High Levels of Contaminants in Ivory Gull *Pagophila eburnea* Eggs from the Russian and Norwegian Arctic

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We found high levels of contaminants, in particular organochlorines, in eggs of the ivory gull *Pagophila eburnea*, a high Arctic seabird species threatened by climate change and contaminants. An 80% decline in the ivory gull breeding population in the Canadian Arctic the last two decades has been documented. Because of the dependence of the ivory gull on sea ice and its high trophic position, suggested environmental threats are climate change and contaminants. The present study investigated contaminant levels (organochlorines, brominated flame retardants, perfluorinated alkyl substances, and mercury) in ivory gull eggs from four colonies in the Norwegian (Svalbard) and Russian Arctic (Franz Josef Land and Severnaya Zemlya). The contaminant levels presented here are among the highest reported in Arctic seabird species, and we identify this as an important stressor in a species already at risk due to environmental change.

Introduction

The ivory gull *Pagophila eburnea* is a high Arctic seabird species associated with sea ice throughout the year (*1*). The ivory gull has an extreme northernly distribution and is on average the northernmost breeding bird species (*2*). The breeding distribution is patchy, with scattered colonies in the Canadian Arctic, Greenland, Svalbard, and the Russian Arctic (*3*). The ivory gull is a rare species; the last population estimate suggests between 8000 and 11500 breeding pairs globally, with about 80% residing in the Russian Arctic (*4*). According to Gilchrist and Mallory (*5*), the ivory gull population in the Canadian Arctic has declined by 80% since the 1980s. The population status in Svalbard and Russia is uncertain because of a lack of historical data, yet these countries are estimated to support 80% of the global breeding population (*6*). The International Union for Conservation of Nature and Natural Resources (IUCN) has classified the ivory gull as near threatened on the IUCN Red List of threatened species, and global warming and pollution have been identified as the major threats to the species (www.iucnredlist.org).

Despite few local sources of contamination in the Arctic, organohalogens of anthropogenic origin have been found in Arctic biota for decades. Anthropogenic contaminants released in temperate regions in the northern hemisphere reach the Arctic by various routes such as atmospheric and oceanic transport (*7*). In recent years, new classes of anthropogenic chemicals such as brominated flame retardants (BFRs) and perfluorinated alkyl substances (PFASs) have become of global environmental concern in addition to the established organochlorines (OCs). Recent studies and reports have shown that both of these compound groups are also widespread in the Arctic environment (*8*−*10*).

Feeding high in the marine food chain, the ivory gull may be exposed to high levels of contaminants through biomagnification (*11*). Studies on contaminant levels in ivory gulls are scarce throughout the Arctic; however, a few studies of the ivory gull from the Canadian Arctic show high levels of organohalogen contaminants in liver and fat (*12, 13*) as well as in eggs (*14*). Additionally, some of the highest concentrations of Hg ever reported in seabird eggs from the Arctic have been found in ivory gull eggs from Canada (*15*).

Relationships between contaminants and various effects in top predators in the Arctic have been demonstrated in a range of studies (*16*). Relationships found include reduced reproductive performance, alterations of the immune system, asymmetry in wing feathers, changes in circulating thyroid hormones, and altered behavior during nesting (*16*). Exposure to high contaminant concentrations is also suggested to influence reproductive hormones and interfere with steroidogenesis in glaucous gulls from the Norwegian Arctic (*17*). Bustnes et al. (*18*) found that antiparasite treatment of glaucous gulls removed negative effects of contaminants on reproductive success; thus, environmental stressors such as parasitism may enhance the detrimental effects of contaminants.

Recent findings in the Canadian Arctic of a declining ivory gull breeding population and high levels of organohalogens and mercury in ivory gulls point toward a knowledge gap in the Norwegian (Svalbard) and Russian Arctic, which are considered the main breeding areas for the ivory gull. The aim of the present study is to examine levels of anthropogenic pollutants in ivory gulls from the northern Barents Sea and the Kara Sea. Thus, levels of mercury and a wide range of organohalogens such as OCs, BFRs, and PFASs were analyzed in ivory gull eggs from four colonies in Svalbard and the Russian Arctic to evaluate one of the potential threats to the species.

Experimental Section

Sample Collection and Preparation. Thirty-five eggs were sampled from individual ivory gull nests within four colonies in Svalbard: Svenskøya (78°47′ N, 26°36′ E, $n = 10$) in 2007, and in northwestern Russia in 2006, Nagurskoe (80°48′ N, 47°37′ E, $n = 6$), Kluyv Cape (81°39′ N, 62°11′ E, $n = 7$) in Franz Josef Land, and Domashny (79°30′ N, 91°05′ E, $n = 12$) in Severnaya Zemlya (Figure S1 of the Supporting Information). One egg was sampled from each nest, and clutch size, which ranged from 1−3 eggs with an average of 2 eggs in this species (*1*), was noted for all sampled nests. To minimize disturbance of the nesting birds, we did not determine egg laying sequence, and eggs were taken randomly from each nest. The eggs were individually wrapped in aluminum foil and stored frozen in separate plastic bags until further

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analyses. During preparation of the samples, we thoroughly removed the eggshell, and the embryo was removed from the thawed egg and weighed when visibly present ($n = 30/35$). The embryos were generally more developed in the Domashny colony (mean ± SD, 11.5 ± 7.9 g), compared to those in the Svenskøya (mean ± SD, 6.4 ± 6.8 g), Nagurskoe (mean ± SD, 4.0 ± 4.0 g), and Cape Klyuv colonies (mean ± SD, 4.2 ± 7.8 g). The range in embryo mass was, however, wide in all four colonies (range, 0−27.5 g). Subsequently, the whole egg content (including the embryo) was homogenized individually using a food blender (Melissa, Adexi group, Risskov, Denmark or Waring Commercial Laboratory Blender, Waring Laboratory, Torrington, CT). The homogenates were separated into aliquots for different analyses and stored at −20 °C until laboratory analysis.

Analyses of OCs and BFRs. The chemical analyses of OCs and BFRs were conducted at the Laboratory of Environmental Toxicology at the Norwegian School of Veterinary Science (Oslo, Norway). The laboratory is accredited for the analyses by Norwegian Accreditation (Kjeller, Norway) according to NS-EN ISO/IEC 17025, test 37, and the analytical quality of the laboratory has been approved in several international intercalibration tests.

Egg homogenate was spiked with internal standards. Lipids were extracted twice using cyclohexane and acetone, and lipid content was determined gravimetrically. The extract was treated twice with ultra clean (purity 98.8%) concentrated H_2SO_4 (Scanpure, Chemscan, Elverum, Norway) for sample clean up. An aliquot for toxaphene analyses required further separation on silica column. The extract was shaded from UV light exposure during the analytical process to prevent degradation of BFRs. All glassware was washed with cyclohexane/acetone (1:1) prior to use.

Separation and quantification of the organic compounds was performed by high-resolution gas chromatographs (GC, Agilent 6890 Series, Agilent Technologies, Santa Clara, CA) coupled to a mass spectrometer (MS, Agilent 6890 Series, Agilent Technologies) for BFRs, toxaphenes, and mono−ortho PCBs (MO-PCBs) or an electron capture detector (ECD, Agilent 5673, Agilent Technologies) for organochlorine pesticides (OCPs) and PCBs. Detection limits for individual compounds were determined as three times the baseline noise level and ranged from 0.12 to 0.68 ng/g ww for the OCPs, 0.20 to 0.44 ng/g ww for the PCBs, 0.20 to 1.00 ng/g ww for the mono−ortho PCBs (MO-PCBs), and 0.01 to 0.30 ng/g ww for the BFRs. Blank samples were below the detection limit for all reported analytes, and recovery and reference samples were deemed acceptable within two times the standard deviation (SD). More details on the extraction and cleanup method, chromatographic separation, and equipment and quality control is given in Murvoll et al. (*19*) for OCs, Andersen et al. (*20*) for toxaphenes, and in Sørmo et al. (*21*) for BFRs.

Analyses of PFASs. Analyses of PFASs were performed by the Analytical Environmental Chemistry Unit at Stockholm University (Sweden). Egg homogenate was spiked with internal standards ($^{18}O_2$-perfluorooctane sulfonate ($^{18}O_2$-PFOS) for sulfonates and $^{13}C_4$-perfluorooctanoic acid ($^{13}C_4$-PFOA) for carboxylates). Extraction was performed twice with 5 mL acetonitrile in an ultrasonic bath. After centrifugation, the supernatant extract was removed and concentrated under nitrogen. The concentrated extract went through dispersive cleanup on graphitised carbon and acetic acid. Approximately 0.2 mL of clean extract was added to 0.2 mL of aqueous ammonium acetate. Precipitation followed, and the extract was centrifuged before the supernatant was added to an autoinjector vial for analysis. Finally, the volume standard 7H-perfluoroheptanoic acid was added.

Analyses were carried out using high-performance liquid chromatography (HPLC, Acquity Ultra Performance LC, Waters, Milford, MA) coupled to high-resolution mass spectrometry (HRMS, Micromass Q-ToF Premier, Waters) for sulfonates or to tandem mass spectrometry (MS-MS, Quattro II Triple Quadropole MS, Micromass, Waters) for carboxylates. Separation was achieved on a Discovery HS C18 column (Supelco, Bellefonte, PA) with a binary gradient of buffered (2 mM ammonium acetate) methanol and water. Method detection limits were determined on the basis of five blank extraction experiments and ranged between 0.01 and 0.05 ng/g ww for the different analytes. Recovery rates of the stable isotope mass-labeled internal standards were on average 68% and 87% for $^{18}O_2$-PFOS and $^{13}C_4$-PFOA, respectively. A fish tissue sample used in an interlaboratory comparison in 2005 was analyzed three times with the samples, and the obtained mean concentrations deviated <20% from the median concentrations in the interlaboratory comparison. More details on the extraction procedure and quantification is given in Verreault et al. (*22*).

Analyses of Hg. The analyses of Hg were performed by the National Veterinary Institute (Oslo, Norway). Homogenate was decomposed with a mixture of nitric acid and hydrogen peroxide using a closed system for microwave digestion. The amount of Hg in the sample was determined using cold vapor atom absorption spectrophotometry (CVAAS, Varian SpectrAA 600, Varian, Inc., Palo Alto, CA). A more detailed description is given in the Supporting Information.

Analysis of stable isotopes. Freeze-dried homogenate samples were analyzed for stable isotope ratios ($\delta^{15}N$ and $\delta^{13}C$) at the Institute for Energy Technology (Kjeller, Norway). A description of the methods is provided in the Supporting Information.

Statistical Analyses. For calculations of mean concentrations ± standard deviation (SD), values below the respective detection limits were replaced by half the detection limit. Compounds detected in <60% of the samples analyzed were excluded from further statistical analyses. Concentrations below the detection limit for contaminants detected in more than 60% of the samples were given values of half the corresponding detection limit for statistical analyses to avoid missing values in the data set. Multivariate data analyses were performed using the multivariate program Unscrambler (version 9.2, Camo AS, Oslo, Norway). Principal component analyses (PCA) were conducted to visualize differences between colonies and to evaluate intracorrelations between contaminant concentrations. The PCA model was validated using full cross validation. Preprocessing of the data set prior to PCA analysis consisted of centering the variables and weighting with the inverse of the standard deviation (1/SD) to ensure equal variance. Univariate, nonparametric analyses were undertaken in R 2.8.1 (R Development Core Team 2008). Statistical analyses were performed with untransformed contaminant concentrations given as wet weight values.

Results and Discussion

The contaminants that were quantified in the eggs and their concentrations are listed in Tables 1 and 2. The organochlorines α- and γ-HCH, heptachlor, aldrin, and the perfluorinated compounds perfluorohexanoate (PFHxA), perfluoroheptanoate (PFHpA), and perfluorobutane sulfonate (PFBS) were below the detection limit in all samples and are therefore not reported. It should be noted that although *p,p′*-DDD, *o,p′*-DDT, *cis*-chlordane, BDE-209, PFOSA, and 6:2 FTS are included in Tables 1 and 2, these were detected and quantified in less than 60% of the samples and were thus excluded from statistical analyses.

OCs dominated the contaminant profile. PCBs and *p,p′*-DDE were present in the highest concentrations (55% and 32% of the OC contaminant load, respectively). The two chlordane compounds oxychlordane and *trans*-nonachlor

TABLE 1. Median and Ranges (min−max) for Organochlorine (ng/g lw) and Hg (μg/g ww) Concentrations Analyzed in Ivory Gull Egg Homogenate Samples from the Svenskøya Colony (Svalbard) and the Nagurskoe, Cape Klyuv, and Domashny Colonies (Russian Arctic)[a]

	Svenskøya		Nagurskoe		Cape Klyuv		Domashny	
	median	min−max	median	min−max	median	min−max	median	min−max
lipid %	9.88	8.63−12.3	10.3	9.46−12.1	9.1	8.11−10.4	9.95	6.95−11.5
δ^{13}C	−20.2	−20.8 to −19.7	−20.3	−20.4 to −19.5	−20.1	−20.6 to −19.4	−20.6	−21.3 to −19.7
δ^{15}N	15.8	15.3−16.2	15.8	15.3−17.6	16.4	15.9−17.7	16.3	14.7−17.2
p,p′-DDT	227	93.7−454	388	292− 481	398	229−693	225	186−434
p,p′-DDE	13200	8860−30500	29800	15000−38100	15300	8940−23600	11000	3380−68000
p,p′-DDD	6.9	nd−58.2	na	na	na	na	na	na
o,p′-DDT	6.87	nd−134	na	na	na	na	na	na
oxychlordane	1610	773−3000	2930	1280−3950	1630	984−2310	1150	648−2620
trans-nonachlor	666	460−1,640	1030	753−5050	1230	291−1840	359	205−561
cis-chlordane	221	93.9−499	na	na	na	na	na	na
β-HCH	107	60.0−168	152	102−293	142	88.4−314	288	210−414
mirex	302	187−510	475	278−713	349	218−430	224	125−600
dieldrin	na	na	556	470−1640	529	234−624	222	173−438
HCB	617	415−1090	931	777−1110	648	396−907	663	405−1020
CHB-26	290	152−1260	595	365−3000	466	138−864	156	84.6−240
CHB-40	72.3	45.1−114	52.7	35.3−63.7	39.5	27.7−55.1	25.3	17.6−38.6
CHB-41	29.1	16.8−73.8	54	26.2−160	50.1	22.5−91.9	18.3	13.1−35.5
CHB-44	46.3	26.0−179	74.8	48.4−423	101	24.5−140	26.5	21.2−49.7
CHB-50	631	312−2060	1390	747−3350	904	330−1240	309	136−404
CHB-62	87.4	49.8−224	228	139−377	208	86.0−284	101	40.4−163
$\sum_6$CHB[b]	1180	628−3910	2430	1390−7370	1910	629−2380	630	337−889
$\sum_{10}$MO-PCB[c]	2180	1190−3240	3490	2120−5630	2120	1350−3010	1680	695−4390
$\sum_{28}$PCB[d]	25500	13500−45000	45500	22500− 62700	28200	16500−38600	16100	7770−53300
Hg	0.14	0.08−0.24	0.23	0.08−0.24	0.2	0.16−0.48	0.11	0.06−0.30

[a] Sample size is $n = 10$, $n = 6$, $n = 7$, and $n = 12$, respectively. Dieldrin and PCB-167 were not analyzed in eggs from Svenskøya, whereas *cis*-chlordane, *p,p′*-DDD, and *o,p′*-DDT were not analysed in eggs from the three colonies in the Russian Arctic as designated by na (not analyzed). nd designates not detected in any samples. [b] Sum of the toxaphene congeners CHB-26, -40, -41, -44, -50, and -62. [c] Sum of mono−ortho PCB-28, -66, -74, -105, -114, -118, -156, -157, -167, and -189. [d] Sum PCB-28, -47, -52, -66, -74, -99, -101, -105, -114, -118, -128, -137, -138, -141, -149, -151, -153, -156, -157, -167, -170, -180, -183, -187, -189, -194, -196, and -206.

TABLE 2. Median and Ranges (min−max) for Brominated Flame Retardants (ng/g lw) and Perfluorinated Alkyl Substance (ng/g ww) Concentrations Analyzed in Ivory Gull Egg Homogenate Samples from the Svenskøya Colony (Svalbard) and the Nagurskoe, Cape Klyuv, and Domashny Colonies (Russian Arctic)[a]

	Svenskøya		Nagurskoe		Cape Klyuv		Domashny	
	median	min−max	median	min−max	median	min−max	median	min−max
BDE-28	1.15	0.55−2.08	2.23	1.65−5.35	2.57	0.62−4.60	0.5	0.23−0.97
BDE-47	85	54.0−134	188	93.0−417	208	51.8−248	25.1	12.7−44.3
BDE-99	18.3	12.2−29.6	29.8	23.4−53.1	27.5	10.1−34.8	6.16	3.26−9.40
BDE-100	11.5	6.70−16.3	16.3	10.5−33.2	15.6	3.46−23.6	2.92	1.60−4.82
BDE-153	13.5	7.90−18.9	19	11.5−27.6	14.7	6.12−21.3	3.89	1.90−11.6
BDE-154	18	11.3−28.2	34.4	21.5−56.7	29.4	8.55−34.1	4.79	2.54−9.52
BDE-209	nd	nd	0.1	nd−0.30	0.21	nd−0.92	0.1	nd−0.45
$\sum_7$BDE[b]	146	101−221	302	164−564	287	80.8−357	51.1	25.4−61.3
HBCD	81.5	42.8−124	136	70.6−272	124	48.4−157	38.1	14.0−115
PFOA	nd	nd	0.3	nd−0.40	0.23	nd−0.31	0.22	nd−0.37
PFNA	1.04	0.40−2.70	1.34	0.77−1.48	0.99	0.65−1.21	1.49	0.83−2.15
PFDcA	2.41	0.85−4.35	3.11	1.42−5.63	3.36	1.10−4.43	3.5	1.21−5.61
PFUnA	12.6	3.16−19.1	12.9	5.82−24.7	11.7	4.66−17.6	10.7	4.84−20.8
PFDoA	3.44	0.94−4.09	2.29	1.04−5.71	2.12	0.89−3.98	1.51	0.87−3.65
PFTriA	10.7	2.7−17.7	8.21	4.80−19.8	7.86	3.54−15.9	5.67	3.43−13.2
PFTeA	0.78	nd−1.37	1.07	0.80−2.46	0.97	0.31−2.61	0.77	0.43−1.72
PFPeDA	0.58	0.14−1.0	1.19	0.85−3.50	0.91	0.53−3.07	0.76	0.48−1.69
PFH*x*S	0.37	0.19−1.46	0.77	0.30−1.38	0.69	0.24−1.31	0.79	0.30−1.90
PFOS	79.2	24.2−113	59.1	25.2−89.9	66.1	20.9−97.3	57.7	17.7−117
PFDcS	0.22	nd−0.76	0.62	0.25−1.27	0.86	0.28−1.32	0.68	0.21−1.80
PFOSA	0.05	0.03−0.20	nd	nd	nd	nd	nd	nd
6:2 FTS	na	na	0.25	0.22−0.32	0.28	0.23−0.37	0.37	0.27−0.47
$\sum_{13}$PFAS[c]	116	33.0−157	91.3	42.7−156	96.9	34.8−149	86.9	30.9−164

[a] Sample size is $n = 10$, $n = 6$, $n = 7$, and $n = 12$, respectively. nd designates not detected in any samples. 6:2 FTS was not analyzed in eggs from Svenskøya as designated by na (not analysed). [b] Sum of BDE-28, -47, -99, -100, -153, -154, and -209. [c] Sum of the perfluorinated alkyl substances PFOA, PFNA, PFDcA, PFUnA, PFDoA, PFTriA, PFTeA, PFPeDA, PFH*x*S, PFOS, PFDcS, PFOSA, and 6:2 FTS.

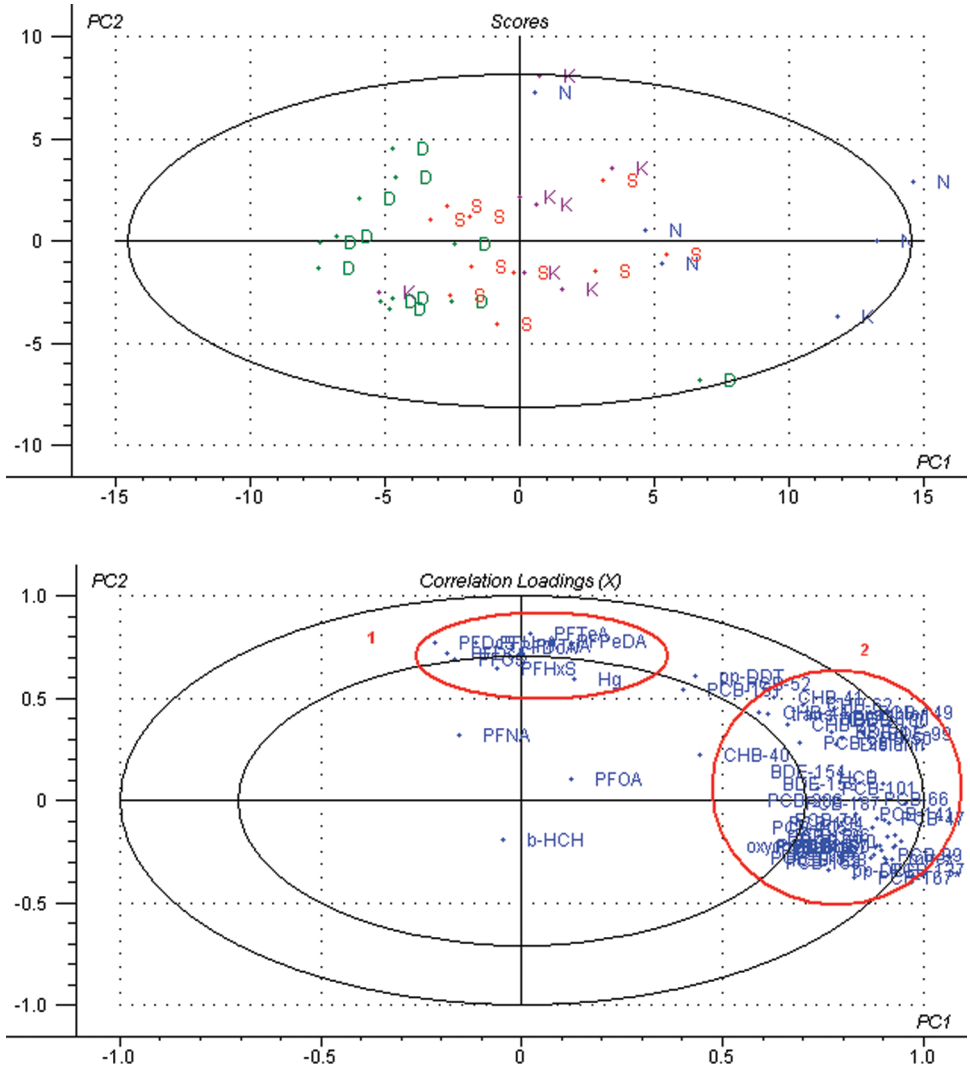

FIGURE 1. Score plot and loading plot from the principal component analysis (PCA) of contaminants measured in ivory gull *Pagophila eburnea* eggs from Svalbard (Norway) and the Russian Arctic (n = 35). PC1 explains 52% and PC2 explains 16% of the variance in the data set (validated, 58%). S, N, K, and D in the score plot designate the Svenskøya, Nagurskoe, Cape Klyuv, and Domashny colonies, respectively. Cluster 1 contains the majority of PFASs, and cluster 2 contains the majority of OCs (PCBs, toxaphenes, and other chlorinated pesticides) and BFRs. The analysis is based on wet weight values.

were also found in high concentrations (3.5% and 1.9% of the OC contaminant load, respectively) as well as the toxaphenes CHB-26 and -50. The BFRs and PFASs were present in considerably lower concentrations. A principal component analysis (PCA) (Figure 1) revealed a high degree of correlation between the majority of the OCs and BFRs as indicated by a high degree of clustering in the loading plot (Figure 1). A second cluster, containing the majority of the PFASs and Hg, was identified and showed a different distribution than the OCs and BFRs. A few compounds were separated from the main clusters such as β-HCH, which was negatively associated with the PFAS/Hg cluster, PFNA, which was negatively associated with the OC/BFR cluster, and PFOA, which was not associated with any of the other compounds analyzed.

The score plot (Figure 1) indicated regional differences in the distribution of contaminants. This was further evaluated by testing for differences between colonies for clusters 1 and 2 (Figure 1) by using one compound as an example for each cluster. Significant differences were found for PCB-153 (cluster 1, Kruskal−Wallis chi-squared = 13.82, $p < 0.003$), whereas PFOS did not differ between colonies (cluster 2, Kruskal−Wallis chi-squared = 1.78, $p < 0.6$). The highest levels of OCs and BFRs were found in the Nagurskoe colony, intermediate levels in the Svenskøya and Cape Klyuv colonies, and the lowest levels in the Domashny colony (Table 1). In contrast, the β-HCH concentrations were highest in the Domashny colony and lowest in the Svenskøya colony (Table 1). Stable nitrogen isotope ratios (δ^{15}N) did not differ between colonies (Kruskal−Wallis chi-squared = 5.86, $p < 0.1$); thus, the trophic level could not explain the differences in contaminant concentrations. Hg and most PFAS concentrations did not differ between colonies (Figure 1, Table 2). It should, however, be noted that the sample size from each of the colonies is low. The differences in contaminant concentrations between the colonies within the remote Arctic may indicate local sources of contamination. Alternatively, the differences may be due to differential routes of long-range transport of contaminants, leading to colony-specific exposure at their breeding grounds and/or in wintering areas. A recent satellite tracking study of ivory gulls breeding in Svalbard and Franz Josef Land has identified two migration routes; westward toward the east coast of Greenland, Labrador Sea, and Davis Strait and eastward throughout the Laptev and East Siberian and Chuckchi Seas toward the Bering Sea (*23*). Furthermore, the between-colony differences in OCs and BFRs may be a result of regional differences in prey preference and/or food web composition. The ivory

TABLE 3. Contaminant Concentrations Reported in Seabird Eggs in the Scientific Literature[a]

	ivory gull (*Pagophila eburnea*)					glaucous gull (*Larus hyperboreus*)		kittiwake (*Rissa tridactyla*)	herring gull (*Larus argentatus*)	kittiwake (*Rissa tridactyla*)	black guillemot (*Cepphus grylle*)	herring gull (*Larus argentatus*)	kittiwake (*Rissa tridactyla*)	Arctic tern (*Sterna paradisaea*)	common guillemot (*Uria aalge*)	
	Svenskøya (2007)	Nagurskoe (2006)	Cape Klyuv (2006)	Domashny (2006)	Canada (2004)	Bjørnøya (2002/2004)	Svalbard (1993)	Svalbard (1993)	northern Norway (2003)	northern Norway (2003)	East Greenland (2001)	Great Lakes (1971−1974)	Canada (2003)	Svalbard (2003)	Sweden (2003)	northern Norway (2003)
lipid %	9.95	10.5	9.15	9.57	10.3	9.68	8.21	9.43	10.3	9.8	11.1	7.3−8.9	9.1			
HCB	629	937	652	657	515	205	80	70	308	488	390		15.7			
β-HCH	114	174	167	298	160		8.8	3.89	14.1	17.7		45−295	6.4			
∑HCH					175	47.5			15	19.9	170	45−295	7.7			
p,p′-DDE	15200	28100	15100	14700	10624		740	240	4,044	1489		35800−90800	43.5			
∑DDT					10774	3559	890	310	4184	1562	1,310	35916−91302				
mirex	319	484	338	242	164	20.8			60.1	82.5		89−7590	2.1			
oxychlordane	1660	2760	1580	1390	1655				421	327		185−553	34.5			
trans-nonachlor	781	1600	1230	372	838				418	146		45−131	2.2			
∑CHL					3240	969	150	90	1125	605	910		45.3			
∑PCB	27200	43200	26700	19000	4877	11786	2090	1110	10669	7938	2160	96000−242000	177			
∑CHB	1410	3060	1690	621		635					1370					
∑BDE	154	312	262	47.5	44.5	549			305−1035	166−308	80			40.9		
HBCD	84.8	141	117	49.6	2.1	142			71.3−136	106−362				4.62		
PFOA	nd	0.28	0.22	0.23		<0.70									nd	nd
PFNA	1.25	1.19	0.94	1.44		<2.33									48	nd
PFDcA	2.48	3.03	2.86	3.26		2.08									nd	nd
PFUnA	12.1	12.9	10.8	12.0		21.4									82	18
PFDoA	2.99	2.50	2.08	2.00		3.35									18	2.7
PFTriA	10.7	9.61	7.89	6.98		15.1										
PFHxS	0.49	0.79	0.66	0.83		<0.27−.23										
PFOS	72.6	55.8	56.2	66.5		104									400	85
Hg	0.15	0.21	0.26	0.15	6.37			0.13	0.1	0.1						
source					*b,c*	*d,e,f*	*g*	*g*	*h,l*	*h,l*	*j*	*k*	*l*	*m*	*n*	*n*

[a] Values are ranges or mean concentrations. Organochlorines (OCs) and brominated flame retardants (BFRs) are given in ng/g lw (exceptions are data from footnotes *f*, *i*, and *k*, which are given in ng/g ww). Perfluorinated alkyl substances are given in ng/g ww. Hg concentrations are given in μg/g ww (exception is data from footnote b, which is given in μg/g dry weight). [b] Braune (*14*). [c] Braune (*15*). [d] Verreault et al. (*37*). [e] Verreault et al. (*38*). [f] Verreault et al. (*39*). [g] Barrett et al. (*40*). [h] Helgason et al. (*32*). [l] Knudsen et al. (*33*). [j] Vorkamp et al. (*41*). [k] Norstrom and Hebert (*26*). [l] Braune (*42*). [m] Jenssen et al. (*34*). [n] Löfstrand et al. (*43*).

gull is an opportunistic feeder, foraging primarily on polar cod *Boreogadus saida* and crustaceans as well as carrion of seals killed by polar bears *Ursus maritimus* and human waste (*1*). Local variation in availability of the various food items may lead to regional differences in contaminant levels as these food items contain different levels of biomagnifying contaminants. The within-colony variations (Figure 1) may be explained similarly. Both migration routes (east and west) are used by ivory gulls from the same colonies and may thus result in exposure to different contaminant compositions and concentrations during winter for ivory gulls from the same colony. In addition, because of the opportunistic feeding, variation in exposure through the diet may also occur within colonies.

A selection of organochlorine pesticides, including six toxaphene congeners, were analyzed and found in relatively high concentrations, with *p,p′*-DDE being the prevailing compound. The *p,p′*-DDE mean concentrations were higher in all four colonies than those previously reported in ivory gull eggs from the Canadian Arctic sampled in 2004 (*14*) (Table 3). Levels of chlordanes, mirex, β-HCH, and HCB were also higher than or similar to those reported in ivory gull eggs from the Canadian Arctic (*14*) (Table 3). Exceptions were the levels of chlordanes (oxychlordane and *trans*-nonachlor), which were lower in the Svenskøya and Domashny colonies compared to those in ivory gull eggs from Canada. The levels of β-HCH were lower in the Svenskøya and Cape Klyuv colonies than those in ivory gull eggs from Canada (*14*) (Table 3). Toxaphenes have not previously been quantified in ivory gull eggs. However, the concentrations of $\sum_6$CHB ranged from 0.5 to three times higher than the concentrations of $\sum_{21}$CHB reported in glaucous gull *Larus hyperboreus* eggs (Table 3). The concentrations of $\sum_{28}$PCB in all four colonies were markedly higher than those of $\sum_{85}$PCB reported in ivory gull eggs from the Canadian Arctic sampled in 1976, 1987, and 2004 (*14*) (Table 3). The concentrations in ivory gull eggs in the current study were approximately four to eight times higher than the concentrations reported in Canadian eggs from 2004 (*14*) (Table 3). The stable nitrogen isotopes ratios (δ^{15}N) in the present study were similar to those reported in ivory gull and glaucous gull eggs from the Canadian Arctic (*14, 24*). Thus, ivory gulls and glaucous gulls feed at a similar trophic level, and comparisons of contaminant concentrations are feasible.

The OC concentrations, in particular *p,p′*-DDE and $\sum_{28}$PCB, were also high in comparison with studies on contaminants in eggs from other seabird species (Table 3). The concentrations are in general among the highest reported in seabird eggs in the Arctic and markedly higher than concentrations reported in seabird eggs in recent years (*8*) (Table 3). For example, the concentrations were higher in the present study than those reported in glaucous gull eggs from Bjørnøya in 2004 (Table 3), a species that is generally known to contain among the highest contaminant concentrations in the Arctic, together with great black-backed gulls *Larus marinus* and great skuas *Stercorarius skua* (*8*). However, the *p,p′*-DDE and $\sum$PCB concentrations herein were lower than those reported in the eggs of birds of prey and gulls in the 1960s and 1970s in temperate areas (*25, 26*). It should be noted that PCBs and DDTs were not regulated in that period, and detrimental effects such as eggshell thinning were widely reported.

The concentrations of individual BDE congeners in the Svenskøya, Nagurskoe, and Cape Klyuv colonies were markedly higher than individual BDE concentrations reported in ivory gull eggs from the Canadian Arctic in 2004, whereas the Domashny colony generally displayed concentrations similar to that reported in Canadian ivory gull eggs (*14*) (Table 3). With respect to HBCD, the differences between the four different colonies studied herein were less pronounced. The levels of HBCD were, however, 20 to 70 times higher in ivory gull eggs from all four colonies studied herein compared to ivory gull eggs from Canada sampled in 2004 (*14*) (Table 3). The higher concentrations of HBCD in comparison with ivory gull eggs from Canada may reflect the more extensive use of HBCD in Europe than in North America and Asia (*27*). Compared to levels of BFRs in eggs from other seabird species, the difference between OCs and BFRs is very clear. The OC concentrations were among the highest concentrations reported in Arctic seabirds, whereas the levels of BFRs were generally lower than levels reported in top predator birds such as glaucous gulls and herring gulls *Larus argentatus* (Table 3). The levels were similar to those in black-legged kittiwakes *Rissa tridactyla* and higher than those in the Arctic tern *Sterna paradisaea* (Table 3).

The presence of perfluorinated compounds has not previously been assessed in ivory gulls. The levels were similar in eggs from all four colonies and higher than the levels of BFRs, with PFOS as the clearly dominating compound (Table 2). The levels of PFASs were similar to those reported in common guillemots *Uria aalge* from northern Norway but lower than in common guillemots from southern Sweden and in glaucous gulls from Bjørnøya (Table 3).

Hg concentrations did not differ between colonies and were roughly five to ten times lower than those reported in ivory gull eggs from the Canadian Arctic (*15*) (Table 3). The latter were among the highest concentrations ever reported for seabird eggs from the Arctic. The concentrations in the present study, however, were similar to that in glaucous gulls and black-legged kittiwakes from Svalbard and northern Norway (Table 3).

Several studies on contaminants in seabirds report on a change in contaminants of concern (*28−30*). The concentrations of the classic OCs are decreasing, whereas the concentrations of new and emerging compound classes (BFRs and PFASs) are increasing (*31−33*). The present study, however, shows that in the ivory gull in the Norwegian and Russian Arctic the OC concentrations are >100 times higher than the BFR and PFAS concentrations. The difference is also clear in comparison to other Arctic seabird species. The levels of OCs are similar to or higher than the top predator seabird species, whereas the levels of BFRs and PFASs are similar to seabird species lower in the food web such as the fish-eating black-legged kittiwakes and guillemots. This may be explained by the more northernly distribution of ivory gulls relative to other seabird species and that the concentrations of contaminants seem to decrease as a function of latitude as shown for PCBs and BFRs in seawater and biota, respectively (*34, 35*).

Although the effects of contaminants in ivory gulls are relatively unstudied, studies of another top predator seabird, the glaucous gull, have shown reproductive, behavioral, developmental, genotoxic, and immunological effects (*16*) at contaminant levels lower than those in the ivory gull. Considering that the levels of OCs in the ivory gull are higher than those in the glaucous gull, we find the contaminants may similarly affect the ivory gull. Furthermore, contaminants inflict stress on organisms, and effects of contaminants may become more severe when the organism experiences other environmental stresses such as climate change (*36*) and parasitism as seen in the glaucous gull (*18*). The future of the ivory gull is challenged by climate change causing changes in ice habitats and associated prey availability. Thus, the ivory gull could experience a combined impact from future environmental change and present high contaminant levels.

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Supporting Information Available

Method descriptions for Hg and stable isotope analyses. Figure S1 illustrates the location of the four colonies in the Norwegian and Russian Arctic. Table S1 and Table S2 provide mean, standard deviation (±SD), and ranges (min−max) for organochlorine and Hg concentrations (Table S1) and brominated flame retardants and perfluorinated alkyl substances concentrations (Table S2). This material is available free of charge via the Internet at http://pubs.acs.org.

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