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# Persistent organic pollutant concentrations in fledglings of two arctic seabird species

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ABSTRACT

Persistent organic pollutants (POPs) and stable isotopes were measured in muscle from fledglings of two arctic seabird species, Northern fulmar (*Fulmarus glacialis)* and Black-legged kittiwakes (*Rissa tridactyla*). The purpose was to compare POP concentrations between species, in an age class that is highly vulnerable to POPs but little studied, relate to diet using stable isotopes, and quantify differences across life stages (egg to adult). Northern fulmar fledglings had significantly higher POP concentrations than kittiwake, consistent with results reported for adults of these species. Surprisingly, carbon and nitrogen stable isotopes did not differ between species, which does not match data for, or the known feeding ecology, of the adults. Fulmar/kittiwake POP concentration ratios varied across life stages indicating variable POP exposure and accumulation with age in seabirds, indicating that of the use of avian species-specific thresholds should only be done with caution in ecosystem-based POP risk management.



## 1. Introduction

Persistent organic pollutants (POPs) are anthropogenic chemicals that are ubiquitous in the environment and can pose health risks to both humans and wildlife (Letcher et al., 2010; Donaldson et al., 2010). Although not widely used in the Arctic, POPs accumulate in this vast region mainly through the process of long-range atmospheric transport and cold-condensation (MacDonald et al., 2000). With long food webs and long-lived animals that accumulate lipids for energy use in periods of low primary production, POPs are of special concern for predatory Arctic marine species because of the ability of POPs to biomagnify in food webs and accumulate in lipids (Borgå et al., 2004; Fisk et al., 2001).

Seabirds are abundant in most Arctic marine ecosystems and demonstrate a variety of feeding strategies, including top predators, and are thus commonly used as indicator species when monitoring contaminant concentrations and effects in the aquatic ecosystems (Donaldson et al., 1999; Elliott et al., 2005; Letcher et al., 2010). To date, most studies of POPs in arctic seabirds have focused on eggs or adult tissues (e.g. Hebert and Weseloh, 2006; Braune, 2007; Helgason et al., 2008; Verrault et al., 2010). However, the most vulnerable life stage to POPs has been shown to be at the chick and juvenile stages when the animal experiencing rapid growth and development (Hario et al., 2004; Jenssen et al., 2010). In light of this vulnerability, there is a need to understand how POP accumulation varies across the young of seabird species. To address this need, seabird fledglings from two common pelagic feeding arctic seabird species, Northern fulmar (*Fulmarus glacialis)* and Black-legged kittiwakes (*Rissa tridactyla*), were collected from Kongsfjorden on Svalbard and analyzed for a range of POPs. These species have different phylogeny, feeding ecology, physiology and life spans (Mehlum and Gabrielsen, 1993; Ellis and Gabrielsen., 2002; Dahl et al., 2003) providing some insights on factors that may influence POPs in young seabirds. As trophic level is the driving factor for contaminant level in adult seabirds (e.g. Fisk et al., 2001; Borgå et al., 2004), the role of diet in determining the chick's contaminant levels is important to assess.

The objectives of this study were to: 1) quantify interspecific variation in POP concentrations between fledglings of two arctic

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seabird species; 2) assess the relative importance of diet, as determined by stable isotopes of nitrogen and carbon, and lipids in POP concentrations; 3) determine if contaminant accumulation in northern fulmar relative to black-legged kittiwake differs across life stages (egg, chicks, juveniles, and adults).

## 2. Material and methods

### 2.1. Sample collection

Northern fulmar ($n = 15$, average mass 785) and kittiwake ($n = 15$, average mass 384 g) chicks were collected in Kongsfjorden (Svalbard, Norway, 78°55′N, 11°56′E) in August–September of 2006. The chicks were collected during the period when they fledge, kittiwakes were caught on the nest site prior to fledging having an approximate age of 40 days, whereas the fulmar had recently fledged with an estimated age of approximately 50 days (Hegseth et al., 2011). The chicks were sacrificed by a blow to the head following approved methods from the Norwegian Animal Care Committee, and carcasses frozen and stored (−20 °C) at the Norwegian Polar Institute in Tromsø. Muscle samples were dissected from the carcasses in September 2009 and used for all chemical and stable isotope analyses, which were performed at the Great Lakes Institute for Environmental Research in Windsor, Ontario, Canada.

### 2.2. Contaminant analysis

Individual muscle samples were analyzed to determine neutral lipid content, moisture content and POP concentrations (PCB 18/17, 31/28, 52, 74, 70, 101, 99, 110, 149, 118, 153, 138, 158, 187, 183, 177, 180, 170, 201, 194, 206, 209, HCB, α-, β- and γ-HCH, Mirex, *trans*- and *cis*-Nonachlor, oxy-, *trans*- and *cis*-Chlordane, *p,p′*-DDT and metabolites). POPs and lipid content were extracted using the micro-extraction method described in Daley et al. (2009, 2011) using PCB 30 as a recovery standard. One milliliter of the extract was removed to gravimetrically quantify the neutral lipids (Drouillard et al., 2004), and the remaining extract was concentrated to 2 mL. Sample cleanup was then performed using florisil chromatography, with first (50 mL hexane; Fisher Scientific, Fair Lawn, NJ) and second fractions (50 mL; hexane/dichloromethane 85/15 v/v; Fisher Scientific, Fair Lawn, NJ) collected. The extraction used a 0.45 μm glass fiber syringe filter in place of a 1 μm filter between extraction columns and vacuum manifold. Following florisil chromatography, samples were concentrated to a final volume of 1 mL and analyzed for POP concentrations using gas chromatography electron capture detection (GC-ECD). For each batch of six samples, a reference homogenate, method blank, external PCB standard (Quebec Ministry of Environment Congener Mix; AccuStandard, New Haven, CT, USA) external certified chlorine pesticide standard (AccuStandard, New Haven, CT, USA) were used to quantify POPs. Recovery of PCB 30 was 70 ± 2% SE across all samples, and concentrations were corrected for recovery and blank corrected. Concentrations of individual PCB congeners measured in the reference homogenate were found to be in within 2 standard deviations of the mean laboratory database value, obtained from the Great Lakes Institute for Environmental Research accredited organic analytical laboratory (Canadian Association for Environmental Analytical Laboratories Accreditation and ISO17025 certified).

### 2.3. Stable isotope analysis

Freeze-dried muscle samples were lipid extracted using 2:1 (v/v) chloroform:methanol to remove potential bias in $\delta^{13}C$ values (Post et al., 2007). Stable isotope values were obtained using a Delta V Advantage isotope ratio mass spectrometer (Thermo Electron Corporation, Bremen, Germany) and 4010 Elemental Combustion System (Costech Instruments, Valencia, CA, USA) and are conveyed in δ notation where $\delta^{13}C$ or $\delta^{15}N = [(R_{sample}/R_{standard})-1] \times 1000$, where $R$ is $^{13}C/^{12}C$ or $^{15}N/^{14}N$. The standard reference materials used were Pee Dee Belemnite carbonate for $CO_2$ and atmospheric nitrogen for $N_2$. The analytical precision, based on the standard deviation of two standards (NIST 8218 bovine liver and internal lab fish muscle (tilapia); $n = 40$ for each standard), was 0.14 and 0.19‰ for $\delta^{15}N$ and 0.05 and 0.05‰ for $\delta^{13}C$, respectively.

### 2.4. Data analysis

Differences in $\delta^{15}N$, $\delta^{13}C$, and lipid % among fledgings of our two study species were examined using two-sample *t* tests.

POPs with values below zero in more than 25% of the samples were excluded from the data set (α-, β- and γ-HCH, PCB 33, 49/44, 52, 87, 151/82, 105/132, 128, 149, 156/171, 187, 191, 169, 195/208 and 205). PCB 74 was also excluded from the data set due to detection errors. Thus, 19 POPs were included in the multivariate statistical analyses (HCB, *trans*-nonachlor, *p,p′*-DDE, Mirex, oxychlordane, PCB 70, 95, 101, 99, 110, 118, 153, 138, 158, 183, 180, 170, 194, 206).

Two principal component analyses (PCA) were performed to investigate collinearity in the: i) contaminant concentrations, and ii) contaminant pattern among the samples. In the concentration PCA, the data (ww) were log transformed and in the pattern PCA, data (ww) were standardized to reflect the relative contribution of each chemical to the total burden. Since the POPs in the present study are lipophilic, and the lipid % differed between the fulmar and kittiwake chicks, lipid % was included as covariable to remove this effect in the PCA of concentrations.

As the contaminants were highly correlated both in the concentration and the pattern PCA, the contaminant that had the highest loading onto principal component 1 (PC1) was selected as representative of the contaminant concentration variability among samples, and was subjected to univariate analysis (general linear model GLM) to investigate the relationship with species and stable isotopes, and their interaction (note, lipid % was only included as a covariate in the GLM of concentrations) with the following model:

$$\text{Contaminant(Log(ww) or pattern)} = \text{SPECIES} + \delta^{15}N + \delta^{13}C + \text{lipid\%} + \text{SPECIES}^{*}\delta^{15}N + \text{SPECIES}^{*}\delta^{13}C.$$

Backward selection on the full model for performed by eliminating the least significant parameter, until only significant explanatory variables remained.

To analyze if the contaminant accumulation during different life stages eggs, fledglings, juveniles and adults was comparable between the species, the concentration ratios between northern fulmar and black-legged kittiwake chicks (fledglings) for specific contaminants (HCB, *trans*-nonachlor, *p,p′* DDE, oxy-Chlorane, and PCB 153) were compared to the species' contaminant ratio in eggs, juvenile and adults. The egg contaminant data are from Prince Leopold Island Migratory Bird Sanctuary (74°02′N, 90°05′W) in Lancaster Sound, Nunavut, Canada (Braune, 2007), juvenile data were from northern fulmar and black-legged kittiwake from Kongsfjorden in 1997 (Borgå, unpublished), the same fjord ecosystem where the chicks were collected. The adult data are from the Northwater Polynya in northern Baffin Bay (Fisk et al., 2001). To avoid any effect of differences in matrices compared (egg, liver (juvenile, adults) and muscle (chicks)), all data were lipid normalized in the ration calculation.

Two-group *t* tests and univariate GLM were performed using the program JMP 9 (SAS Institute, Cary, NC, USA). PCA were conducted using Canoco 4.0 (Micropower, Ithaca, NY, USA). Statistical tests were considered significant at $\alpha < 0.05$.

## 3. Results

### 3.1. Interspecific differences in fledgling POP accumulation

Northern fulmar and black-legged kittiwake fledglings did not differ in $\delta^{13}C$ ($T_{13,14} = -0.02$, $P = 0.98$) or $\delta^{15}N$ ($T_{13,14} = 1.87$, $P = 0.07$), but lipid % were higher in northern fulmar than in black-legged kittiwake ($T_{13,14} = 6.43$, $P < 0.0001$).

The mean concentrations of all measured organochlorine contaminants were higher, for most more than 5 times, in northern

**Table 1**
Comparison of mean ± SD stable isotope values, lipid %, concentration (ng/g ww) of 19 contaminants measured in muscle and included in our statistical analyses of Northern fulmar and Black-legged kittiwake fledglings collected at Kongsfjorden (Svalbard, Norway, 78°55′N, 11°56′E) during August–September 2006.

| | Northern fulmar ($n = 13$) | Black-legged kittiwake ($n = 14$) |
|---|---|---|
| $\delta^{15}N$ | 12.5 ± 0.4 | 12.0 ± 0.8 |
| $\delta^{13}C$ | −22.0 ± 0.5 | −22.0 ± 0.7 |
| Lipid % | 0.7 ± 0.1 | 0.3 ± 0.2 |
| HCB | 31.5 ± 20.6 | 3.8 ± 1.4 |
| trans-Nonachlor | 12.0 ± 10.3 | 1.6 ± 0.9 |
| *pp*'-DDE | 213.3 ± 302.7 | 26.4 ± 70.8 |
| Mirex | 8.0 ± 5.9 | 1.0 ± 0.7 |
| oxy-Chlordane | 52.4 ± 38.7 | 2.7 ± 2.0 |
| PCB 70 | 1.9 ± 1.7 | 0.6 ± 0.5 |
| PCB 95 | 6.9 ± 6.6 | 1.3 ± 0.6 |
| PCB 101 | 5.3 ± 4.4 | 1.2 ± 0.6 |
| PCB 99 | 16.9 ± 13.0 | 2.9 ± 2.7 |
| PCB 110 | 3.9 ± 2.6 | 1.2 ± 0.5 |
| PCB 118 | 30.9 ± 26.4 | 4.1 ± 3.1 |
| PCB 153 | 66.7 ± 47.8 | 11.3 ± 11.0 |
| PCB 138 | 38.4 ± 29.9 | 8.5 ± 9.8 |
| PCB 158 | 4.2 ± 3.7 | 0.6 ± 0.8 |
| PCB 183 | 8.3 ± 6.6 | 1.5 ± 1.4 |
| PCB 180 | 33.7 ± 22.8 | 5.4 ± 5.4 |
| PCB 170 | 12.6 ± 10.3 | 2.0 ± 2.0 |
| PCB 194 | 4.7 ± 4.1 | 0.6 ± 0.5 |
| PCB 206 | 2.3 ± 2.3 | 0.3 ± 0.1 |

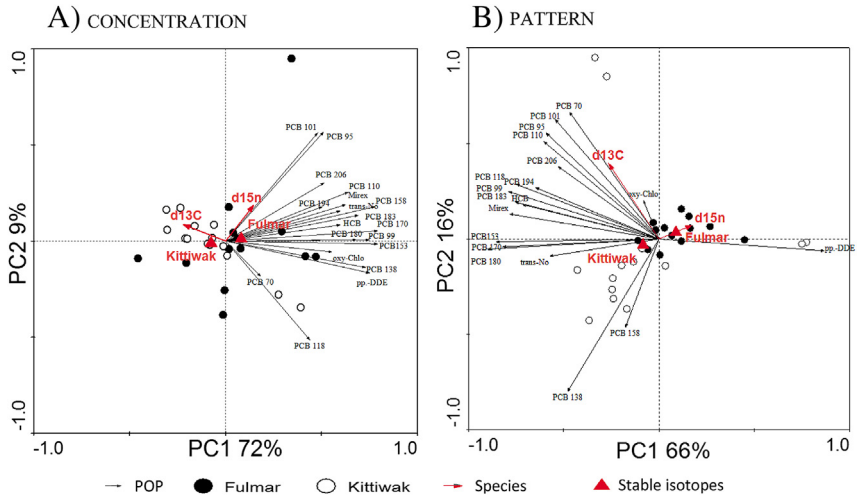


**Fig. 1.** Principal coordinate analysis triplots based on log transformed contaminant concentrations (A) and patterns (B) with lipid as covariate. Triplot includes chick samples (circles), contaminants (black arrows), and sample characteristics (passive environmental variables, bold).

fulmar than in black-legged kittiwake (Table 1). The PCA of contaminant concentrations revealed that 72% of the variation was accounted for by principal component 1 (PC1) and 9% by PC2 (Fig. 1A). PCB 153 had the highest loading onto PC1, and all contaminants loaded positively onto PC1. Northern fulmar and black-legged kittiwake separated along PC1, consistent with the measured contaminant concentrations. The exception were two black-legged kittiwake with sample scores that fell with the northern fulmar on the PCA plot and also had high contaminant levels, in the upper range of concentrations found in northern fulmar.

The PCA of organochlorine contaminant pattern revealed 66% of the variation was accounted for by PC1 and 16% with PC2 (Fig. 1B). The two black-legged kittiwakes that had high contaminant concentrations with sample scores that separated from the other kittiwakes in the concentration PCA, were also separated from the other kittiwakes .on the pattern PCA, which was likely is driven by high relative contribution of *p,p′* DDE (Fig. 1B). If these are eliminated and the PCA reanalyzed, the species are more overlapping in pattern along PC1 (44%) but are still separated along PC2 (27%), with slightly higher relative contribution of the persistent contaminants such as PCB 138 and PCB 153 in black-legged kittiwake, whereas the northern fulmars have slight higher relative contribution of the metabolites *p,p′* DDE and oxy-chlordane (Fig. 1B).

Due to its high loading on PC1 for both the concentrations and pattern analysis, PCB 153 was used as the representative contaminant to assess the influence of species and feeding ecology, as indicate by $\delta^{15}N$ and $\delta^{13}C$, in the backwards selection of the full GLM model. In the final model of PCB 153 concentrations, only species and $\delta^{13}C$ were significant, with higher PCB 153 concentrations higher in northern fulmar (mean ± SE: 72.2 ± 9.2) than black-legged kittiwake (11.3 ± 8.5) ($n = 26$, $R^2 = 0.81$, $F$-ratio = 14.7, $P = 0.0009$), and with decreasing PCB 153 concentrations with increasing $\delta^{13}C$ values ($F$-ratio = 9.7, $p = 0.0051$). In the final model of PCB 153 The relative contribution to sum contaminants, only species was significant, with higher contribution in black-legged kittiwake (16.5 ± 0.78) than in northern fulmar (13.7 ± 0.85) ($n = 26$, $R^2 = 0.20$, $T = 6.0$, $P = 0.02$).

### 3.2. Comparing interspecific differences in POP concentration ratio across life stages

The lipid-normalized concentration ratios between northern fulmar and black-legged kittiwake chicks (fledglings) for HCB, *trans*-nonachlor, *p,p′* DDE, oxy-Chlorane, and PCB 153 were compared to the species' contaminant ratio in eggs, juvenile and adults (Table 2). For most chemicals and life stages, the fulmar had higher contaminant levels compared to kittiwake (ratio > 1), with the exception of HCB and PCB 153 in eggs that were lower or similar in fulmar than kittiwake (ratio ≤ 1). The *p,p′* DDE and oxychlordane ratios in juveniles were particularly high, and seemed extreme values. After rechecking the data these values could not however be considered outliers. Both ratios of HCB and trans-nonachlor decreased from chicks to adults, showing less species difference with age.

## 4. Discussion

Previous studies have reported juvenile and adult northern fulmars to occupy higher trophic levels, based on $\delta^{15}N$ and stomach content analysis (Mehlum and Gabrielsen, 1993; Dahl et al., 2003), and to have higher contaminant concentrations (Fisk et al., 2001), than black-legged kittiwakes. Because stable isotope and contaminants are maternally transferred from parent to egg (Hebert and Weseloh, 2006), we predicted northern fulmar fledglings to have higher $\delta^{15}N$ values and POP concentrations relative to black-legged

**Table 2**
Ratio of lipid normalized concentrations of selected contaminants ([Northern fulmar]/[Black-legged kittiwake]) in different life stages of these arctic seabirds.

| Life stage[a] | PCB 153 | HCB | trans-Nonachlor | *pp*'-DDE | oxy-Chlordane | Data source |
|---|---|---|---|---|---|---|
| Egg (whole – 1998) | 0.8 | 1.0 | 4.8 | 2.5 | 2.9 | Braune, 2007 |
| Egg (whole – 2003) | 0.8 | 0.7 | 3.1 | 2.2 | 2.4 | Braune, 2007 |
| Fledgling (muscle – 2006) | 2.0 | 2.8 | 2.5 | 2.1 | 6.2 | Present study |
| Juvenile (liver – 1997) | 4.2 | 2.9 | 2.1 | 16.6 | 26.6 | Borgå *unpublished* |
| Adult (liver – 1998) | 2.7 | 1.8 | 1.4 | 3.0 | 8.0 | Fisk et al., 2001 |

[a] Life stage includes tissue type and year of collection.

kittiwake. Surprisingly, $\delta^{15}N$, nor $\delta^{13}C$, differed as expected. Despite this, POP concentrations of POP were higher levels in the northern fulmar fledglings. Our results also indicated that the interspecies ratio of POP concentrations differed across life stages (egg through adult) for a suite of contaminants. Overall, our findings suggest: 1) $\delta^{15}N$ may not accurately predict POP concentrations in seabird fledglings, and; 2) risk assessments based on samples from single life stages could result in erroneous extrapolations to other age classes or species, even among those species breeding in a specific area.

### 4.1. POP accumulation in kittiwake and fulmar fledglings

Northern fulmar fledglings had higher concentrations of all 19 contaminants included in our analyses, relative to black-legged kittiwakes. These results corroborate those of Fisk et al. (2001), who found elevated contaminant concentrations in northern fulmar relative to black-legged kittiwakes at the adult life stages, and also higher trophic levels in fulmar than kittiwake. These differences in contaminant concentration in adults were attributed to the different feeding ecology of these seabirds. Northern fulmar feed on a varied diet including fish, zooplankton, squid and polychaetes, but also scavenge dead marine mammals, which have high POP levels (Lydersen et al., 1989; Mehlum and Gjertz, 1984; Camphuysen and van Franeker, 1997). Black-legged kittiwake typically feed on zooplankton and subsurface fish such as polar cod (*Boreagadus saida*) (Lønne and Gabrielsen, 1992; Mehlum and Gabrielsen, 1993) and occupy lower trophic levels (Dahl et al., 2003), and are not known to scavenge. In addition, difference in overwintering area might contribute to differences in chemical exposure, although recent studies of another avian wildlife species (great skua *Stercorarius skua*), showed that only a minor fraction of the contaminant levels in the adults on the breeding site was related to the overwintering area (Leat et al., 2013). In the great skua chicks however, the contaminant level differed as much as 50% depending on the mother's overwintering area (Bourgeon et al., 2013).

Black-legged kittiwakes had higher relative contribution of the persistent contaminants such as PCB 138 and PCB 153 compared to northern fulmar (Fig. 1B), which could reflect greater accumulation in more southerly locations close to temperate POP sources (Buckman et al., 2004). Kittiwake move further south during the winter (Braune, 2007). In contrast, northern fulmars had slightly higher relative contribution of the metabolites *p,p′*-DDE and oxy-chlordane (Fig. 1B). This concurs with measurements of biotransformation enzymes and PCB metabolites, indicating higher biotransformation in northern fulmars than in black-legged kittiwakes (Helgason et al., 2010). But it could also reflect scavenging of marine mammals by northern fulmar.

Measures of trophic level, particularly $\delta^{15}N$, have been shown to be positively correlated with POP concentrations across 7 arctic seabird species, including adult northern fulmar and black-legged kittwake (Buckman et al., 2004). However, our results indicate that for fledglings of these species, $\delta^{15}N$ does not accurately predict differences in POP accumulation. Similarly mean $\delta^{13}C$ values did not differ between northern fulmar and black-legged kittiwake fledglings in our study.

The lack of $\delta^{15}N$ difference between these two arctic seabird species may reflect a change in feeding strategy by the northern fulmar. In Arctic food webs, northern fulmar are known to be a scavenger with a highly plastic diet, able to fly long distances offshore to obtain pelagic fish (i.e., Gadids), fishing discards, and pelagic zooplankton (i.e., Calanus sp.) (Hatch and Nettleship, 1998; Phillips et al., 1999; Byers et al., 2010). During breeding season however, adult seabirds have increased constraints as they provision food for young, resulting in more local (nearshore) food fed to chicks/fledglings compared with that eaten by the adults (nearshore) (Furness and Todd, 1984; Barrett et al., 2007; Ojowski et al., 2001). In addition, fulmars produce stomach oil from prey as feed for chicks by retaining and concentrating the oils. This stomach oil is energy dense, and has higher contaminant content compared to prey relative to energy density (Foster al., 2010). There is however no information available on the relationship between stable isotopes in stomach oils compared to other body matrixes. This change in diet of chick rearing adults supports the optimal foraging theory, which predicts that seabirds, which can obtain multiple prey items, or convert prey to stomach oil, should optimize foraging loads with several small fish with increased energy densities (Barrett et al., 2007). This study also indicates that optimal foraging theory may also result in changes in POP concentrations.

### 4.2. Species difference in POP accumulation between life stages

If the intent is to monitor spatial variation in contaminants, as reflected by egg or fledgling data, the assumption is that these life stages reflect the local exposure through maternal transfer or diet. However, birds differ in their energy allocation to the egg, where some use more of the stored energy reserved rather than new acquired energy and contaminants. This will be reflected in the contaminants and isotopic signature in the eggs (Morrissey et al., 2010). The ratio of POP concentrations between northern fulmer and black-legged kittiwake varied across the different POPs and life stages. Similar PCB 153 and HCBz concentrations reported for kittiwake and fulmar eggs (Ratio $\cong$ 1), despite higher concentrations in fulmar than kittiwake adults (Ratio $>$ 1) (Table 2), suggest that both kittiwake and fulmar use local diet (exogeneous resources) in the egg production, i.e. that they are income breeders, rather than being capital breeders using the body energy reserves (endogenous resources). However, ratios of trans-nonachlor, and the metabolites *p,p′* DDE and oxy-chlordane, were much higher in the northern fulmar fledglings, which is consistent with higher levels of these contaminants in adults. Most birds, including larids such as kittiwake, and its close kin glaucous gull *Larus hyperboreus* (Verrault et al., 2006), are considered to be income breeders (Drent and Daan, 1980; Gabrielsen, unpublished). Although income breeding with use of exogeneous resources by breeding fulmars is supported by reproductive ecological studies from the Canadian Arctic (Mallory et al., 2008), the same authors suggest that lipids and proteins are predominantly from endogeneous reserves whereas as calcium is from exogeneous resources (Mallory et al., 2006, 2008a), and that both lipids and contaminants are transferred from mother to the egg in the egg-laying process (Mallory et al., 2006).

The POP ratios were generally greater, i.e., high concentrations in the northern fulmar, in the fledgling and juvenile stages than the egg stage. This support that the elevated POP levels in fulmar fledglings is due to elevated exposure through post-hatching exposure, and that this exposure is due to contaminants being concentrated in the stomach oil (Foster et al., 2010), rather than the fulmars being fed from a higher trophic level, as the fledglings do not differ in $\delta^{15}N$. Northern fulmar feed the chicks with diet caught close to the colony initially, and then later switch to longer foraging trips, resulting in stomach oil being an important food source (Mallory and Forbes, 2008). At fledgling, the fulmars were twice the size of kittiwake at comparable ages, thus the effect of growth dilution would be expected to be greater in fulmar than kittiwake (Drouillard et al., 2003), although this did not dilute the concentrations measured in this or past studies (Table 2).

### 4.3. Importance of life stage in assessing POP risk to arctic seabirds

Monitoring and assessing POP concentrations in arctic animals often requires sampling different life stags (i.e., eggs or fledglings)

due to logistical and ethical constraints. The result of this study suggests seabirds accumulate contaminants differently across life stages, and that this varies with species and specific contaminants. Thus, exposure to and burdens of POPs, needed for risk assessments and extrapolation of species-specific thresholds for effects (e.g. Wang et al., 2011), should only be done with caution in ecosystem-based management.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envpol.2013.09.007.

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