Environ. Sci. Technol. **2006**, *40,* 2826−2831

Organochlorines in Antarctic and Arctic Avian Top Predators: A Comparison between the South Polar Skua and Two Species of Northern Hemisphere Gulls

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Different organochlorine compounds (OCs) were measured in the blood of breeding south polar skuas (*Catharacta maccormicki*) at Svarthamaren, Dronning Maud Land (Antarctica) and compared to those in two species of northern hemisphere gulls: the Arctic glaucous gull (*Larus hyperboreus*) and the subarctic great black-backed gull (*Larus marinus*). The skuas had 8% and 29% of the ∑OC levels (45 ng/g, wet weight) of glaucous gulls (591 ng/g) and great black-backed gulls (158 ng/g), respectively. Polychlorinated biphenyls (PCBs) and *p,p′*-dichlorodiphenyldichloroethylene (*p,p′*-DDE) were very low in skuas compared to northern gulls, but the mean hexachlorobenzene (HCB) level was 1.7 times higher than in great black-backed gulls and one-third of the glaucous gull level. Mirex levels in skuas were among the highest reported in birds, the mean level being 3 and 26 times higher than those in glaucous gull and great black-backed gulls, respectively. In skuas, the mean levels of HCB, oxychlordane, *p,p′*-DDE, and PCBs increased by about 30% during a 2-week period, and mirex increased by nearly 60%. In glacuous gulls, HCB, *p,p′*-DDE, and PCBs increased by 10−20%. For HCB, mirex, and oxychlordane, only a relatively small proportion of the increase in skuas could be explained by changes in lipid pools and the levels at first sampling, compared to glaucous gulls. Thus, skuas were probably accumulating these compounds when present in Antarctica. *p,p′*-DDE and PCB levels, in contrast, seemed much more stable in the skuas. Relatively high levels of mirex and HCB in south polar skuas are concerning with regard to potential adverse effects.

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Introduction

Various organochlorine compounds (OCs) were discovered in both polar regions in the 1960s and 1970s (*1*, *2*). The geographical features in the two polar regions are different: the Arctic is a perennial frozen sea surrounded by urbanized and industrialized continents, whereas Antarctica is an ice-covered continent isolated from other areas by the Southern Ocean. In addition, the southern hemisphere is less populated than the northern hemisphere. The levels of most OCs are lower in Antarctic biota than in Arctic biota (*3*−*5*), although some semivolatile compounds, such as hexachlorobenzene (HCB) and some polychlorinated biphenyl (PCB) congeners might be relatively high in Antarctica (*6*, *7*).

In the Arctic, exposure and effects of OCs on various organisms have been well documented (*8*), whereas less is known about OCs in Antarctica (*3*, *5*). Organisms inhabiting the two polar regions experience relatively similar natural environments, suggesting that comparisons between ecologically equivalent species in the Arctic and Antarctica, in the same stage of their annual cycle, will add important information regarding exposure to OCs. Previously, OC concentrations in different top predators (birds versus mammals) have been compared between Antarctica and the Arctic (*4*, *9*). However, to our knowledge, no study has compared OC residues in ecologically equivalent avian top predators from the two polar regions, using the same measuring compartments (e.g., eggs, livers, adipose tissue, or blood). In both the high Arctic and Antarctica, avian top predator niches are occupied by predatory and scavenging gulls (*Larus* spp.) and skuas (*Catharacta* spp.) (*10*, *11*). In the present study, blood residues of OCs in breeding south polar skuas (*Catharacta maccormicki*), a plentiful avian top predator on the Antarctic continent (*11*), were compared to those of breeding Arctic glaucous gulls (*Larus hyperboreus*) and subarctic great black-backed gulls (*Larus marinus*). The three species are all marine top predators feeding on a wide range of prey, and they have similar annual behaviors (*10*, *11*). South polar skuas often cross the equator during the Antarctic winter and are commonly found in the North Pacific region, even north of the Arctic Circle (*11*). The glaucous gulls and great black-backed gulls move south from their breeding grounds and winter in subarctic and temperate areas (*12*).

A central question is the extent to which OCs accumulate in migrating organisms when present in the Antarctic. In south polar skuas, the OC composition might be different from that in seabirds that are resident in the Southern Ocean (*4*, *13*−*17*), and it has been suggested that most of the OCs in adult skuas are accumulated north of the Antarctic convergence (*4*, *13*, *14*, *16*). This suggestion predicts that most of the OC intake will be eliminated from the body by various processes and that the OC burdens in skuas will be relatively stable when they are in the Antarctic (*18*). Hence, short-term changes in OC concentrations in the blood between two sampling points will largely be determined by lipid dynamics and the levels at the first sampling (*19*−*22*). To study potential accumulation of OCs in breeding south polar skuas, we measured concentrations of different OCs in the blood of the same individuals twice, with 2 weeks between the two blood samples. We then examined how well the changes in the lipid pools and the first OC levels measured could predict the levels in the second blood sample. For comparison, the same analyses were done on glaucous gulls.

Study Area and Methods

The colonies of the species studied were all situated near large concentrations of other seabird species. South polar

10.1021/es051920q CCC: $33.50
Published on Web 03/11/2006

skuas were studied at Svarthamaren (71° 53′ S, 05° 10′ E) in Dronning Maud Land (Antarctica) in December 2001 and January 2002. Details about the study area have been described in Mehlum et al. (*23*). Svarthamaren is the largest breeding colony of Antarctic petrels (*Thalassoica antarctica*) in the world, with about 250 000 pairs. This petrel colony supports a breeding population of 80−90 pairs (250 individuals) of south polar skuas. Svarthamaren is approximately 200 km from open sea, and during the breeding season, skuas feed on eggs and young of petrels (*24*).

Glaucous gulls were studied at Bear Island (74° 30′ N, 19° 01′ E) in the Norwegian Arctic in May and June 2001. The island has one of the largest concentrations of breeding seabirds in the northeastern Atlantic, and details about the study area can be found in Bustnes et al. (*25*). Breeding glaucous gulls at Bear Island feed on a wide range of prey including eggs, young and adults of other seabird species, and also fish and crustaceans (*25*).

Great black-backed gulls were studied in two seabird colonies on the Norwegian coast in May and June 2001: Loppa (70° 20′ N, 21° 24′ E) and Hornøya (70° 22′ N, 31° 10′ E). The colony at Loppa has been described by Helberg et al. (*26*), whereas Furness and Barrett (*27*) have provided a description of Hornøya. No detailed studies of the diets of great black-backed gulls have been carried out in these colonies, but the feeding ecology of breeding great black-backed gulls is generally well-known. The diet consists of a wide variety of prey, such as other seabirds, fish, and crustaceans (*10*, *28*, *29*).

The gulls were all caught on their nests using a radio-triggered trap (*26*), whereas the skuas were caught with a nest trap or by using a rod with a snare. Blood was sampled from the wing vein (ca. 10 mL) with a syringe, and body mass (±5 g) was measured on all birds using a spring balance.

All birds were sexed, south polar skuas by using a molecular method described by Fridolfsson and Ellegren (*30*). Of a total of 142 skuas, there were 73 females and 69 males. Sexing of glaucous gulls ($n = 40$; 20 males and 20 females) is described in Bustnes et al. (*31*) and that of great black-backed gull ($n = 39$; 20 males and 19 females) is described in Helberg et al. (*26*).

To record changes in OC concentrations in south polar skuas during the breeding season, a subsample ($n = 66$) was recaptured after 2 weeks, and new blood samples were taken. For comparison, we included a data set of OCs from nesting glaucous gulls collected at Bear Island in 1997 ($n = 25$), from which blood was sampled at about 2-week intervals (mean = 16 days) (*21*).

Chemical Analyses. The OC analyses were carried out at the Environmental Toxicology Laboratory at the Norwegian School of Veterinary Science/National Veterinary Institute. Samples of whole blood (ca. 8 g) were weighed, and an internal standard (CB-29 and CB-112) was added. The methods used for extraction (cyclohexane and acetone), cleanup (with sulfuric acid; one blank sample consisting of solvents was analyzed for every batch of samples analyzed), and quantification (gas chromatographic) of the samples are described in Andersen et al. (*32*). Percent extractable fat was determined gravimetrically. Aliquots of the final extracts were injected on an Agilent gas chromatograph with an electron-capture detector (GC-ECD) (6890 Series, Agilent Technologies, Palo Alto, CA). The GC was equipped with two capillary columns (SPB-5 and SPB-1701, Supelco, Inc., Bellefonte, PA). Quantification was done within the linear range of the detector. Detection limits were defined as 3 times the background noise. The detection limits were 0.01−0.02 ng/g of wet weight for the individual PCB congeners, 0.005−0.01 for HCB, and 0.01−0.02 ng/g for oxychlordane and *p*,*p*′-DDE. GC conditions, temperature program, and quality-assurance procedures are described in Andersen et al. (*32*). In addition, the results for mirex were verified on a GC coupled to an Agilent 5973 quadropole mass spectrometer (MS) operating in selected-ion-monitoring (SIM) mode on negative chemical ionization (NCI). Methane was used as the reagent gas. The temperature was 106, 150, and 280 °C for the quadrupole, the ion source, and the interface, respectively. The following ions were selected: internal standard PCB-112, m/z 323.9, 325.9; and mirex, m/z 436.6, 438.6, 440.6. The GC conditions were the same as for GC-ECD.

Analytical standards of the laboratory are certified by participation in international intercalibration tests [QUASIMEME Laboratory Performance studies 2001, Round 24, Exercise 473 BT-2, PCBs and OC pesticides in biota, and AMAP (Arctic Monitoring and Assessment Programme), Rounds 1 and 2 in 2001 and Rounds 1−3 in 2002, PCBs and OC pesticides in human blood). Certified international reference materials (CRM 349 and 350, ICES cod liver oil and mackerel oil) are analyzed regularly with results within the given ranges. The laboratory is accredited for these analyses according to the requirements of NS-EN 45001 (Norwegian and European standards) and ISO/IEC Guide 25.

A total of 21 different OCs were analyzed in all three species (Table 1), including the following PCB congeners (IUPAC numbers): CB-101, -99, -149, -118, -153, -105, -138, -187, -183, -156, -180, -170, -196, -194, -206. The correlations between the sum of PCB congeners and most of the different congeners in skuas were very high (r values between 0.85 and 0.99). Exceptions were minor congeners such as PCB-101 ($r = 0.63$), PCB-149 ($r = 0.68$), and PCB-157 ($r = 0.73$). Such high correlations have also been reported in glaucous gulls (*21*) and great black-backed gulls (*22*). Little information can thus be gained from analyzing each congener, and only analyses using the sum of PCB congeners (denoted PCBs) are reported. When OC levels were compared between the two blood samplings, a limited number of PCB congeners were included (CB-99, -118, -153, -138, -180, -170) because the other congeners were not repeatedly measured in glaucous gulls.

We used wet-weight (ww) concentrations of the OCs because we analyzed the relationships between changing blood lipids and OC levels in the blood. However, for the comparison of levels between the south polar skuas and the two gull species, we provide both lipid-weight (lw) and wet-weight concentrations (Table 1). In many skuas and glaucous gulls, the blood lipid percentages changed somewhat from the first to the second blood sampling, but the mean blood lipid contents of the two species (0.45% vs 0.42% and 0.60% vs 0.66% in skuas and gulls, respectively) did not change significantly ($p > 0.20$).

Statistical Analyses. Statistical analyses were carried out using SAS (*33*). We used pairwise nonparametric statistics (Wilcoxon signed rank test) when comparing the levels in the two blood samples. When parametric statistics were used, OC values were $\log_{10}$-transformed to approximate a normal distribution. We used generalized linear models, PROC GENMOD (*33*), with the concentration of each of the OCs in the second blood sample (wet weight) as dependent variables. Explanatory variables were the changes in body condition between blood samplings (percentage change in body mass), the changes in the percentage blood lipids between blood samplings, and the concentrations of the same OCs in the first blood sample. Variables were added in order, and we used a type 1 sum of squares to establish the amount of additional variation explained by entering each variable (*34*). Standard errors (SEs) are given for all means. The probability of being caught once or twice was not related to sex, body size, body mass, or ∑OC ($p > 0.05$).

TABLE 1. Concentrations of Organochlorine Contaminants in the Blood of Antarctic South Polar Skuas, Subarctic Great Black-Backed Gulls, and Arctic Glaucous Gulls[a]

	south polar skuas ($n = 142$)			great black-backed gulls ($n = 39$)			glaucous gulls ($n = 40$)		
	$\bar{x}$	SE	range	$\bar{x}$	SE	range	$\bar{x}$	SE	range
HCB	7.2	0.3	0.6−21.2	4.3	0.6	0.6−21.5	20.7	1.7	6.8−45.7
	2.3	0.1	0.6−8.7	1.0	0.1	0.3−5.2	4.5	0.4	1.6−13.5
β-HCH	0.1	0.1	<0.1−6.5	0.2	<0.1	<0.1−0.8	1.2	0.1	0.2−5.2
	<0.1	<0.1	<0.1−1.5	0.1	<0.1	<0.1−0.3	0.3	<0.1	0.1−0.9
oxychlordane	1.3	0.1	0.2−4.3	3.1	0.7	0.2−22.6	14.3	1.4	3.7−50.1
	0.4	<0.1	0.1−1.9	0.6	0.1	0.1−3.2	3.2	0.4	1.1−11.4
trans-nonachlor	0.2	<0.1	<0.1−1.6	1.7	0.3	0.1−11.2	1.3	0.1	0.4−4.6
	0.1	<0.1	<0.1−0.3	0.4	0.1	0.1−2.7	0.3	<0.1	0.1−1.5
p,p′-DDE	6.8	0.5	0.4−40.9	23.2	4.9	2.3−158.1	97.6	8.4	18.5−245.6
	2.0	0.1	0.4−11.9	5.3	1.0	1.3−38.6	21.0	2.1	4.1−74.9
mirex	20.7	1.1	1.0−69.2	0.8	0.1	0.1−4.1	6.9	0.8	1.6−28.4
	6.5	0.4	1.2−24.4	0.2	<0.1	<0.1−0.8	1.5	0.2	0.3−4.8
PCBs	9.0	0.6	1.0−50.5	124.7	21.9	9.8−781.2	448.7	51.4	84.3−1576.1
	2.7	0.1	0.7−9.6	29.2	3.6	4.8−101.5	100.2	12.9	14.6−342.5
∑OCs	45.3	2.2	3.4−156.8	157.9	27.6	14.2−951.7	590.8	60.9	124.8−1913.6
	14.1	0.7	3.2−51.5	36.8	4.6	7.1−152.3	130.9	15.4	22.0−416.0

[a] Arithmetic means ($\bar{x}$), standard error (SEs), and ranges of wet-weight concentrations (ng/g) in the first rows and lipid-weight concentrations (μg/g) in the second rows. Data from 2001 and 2002.

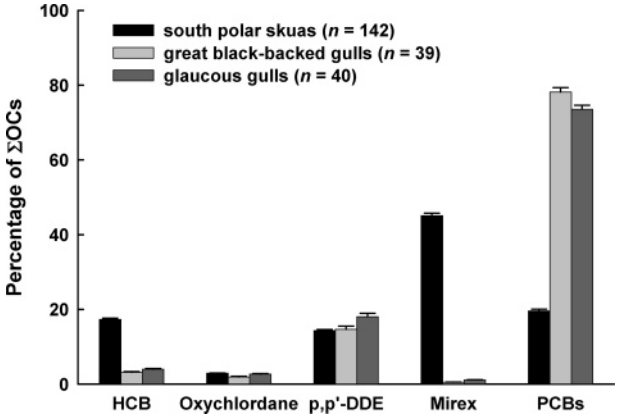

FIGURE 1. Relative contributions (%) of different organochlorines [hexachlorobenzene (HCB), oxychlordane, *p,p*′-dichlorodiphenyldichloroethylene (*p,p*′-DDE), mirex, and polychlorinated biphenyls (PCBs)] to ∑OCs (mean and standard error) in Antarctic south polar skuas, subarctic great black-backed gulls, and Arctic glaucous gulls. β-HCH (β-hexachlorocyclohexane, <0.3% of ∑OCs) and *trans*-nonachlor (<1.5% of ∑OCs) are not included in the figure. Data from 2001 and 2002.

Results and Discussion

Organochlorine Levels and Composition. On average, the south polar skuas had 8% and 29% of the blood ∑OCs concentrations (45 ng/g, ww) found in glaucous gulls (591 ng/g) and great black-backed gulls (158 ng/g), respectively (Table 1). Notably, the concentrations of PCBs, *p,p*′-DDE, and oxychlordane were much lower in the skuas (Table 1). PCBs made up 20% of the contaminants in skuas compared to 74% in glaucous gulls and 78% in great black-backed gulls (Figure 1). The relative contributions of *p,p*′-DDE and oxychlordane to ∑OCs, however, were similar in all three species (14−18%, Figure 1). The lower levels of persistent heavily chlorinated OCs in south polar skuas, compared to northern gulls, were in accordance with other studies of OCs from the polar regions (*5*, *8*). Because heavily chlorinated compounds have a relatively low potential for long-range transport through the atmosphere, the differences between the polar regions are probably mainly a result of the distances to the pollution sources (*4*, *5*, *35*, *36*).

The level of the semivolatile HCB was relatively high in skuas (7 ng/g), with the mean level being 1.7 times higher than in great black-backed gulls and one-third of the level in glaucous gulls (Table 1). HCB also contributed relatively more to ∑OCs in skuas (17%) than in glaucous gulls (4%) and great black-backed gulls (3%) (Figure 1). Previous studies of Antarctic biota have also reported high levels of HCB (*6*, *7*), which is thought to be mainly a result of cold condensation and global fractionation (*7*, *35*, *37*). However, previously, there was also substantial use of HCB in Australia (*3*, *38*), which might be a contributing factor for the relatively high levels found in south polar skuas at Svarthamaren.

Mirex was the dominant OC in south polar skuas ($\bar{x}$ = 21 ng/g ww, maximum 69 ng/g, making up 45% of ∑OCs), with the mean level being 3 and 26 times higher than those in glaucous gulls (1.2% of ∑OCs) and great black-backed gulls (0.5% of ∑OCs), respectively (Table 1, Figure 1). We are aware of no studies that have measured mirex in whole blood of birds, but plasma concentrations have been reported (*39*−*44*). Whole blood concentrations were transformed to plasma concentrations by assuming that 75% of the mirex was in the plasma and 25% in the red blood cells (*45*) and that south polar skua had 55% plasma and 45% red blood cells (*46*). This gave mean plasma levels of 28 ng/g mirex in the first blood samples and 43 ng/g in the second samples. Among birds, the highest published plasma levels of mirex, a mean of 29 ng/g, are from adult sharp-shinned hawk (*Accipiter striatus*) (*39*), whereas other studies on birds of prey have reported concentrations below 20 ng/g (*40*−*44*).

Antarctic petrels (*Thalassonica antarctica*), the main prey of skuas at Svarthamaren (*24*), feed off the Antarctic Coast (*47*). In nearby areas, mirex levels increased dramatically in fish between 1987 and 1996 (*7*). Moreover, in three south polar skuas collected at Svarthamaren in the early 1990s, the liver residues of mirex and HCB were equal (*48*), whereas in this study, mirex was 3 times higher than HCB. Because HCB seems to be relatively stable in Antarctica (*7*), mirex has probably also increased in skuas at Svarthamaren.

Mirex is an insecticide and flame retardant that was banned in the United States in 1978. It has been commonly used in the southern hemisphere, for example, Australia, South Africa, and South America, to combat ants and termites, but quantities of use are not known (*49*). It was still used in Australia and China in the late 1990s (*50*). Mirex is among the most persistent OCs known (*49*), and despite its semivolatility, which promotes long-range transport (*7*, *49*, *51*), sorption of mirex to fast-settling aerosols and particles in

TABLE 2. Changes in Concentrations (ng/g) of Different Organochlorines in the Blood of Individual Breeding South Polar Skuas and Glaucous Gulls during a 2-Week Period[a]

	$\bar{x}_1$	SE_1	$\bar{x}_2$	SE_2	*p* value[b]	% increase of mean level
South Polar Skua ($n = 66$)						
HCB	7.2	0.3	9.3	0.4	<0.0001	29
oxychlordane	1.3	0.1	1.7	0.1	<0.0001	31
p,p′-DDE	7.1	0.6	9.5	0.8	<0.0001	34
mirex	20.0	1.2	31.4	1.8	<0.0001	57
PCBs[c]	7.3	0.7	9.8	0.8	<0.0001	34
Glaucous Gull ($n = 25$)						
HCB	21.8	4.5	25.9	5.2	0.45	19
oxychlordane	29.9	5.8	29.9	5.6	0.99	0
p,p′-DDE	98.4	18.0	109.4	17.7	0.67	11
mirex	–	–	–	–	–	–
PCBs[c]	465.4	101.1	504.4	91.2	0.52	8

[a] Arithmetic means ($\bar{x}_1$ and $\bar{x}_2$) and standard errors (SE_1 and SE_2) of wet-weight concentrations at the first and the second blood samplings and percentage increases in the mean levels between the samplings. [b] Wilcoxon signed rank test for differences in wet-weight concentration at first and second samplings. [c] PCBs in this analysis consist of the following congeners: CB-101, -99, -118, -153, -138, -180, and -170.

the lower troposphere reduces its transport potential (*52*). Thus, cold condensation and global fractionation are probably not very important for mirex transport, and other slower transport mechanisms can be sought (*7*). However, the reasons for the high levels of mirex in south polar skuas at Svarthamaren remain unresolved.

Organochlorine Accumulation during the Breeding Season. In skuas, the mean levels of most OCs increased by about 30% between the two blood samplings, and the mirex level increased by nearly 60% (Table 2). In glaucous gulls, mirex was not measured; the mean levels of the other OCs, except oxychlordane, increased by 10−20%, but these changes were not statistically significant (Table 2). Changes in lipid pools between the two samplings had similar effects in both glaucous gulls and skuas, i.e., a drop in body lipids and increase in blood lipids resulted in increased concentrations of OCs in the blood (Table 3). Hence, there were no statistical interactions between species and changes in body lipids or blood lipids, on the second measured OC levels (p values between 0.17 and 0.92). For HCB ($p < 0.05$) and oxychlordane ($p < 0.01$), however, there were significant statistical interactions between the first levels measured and species, but not for PCBs ($p = 0.85$) and *p,p′*-DDE ($p = 0.36$). Hence, after controlling for changes in lipids, more of the increase in HCB (53%) and oxychlordane (67%) concentrations in glaucous gulls could be explained by the first concentration, compared to the skuas (11% and 19%, respectively; Table 3). Similarly, in skuas, only 13% of the increase in mirex could be explained by the first measured level (Table 3). Thus, the increases in HCB and mirex seem to be more related to local exposure than to lipid dynamics, suggesting that skuas are accumulating these compounds during the breeding season at Svarthamaren. In skuas, a higher proportion of the increase in *p,p′*-DDE and PCBs between samplings could be explained by the first measured level (35% and 42%, respectively; Table 3), compared to HCB and mirex, and also compared to glaucous gulls (27% and 56%; Table 3). A high predictability of OCs between blood samplings (controlling for changes in lipid pools) indicates that OC levels are relatively stable and that intake and elimination are balanced (*18*, *20*−*22*, *53*). Moreover, high predictability of second levels, controlling for lipid dynamics, have also been found in individuals measured in two subsequent breeding seasons, both in glaucous gulls (*21*) and in great black-backed gulls (*22*), suggesting relatively stable OC levels in these species during breeding.

Although south polar skuas can spend parts of the year at northern latitudes (*11*), the OC composition in skuas from Svarthamaren was very different from that in northern hemisphere gulls, for example, the ratio between HCB and PCBs (*54*−*56*). The HCB/PCBs ratio is usually higher at low trophic levels because of the lower persistence of HCB compared to heavy chlorinated PCB congeners (*57*). In skuas

TABLE 3. Factors Predicting Changes in Concentrations (Wet Weight) of Different OCs in the Blood of Breeding South Polar Skuas (Data from 2001/2002) and Breeding Glaucous Gulls (Data from 1997) 2 weeks Apart: Percent Changes in Body Mass, Changes in Blood Lipid Percentage, and Levels of OCs at First Sampling[a]

	south polar skuas ($n = 66$)[b]					glacous gulls ($n = 25$)[c]				
	F	*P*	estimate	SE	partial R^2	*F*	*p*	estimate	SE	partial R^2
HCB Second Sampling[d]										
change in body mass	4.4	<0.05	−0.02	0.01	0.05	7.9	<0.05	−0.03	0.01	0.11
change in blood lipids	8.3	<0.01	0.30	0.08	0.10	5.3	<0.05	0.37	0.24	0.07
HCB first sampling	9.1	<0.01	0.30	0.10	0.11	38.9	<0.0001	0.73	0.12	0.53
Oxychlordane Second Sampling[d]										
change in body mass	6.3	<0.05	−0.02	0.01	0.07	6.7	<0.05	−0.03	0.01	0.06
change in blood lipids	7.5	<0.01	0.35	0.08	0.08	9.8	<0.01	0.55	0.20	0.09
oxychlordane first sampling	17.4	<0.0001	0.38	0.09	0.19	77.5	<0.0001	0.84	0.10	0.67
***p,p′*-DDE Second Sampling[d]**										
change in body mass	9.6	<0.01	−0.02	0.01	0.08	9.0	<0.01	−0.03	0.01	0.20
change in blood lipids	6.0	<0.05	0.46	0.10	0.05	2.3	0.14	0.28	0.25	0.05
p,p′-DDE	42.5	<0.0001	0.58	0.09	0.35	12.1	<0.01	0.45	0.13	0.27
Mirex Second Sampling[d]										
change in body mass	4.8	<0.05	−0.02	0.01	0.05	–	–	–	–	–
change in blood lipids	12.1	<0.01	0.41	0.10	0.13	–	–	–	–	–
mirex first sampling	11.9	<0.01	0.33	0.10	0.13	–	–	–	–	–
PCBs Second Sampling[d]										
change in body mass	6.0	<0.05	−0.02	0.01	0.05	5.3	<0.05	−0.03	0.01	0.08
change in blood lipids	5.1	<0.05	0.49	0.10	0.04	4.6	<0.05	0.40	0.23	0.06
PCBs first sampling	53.3	<0.0001	0.66	0.09	0.42	40.0	<0.0001	0.69	0.11	0.56

[a] Note that, because of significant statistical interactions between species and some of the compounds, each of the species was analyzed separately. [b] Degrees of freedom = 3, 62. [c] Degrees of freedom = 3, 21. [d] General linear model (PROC GENMOD), type 1 sum of squares (*33*).

at Svarthamaren, the HCB/PCBs ratio was 0.8, whereas this ratio was less than 0.05 in glaucous gulls and great black-backed gulls. Moreover, other studies of south polar skuas have reported HCB/PCBs ratios (0.03 and 0.12) more similar to those of northern gulls (*4*, *16*, *17*). Even though varying numbers of PCB congeners have been included in the different studies, the present study suggests that skuas at Svarthamaren are exposed to HCB locally. This probably results from high HCB levels in the prey. In 1991−1992, the mean HCB/PCBs ratio in juvenile Antarctic petrels at Svarthamaren was 10 (*48*). The diet of coastal skuas is dominated by penguins, fulmars, and remains of seals (*58*), in which HCB is proportionally less important (reported HCB/PCBs ratios are usually below 2) than in Antarctic petrels at Svarthamaren (*4*, *6*, *15*, *16*, *48*, *51*).

South polar skuas probably accumulate a significant proportion of their OC burdens north of the Antarctic convergence, as suggested by other studies (*4*, *13*, *16*). This study, however, indicates that, in skuas at Svarthamaren, the breeding season is also important for the accumulation of HCB and mirex. How much of the body burdens that can be attributed to Antarctic accumulation is, however, difficult to assess. For example, the observed increase in OC levels between our two blood samplings might also be caused by physiological processes for which changes in body mass and blood lipids might not be very good predictors, e.g., depletion of specific fat reserves. The apparent increase of mirex in skuas at Svarthamaren in the early 1990s (*48*) could also result from a change in migration habits or a different age composition in the skua population in the decade following the first OC measurements.

Although the present OC levels in skuas might not constitute a major threat to the skua population at Svarthamaren, the relatively high HCB levels and increasing mirex levels are worrying, particularly because Antarctica is considered the last pristine continent on the globe and because continuous increases eventually will lead to adverse effects.

Acknowledgments

We are grateful to a number of people, including the staff at the Norwegian research station (Troll) in Antarctica; Øystein Miland, Magnus Fjeld, Morten Helberg, and Kai Ove Kristiansen for help during the field work; and Anuschka Polder and Vidar Berg for carrying out the laboratory analyses. We thank Katrine Borgå and four reviewers for comments that led to major changes in previous drafts of this article. This study was financed by the Norwegian Research Council and Norwegian Institute for Nature Research.

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Received for review September 28, 2005. Revised manuscript received January 31, 2006. Accepted February 9, 2006.

ES051920Q