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TEMPORAL VARIATION IN CIRCULATING CONCENTRATIONS OF ORGANOCHLORINE POLLUTANTS IN A PELAGIC SEABIRD BREEDING IN THE HIGH ARCTIC

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Abstract: The present study explored short-term temporal variations in circulating concentrations of 3 legacy organochlorines with different physicochemical properties (polychlorinated biphenyl 153 [PCB-153], *p,p′*-dichlorodiphenyldichloroethylene [DDE], and hexachlorobenzene [HCB]) in breeding kittiwakes (*Rissa tridactyla*) in a colony in Svalbard (78°N), Norwegian Arctic. Concentrations were measured in blood of a large number ($n = 412$–521 blood samples, depending on the data analyses) of prebreeding, incubating, and chick-rearing birds over a period of 5 yr (2007–2011). The PCB-153 concentrations were equal in male and female blood in the prebreeding period, whereas females had significantly lower concentrations during incubation and chick rearing, probably because of their ability to eliminate organochlorines through egg laying. A similar temporal pattern was observed with DDE, although the lower concentrations in incubating females were not significant. Males and females had similar concentrations of HCB over all reproductive stages. The concentrations of all 3 compounds varied greatly between years. The concentrations of PCB-153 tended to decline over the study period, whereas concentrations of HCB showed an increasing trend, especially among chick-rearing males late in the season. Concentrations of PCB-153 increased approximately 2.5 times from the prebreeding to the chick-rearing period, concurrent with mobilization of body lipids (reduced body mass). A similar, but less pronounced trend was found for HCB. For DDE, however, kittiwakes had the highest concentrations in the prebreeding period, suggesting relatively high exposure in their winter areas. The present study documented large variations in circulating concentrations of legacy organochlorines among and within breeding seasons in kittiwakes, but the alterations within seasons were relatively consistent from year to year. *Environ Toxicol Chem* 2017;36:442–448. © 2016 SETAC

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INTRODUCTION

Organochlorines are lipid-soluble pollutants that may undergo long-range transport to the Arctic, where they biomagnify in local food webs [1,2]. Because of their high trophic positions, Arctic seabirds accumulate relatively high loads of such compounds [3,4]. Many organochlorines were, however, banned in most countries decades ago (e.g., dichlorodiphenyltrichloroethane [DDT] and polychlorinated biphenyls [PCBs]), which has resulted in declining concentrations in Arctic biota, including seabirds [5,6].

In seabirds, as in other wildlife species, organochlorines are distributed among different body compartments; they may be stored in lipids within various organs or in adipose tissue, or they may circulate in the bloodstream. Three main processes determine the concentrations of circulating organochlorines: 1) intake via food; 2) degree of remobilization of organochlorines from adipose tissue; and 3) removal through different elimination routes, including egg laying [7]. The lipid content of blood and tissue is also an important determinant for these concentrations [8].

The organochlorine concentrations in blood of Arctic seabirds may show high interannual variation because of temporal variability in long-range transport through alterations in the atmosphere and oceans [9–11], diet (namely, variation in the availability of prey with different lipid and organochlorine loads [12,13]), and/or temperature (i.e., at low temperatures the daily energy expenditure and thus lipid metabolism increase, which remobilizes more stored organochlorines, resulting in subsequent increases in the circulating concentrations [8,14]). Arctic seabirds may also carry organochlorines during migration (biotransport), and annual variation during breeding may be a reflection of the variation in organochlorine exposure at the wintering grounds [15,16].

Variation in circulating organochlorine concentrations within breeding seasons also may arise from altered transport, diet, and remobilization as a result of temperature variability, but also because the body condition (lipid stores) of seabirds often varies consistently within breeding seasons [17,18]. Moreover, there may be variation across the sexes, and females may eliminate some of their organochlorine loads through egg production. Although some seabird studies have found lower concentrations of organochlorines in the blood of incubating females compared with males [19–21], the importance of egg

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laying as a determinant for organochlorines in blood has been little studied in wild birds [7,22].

The circumpolar black-legged kittiwake (*Rissa tridactyla*; hereafter called kittiwake) is a pelagic and surface-feeding seabird with a diet of different fish species and invertebrates [23]. Arctic breeding kittiwakes usually lay 2 eggs (1–3) and incubate them for approximately 27 d. Hatching occurs in early July, and parents rear chicks at the nest for 4 wk to 5 wk [24]. The kittiwake leaves the Arctic in October/November and returns in April [25,26]. To explore the short-term dynamics of circulating organochlorines, we measured 3 legacy organochlorines with different physicochemical properties—PCB-153, *p,p′*-dichlorodiphenyldichloroethylene (DDE), and hexachlorobenzene (HCB)—in more than 500 kittiwake blood samples from a colony at Svalbard, Norway, over 5 yr. Samples were collected during 3 reproductive stages (April: prebreeding; mid-June: incubation; and late July: chick rearing). Hexachlorobenzene is a semivolatile compound with high long-range transport potential and is found at high concentrations in remote locations such as the Arctic and the Antarctic. In comparison, PCB-153 is a much heavier and very persistent molecule with a relatively lower atmospheric transport potential. A metabolite of DDT, DDE occurs in seabirds at a rate correlating to a varying degree with other legacy organochlorines such as PCBs [14,27–32], even if historical and industrial applications have been quite different. These 3 organochlorines were chosen as key compounds because they have been linked to changes in physiology, reproduction, and survival of Svalbard kittiwakes and they represent a broad range of physiochemical properties characteristic of the organochlorine class of compounds [3,33,34].

In the present study, we first hypothesized that egg laying induces differences in organochlorine circulating concentrations between the sexes, as females may reduce their organochlorine loads through contaminant deposition into their eggs. Consequently, we predicted that concentrations would be equal for male and female kittiwakes prior to egg laying, but lower for females after egg laying. Second, because the body condition of kittiwakes tends to decline from the prelaying to the chick-rearing stages [18,35,36], we hypothesized that organochlorines from adipose tissue would increasingly remobilize, thus increasing blood concentrations as breeding progressed. One central question was whether changes in body mass (body lipids) over the breeding season could explain alterations in organochlorine concentrations, or whether some other factors related to the different reproductive stages would be of importance. Based on the different physiochemical properties of the 3 organochlorines, we predicted different dynamics in kittiwakes, with a stronger fluctuation in HCB concentrations over the breeding season, relative to PCB-153 and DDE (higher volatility, lower octanol-water partition coefficient [K_{OW}], and less lipophilicity of HCB compared with PCB and DDE). We tested the hypotheses for both wet weight and lipid normalized concentrations.

MATERIALS AND METHODS

Study species and field procedures

The kittiwake is a long-lived gull with a circumpolar distribution, breeding in colonies on cliffs. In Svalbard, it feeds mainly on capelin (*Mallotus villosus*), polar cod (*Boreogadus saida*), and amphipods [37,38]. Krykkjefjellet, our study colony, is a seabird cliff located 6 km southeast of Ny-Ålesund in Kongsfjorden, Svalbard, Norway (78°54′N, 12°13′E). The kittiwakes were caught on their nest with a snare on a long fishing rod. All birds were in adult breeding plumage, that is, they had no dark patches on their heads or black fields on their outer primaries [23].

Blood samples for contaminant analyses were taken from both sexes during the prebreeding, incubation, and chick-rearing periods between 2007 and 2011. Samples (∼1.5 mL of blood) were taken from the brachial vein using a heparin-treated 2-mL syringe and a 23-G needle. In the field, the samples were immediately stored in darkness at ambient temperatures in June and July. In April, the samples were kept from freezing. After returning from the field, all the samples were frozen at –20 °C.

Body mass and skull length (head and bill) were measured with an accuracy of 5 g and 0.1 mm, respectively, and the birds were banded with a metal and 3-letter–coded plastic ring [34]. Confirmation of breeding status (prelaying, incubation, and chick rearing) was done by inspecting nest content using a mirror at the end of a long rod.

Permissions for fieldwork and blood sampling of the birds were granted by the Governor of Svalbard and complied with the Norwegian Regulations on Animal Experimentation.

POP analyses

The concentrations of persistent organic pollutants (POPs) in the blood samples were analyzed at the Norwegian Institute for Air Research in Tromsø, Norway. Details regarding the analyses are provided in Herzke et al. [39] and in Nordstad et al. [36]. Lipid contents in the blood samples were analyzed gravimetrically. We analyzed blood lipids for all years, except in 2009 because of a laboratory problem. We analyzed the correlations of different factors on both wet weight and lipid normalized concentrations.

Molecular sexing

The sex of the birds was determined at the Centre d'Etudes Biologiques de Chizé (CEBC-CNRS, University of La Rochelle, France). To sex the birds, DNA was extracted from red blood cells, and the CHD gene was amplified in a polymerase chain reaction procedure, as described by Weimerskirch et al. [40].

Statistical analysis

Statistical analyses and plotting of results were carried out in R [41]. All tests were two-tailed, the null-hypothesis was rejected at an α-level of 0.05, and we used the treatment contrast comparing each level of a factor with its baseline level. Standard plotting diagnostics tools were used in all analyses, and as none of the residuals was normally distributed, the responses were $\log_e$-transformed.

Prior to the statistical analyses, we assessed collinearity in several steps. First, we assessed the extent to which kittiwake body mass varied as a function of the other predictors by forming a set of different a priori models. The selected model explained >60% of the variance in body mass. Because body mass was related to year, period, and sex in addition to 2 interactions involving period, we chose to separate the analyses between the sexes. Second, collinearity was then assessed by checking whether the effect sizes or their level of statistical significance differed, depending on whether each of the other predictors was excluded or not. Third, the variance inflation factor, with a cut-off value of 5, was used to assess which predictors were collinear and consequently should be dropped prior to the analyses [42]. Because we were unable to reveal any collinearity, we concluded that our separation of the analyses of

contaminants between the sexes was sufficient to avoid potential problems with serious confounding.

We performed our statistical analyses in several steps. First, we performed a set of overall analyses to assess the extent to which the different responses varied according to period and sex (keeping body mass out because of the collinearity issues outlined above), by fitting linear mixed-effect models [43], with reproductive period, sex, and their interaction as fixed effects; the constant term for year was used as a random effect (i.e., random intercepts only). Second, we performed more detailed analyses (on each sex separately), where we fitted linear models, using the lm function in R to assess the effects of body mass, period, and year. In these analyses, we calculated the second-order Akaike's Information Criterion (AICc) values for several candidate models [42,44]. The models used for inference were selected by forming a set of candidate models in which we rescaled and ranked models relative to the model with the lowest AICc value (Δ_i denotes this difference for model i), and then selecting the simplest model with a $\Delta_i \leq 1.5$, even though we also provide Akaike's weights. Model selection was performed using the AICcmodavg library in R [45]. We kept body mass in all models based on our a priori expectations, whereas the other covariates were excluded or included in the different candidate models. It can be argued that linear mixed-effect models using individual as a random effect represent a more correct statistical approach than the linear model approach applied in the present analyses [42]. Nonetheless, there are several reasons why we applied linear models and not linear mixed-effect models. First, of our total sample of 529 observations, 27 were data from unknown individuals. Second, and more importantly, approximately 50% of our observations (from known individuals) were single samples taken from 1 individual and 70% consisted of individuals sampled only once or twice (both sexes), whereas only 15% (males) and 10% (females) consisted of individuals that had been sampled $\geq$4 times. Third, as a precautionary action we fitted linear mixed-effect versions of all selected models, that is, a model with the same fixed effects and random intercepts only, using the nlme library [46]. Because neither the estimates nor the statistical significance for our estimates changed notably when the reported outputs for the analyses using period and body mass as predictors were compared with linear mixed-effect models (results not shown), we conclude that our inference were not sensitive to our choice of statistical approach.

RESULTS AND DISCUSSION

Differences between sexes

Studies of different seabird species have shown that males may have higher circulating concentrations of organochlorines than females during breeding [19–21], but this does not appear to be consistent [47]. Differences in organochlorine loads between sexes have been attributed to both egg laying and diet specialization [7,22]. Because we had data both prior to and after egg laying ($n = 521$), we were able to test the hypothesis that such differences were an effect of female kittiwakes eliminating organochlorines through the eggs. In the linear mixed-effect models (i.e., when year was used as a random factor), the sexes had equal levels of PCB-153 in the prelaying period, whereas males had higher concentrations during incubation and chick rearing (~10%), interactions being significant for lipid-normalized concentrations ($p = 0.033$; Supplemental Data, Table S4A), and marginally significant ($p = 0.075$; Supplemental Data, Table S3A) for wet weight concentrations (Figure 1A; Supplemental Data, Figure S1A; bar plots are used for visualizing model predictions). For DDE, the differences were in the same direction as PCB-153, but the blood concentrations tended to decline over the breeding season in both sexes, and the interactions between period and sex were not significant ($p = 0.107$; Figure 1B; Supplemental Data, Figure S1B and Tables S3B, S4B). This suggests that egg laying has some impact on the circulating concentrations of DDE in the breeding season; but the effect appears to be weak, and it is important to note the variation among and within breeding seasons (Figure 2A–C; Supplemental Data, Figure S2A–C). That is, in some years females had equally high blood concentrations as males during both incubation and chick-rearing periods. This might be a result of poor feeding conditions in which females are forced to emancipate their body lipid reserves and thereby remobilize more organochlorines during egg laying and incubation periods [21]. For HCB, however, there appeared to be no difference (interaction: $p = 0.38$) between sexes in any of the periods (Figure 1C; Supplemental Data, Figure S1C and Tables S3C and S4C). This was unexpected because maternal transfer of contaminants to eggs often favors low K_{OW} and/or less persistent organochlorines, whereas more lipophilic compounds such as PCB-153 are more likely to be retained in the mother's adipose tissue [48–50]. The lack of difference between the sexes after egg laying could result from the relatively high continuous exposure of HCB in our study area. Hence, the observed air

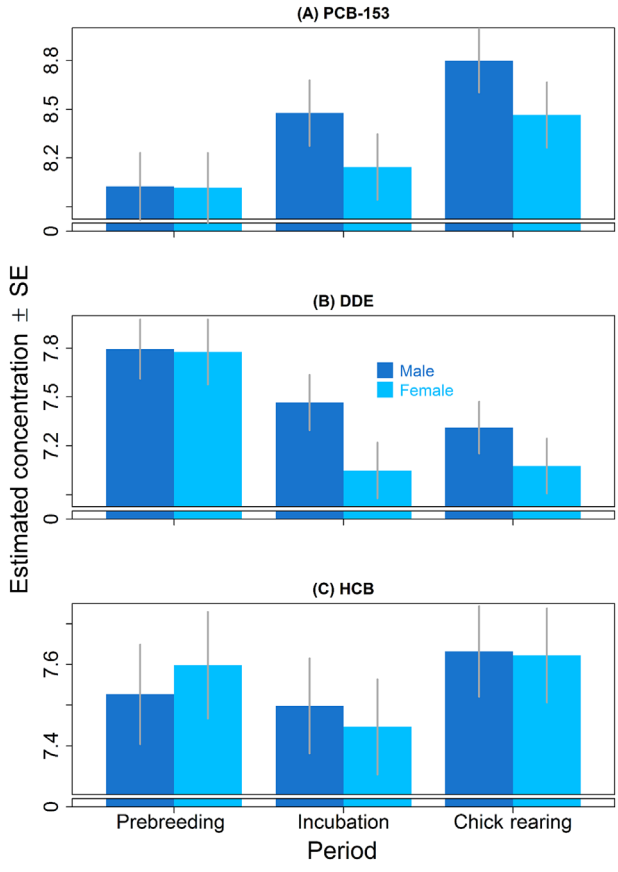

Figure 1. Estimated (i.e., model predictions with precision [±1 standard error (SE)]) as bars, wet weight concentrations (log pg/g; from linear mixed-effects where we controlled for year as a random factor) of (**A**) polychlorinated biphenyl 153 (PCB-153), (**B**) *p,p′*-dichlorodiphenyldichloroethylene (DDE), and (**C**) hexachlorobenzene (HCB) in male and female kittiwakes in different reproductive stages (prebreeding, incubation, and chick rearing). Data from Kongsfjorden, Svalbard, Norway, 2007–2011.

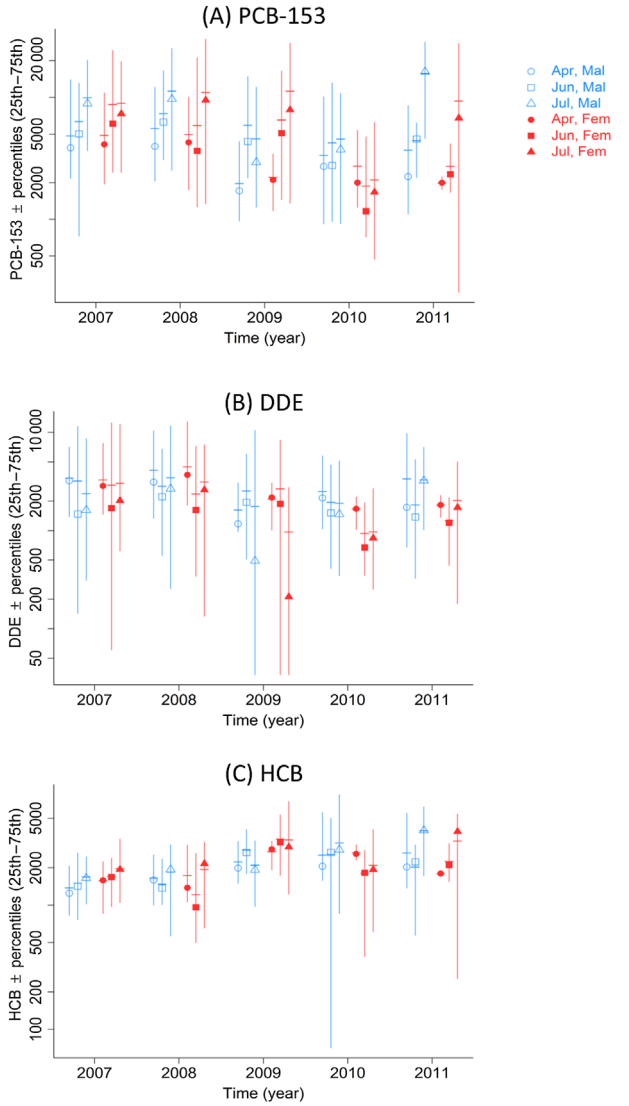

Figure 2. Plot showing descriptive statistics: average (points), median (dashes), and 25th and 75th percentiles (bars) for wet weight concentrations (pg/g wet wt) of (**A**) polychlorinated biphenyl 153 (PCB-153), (**B**) *p,p′*-dichlorodiphenyldichloroethylene (DDE), and (**C**) hexachlorobenzene (HCB) in male (blue bars) and female (red bars) kittiwakes in different reproductive stages (prebreeding, incubation, and chick rearing). Data from Kongsfjorden, Svalbard, Norway, 2007–2011. Mal = male; Fem = female.

concentrations on Svalbard are 80 pg/m^3 for HCB and only 10 pg/m^3 for PCB, showing different background exposure [51]. Moreover, in the same location and time period as the present study, blood concentrations of HCB increased more during incubation fast in common eiders (*Somateria mollissima*), a benthic top predator, than did concentrations of PCB-153, suggesting high intake of HCB during prebreeding accumulation of body reserves [14]. Hence, female kittiwakes in Kongsfjorden may rapidly regain the loads lost through the eggs, and thus potential differences between sexes may not be detected. Alternatively, HCB has a relatively low affinity for adipose tissue compared with other compounds [50,52], and this compound may therefore be more readily redistributed from body fat to blood after egg laying.

Temporal variation in organochlorines and the effect of body condition

Descriptive data on concentrations for both sexes ($n = 270$ males and 224 females) can be found in the Supplemental Data, Table S5. The sexes were analyzed separately, and for each contaminant, the same models were selected and used for inferences (Supplemental Data, Tables S1 and S2). For wet weight, the best models explained 37% and 34% of the variance in blood concentrations for PCB-153 for male and female kittiwakes, respectively (Supplemental Data, Table S6A), whereas the corresponding values were 16% and 21% for DDE (Supplemental Data, Table S6B), and 19% and 18% for HCB (Supplemental Data, Table S6C). The corresponding values for lipid-normalized concentrations were within the same order of magnitude, although lipid data for 2009 were lacking (Supplemental Data, Table S7A–C).

The variation in wet weight blood concentrations among years was generally the most important variance component, explaining 23% and 30% (partial R^2) of the variation in PCB-153 in males and females, respectively. The corresponding values were 8% and 12% for DDE, and 10% and 8% for HCB, respectively. For PCB-153, the mean wet weight concentrations over the whole seasons varied from approximately 4000 pg/g to 8000 pg/g (wet wt) between years in males, and between approximately 2200 pg/g to 7500 pg/g in females (Supplemental Data, Table S5). The individuals sampled from 2009 to 2011 had lower levels (negative estimates for these years after controlling for body mass) compared with the first year of the study (2007), whereas the levels in 2008 were slightly higher, although not significantly different from 2007 (Supplemental Data, Table S6A). Interestingly, 2008 was a very cold summer [14], and kittiwakes may have been forced to increase daily energy expenditure by metabolizing more lipids and thus remobilizing more PCBs to the blood [14]. The lipid-normalized concentrations for PCB-153 (Supplemental Data, Figure S2A) showed a similar pattern as for wet weight, especially in females (Supplemental Data, Table S7A and Figure S2A), suggesting that PCBs are declining in the study area consistently with declining background exposure [53].

For DDE, mean concentrations in males varied from approximately 2000 pg/g to 3500 pg/g (wet wt) between years, over all seasons, and between approximately 1700 pg/g to 3300 pg/g in females (Supplemental Data, Table S5). Males sampled in 2009 had lower wet weight concentrations compared with 2007, whereas the concentrations in other years (2008 and 2010–2011) were not significantly different from 2007. For the females, however, all years except 2008 showed lowered levels compared with 2007, similar to PCB-153 (Supplemental Data, Table S6B and Figure S2B). For lipid-normalized concentrations, however, year did not improve the statistical models and was not included in the best model after controlling for reproductive period and body mass (Supplemental Data, Table S7B and Figure S2B). Consistent temporal trends of legacy organochlorines may be impossible to document with certainty over just 5 yr, and for DDE it seems more likely that the trends observed are results of differences in lipid content in blood between years.

The mean concentrations of HCB in male kittiwakes varied from approximately 1500 pg/g to 2900 pg/g (wet wt) between years over the whole seasons, and between approximately 1600 pg/g to 3200 pg/g in females (Supplemental Data, Table S5). For HCB, however, the wet weight concentrations tended to increase over the years when body mass was controlled for (Supplemental Data, Table S6C and Figure S2C). The temporal patterns were, however, different between the sexes: males showed increasing levels of HCB from 2009 to 2011 (relative to 2007), whereas females showed lower levels in 2008 and higher levels in 2009 compared with 2007

(Supplemental Data, Table S5C and Figure S2C). For lipid-normalized concentrations, there was still an increase of HCB in 2008 and 2010 compared with 2007 after controlling for body mass and reproductive period (Supplemental Data, Table S7C and Figure S2C). Hence, despite the short period, wet weight concentrations showed a directional increase for HCB, especially in males (Figure 2C; Supplemental Data, Figure S2C). The changes in HCB concentrations may be expected because the background exposure of HCB in Kongsfjorden is increasing [53]. This explanation is strengthened by the fact that the most pronounced increase seemed to occur late in the breeding season, when the birds had spent approximately 4 mo in the Kongsfjorden area.

Although the interyear variation in blood concentrations was large, there was also considerable variation between the different reproductive stages. For PCB-153, the lowest wet weight concentrations were generally found in the prebreeding periods, increasing on average approximately 2.5 times until the chick-rearing periods (Figure 2A; Supplemental Data, Table S5). The increase for HCB was on average approximately 1.2 times over the same period (Figure 2C; Supplemental Data, Table S5). For both compounds, the increase occurred concurrently with reductions in body mass (Figure 3), and the changes in body mass (lipid stores) eliminated reproductive stage as a significant predictor in the statistical models (Supplemental Data, Tables S6A and S6C). For PCB-153, body mass explained 26.5% of the variation in males, but only 9% in females, possibly an effect of egg laying. The values for HCB were lower: 6% and 3% for males and females, respectively. For PCB-153, the lipid-normalized concentrations showed similar patterns as wet weight (Supplemental Data, Table S6A and Figure S2A), whereas the best model also included reproductive stage for lipid-normalized HCB concentrations. The effect of body mass was, however, not included in the best model for females (Supplemental Data, Table S6C and Figure S2C). The relatively low explanatory power of the statistical models for HCB compared with PCB-153 may again originate from the higher local exposure of HCB and more rapid remobilization of this compound.

A different pattern was seen for DDE compared with the other compounds, because the highest concentrations were found in the prebreeding periods, mean concentrations being approximately 1.25 times higher than during incubation, with a slight increase during chick rearing (Figure 2B; Supplemental Data, Table S5). Changes in body mass explained 5% and 3% of the wet weight concentrations of DDE in male and female kittiwakes, respectively, whereas the corresponding values for the reproductive stage predictor were 9% and 8% (Supplemental Data, Table S6B). The lipid-normalized DDE concentrations (Supplemental Data, Figure S2B) showed the same pattern as for wet weight concentrations with regard to reproductive stage and body mass (Supplemental Data, Table S7B). Hence, despite decreasing body mass from April to June (Figure 3), DDE in blood decreased, suggesting that the breeding area in Kongsfjord has lower background exposure of DDE, or the mother compound DDT, than the winter areas. Kittiwakes thus seem to eliminate DDE from their bodies relatively quickly until concentrations reach equilibrium with their breeding environment [7]. This indicates that kittiwakes are net-transporters of DDE/DDT to the High Arctic. The kittiwakes breeding in Kongsfjorden winter at 40°N to 60°N in the North Atlantic, roaming across the western (Grand Banks and Labrador Sea), central (Mid-Atlantic), and eastern parts (Mid-Atlantic Ridge to Portugal/Ireland) [25,26]. Exposure to organic pollutants in this offshore region is not well studied; that is, it is not known whether the high levels of DDE compared with other legacy organochlorines in prebreeding kittiwakes can be attributed to this region. However, Espín et al. [54] reported that razorbills (*Alca torda*) were exposed to high amounts of DDT along the coast of Spain, which was almost completely metabolized when they reached their breeding grounds in Northern Europe. In Norwegian lesser black-backed gulls (*Larus fuscus*), high levels of DDE were found in eggs and blood of birds wintering in African lakes where DDE is a dominating contaminant, compared with gulls wintering in areas dominated by PCB [15]. This may indicate that DDE and DDT are compounds prone to biotransport.

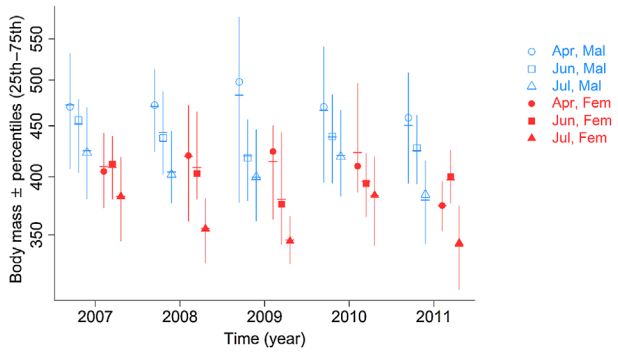

Figure 3. Plot showing descriptive statistics: average (points), median (dashes), and 25th and 75th percentiles (bars) for body mass in male (blue) and female (red) kittiwakes in different reproductive stages (prebreeding, incubation, and chick rearing). Data from Kongsfjorden, Svalbard, 2007–2011. Mal = male; Fem = female.

Diet variability may cause variation in circulating concentrations of organochlorines [13]. In 2007, when the study started, 75% of the kittiwake diet during chick rearing consisted of capelin, a relatively lipid-rich fish, whereas capelin made up <15% of the diet in the other years. In 2010, low trophic krill (Euphausiids) made up nearly 50% of the diet. In 2009 and 2011, nearly 50% of the diet was made up of polar cod (G.W. Gabrielsen, unpublished data). Although high concentrations of organochlorines in 2007 could potentially result from high intake of lipid-rich capelin, this cannot explain the high levels in 2008. Hence, there seems to be no consistent pattern in the diet data (e.g., trophic position of prey), which is consistent with the variation in organochlorine concentrations in the present study. There may be several reasons for this, notably that the diet data were collected over a limited period of the breeding stage (during chick rearing), whereas blood was sampled over the whole breeding season. It might also be that diet samples were intended for the chicks, whereas the adults were feeding on different prey, as has been found in some other seabirds [55].

The present study demonstrated large variations in circulating concentrations of different legacy organochlorines during breeding in high arctic kittiwakes. First, egg laying seemed to reduce circulating levels of PCB-153 in females relative to males. This effect, however, was surprisingly not significant for DDE and was not found for HCB. The organochlorines behaved differently in the birds, and relatively simple statistical models may explain much of the variation in circulating concentrations of PCB-153, the most persistent compound. For HCB, however, the present study suggests that local exposure during the breeding season may be more important relative to the other compounds. The fact that HCB tended to increase over

the years supports this explanation because background HCB is increasing in the Kongsfjorden area [53]. This is worrying because HCB has been associated with lower adult survival probabilities in this kittiwake population [34]. For DDE, the situation seems to be more complex, because the birds appear to carry this compound from the wintering grounds. For all 3 compounds, however, the present study demonstrates great variance between different reproductive stages, with mean PCB-153 concentrations increasing approximately 2.5 times over the breeding season. Moreover, these differences seem to be consistent among years, and much of the differences can be explained by reductions in the birds' lipid stores. This could be a result of energetic stress during the breeding period [18]. The importance of different environmental factors (e.g., climate variables) in causing variability is poorly understood, and more data over several years are necessary to elucidate such links. Moreover, variation in diet probably has a great impact on organochlorine intake of kittiwakes and should be addressed in future studies (e.g., by measuring isotopes). The present study, however, emphasizes that sampling time is an important factor if seabird tissue, such as blood, is used for monitoring purposes. In the future, this might become an even more important issue because many seabirds are threatened, notably pelagic species such as kittiwakes [56], and the need for noninvasive sampling methods is increasing. Blood sampling is a viable alternative to various forms of invasive sampling.

Supplemental Data—The Supplemental Data are available on the Wiley Online Library at DOI: 10.1002/etc.3560.

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Data availability—Data, associated metadata, and calculation tools are available from the corresponding author (jan.o.bustnes@nina.no).

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