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Abstract

Contaminants detected in the Arctic are generally explained by long-range transport from temperate areas. However, local sources may also be of importance. Eggs from black-legged kittiwake *Rissa tridactyla* collected in Kongsfjorden and two Russian settlements (Barentsburg and Pyramiden) were analysed in order to investigate the influence of local contamination. The eggs were analysed for a range of contaminants, including organochlorines (OCs), brominated flame retardants (BFRs), perfluorinated alkyl substances (PFASs) and a range of trace elements. Few significant differences were found between the three different locations. It is suggested that the contaminants found in breeding black-legged kittiwakes are a result of long-range transported contaminants and not local contamination.

Introduction

Contaminants detected in the remote and pristine Arctic is generally explained by long-range transport of contaminants from the more polluted temperate regions (AMAP, 2004). Identified transport pathways are by the atmosphere, ocean currents, transpolar ice drift, the large Arctic rivers and migrating biota (Oehme, 1991). However, local sources may also be of importance (Sysselmannen, 2008). Local sources in Svalbard may result from mining activities, the settlements and tourism. This includes release of heavy metals as a result of mining, use and improper disposal of PCB-containing oil, paint and other appliances, sewage from the settlements, landfills and boat traffic (Sysselmannen, 2008). In this report, "Svalbard" as a location refers mainly to Spitsbergen, except for ivory gulls samples which were taken from Kong Karls Land. Bjørnøya is referred to as a separate location (although it is part of the Svalbard archipelago).

Several studies have investigated abiotic and biotic samples in and near the settlements in Svalbard to evaluate the presence of local sources of contamination. Jartun et al. (2007) investigated PCBs in soil, paint, concrete and capacitors in Barentsburg, Pyramiden and Longyearbyen and reported on high concentrations in samples from Barentsburg and Pyramiden. E.g. the concentrations in soil in Barentsburg and Pyramiden were higher than those found in cities, such as Bergen, on mainland Norway. Cochrane et al. (2001), however, did not find elevated levels of PCBs outside the same settlements when investigating marine sediments, although some differences were seen for oil components. Hop et al. (2001) analysed macro-benthos from fjords around the settlements on Spitsbergen and found higher concentrations of PCBs and PAHs close to the settlements relative to further out in the fjords, indicating local input from the settlements. Furthermore, different PCB congener profiles were found, separating the Norwegian and Russian fjords (Hop et al., 2001). The highly contaminated surface soil in the Russian settlements Barentsburg and Pyramiden and PCBs in paint and electrical components are identified as possible sources for local input of contaminants on Spitsbergen (Jartun et al., 2007).

The black-legged kittiwake *Rissa tridactyla* is a medium-sized gull (350-500 g). It is the most numerous gull species in the world (Strøm, 2006). The kittiwake is primarily feeding on invertebrates and fish sized up to 15-20 cm, where polar cod *Boreogadus saida*, capelin *Millotus villosus*, amphipods and euphasiids are common components of the diet on Spitsbergen (Mehlum and Gabrielsen, 1993; Strøm, 2006). It is a common breeder all over Svalbard and is a colony breeder. The egg laying typically occur in the first half of June. A normal clutch consists of two eggs, although one and three eggs may occur (Strøm, 2006).

Eggs of seabirds have commonly been used for monitoring contaminant levels in the Arctic marine ecosystem for decades (e.g. Barrett et al., 1996; Braune et al., 2001; Helgason et al., 2008). Contaminants are being transferred to the egg during egg formation, thus the contaminant concentrations represent maternal levels of contamination at the time of egg-laying (Verreault et al., 2006).

The settlement in Kongsfjorden, Ny-Ålesund, started as a mining town in 1916. However, after a series of accidents with a last major accident in 1962, all mining activities were stopped in 1963 (Hisdal, 1998). Since the 1960s, Ny-Ålesund has developed into a centre for Arctic scientific research, with about 25 people based there throughout the year and a manifold increase in activity during the summer season (Sysselmannen, 2009). Barentsburg and Pyramiden are mining settlements run by the Russian mining company Trust Arktikugol. Barentsburg had a population of about 1500 inhabitants at the most, however it has decreased to about 500 inhabitants (March 2007) since the 1990s (Sysselmannen, 2009). Pyramiden was inhabited by 1000 people at the most; however the mining activities were closed down in 1998 due to difficulties with extracting the coal. The settlement in Pyramiden is now deserted (Sysselmannen, 2009).

Organochlorines comprise chlorinated organic contaminants which can be divided in two groups; pesticides and industrial chemicals. The organochlorine pesticides include DDTs, HCHs, chlordanes and mirex. Use of these pesticides is generally banned in developed countries, although some use still occurs in developing countries. Industrial chemicals include those that are or were deliberately produced or are unintentional by-products from the production of other organic compounds (AMAP, 2004). HCB is both a fungicide and a by-product in the production of chlorinated pesticides and industrial chemicals (Fiedler, 2000). For simplicity, HCB is listed with the pesticides throughout this report. PCBs have been widely used in a wide range of applications, such as in hydraulic oils, as flame retardants, as electric fluids in transformers and capacitors and in paints (Fiedler, 2000). Production and export of PCBs terminated in most countries in the 1970s and 1980s, although the products were continued to be in use in closed appliances (Fiedler, 2000). The phasing out of these appliances have been slow; the final deadline for phasing out PCB-containing capacitors in Norway was in 2008 (SFT, 2008). The phasing out is ongoing in Barentsburg (Sysselmannen, 2009).

Two groups of emerging compound classes are the brominated flame retardants (BFRs) and the perfluorinated alkyl substances (PFASs). BFRs include the BDEs and HBCD, which are used as additive flame retardants in a variety of products, such as electronic equipment, textiles and building materials (Birnbaum and Staskal, 2004). The BDEs are structurally related to the PCBs, and may thus have similar effects on the biota (de March et al., 1998). PFASs are a group of chemicals characterized by carbon chains of variable lengths where all hydrogen atoms have been replaced by fluorine, resulting in virtually indestructible compounds due to the strong carbon-fluorine bonds (AMAP, 2004). PFASs have been widespread in use since 1966 as additives in industrial and consumer products such as fire-fighting formulation, varnishes, lubricants, copier and toner and for paper, leather and textile treatments (Prevedouros et al., 2006). Perfluorooctane sulfonate (PFOS), the PFASs which has been dominating in biota (Martin et al., 2004; Houde et al., 2006), has been voluntarily phased out by the main manufacturer (AMAP, 2004).

Trace elements are naturally occurring substances, however human activities, such as mining and smelting, may increase environmental level of these elements (Walker et al., 2001). Elements are either essential elements, they are necessary for normal functioning of the organism, or non-essential, they have no known biological function (Goyer and Clarkson, 2001).

The objective of the present study was to assess the concentrations of old (organochlorines) and new (brominated flame retardants and perfluorinated alkyl substances) organic contaminants, as well as mercury and other trace elements, in black-legged kittiwake eggs from Barentsburg, Pyramiden and Kongsfjorden. The study aims to evaluate if there is influence of contaminants on biota from possible local, active sources in the Russian settlements in Svalbard.

Materials and methods

Sampling procedures

A total of 30 black-legged kittiwake eggs were sampled from Kongsfjorden, Barentsburg and Pyramiden (figure 1), with ten eggs from each locality. In Barentsburg and Pyramiden the eggs were sampled from kittiwake nests in close association with buildings (e.g. window sills; figure 2), whereas in Kongsfjorden the sampling occurred at a distance from the settlement. The sampling occurred during a short time period early in the incubation period (table 1). After sampling, the eggs were wrapped in aluminium foil and frozen the same day. The eggs were weighed, and length and width were measured with a still calliper (table 1). The eggshell was thoroughly removed and whole individual eggs were homogenised using an all-metal Hamilton Beach Drink Mixer (350 Watts; Soiltest Inc., Evanston, IL, US) and homogenate was separated into aliquots for different analyses and stored in cryo tubes at -20 °C until analysed.

Table 1 Sampling date and arithmetic mean measures with standard deviation (±SD) and ranges (min-max) for mass, width and length of black-legged kittiwake eggs sampled from Kongsfjorden, Barentsburg and Pyramiden. Sample size is n=10 for each location.

		Kongsfjorden	**Barentsburg**	**Pyramiden**
Sampling date		23.06.2008	24.06.2008	26.06.2008
Mass (g)	Mean ± SD	47.40 ± 2.58	47.00 ± 2.90	46.06 ± 3.71
	Min - Max	43.40 – 53.40	41.19 – 52.23	40.57 – 51.98
Width (mm)	Mean ± SD	411 ± 9	411 ± 11	404 ± 12
	Min - Max	397 – 429	398 – 428	379 – 418
Length (mm)	Mean ± SD	565 ± 18	557 ± 19	563 ± 30
	Min - Max	538 – 607	512 – 572	528 – 610

Figure 1 Map of Svalbard. Black-legged kittiwake eggs were sampled from Kongsfjorden, Barentsburg and Pyramiden.

Figure 2 Black-legged kittiwakes breeding in window sills in buildings in Barentsburg (left) and Pyramiden. Photo: Marzena Kaczmarska (left) and Harvey Goodwin.

Analyses

All eggs were analysed for a suite of OCs, BFRs, PFASs and trace elements. The organochlorine pesticides (OCPs) analysed and quantified were DDTs (*p,p'*-DDT, *p,p'*-DDE *p,p'*-DDD, *o,p'*-DDT, *o,p'*-DDD,), chlordanes (oxychlordane, *trans*-chlordane, *trans*-nonachlor, *cis*-nonachlor), HCHs (α-, β- and γ-), mirex, HCB and toxaphenes (CHB-26, -40, -41, -44, -50 and -62). Other OCs analysed were PCBs (PCB-28, -31, - 47, -52, -66, -74, -99, -101, -105, -114, -118, -128, -137, -138, -141, -151, -153, -156, -157, -167, -170, -180, -183, -187, -189, -194 and -206). The BFRs analysed and quantified were HBCD (sum of α-, β- and γ-HBCD) and BDEs (BDE-28, -47, -99, -100, -153, -154, 183, -206, -207, -208 and -209). The PCB and BDE congeners follow the numbering given in Ballschmiter and Zell (1980), later adapted by the International Union of Pure and Applied Chemistry (IUPAC). The PFASs analysed and quantified were perfluorohexanoate (PFHxA), perfluoroheptanoate (PFHpA), perfluorooctanoate (PFOA), perfluorononanoate (PFNA), perfluorodecanoate (PFDcA), perfluoroundecanoate (PFUnA), perfluorododecanoate (PFDoA), perfluorotridecanoate (PFTriA), perfluorotetradecanoate (PFTeA), perfluoropentadecanoate (PFPeDA), perfluorooctane sulfonamide (PFOSA), perfluorobutane sulfonate (PFBS), perfluorohexane sulfonate (PFHxS), perfluorooctane sulfonate (PFOS) and perfluorodecane sulfonate (PFDcS). The following metals were analysed and reported; selenium (Se), zinc (Zn), cadmium (Cd), molybdenum (Mo), tin (Sn), mercury (Hg), thallium (Tl), lead (Pb), lithium (Li), vanadium (V), chromium (Cr), manganese (Mn), cobalt (Co), nickel (Ni), copper (Cu), antimony (Sb) and arsenic (As). Furthermore, stable isotopes ratios ($\delta^{15}N$ and $\delta^{13}C$) were determined.

Analyses of OCs and BFRs

Analyses of OCs and BFRs were carried out at the Laboratory of Environmental Toxicology at the Norwegian School of Veterinary Science (Oslo, Norway). Lipids were extracted twice from egg homogenate by acetone/cyclohexane extraction. Lipid content was determined gravimetrically. Extracts were treated twice with sulphuric acid for sample clean up. An aliquot for toxaphene analyses required further separation on silica columns. Finally, contaminants were separated and quantified using high resolution gas chromatographs (GC) with mass spectrometer (MS) or electron capture detection (ECD). More details on the chromatographic separation and equipment is given in Murvoll et al. (2006) for OCs, in Andersen et al. (2006) for toxaphenes and in Sørmo et al. (2006) for BFRs.

The laboratory is accredited by Norwegian Accreditation (Kjeller, Norway) according to NS-EN ISO/IEC 17025, test 137, and the analytical quality of the laboratory has been approved in several intercalibration tests. As standard procedure, recoveries of spiked samples, blanks and reference samples were analysed in each series and acceptable results were achieved.

Analyses of PFASs

PFAS analyses were conducted by the Analytical Environmental Chemistry Unit at the Stockholm University (Sweden). Egg homogenate (1 g) was spiked with internal standards (isotope labelled PFHxA, PFOA, PFNA, PFDcA, PFUnA, PFDoA, PFHxS and PFOS) Extraction was performed with two times 5 mL acetonitrile in an ultrasonic bath. After centrifugation, the supernatant extract was removed and the combined acetonitrile phases were concentrated under nitrogen to 1 mL. The concentrated extract went through dispersive clean-up on graphitised carbon and acetic acid. Clean extract was added to aqueous ammonium acetate and precipitation followed. Clear supernatant was transferred to an autoinjector vial after centrifugation. High performance liquid chromatography coupled to high resolution mass spectrometry (HPLC-HRMS, for sulfonates) or tandem mass

spectrometry (MS-MS, for carboxylates) was applied. More details on the extraction procedure, instrumental setup and quantification is given in Verreault et al. (2007).

Method detection limits for all analytes were determined on the basis of four blank extraction experiments and ranged between 0.02 and 1.0 ng/g wet weight for the different analytes. The recoveries of the stable isotope mass-labelled internal standards were determined. Recovery rates were on an average MPFHxA 83%, MPFOA 85%, MPFNA 95%, MPFDcA 79%, MPFUnA 81%, MPFDoA 74%, MPFHxS 64% and MPFOS 82%. Two samples were analysed in duplicates on different days. Concentration differences found in the replicates were <15% for all of the paired results.

Analyses of metals

Freeze-dried homogenate samples were added 50% HNO_3, giving a final volume of 50 ml. The biological material was digested using an UltraClave (Milestone Inc., Bergamo, Italy) using a pre-set temperature profile. The metals were quantified using high resolution inductive coupled plasma mass spectrometry (HR-ICP-MS; Element 2, Thermo Electronics). The measurements were verified against certified reference material.

Analyses of stable isotopes

Freeze-dried homogenate samples were analysed for stable isotope ratios ($\delta^{15}N$ and $\delta^{13}C$) at the Institute for Energy Technology (Kjeller, Norway). Lipids were removed by Soxhlet extraction with dichlormethane added 7% methanolin. The sample was then dried at 80 °C before rinsing with 2 N HCl to remove traces of carbonates. Next, the sample was rinsed with distilled water and dried at 80 °C, before combustion with O_2 and Cr_2O_3 in a Carlo Erba NCS Elemental Analyser. Finally, the combustion products were separated on a Poraplot Q column and $\delta^{15}N$ and $\delta^{13}C$ were determined on a Micromass Optima mass spectrometer. International standards, Pee Dee Belemnite (PDB: USGS 24) for $\delta^{13}C$ and atmospheric air (IAEA-N-1 and 2) for $\delta^{15}N$, were generally run for each 10 samples. A detailed description of the method is given in Søreide et al. (2006).

Statistical analyses

For calculations of mean ± standard deviation (SD) concentrations only values above the respective detection limits were included, denoted by a lower sample size (n). Similarly, only values above the detection limit were included when calculating sums (Σ) of compound classes or congeners. Contaminants detected in less than 60% of the samples analysed 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. Statistical analyses were performed with contaminant concentrations given as wet weight values. Univariate non-parametric tests were used to evaluate contaminant differences between the three locations. A Kruskal-Wallis test with a pairwise Mann-Whitney U *post hoc* test was used to test for differences between the three groups (Dytham, 2003). Statistical significance level was set to $\alpha = 0.05$.

Results & discussion

The compounds γ-HCH, *trans*-chlordane, *o,p'*-DDD, *p,p*-DDD, *o,p*-DDT, PCB-31, PCB-151, PFHxA, PFHpA and PFBS were below the detection limit in all samples analysed and are therefore not reported. α-HCH, PCB-141, Sn and Sb were detected in less than 60% of the samples and were thus excluded from statistical analyses.

One of the samples from Barentsburg contained considerably higher concentrations of OCs and BFRs compared to the other samples from Barentsburg. The concentration was two to eight times higher than the median concentration for the OCPs, with an exception being *p,p'*-DDE which was 42 times higher than the median. Similarly, the concentration was two to 20 times higher than the median for the PCBs, with the largest differences found for PCB-128 and -187, and from similar to up to 14 times (BDE-154) higher than the median for the BFRs. The only exceptions where other samples contained higher concentrations of OCs were for CHB-26 and CHB-62. Nothing in the analytical quality control and quality assurance parameters indicate that the results are not to be trusted, thus we assume that this is an individual with considerably higher levels of contamination. Thus, for comparisons between the locations and with other studies it is recommended that the median value is used and not the mean. Explanations for these elevated levels in one individual are not known, however such large individual differences should be taken into account when determining sample size in similar studies.

Analytical quality of BDEs

The quality control and quality assurance parameters for BDE-153, -183, -206, -207, -208 and -209 were not within accepted values. Analyses of blank samples (solvent only) show a varying degree of contamination of the above-mentioned BDEs, thus no set level of contamination can be defined. A known source of BDE-contamination in laboratories is dust. Thomson et al. (2001) investigated BFRs in laboratory air after detection in blank samples, and reported that BFRs in air adsorb to glass surfaces. As a preventive measure in the present study, all glassware was rinsed before use and the samples were kept covered as much as possible during the extraction procedure. Despite unacceptable QC/QA parameters, the measured values for these BDEs are presented here (appendix A, table A1), together with blank values (appendix A, table A2). Due to the prevalence of BDE-contamination in most laboratories, there is generally a lack of knowledge on the levels of the higher brominated BDEs and in particular BDE-209. Thus, the concentrations given in table A1 should only be used with extreme caution and in light of the contamination problem and blank values (table A2). Despite the contamination problem, it can be inferred that the concentrations of higher brominated BDEs are relatively low (e.g. compared to the dominating BDE; BDE-47) and BDE-209 is probably present in higher concentrations than BDE-206, 207 and 208.

Organic contaminants

Concentrations of all quantified organic contaminants are summarised in appendix B (table B1-B3). Organochlorines were dominating the contaminant profile, with the highest concentrations of single compounds being *p,p'*-DDE, PCB-153, PCB-138 and HCB. The BDEs and PFASs were present in lower concentrations, with the dominating compounds being HBCD and BDE-47 and PFOS, respectively. There were few significant differences between the three locations in organochlorine contaminant level (appendix C). HCB (Mann-Whitney U test; U=82, p=0.015) and β-HCH (Mann-Whitney U test; U=82, p=0.015) were significantly higher in Barentsburg than in Kongsfjorden. CHB-41 (Mann-Whitney U test; U=80, p=0.023) and *p,p'*-DDT (Mann-Whitney U test; U=86, p=0.005) were significantly higher in Pyramiden compared to Kongsfjorden. No significant differences between the three locations were found for any of the BFRs. However, it should be noted that there were significant differences in stable nitrogen isotopes ratios ($\delta^{15}N$) between Kongsfjorden and Barentsburg and Pyramiden, with the black-legged kittiwakes feeding somewhat lower in the food web in Kongsfjorden. This may confound the results and the differences seen may be a result of small differences in feeding.

Several of the PFASs were significantly different in the three locations. PFNA, PFDcA, PFUnA, PFHxS, PFOS, PFDcS and ΣPFAS were significantly higher in Pyramiden than in Kongsfjorden (see appendix C for details on statistical output). PFHxS and PFDcS were also significantly higher in Barentsburg compared to Kongsfjorden (see appendix C for details on statistical output). The concentrations of HCB in the present study were roughly 0.5 times the concentrations in black-legged kittiwake eggs from Svalbard sampled in 1993 (Barrett et al., 1996), but similar to the concentrations reported in eggs from northern fulmar *Fulmarus glacialis* from the Faroe Islands, black guillemot *Cepphus grylle* from east Greenland and black-legged kittiwake and northern fulmar from northern Norway (Vorkamp et al., 2004; Fängström et al., 2005; Helgason et al., 2008). The concentrations in the present study were two to three times higher than the concentrations in black-legged kittiwakes and northern fulmars from Canada in 2003 (Braune, 2007).

The concentrations of HCHs were lower in the present study than concentrations reported in eggs from black-legged kittiwakes and northern fulmars from Canada, black guillemot from east Greenland, black-legged kittiwake from Svalbard in 1993 and glaucous gull from Bjørnøya (Vorkamp et al., 2004; Fängström et al., 2005; Verreault et al., 2005b; Braune, 2007). The concentrations herein were similar to that reported in eggs from black-legged kittiwakes in northern Norway (Helgason et al., 2008).

The chlordane concentrations in the present study were approximately 0.5 times the concentrations in black guillemot eggs from east Greenland and similar to or slightly lower than in black-legged kittiwake eggs from northern Norway (Vorkamp et al., 2004; Helgason et al., 2008). The concentrations were roughly three times higher in glaucous gull *Larus hyperboreus* eggs from Bjørnøya and two times higher in black-legged kittiwake eggs from Svalbard in 1993 than in the present study (Barrett et al., 1996; Verreault et al., 2005b). However, in comparison with a Canadian study, the concentrations of *cis*-nonachlor were roughly ten times higher in the present study than in eggs from black-legged kittiwakes and northern fulmars, whereas oxychlordane was present in markedly lower concentrations (about 20%) than in eggs from black-legged kittiwakes and northern fulmars (Braune, 2007).

The concentrations of mirex in black-legged kittiwake eggs from Svalbard were similar to concentrations reported in northern fulmar eggs from Canada and black-legged kittiwake eggs from northern Norway (Braune, 2007; Helgason et al., 2008). The concentrations were however three to four times higher than in black-legged kittiwake eggs from Canada and glaucous gull eggs from Bjørnøya (Verreault et al., 2005b; Braune, 2007).

The present study indicate that the concentrations of DDTs in black-legged kittiwake eggs have decreased since the 1990s; the concentrations of *p,p'*-DDE were five times higher in black-legged kittiwake eggs from Svalbard in 1993 than in the present study (Barrett et al., 1996, figure 3A). Furthermore, the concentrations herein were lower than in eggs from northern fulmars from Canada and Faroe Islands, black guillemot from east Greenland and glaucous gull from Bjørnøya (Vorkamp et al., 2004; Fängström et al., 2005; Verreault et al., 2005b; Braune, 2007, figure 4A). The concentrations herein were however higher than in black-legged kittiwake eggs from Canada and similar to black-legged kittiwake eggs from northern Norway (Braune, 2007; Helgason et al., 2008, figure 3A).

Toxaphenes have not been routinely analysed in seabird eggs, thus the reports on toxaphene concentrations are few. However, the toxaphene concentrations in the present study were lower than concentrations reported in eggs from black guillemots from east Greenland, glaucous gulls from Bjørnøya, ivory gulls *Pagophila eburnea* from Kong Karls Land and

Russia and black-legged kittiwakes and northern fulmars from Canada (Braune and Simon, 2004; Vorkamp et al., 2004; Verreault et al., 2005b; Miljeteig et al., 2007).

As for DDTs, the PCB concentrations have decreased since the 1990s; the PCB concentrations were two times higher in black-legged kittiwake eggs from Svalbard in 1993 than in the present study (Barrett et al., 1996, figure 3A). Furthermore, the concentrations in the present study were lower than in eggs from northern fulmar from the Faroe Islands, black-legged kittiwake from northern Norway and glaucous gull from Bjørnøya (Fängström et al., 2005; Verreault et al., 2005b; Helgason et al., 2008, figure 3A and 4A). However, the concentrations herein were two to three times higher than in eggs from black-legged kittiwakes and northern fulmars from Canada and black guillemots from east Greenland (Vorkamp et al., 2004; Braune, 2007, figure 3A and 4A).

The BDE concentrations in the present study were higher than concentrations reported in eggs from black-legged kittiwakes from Canada, northern fulmars from the Faroe Islands and Arctic terns *Sterna paradisaea* from Svalbard (Braune and Simon, 2004; Fängström et al., 2005; Karlsson et al., 2006; Jenssen et al., 2007, figure 3B and 4B). The concentrations were, however, lower than in eggs from black-legged kittiwakes and northern fulmars from northern Norway and glaucous gulls from Bjørnøya, and similar to concentrations reported in black guillemot eggs from east Greenland (Verreault et al., 2004; Vorkamp et al., 2004; Knudsen et al., 2005, figure 3B and 4B). The HBCD concentrations in the present study were markedly higher than in Arctic tern eggs from Svalbard (Jenssen et al., 2007), but lower than concentrations in eggs from black-legged kittiwakes from northern Norway, glaucous gulls from Bjørnøya and common guillemot *Uria algae* from the Baltic (Sellström et al., 2003; Verreault et al., 2004; Knudsen et al., 2005).

The concentrations of PFOS, the most prevailing PFAS, were generally lower than in eggs from common guillemots from northern Norway, glaucous gulls from Bjørnøya and ivory gulls from Kong Karls Land and Russia (Verreault et al., 2005a; Miljeteig et al., 2007; Löfstrand et al., 2008, figure 4C). The concentrations were 10% of concentrations reported in common guillemot eggs from the Baltic (Holmström et al., 2005; Löfstrand et al., 2008, figure 4C). The PFOS concentrations were however similar to concentrations reported in eggs from common guillemots in Iceland and Faroe Islands and herring gulls *Larus argentatus* from northern Norway (Verreault et al., 2007; Löfstrand et al., 2008, figure 4C). The concentrations of the other PFASs were generally similar or lower than in eggs from glaucous gulls from Bjørnøya, ivory gulls from the Russian Arctic and Kong Karls Land and common guillemots from north west Europe (Verreault et al., 2005a; Miljeteig et al., 2007; Löfstrand et al., 2008). The concentrations were however higher than in herring gull eggs from northern Norway (Verreault et al., 2007).

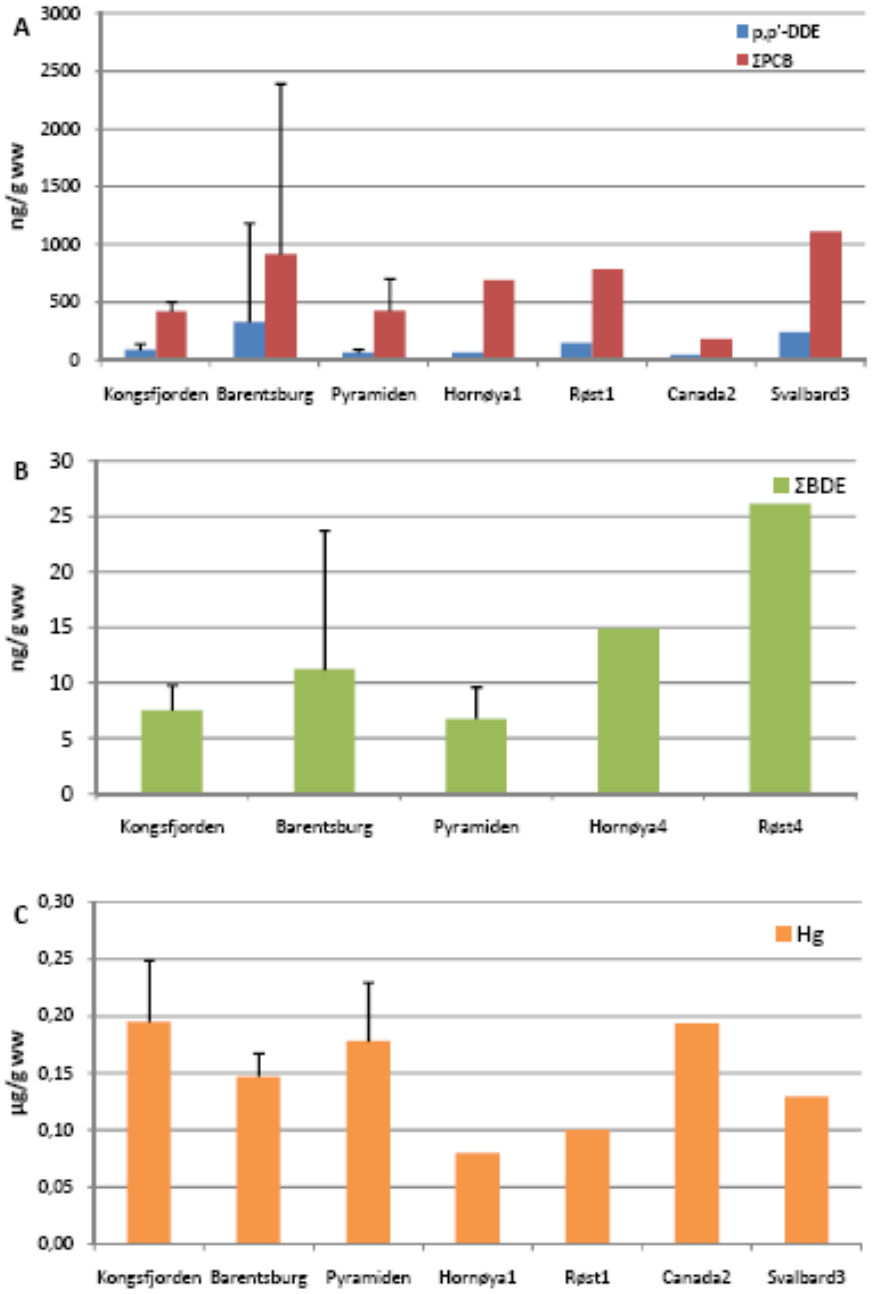

Figure 3 Mean concentrations of (A) *p,p*'-DDE, ΣPCB, (B) ΣBDE and (C) Hg in black-legged kittiwake eggs from Svalbard, northern Norway and Canada. Mean values from the present study are presented with standard deviation (SD), the large SD in Barentsburg is explained by one individual egg with very high contaminant concentrations. 1 Helgason et al. (ww-values were estimated from lipid %), 2 Braune (2007) (ww-values for Hg were estimated from moisture %), 3 Barrett et al. (1996), 4 Knudsen et al. (2005). Hg ww-values from the present study were calculated from dw based on % dry mass, to facilitate comparison with other studies.

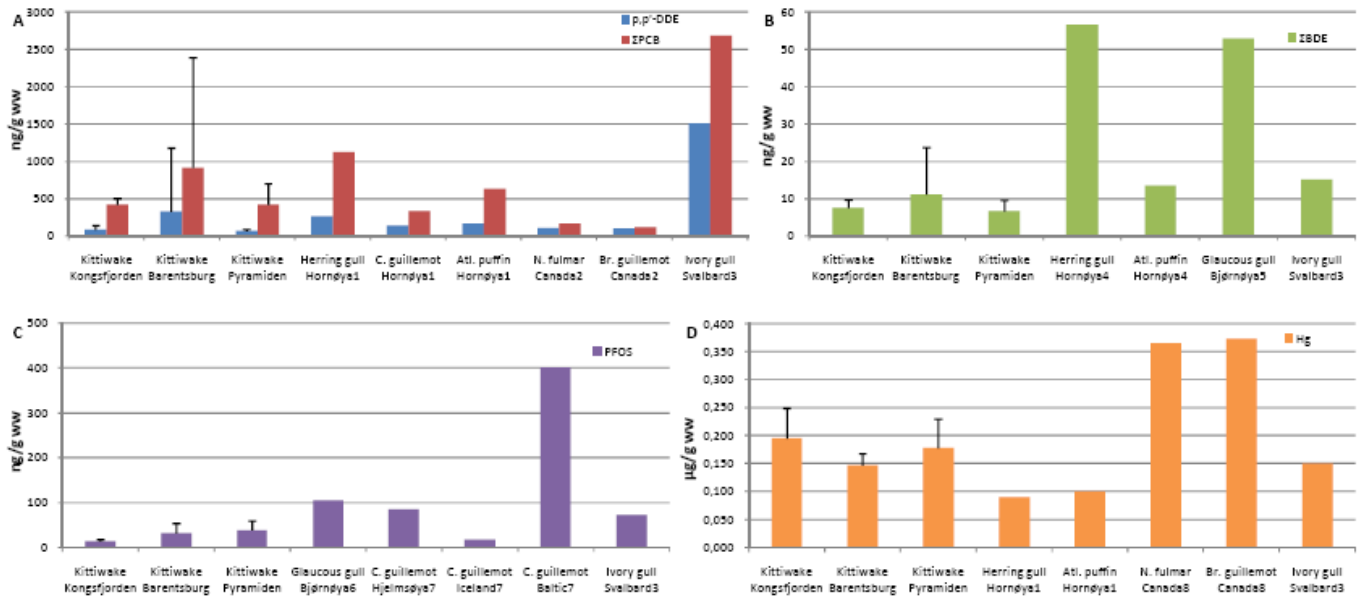

Figure 4 Mean concentrations of (A) *p,p*'-DDE, ΣPCB, (B) ΣBDE, (C) PFOS and (D) Hg in seabird eggs from Svalbard, north-western Europe and Canada. Mean values from the present study are presented with standard deviation (SD), the large SD in Barentsburg is explained by one individual egg with very high contaminant concentrations. 1 Helgason et al. (2008) (ww-values were estimated from lipid %), 2 Braune (2007) (ww-values for Hg were estimated from moisture%), 3 Miljeteig et al. (2007), 4 Knudsen et al. (2005), 5 Verreault et al. (2004), 6 Verreault et al. (2005a), 7 Löfstrand et al. (2008), 8 Braune and Simon (2004). Hg ww-values from the present study were calculated from dw based on % dry mass, to facilitate comparison with other studies.

Trace elements

A selection of elements were analysed and is summarized in appendix B (table B4). However, only a few were significantly different between the locations (see appendix C). V was significantly higher in Barentsburg than in Kongsfjorden and Pyramiden. As was significantly higher in Pyramiden than in Kongsfjorden and Barentsburg. It is also noteworthy that Sn was detected in more samples (9/10) in Kongsfjorden than in Barentsburg (0/10) and Pyramiden (4/10). Thus, in contrast to for organic contaminants, some of the elements were found in higher concentrations in Kongsfjorden than in the two other locations.

The Hg concentrations were lower than in eggs from northern fulmars and Brünnich's guillemots *Uria lomvia* from Canada, and similar to concentrations in black-legged kittiwake eggs from Canada and Svalbard (Barrett et al., 1996; Braune et al., 2001; Braune and Simon, 2004, figure 3C and 4D). The Hg concentrations were however higher than in eggs from herring gull, black-legged kittiwake and atlantic puffin *Fratercula arctica* from northern Norway and common eider *Somateria mollissima* from Alaska (Burger et al., 2008; Helgason et al., 2008, figure 3C and 4D).

Concentrations of other metals/elements are not routinely analysed in seabird eggs. The concentrations of Se were similar to or slightly higher than in eggs from black-legged kittiwakes, northern fulmars and Brünnich's guillemots from Canada and higher than in common eider eggs from Alaska (Braune et al., 2001; Braune and Simon, 2004; Burger et al., 2008). The concentrations of Cu were similar in black-legged kittiwake eggs from Canada and lower than in eggs from northern fulmar and Brünnich's guillemot from Canada (Braune and Simon, 2004). The concentrations of Zn were similar to the concentrations reported in eggs from black-legged kittiwakes, northern fulmars and Brünnich's guillemots from Canada (Braune and Simon, 2004). The concentrations of Mn and Cd were similar to concentrations

reported in common eider eggs from Alaska, whereas concentrations of As, Cr and Pb were lower than in common eider eggs from Alaska (Burger et al., 2008).

PCB profile

None of the concentrations of any of the analysed PCB-congeners were significantly different between black-legged kittiwake eggs from the three locations on Spitsbergen. Hop et al. (2001) compared the PCB profiles found in their study with known profiles of technical PCBs, and found differences in PCB congener distribution between fjords on Spitsbergen, indicating local pollution. The difference was particularly clear for PCB-118, which was proportionally higher in Billefjorden and Grønfjorden, the fjords outside the Pyramiden and Barentsburg, than in Kongsfjorden, Adventfjorden and Isfjorden (Hop et al., 2001). Thus, the differences could arise from use of different technical PCB mixtures in the Russian versus Norwegian settlements (Hop et al., 2001). In the present study, however, no differences between the three locations were found in the PCB congener profiles (figure 5). Thus, differences in PCB concentrations and pattern between the different fjords on Spitsbergen are not present in black-legged kittiwakes breeding in the region.

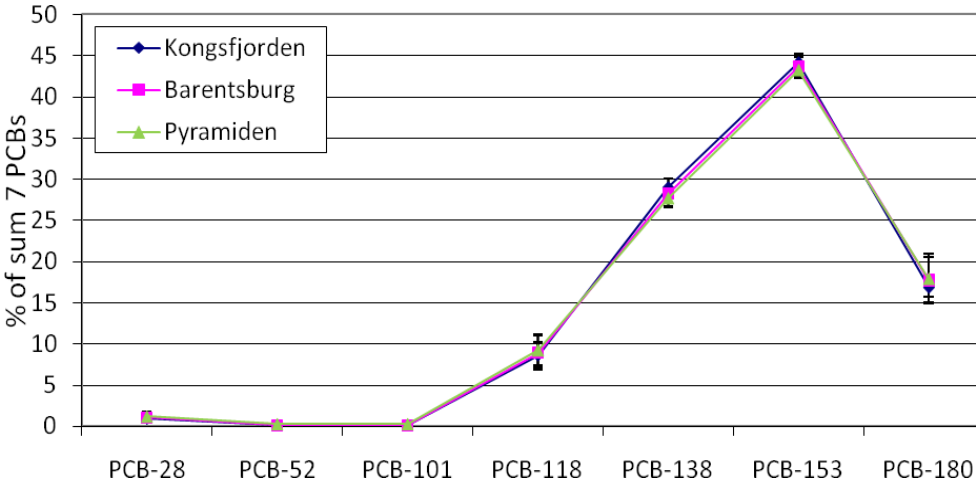

Figure 5 Mean distribution of 7 PCB congeners in black-legged kittiwake eggs from Kongsfjorden, Barentsburg and Pyramiden.

Toxicological evaluation

In order to evaluate possible effects on the current levels of contaminants in black-legged kittiwake egg, the levels were compared to threshold levels for biological effects. However, it should be noted that threshold data have limitations and extrapolating across species should be done with care. The PCB concentrations in black-legged kittiwake eggs from Svalbard were lower than the lowest observed effect levels (LOEL; 3500-22000 ΣPCB ng/g ww) for various endpoints of reproductive success (hatching success, egg mortality, deformities and parental attentiveness) in eggs. An exception is one egg from Barentsburg with considerably higher concentrations than the remaining eggs in the present study, which had concentrations (5081 ng/g ΣPCB) in the lower range of the LOEL. The concentrations in black-legged kittiwake eggs were considerably lower than the DDE concentrations (15000-20000 ng/g ww) resulting in eggshell thinning in peregrine falcon eggs.

Conclusions

The contaminant concentrations did generally not differ between locations in eggs from black-legged kittiwakes breeding in Kongsfjorden, Barentsburg and Pyramiden. Hop et al. (2001) reported on differences in contaminant levels in macro-benthos in fjords near the settlements in Svalbard. These differences were however not evident at a higher trophic level, i.e. in black-legged kittiwakes breeding in the region. The black-legged kittiwake spends only a part of the year in the breeding area, and in the other parts of the year it may be exposed to different contaminant levels and composition. Furthermore, black-legged kittiwakes collect their food so far out in the fjord or sea that they are unaffected by contamination at the breeding site. This may at least in part explain the lack of differences in contaminants with on Spitsbergen in black-legged kittiwake eggs. Thus, we conclude that local sources of pollution do not affect black-legged kittiwakes breeding in the area.

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Appendix

Appendix A – Higher brominated BDEs and blank values

Table A1 Arithmetic mean concentrations (ng/g ww) with standard deviation (±SD), median and ranges (min-max) for brominated flame retardants with not acceptable quality assurance and quality control parameters (see table 3 for blank values) in black-legged kittiwake homogenate samples from Kongsfjorden, Barentsburg and Pyramiden. Sample size is n=10 for each location, and number of samples above the respective detection limit is given for each compound. nd denotes not above the detection limit.

	Kongsfjorden				Barentsburg				Pyramiden			
	N	**Mean ± SD**	**Median**	**Min - Max**	**N**	**Mean ± SD**	**Median**	**Min – Max**	**N**	**Mean ± SD**	**Median**	**Min – Max**
BDE-153	10/10	0.99 ± 1.04	0.61	0.34 – 3.71	10/10	0.90 ± 0.94	0.58	0.31 – 3.54	10/10	0.69 ± 0.51	0.49	0.21 – 1.53
BDE-183	10/10	1.07 ± 2.59	0.15	0.06 – 8.41	10/10	0.12 ± 0.04	0.11	0.07 – 0.18	10/10	2.11 ± 4.56	0.13	0.07 – 14.02
BDE-206	2/10	1.12 ± 1.19	0.63	0.25 – 2.48	3/10	nd	nd	nd	0/10	0.27 ± 0.02	0.27	0.26 – 0.29
BDE-207	5/10	0.24 ± 0.30	0.1	0.05 – 0.78	5/10	0.04 ± 0.004	0.04	0.03 – 0.04	3/10	0.69 ± 1.05	0.11	0.05 – 2.51
BDE-208	2/10	0.10 ± 0.11	0.06	0.02 – 0.22	3/10	nd	nd	nd	0/10	0.04 ± 0.01	0.04	0.03 – 0.04
BDE-209	10/10	24.5 ± 53.0	1.8	0.13 – 170	10/10	0.29 ± 0.48	0.11	0.05 – 1.62	10/10	2.37 ± 6.47	0.34	0.14 – 20.8
ΣBDE2	10/10	38.2 ± 52.6	12.9	7.51 – 178	10/10	7.84 ± 2.93	7.55	4.47 – 12.6	10/10	13.4 ± 9.6	8.66	0.94 – 29.5

Table A2 Concentrations (ng/g ww) of higher brominated BDEs measured in blank samples (solvent only) analysed with black-legged kittiwake eggs from Kongsfjorden, Barentsburg and Pyramiden.

	Blank 1	**Blank 2**	**Blank 3**	**Blank 4**	**Blank 5**
BDE-153	n.d.	n.d.	n.d.	n.d.	n.d.
BDE-183	0.45	0.49	0.71	0.16	0.07
BDE-206	0.72	n.d.	n.d.	n.d.	n.d.
BDE-207	0.18	n.d.	n.d.	n.d.	n.d.
BDE-208	0.18	n.d.	n.d.	n.d.	n.d.
BDE-209	23.10	1.24	0.43	0.47	0.50

Appendix B – Contaminant concentrations

Table B1 Arithmetic mean concentrations (ng/g ww) with standard deviation (±SD), median and ranges (min-max) for organochlorines (OCs) analysed in black-legged kittiwake egg homogenate samples from Kongsfjorden, Barentsburg and Pyramiden. Sample size is n=10 for each location, and number of samples above the respective detection limit is given for each compound. nd denotes not above the detection limit.

	Kongsfjorden				Barentsburg				Pyramiden			
	N	**Mean ± SD**	**Median**	**Min - Max**	**N**	**Mean ± SD**	**Median**	**Min – Max**	**N**	**Mean ± SD**	**Median**	**Min - Max**
Lipid%	10/10	9.94 ± 0.96	9.65	8.94 – 11.71	10/10	9.92 ± 0.70	9.96	8.80 – 10.85	10/10	9.45 ± 0.58	9.48	8.71 – 10.52
$\delta^{13}C$	10/10	-20.0 ± 0.1	-20	-20.2 - -19.8	10/10	-19.9 ± 0.2	-19.8	-20.2 - -19.4	10/10	-20.2 ± 0.1	-20.2	-20.4 - -20.0
$\delta^{15}N$	10/10	12.1 ± 0.3	12.1	11.4 – 12.5	10/10	12.7 ± 0.6	12.7	11.9 – 14.1	10/10	13.3 ± 0.7	13.3	12.3 – 14.0
HCB	10/10	32.1 ± 5.5	31.7	25.1 – 42.7	10/10	46.6 ± 19.4	40.8	26.5 – 96.6	10/10	35.5 ± 9.9	35.2	19.8 – 53.2
α-HCH	0/10	nd	nd	nd	2/10	0.11 ± 0.08	0.11	nd– 0.17	1/10			nd – 0.11
β-HCH	10/10	2.02 ± 0.42	1.99	1.43 – 2.86	10/10	2.91 ± 1.14	2.67	1.59 – 5.86	10/10	2.07 ± 0.63	1.94	1.19 – 3.20
γ-HCH	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
Oxychlordane	10/10	21.9 ± 4.8	21.5	15.6 – 32.11	10/10	39.4 ± 50.8	25.5	14.3 – 183	10/10	18.9 ± 6.3	19	9.08 – 28.7
***trans*-Chlordane**	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
***trans*-Nonachlor**	10/10	5.17 ± 2.32	5.11	1.44 – 8.60	10/10	5.14 ± 3.9	4.76	1.37 – 15.0	10/10	6.79 ± 4.00	5.47	2.07 – 15.8
***cis*-Nonaklor**	10/10	9.41 ± 2.17	9.48	6.43 – 13.2	10/10	13.9 ± 16.0	8.93	4.73 – 58.8	10/10	9.47 ± 3.12	9.13	6.19 – 17.3
ΣChlordane	10/10	36.5 ± 8.13	35.9	26.0 – 53.5	10/10	58.4 ± 70.3	36.8	20.4 – 257	10/10	35.1 ± 9.2	35.4	23.6 – 50.1
Mirex	10/10	7.95 ± 1.60	8.22	5.47 – 10.2	10/10	13.9 ± 18.5	8.01	5.14 – 66.0	10/10	7.69 ± 4.35	6.43	3.88 – 18.5
***p,p*'-DDE**	10/10	84.5 ± 56.0	79.5	27.3 – 223	10/10	331 ± 852	64.8	20.0 – 2755	10/10	67.4 ± 23.9	63.8	32.6 – 104
***o,p*'-DDD**	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
***p,p*'-DDD**	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
***o,p*'-DDT**	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
***p,p*'-DDT**	10/10	7.06 ± 1.86	6.97	4.13 – 10.0	10/10	7.87 ± 3.79	7.49	3.07 – 15.9	10/10	10.1 ± 3.1	10.2	3.82 – 15.9
ΣDDT	10/10	91.5 ± 56.8	86.9	31.5 – 230	10/10	339 ± 855	74.8	23.0 – 2771	10/10	77.5 ± 25.2	74.5	42.7 – 119
PCB-28	10/10	2.83 ± 0.60	2.65	2.02 – 4.13	10/10	3.63 ± 1.07	3.54	2.23 – 5.20	10/10	2.91 ± 0.76	2.81	1.62 – 4.30
PCB-31	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
PCB-47	10/10	3.17 ± 0.55	3.17	2.38 – 4.24	10/10	5.57 ± 6.64	3.58	2.20 – 24.3	10/10	2.84 ± 0.72	3.02	1.82 – 3.84
PCB-52	10/10	0.47 ± 0.06	0.47	0.38 – 0.58	10/10	0.56 ± 0.20	0.5	0.39 – 1.10	10/10	0.66 ± 0.43	0.49	0.39 – 1.77
PCB-66	10/10	9.17 ± 1.03	9.54	7.03 – 10.4	10/10	11.5 ± 4.7	11.1	6.08 – 23.3	10/10	8.29 ± 2.16	8.51	4.91 – 11.7
PCB-74	10/10	5.20 ± 0.76	5.53	3.63 – 6.05	10/10	7.62 ± 5.85	6.32	3.15 – 23.8	10/10	4.73 ± 1.31	4.99	2.68 – 6.76
PCB-99	10/10	28.0 ± 5.3	29.5	19.5 – 36.6	10/10	57.3 ± 89.0	32.7	15.6 – 310	10/10	24.4 ± 8.9	25.5	12.3 – 40.6
PCB-101	9/10	0.50 ± 0.08	0.49	nd – 0.63	8/10	0.93 ± 0.98	0.59	nd – 3.34	9/10	0.78 ± 0.48	0.52	nd – 1.82
PCB-105	9/10	7.39 ± 1.33	7.56	nd – 9.04	10/10	11.2 ± 9.8	9.44	3.82 – 38.3	10/10	6.86 ± 2.09	7.12	3.55 – 9.99

PCB-114	9/10	0.67 ± 0.12	0.7	nd – 0.81	10/10	1.10 ± 1.04	0.84	0.37 – 4.00	10/10	0.61 ± 0.21	0.63	0.30- 0.98
PCB-118	10/10	25.2 ± 5.1	25.3	18.2 – 33.3	10/10	45.9 ± 53.1	33.2	13.3 – 195	10/10	24.4 ± 8.3	24.6	12.2 – 39.0
PCB-128	10/10	2.93 ± 1.01	3.07	1.42 – 4.65	10/10	8.63 ± 18.57	3.12	1.42 – 61.4	10/10	2.85 ± 1.38	2.52	1.24 – 6.01
PCB-137	10/10	4.89 ± 0.98	5.1	3.50 – 6.33	10/10	10.7 ± 18.1	5.34	2.59 – 62.1	10/10	4.50 ± 2.67	4.06	1.97 – 11.0
PCB-138	10/10	86.4 ± 19.6	89.2	59.0 – 119	10/10	194 ± 334	96.4	42.6 – 1143	10/10	81.8 ± 52.0	70.2	34.0 – 213
PCB-141	0/10	nd	nd	nd	1/10		0.49	nd – 0.49	0/10	nd	nd	nd
PCB-151	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
PCB-153	10/10	131 ± 28	137	89.1 – 172	10/10	282 ± 449	147	69.2 – 1554	10/10	130 ± 91	109	53.7 – 366
PCB-156	9/10	5.25 ± 1.02	5.39	nd – 6.62	10/10	9.47 ± 10.3	6.67	2.83 – 38.2	10/10	5.24 ± 2.72	4.6	2.28 – 11.3
PCB-157	10/10	2.44 ± 1.97	1.93	1.39 – 7.98	10/10	3.78 ± 5.15	2.25	1.01 – 18.3	10/10	1.81 ± 0.94	1.64	0.81 – 3.96
PCB-167	9/10	3.33 ± 0.64	3.36	nd – 4.14	10/10	6.02 ± 6.55	4.13	1.91 – 24.3	10/10	3.35 ± 1.89	3	1.43 – 7.92
PCB-170	10/10	16.1 ± 3.7	17.6	10.3 – 20.3	10/10	38.0 ± 63.6	16.8	8.01 – 218	10/10	18.5 ± 17.5	13.3	6.33 – 65.8
PCB-180	10/10	50.4 ± 12.4	53.3	31.8 – 65.4	10/10	127 ± 222	51.9	26.4 – 755	10/10	58.9 ± 57.2	41	20.4 – 214
PCB-183	10/10	12.9 ± 2.9	13.8	8.41 – 16.6	10/10	29.2 ± 48.4	13.7	6.44 – 166	10/10	14.0 ± 11.7	10.1	5.32 – 45.2
PCB-187	10/10	16.3 ± 3.9	16.3	10.1 – 22.6	10/10	44.3 ± 90.5	15.4	6.81 – 302	10/10	17.5 ± 14.1	12.9	6.32 – 55.1
PCB-189	9/10	0.38 ± 0.09	0.37	nd – 0.51	10/10	0.95 ± 1.54	0.45	0.22 – 5.31	10/10	0.44 ± 0.37	0.33	0.16 – 1.42
PCB-194	10/10	5.46 ± 1.30	5.72	3.53 – 7.21	10/10	14.4 ± 25.9	5.56	3.11 – 87.6	10/10	6.46 ± 5.68	4.52	2.46 – 21.7
PCB-206	10/10	1.58 ± 0.37	1.62	1.01 – 2.13	10/10	3.39 ± 5.12	1.68	0.98 – 17.9	10/10	1.81 ± 1.17	1.23	0.82 – 4.30
ΣMOPCB	10/10	43.0 ± 9.6	43.6	26.7 – 56.6	10/10	78.5 ± 87.4	56.7	23.4 – 324	10/10	42.7 ± 16.2	42.2	20.7 – 74.3
ΣPCB	10/10	421 ± 83	436	293 – 521	10/10	918 ± 1470	476	222 – 5081	10/10	424 ± 280	358	178 – 1145
CHB-26	10/10	6.36 ± 2.78	6.41	1.69 – 12.2	10/10	7.64 ± 6.34	5.6	2.21 – 24.3	10/10	7.14 ± 2.82	6.88	1.74 – 12.5
CHB-40	10/10	4.39 ± 1.54	4.28	1.48 – 7.20	10/10	5.08 ± 2.36	5.27	1.94 – 9.17	10/10	6.09 ± 1.77	6.79	2.09 – 7.77
CHB-41	10/10	0.65 ± 0.18	0.66	0.31 – 0.91	10/10	0.93 ± 0.68	0.85	0.29 – 2.68	10/10	1.09 ± 0.40	1.18	0.37 – 1.54
CHB-44	10/10	0.55 ± 0.20	0.58	0.23 – 0.95	10/10	0.64 ± 0.27	0.71	0.22 – 1.15	10/10	0.91 ± 0.46	0.82	0.35 – 1.91
CHB-50	10/10	14.2 ± 5.9	12.6	5.39 – 25.0	10/10	16.8 ± 11.5	15.5	6.44 – 46.3	10/10	15.1 ± 4.83	16.2	5.33 – 22.6
CHB-62	10/10	0.69 ± 0.36	0.63	0.32 – 1.56	10/10	0.80 ± 0.33	0.78	0.29 – 1.34	10/10	1.14 ± 0.80	0.96	0.32 – 2.48
ΣCHB	10/10	26.8 ± 10.2	25.8	9.43 – 43.9	10/10	31.9 ± 16.3	32.7	11.4 – 69.4	10/10	31.5 ± 10.1	33.4	10.2 – 46.4

Table B2 Arithmetic mean concentrations (ng/g ww) with standard deviation (±SD), median and ranges (min-max) for brominated flame retardants (BFRs) analysed in black-legged kittiwake egg homogenate samples from Kongsfjorden, Barentsburg and Pyramiden. Sample size is n=10 for each location, and number of samples above the respective detection limit is given for each compound. nd denotes not above the detection limit.

	Kongsfjorden				Barentsburg				Pyramiden			
	N	**Mean ± SD**	**Median**	**Min - Max**	**N**	**Mean ± SD**	**Median**	**Min – Max**	**N**	**Mean ± SD**	**Median**	**Min - Max**
Lipid%	10/10	9.94 ± 0.96	9.65	8.94 – 11.71	10/10	9.92 ± 0.70	9.96	8.80 – 10.85	10/10	9.45 ± 0.58	9.48	8.71 – 10.52
BDE-28	10/10	0.16 ± 0.05	0.16	0.07 – 0.25	10/10	0.18 ± 0.06	0.17	0.09 – 0.27	10/10	0.16 ± 0.05	0.15	0.09 – 0.29
BDE-47	10/10	4.33 ± 1.29	4.84	2.40 – 5.72	10/10	6.13 ± 6.24	4.34	1.92 – 23.5	10/10	3.93 ± 1.62	3.84	1.73 – 6.68
BDE-99	10/10	1.28 ± 0.37	1.38	0.77 – 1.79	10/10	1.73 ± 1.48	1.3	0.57 – 5.75	10/10	1.16 ± 0.59	0.97	0.46 – 2.06
BDE-100	10/10	0.76 ± 0.23	0.84	0.42 – 1.07	10/10	1.15 ± 1.35	0.74	0.34 – 4.94	10/10	0.68 ± 0.29	0.65	0.30 – 1.15
BDE-154	10/10	1.01 ± 0.38	0.98	0.55 – 1.71	10/10	2.02 ± 3.47	0.83	0.54 – 11.9	10/10	0.80 ± 0.37	0.67	0.37 – 1.47
ΣBDE	10/10	7.53 ± 2.24	8.26	4.27 – 10.1	10/10	11.2 ± 12.5	7.47	3.46 – 46.3	10/10	6.74 ± 2.85	6.27	2.95 – 11.6
HBCD	10/10	8.83 ± 9.68	5.2	2.79 – 34.0	10/10	7.02 ± 4.21	6.47	2.24 – 17.3	10/10	5.16 ± 2.51	4.97	2.36 – 9.70

Table B3 Arithmetic mean concentrations (ng/g ww) with standard deviation (±SD), median and ranges (min-max) for perfluorinated alkyl substances (PFASs) analysed in black-legged kittiwake egg homogenate samples from Kongsfjorden, Barentsburg and Pyramiden. Sample size is n=10 for each location, and number of samples above the respective detection limit is given for each compound. nd denotes not above the detection limit.

	Kongsfjorden				Barentsburg				Pyramiden			
	N	**Mean ± SD**	**Median**	**Min - Max**	**N**	**Mean ± SD B**	**Median**	**Min – Max**	**N**	**Mean ± SD P**	**Median**	**Min - Max**
PFHxA	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
PFHpA	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
PFOA	6/10	0.39 ± 0.11	0.36	nd – 0.55	10/10	0.48 ± 0.30	0.4	0.28 – 1.26	9/10	0.43 ± 0.13	0.38	nd – 0.65
PFNA	10/10	0.79 ± 0.17	0.76	0.57 – 1.03	10/10	1.51 ± 0.79	1.23	0.74 – 2.93	10/10	1.85 ± 0.75	1.69	0.86 – 2.96
PFDcA	10/10	1.27 ± 0.38	1.1	0.9 – 2.03	10/10	2.20 ± 1.25	1.98	0.76 – 4.56	10/10	2.96 ± 1.65	2.69	0.94 – 5.78
PFUnA	10/10	6.89 ± 2.51	5.61	4.49 – 11.4	10/10	11.2 ± 6.2	10.2	3.62 – 22.7	10/10	15.3 ± 8.37	14.7	4.93 – 27.9
PFDoA	10/10	2.21 ± 0.75	1.86	1.47 – 3.78	10/10	2.89 ± 0.98	2.82	1.53 – 4.98	10/10	3.52 ± 1.40	3.6	1.7 – 5.69
PFTriA	10/10	9.50 ± 3.97	7.89	6.06 – 17.1	10/10	10.3 ± 2.0	9.99	7.38 – 13.8	10/10	11.3 ± 3.27	11.7	6.79 – 15.8
PFTeA	10/10	1.34 ± 0.59	1.11	0.79 – 2.44	10/10	1.21 ± 0.25	1.14	0.88 – 1.51	10/10	1.29 ± 0.30	1.28	0.88 – 1.78
PFPeDA	10/10	1.78 ± 0.75	1.42	1.08 – 3.25	10/10	1.52 ± 0.32	1.46	1.06 – 1.93	10/10	1.53 ± 0.42	1.58	0.96 – 2.08
PFOSA	2/10	0.05 ± 0.01	0.05	nd – 0.05	5/10	0.05 ± 0.01	0.05	nd – 0.07	5/10	0.07 ± 0.03	0.05	nd – 0.12
PFBS	0/10	nd	nd	nd	0/10	nd	nd	nd	0/10	nd	nd	nd
PFHxS	10/10	0.18 ± 0.03	0.18	0.12 – 0.21	10/10	0.25 ± 0.10	0.22	0.16 – 0.47	10/10	0.31 ± 0.09	0.29	0.21 – 0.5
PFOS	10/10	13.4 ± 4.3	12.9	8.68 – 20.9	10/10	30.9 ± 22.9	25	9.28 – 73.6	10/10	38.7 ± 20.9	40.4	12.1 – 66.6
PFDcS	10/10	0.24 ± 0.10	0.21	0.13 – 0.43	10/10	0.41 ± 0.25	0.37	0.17 – 0.96	10/10	0.53 ± 0.30	0.56	0.16 – 0.97
ΣPFAS	10/10	37.8 ± 12.5	32.5	25.1 – 63.0	10/10	62.9 ± 33.6	56.7	29.3 – 127	10/10	77.7 ± 36.3	79.6	30.1 – 130

Table B4 Arithmetic mean concentrations (µg/g dw) with standard deviation (±SD), median and ranges (min-max) for elements analysed in black-legged kittiwake egg homogenate samples from Kongsfjorden, Barentsburg and Pyramiden. Sample size is n=10 for each location, and number of samples above the respective detection limit is given for each compound. An exception is Co from Barentsburg, where one sample was excluded due to suspected contamination of the sample. nd denotes not above the detection limit.

	Kongsfjorden				Barentsburg				Pyramiden			
	N	**Mean ± SD**	**Median**	**Min - Max**	**N**	**Mean ± SD**	**Median**	**Min - Max**	**N**	**Mean ± SD**	**Median**	**Min – Max**
dw%	10/10	24.9 ± 6.5	25	10.6 - 38.0	10/10	24.3 ± 0.8	24.3	22.7 - 25.7	10/10	24.5 ± 0.8	24.5	23.2 - 25.8
Se	10/10	3.69 ± 0.53	3.73	2.87 - 4.27	10/10	3.11 ± 0.47	3.03	2.51 - 3.86	10/10	3.16 ± 0.46	3.2	2.32 - 3.65
Zn	10/10	60.5 ± 7.8	58.7	48.6 - 73.9	10/10	63.6 ± 5.3	63.6	54.7 - 72.6	10/10	64.2 ± 10.3	60.3	48.1 - 81.8
Cd	9/10	0.0063 ± 0.0119	0.0022	0.0006 - 0.0378	9/10	0.0015 ± 0.0010	0.0014	0.0004 - 0.0038	10/10	0.0017 ± 0.0011	0.0015	0.0006 - 0.0042
Mo	10/10	0.171 ± 0.026	0.166	0.135 - 0.216	10/10	0.177 ± 0.029	0.178	0.136 - 0.242	10/10	0.159 ± 0.019	0.159	0.112 - 0.181
Sn	9/10	0.0093 ± 0.0096	0.0042	0.0022 - 0.0268	0/10	nd	nd	nd	4/10	0.0037 ± 0.0025	0.0025	0.0023 - 0.0074
Hg	10/10	0.783 ± 0.216	0.718	0.526 - 1.138	10/10	0.605 ± 0.085	0.6	0.458 - 0.705	10/10	0.727 ± 0.210	0.713	0.476 - 1.110
Tl	10/10	0.0040 ± 0.0010	0.004	0.0021 - 0.0054	10/10	0.0051 ± 0.0017	0.0055	0.0025 - 0.0070	10/10	0.0046 ± 0.0023	0.0041	0.0025 - 0.0100
Pb	10/10	0.0056 ± 0.0025	0.0047	0.0030 - 0.0098	10/10	0.0136 ± 0.0255	0.005	0.0033 - 0.0859	10/10	0.0110 ± 0.0076	0.0064	0.0045 - 0.0242
Li	10/10	0.136 ± 0.081	0.116	0.045 - 0.309	10/10	0.170 ± 0.259	0.063	0.020 - 0.852	10/10	0.217 ± 0.214	0.145	0.043 - 0.755
V	10/10	0.0130 ± 0.0034	0.0121	0.0082 – 0.0183	10/10	0.0450 ± 0.0490	0.0319	0.0144 - 0.1788	10/10	0.0146 ± 0.0123	0.0112	0.0043 - 0.0426
Cr	10/10	0.037 ± 0.026	0.025	0.011 - 0.091	10/10	0.026 ± 0.028	0.018	0.006 - 0.100	10/10	0.024 ± 0.012	0.02	0.008 - 0.045
Mn	10/10	1.91 ± 0.44	1.87	1.21 - 2.54	10/10	1.98 ± 0.63	1.77	1.04 - 3.12	10/10	2.11 ± 0.65	1.93	1.30 - 2.89
Co	10/10	0.019 ± 0.005	0.018	0.013 - 0.027	9/9	0.023 ± 0.008	0.023	0.010 - 0.034	10/10	0.018 ± 0.005	0.019	0.010 - 0.025
Ni	10/10	0.062 ± 0.071	0.031	0.011 - 0.210	10/10	0.026 ± 0.037	0.017	0.007 - 0.128	10/10	0.025 ± 0.021	0.018	0.006 - 0.069
Cu	10/10	2.57 ± 0.31	2.46	2.18 - 3.28	10/10	2.46 ± 0.30	2.38	2.14 - 3.01	10/10	2.51 ± 0.22	2.53	2.18 - 2.80
Sb	2/10	0.0006 ± 0.0000	0.0006	0.0006 - 0.0006	2/10	0.0007 ± 0.0003	0.0007	0.0005 - 0.0010	1/10	0.0005	0.0005	0.0005
As	10/10	0.381 ± 0.053	0.379	0.296 - 0.459	10/10	0.357 ± 0.107	0.329	0.253 - 0.591	10/10	0.609 ± 0.204	0.582	0.328 - 0.9730

Appendix C – Differences between locations

Table C1 U- and p-values for significant (in bold) and near significant ($p<0.08$) differences in contaminant concentrations between black-legged kittiwake eggs from Kongsfjorden, Barentsburg and Pyramiden tested pair wise with Mann-Whitney U test. All contaminant concentrations were first tested with a Kruskal-Wallis test, and only significant differences were further tested with Mann-Whitney U test to establish between which areas the differences were found.

	Kongsfjorden vs Barentsburg		**Kongsfjorden vs Pyramiden**		**Barentsburg vs Pyramiden**	
	U	p	U	p	U	p
$\delta^{13}C$	73	0.08	84	**0.0099**	93	**0.0011**
$\delta^{15}N$	82.5	**0.0151**	4	**0.0006**		
HCB	82	**0.0147**				
bHCH	82	**0.0147**			76	0.0524
ppDDT			86	**0.0052**	25	0.063
CHB-41			80	**0.0232**		
PFNA	83	0.0115	8	**0.0017**		
PFDcA	74.5	0.0695	16	**0.0089**		
PFUnA			16	**0.0089**		
PFHxS	83	**0.0134**	0.5	**0.0002**		
PFOS			14	**0.0052**		
PFDcS	77.5	**0.0411**	19.5	**0.0231**		
ΣPFAS	76	0.0524	16	**0.0089**		
V	89	**0.0021**	39	0.4359	88	**0.0029**
As			86	**0.0052**	11	**0.0021**

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