

## Organochlorine contaminants in seven species of Arctic seabirds from northern Baffin Bay

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**“Capsule”:** Concentrations of organochlorides in high Arctic seabirds are influenced by trophic level, migration, scavenging and biotransformation.

### Abstract

Organochlorine contaminants (OCs) were determined in liver and fat of seven species of seabirds (*Alle alle*, *Uria lomvia*, *Cephus grylle*, *Rissa tridactyla*, *Pagophila eburnea*, *Larus hyperboreus*, and *Fulmaris glacialis*) collected in May/June 1998 from the North-water Polynya in northern Baffin Bay. OC concentrations ranged over an order of magnitude between seabird species and OC groups, with PCBs having the highest concentrations followed by DDT, chlordane, HCH and CIBz. Positive relationships between  $\delta^{15}\text{N}$  (estimator of trophic level) and OC concentrations (lipid basis) were found for all OC groups, showing that trophic position and biomagnification significantly influence OC concentrations in Arctic seabirds. Concentrations of a number of OCs in particular species (e.g., HCH in *P. eburnea*) were lower than expected based on  $\delta^{15}\text{N}$  and was attributed to biotransformation. *P. eburnea* and *F. glacialis*, which scavenge, and *R. tridactyla*, which migrate from the south, were consistently above the  $\delta^{15}\text{N}$ –OC regression providing evidence that these variables can elevate OC concentrations. Stable isotope measurements in muscle may not be suitable for identifying past scavenging events by seabirds. OC relative proportions were related to trophic position and phylogeny, showing that OC biotransformation varies between seabird groups. Trophic level, migration, scavenging and biotransformation all play important roles in the OCs found in Arctic seabirds.

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### 1. Introduction

Organochlorine contaminants (OCs) are a diverse group of anthropogenic pollutants that are of industrial and agricultural origin. Although they are rarely used in the Arctic, OCs have been observed there for more than 30 years and remain a concern for wildlife and human health (de March et al., 1998; Hansen, 1998). Although there is a fairly large dataset on OC levels in Canadian

Arctic seabird eggs (Braune et al., 2001, 2002) there are limited data for adult bird tissue and information about variables, such as migration, dietary patterns, or gender, which may influence these concentrations (Muir et al., 1997; de March et al., 1998).

Seabird species feed over a range of trophic levels (Hobson et al., 1995, 2002), from small pelagic zooplankton and fish (Gaston and Jones, 1998) through seabird chicks and the carrion of polar bear kills (Godfrey, 1986). Various seabird species also migrate over a range of distances (Gaston and Jones, 1998; Godfrey, 1986). These behaviors result in a large range of OC concentrations across and within Arctic seabird species.

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Borgå et al. (2001) noted that OC concentrations varied by an order of magnitude among seabird species in the Barents Sea. Concerns about the biological effects of high levels of OCs in some Arctic seabird species, such as glaucous gulls (*L. hyperboreus*), have also been noted. For example, a positive relationship between parasite infestation and OC levels was found in glaucous gulls from Svalbard region (Sagerup et al., 2000).

Stable isotopes of nitrogen ( $\delta^{15}\text{N}$ ) can be used as a tracer of trophic position in marine foodwebs (Hobson and Welch, 1992) and provide a continuous variable to assess the biomagnification of OCs through food webs (Kidd et al., 1998). Slopes of  $\delta^{15}\text{N}$ -[OC] relationships give a relative rate of bioaccumulation or biomagnification in aquatic food chains (Broman et al., 1992; Rolff et al., 1993) and can be used to assign an overall food web magnification factor (FWMF) (Fisk et al., 2001a). However there have been few attempts to use stable isotopes to examine the behavior of OCs within a single group of animals, such as seabirds.

An extensive multidisciplinary study on the Northwater Polynya (NOW), located in northern Baffin Bay, afforded the opportunity to collect seven species of adult seabirds for determination of OCs in liver and fat tissue and  $\delta^{15}\text{N}$  values in muscle. The NOW is an area consisting of year-round open water that is one of the most productive marine areas in the Canadian Arctic. It supports large numbers and many species of seabirds, which occupy a range of trophic levels. Species collected included three alcids [dovekie (*Alle alle*), thick-billed murre (*Uria lomvia*), and black guillemot (*Cephus grylle*)], three larids [(black-legged kittiwake (*Rissa tridactyla*), ivory gull (*Pagophila eburnea*), and glaucous gull) and one procellariid (northern fulmar (*Fulmarus glacialis*)]. These species use several feeding and migration strategies (Table 1) allowing an examination of the effect of these variables on OC concentrations in Arctic seabirds. Results for chlordanes compounds and metabolites, including enantiomeric fractions of chiral components, has been reported previously (Fisk et al., 2001b).

## 2. Methods

### 2.1. Field collection, species and sample size

As part of a larger study, seabirds were collected from the NOW (Fig. 1) in May and June of 1998 by shotgun. All seabirds were determined to be adults based on plumage, time of collection, and the fact that some had developing eggs and others had well developed gonads. Seabirds were dissected shortly after collection, and liver, subcutaneous or abdominal fat, and pectoral muscle samples were placed in Whirl Pak™ bags and frozen until analyzed for stable isotope (muscle only) and OCs (liver and fat). Mass measurements were taken from all seabirds prior to dissection (Table 1). A total of

Table 1  
Biological characteristics of seabird species collected in the Northwater Polynya

Species	Family	n	Muscle $\delta^{15}\text{N}$ <sup>a</sup>	Relative trophic level <sup>b</sup>	Weight (g) <sup>c</sup>	Diet	Migrating species	Month of egg laying	Winter habitat	Ref. <sup>d</sup>
Dovekie	Alcidae	10	11.6±0.3 D	3	161±3.5	Zooplankton/fish	Yes	Late June-early July	St. Lawrence estuary and eastern seaboard of NA	1,2
Thick-billed murre	Alcidae	10	13.8±0.2 B	3.9	957±11.9	Zooplankton/fish	Yes	Late June-early July	North Atlantic, coastal Newfoundland to southern Greenland	2
Black guillemot	Alcidae	9	14.9±0.2 B	4.4	415±13.4	Zooplankton/fish	No	Late June-early July	Arctic ice edges	2
Black-legged kittiwake	Laridae	10	13.3±0.2 C	3.7	387±9.8	Zooplankton/fish	Yes	Late May-June	Eastern seaboard of NA	3
Ivory gull	Laridae	5	14.1±0.3 BCD	4.0	537±25.6	Zooplankton/fish/carrion	No	Late June-early August	Arctic ice edges	4
Glaucous gull	Laridae	11	16.4±0.3 A	5.0	1590±84.6	Zooplankton/fish/carrion/seabird chicks	Yes	June-July	Eastern seaboard of NA and Great Lakes	5
Northern fulmar	Procellariidae	10	14.0±0.15 B	4.0	680±34.2	Zooplankton/fish/carrion	Yes	June	North Atlantic east of Greenland	6

<sup>a</sup>  $\delta^{15}\text{N}$  values are mean ± 1 SE and those with the same letter are not significantly different ( $P < 0.05$ ).

<sup>b</sup> The relative trophic level was calculated assuming the dovekie occupied trophic level 3 and using the equation  $\text{TL} = (\delta^{15}\text{N} - \delta^{15}\text{N}_{\text{dovekie}}) / 2.4 + 3$ , modified from equations described in Hobson et al. (1995).

<sup>c</sup> Weight values are mean ± 1 SE.

<sup>d</sup> References: 1, Stenhouse and Montevecchi (1996); 2, Gaston and Jones (1998); 3, Baird (1994); 4, Haney and Macdonald (1995); 5, Godfrey (1986); 6, Hatch and Nettleship (1998).

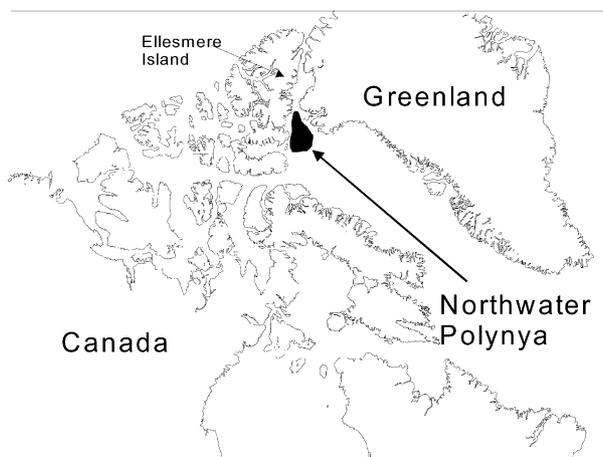


Fig. 1. Approximate location and size of the Northwater Polynya in May/June at the time when seabirds were collected.

65 liver and 60 fat samples were analyzed for OCs. Five birds did not have sufficient fat for collection and analysis. The number of samples analyzed per seabird species and the sex of the seabirds are presented in Tables 2 and 3.

## 2.2. Chemicals and standards

All solvents (pesticide grade) and sodium sulfate ( $\text{Na}_2\text{SO}_4$ ) were obtained from BDH Inc. (Toronto, ON). Pesticide grade Florisil, 60–100 mesh was obtained from the Floridin Corp. (Berkeley Spring, WV, USA). Bio-beads SX-3 used in the GPC column were purchased from Analytical Biochemistry Laboratories Ltd., (Columbia, MO, USA). Non-racemic standards of oxychlordan, heptachlor epoxide, and *cis*- and *trans*-chlordan were obtained from EQ Laboratories (Atlanta, GA, USA). Standards of MC5 and MC7 were donated by M. Ohme (University of Basel, Switzerland).

## 2.3. Stable isotope analysis

Stable-carbon and nitrogen isotope assays were performed on 1 mg sub-samples of homogenized materials by loading into tin cups and combusting at 1800 °C in a Robo-Prep™ elemental analyzer. Resultant  $\text{CO}_2$  and  $\text{N}_2$  gases were then analyzed using an interfaced Europa 20:20 continuous-flow isotope ratio mass spectrometer (CFIRMS) with every 5 unknowns separated by 2 laboratory standards. Stable isotope abundances were expressed in  $\delta$  notation as the deviation from standards in parts per thousand (‰) according to the following equation:

$$\delta^{15}\text{N} = \left[ \left( \frac{R_{\text{sample}}}{R_{\text{standard}}} \right) - 1 \right] \times 1000, \quad (1)$$

where  $R$  is the ratio  $^{15}\text{N}/^{14}\text{N}$ . The  $R_{\text{standard}}$  value was based on atmospheric  $\text{N}_2$ . Replicate measurements of internal laboratory standards (albumen) indicate measurement errors of  $\pm 0.3\text{‰}$ .

## 2.4. Extraction, cleanup and analysis of samples for organochlorines

Sample extraction and cleanup procedures have been published previously (Norstrom et al., 1988; Letcher et al., 1995). Briefly, a representative sample of tissue (approximately 2 and 5 g for fat and liver, respectively) was ground with anhydrous sodium sulfate, spiked with the internal standard [ $\delta$ -hexachlorocyclohexane ( $\delta$ -HCH), 2,2',3,4,4',5,6,6'-octachlorobiphenyl (PCB 204), tris(4-chlorophenyl)methane (TCPMe) and octachloronaphthalene (OCN)] and extracted with 100 ml (1:1) methylene chloride/hexane. A fraction of the extract was used to determine lipids gravimetrically. Lipids were removed from the sample by automated gel permeation chromatography (GPC). The lipid-free eluate, containing the OCs, was evaporated to 1 ml and applied to a Florisil column (8 g, 1.2% deactivated). Organochlorines were recovered by consecutive elution with 35 ml hexane [Fraction 1 (F1)], 38 ml of 85% hexane: 15% DCM (F2), and 52 ml of 50% hexane: 50% DCM (F3). F1 contained 90% of the chlorobenzenes, 75% of *trans*-nonachlor, 50% of the *o,p*-DDE and *o,p*-DDT, 15% of the *p,p*-DDT, 95% of the *p,p*-DDE, and 100% of the PCBs. F2 contained 5% of *p,p*-DDE, 10% of the chlorobenzenes, 25% of *trans*-nonachlor, 50% *o,p*-DDT and *o,p*-DDE, 90% of *p,p*-DDT, and 100% of  $\alpha$ -hexachlorocyclohexane (HCH),  $\beta$ HCH, oxychlordan, *trans*-chlordan, *cis*-chlordan, *o,p*-DDD, *p,p*-DDD and *cis*-nonachlor. Fraction 3 (F3) contained 75% of  $\delta$ HCH, and 100% of heptachlor epoxide and TCPMe. All fractions were roto-evaporated, transferred to 2,2,4-trimethyl pentane and were evaporated to approximately 125 and 1000  $\mu\text{l}$  for liver and fat samples, respectively. Aldrin was added as a volume corrector.

Samples were analyzed on a Hewlett Packard 5890 gas chromatograph (GC) equipped with a 60 m $\times$ 0.25 mm DB-5 column (J & W Scientific, CA, USA) and a  $^{63}\text{Ni}$ -electron capture detector (ECD). The carrier gas was  $\text{H}_2$  and  $\text{N}_2$  was used as the make-up gas for the ECD. External standards were run after every 6 samples. MC5 and MC7 were quantified based on the response of a *cis*-chlordan standard. Across all samples ( $n=125$ ), percent recovery of recovery standards were  $92.0 \pm 1.1$  (mean  $\pm 1$  SE),  $95.2 \pm 1.5$ ,  $93.0 \pm 3.7$  for PCB 204, OCN and  $\delta$ -HCH, respectively. Concentrations of OCs were not corrected for these recoveries.

## 2.5. Statistical analysis

Differences in  $\delta^{15}\text{N}$  values between species, tissues and sex were compared with an ANOVA and a Newman–Keuls *a posteriori* test.

OC concentration data were non-normally distributed and log-transformed before statistical analysis. Lipid

Table 2  
OC concentrations (ng/g wet weight) and lipid content (mean  $\pm$  1 SE) in livers of Arctic seabirds collected in 1998 from northern Baffin Bay<sup>a</sup>

Family species	Alcidae			Laridae			Procellariidae northern fulmar
	Dovekie	Thick-billed murre	Black guillemot	Black-legged kittiwake	Ivory gull	Glaucous gull	
<i>n</i> (sex)	7 (3 F, 4 M)	10 (5 F, 5 M)	9 (2 F, 7 M)	10 (6 F, 4 M)	5 (2 F, 3 M)	11 (6 F, 5 M)	10 (5 F, 5 M)
lipid%	4.0 $\pm$ 0.2	4.1 $\pm$ 0.5	3.4 $\pm$ 0.3	4.1 $\pm$ 0.5	3.4 $\pm$ 0.6	5.6 $\pm$ 0.4	3.8 $\pm$ 0.6
PCBz	0.60 $\pm$ 0.10	1.1 $\pm$ 0.1	0.5 $\pm$ 0.1	1.1 $\pm$ 0.10	1.3 $\pm$ 0.2	2.5 $\pm$ 0.25	0.92 $\pm$ 0.086
HCBz	2.0 $\pm$ 0.33	9.8 $\pm$ 1.2	7.5 $\pm$ 1.2	11.6 $\pm$ 1.1	18.3 $\pm$ 2.6	26.1 $\pm$ 1.8	17.4 $\pm$ 1.6
$\Sigma$ CBz	2.9 $\pm$ 0.47	11.7 $\pm$ 1.3	8.6 $\pm$ 1.4	13.2 $\pm$ 1.2	20.1 $\pm$ 2.8	30.3 $\pm$ 2.1	18.7 $\pm$ 1.7
$\alpha$ HCH	0.54 $\pm$ 0.13	0.30 $\pm$ 0.059	0.3 $\pm$ 0.1	0.17 $\pm$ 0.027	0.16 $\pm$ 0.035	0.18 $\pm$ 0.029	0.33 $\pm$ 0.044
$\beta$ HCH	2.8 $\pm$ 0.67	2.2 $\pm$ 0.34	5.4 $\pm$ 0.7	2.2 $\pm$ 0.28	8.3 $\pm$ 2.3	23.7 $\pm$ 3.6	1.3 $\pm$ 0.12
$\gamma$ HCH	0.17 $\pm$ 0.058	0.19 $\pm$ 0.022	0.05 $\pm$ 0.01	0.12 $\pm$ 0.016	0.054 $\pm$ 0.004	0.063 $\pm$ 0.016	0.080 $\pm$ 0.004
$\Sigma$ HCH	3.5 $\pm$ 0.82	2.6 $\pm$ 0.35	5.7 $\pm$ 0.71	2.5 $\pm$ 0.3	8.5 $\pm$ 2.3	23.9 $\pm$ 3.6	1.8 $\pm$ 1.7
t-Chlordane	0.26 $\pm$ 0.068	0.045 $\pm$ 0.030	nd	nd	nd	nd	Nd
c-Chlordane	0.43 $\pm$ 0.099	0.35 $\pm$ 0.04	0.98 $\pm$ 0.11	0.49 $\pm$ 0.040	1.6 $\pm$ 0.2	1.7 $\pm$ 0.24	0.36 $\pm$ 0.049
t-Nonachlor	3.1 $\pm$ 0.56	0.62 $\pm$ 0.08	5.9 $\pm$ 0.76	3.0 $\pm$ 0.31	19.1 $\pm$ 6.0	21.4 $\pm$ 3.0	3.7 $\pm$ 0.37
c-Nonachlor	1.4 $\pm$ 0.35	1.1 $\pm$ 0.16	6.7 $\pm$ 0.65	2.1 $\pm$ 0.18	5.1 $\pm$ 1.2	7.3 $\pm$ 0.98	0.27 $\pm$ 0.042
MC-5	0.6 $\pm$ 0.1	0.07 $\pm$ 0.01	2.2 $\pm$ 0.3	2.2 $\pm$ 0.3	3.5 $\pm$ 0.9	4.8 $\pm$ 0.6	3.7 $\pm$ 0.5
MC-7	nd	0.04 $\pm$ 0.006	nd	0.04 $\pm$ 0.007	nd	0.1 $\pm$ 0.02	0.077 $\pm$ 0.009
Oxychlordane	1.8 $\pm$ 0.41	3.1 $\pm$ 0.38	4.7 $\pm$ 0.47	11.2 $\pm$ 1.4	41.5 $\pm$ 17.4	59.3 $\pm$ 7.6	73.9 $\pm$ 6.9
HE	2.5 $\pm$ 0.4	1.3 $\pm$ 0.16	4.3 $\pm$ 1.1	6.8 $\pm$ 1.1	19.0 $\pm$ 7.0	25.5 $\pm$ 2.6	13.7 $\pm$ 1.5
$\Sigma$ CHLOR	10.2 $\pm$ 1.9	6.7 $\pm$ 0.72	24.9 $\pm$ 2.5	25.8 $\pm$ 3.0	89.7 $\pm$ 25.9	120 $\pm$ 12.0	95.7 $\pm$ 6.9
<i>p,p'</i> -DDE	8.9 $\pm$ 1.5	31.8 $\pm$ 3.8	51.7 $\pm$ 10.9	56.3 $\pm$ 6.3	252 $\pm$ 49	366 $\pm$ 52.7	149 $\pm$ 18.7
<i>p,p'</i> -DDD	nd	0.49 $\pm$ 0.043	1.4 $\pm$ 0.22	nd	2.5 $\pm$ 1.4	7.6 $\pm$ 2.9	14.8 $\pm$ 2.8
<i>p,p'</i> -DDT	0.50 $\pm$ 0.078	1.1 $\pm$ 0.09	1.5 $\pm$ 0.23	2.7 $\pm$ 0.3	6.5 $\pm$ 1.4	8.4 $\pm$ 1.3	10.1 $\pm$ 1.8
$\Sigma$ DDT	9.4 $\pm$ 1.5	33.4 $\pm$ 3.8	54.5 $\pm$ 11.0	58.9 $\pm$ 6.5	260 $\pm$ 50.6	382 $\pm$ 52	174 $\pm$ 22.9
OCS	0.15 $\pm$ 0.01	0.41 $\pm$ 0.05	0.51 $\pm$ 0.08	0.75 $\pm$ 0.09	0.65 $\pm$ 0.08	0.76 $\pm$ 0.08	3.7 $\pm$ 0.5
Dieldrin	4.4 $\pm$ 0.5	4.1 $\pm$ 0.5	7.9 $\pm$ 1.7	12.7 $\pm$ 1.5	29.3 $\pm$ 6.6	34.8 $\pm$ 4.2	20.5 $\pm$ 2.2
Mirex	0.24 $\pm$ 0.03	0.43 $\pm$ 0.06	1.3 $\pm$ 0.4	3.1 $\pm$ 0.3	7.1 $\pm$ 1.8	9.4 $\pm$ 2.0	4.1 $\pm$ 0.5
PCB 28	0.4 $\pm$ 0.1	1.2 $\pm$ 0.2	0.9 $\pm$ 0.1	2.9 $\pm$ 0.4	2.7 $\pm$ 0.4	4.9 $\pm$ 0.6	2.0 $\pm$ 0.2
PCB 31	nd	nd	nd	nd	nd	0.2 $\pm$ 0.0	nd
PCB 52	nd	nd	nd	nd	nd	2.3 $\pm$ 0.5	nd
PCB 101	0.7 $\pm$ 0.1	0.8 $\pm$ 0.1	2.8 $\pm$ 0.4	2.6 $\pm$ 0.2	3.9 $\pm$ 0.5	8.3 $\pm$ 1.0	0.4 $\pm$ 0.0
PCB 105	0.4 $\pm$ 0.1	1.4 $\pm$ 0.3	1.5 $\pm$ 0.2	3.2 $\pm$ 0.3	7.0 $\pm$ 1.4	8.5 $\pm$ 1.0	5.5 $\pm$ 0.8
PCB 118	1.5 $\pm$ 0.2	3.6 $\pm$ 0.5	5.8 $\pm$ 0.9	11.2 $\pm$ 1.1	26.8 $\pm$ 5.5	35.1 $\pm$ 4.6	16.6 $\pm$ 2.1
PCB 138	2.4 $\pm$ 0.3	5.2 $\pm$ 0.8	6.6 $\pm$ 1.5	22.5 $\pm$ 2.1	50.7 $\pm$ 11.4	66.0 $\pm$ 9.8	20.0 $\pm$ 2.4
PCB 153	3.3 $\pm$ 0.5	6.3 $\pm$ 1.0	9.4 $\pm$ 2.4	25.5 $\pm$ 2.4	65.4 $\pm$ 14.9	93.6 $\pm$ 17.6	34.3 $\pm$ 3.6
PCB 156	0	0.7 $\pm$ 0.1	1.0 $\pm$ 0.2	3.9 $\pm$ 0.4	9.3 $\pm$ 2.4	11.4 $\pm$ 3.1	47.5 $\pm$ 0.6
PCB 180	1.0 $\pm$ 0.2	2.0 $\pm$ 0.3	3.6 $\pm$ 1.2	14.0 $\pm$ 1.4	34.1 $\pm$ 8.6	49.3 $\pm$ 13.5	20.7 $\pm$ 2.5
$\Sigma_{10}$ PCB	9.6 $\pm$ 1.4	21.4 $\pm$ 3.2	31.6 $\pm$ 6.8	85.9 $\pm$ 8.1	200 $\pm$ 44.7	280 $\pm$ 49.1	104 $\pm$ 12.1
$\Sigma$ PCB	15.7 $\pm$ 3.2	37.3 $\pm$ 5.1	59.6 $\pm$ 11.3	143 $\pm$ 13.4	325 $\pm$ 71.3	453 $\pm$ 75.2	158 $\pm$ 18.5
% of PCB 10	61.15	57.37	53.02	60.07	61.54	61.81	65.82

<sup>a</sup>  $\Sigma$ OC concentrations, except  $\Sigma$ DDT, were not found to vary between sexes and were combined. The 10 PCB congeners reported are the most commonly measured in Arctic biota (de March et al., 1998) (nd, non-detect; detection limits approximately 0.02 ng/g).

content was found to be statistically different between tissues and among species (General linear model (GLM),  $P < 0.05$ ) and therefore all concentrations were lipid normalized ([OC]/lipid percentage) prior to statistical analysis. Variation in the contaminant data was examined at the  $\Sigma$ OC group level. The influence of four variables (species, tissue, sex, and  $\delta^{15}\text{N}$  value) on OC concentrations were first examined with a GLM using the following equation:

$$\text{Log} [\Sigma\text{OC}] = \mu + \delta^{15}\text{N} + \text{species} + \text{tissue} + \text{sex} + \epsilon,$$

where  $\Sigma$ OC is the sum of concentrations of  $\Sigma$ CIBz,  $\Sigma$ HCH,  $\Sigma$ CHLOR,  $\Sigma$ DDT or  $\Sigma$ PCB,  $\mu$  is a constant

and  $\epsilon$  is an error term. The significance of each variable was then assessed with type III sum of squares test using SAS for Windows.

The influence of tissue on  $\Sigma$ OC concentrations in seabirds was found to be significant, and therefore a separate GLM was run for fat and liver for each  $\Sigma$ OC group using the equation:

$$\text{Log} [\Sigma\text{OC}] = \mu + \delta^{15}\text{N} + \text{species} + \text{sex} + \epsilon, \quad (2)$$

where  $\Sigma$ OC is the sum of concentrations of  $\Sigma$ CIBz,  $\Sigma$ HCH,  $\Sigma$ CHLOR,  $\Sigma$ DDT or  $\Sigma$ PCB in fat or liver,  $\mu$  is a constant and  $\epsilon$  is an error term. The significance of each variable was then assessed with type III sum of squares test. Differences in OC concentrations between species

Table 3  
OC concentrations (ng/g wet weight) and lipid content (mean  $\pm$  1 SE) in fat of Arctic seabirds collected in 1998 from northern Baffin Bay<sup>a</sup>

Family species	Alcidae			Laridae			Procellariidae Northern fulmar
	Dovekie	Thick-billed murre	Black guillemot	Black-legged kittiwake	Ivory gull	Glaucous gull	
<i>n</i>	10 (5 F, 5 M)	10 (5 F, 5 M)	7 (1 F, 6 M)	8 (5 F, 3 M)	4 (2 F, 2 M)	11 (6 F, 5 M)	10 (5 F, 5 M)
lipid%	63.7 $\pm$ 2.1	60.0 $\pm$ 1.9	60.0 $\pm$ 6.0	72.4 $\pm$ 3.9	81.1 $\pm$ 5.0	72.8 $\pm$ 4.2	71.9 $\pm$ 4.0
PCBz	21.3 $\pm$ 2.5	16.7 $\pm$ 1.2	26.8 $\pm$ 3.6	21.5 $\pm$ 2.3	40.2 $\pm$ 13.4	49.8 $\pm$ 3.1	34.7 $\pm$ 1.4
HCBz	63.5 $\pm$ 5.4	149 $\pm$ 13.6	222 $\pm$ 25.4	186 $\pm$ 19.1	396 $\pm$ 108	427 $\pm$ 31.9	410 $\pm$ 29.9
$\Sigma$ CBz	102 $\pm$ 8.3	178 $\pm$ 15.0	277 $\pm$ 32.4	223 $\pm$ 84.7	459 $\pm$ 129	508 $\pm$ 35.8	460 $\pm$ 31.2
$\alpha$ HCH	42.9 $\pm$ 8.5	11.4 $\pm$ 1.1	44.2 $\pm$ 5.6	4.8 $\pm$ 0.4	9.3 $\pm$ 3.0	13.1 $\pm$ 3.6	14.1 $\pm$ 1.3
$\beta$ HCH	93.9 $\pm$ 5.2	35.4 $\pm$ 4.2	111 $\pm$ 15.6	25.0 $\pm$ 2.7	99.7 $\pm$ 19.8	310 $\pm$ 36.3	29.3 $\pm$ 2.3
$\gamma$ HCH	12.2 $\pm$ 2.0	3.8 $\pm$ 0.31	5.7 $\pm$ 0.8	3.0 $\pm$ 0.25	3.2 $\pm$ 0.5	2.4 $\pm$ 0.2	2.8 $\pm$ 0.23
$\Sigma$ HCH	149 $\pm$ 12.4	50.6 $\pm$ 4.1	161 $\pm$ 20.6	32.8 $\pm$ 3.0	112 $\pm$ 21.1	327 $\pm$ 39.0	45.2 $\pm$ 3.0
t-Chlordane	8.9 $\pm$ 2.2	Nd	nd	nd	nd	nd	nd
c-Chlordane	18.0 $\pm$ 2.5	7.7 $\pm$ 0.77	22.4 $\pm$ 3.0	11.1 $\pm$ 1.1	45.1 $\pm$ 14.6	44.6 $\pm$ 6.5	11.1 $\pm$ 0.89
t-Nonachl	147 $\pm$ 10.5	15.2 $\pm$ 1.3	140 $\pm$ 17.6	59.7 $\pm$ 5.6	428 $\pm$ 163	407 $\pm$ 52.3	124 $\pm$ 14.3
c-Nonachl	71.2 $\pm$ 5.1	25.2 $\pm$ 4.0	189 $\pm$ 24.2	34.1 $\pm$ 2.1	92.2 $\pm$ 42.9	135 $\pm$ 15.1	4.6 $\pm$ 0.41
MC-5	48.5 $\pm$ 5.5	9.0 $\pm$ 1.0	89.0 $\pm$ 11	55.8 $\pm$ 5.3	60.1 $\pm$ 3.3	107 $\pm$ 10.4	98.0 $\pm$ 9.1
MC-7	0.78 $\pm$ 0.12	0.70 $\pm$ 0.089	0.85 $\pm$ 0.13	0.66 $\pm$ 0.05	0.86 $\pm$ 0.5	1.5 $\pm$ 0.2	0.67 $\pm$ 0.06
Oxychlordane	69.7 $\pm$ 5.4	66.1 $\pm$ 6.7	138 $\pm$ 15.5	155 $\pm$ 16.7	698 $\pm$ 175	888 $\pm$ 104	847 $\pm$ 8.8
HE	94.9 $\pm$ 7.4	34.6 $\pm$ 4.7	101 $\pm$ 8.9	68.3 $\pm$ 9.1	293 $\pm$ 95.6	401 $\pm$ 32.9	110 $\pm$ 18.6
$\Sigma$ CHLOR	459 $\pm$ 32.8	158 $\pm$ 14.9	681 $\pm$ 75.9	385 $\pm$ 33.9	1618 $\pm$ 297	1985 $\pm$ 196	1195 $\pm$ 92.1
<i>p,p'</i> -DDE	348 $\pm$ 31.8	621 $\pm$ 56.1	533 $\pm$ 68.4	859 $\pm$ 141	5497 $\pm$ 474	3886 $\pm$ 301	3093 $\pm$ 363
<i>p,p'</i> -DDD	nd	10.1 $\pm$ 0.90	38.1 $\pm$ 5.3	12.5 $\pm$ 0.82	nd	36.1 $\pm$ 7.4	49.3 $\pm$ 5.8
<i>p,p'</i> -DDT	16.0 $\pm$ 2.4	26.4 $\pm$ 2.5	31.0 $\pm$ 2.3	49.8 $\pm$ 6.6	220 $\pm$ 97.1	414 $\pm$ 94.7	360 $\pm$ 59.6
$\Sigma$ DDT	364 $\pm$ 63.5	658 $\pm$ 57.2	602 $\pm$ 74.6	921 $\pm$ 147	5717 $\pm$ 463	4336 $\pm$ 355	3502 $\pm$ 422
OCS	5.1 $\pm$ 0.64	8.2 $\pm$ 0.88	11.7 $\pm$ 1.7	11.6 $\pm$ 1.7	15.4 $\pm$ 2.1	15.2 $\pm$ 1.6	28.8 $\pm$ 3.6
Dieldrin	175 $\pm$ 14.8	76.4 $\pm$ 9.6	135 $\pm$ 15	103 $\pm$ 10.7	292 $\pm$ 41.9	389 $\pm$ 53.9	133 $\pm$ 17.0
Mirex	10.1 $\pm$ 1.1	11.4 $\pm$ 1.1	16.7 $\pm$ 2.3	64.2 $\pm$ 10.0	203 $\pm$ 15.9	226 $\pm$ 54.5	162 $\pm$ 24.0
PCB 28	15.8 $\pm$ 1.0	23.4 $\pm$ 1.9	27.4 $\pm$ 4.3	48.5 $\pm$ 5.8	86.0 $\pm$ 16.5	121 $\pm$ 13.8	79.2 $\pm$ 6.3
PCB 31	nd	0.27 $\pm$ 0.1	3.8 $\pm$ 0.6	1.3 $\pm$ 0.1	0.9 $\pm$ 0.1	5.3 $\pm$ 1.4	0.4 $\pm$ 0.1
PCB 52	4.6 $\pm$ 0.5	nd	13.6 $\pm$ 2.4	0.2 $\pm$ 0.2	nd	68.6 $\pm$ 10.1	nd
PCB 101	9.9 $\pm$ 1.6	12.2 $\pm$ 1.5	74.6 $\pm$ 12.7	22.1 $\pm$ 3.2	94.9 $\pm$ 19.4	193 $\pm$ 2.6	17.7 $\pm$ 3.6
PCB 105	9.1 $\pm$ 1.8	17.9 $\pm$ 3.0	24.3 $\pm$ 4.2	60.9 $\pm$ 12.7	192 $\pm$ 14.0	223 $\pm$ 38.4	231 $\pm$ 34.7
PCB 118	64.1 $\pm$ 5.6	71.4 $\pm$ 5.8	133 $\pm$ 17.5	273 $\pm$ 39.5	1011 $\pm$ 70.1	977 $\pm$ 146	674 $\pm$ 84.3
PCB 138	87.8 $\pm$ 9.6	104 $\pm$ 10.4	157 $\pm$ 21.5	536 $\pm$ 74.3	1784 $\pm$ 129	1680 $\pm$ 242	782 $\pm$ 109
PCB 153	127 $\pm$ 14	154 $\pm$ 15.7	237 $\pm$ 32.7	762 $\pm$ 105	3089 $\pm$ 221	3188 $\pm$ 522	1915 $\pm$ 222
PCB 156	Nd	14.3 $\pm$ 1.2	16.9 $\pm$ 2.8	66.1 $\pm$ 15.6	206 $\pm$ 23.1	226 $\pm$ 70.3	174 $\pm$ 21.6
PCB 180	47.6 $\pm$ 5.4	36.4 $\pm$ 5.9	47.8 $\pm$ 6.6	366 $\pm$ 58.2	1235 $\pm$ 92.9	781 $\pm$ 137	922 $\pm$ 131
$\Sigma_{10}$ PCB	366 $\pm$ 38	434 $\pm$ 41	737 $\pm$ 103	2137 $\pm$ 300	7702 $\pm$ 527	7465 $\pm$ 1053	4795 $\pm$ 603
$\Sigma$ PCB	635 $\pm$ 63.5	772 $\pm$ 62.2	1263 $\pm$ 177	3343 $\pm$ 480	11664 $\pm$ 796	11719 $\pm$ 1891	6832 $\pm$ 894
% of PCB in 10	57.64	56.22	58.35	63.92	66.03	63.70	70.18

<sup>a</sup>  $\Sigma$ OC concentrations were not found to vary between sexes and were combined. The 10 PCB congeners reported are the most commonly measured in Arctic biota (de March et al., 1998) (nd, non-detect; detection limits approximately 0.02 ng/g).

were compared with a Scheffe's aposteriori test. All statistical tests were performed with SAS for Windows Version 8.0 (SAS Inc., Cary, NC).

### 3. Results

#### 3.1. Characteristics of seabirds

All seabirds used for organochlorine analysis appeared in good nutritional condition; that is, there were no visual signs of wasting or malnutrition and subcutaneous fat levels were normal. Mean  $\delta^{15}\text{N}$  values in muscle and masses of seabird species are presented in

Table 1.  $\delta^{15}\text{N}$  values differed significantly among seabird species ( $P < 0.001$ ; ANOVA,  $F$ -value = 47.1,  $df = 6,44$ ,  $n = 58$ ) but not between sexes within species ( $P = 0.25$ ; ANOVA,  $F$ -value = 1.46,  $df = 1,44$ ,  $n = 58$ ) or species  $\times$  sex ( $P = 0.73$ ; ANOVA,  $F$ -value = 0.59,  $df = 6,44$ ,  $n = 58$ ). Based on  $\delta^{15}\text{N}$  results, glaucous gulls were feeding at the highest trophic level followed by black guillemot, ivory gull, northern fulmar, thick-billed murre, black legged kittiwake and dovekie (Table 1).

#### 3.2. Concentrations and relative proportions of OCs

Wet weight concentrations of OC groups in liver and fat are summarized in Tables 2 and 3, respectively.

Concentrations of  $\Sigma$ PCB were the highest among the OC groups observed in all seabird species, and attained the highest concentrations in the gulls (glaucous gulls, ivory gull and black-legged kittiwake) and the procellariid (northern fulmar).  $\Sigma$ DDT and  $\Sigma$ CHLOR were the next OC groups with the next highest concentrations followed by  $\Sigma$ CIBz and  $\Sigma$ HCH. The relative proportions of  $\Sigma$ OC groups varied between liver and fat and between species (Fig. 2).

$\Sigma$ DDT, which was 86–97% *p,p'*-DDT in the liver and fat of all 7 seabird species, had the highest concentrations of any individual OC compound, followed by PCBs 138 and 153 and oxychlorane. The ten PCB congeners commonly measured in Arctic biota (de March et al., 1998) describe 53–70% of the total PCB burden in the liver and fat of all 7 seabird species. Oxychlorane was 15–20% of  $\Sigma$ CHLOR in dovekie and black guillemot but 40–49% in the gulls and thick-billed murre and 71–77% in northern fulmar. The remainder was largely *trans*-nonachlor and heptachlor epoxide.  $\Sigma$ CIBz was 62–93% hexachlorobenzene, 5–21% pentachlorobenzene and 3–12% tetrachlorobenzenes.

$\Sigma$ HCH was 1–29%  $\alpha$ -HCH and 63–99  $\beta$ -HCH, but for most species was >85%  $\beta$ -HCH.

### 3.3. Variables influencing OC concentrations

Significant differences in OC concentrations (lipid basis) between all species pairs were observed for all  $\Sigma$ OC groups when liver and fat data were combined ( $P < 0.0001$ ; GLM, all  $F$ -values  $> 10.2$ ,  $df = 1,6$ ,  $n = 113$ , all  $P$ -values  $< 0.05$ ). Significant differences between fat and liver using all species were present for  $\Sigma$ CIBz,  $\Sigma$ HCH, and  $\Sigma$ PCB ( $P < 0.05$  GLM,  $F$ -value = 6.62, 4.10, 27.29 respectively,  $df = 1,1$ ,  $n = 113$ ) but not for  $\Sigma$ CHLOR and  $\Sigma$ DDT. Concentrations (lipid basis) of  $\Sigma$ CIBz were higher in liver but  $\Sigma$ HCH and  $\Sigma$ PCB were greater in fat. Due to the significance of tissue on a number of  $\Sigma$ OC group concentrations, further statistical analyses were run separately for liver and fat. Lipid-corrected concentrations of OC components did not significantly vary between sex for any species, except  $\Sigma$ DDT in liver tissue ( $P = 0.0137$ ; GLM,  $F$ -value = 6.60,  $df = 1,6$ ,  $n = 57$ ) where concentrations in females were

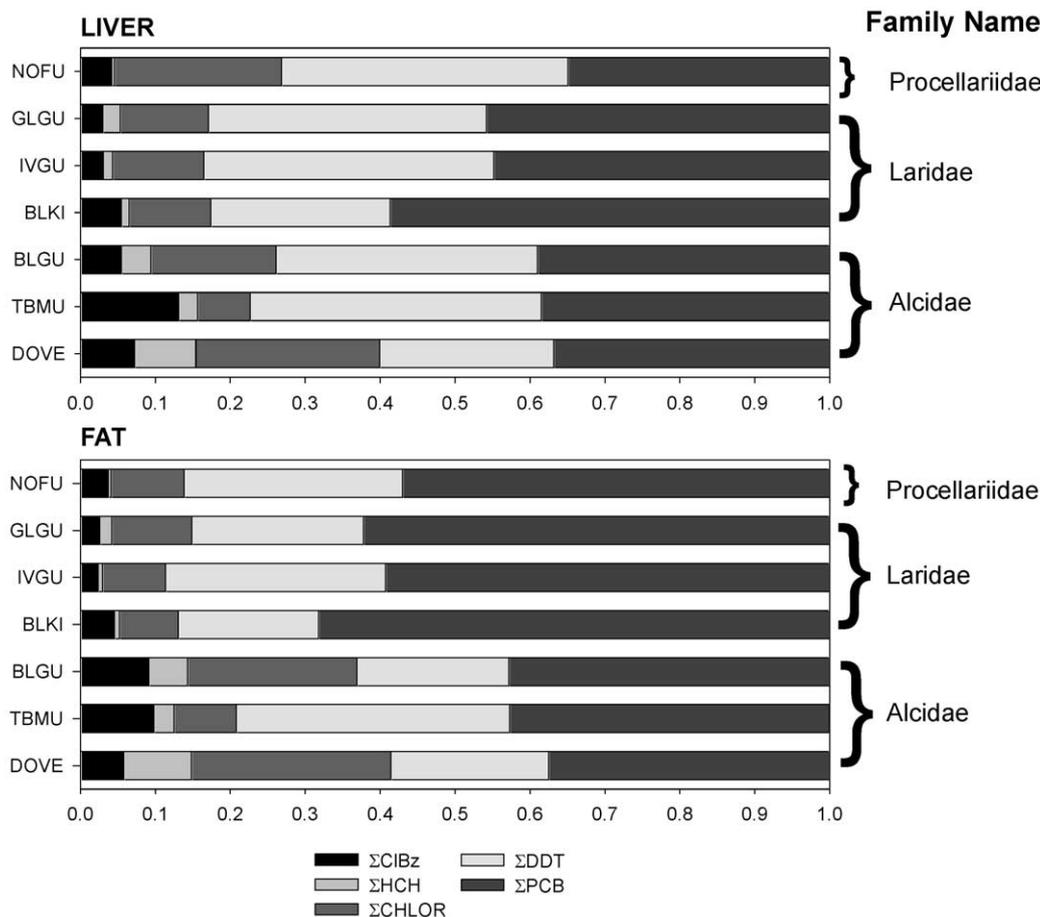


Fig. 2. Relative proportions of  $\Sigma$ OC groups in the liver and fat of Arctic seabirds from northern Baffin Bay. Sample numbers and concentrations are presented in Tables 2 and 3. Species codes: DOVE = dovekie, TBMU = thick-billed murre, BLGU = black guillemot, BLKI = black legged kittiwake, IVGU = ivory gull, GLGU = glaucous gull and NOFU = northern fulmar.

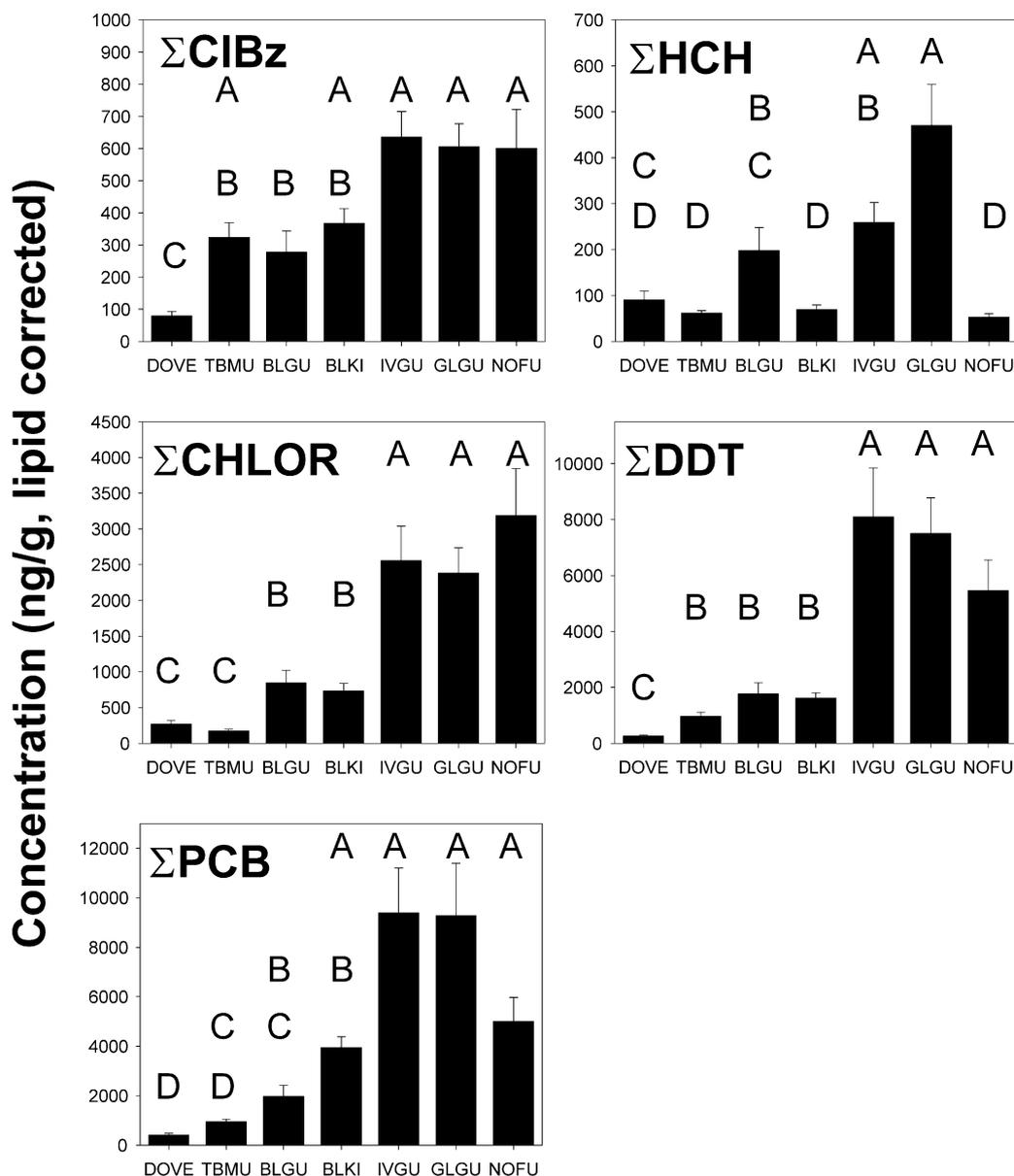


Fig. 3. Lipid corrected concentrations (mean  $\pm$  SE, ng/g) of  $\Sigma$ CIBz,  $\Sigma$ HCH,  $\Sigma$ CHLOR,  $\Sigma$ DDT and  $\Sigma$ PCB in liver tissue of NOW seabirds. Male and female did not significantly differ ( $P < 0.05$ ) except for  $\Sigma$ DDT, and were combined. Bars with same letter do not differ significantly ( $P > 0.05$ ). Species codes: DOVE = dovekie, TBMU = thick-billed murre, BLGU = black guillemot, BLKI = black legged kittiwake, IVGU = ivory gull, GLGU = glaucous gull and NOFU = northern fulmar.

found to be lower than males. Comparison of OC concentrations in liver between species is presented in Fig. 3. In general, statistically significant differences between species for each  $\Sigma$ OC group were similar for both liver and fat (data not shown), although some exceptions exist. Values of  $\delta^{15}\text{N}$  was found to be a significant variable influencing  $\Sigma$ HCH concentrations ( $P < 0.01$ , 0.02; GLM,  $F$ -value = 7.56, 6.04,  $df = 1, 6$ , 1, 6,  $n = 57$ , 55 for liver and fat, respectively), but not for the other  $\Sigma$ OC groups in both liver and in fat using the GLM. Significant linear regressions were found between concentrations of all  $\Sigma$ OC groups and  $\delta^{15}\text{N}$  values for both liver and fat (Table 4 and Fig. 4).

#### 4. Discussion

This study shows the importance of trophic position, as described by consumer tissue  $\delta^{15}\text{N}$  values, and bio-magnification to observed OC concentrations in Arctic seabirds. Concentrations of OCs varied between seabird species, with the highest concentrations (lipid or wet weight basis) in the higher trophic level seabirds. Positive linear relationships between  $\delta^{15}\text{N}$  values and lipid-based OC concentration were found for all OC groups (Fig. 4). Although  $\delta^{15}\text{N}$  value was not found to be a significant variable describing OC concentration among species using GLM analysis, most of the variability

Table 4  
Intercepts, slopes, coefficient of determination and *P*-values for log [OC] (lipid basis)- $\delta^{15}\text{N}$  regression in Arctic seabirds from northern Baffin Bay

Organo chlorine component	Intercept	Slope	$r^2$	<i>P</i> -value
<i>Liver</i>				
$\Sigma\text{CIBz}$	8.315	0.309	0.294	<0.001
$\Sigma\text{HCH}$	5.438	0.435	0.447	<0.001
$\Sigma\text{CHLOR}$	7.901	0.405	0.235	<0.001
$\Sigma\text{DDT}$	6.588	0.558	0.413	<0.001
$\Sigma\text{PCB}$	8.066	0.471	0.325	<0.001
<i>Fat</i>				
$\Sigma\text{CIBz}$	8.658	0.299	0.474	<0.001
$\Sigma\text{HCH}$	8.351	0.244	0.172	0.001
$\Sigma\text{CHLOR}$	9.423	0.308	0.271	<0.001
$\Sigma\text{DDT}$	8.827	0.402	0.349	<0.001
$\Sigma\text{PCB}$	8.903	0.447	0.338	<0.001

described by  $\delta^{15}\text{N}$  value was accounted for in the GLM analysis by species. Significant relationships between OC concentrations and  $\delta^{15}\text{N}$  values (Hop et al., 2002) and trophic level based on  $\delta^{15}\text{N}$  value (Fisk et al., 2001a) have been observed in Arctic marine food webs. These food web relationships were stronger than those observed within the subset of seabirds in this study (i.e. had a higher *P*-value).

The slope of the [OC]- $\delta^{15}\text{N}$  relationship gives an estimate of the magnitude of biomagnification between different OC groups (Fisk et al., 2001a; Borgå et al., 2001; Broman et al., 1992; Rolff et al., 1993). The greatest slopes were observed for PCBs and DDT (Table 4), which is due to their high hydrophobicity and recalcitrant nature. These results demonstrate that the chemical-physical properties of OCs are a significant variable influencing their levels in Arctic seabirds. Similar conclusions were made for an entire Arctic marine food web that included invertebrates, fish, seabirds and marine mammals (Fisk et al., 2001a).

OC concentrations in a number of seabird species consistently fell below or above the  $\delta^{15}\text{N}$ -[OC] relationships, providing insights into other factors that influence OC concentrations. That is, OC concentrations in a number of species were lower or higher than expected based on their muscle  $\delta^{15}\text{N}$  value or trophic level. For example, concentrations of most OCs in ivory gull and northern fulmar, species known to scavenge on marine mammal carcasses and offal (Salmonsén, 1950; Renaud and McLaren, 1982; Hobson and Welch, 1992; Hatch and Nettleship, 1998), were higher than expected based on their  $\delta^{15}\text{N}$  values. This likely reflects occasional increased exposure to OCs via the scavenging on marine mammals as such activity would not result in long-term average trophic increase (based on muscle protein  $\delta^{15}\text{N}$  values) per se but would result in a pulse of contaminants that would be stored in fats (Muir et al., 1995; Fisk et al., 2001a). The half-life of most OCs are

much longer (e.g.,  $t_{1/2}$  of most persistent PCBs in birds are >1 year; Clark et al., 1987) than that of the turnover rate of elemental nitrogen in muscle ( $t_{1/2}$  muscle in birds <30 days; Hobson and Clark, 1992). Therefore, the levels of OCs would remain elevated compared with  $\delta^{15}\text{N}$  values for a significant length of time after a scavenging event, pushing that seabird above the expected [OC]- $\delta^{15}\text{N}$  relationship.

Periodic migration to areas of differing OC contamination will also result in OC burdens in seabirds that differ from location-specific  $\delta^{15}\text{N}$ -[OC] relationship. Seabirds migrating to a more contaminated region will have OC concentrations that are lower than expected based on their muscle  $\delta^{15}\text{N}$  values associated with the less contaminated area. Conversely, periodic migration to a less contaminated region would result in OC burdens that are lower than expected. The influence of migration is apparent in the relatively high PCB concentrations observed in the black-legged kittiwake. This species does not scavenge, feeding on a diet of zooplankton and fish, but migrates to the eastern seaboard of North America (Baird, 1994). This migration results in exposure to most OCs, particularly PCBs, which occur in higher concentrations than found in the northern Baffin Bay region (de March et al., 1998). The other migrating species in this study do not make as far a journey as the kittiwake and therefore the discrepancy in OC concentrations in winter and summer habitats is likely not as large as that seen for kittiwakes.

Further evidence of the influence of migration and scavenging is the linear relationships seen when only the non-scavenging, non- or limited-migrating species are examined. These included dovekie, thick-billed murre (non-scavenging) and black guillemot (non- or limited-migrating species). For most OCs the concentrations in these species are lower than migrating and/or scavenging seabirds of similar  $\delta^{15}\text{N}$  or trophic level values.

The influence of migration on OC levels in seabirds in relation to expected concentrations based on the local food web needs to be put in perspective. The time for the OC levels in a seabird to approach the [OC]- $\delta^{15}\text{N}$  value relationship for a new region will vary with the whole body half-life of the chemical and the difference in the level of contamination in the two regions. Chemicals which have a shorter half life in birds will more rapidly approach the [OC]- $\delta^{15}\text{N}$  relationship for the new region than chemicals that have a long half life. This is observed for  $\Sigma\text{CIBz}$  and  $\Sigma\text{HCH}$ , the OCs that likely have among the shortest half lives of the chemicals included in this study (Clark et al., 1987). There is much less variability in concentrations of  $\Sigma\text{CIBz}$  and  $\Sigma\text{HCH}$  among the seabird species than for the other OC groups ( $\Sigma\text{PCBs}$ ,  $\Sigma\text{DDT}$  and  $\Sigma\text{CHLOR}$ ), which are dominated by longer half-life components, such as CB153, CB180, *p,p'*-DDE and oxychlorane (Clark et al., 1987; Drouillard et al., 2001).

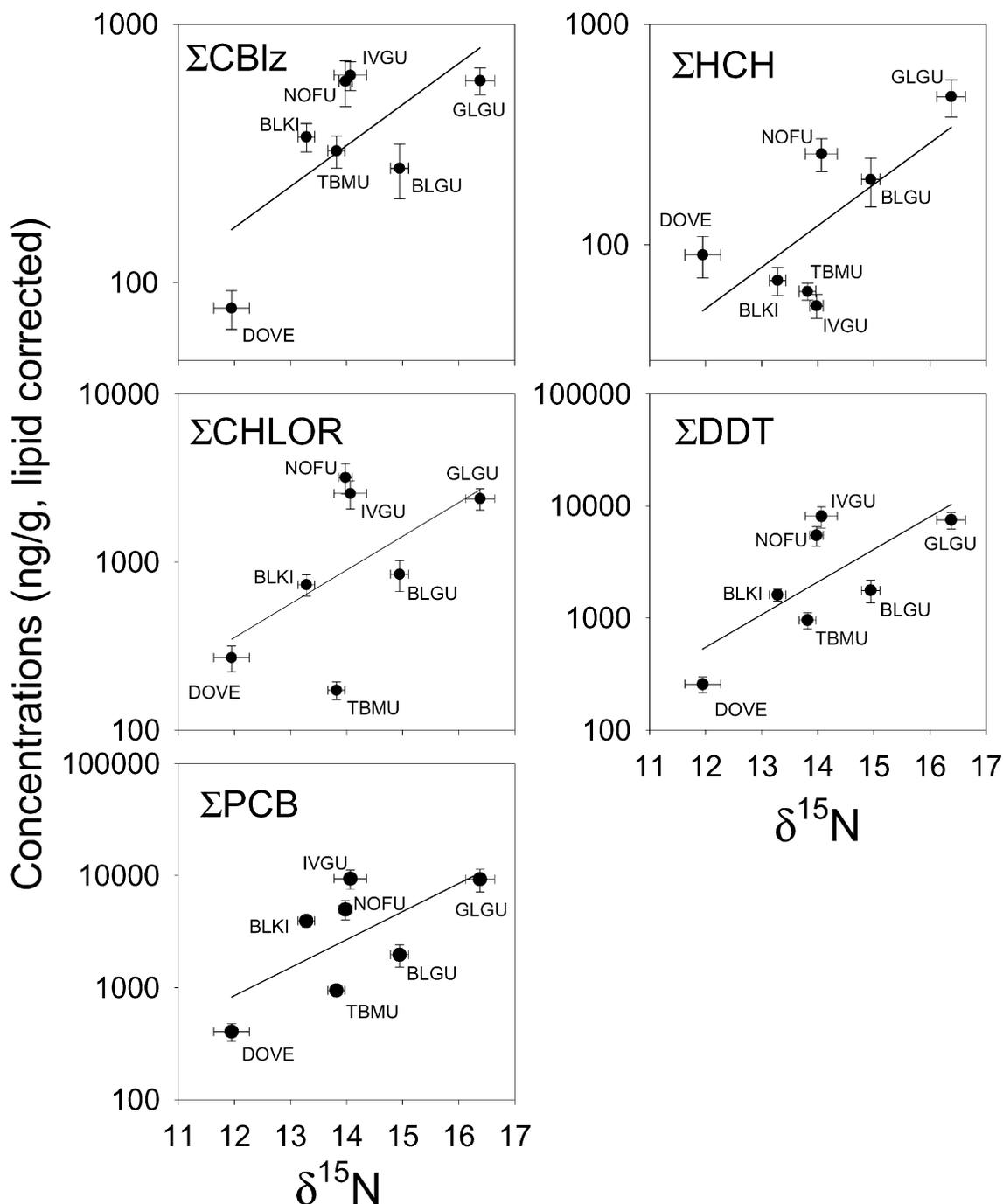


Fig. 4.  $\delta^{15}\text{N}$ -OC concentration ( $\Sigma\text{CIBz}$ ,  $\Sigma\text{HCH}$ ,  $\Sigma\text{CHLOR}$ ,  $\Sigma\text{DDT}$ , and  $\Sigma\text{PCB}$ ) relationship in NOW seabird livers. Species codes: DOVE = dovekie, TBMU = thick-billed murre, BLGU = black guillemot, BLKI = black legged kittiwake, IVGU = ivory gull, GLGU = glaucous gull and NOFU = northern fulmar. See Table 5 for statistics.

Biotransformation can also influence OC concentration in seabirds, resulting in levels that are lower than expected based on the  $[\text{OC}]-\delta^{15}\text{N}$  relationship. Examples are the chlordane levels in thick-billed murre and HCH levels in the ivory gull, which are much lower than expected compared to other seabird species. Recent papers on chlordane in these seabirds (Fisk et al., 2001b) and HCHs in the north Baffin Bay food web (Moisey et al., 2001) provide additional evidence that

biotransformation selectively reduces concentrations of these OCs in some species.

#### 4.1. Relative proportions of OCs in seabirds

The relative proportions of OCs differed between seabird families providing more evidence of the influence of trophic position, migration and biotransformation on OC levels in seabirds. The proportions of OCs

followed the phylogenetic relationship (i.e., family groups) among the seabird species, with a general decrease in the relative amounts of  $\Sigma$ HCH,  $\Sigma$ CHLOR, and  $\Sigma$ CIBz but an increase in  $\Sigma$ DDT and  $\Sigma$ PCB from alcids to larids and procellariids (Fig. 2). With the exception of the black guillemot, the larids and procellariids feed at a higher trophic level than alcids. Therefore, this increase in relative proportion of the PCBs and DDTs between families is due to a large extent to the process of biomagnification.

Biomagnification, however, is not the only process that drives the relative proportions of OCs in seabirds. Two species, black guillemot and black-legged kittiwake, do not feed at the same trophic level yet have similar relative proportions of OCs as the other species in their respective families. Black guillemot, an alcid, fed at the second highest trophic position, based on  $\delta^{15}\text{N}$  values, but had an OC profile similar to its lower trophic-level family members, thick billed murres and dovekies. Black guillemots in the North Water do not migrate to southerly habitats (Renaud and Bradstreet, 1980) or scavenge (Robards et al., 2000). Therefore the higher proportions of PCBs observed in the Procellariidae and Laridae species may be due in part to migration and the scavenging by those species on higher trophic level organisms, as discussed above, which would have a high proportion of PCBs compared to zooplankton and fish (Borgå et al., 2001). The high proportion of PCBs in the black-legged kittiwake is likely due to migration south, as discussed above.

#### 4.2. Tissues

OC concentrations (wet weight) were greater in fat than liver for all OC groups across all seabird species. This is due to the high lipid content of fat and is expected because of the hydrophobic nature of OCs (Mackay et al., 1999). On a lipid basis, concentrations of  $\Sigma$ DDT and  $\Sigma$ CHLOR did not vary between tissues but  $\Sigma$ HCH and  $\Sigma$ PCB concentrations were greater in fat than liver and  $\Sigma$ CIBz levels were higher in liver. These differences between liver and fat for some OC groups are due to a combination of tissue-specific retention other than solubility in lipids (e.g., binding to CYP proteins in liver), behavior of the seabird species and dilution of hepatic lipid with dietary lipid having lower OC concentration than in the bird's lipid (Drouillard and Norstrom, 2000).

Changes in feeding behavior can also influence differences in OC concentrations between tissues. A prime example of this is the dovekie. At the time of collection, this species was feeding on small zooplankton (e.g., Calanoid copepods) in preparation for reproduction (Karnovsky and Hunt, 2002). Later in the year the dovekie consumed more fish (Karnovsky and Hunt, 2002). These low trophic level zooplankton have lower OC concentrations than pelagic fish (Fisk et al., 2001a).

Biotransformation may also result in lower concentrations in the liver compared with fat as the liver is an active site of biotransformation. This may occur with HCH, as seabirds are known to readily biotransform both  $\alpha$ - and  $\gamma$ -HCH (Moisey et al., 2001) but this would seem unlikely for the PCBs, as a majority of PCB congeners constituting  $\Sigma$ PCB are recalcitrant in birds (Drouillard et al., 2001).

#### 4.3. Gender

Significant gender differences in lipid-corrected concentrations were only observed for  $\Sigma$ DDT in liver suggesting that reproduction, in particular egg laying, did not have a lasting effect on OC concentrations in these Arctic seabird species. The seabirds for this study were collected prior to their egg laying season, which generally occurs in June and July, and egg laying could influence OC levels in female seabirds after the eggs are laid. This is only significant for birds that produced a large number of high lipid eggs (Drouillard and Norstrom, 2000).

#### 4.4. Comparison to other studies

In general, levels of OCs in the NOW seabirds were similar to other studies on Canadian Arctic seabirds (Braune et al., 2001) but are lower than European Arctic seabirds (Borgå et al., 2001), consistent with past compilations of seabird OC data (de March et al., 1998). The exception to this trend was  $\Sigma$ HCH, where levels were lower in the Svalbard seabirds compared with those found in the northern Baffin Bay seabirds of this study. HCH concentrations are higher in the Canadian Arctic because of its closer proximity to India and China, where until very recently HCH has continued to be used (Li et al., 2001). HCH use has been restricted or banned in North America and Europe for nearly a decade resulting in lower levels in the European Arctic (de Wit et al., 2003). These trends are also consistent with spatial trends of OCs observed in marine mammals, including the ringed seal (Muir et al., 2000) and polar bear (*Ursus maritimus*, Norstrom et al., 1998). Concentrations of OCs in these high Arctic seabirds are lower than what has been observed in seabirds from temperate regions such as the Great Lakes (Hebert et al., 1999).

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