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Halogenated Organic Contaminants and mercury in dead or dying seabirds on Bjørnøya (Svalbard)

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Photo: Hallvard Strøm, Norwegian Polar Institute

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1. Preface

In the present study liver and brain samples of 21 glaucous gulls (*Larus hyperboreus*) and two great black-backed gulls (*Larus marinus*) found dead or dying on Bjørnøya were analyzed for polychlorinated biphenyls (PCBs), pesticides, brominated flame retardants (BFRs), mercury (Hg), perfluorinated alkyl substances (PFAS), antracene, trichlorobenzenes (TCB), siloxane-D5, chlorinated paraffins and octyl/nonyl phenols. Autopsies were performed on all the dead carcasses. The organochlorine (OC) levels found in the present study were compared to that reported in glaucous gulls found dead on Bjørnøya in 1989 (Gabrielsen et al., 1995).

This project was a collaboration between the Norwegian Polar Institute, Tromsø; National Veterinary Institute, Oslo; National Veterinary Institute, Tromsø; Norwegian School of Veterinary Science, Oslo; Norwegian Institute for Air Research, Kjeller; and Tromsø University Museum, Tromsø.

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Cover picture: A female glaucous gull lying dead on its nest on Bjørnøya. The mate and the three small chicks were still alive. July 2006. Photo: Hallvard Strøm, Norwegian Polar Institute.

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3. Sammendrag

Formålet med denne studien var å fastslå miljøgiftsnivåene i 23 (21 polarmåker og to svartbak) sjøfugl funnet død eller døende på Bjørnøya. Miljøgiftsnivåene i denne studien ble sammenliknet med nivåene som ble rapportert i polarmåker funnet døde på Bjørnøya i 1989. Alle polarmåker og svartbakk som inngår i denne studien ble obdusert.

Obduksjon
Ti av totalt 23 fugler ble diagnostisert som totalt til sterk avmagret. Sju fugler ble diagnostisert til å være avmagret. Avmagringen ble ikke vurdert som direkte dødsårsak. Seks fugler ble funnet i normal til litt under middels hold. En plausibel diagnose ble bare funnet for 3 av de 23 fuglene. Disse viste henholdsvis, traume, hemoragisk enteritt og perforasjon av magesekken av beinbit. De resterende fugler ble enten diagnostisert som total/sterk avmagret uten påvisbar årsak, til å ha uspesifikke tegn på sirkulasjonssvikt eller en udiagnostisert dødsårsak.

Organokloriner (OCer)
Høye lever og hjernenivåer av polyklorerte bifenyler (PCBer) ble rapportert i denne studien. Nivåene av PCBer i polarmåker og svartbak i denne studien var høyere enn det som tidligere har blitt rapportert i frittlevende sjøfugler fra arktiske områder.

Rapporterte lever- og hjernekonsentrasjoner av ∑PCBer i denne studien overstiger terskelnivåer for biologiske effekter i fugl.

Høye konsentrasjoner av pestisider ble funnet i denne studien. Disse nivåene var høyere enn det som tidligere har blitt rapportert i frittlevende sjøfugl fra Arktis, inkludert det som tidligere har blitt funnet i polarmåke og svartbak fra Bjørnøya og Jan Mayen.

Organobrominer
Hjerne og leverkonsentrasjoner av ∑polybromerte difenyletere (BDEer) var også svært høye i denne studien.

α-hexabromocyclododekan (HBCD) var den eneste HBCD enantiomeren som ble funnet i denne studien.

Nivåene av bromerte flammehemmere i denne studien var høyere enn det som tidligere har blitt rapportert i arktiske fugler, inkludert det som har blitt funnet i frittlevende polarmåker fra Bjørnøya.

Perfluorerte alkyl substanser (PFAS), antracen, triklorbenzen (TCB), siloksan-D5, klorerte paraffiner og oktyl/nonyl fenoler
Perfluoroktan sulfonat (PFOS) var den eneste PFAS som ble funnet over målbare verdier i denne studien. Nivåene av PFOS var høye sammenliknet med tidligere rapporterte konsentrasjoner i andre sjøfugler. Nivåene av fluorforbindelser var sammenlignbare med det som tidligere har blitt funnet i sjøfugl fra mer industrialiserte og forurensede områder.

Nivåene av antracen, nonylfenoler og TCB var gjennomgående lave i denne studien. Konsentrasjonen av klorerte paraffiner (CPer) (kort kjedete (SCCPs) og medium kjedete (MCCPs)) og oktylfenol ble ikke funnet over deteksjonsgrensen i noen av fuglene. Siloksan-D5 ble rapportert over deteksjonsgrensen i alle polarmåkene i denne studien.

Kvikksølv
Leverkonsentrasjonene av kvikksølv i denne studien var sammenlignbar med tidligere rapporterte nivåer i arktisk sjøfugl.

Sammenligning av OC nivåer i polarmåker funnet død på Svalbard i 1989 og i 2003/2004/2005
Levernivåene av OCer var betydelig høyere i 1989 sammenlignet med nivåene som ble funnet i 2003/2004/2005. Dette er i samsvar med den nedadgående trenden av tradisjonelle OCer i de fleste tidstrendstudier. I kontrast til dette var miljøgiftsnivåene i hjerneprøver fra 1989 lik nivåene som ble rapportert i hjerneprøver fra 2003/2004/2005. Dette kan være en indikasjon på at fuglene i denne studien var i dårligere hold sammenlignet med fuglene som ble funnet i 1989. Fettløselige miljøgifter lagres i fettvev. Ved avmagring redistribueres de persistente miljøgiftene fra fettdepot til vev med relativt høy fettprosent og stor gjennomblødning (eks. hjerne). Konsentrasjonene i for eksempel hjerne vil da bli relativt høyere.

Når man sammenligner mønsteret av miljøgifter i lever og hjerneprøver fra 1989 og 2002/2003/2005, er det en høyere andel av pestisider og høyklorerte PCBer i prøvene fra 2003/2004/2005. PCB ble hovedsakelig produsert og brukt i 1930-årene til 1980-årene, med etterfølgende toppnivåer i biotaprøver i perioden fra 1970-årene til 1990-årene. De høyklorerte PCBer er mer persistente enn de lavklorerte kongenerne. Dette kan mest sannsynlig forklare de relativt høyere nivåene av høyklorerte PCBer i prøvene fra 2002/2003/2005. Forskjell i fuglenes ernæringsstatus mellom prøvetakingsårene kan også medvirke til forskjeller i kontaminantmønster.

Toksikologisk evaluering og konklusjoner
Det ble funnet svært høye nivåer av de fleste halogenerte organiske miljøgifter (HOCer) i de døde polarmåkene i denne studien. Nivåene av HOCs i denne studien er noen av de høyeste som er rapportert hos arktisk sjøfugl.

Ca. 40-45 % av fuglene i denne studien ble funnet å være totalt til sterkt avmagret. Ved mobilisering (forbrenning) av kroppslipider vil persistente miljøgifter som er akkumulert i fett bli redistribuert til vitale organer med relativt høyt lipidinnhold som for eksempel hjerne og lever. Observasjoner av døende polarmåker på Bjørnøya med tilsynelatende unormal adferd kan indikere at de høye nivåene av miljøgifter i disse fuglene kan være en indirekte eller direkte dødsårsak.

4. Summary

The aim of the present project was to determine contaminant levels in liver and brain samples of 23 seabirds (21 glaucous gulls and two great black-backed gulls) found dead or dying on Bjørnøya. The levels found in the present study were compared to that reported in glaucous gulls found dead on Bjørnøya in 1989. Furthermore autopsies were performed on all the dead carcasses.

Autopsies
Ten birds of a total of 23 birds were found to be completely or severely emaciated. Seven birds were found to be emaciated, but the emaciation was probably not so severe that it could be the cause of the death. Six birds were found to be in normal or slightly below normal condition. A plausible diagnosis was established only for 3 of the 23 birds: That is trauma, haemorrhagic enteritis and bone splint perforation of stomach. The remaining birds have either received the diagnosis complete/severe emaciation without obvious reason, unspecific signs of circulatory failure or none diagnosis at all.

Organochlorines (OCs)
High levels of polychlorinated biphenyls (PCBs) were found in the present study.

The levels of PCBs in the glaucous gulls and great black-backed gulls of the present study were much higher than that previously reported in free-living seabirds from the Arctic.

Liver and brain wet weight concentrations of ∑PCBs in the glaucous gulls and the great black-backed gulls exceeded the threshold levels for effects in birds.

The levels of pesticides were also high in the present study, and higher than that previously reported in free-living seabirds from the Arctic, including glaucous gulls and great black-backed gull from Bjørnøya and Jan Mayen.

Organobromines
In concert with the high levels of OCs, the levels of ∑polybrominated diphenylethers (BDE) were high in the present study.

α-hexabromocyclododecane (HBCD) was the only HBCD enantiomer found in the present study

The levels of brominated flame retardant in the glaucous gulls and great black-backed gulls of the present study were higher than that previously reported in other Arctic birds, including free-living glaucous gulls from Bjørnøya.

Perfluorinated alkyl substances (PFAS), antracene, trichlorobenzenes (TCB), siloxane-D5, chlorinated paraffins and octyl/nonyl phenols
Of two analyzed PFAS only one (perfluorooctane sulfonate (PFOS)) were detected in the glaucous gulls of the present study. The levels of PFOS in liver samples of glaucous gulls

in the present study were high compared to the levels reported in other Arctic seabirds, and comparable to the liver levels reported in seabirds from more polluted and industrialized regions

Generally, low levels of anthracene, nonylphenol and TCB were detected in the present study. Chlorinated paraffins (CPs) (short chained (SCCPs) and medium chained (MCCPs)) and octylphenol were not detected above the detection limit in any of the glaucous gulls found dead on Bjørnøya. Siloxane-D5 was detected in all the glaucous gulls of the present study.

Mercury
Concentrations of mercury in the liver of glaucous gulls and great black-backed gulls were comparable to the levels reported in other Arctic seabird species.

Comparisons of OC levels reported in glaucous gulls found dead on Svalbard in 1989 and in 2003/2004/2005
The liver levels of legacy OCs were considerably higher in 1989 compared to the levels found in 2003/2004/2005. This is in accordance with the downward trends of legacy OCs reported in most biota. In contrast, brain levels of OCs from 1989 were comparable to the levels found in 2003/2004/2005. This result might indicate that the birds of the present study were in a poorer nutritional condition than the 1989 birds. When body lipids are mobilized during fasting there is a redistribution of accumulated contaminants, e.g., lipid soluble HOCs accumulated in fat becomes redistributed to other tissues, such as the brain.

The contaminant pattern comparisons in liver and brain samples collected in 1989 and 2002/2003/2005 suggested a higher proportion of pesticides and higher chlorinated PCBs in the 2003/2004/2005 samples. PCBs were produced and released into the environment mainly in the 1930s to the 1980s, reaching peak levels between 1970s and 1990s. Since then, the levels have generally declined in the abiotic and biotic environment. The higher chlorinated PCBs are more persistent than the lower chlorinated congeners. This could probably explain the relatively higher levels of these congeners in the glaucous gulls collected in 2003/2004/2005. Difference in nutritional condition of the birds between the sampling years could also influence the contaminant pattern.

Toxicological evaluation and conclusions
Very high levels of most halogenated organic contaminants (HOCs) were found in the dead glaucous gulls of the present study. To our knowledge this is some of the highest HOC concentrations that have been reported in Arctic seabirds.

Approximately 40-45 % of the birds in the present study were found to be completely or severely emaciated. When body lipids are mobilized contaminants accumulated in fat tissue becomes redistributed to vital organs with relatively high lipid content and blood perfusion, i.e. liver and brain. Observations of dying glaucous gulls on Bjørnøya with apparently abnormal behaviour may indicate that high levels of contaminants may be a contributing factor to the birds death, directly or indirectly.

5. Introduction

Bjørnøya is situated between the mainland of Norway and the southern tip of Spitsbergen (74°30'N, 19°00'E). Approximately 500 000 breeding pairs of seabirds remain in the waters around and at the southern part of Bjørnøya during the breeding season (Mehlum and Gabrielsen, 1995). The main species are common guillemot (*Uria aalge*), Brünnich's guillemot (*Uria lomvia*), black-legged kittiwake (*Rissa tridactyla*), northern fulmar (*Fulmarus glacialis*), little auk (*Alle alle*) and glaucous gull (Bakken and Mehlum, 1988). The breeding population of glaucous gull on Bjørnøya was estimated to approximately 2000 pairs in 1986 (Bakken and Mehlum, 1988). However, long-term population monitoring and a survey of the breeding population conducted in 2006 indicate that this number has dropped considerable (Strøm, 2006).

Although Bjørnøya is a remote island halogenated organic contaminants (HOCs) have been reported to be ubiquitously present (Evenset et al., 2004; 2005; Knudsen et al., 2006; Verreault et al., 2005a-c). Very high levels of HOCs have been found in glaucous gulls breeding on Bjørnøya (e.g., Verreault et al., 2005a-c). The high levels of HOCs reported in glaucous gulls exceed threshold levels associated with reproductive effects in birds (AMAP, 2004). Furthermore, HOC concentrations have been found to be related to increased nematode intensities, decreased reproduction and survival, fluctuating asymmetry in wing feather, decreased feeding effectiveness and reduced levels of thyroid hormones (T4 and T4:T3 ratio) (Sagerup et al., 2000; Bustnes et al., 2001; 2002; 2003; Verreault et al., 2004).

Since 1986, scientists from the Norwegian Polar Institute have found glaucous gulls dead or dying in convulsions close to the seabird colonies at the southern part of Bjørnøya. In 1989, 12 individuals were analyzed for environmental contaminants. Very high levels of persistent organic pollutants (HOCs) were detected. Although a toxicological evaluation of the HOC levels was difficult, it was not excluded that the HOC levels had contributed to the death of the gulls. Autopsies did not reveal any specific cause of death (Gabrielsen et al., 1995).

The main objective in the present study was to assess the levels of a wide range of HOCs (polychlorinated biphenyls (PCBs), pesticides, brominated flame retardants (BFRs), mercury (Hg), perfluorinated alkyl substances (PFAS), antracene, trichlorobenzenes (TCB), siloxane-D5 and octyl/nonyl phenols in liver and brain samples of glaucous gulls and great black-backed gulls found dead or dying on Bjørnøya in 2003, 2004 and 2005. Autopsies were performed on all the dead carcasses. Lastly, the organochlorine (OC) levels found in the present study were compared to the levels reported in glaucous gulls found dead on Bjørnøya in 1989.

6. Materials and Methods

6.1. Sampling and biometric measurements

26 glaucous gulls and two great black-backed gulls were found dead or dying on Bjørnøya (74.30°N, 19.01°E) (Figure 1) in 2003, 2004 and 2005. Liver and brain samples were collected from the dead birds, and biometrical measurements conducted. Because of analytical costs only 21 of the 26 dead glaucous gulls were analyzed for contaminants and included in the present study (Table 1).

Figure 1. Map of the European Arctic. Bjørnøya is located halfway between Spitsbergen and mainland Norway.

Table 1. Biometrical measurements of the glaucous gulls (N = 21) and the great black-backed gulls (N = 2) found dead at Bjørnøya in 2003, 2004 and 2005. The last number in the ID number indicates the year of collection.

Species	ID	Ringed	Age	Sex	Weight (g)	Wing (mm)	Skull (mm)	Beak length (mm)	Beak height (mm)
GG [a]	2-03	-	Adult	F [d]	NR	NR	NR	NR	NR
GG	3-03	-	Adult	M [e]	1610	NR	NR	NR	NR
GG	4-03	-	Adult	F	822	459	137	58	20.4
GG	5-03	397753/YellowMV	Adult	F	947	447	137	60.2	21.3
GG	6-03	-	Adult	F	1241	462	140	59.5	20.8
GG	3-04	-	Adult	F	1090	452	140	61.2	20.9
GG	4-04	392161/WhiteOO	Adult	F	1367	452	134	55.8	19.9
GG	5-04	-	Adult	F	879	437	132	58.5	20.5
GG	6-04	-	Adult	F	1097	447	135	60.3	20.7
GG	7-04	-	Adult	F	1010	452	142	62	20.1
GG	8-04	-	Adult	F	1414	455	142	59.3	20
GG	9-04	-	Adult	M	1027	469	154	64.3	22.9
GG	10-04	-	Adult	F	844	441	148	59.8	20.7
GG	11-04	-	Adult	M	1123	482	157	59.7	23.3
GG	12-04	380858/YellowEK	Adult	M	1686	482	161	71	24.4
GG	1-05	-	Adult	M	1766	486	160	71	23
GG	2-05	-	Adult	M	1332	486	155	62	22
GG	3-05	-	Adult	F	1218	474	143	59.5	20.3
GG	4-05	-	Adult	M	1532	475	149	63	23
GG	5-05	-	Adult	M	1749	495	160	73	24
GG	7-05	White98	7	M	1055	485	152	63.6	22.2
GBBG [b]	LM 1-03	-	NR [c]	M	NR	NR	NR	NR	NR
GBBG	LM 2-03	-	NR	F	NR	NR	NR	NR	NR

[a] Glaucous gull
[b] Great black-backed gull
[c] Not recorded
[d] Female
[e] Male

6.2. Autopsies

The cause of death was investigated through autopsies. The autopsies were performed according to standard operating procedures at the National Veterinary Institute, Norway. Tissue samples from heart, lung, liver, kidney, brain, pancreas, spleen, gonads, adrenal, thyroid and breast muscle were routinely fixed in phosphate buffered formalin and later prepared for histological examination.

Bacteriological examination was performed according to standard operating procedures at the National Veterinary Institute, Norway. Bacteriological examination was performed only when the macroscopic findings indicated a possible infection (5 cases).
Lead content in liver was analyzed in one case due to the finding of subcutaneous lead shots during autopsy.

The body condition of all the birds was evaluated from the amount of fat and muscles on the cadaver (Table 2).

Table 2. Scale of body condition in birds

0	Complete emaciation	No fat neither in the abdominal cavity, nor on the heart. Atrophic breast muscles. Lack of energy is considered the direct cause of death.
1	Severe emaciation	Atrophic breast muscles. Very little fat in the abdominal cavity and the heart. Emaciation is a direct or indirect cause of death.
2	Emaciation	Atrophic breast muscles. Moderate fat reserves.
3	Slightly below normal condition	Close to normal breast muscles. Some fat reserves.
4	Normal condition	Normal breast muscles. Normal fat reserves.
5	Fat	Normal breast muscles. Extensive fat reserves in corium and in the abdominal cavity.

6.3. Chemical analyses

For details on analyzed contaminants and methods see Table 3.

6.3.1. Chemical analyses of PCBs, pesticides, PBDEs and HBCD

The chemical analyses of PCBs, pesticides, PBDEs and HBCD were performed at the laboratory of environmental toxicology at the Norwegian School of Veterinary Science (MT Lab). Polychlorinated biphenyls (PCBs; i.e. CB-28, 52, 74, 66, 101, 99, 110, 149, 118, 114, 105, 141, 153, 138, 128, 156, 157, 187, 183, 180, 170, 194, 206, 209), hexachlorobenzene (HCB), chlordanes (oxychlordane, cis-chlordane, trans-nonachlor), mirex, hexachlorocyclohexanes (α-HCH, β-HCH, γ-HCH), 1,1-dichloro-2,2-bis(4-chloro-phenyl) ethylene (p,p'-DDE), polybrominated diphenylethers (PBDEs, i.e. BDE-28, 47, 100, 99, 154, 153, 183, 206, 207, 208 and 209) and hexabromocyclododecane (α-HBCD,

β-HBCD, γ-HBCD and total-HBCD) were analyzed in 21 brain and liver samples of glaucous gulls and two great black-backed gulls.

Extraction and cleanup

The content of the samples were homogenized in a food blender. The homogenates (~3 g) were weighed in 80 mL centrifugation tubes and spiked with the internal standards (CB-29, 112 and 207; BDE-77, BDE-119, BDE-181 and ^{13}C-BDE-209 (Cambridge Isotope Laboratories, Inc., Andover, MA, USA). The lipids were extracted twice using cyclohexane and acetone (3:2). The supernatants of both extractions were merged and concentrated to about 1 mL using a Zymark® evaporation system (TurboWap II, Zymark Corporation, Hopkinton, MA, USA) at 40°C, and by a gentle flow of nitrogen. The concentrated lipid extracts were quantitatively transferred to volumetric flasks, and the final volume adjusted to 5 mL with cyclohexane. The lipid determination was done gravimetrically using 1 mL aliquot of the sample. For cleanup (i.e., removal of lipids) the rest of the lipid extracts were treated twice with ultra clean (purity 98.8%) concentrated H_2SO_4 (Scanpure, Chemscan AS, Elverum, Norway). The sample concentrates were transferred to dark gas chromatography (GC) vials.

Detection of OCs

Separation of all the organic compounds was performed by high-resolution gas chromatography/electron capture detection (HRGC-ECD; Agilent 6890 Series; Agilent Technologies, Palo Alto, CA, USA). To obtain the chromatographic separation, two columns (SPB-5 and SPB-1701, 60m, 0.25 mm ID and 0.25 μm film layer) of different polarity and selectivity were used.

Detection limits for individual compounds were determined as three times the noise level (median detection limits for brain and liver levels of HCB (0.1 and 0.05 ng/g ww, respectively), HCHs (0.1 and 0.04 ng/g ww, respectively), chlordanes (0.2 and 0.07 ng/g ww, respectively), DDTs (0.3 and 0.07 ng/g ww, respectively), mirex (0.3 and 0.1 ng/g ww, respectively), PCBs (0.3 and 0.1 ng/g ww, respectively)). Quality assurance and control procedures were applied an approved.

Detection of BDE-28, -47, -100, -99, -154, -153, -183 and total HBCD

Aliquots (1μl) of the concentrates were automatically injected (Agilent Auto sampler, Agilent Technologies, Avondale, PA, USA) and the gas chromatographic separation of PBDEs and HBCD was performed by a Hewlett Packard 6890 Series, equipped with a pulsed splitless injector (at 250°C) connected to a MS quadrupol detector (Agilent Technologies, Avondale, PA, USA). The mass spectrometer was operated in the electron capture mode with methane as buffer gas. The PBDEs and HBCDs were monitored using negative chemical ionization in selected ion monitoring (SIM) at m/z ratios 79 and 81. The detection limits of BDE-28, 47, 100, 99, 154, 153, 183 in brain and liver samples were 0.025 and 0.25 ng/g ww, respectively. The detection limits of total HBCD in brain and liver samples were 0.25 and 1.5. Quality assurance and control procedures were applied and approved. Details on chromatographic separation and analytic quality of the laboratory are described by Murvoll et al. (2005).

Detection of BDE-206, BDE-207, BDE-208 and BDE-209
A programmable temperature vaporization (PTV) injector (Agilent Technologies) was used to inject the nona-BDEs and BDE-209. 1 µL was injected for analysis on a GC-MS (J&W Scientific, Agilent Technologies). The separation and identification of the compounds was performed by a 10 m long DB-5-MS column (10 m × 0.25 mm I.D., 0.1 µm film thickness; J&W Scientific, Agilent Technologies). Nona-BDEs and BDE-209, in addition to ^{13}C-BDE-209 were monitored using negative chemical ionization. Selected ion monitoring (SIM) was set at *m/z* 484.5 and 486.5, and 494.5 and 498.5.

The quantification standards were made using pure standards of BDE-206, BDE-207, BDE-208 and BDE-209 (Cambridge Isotope Laboratories, Inc., Andover, MA, USA). The median detection limits (signal-to-noise ratio of 1:3) of BDE-206, BDE-207, BDE-208 and BDE-209 in brain and liver samples was 0.05 and 0.1 ng/g ww, respectively. Quality assurance and control procedures were applied and approved. Blanks were calculated and are presented in Figure 2.

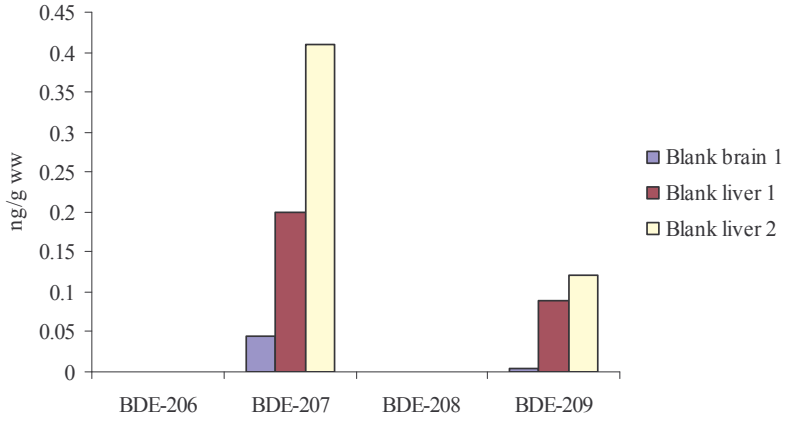


Figure 2. Procedural blanks of nona-BDEs (BDE-206, 207 and 208) and deca-BDE (BDE-209).

Detection of α-, β- and γ-HCBD
For determination of α-, β- and γ-HBCD, the extracts were analyzed using an API 3000 LC-MS-MS system (triple quadrupole) (Applied Biosystem, USA) connected to a C18 column (15 cm x 2.1 mm, 5 µm) (Supelco). As mobil phases ammonium acetate in water (A) and ammonium acetate in 99 % acetonitrile and 1% water (B) were used with a flow of 0.2 mL/min and gradients of 70 % B to 100 % B in 10 min, hold 5 min at 100 % B. The detection was performed by MRM (multiple reaction monitoring) and the mass transition ion-pair was selected as m/z 640.7-m/z 80.8. The median detection limits of α-, β- and γ-HBCD in brain and liver samples were 0.1 and 0.1 ng/g ww, respectively.

Quality assurance
The laboratory is accredited for the methods of screening routinely analyzed OCs (PCBs, pesticides) and PBDEs congeners, including BDE-209, in biological samples according to the requirements of the NS-EN ISO/IEC 17025 (TEST 051). An accreditation of the method of analyzing nona-BDEs in biological samples is currently in preparation.

6.3.2. Chemical analyses of mercury

Mercury was analysed by the National Veterinary Institute, Oslo, Norway. The analytical method is accredited after NS-EN ISO/IEC 17025 by the Norwegian Accreditation.

In short, the samples were digested by a mixture of nitric acid and hydrogen peroxide in a closed system using a microwave oven (Milestone) and analysed by cold vapour atomic absorption spectrometry (CVAAS) (Varian inc.) (tin(II) chloride (Merck) reduction at 253.7 nm and D_2-background correction). The instrument is calibrated by an external solution. For a detailed description of the method see Welz and Sperling (1999).

Detection limits (3 × standard deviation of blank samples) were 0.01 mg/kg. The measurement uncertainty was 20 %. Certified reference materials, such as TORT-1 and LUTS-2 (NRC), blanks and internal quality solutions were analysed together with the samples in every run. The laboratory's accredited analytical quality was approved in several international intercalibration tests (FAPAS, Quasimeme, and National Food Administration, Sweden).

6.3.3. Chemical analyses of perfluorinated alkyl substances, antracene, trichlorobenzenes, siloxane-D5 and octyl/nonyl phenols

Ten randomly selected liver samples (Table 4) were analyzed for perfluorinated alkyl substances (PFAS), antracene, chlorinated paraffins (SCCP/MCCP), trichlorobenzenes (TCB), siloxane-D5 at NILU, Kjeller. Octyl/nonyl phenols were analyzed at the Swedish Environmental Research Institute IVL.

Analysis of SCCP/MCCP, anthracene, TCBs, and D5

The samples were homogenized with sodium sulphate. The mixture was filled into glass columns and an internal standard mixture was added on top of the columns. The lipophilic compounds were eluted by a slow flow of cyclohexane. Both TCBs and D5 were analyzed without any further treatment. For the determination of the other analytes lipids were removed by gel permeation chromatography (GPC) on a 50 g Biobeads SX-3 with cyclohexane/ethyl acetate (50/50) and an additional separation by chromatography on silica gel. Before quantification 1,2,3,4-tetrachloro-naphthalene was added as recovery standard.

The separation of the different compounds was performed by high-resolution gas chromatography (HRGC) on a Hewlett-Packard HP 6890 with splitless injection of 1 µl aliquot of the sample extract and helium as a carrier gas. For detection and quantification the following mass spectrometers were used: a Hewlett-Packhard HP5973MSD low resolution mass spectrometer and a Micromass AutoSpec (formerly VG Analytical AutoSpec) high resolution mass spectrometer (res> 10 000). For details see Table 3.

Table 3. List of analytes determined in liver and brain tissue of glaucous gulls found dead on Bjørnøya in 2003, 2004 and 2005, analytical laboratories involved and methods used. Methods used: gas chromatograph (GC)-high resolution-mass spectrometer (HRMS) in the electron chemical ionization mode (ECNI), GC-low resolution (LR)-mass spectrometer (MS)-MS, liquid chromatograph (LC)-MS-MS, LC-MS combined with time of flight (TOF) and cold vapour atomic absorption spectrometry (CVAAS).

PARAMETER	LABORATORY	METHODS
ORGANOCHLORINES (OC) AND METABOLITES		
Legacy OCs (routinely analysed)		
Polychlorinated biphenyls (PCBs)	MT Lab	GC-(ECNI)
Hexachlorobenzene (HCB)	MT Lab	GC-(ECNI)
Trichlorobenzenes	NILU	GC-HRMS
Chlordanes and metabolites (CHL)	MT Lab	GC-(ECNI)
Mirex	MT Lab	GC-(ECNI)
Dichlorodiphenyltrichloroethane (DDT) and metabolites	MT Lab	GC-(ECNI)
Hexachlorocyclohexanes (HCH)	MT Lab	GC-(ECNI)
BROMINATED FLAME RETARDANTS (BFR)		
BFR		
Polybrominated diphenyl ethers (PBDEs)	MT Lab	GC-(ECNI)MS
Hexabromocyclododecane (HBCD)	MT Lab	LC-MS-MS
PERFLUORINATED ALKYL SUBSTANCES (PFAS) AND OTHER COMPONDS		
Perfluorooctane sulfonate (PFOS)	NILU	LC-MS-TOF
Perfluorooctanoic acid (PFOA)	NILU	LS-MS-TOF
Antracene	NILU	GC(ECNI)MS
Siloxane-D5	NILU	GC-HRMS
Octyl/nonyl phenols	Swedish Env. Res. Inst.	GC(ECNI)MS
MERCURY	VI	CVAAS

PFAS extraction and clean-up

The samples were homogenized in high-purity lab water (one part sample, 5 parts MilliQ-water; MilliQ, Millipore Corp.) using an Ultra-Turrax homogenizer. From this homogenate 1 g sample in a PP-centrifuge tube was spiked with 20 µl ISTD (corresponding to 20 ng/g liver) and 2.7 g 2 mM NH4OAc in methanol/water (1:1) was added. The mixture was extracted three times for 10 min in an ultrasonic bath, and the mixture filtrated through micron centrifuge filter (14000 rpm, 15-45 min) before it was transferred to an autosampler vial.

An Agilent high performance liquid chromatography system (HPLC, 1100 series, Agilent, Palo Alto, CA) in combination with a time-of-flight high resolution mass spectrometer (LC-TOF: Waters-Micromass, Manchester, UK) was used for quantification of PFAS. PFAS were quantified with electrospray ionisation (ESI) in negative ion mode.

Octyl- and nonylphenol

The samples were acidified, spiked with surrogate standards and homogenised in acetone. The homogenates were further extracted twice with pentane/MTBE. Acidified water was added to the combined extracts. The organic phase was separated and concentrated to a small volume. Most of the lipids were removed by semi preparative gel permeation chromatography. The fraction containing the analytes was concentrated and acetylated using acetic acid anhydride and sodium acetate. After chromatography on silica gel, analysis was performed on a 6890N gas chromatograph coupled to a 5973 N mass selective detector (Agilent). The fused silica capillary column (VF-5MS 30 m x 0.25 mm i.d. x 0.25 µm film thickness, Varian) was held at 45°C for 1 min, ramped 15°C/min to 200°C, 5°C/min until 300°C and held at 300°C for 5 min. Helium was used as carrier gas. The detector was used in electron ionization selected ion monitoring mode. The reported concentrations were corrected according to the surrogate standard losses.

Table 4. Individuals analyzed at NILU. GG = glaucous gulls.

Species	ID
GG	4-03
GG	6-03
GG	6-04
GG	7-04
GG	8-04
GG	11-04
GG	12-04
GG	2-05
GG	4-05
GG	7-05

6.4 Statistics

All multivariate statistics were conducted using CANOCO 4.5 for Windows (Microcomputer Power, Ithaca, USA, 2002).

A principal component analysis (PCA) was used to investigate HOC patterns in brain and liver samples. The HOC patterns in glaucous gulls were calculated as a proportion to ∑HOCs (i.e., lipid weight concentrations of HOC congeners were standardized by norm prior to the analysis) (Ter Braak and Šmilauer, 1998).

7. Results and discussion

7.1. Autopsies

7.1.1. General comment

The organs of some of the birds had decayed considerably, e.g., the pancreas and spleen were difficult to find in individuals in which the putrefaction was well developed. Freezing/thawing and autolysis had severely deteriorated the quality of the histological sections, and this made the interpretation of histological changes difficult in many cases.

7.1.2. Autopsy findings

Ten birds (43 %) were found to be completely (n=5) or severely (n=5) emaciated. In one case the emaciation could probably be attributed to a splint of bone that had penetrated the stomach (LM-2-03, Table 5). Another case appeared anaemic (9-04, table 5), but whether anaemia had been the cause of emaciation or emaciation the cause of anaemia is left to speculations. The remaining 8 birds did not reveal pathological changes that could explain the emaciation.

Seven birds (30 %) were found to be emaciated, but the emaciation was judged as not being so severe that it could be directly involved as the cause of death. One of these birds was euthanized due to a broken wing (3-04, Table 5). Another of these cases (6-04) had no other findings than emaciation. The remaining 5 birds all showed various degrees of oedema in the lungs, often combined with transudate in the pericardial sac, which in two cases contained fibrin. These changes are considered unspecific signs of circulatory failure. Bacteriological examination of 3 of these cases was all negative.

Six birds (26 %) were found to be in normal (n=2) or slightly below normal condition (n=4). One bird in normal condition had a haemorrhagic enteritis (12-04, Table 5). Bacteriological examination of internal organs and intestine was negative. An attempt to isolate *Salmonella* sp. from the intestines by use of selective enrichment was also negative, and the cause of the enteritis could not be established. Three other birds in this group had lung oedema; two also had fibrinous transudate in the pericardial sac, similar to the findings in emaciated birds. Bacteriological examination of one of these cases was negative. Two cases showed no pathological findings.

All together, a plausible diagnosis was established only for 3 (13 %) of the 23 birds: That is trauma (3-04), haemorrhagic enteritis (12-04) and bone splint perforation of stomach (LM-2-03). The remaining birds have either received the diagnosis complete/severe emaciation without obvious reason (n=9), unspecific signs of circulatory failure (n=8) or none diagnosis at all (n=3).

As an incidental finding we observed one or more cysts of *Sarcocystis* sp. in histological sections from breast muscles in 5 (24 %) of the birds. Such muscle cysts are normally not of clinical significance.

Table 5. Main diagnoses from the autopsies. GG = glaucous gulls, GBBG = great black-backed gull.

Species	ID	Body condition	Main diagnoses from the autopsy
GG	2-03	Emaciation	Lung oedema
GG	3-03	Slightly below normal condition	None
GG	4-03	Severe emaciation	Found in a moribund state by the Governor of Svalbard. Euthanised. No other findings than severe emaciation
GG	5-03	Severe emaciation	None other than severe emaciation
GG	6-03	Emaciation	Lung oedema. Fibrinous transudate in pericardium and abdomen
GG	3-04	Emaciation	Metacarpal fracture (right wing). Euthanised
GG	4-04	Normal body condition	Found in a moribund state. Congestion and oedema of lung, fibrinous transudate in the abdominal cavity (ascites). Bacteriological test negative
GG	5-04	Complete emaciation	None other than complete emaciation
GG	6-04	Emaciation	None other than emaciation
GG	7-04	Severe emaciation	None other than severe emaciation
GG	8-04	Slightly below normal condition	None
GG	9-04	Complete emaciation	Anaemia (extremely pale carcass)
GG	10-04	Complete emaciation	None other than complete emaciation
GG	11-04	Severe emaciation	None other than severe emaciation
GG	12-04	Normal body condition	Found in a moribund state. Hemorrhagic enteritis. Severe congestion and oedema in lungs. Bacteriological test negative
GG	1-05	Emaciation	Lung oedema, fibrinous transudate in pericardial sac. Bacteriological test negative
GG	2-05	Emaciation	Slight oedema in lungs, transudate in pericardial sac. Bacteriological test negative. Old lead shots found in the skin, lead analyzed. The concentrations were low (0.05µg/g, compared to the levels in control birds (without lead shots) < 0.01 and 0.09 µg/g)
GG	3-05	Emaciation	Lung oedema. Bacteriological test negative
GG	4-05	Slightly below normal condition	Severe lung oedema, fibrinous transudate in pericardial sac
GG	5-05	Slightly below normal condition	Severe lung oedema.
GG	7-05	Complete emaciation	None other than complete emaciation
GBBG	LM-1-03	Complete emaciation	None other than complete emaciation
GBBG	LM-2-03	Severe emaciation	Perforation of the stomach by a splint of bone (chronic lesion)

7.2. Organochlorines (OCs)

PCBs

$\sum PCB_{24}$[1] concentrations in the liver and brain samples of the glaucous gulls of the present study ranged from 84,054 ng/g lw to 4,273,992 ng/g lw, and from 16,680 ng/g lw to 711,468 ng/g lw, respectively (Table 6). The PCB profile in both liver and brain samples of glaucous gulls was dominated by hexa-PCBs, hepta-PCBs and penta-PCBs (Table 6; Figure 3). The liver levels of $\sum PCB_{24}$ in glaucous gulls were higher than the reported brain levels (Table 6). This suggests that the brain tissue is better protected for contamination than the liver tissue in spite of high fat concentrations (7.2 versus 4.8 % lipids in brain and liver tissue, respectively). A better protection for contamination in the brain compared to the liver tissue have been reported in most animals (however, fish does not have this), and has been suggested to be a result of the blood-brain barrier (Bachour et al., 1998).

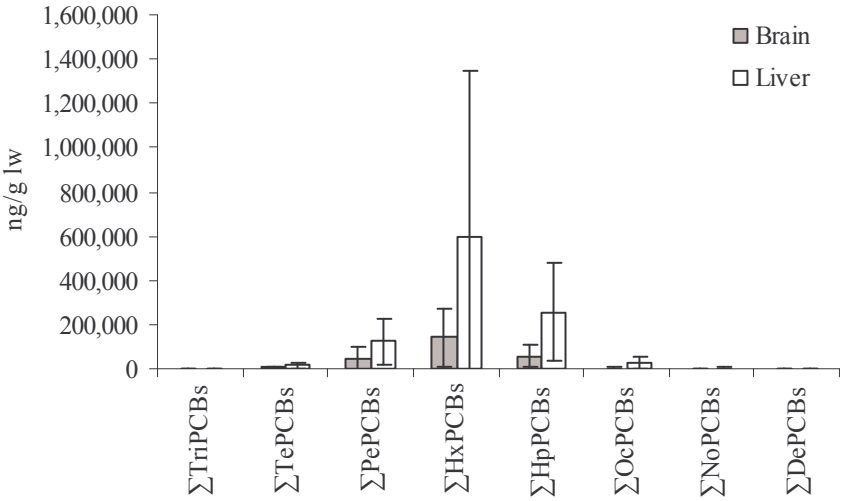


Figure 3. Mean (± SD) concentrations (ng/g lw) of sum (∑) PCB groups in brain and liver samples of glaucous gulls found dead on Bjørnøya in 2003/2004/2005. N = 21.

The brain levels of $\sum PCB_{24}$ in one of the great black-backed gulls were higher than the maximum brain levels of $\sum PCB_{24}$ found in glaucous gulls (Tables 6 and 7; 811,788 and 711,468 ng/g lw, respectively). In contrast, the maximum liver levels of $\sum PCB_{24}$ were found in a glaucous gull (maximum liver levels in glaucous gulls and great black-backed gulls: 4,273,992 ng/g lw and 1,875,746 ng/g lw, respectively) (Tables 6 and 7). As with the glaucous gulls, the PCB profile in both liver and brain samples of great black-backed gulls was dominated by hexa-PCBs and hepta-PCBs (Figure 4).

The levels of ∑PCBs in the glaucous gulls and great black-backed gulls of the present study were much higher than that previously reported in free-living glaucous gulls from

[1] PCB-28, 52, 74, 66, 101, 99, 110, 149, 118, 114, 105, 141, 153, 138, 128, 156, 157, 187, 183, 180, 170, 194, 206, 209

Bjørnøya (e.g., 16,000 ng/g lw to 300,000 ng/g lw) (Henriksen et al., 2000; Borgå et al., 2001; Herzke et al., 2003), and great black-backed gull from Jan Mayen (138,623 ng/g lw; Gabrielsen et al., 1997).

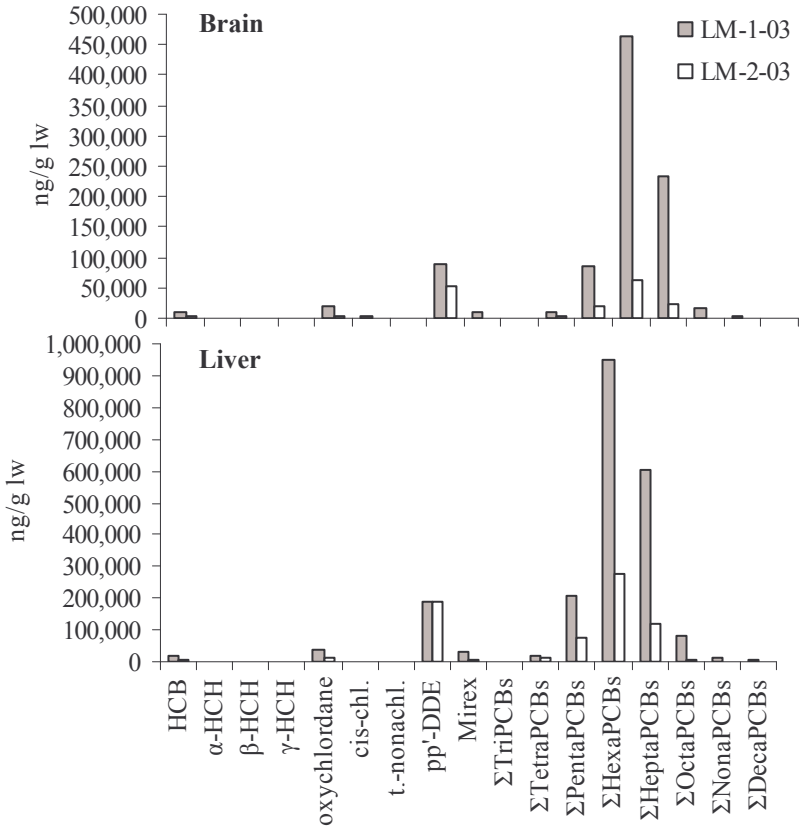


Figure 4. Individual concentrations (ng/g lw) of organochlorines (OCs) in brain and liver samples of great black-backed gull. N = 2 (LM-1-03 and LM-2-03).

The $\sum PCB_{24}$ concentrations (lipid normalized) in the present study were also much higher than liver concentrations of ∑PCB found in northern fulmars from Jan Mayen (14,292 ng/g lw; Gabrielsen et al., 1997), black guillemots (*Cepphus grylle*) from Barents Sea (2188 ng/g lw; Borgå et al., 2001), black-legged kittiwakes from the Barents Sea (17,980 ng/g lw; Borgå et al., 2001), ivory gull (*Pagoohila eburnea*) from Northern Baffin Bay (9,559 ng/g lw; Fisk et al., 2001), and great skua (*Stercorarius skua*) from Jan Mayen (338,021 ng/g lw; Gabrielsen et al., 1997).

When comparing mean liver and brain wet weight concentrations of $\sum PCB_{24}$ (43,000 and 18,000 ng/g ww) in the glaucous gulls and the liver and brain levels of $\sum PCB_{24}$ in great black-backed gulls (28,000 and 101,000 ng/g ww, and 7,000 and 59,000 ng/ ww, respectively in the two great black-backed gulls) with the no-observed-effect-level (NOEL), and lowest-observed-adverse-effect-level (LOAEL) in night heron, common tern (*Sterna hirundo*), double-crested cormorant (*Phalacrocorax auritis*), herring gull (*Larus argentatus*), bald eagle (*Haliaeetus leucocephalus*) and forster's tern (*Sterna forsteri*), the birds examined in the present study exceed/are equal to (AMAP, 2004):

- NOEL for hatching success in Forster's tern (2,300 ng/g ww)

- LOAEL for egg mortality in double-crested cormorant (3,500 ng/g ww)
- LOAEL for egg mortality in bald eagle (4,000 ng/g ww)
- LOAEL for egg mortality and deformities in herring gull (5,000 ng/g ww)
- LOAEL for hatching success in common tern (7,600 ng/g ww)
- LOAEL for reproduction in common tern (8,000 ng/g ww)
- NOEL for reproduction in night heron (*Nycticorax sp.)* (10,900 ng/g ww)

There are large inter-specific differences in sensitivity to HOC exposure, e.g., doves have been found to be more sensitive to HOC effects than seabirds (AMAP, 2004). Tissue-specific toxicity thresholds of HOCs have not been established for glaucous gulls or great black-backed gulls. Thus, it is uncertain if the levels reported in the present study have an effect on reproduction even though the levels exceeds toxicity thresholds reported for other species of birds.

Table 6. Means with standard deviation (± SD) and ranges (min-max) of the sum (∑) concentrations (ng/g lipid weight (lw)) of PCBs in brain and liver samples of glaucous gulls.

	Brain						Liver					
	Mean	**±**	**SD**	**Min**	**-**	**Max**	**Mean**	**±**	**SD**	**Min**	**-**	**Max**
Lipid %	7.2	±	0.4	6.2	-	8.3	4.8	±	1.9	2.9	-	10.4
∑TriPCBs$_1$[2]	620	±	604	42.7	-	2,034	1,520	±	1,207	165	-	3,846
∑TePCBs$_3$[3]	5,318	±	5,151	510	-	17,376	13,962	±	10,866	2,159	-	33,794
∑PePCBs$_8$[4]	45,593	±	53,104	3,137	-	212,363	125,661	±	102,880	14,375	-	328,107
∑HxPCBs$_5$[5]	140,898	±	131,236	6,208	-	402,840	599,678	±	743,929	47,132	-	3,373,707
∑HpPCBs$_4$[6]	58,321	±	53,234	2,914	-	144,573	257,519	±	224,387	18,216	-	660,348
∑OcPCBs$_1$[7]	3,684	±	3,374	176	-	8,414	27,719	±	26,290	1,303	-	72,500
∑NoPCBs$_1$[8]	392	±	350	37.5	-	1,030	4,471	±	3,937	264	-	11,056
∑DePCBs$_1$[9]	217	±	145	55.3	-	481	2,468	±	2,014	196	-	5,329
∑PCBs$_{24}$	255,044	±	240,394	16,680	-	711,468	1,032,998	±	1,043,670	84,054	-	4,273,992

Table 7. Individual concentrations (ng/g lipid weight (lw)) of ∑PCBs in brain and liver samples of great black-backed gulls (N = 2).

	Brain		Liver	
	Lipid %	**∑PCBs**	**Lipid %**	**∑PCBs**
LM-1-03	7.3	811,788	5.4	1,875,746
LM-2-03	6.6	109,211	5.7	495,653

[2] PCB-28
[3] PCB-52, 74, 66
[4] PCB-101, 99, 110, 118, 114, 105
[5] PCB-153, 141, 149, 138, 128, 156, 157
[6] PCB-187, 183, 180, 170
[7] PCB-194
[8] PCB-206
[9] PCB-209

Pesticides

Mean HCB concentrations in liver and brain samples of glaucous gulls ranged from 2,571 to 206,423 ng/g lw, and 827 to 27,012 ng/ lw, respectively (Table 8). The HCB levels in the great black-backed gulls were comparable to the levels reported in the glaucous gulls (liver and brain: 6,049 and 17,681 ng/g lw; 2,452 and 10,556 ng/g lw) (Figure 4). The levels of HCB (liver: 1,271 ng/g ww; brain: 582 ng/g ww) in the present study were well below the NOEL reported in kestrels (*Falco tinnunculus*) (40,000-49,000 ng/g ww) (AMAP, 2004).

p,p'-DDE liver and brain concentrations in the glaucous gulls of the present study were ranging from 17,237 to 732,320 ng/g lw and from 4,369 to 231,951, respectively (Table 8). Mean liver levels in glaucous gulls were approximately 3.4 times higher than the brain levels (Figure 5). In great black-backed gulls the liver levels were higher than the brain levels (liver and brain: 189,017 and 190,247; 53,955 and 87,186 ng/g lw, respectively) (Figure 4).

Mean liver levels of $\sum HCH_3$[10] in glaucous gulls were approximately 4.7 times higher than brain levels (114 to 3,354 ng/g lw, and 17 to 871 ng/g lw, respectively) (Table 8; Figure 5). These levels were comparable to the levels reported in great black-backed gulls (liver and brain: 229 and 1,085 ng/g lw, and 36 and 252 ng/g lw, respectively) (Figure 4).

$\sum Chlordane_3$[11] concentrations in liver and brain samples of glaucous gulls were ranging from 2,596 to 105,981 ng/g lw, and 793 to 43,623, respectively. The mean liver levels were approximately 2.4 times higher than the brain levels (Table 8; Figure 5). Also in the great black-backed gulls, the liver levels were higher than the brain levels (liver and brain: 13,123 and 40,979 ng/g lw; 5,717 and 22,829 ng/g lw) (Figure 4).

Liver and brain concentrations of mirex in the glaucous gulls of the present study were ranging from 1,066 to 35,068 ng/g lw, and 216 to 8,173 ng/ lw, respectively (Table 8; Figure 5). The mirex levels in the great black-backed gulls were comparable to the levels reported in the glaucous gulls (Figure 4). As with the glaucous gulls, the liver levels were higher than the brain levels (liver and brain: 4,250 and 30,853 ng/g lw; 826 and 9,047 ng/g lw, respectively) (Figure 4).

[10] α-HCH, β-HCH, γ-HCH
[11] Oxychlordane, cis-chlordane, trans-nonachlor

Table 8. Means with standard deviation (± SD) and ranges (min-max) of the sum (∑) concentrations (ng/g lipid weight (lw)) of OCs in brain and liver samples of glaucous gulls.

	Brain						Liver					
	Mean	±	**SD**	**Min**	-	**Max**	**Mean**	±	**SD**	**Min**	-	**Max**
Lipid %	7.2	±	0.4	6.2	-	8.3	4.8	±	1.9	2.9	-	10.4
HCB	8,274	±	7,749	827	-	27,012	26,416	±	43,145	2,571	-	206,423
$\sum HCH_3$	221	±	240	17.0	-	871	1,038	±	952	114	-	3,354
$\sum Chlordanes_3$	12,275	±	13,967	793	-	43,623	29,825	±	28,456	2,596	-	105,981
p,p'-DDE	63,768	±	66,355	4,369	-	231,951	215,109	±	198,063	17,237	-	732,320
Mirex	2,925	±	2,696	216	-	8,173	13,039	±	11,321	1,066	-	35,068

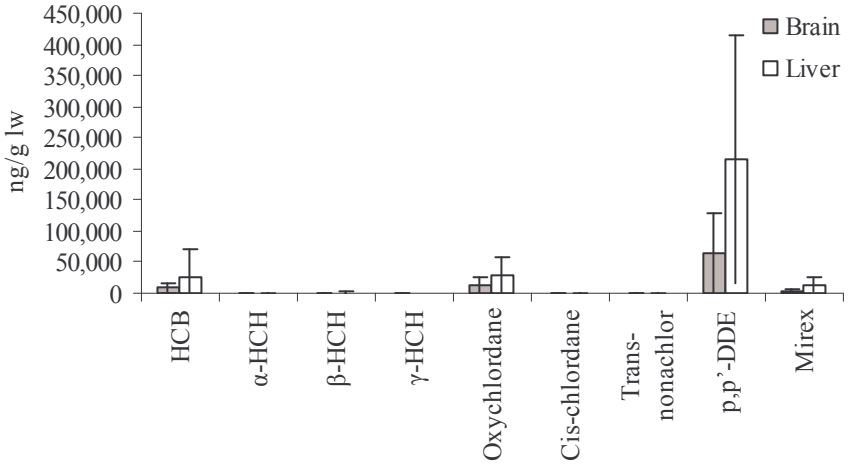


Figure 5. Mean (± SD) concentrations (ng/g lw) of pesticides in brain and liver samples of glaucous gulls found dead on Bjørnøya in 2003/2004/2005. N = 21.

The levels of pesticides in the glaucous gulls and great black-backed gulls of the present study were much higher than that previously reported in free-living seabirds from the Arctic, including glaucous gulls and great black-backed gull from Bjørnøya and Jan Mayen (Table 9).

Exposure to pesticides has been shown to affect the reproduction, induce the monooxygenases, suppress the immune system and the hormone homeostasis. Additionally, several of the pesticides and their metabolites have been shown to be both toxic and carcinogenic (AMAP, 2004).

Table 9. OC concentrations (ng/g lw) in liver samples reported in the scientific literature.

Species	Latin name	HCB	∑HCHs	∑CHLs	∑DDTs	Study area	Source
Brünnich's guillemot	*Uria lomvia*	2,056	148	416	5,440	Barents Sea	Evenset et al., 2002
Black guillemot	*Cepphus grylle*	335	36	292	715	Barents Sea	Borgå et al., 2001
Black-legged kittiwakes	*Rissa tridactyla*	866	43	448	1471	Barents Sea	Borgå et al., 2001
Ivory gull	*Pagophila eburnea*	538	250	2,638	7,647	N Baffin Bay	Fisk et al., 2001
Glaucous gull	*Larus hyperboreus*	4,090	253	5,530	41,937	Barents Sea	Borgå et al., 2001
Glaucous gull	*Larus hyperboreus*	2,254	-	-	24,822	Bjørnøya	Henriksen et al., 2000
Great black-backed gulls	*Larus marinus*	2,826	381	7,870	45,507	Jan Mayen	Gabrielsen et al., 1997
Northern fulmar	*Fulmarus glacialis*	758	13	3,583	9,746	Jan Mayen	Gabrielsen et al., 1997
Great skua	*Stercocarius skua*	5,057	368	19,394	115,213	Jan Mayen	Gabrielsen et al., 1997

OC pattern comparison in brain and liver samples

The pattern comparison of HOC congeners in glaucous gulls suggested a similar congener pattern in liver and brain samples (Figure 6). This is similar to the pattern found in black-legged kittiwakes (Henriksen et al., 1996). Although, in kittiwakes the brain tissue had a lower affinity for the higher chlorinated congeners (Henriksen et al., 1996).

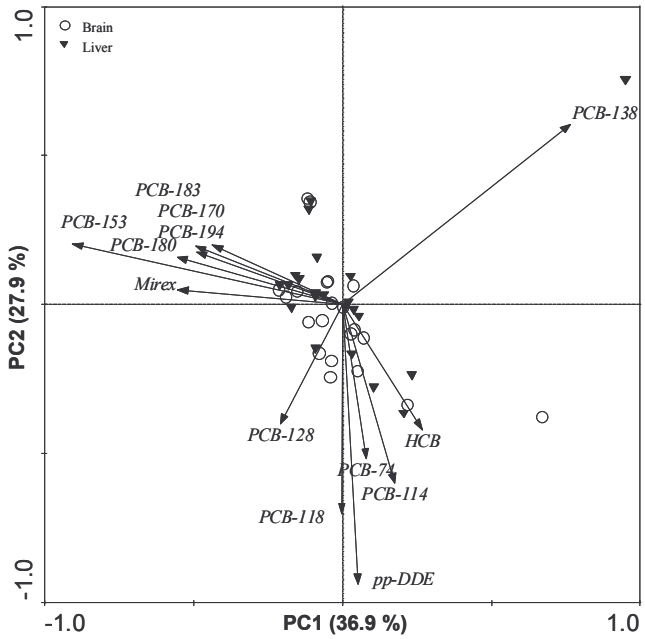


Figure 6. Indirect ordination (Principal component (PC) analysis) of organochlorines (OCs). Variables (OCs) point in the direction of increasing concentrations. Individual samples (liver (N = 21) and brain (N = 21)) are presented. Percent variability explained by the two first PCs, PC1 and PC2, is given in brackets.

7.3. Brominated flame retardants

PBDEs

$\sum BDE_{11}$[12] concentrations in the brain and liver samples of the glaucous gulls of the present study ranged from 221 ng/g lw to 10,855 ng/g lw, and from 1,819 ng/g lw to 102,788 ng/g lw, respectively (Table 10). The BDE profile in both liver and brain samples of glaucous gulls was dominated by tetra-BDEs and penta-BDEs (Table 10; Figure 7). The liver levels of ∑BDEs in glaucous gulls were higher than the reported brain levels (Table 10).

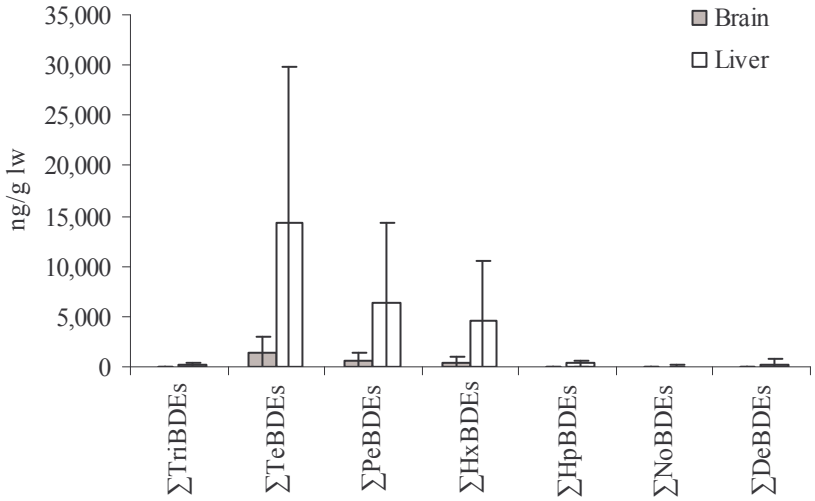


Figure 7. Mean (± SD) concentrations (ng/g lw) of the sum (∑) polybrominated diphenylethers (BDEs) in brain and liver samples of glaucous gulls found dead on Bjørnøya in 2003/2004/2005. N = 21.

The brain and liver levels of $\sum BDE_{11}$ in the great black-backed gulls were lower than the maximum brain and liver levels of ∑BDEs found in glaucous gulls (Tables 10 and 11). The PBDE profile in both liver and brain samples of great black-backed gulls was dominated by tetra-BDEs and hexa-BDEs (Figure 8).

The levels of $\sum BDE_{11}$ in the glaucous gulls and great black-backed gulls of the present study were higher than that previously reported in free-living glaucous gulls from Bjørnøya (Table 12).

The ∑BDE concentrations (lipid normalized) in the present study were also higher than ∑BDE concentrations found in other bird species (Table 12).

[12] BDE-28, 47, 100, 99, 154, 153, 183, 206, 207, 208 and 209

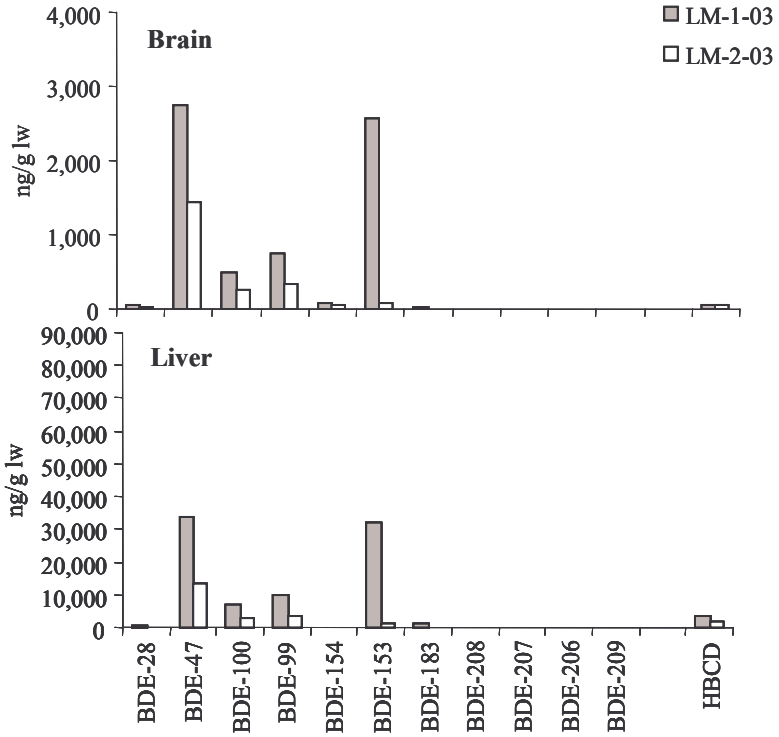


Figure 8. Individual concentrations (ng/g lw) of brominated flame retardants, i.e., individual concentrations of polybrominated diphenylethers (BDEs) and hexabromocyclododecane (HBCD) in brain and liver samples of great black-backed gull. N = 2 (LM-1-03 and LM-2-03).

HBCDs

α-HBCD concentrations in the brain and liver samples of the glaucous gulls of the present study ranged from 5.1 ng/g lw to 475 ng/g lw, and from 195 ng/g lw to 15,027 ng/g lw, respectively (Table 10). The brain and liver levels of α-HBCDs in the great black-backed gulls were lower than the maximum brain and liver levels of α-HBCD found in glaucous gulls (Tables 10 and 11).

α-HBCD was the only enantiomer found in glaucous gulls and great black-backed gulls in the present study (Tables 10 and 11). β-HBCD and γ-HBCD isomers were below the method limits of detection in all samples. This is in good agreement with previous findings reporting a strong prevalence of α-HBCD in animals (Morris et al., 2004; Knudsen et al., 2005; 2006).

The levels of α-HBCD in the glaucous gulls and great black-backed gulls of the present study were higher than that (α-HBCDs or total-HBCD) previously reported in free-living glaucous gulls from Bjørnøya and other bird species (Table 12).

Table 10. Means[a] with standard deviation (± SD) and ranges (min-max) of the sum (∑) concentrations (ng/g lipid weight (lw)) of brominated flame retardants, i.e., polybrominated diphenylethers (BDEs) and hexabromocyclododecane (HBCD) in brain and liver samples of glaucous gulls.

	Brain							Liver						
	Mean	±	SD	Min	-	Max	N [b]	Mean	±	SD	Min	-	Max	N [b]
Lipid %	7.1	±	0.4	6.2	-	8.3	21/21	4.8	±	1.9	2.9	-	10.4	21/21
∑Tri-BDEs$_1$[13]	20.2	±	22.2	0.5	-	65.7	21/21	171	±	183	10.1	-	590	21/21
∑TeBDEs$_1$[14]	1462	±	1571	134	-	5,893	21/21	14,228	±	15,542	1,182	-	56,814	21/21
∑PeBDEs$_2$[15]	601	±	745	51.6	-	2,942	21/21	6,376	±	7,882	458	-	28,801	21/21
∑HxBDEs$_2$[16]	451	±	588	27.5	-	1,929	21/21	4,545	±	6,090	147	-	21,346	21/21
∑HpBDEs$_1$[17]	7.7	±	8.3	0.8	-	28.1	21/21	299	±	378	5.5	-	1,174	16/21
∑NoBDEs$_3$[18]	1.7	±	1.3	nd	-	4.1	15/21	66.8	±	79.7	2.6	-	272	19/21
∑DeBDEs$_1$[19]	2.9	±	3.7	nd	-	9.5	5/21	186	±	583	5.5	-	2,586	20/21
∑BDEs$_{11}$	2,544	±	2,856	221	-	10,855	21/21	25,777	±	28,980	1819	-	102,788	21/21
α-HBCD	98.9	±	136	5.1	-	475	21/21	3,026	±	4,322	195	-	15,027	21/21

[a] Arithmetic means are reported for samples with analyte concentrations above the method detection limits only. [b] Samples above the detection limit relative to samples analyzed.

Brominated flame retardant patterns in brain and liver samples

There were no clear differences in BFR congener pattern in glaucous gulls comparing brain and liver samples in the present study (Figure 9). However, there was a tendency of relatively higher concentrations of BDE-47 and BDE-154 and BDE-100 in the brain samples. The finding of relatively similar congener pattern comparing brain and liver tissue is similar to the results recently presented for terrestrial birds from Belgium. In the birds from Belgium no differences could be seen in the BDE congener pattern between brain and liver tissue within individuals belonging to the same species (Voorspoels et al., 2006).

Table 11. Individual concentrations (ng/g lipid weight (lw)) of ∑polybrominated diphenylethers (BDEs) and hexabromocyclododecane (HBCD) in brain and liver samples of great black-backed gulls. N = 2 (LM-1-03 and LM-2-03).

	Brain			Liver		
	Lipid %	∑BDEs	α-HBCD	Lipid %	∑BDEs	α-HBCD
LM-1-03	7.3	6,748	44.8	5.4	84,380	3699
LM-2-03	6.6	2,167	44.7	5.7	20,844	1881

[13] BDE-28
[14] BDE-47
[15] BDE-99, 100
[16] BDE-153, 154
[17] BDE-183
[18] BDE-206, 207, 208
[19] BDE-209

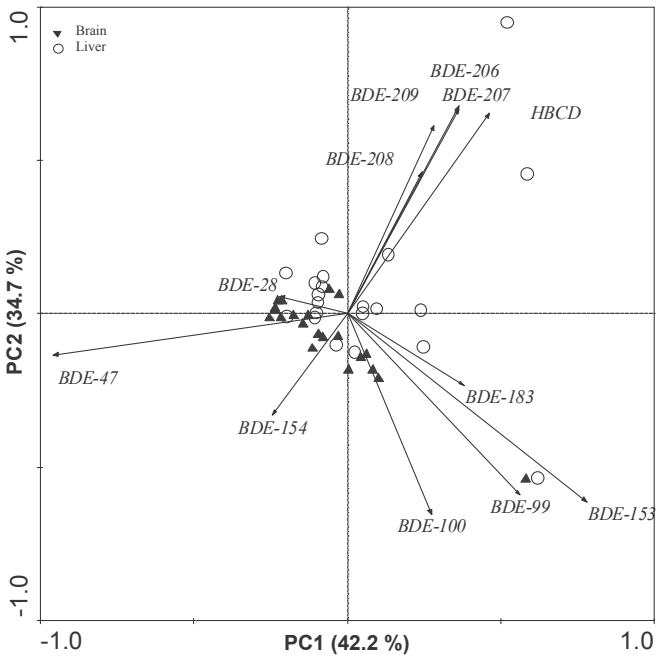


Figure 9. Indirect ordination (Principal component (PC) analysis) of brominated flame retardants (BFRs). Variables (BFRs) point in the direction of increasing concentrations. Individual samples (liver ($N = 21$) and brain ($N = 21$)) are presented. Percent variability explained by the two first PCs, PC1 and PC2, is given in brackets.

Table 12. Mean PBDE and HBCD concentrations (ng/g lw) in liver or plasma samples reported in the scientific literature.

Species	Latin name	∑PBDE	HBCD	Tissue	Study area	Source
Common buzzard	*Buteo buteo*	130	-	Brain	Belgium	Voorspoels et al., 2006
Common buzzard	*Buteo buteo*	480	-	Liver	Belgium	Voorspoels et al., 2006
Sparrow hawk	*Accipiter nisus*	1200	-	Brain	Belgium	Voorspoels et al., 2006
Sparrow hawk	*Accipiter nisus*	4900	-	Liver	Belgium	Voorspoels et al., 2006
Glaucous gull	*Larus hyperboreus*	1,312 (male)	22.1	Plasma	Bjørnøya	Verreault et al., 2005b
Glaucous gull	*Larus hyperboreus*	1,338 (female)	21.6	Plasma	Bjørnøya	Verreault et al., 2005b
European shag	*Phalacrocorax aristotelis*	251	417	Yolk sac	Sklinna, Norway	Murvoll et al., 2006a
Black-legged kittiwake	*Rissa tridactyla*	653 (males)	335	Yolk sac	Runde, Norway	Murvoll et al., 2006b
Black-legged kittiwake	*Rissa tridactyla*	438 (females)	205	Yolk sac	Runde, Norway	Murvoll et al., 2006b
Black-legged kittiwake	*Rissa tridactyla*	419 (males)	111	Yolk sac	Kongsfjorden, Norway	Murvoll et al., 2006b
Black-legged kittiwake	*Rissa tridactyla*	517 (females)	129	Yolk sac	Kongsfjorden, Norway	Murvoll et al., 2006b
Northern fulmar	*Fulmarus glacialis*	nd	14.8	Liver	Bjørnøya	Knudsen et al., 2006

7.4. Perfluorinated alkyl substances (PFAS)

Of two analyzed PFAS only one were detected in the glaucous gulls of the present study (Table 13).

The levels of PFOS in liver samples of glaucous gulls in the present study were high compared to the levels reported in other Arctic seabirds (Table 14), and comparable to the liver levels reported in seabirds from more polluted and industrialized regions, such as the USA, Italy and Korea (concentrations ranging from < 12 to 1780 ng/g ww) (Giesy and Kannan, 2001; Kannan et al., 2001). The levels in the present study were well below the NOAEL (15 000 ng/g ww in liver) and LOAEL (58 000 ng/g ww in liver) for second-generation effects in rats (AMAP, 2004).

Table 13. Ranges (min-max) of the concentrations (ng/g wet weight (ww)) of PFAS, antracene, trichlorobenzenes, siloxane-D5 and octyl/nonyl phenols in liver samples of glaucous gulls. N = samples above the detection limit relative to samples analyzed.

	Liver			
	Min	**-**	**Max**	**N**
NILU:				
Perfluorooctane sulfonate (PFOS)	21.0	-	629	10/10
Perfluorooctanoic acid (PFOA)		-		0/10
Antracene	0.3	-	48.0	10/10
SCCP		-		0/10
MCCP		-		0/10
Siloxane-D5	32.2	-	68.8	10/10
1,3,5-Trichlorobenzene		-		0/10
1,2,3-Trichlorobenzene	0.01	-	0.02	5/10
1,2,4-Trichlorobenzene	0.04	-	0.1	10/10
Swedish Environmental Research Institute (IVL):				
Octylphenol		-		0/10
Nonylphenol	70	-	3,500	4/10

Table 14. Mean PFOS concentrations (ng/g ww) in liver or plasma samples reported in the scientific literature.

Species	Latin name	PFOS	Tissue	Study area	Source
Black guillemot	*Cepphus grylle*	13	Liver	Greenland	Bossi et al., 2005
Glaucous gull	*Larus hyperboreus*	134	Plasma	Bjørnøya	Verreault et al., 2005c
Northern fulmar	*Fulmarus glacialis*	0.7	Liver	Canada	Butt et al., 2005
Northern fulmar	*Fulmarus glacialis*	24	Liver	Faroe Islands	Bossi et al., 2005
Northern fulmar	*Fulmarus glacialis*	3.4	Liver	Bjørnøya	Knudsen et al., 2006

7.5. Anthracene, chlorinated paraffins, trichlorobenzenes, siloxan-D5 and octyl/nonyl phenols

Antracene
Anthracene is a tricyclic aromatic hydrocarbon (PAH). Anthracene is readily oxidized to form several oxidation products such as anthraquinone and hydroxy-anthraquinones. The oxidation products might be further oxidized to products which generally are more toxic than the parent compounds (Mellakin et al., 1999). In concert with this, anthracene is toxic to e.g. fish and algae (Choi and Oris, 2003; Mellakin et al., 1999).

Generally, low levels of anthracene were detected in the present study (Table 13). Information of levels of anthracene in the environment is scarce. In liver samples of redheads (*Aythya Americana*) from USA anthracene were not detected (Michot et al., 1994), whereas in barn owl (*Tyto alba*) from Spain anthracene was detected in the range nd – 1.13 µg/kg dry matter (Amigo et al., 2000).

Chlorinated paraffins
Chlorinated paraffins (CP) are a group of *n*-alkenes which typically is divided into short-chain chlorinated paraffins (C_{10-13}, SCCPs), medium-chain chlorinated paraffins (C_{14-19}, MCCPs) and long-chain chlorinated paraffins ($C_{>20}$, LCCPs) depending on their carbon chain length. The CPs are bioaccumulative, toxic (Tomy et al., 1998) and long-range transported (Tomy et al., 1999). In concert with this, Borgen et al. (2002) measured SCCP in ambient air at Bjørnøya in the range 1800 – 10600 pg/m^3.

SCCPs and MCCPs were not detected above the detection limit in any of the glaucous gulls found dead on Bjørnøya (see table 13). This is in contrast with the findings in a previous study of SCCPs and MCCPs in liver samples of Arctic char, little auk and kittiwake collected at Bjørnøya (Reth et al., 2006). The Arctic char, little auks and black-legged kittiwakes were found with concentrations of SCCPs and MCCPs in the range 5-88 ng/g ww and 5-370 ng/g ww, respectively (Reth et al., 2006). Chlorinated paraffins have previously been shown to be readily oxidized by most homeotherms (Muir et al.,

1999), and the concentrations differences between the birds in the present study, the little auk and the black-legged kittiwakes in the study by Reth et al. (2006) might be explained by species-specific oxidation differences for CPs or migration differences. However, it might also be related to analytical differences and needs a more thorough investigation before any conclusions can be drawn.

Trichlorobenzenes

Trichlorobenzenes (TCBs) are obtained by chlorination of benzene and are used in various industrial processes. In a study of male and female rats fed diets containing TCB isomers (1,3,5-TCB, 1,2,3-TCB and 1,2,4-TCB) at 1, 10, 100 or 1000 ppm for 13 weeks it was concluded that the no-observable-adverse-effect levels for the three TCBs were 100 ppm (Côte et al., 1988). Very low levels of TCB were found in the present study (Table 13) which suggests that the levels were to low to affect the health of the birds. The results of the present study also supports the findings in a recent study which suggested a low to moderate bioaccumulation potential of TCB, and a low biomagnification of TCB in the food chain because of relatively high elimination rate constants (van Wijk et al., 2006). There have not been many studies analyzing TCBs levels in Arctic birds.

Siloxane-D5

Siloxane-D5 is a cyclic siloxane with a wide range of commercial applications, e.g., industrial, consumer product and dry cleaning. Studies investigating the effects of D5 exposure (160 ppm D5 vapours, 6 h/day, 7 days/week, for 28 days) on the expression and activity of selected rat hepatic phase I and phase II metabolizing enzymes indicate that the effect of D5 vapors on rats are similar to that reported for phenobarbital (McKim Jr et al., 1999). Furthermore, siloxanes have been shown to exhibit estrogenic activity in mice (He et al., 2003). In rats injected with siloxanes, individual siloxanes were measured in 10 different organs (brain, heart, kidney, liver, lung, mesenteric lymph nodes, ovaries, spleen, skeletal muscle, and uterus). Highest levels of cyclosiloxanes were found in the mesenteric lymph nodes, ovaries, and uterus, but all organs examined contained cyclosiloxanes. Of the individual cyclosiloxanes measured, selective retention of decamethylcyclopentasiloxane and dodecamethylcyclohexasiloxane relative to octamethylcyclotetrasiloxane was seen in all organs at all time points studied (Kala et al., et al., 1998).

There are few studies investigating the levels of D5 in free ranging animals. D5 was detected in all the glaucous gulls of the present study and the concentrations in the liver samples of glaucous gulls were ranging from 32.2-68.8 ng/g ww, see table 13. These levels are as high as several of the OC-, and PBDE- congeners reported in the present study. It is difficult to assess the toxicological potential of this compound in Arctic birds, nevertheless, it can be concluded from the present study that this compound is present in the Arctic environment. Siloxane-D5 have been detected in marine fish samples from Denmark and Norway, freshwater fish from Finland and Norway, and marine mammals from Denmark and Faroe Islands (concentrations ranging from nd-2200 ng/g ww) (Lennart et al., in press). In contrast to this and the findings in the present study, D5 was neither detected in northern fulmar and black guillemots from Faroe Islands, nor in herring gull eggs from Sweden (Lennart et al., in press).

Alkylphenols
Alkylphenols are used in a variety of commercial products such as in plastics and as detergents. Alkylphenolic compounds, such as octylphenol and nonylphenol, have been shown to be estrogenic in fish, birds, and mammals (White et al., 1994). For example in a study on quail eggs nonylphenol (NP) and octylphenol (OP) was shown to exhibit relatively high binding affinity to the estrogen receptor, indicating that NP and OP have endocrine disrupting properties (Shimada et al., 2005).

Octylphenols was not found in any of the glaucous gulls of the present study (Table 13). Nonylphenols was reported in four out of the ten analyzed glaucous gulls. The levels were ranging from 70-3500 ng/g ww, se table 13. The octanol-water-partition coefficients (log K_{ow}) of the alkylphenols indicate a potential for bioaccumulation. To our knowledge there exist few data on levels of alkylphenols in free-ranging aquatic organisms.

7.6. Mercury (Hg)

Concentrations of mercury in liver of glaucous gulls (Table 15) and great black-backed gulls (Table 16) were comparable to the levels reported in other Arctic seabird species, e.g., black-legged kittiwakes, Brünnich's guillemots and black guillemots (Table 17), and that previously reported in glaucous gulls (Table 17). The levels were generally lower than that reported in northern fulmars, but higher than that reported in little auks (Table 17).

Table 15. Means with standard deviation (± SD) and ranges (min-max) of the concentrations (µg/g wet weight (ww)) of mercury in liver samples of glaucous gulls.

	Liver					
	Mean	**±**	**SD**	**Min**	**-**	**Max**
Hg	1.5	±	1.1	0.3	-	4.3

Table 16. Individual concentrations (µg/g ww) of mercury in liver samples of Great black-backed gulls (N = 2).

	Liver
	Hg
LM-1-03	3.4
LM-2-03	1.2

Laboratory studies have identified a number of effects after Hg exposure. However, the mercury levels in the birds of the present study were well below the threshold level for lethal effects (AMAP, 1998), malnutrition (Spalding et al., 1994), chronic diseases (Spalding et al., 1994), embryo mortality (Wolfe et al., 1998) and brain lesions (Wolfe et al., 1998) in birds.

Table 17. Hg concentrations (µg/g ww) in liver samples reported in the scientific literature.

Species	Latin name	Hg	Study area	Source
Brünnich's guillemot	*Uria lomvia*	1.1	Northern Baffin Bay	Borgå et al., 2006
Black guillemot	*Cepphus grylle*	1.2	Northern Baffin Bay	Borgå et al., 2006
Little auk	*Alle alle*	0.3	Northern Baffin Bay	Borgå et al., 2006
Northern fulmar	*Fulmarus glacialis*	3.4	Northern Baffin Bay	Borgå et al., 2006
Northern fulmar	*Fulmarus glacialis*	3.0	Bjørnøya	Knudsen et al., 2006

7.7. Comparison of OC levels in glaucous gulls found dead on Svalbard in 1989 and in 2003/2004/2005

Concentration comparisons

The liver levels of legacy HOCs were considerably higher in 1989 compared to the levels found in the present study (Figures 10 and 11). This is in accordance with the downward trends of legacy HOCs reported in most biota (AMAP, 2004).

Levels of OCs measured in the brain samples collected from the 1989 and 2003/2004/2005 birds were comparable. This is in contrast to the results from the liver comparison, and might indicate that the birds of the present study were in a poorer nutritional condition than the 1989 birds. When body lipids are mobilized during fasting there is a redistribution of accumulated contaminants, e.g., lipid soluble HOCs accumulated in fat becomes redistributed to other tissues, such as the brain.

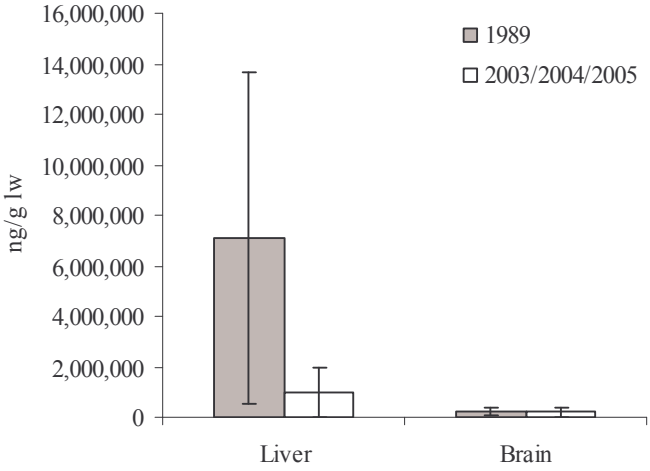


Figure 10. Mean (± SD) concentrations (ng/g lw) of ∑PCBs in liver and brain samples of glaucous gulls found dead on Bjørnøya in 1989 and 2003/2004/2005. N = 12 and 21 in 1989 and 2003/2004/2005, respectively.

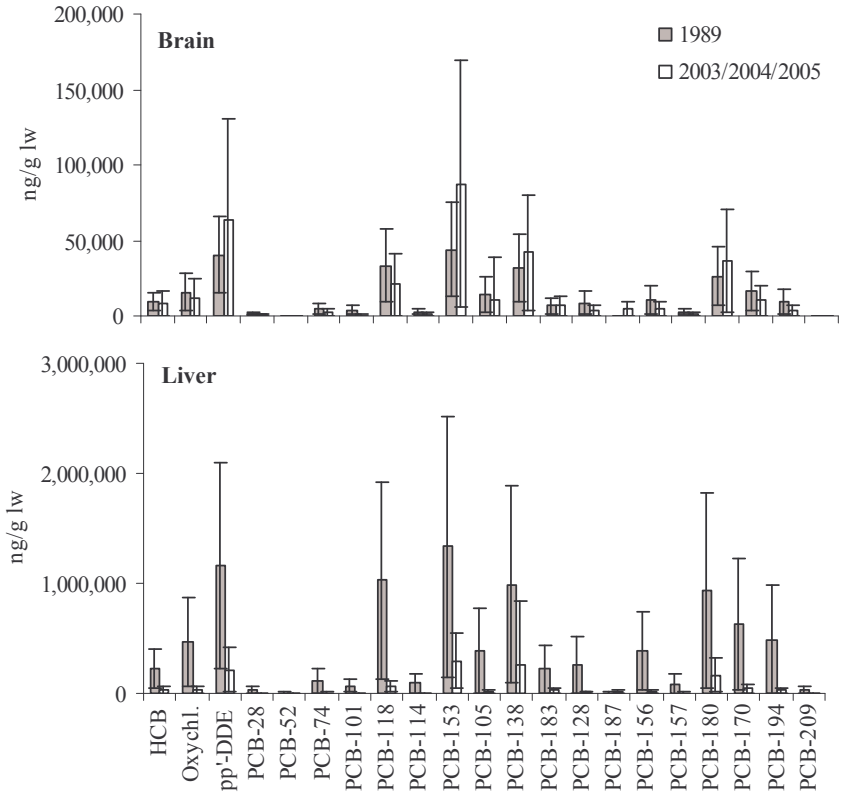


Figure 11. Mean (± SD) concentrations (ng/g lw) of individual PCB congeners, HCB, oxychlordane and p,p'-DDE in brain and liver samples of glaucous gulls found dead on Bjørnøya in 1989 and 2003/2004/2005. N = 12 and 21 in 1989 and 2003/2004/2005, respectively.

Pattern comparisons

The HOC patterns in liver and brain samples collected in 1989 and 2002/2003/2005 (Figure 12) suggest a higher proportion of pesticides and higher chlorinated PCBs in the 2003/2004/2005 samples. PCBs were produced mainly from the 1930s to 1980s, reaching peak levels in the environment between 1970s and 1990s. Since then, the levels have generally declined in the abiotic environment, and in biota, such as in seabirds from Arctic regions, Europe, North America and the Baltic (AMAP, 2004; Bignert et al., 1998). The higher chlorinated PCBs are more persistent than the lower chlorinated congeners which can explain the relatively higher levels of these congeners in the glaucous gulls collected in 2003/2004/2005. Another explanation could be a difference in nutritional condition between the sampling years or differences in fat mobilization, e.g. during starvation and mobilization of fat, the contaminants accumulated in the fat undergo redistribution to vital organs having relatively high lipid content. During redistribution elimination of particularly the less persistent contaminants may increase resulting in a change in contaminant pattern following redistribution.

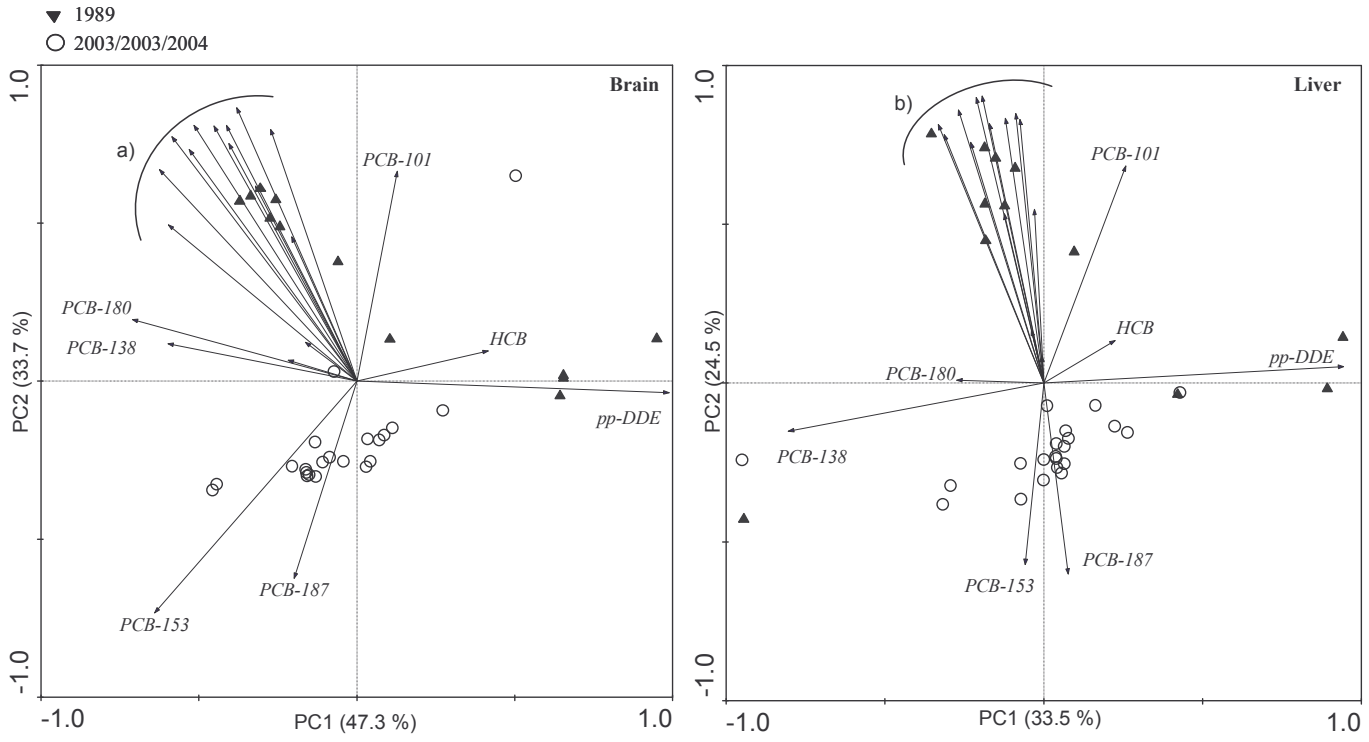


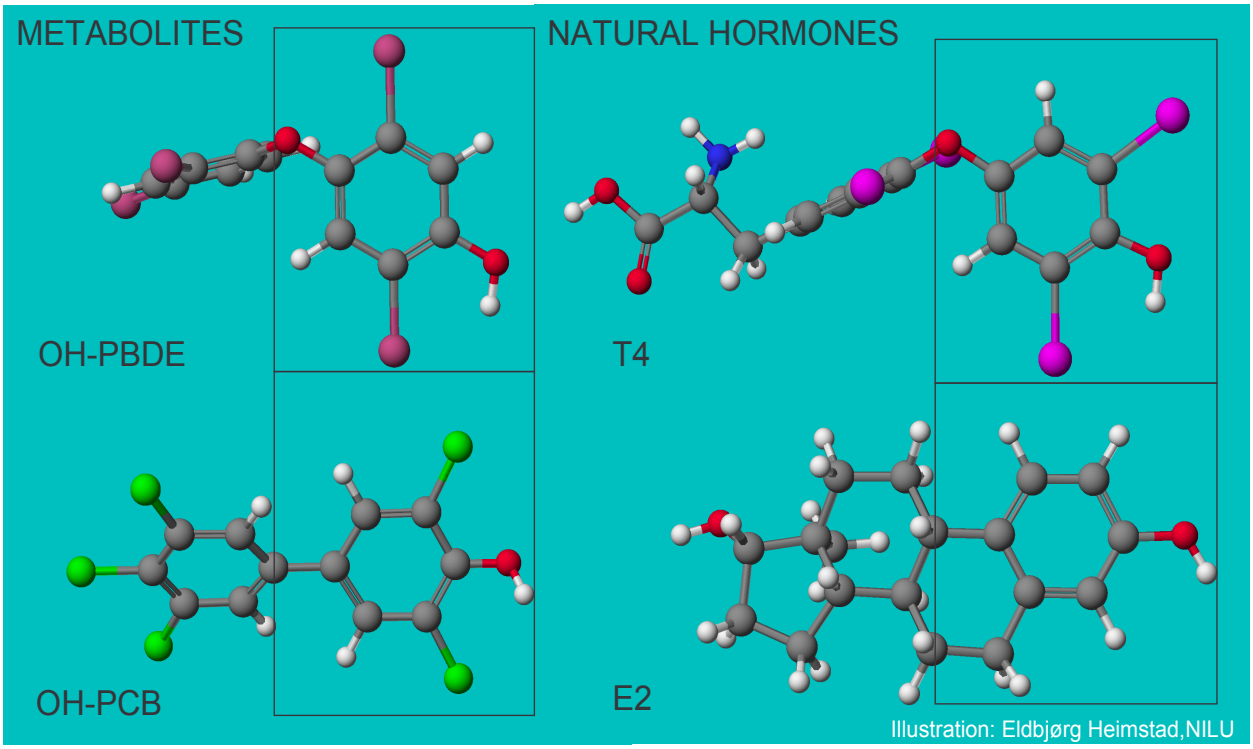
Figure 12. Indirect ordination (Principal component (PC) analysis) of halogenated organic contaminants (HOCs). The congener pattern was calculated as a proportion to ∑HOC (i.e., lipid weight concentrations of HOC congeners were standardized by norm prior to the analysis). Variables (HOCs) point in the direction of increasing concentrations. Individual samples (1989 (N = 11) and 2003/2004/2005 (N = 22)) are presented. Percent variability explained by the two first PCs, PC1 and PC2, is given in brackets. a = from left to right: PCB-183, 157, 170, 128, 74, 28, 194, 118, 156, 114, 105 and oxychlordane. b = from left to right: PCB-183, 194, 170, 209, 105, 157, 118, 74, 128, 156, oxychlordane, PCB-114.

7.8. Toxicological evaluation and conclusions

Very high levels of most HOCs were found in the dead glaucous gulls and great black-backed gulls of the present study. To our knowledge this is some of the highest HOC concentrations ever reported in Arctic seabirds. Generally, the highest levels of contaminants were found in the birds that were diagnosed as completely emaciated, severely emaciated or emaciated (the 0, 1 and 2 group, respectively, Table 2) (Figure13).

Approximately 40-45 % of the birds in the present study were found to be completely or severely emaciated. High concentrations of HOCs in storage compartments, such as fat tissue, do not necessarily imply biological effects. However, when body lipids are mobilized (e.g., during emaciation) contaminants accumulated in fat tissue becomes redistributed, i.e. they become distributed into the blood circulation of the organism. In the liver, biotransformation enzymes metabolize the parent compounds to more polar metabolites that, preferably, are excreted in the urine and faeces. However, some of the metabolites that are produced by the biotransformation system might be even more potent than the parent compounds (Letcher et al., 2000). For example, the PCB and PBDE

hydroxy metabolites (OH-PCB/PBDEs) are very similar to endogenous hormones and as such have a binding capacity to transport proteins similar to, or even higher than, the endogenous hormones, and as such might disturb the normal hormone homeostasis (AMAP, 2004).



It is difficult to assess if the high levels of contaminants in the present study are influencing the survival of the glaucous gulls at Bjørnøya. For example, for "emergency" contaminants such as brominated flame retardants and fluorinated compounds, the toxicity thresholds have not been extensively studied. Furthermore, there are large differences in sensitivity to pollutant exposure between avian species, e.g. seabirds are generally less sensitive than laboratory and freshwater birds, making direct concentration comparisons rather difficult. Previous glaucous gull studies have reported a variety of effects, e.g. reproductive (Bustnes et al., 2003), behavioral (Bustnes et al., 2001), developmental (Bustnes et al., 2002), genotoxic (Østby et al., 2005) and immunological effects (Sagerup et al., 2000), as well as associations between thyroid hormones, steroid hormones, BMR/FMR and HOCs (Verreault et al., 2004; 2006a-b).

As in 1989, it cannot be excluded that the HOC levels had contributed to the death of the gulls. However, more research must be conducted in order to understand the complex interactions between contaminant mixtures and biological effects.

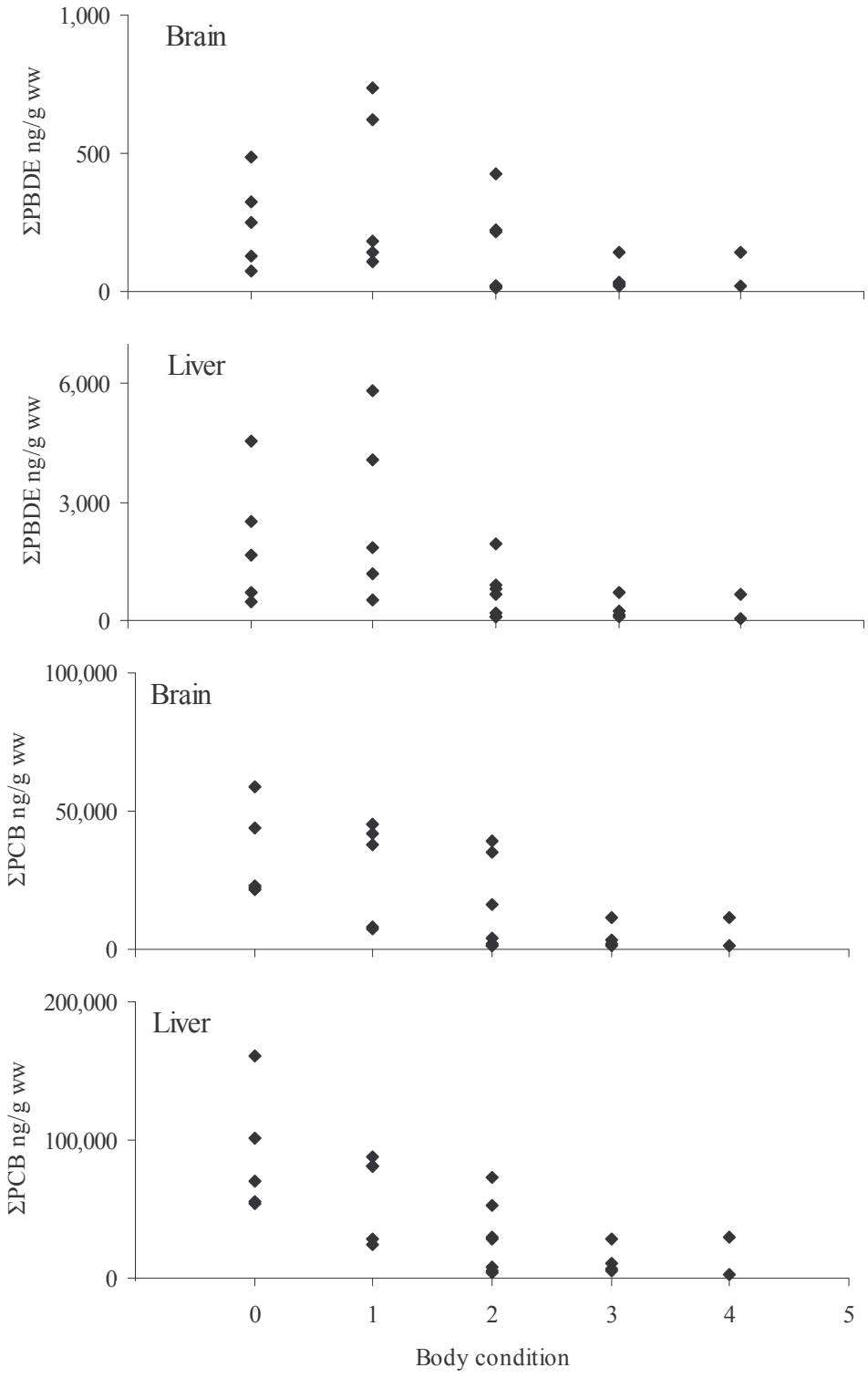


Figure 13. Body condition in relation to concentrations of ∑PCBs and ∑PBDEs (ng/g wet weight (ww)) in glaucous gulls (N=21) and great black-backed gulls (N=2) of the present study.

Observations of dying glaucous gulls on Bjørnøya with apparently abnormal behaviour may indicate that high levels of contaminants may be a contributing factor to the birds death, directly or indirectly (H. Strøm pers. obs.). Several of the individuals included in this study were dying when found. Typically, the gulls lost their balance, their ability to fly and general body coordination (e.g. of their legs or head). They usually started to show this abnormal behaviour two to three days before they died. During this period, they abandoned their nest/breeding colony, and moved to nearby "clubs" or simply sat on the tundra until they died (H. Strøm pers. obs.).

Most of the dead or dying glaucous gulls were found early in the chick rearing period, usually in late June or early July. This mortality was only seen in the glaucous gull and the great-black backed gull. If food shortage was the direct cause of death in these birds, one could expect to see some indication of food shortage (and eventually death) in some of the other surface feeding seabirds breeding on Bjørnøya, like the northern fulmar, black-legged kittiwake or great skua. Long-term population monitoring indicates a huge decline in the breeding population of glaucous gulls on Bjørnøya in the period 1986-2006 (Strøm, 2006). A change in food availability is one parameter which may explain this decline, and stress due to food shortage in combination with high levels of contaminants may be a contributing factor.

8. Acknowledgements

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Tittel - norsk og engelsk
Halogenated Organic Contaminants (HOCs) and mercury in dead or dying seabirds on Bjørnøya (Svalbard)
Halogenerte miljøgifter og kvikksølv i sjøfugl funnet død på Bjørnøya (Svalbard)

Sammendrag – summary
In the present study liver and brain samples of 21 glaucous gulls (*Larus hyperboreus*) and two great black-backed gulls (*Larus marinus*) found dead or dying on Bjørnøya were analyzed for halogenated organic contaminants. Autopsies were performed on all the dead carcasses. The organochlorine (OC) levels found in the present study were compared to that reported in glaucous gulls found dead on Bjørnøya in 1989.

4 emneord Polarmåke, svartbak, miljøgifter, obduksjon	4 subject words Glaucous gull, great black-backed gull, pollutants, autopsies