAC system; abbreviations are the same as those used in Figure 1).

the 46 congeners), HCB, β-HCH, and ΣCHL (sum of oxychlordane, *trans*-chlordane, *cis*-chlordane, *trans*-nonachlor, *cis*-nonachlor, and heptachlor epoxide; Figure 1; Table 2). PCB congeners 153, 118, 138, 99, and 151 were major contributors to ΣPCBs (Figure 2). On average, oxychlordane comprised 69.6% of all chlordane compounds.

Geographic Differences. Significant differences in POP concentrations were present among the colonies (Wilks' $\lambda = 0.0157$, $F_{28,142} = 11.0$, $P < 0.0001$; Table 2). With the exceptions of HCB and β-HCH, contaminant levels tended to be significantly higher in the murre eggs collected at St. Lazaria Island in 1999 compared to those in other colonies (Figure 1, Table 2). Total mercury values in these same eggs exhibited a geographical pattern similar to the PCB, 4,4′-DDE, and ΣCHL values, with Gulf of Alaska concentrations significantly higher than Bering Sea concentrations (*27*). Also, PCAs demonstrated that the pattern of contaminants varied among colonies. The first three principal components (PCs) accounted for 70% of the total variation in geographic differences in POP patterns among common murre colonies (including Little Diomede Island, Figure 3a and b). Samples containing high concentrations of HCB, 4,4′-DDE, and dieldrin had low loadings on PCs 1−3, respectively, while high concentrations of PCB congeners 170 and 180, 99 and 188, and 105 and 118 caused high loadings on PCs 1−3, respectively (Figure 3b). PC 1 appeared to be related to vapor pressure. The PCA plot clearly showed that the Gulf of Alaska colonies (upper right group consisting of East Amatuli and St. Lazaria islands) were separated from the Bering Sea colonies (lower left group consisting Little Diomede and St. George islands), with Bogoslof Island (upright triangles) intermediate between the two areas (Figure 3a). The higher POP values in the Gulf of Alaska eggs followed a pattern similar to the one observed a quarter of a century ago (*28*).

Differences in POP levels between the Gulf of Alaska and Bering Sea eggs probably resulted from differences in summer and winter foraging areas, prey species, and concentrations of contaminants in regional food webs. Also, differences in atmospheric and oceanic transport patterns and contaminant sources probably played important roles.

Species Differences. Significant differences in POPs were found between the two closely related murre species (Wilks' $\lambda = 0.0853$, approximate $F_{12,80} = 10.2$, $P = <0.0001$; Table 2). Although these differences were difficult to see in the contaminant values (Figure 1, Table 2), a much clearer pattern emerged from the PCA: the first three PCs accounted for 71% of the total variation (Figure 3c and d). Samples containing high concentrations of HCB loaded low on PC1 and high concentrations of 4,4′-DDE had low loadings on PCs 2 and 3, while high concentrations of PCB congeners 180 and 138, 187 + 182, 170 + 190, and 66 and 28 had high loadings on PCs 1−3, respectively (Figure 3d). Although, the PCA was conducted between common and thick-billed murre eggs, the colony locations were included in the plot to help interpretation (Figure 3c). Some separation between the common and thick-billed murre eggs was evident when the colony and species data were combined. However, the separation between the species became more noticeable

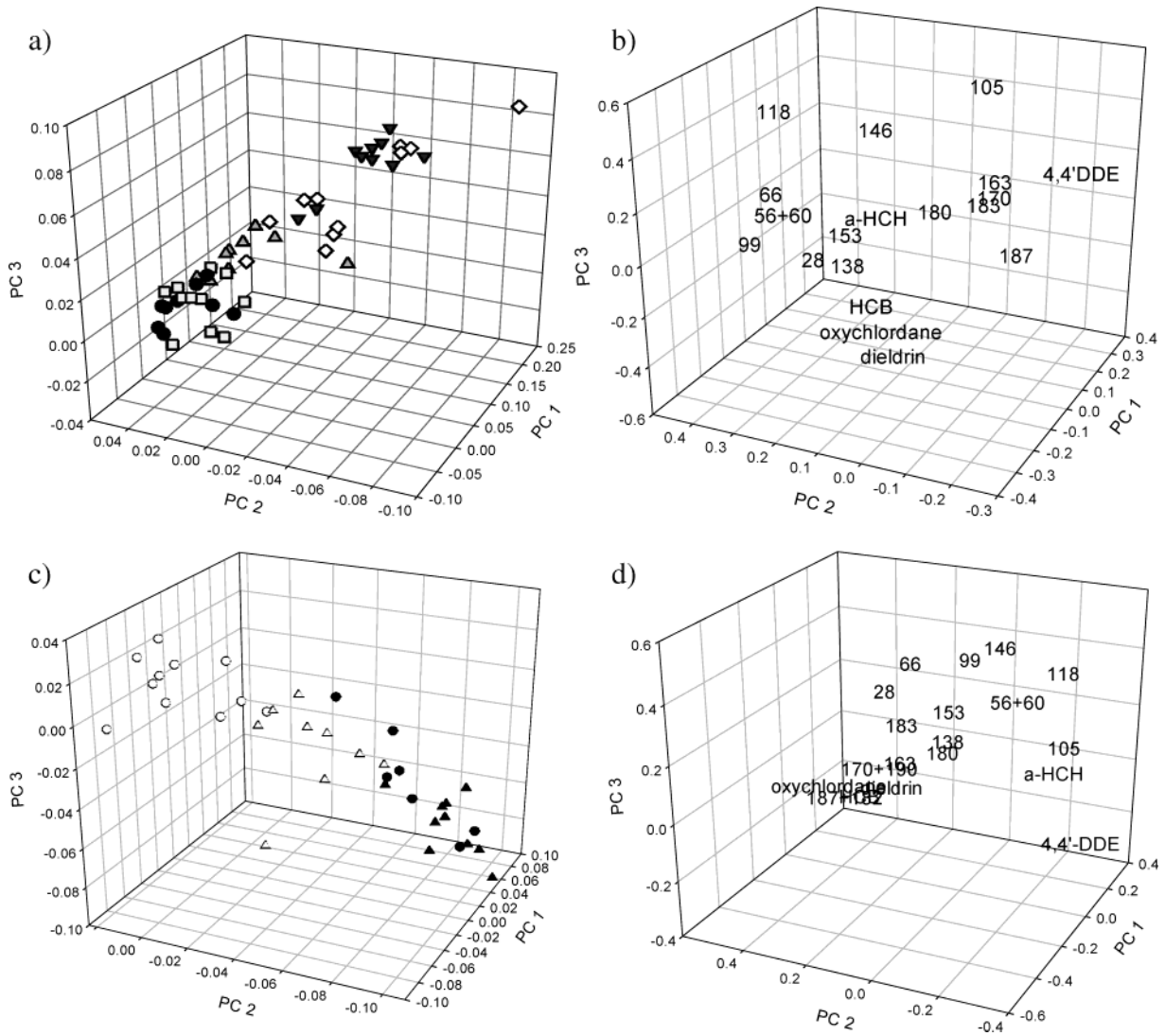

FIGURE 3. (a) Principle components analysis (PCA) showing geographical differences in contaminants in Alaskan common murre (*Uria aalge*) eggs (circles = Little Diomede Island [*U.* spp.], squares = St. George Island, triangles = Bogoslof Island, diamonds = East Amatuli Island, and upside-down triangles = St. Lazaria Island). (b) Geographical component loadings where numbers are PCB congeners based on the IUPAC system. (c) PCA showing differences in contaminants between common (*U. aalge*, white) and thick-billed murre (*U. lomvia*, black) eggs from Bogoslof (triangles) and St. George (circles) islands. (d) Species component loadings where numbers are PCB congeners based on the IUPAC system.

when the Bogoslof and St. George colonies were examined separately (Figure 3c).

The differences in POP levels in the common and thick-billed murre eggs were probably related to differences in foraging depths, prey types, and summering and wintering locations. Although common and thick-billed murres are both diving piscivores, there are differences in their diets (*10*). Both common and thick-billed murres feed on Pacific sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), and cod (Gadidae). However, thick-billed murres tend to feed farther from shore at greater depths (>61 m; *8*) compared to common murres (>45 m; *8*) and often also prey on benthic species, including pricklebacks (Stichaeidae), sculpins (Cottidae), flounder (Pleuronectidae), and pandalid and crangonid shrimp, whereas common murres tend to feed on mid-water fishes (e.g., *9*−*10*, *15*, *29*−*31*). More hydrophobic compounds, such as DDT, tend to sorb to particles that sink and accumulate in sediments and benthic food webs (*32*), which may explain the higher concentrations of these POPs in the eggs from the deeper diving thick-billed murres. In general, resource partitioning probably explains most of the differences in POP levels found in the eggs of the two species.

Wintering areas may be another factor contributing to between-species differences in egg POP levels. However, contributions of POPs from wintering areas are probably relatively small, because murres move onto their breeding grounds several weeks prior to laying eggs (*15*−*16*) and yolks form within 8−12 days (*33*). As a result, egg contents are much more likely to reflect contaminant patterns in the vicinities of the nesting colonies than patterns on the wintering grounds, although females probably do offload small amounts of residual contaminants from the wintering areas in the eggs.

Temporal Differences. Common murre eggs were collected at St. George and Bogoslof islands in 1973−1976 and analyzed for contaminants (*28*). However, some compounds measured by the current study were not included in the earlier work. Also, direct comparisons cannot be made between historical and current PCB values because of the differences between modern analytical methods and the techniques used to measure PCBs during the 1970s (packed column GC, Aroclor method; see *34*−*35*). However, valid comparisons can be made for other analytes common to the data sets.

TABLE 3. Results (ng/g wet mass) from Ohlendorf et al.'s (*28*) 1970s Study Compared with Results from the Current Study[a]

	Ohlendorf et al. (1982)		this study					
	BOCO	SGCO	BOCO	SGCO	BOCO		SGCO	
collection date	1973−1976	1973−1976	2000	1999				
number of eggs	7	11	9	11				
compound	mean ± SD	mean ± SD	mean ± SD	mean ± SD	t_{14}	*P*	t_{20}	*P*
4,4′- DDE	119 ± 15	273 ± 270	77.0 ± 18	73.5 ± 22	**4.90**	**0.0002**	**2.45**	**0.0240**
HCB	66 ± 43	79 ± 32	62.2 ± 20	83.7 ± 16	0.234	0.819	0.433	0.670
cis-nonachlor	8 ± 10		0.773 ± 0.43		**2.21**	**0.0459**		
dieldrin	34 ± 49	9 ± 12	2.28 ± 0.50	4.16 ± 3.5	1.99	0.0677	1.28	0.214
heptachlor epoxide	4 ± 4.1	12 ± 5.1	1.63 ± 1.2	2.89 ± 1.3	1.67	0.124	**5.75**	**<0.001**
oxychlordane	5 ± 3.7	18 ± 10	7.74 ± 2.3	9.70 ± 2.5	1.77	0.100	1.95	0.0649

[a] Values in **boldface** were significant ($P < 0.05$). Abbreviations are the same as those used in Figure 1.

Ohlendorf et al. (*28*) analyzed common murre eggs collected at Bogoslof Island in the 1970s for 4,4′-DDE, *cis*-nonachlor, dieldrin, HCB, heptachlor epoxide, and oxychlordane. Although dieldrin levels were lower in the current study, only c*is*-nonachlor and 4,4′-DDE were significantly lower ($P < 0.05$) than the historical values (Table 3).

Ohlendorf et al. (*28*) also analyzed common murre eggs collected at St. George Island in the 1970s for the same compounds found at Bogoslof Island, with the exception of *cis*-nonachlor. Values obtained during the current study suggest that a significant decline ($P < 0.05$) has occurred in levels of 4,4′-DDE and heptachlor epoxide concentrations over the last 25−30 years (Table 3). The lower levels found in the Bogoslof and St. George island common murre eggs followed the same declining trend reported for ΣDDT in common murre eggs collected at Baltic Sea colonies (*36*) and thick-billed murre eggs collected at Prince Leopold Island in the eastern Canadian high Arctic (*19*) during the 1970s−1990s.

In contrast, HCB values in the Bogoslof and St. George common murre eggs appear to have remained relatively stable over the last quarter century (Table 3). This stability probably reflects continued HCB production as a byproduct in the manufacture of several industrial chemicals and incineration of waste products (*37*). Although production of HCB is declining, the estimated global output of HCB from developed countries was still 23 000 kg/y in the mid-1990s (*38*). Oxychlordane levels appeared to be declining at St. George Island and increasing at Bogoslof Island, but these changes were not significant (Table 3). On the basis of atmospheric and oceanic currents, potential sources of contaminants into Alaska include Russia, eastern Asia, and North America (see *7*). Although chlordane compounds were banned in Japan in 1971 and Korea in 1986, the United States, China, and Mexico still allow some very restricted usage of chlordane (*39*).

Aldrin and its breakdown product, dieldrin, were banned in Mexico in 1982, Singapore in 1984, and in Russia, but Japan allows use with governmental approval and the United States and Korea still allow restricted usage (*40*). Although dieldrin levels appeared to have declined at both St. George and Bogoslof islands, these changes were also not significant (Table 3). These compounds, along with heptachlor epoxide, the metabolite of heptachlor (which was banned in Singapore in 1984 with only restricted uses allowed in the United States, Mexico, Japan, and Korea since at least 1988 (*41*)) may be slowly degrading in the marine environment. Heptachlor epoxide also appeared to be declining at both colonies, but this change was only significant at St. George Island (Table 3). Although *cis*-nonachlor declined significantly at Bogoslof Island (Table 3), this contaminant was not reported at St. George Island in the 1970s (*28*).

Comparisons to Other Regions. Direct comparisons with literature values for some of the contaminants found in the murre eggs were difficult to make because analytical methods have varied over the years. This was particularly true for PCBs, because many of the historical values were obtained by using Aroclor standards instead of using the current method of summing PCB congener values. Turle et al. (*35*) reported that levels of Aroclor 1254/1260 (1:1) were slightly more than twice that of the sum of 41 PCB congeners in herring gull (*Larus argentatus*) eggs. Summing PCB congeners can make it difficult to conduct comparisons because different PCB congeners and different numbers of congeners may be used to obtain the sum. However, several general observations can be made for some of the contaminants by comparing the current data with literature values (Table 4; please note that some of the data presented from eastern Canada represent re-analysis of the same eggs and not independent samples collected from the same location). Levels of contaminants were generally higher in eggs from Scandinavia than eggs from eastern Canada and Alaska. For example, 4,4′-DDE wet mass means ranged from 510 to 1070 ng/g in common murre eggs collected in Norway in 1972 vs 119 to 273 ng/g in common murre eggs collected in Alaska in 1973−1976. ΣCHL concentrations in Alaskan murre eggs were generally lower than values obtained in Canada and Norway in 1992 and 1998 (Table 4). Similar results were found for ΣPCBs in polar bears and ringed seals: Alaskan levels were the lowest and Scandinavian levels were the highest (*42*). Percent lipids in murre eggs appeared to be relatively consistent among studies, averaging about 12%; however, the common murre eggs from East Amatuli Island fell below this level (Table 4). Thick-billed murre eggs from the current study contained concentrations of 4,4′-DDE and HCB that were similar to those in thick-billed murre eggs collected in northeastern Canada in 1998 (Table 4). Values for ΣHCHs in eggs from the current study where β-HCH was measurable (Little Diomede Is., St. George Is. common murres, and St. Lazaria Is.) were similar to the levels reported in Canadian murre eggs collected in 1993 and 1998 (Table 4).

Future Research. Although differences in POP patterns and levels among the Alaskan colonies and between common and thick-billed murres cannot be explained fully, they are probably related to variations in prey preferences and local and regional food webs. To develop a better understanding of the trophic level differences that probably exist between the species and among the colonies, we plan to measure stable carbon and nitrogen isotope ratios and develop fatty acid profiles for eggs and primary prey species.

Wintering locations and diets and their effect on POP levels in murre eggs are also poorly understood. Obtaining information on adult female winter diets, and tagging and tracking adult female birds to locate wintering areas is beyond

TABLE 4. Literature Values for Common (*Uria aalge*) and Thick-Billed (*U. lomvia*) Murre Eggs Compared with Values from the Current Study[a]

date collected	species	location	% lipid		4,4′-DDE		ΣPCB		PCB method[b]	HCB		ΣCHL		ΣHCH		*N*	ref
			mean	SD	mean	SD	mean	SD		mean	SD	mean	SD	mean	SD		
		Western Europe															
1969-1972	*U. aalge*	Skomer (SW Wales)			1570	170[c]	8500	1240[c]	NS							10	43
1969-1972	*U. aalge*	Scare Rocks (SW Scotland)			1710	215[c]	12520	2210[c]	NS							10	43
1969-1972	*U. aalge*	St. Kilda (NW Scotland)			600	50[c]	490	335[c]	NS							10	43
May 1972	*U. aalge*	71°05′N-Hjelmsoy, Norway	13[d]	8.5-25[e]	740	180	2010	760	NS							11	44
May 1972	*U. aalge*	70°20′N-Hornoy, Norway	13[d]	8.5-25[e]	1070	480	3230	1500	NS							10	44
May 1972	*U. aalge*	67°30′N- Rost, Norway	13[d]	8.5-25[e]	890	420	2080	1190	NS							10	44
May 1972	*U. aalge*	62°25′N-Runde, Norway	13[d]	8.5-25[e]	510	160	1450	510	NS							10	44
1974-76&79	*U. aalge*	Stora Karlso, Central Baltic	12.1	0.56	290	86	230	56	NS							20	36
1980	*U. aalge*	Skomer (SW Wales)			1010	225[c]	2350	1770[c]	NS							10	43
1980	*U. aalge*	Scare Rocks (SW Scotland)			1230	80[c]	5450	820[c]	NS							10	43
1980	*U. aalge*	St. Kilda (NW Scotland)			990	205[c]	1520	460[c]	NS							10	43
1983	*U. aalge*	E. Finnmark (Norway)	11	1	940	230	640	180	A	170	40			13[f]	2	10	18
1983	*U. aalge*	W. Finnmark (Norway)	12.2	3.6	690	240	700	290	A	130	40			7[f]	2	9	18
1983	*U. aalge*	S. Troms/N. Nordland (Norway)	10.5	1.4	490	90	360	120	A	90	10			6[f]	2	7	18
1983	*U. aalge*	Lofoten (Norway)	11.1	2.1	330	70	790	340	A	130	40			5[f]	6	8	18
1990	*U.* spp.	Bear I., Svalbard	14.30	2.69	229	54	465	210	Σ 21	83	21	23[g]	15	2	2	13	45
1992-1993	*U. aalge*	E. Finnmark (Norway)	11.77	1.28	250	30	480	60	Σ 21	90	10	40	10	2.27[f]	0.59	5	46
1992-1993	*U. lomvia*	E. Finnmark (Norway)	11.26	0.76	340	50	530	140	Σ 21	110	10	50	10	3.59[f]	1.03	5	46
1992-1993	*U. aalge*	Kola Pen. (Norway)	11.73	1.59	310	190	980	280	Σ 21	100	20	40	10	2.88[f]	1.29	5	46
1992-1993	*U. lomvia*	Kola Pen. (Norway)	11.39	1.24	290	40	920	80	Σ 21	100	10	40	0	4.11[f]	2.02	5	46
1992-1993	*U. lomvia*	Svalbard (Norway)	12.36	0.41	400	170	500	70	Σ 21	70	20	40	20	5.82[f]	2.14	5	46
		Eastern Canada															
1971	*U. aalge*	50°10′-60°N-Ile Ste-Marie, Quebec	17		2030		2210		A							4	47
1975	*U. lomvia*	Prince Leopold I.	12.6		310		720		A							12	48
1975	*U. lomvia*	Prince Leopold I.	12.6	0.65	297	152	708	267	A	97	39	18.4[g]	6.4	3.5[f]	9.7	12	49
1976	*U. lomvia*	Prince Leopold I.	12.4	1.2[c]	232[h]	28[c]	360	59[c]	Σ 67	142[i]	18[c]	36	3[c]	12	1[c]	3 pools of 3	19
1976	*U. lomvia*	Prince Leopold I.	14.3		440		1010		A							10 (pooled)	48
1976	*U. lomvia*	Prince Leopold I.	14.3		340		230		A	127		30[g]		10[f]		1	49
1977	*U. lomvia*	Prince Leopold I.	11.7	0.4[c]	232[h]	22[c]	346	45[c]	Σ 67	117[i]	21[c]	26	8[c]	11	2[c]	3 pools of 3	19
1977	*U. lomvia*	Prince Leopold I.	12.6		390		910		A							10	48
1977	*U. lomvia*	Prince Leopold I.	12.64	1.43	377	152	854	434	A	109	35	24[g]	8.1	11[f]	3.2	10	49
1987	*U. lomvia*	Prince Leopold I.	11.4	0.9[c]	156[h]	19[c]	210	25[c]	Σ 67	85[i]	10[c]	33	2[c]	19	2[c]	3 pools of 3	19
1988	*U. lomvia*	Prince Leopold I.	10.8	0.5[c]	104[h]	16[c]	167	27[c]	Σ 67	85[i]	2[c]	33	3[c]	13	1[c]	3 pools of 3	19
1993	*U. lomvia*	Prince Leopold I.	11.4	0.4[c]	139[h]	21[c]	149	20[c]	Σ 67	54[i]	6[c]	24	3[c]	20	2[c]	5 pools of 3	19
1993	*U. lomvia*	Prince Leopold I.	13.5	0.5[c]	134[h]	14[c]	155	8[c]	Σ 42	49[i]	8[c]	21	2[c]	22	2[c]	5 pools of 3	50
1993	*U. lomvia*	Coburg I.	12.2	0.2[c]	309[h]	37[c]	420	18[c]	Σ 42	78[i]	8[c]	39	1[c]	18	1[c]	5 pools of 3	50
1993	*U. lomvia*	Digges I.	12.5	0.1[c]	311[h]	29[c]	434	38[c]	Σ 42	129[i]	7[c]	63	6[c]	18	2[c]	5 pools of 3	50
1993	*U. lomvia*	Coats I.	14.5	0.3[c]	326[h]	35[c]	360	39[c]	Σ 42	124[i]	9[c]	58	4[c]	23	1[c]	5 pools of 3	50
1998	*U. lomvia*	Coats I.	12.4	0.2[c]	141[h]	8[c]	172	11[c]	Σ 42	54[i]	5[c]	24	2[c]	10	1[c]	5 pools of 3	50
1998	*U. lomvia*	Prince Leopold I.	12.9	0.4[c]	100[h]	8[c]	129	8[c]	Σ 42	53[i]	3[c]	29	4[c]	17	1[c]	5 pools of 3	50
1998	*U. lomvia*	Prince Leopold I.	12.9	0.4[c]	100[h]	7[c]	130	9[c]	Σ 67	53[i]	2[c]	30	4[c]	17	1[c]	5 pools of 3	19

date collected	species	location	% lipid		4,4′-DDE		ΣPCB		PCB method	HCB		ΣCHL		ΣHCH		N	ref
			mean	SD	mean	SD	mean	SD		mean	SD	mean	SD	mean	SD		
		Alaska															
1973	*U. aalge*	Bogoslof I. (Aleutian Islands)	9.31[d]	0.17	119	15	126	46	A	66	40	5[g]	4			7	28
1974&1976	*U. lomvia*	Ugaiushak I. (Gulf of Alaska)	9.08[d]	0.22	147	41	259	301	A			19[g]	18			6	28
1974	*U. aalge*	Ugaiushak I. (Gulf of Alaska)	9.31[d]	0.17	202	213	168	300	A	27	15	8[g]	7			7	28
1975	*U. aalge*	St. George I. (Bering Sea)	9.31[d]	0.17	273	266	270	85	A	79	32	18[g]	10			11	28
1975	*U. aalge*	St. Paul I. (Bering Sea)	9.31[d]	0.17	135	56	205	73	A	80	29	26[g]	11			10	28
1976	*U. aalge*	Middleton I. (Gulf of Alaska)	9.31[d]	0.17	649	518	1050	1371	A			42[g]	15			10	28
1976	*U. aalge*	Bluff (Seward Peninsula)	9.31[d]	0.17	141	63	182	77	A	111	49	23[g]	16			10	28
1976	*U. lomvia*	King I. (Bering Sea)	9.08[d]	0.22	166	74	307	124	A	98	54	21[g]	8			10	28
1999	*U. aalge*	St. Lazaria I. (Gulf of Alaska)	12.3	0.87	298	91	241	99	Σ 46	38.7	7.8	11.5	9.8	19.1	6.8	10	this study
1999	*U. aalge*	East Amatuli I. (Gulf of Alaska)	8.97	1.4	142	79	99.1	31	Σ 46	42.2	9.5	11.7	6.1	1.79	0.88	11	this study
1999	*U. aalge*	St. George I. (Bering Sea)	12.3	1.6	73.5	22	86.4	45	Σ 46	83.7	16	15.0	7.6	21.5	8.2	11	this study
1999	*U.* spp.	Little Diomede I. (Bering Sea)	12.8	2.3	70.3	12	92.8	25	Σ 46	85.5	19	19.6	5.6	25.0	9.3	9	this study
2000	*U. aalge*	Bogoslof I. (Aleutian Islands)	10.9	1.5	77.0	18	76.2	25	Σ 46	62.2	20	12.0	2.9	3.09	1.0	9	this study
2000	*U. lomvia*	Bogoslof I. (Aleutian Islands)	11.0	1.4	115	33	90.6	29	Σ 46	51.7	12	11.3	3.4	2.55	0.54	10	this study
2000	*U. lomvia*	St. George I. (Bering Sea)	10.5	1.4	94.6	14	88.8	22	Σ 46	52.5	10	9.55	2.5	2.31	1.1	7	this study

[a] All values are in ng/g wet mass, except where noted. [b] Methods used to analyze PCBs were either not stated (NS), based on Aroclor standards 1254 or 1:1 1254/1260 (A), or reported as the sum of PCB congeners (Σ followed by number of congeners used). [c] SE. [d] Mean for group. [e] Range. [f] β-HCH. [g] Oxychlordane. [h] ΣDDT. [i] ΣChlorobenzenes.

the scope of STAMP; however, if data on these topics become available from other researchers, they will be integrated into this study.

Some of the murre eggs that have been obtained at multispecies colonies by rural residents have not been identified to species. To overcome this potential problem and make it easier for local residents to collect eggs for the study, genetic analyses will be run on egg contents to help verify the species from which the eggs came. This will also provide useful information on the possible presence of hybrid eggs in the data set.

Murre eggs collected at additional Alaskan colonies will be banked to provide better information on geographical differences in POP levels and increase the number of samples that will be available to future researchers for tracking temporal changes in contaminants. We also intend to expand the STAMP program to include eggs from some additional seabird species (e.g., black-legged kittiwakes, *Rissa tridactyla*; glaucous gulls, *Larus hyperboreus;* glaucous-winged gulls, *L. glaucescens*; auklets, *Aethia* spp.; black guillemots, *Cepphus grylle;* and storm-petrels, *Oceanodroma* spp.). Adding several new species to the study will provide valuable additional information on POP levels in northern marine environments.

Acknowledgments

We thank the following individuals for their help in developing and supporting STAMP: Lyman Thorsteinson, Scott Hatch, and Leslie Chappel, USGS-BRD; Vernon Byrd, Tony DeGange, Art Sowls, Dave Irons, Leslie Slater, Arthur Kettle, Laura Greffenius, Alexis Paul, Susan Hatch, Laurie Ness, Nora Rojek, and Kent Sundseth, USFWS; the residents of Little Diomede Island; Earl Kingik and the Point Hope Village IRA Council; Ed Murphy, Alan Springer, Loren Buck, Kevin Winker, and Dean Kildaw, University of Alaska − Fairbanks; and Cleveland Cowles and Steve Treacy, Minerals Management Service. We also thank Bryan Wakeford, Canadian Wildlife Service, for providing the herring gull egg reference material.

Disclaimer

Certain commercial equipment or instruments are identified in this paper to adequately specify the experimental procedures. Such identification does not imply recommendations or endorsement by the National Institute of Standards and Technology nor does it imply that the equipment or instruments are the best available for the purpose.

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Received for review September 8, 2003. Revised manuscript received December 1, 2003. Accepted December 10, 2003.

ES034987R