Studies on glaucous gulls (Larus hyperboreus) breeding in the Barents Sea have reported that high blood levels of halogenated organic contaminants in this species might cause reproductive, behavioral, and developmental stress. However, potential endocrine system modulation caused by contaminant exposure has yet not been reported in this Arctic apical predator. In this present study we aimed to investigate whether the current levels of a selection of organochlorines (OCs) were associated with altered circulating levels of thyroid hormones (THs) in free-ranging adult glaucous gulls breeding at Bear Island in the Barents Sea. Blood concentrations of 14 polychlorinated biphenyls, hexachlorobenzene (HCB), oxychlordane, and \( p,p'-\)dichlorodiphenyldichloroethylene (\( p,p'-\)DDE) were quantified, in addition to free and total thyroxine (\( T_4 \)) and triiodothyronine (\( T_3 \)). EDCs also included polychlorinated dibenzo-\( p \)-dioxins (PCDDs), dichlorodiphenyldichloroethanes (DDEs), hydroxylated metabolites of PCBs (OH-PCBs), and polychlorinated biphenyls (PCBs).

Many studies have reported reduced levels of thyroxine (\( T_4 \)) with increasing organochlorine (OC) levels, associated with either no or minimal effects on levels of triiodothyronine (\( T_3 \)). THs in birds regulate metabolic heat production (thermoregulation), growth, body weight, development of central nervous system, cell differentiation and maturation, hatching, molt, and reproduction (McNabb 2000). Iodine, an essential element for TH synthesis, is stored in excess as iodide from dietary uptake (McNabb 2002). THs in birds are carried in the plasma bound to transport proteins, which is albumin or transthyretin (TTR). Most of the \( T_4 \) in birds is associated with albumin, which has low-affinity binding sites with limited specificity for \( T_4 \) or \( T_3 \) compared with TTR in mammals (Astier 1980; Davidson et al. 1978; Merryman and Buckles 1998a). Factors that influence thyroid functions include dietary iodine (I- availability), activity, ambient temperature, photoperiod, body condition, seasonality, and age (McNabb 2000).

A wide range and occasionally very high levels of halogenated organic contaminants have been reported in glaucous gulls (Larus hyperboreus; Bourne and Bogan 1972; Gabrielsen et al. 1995; Savinova et al. 1995), an apical predator breeding in the Barents Sea (Løvenskiold 1964). Studies on the glaucous gull have suggested that high blood levels of halogenated organic contaminants in this species might cause reproductive, behavioral, and developmental stress (Bustnes et al. 2001a, 2002, 2003b). In these studies, high levels of OCs have been associated with reduced parental attentiveness during incubation, higher rate of feather asymmetry, and decreased reproductive success. Contaminant-induced modulation of the bird’s hormone and/or nervous system has been proposed as the underlying mechanism for the alteration of these biologic functions.

In this study we aimed to investigate whether the current blood levels of a selection of OCs were related to circulating plasma levels of \( T_4 \) and \( T_3 \) in free-ranging adult glaucous gulls breeding at Bear Island in the Barents Sea. Because halogenated organic contaminants have been linked to adverse biologic effects in free-ranging avian species (e.g., Barron et al. 1995), there might be a causative link between blood levels of these contaminants and the adverse reproductive, behavioral, and developmental effects reported in glaucous gulls (Bustnes et al. 2001a, 2002, 2003b). Levels of THs, which are involved directly or indirectly in the regulation/initiation of reproduction, behavior, and development, may be altered in glaucous gulls exposed to high concentrations of OCs through their diet. Assessment of circulating TH status has been suggested to be a useful biomarker of response in free-ranging animals exposed to contaminants (Fox 1993; Peakall 1992; Rolland 2000). According to Peakall (1992), the ratio between \( T_4 \) and \( T_3 \) \( (\frac{T_4}{T_3}) \) seems to be the most sensitive indicator revealing effects of contaminant exposure. A lower \( \frac{T_4}{T_3} \) ratio, associated with increasing levels of halogenated organic contaminant in an organism, is likely to indicate alteration of TH homeostasis mediated by contaminant toxicity.
Materials and Methods

Study area. The field sampling was conducted at the south and southeast coast of Bear Island (74°21' N, 19°05' E) in the western Barents Sea during spring 2001. Bear Island has some of the largest seabird colonies in the Barents Sea, with several hundred thousand breeding pairs. The breeding population of glaucous gulls at Bear Island is estimated to be approximately 2,000 pairs (Mehlum and Bakken 2000). The breeding season at Bear Island is characterized by continuous daylight, an average temperature of 4–5°C, and periods of strong winds and even snowfall. Samples of glaucous gulls were taken from two major breeding colonies: Evjebuka and Sørhamna. Blood levels of OCs in glaucous gulls from these two colonies are reported to be different, presumably due to different feeding ecology (Bustnes et al. 2000). Evjebuka is located farther away from the main seabird cliff, about 20–30 m above sea level (Figure 1). The edge of the main seabird cliff, about 100–150 m above sea level, whereas Sørhamna is located farther away from the main seabird cliff and 20–30 m above sea level (Figure 1).

Field sampling. A total of 83 glaucous gulls were captured on their nests during the incubation period (Løvenskiold 1964), using a nest trap. The trap consisted of a snare placed on the edge of the nest bowl and attached to a mechanism triggered by a radio transmitter. Because nearly all nests in the breeding colonies were accessible, the nesting individuals were selected randomly for capture. The birds were given alpha-coded plastic leg bands and numbered steel rings. After capture, several biometric measurements were recorded: wing length (± 1 mm), bill, tarsus, and head length (± 0.1 mm), and body mass (± 10 g). Because all birds captured were incubating, they were assumed to be sexually mature, that is, at least 5 years of age (Gilchrist 2001). The age of the birds was assumed to be equally distributed between the two breeding colonies. The sex of the individuals was determined using the total head and bill length, as recommended by Coulson et al. (1983) for Laridae species. Adult male glaucous gulls from Bear Island have on average a bill longer than 61.5 mm and a total head and bill longer than 142 mm (Henriksen EO, unpublished data).

A blood sample (12 mL) was collected from the brachial vein with a heparinized 20-mL syringe and a 21-gauge hypodermic needle and was kept dark on ice during transport to the field laboratory. The whole-blood samples for OC analyses (6 mL) were transferred to 5-mL cryogenic vials and stored in a −20°C propane-driven freezer. The whole blood is documented to be a reliable matrix for quantification of OCs in incubating glaucous gulls (Bustnes et al. 2001b; Henriksen et al. 1998). The plasma for TH quantification was obtained by centrifugation of whole blood (6 mL; 5,000 rpm, 7 min), transferred to 1.2-mL cryogenic vials, and stored in liquid nitrogen. Both whole-blood and plasma samples were frozen within 6 hr of collection until thawed for analyses.

This project received approval from the Norwegian Animal Care Committee for research involving animals, and the permission to capture glaucous gulls at Bear Island was given by the Governor of Svalbard (Norway).

Contaminant analyses. The quantification of OCs in whole blood was performed at the Environmental Toxicology Laboratory at the Norwegian School of Veterinary Science, Oslo, Norway. This laboratory is accredited as a testing laboratory for OCs according to the requirements of NS-EN 45001 and ISO/IEC Guide 25.

The whole blood samples were weighed, and internal standards (PCB-29 and PCB-207) were added. The samples were extracted twice with cyclohexane and acetone, and the percentage of extractable plasma fat (± 0.01%) was determined gravimetrically. The extracted plasma fat in each sample was redissolved in cyclohexane and washed with ultrapure sulfuric acid, according to Brevik (1978). Aliquots of the fat-free extracts were injected automatically on a high-resolution gas chromatograph (HRGC; Agilent 6890 Series gas chromatography system; Agilent Technologies, Palo Alto, CA, USA), equipped with a split/splitless injector and two micro-electron capture detectors (360°N, 300°C). Two columns (SPB-5 and SPB-1701: 60 m, 0.25 mm inner diameter, and 0.25 μm film layer; Supelco Inc., Bellefonte, PA, USA), of different polarity and selectivity, were used to obtain the desired chromatographic separation, both connected to a 1-m deactivated precolumn. Quantification was performed using PCB-29 and PCB-207 as internal standards in each sample. The OCs were identified on the basis of their retention time on the HRGC columns. Chromatographic data were interpreted using HP ChemStation Plus, Rev. A.07.01 (Hewlett-Packard Co., Palo Alto, CA, USA). Details on extraction, cleanup, chromatographic separation, and analytic quality are described by Bernhoft et al. (1997), with modifications by Andersen et al. (2001).

The following OCs were quantified: hexachlorobenzene (HCB), oxychlordane, \( p,p' \)-dichlorodiphenyldichloroethylene \( (p,p'\text{-DDT}) \), and 14 PCB congeners with International Union for Pure and Applied Chemistry numbers (Ballschmiter and Zell 1980) 31, 52, 101, 99, 118, 114, 153, 105, 138, 157, 180, 170, and 189, listed in order of their retention time. The 14 individual PCB congeners were significantly correlated with \( \Sigma \text{PCB} \) (Pearson \( R \), \( r^2 \geq 0.68, p < 0.000001 \)), although the correlation was weak for PCB-52 (Pearson \( R, r^2 = 0.11, p = 0.006 \)). All OC concentrations were intercorrelated for both sexes.

Standard procedures were used to ensure quality assurance and control, and the results were within the laboratory’s accredited requirements for precision, linearity, and sensitivity. Detection limits for individual compounds were determined as three times the noise level and were between 0.003 and 0.013 ng/g wet weight (ww). All calculations were done within the linear range of the detector’s five-level calibration curve. The reproducibility was tested continuously by analyzing PCB levels in the laboratory’s own reference sample (seal blubber). The results were within the mean coefficient of variance for the year 2000 (8.7%). The repeatability of the HRGC performance was tested by repeated injection of standard compounds at regular time intervals. Percent recoveries and coefficients of variance of OCs in spiked sheep blood varied from 83 to 119% and from 0.62 to 10.35%, respectively. Blank samples were included in each series to test for interference.

TH analyses. The TH quantification was performed at the Department of Biology at the University of Science and Technology, Trondheim, Norway.

Radioimmunoassays were used to determine the plasma concentration of total (T) and free (F) \( T_3 \) and \( T_4 \), with commercially available kits (Coat-A-Count; Diagnostic Products Corporation Inc., Los Angeles, CA, USA). The detection limits of the \( T_3 \), \( T_4 \), \( FT_3 \), and \( FT_4 \) kits were 0.11 nmol/L, 3.22 nmol/L, 0.31 pmol/L, and 0.13 pmol/L, respectively. Analytic results under the minimum detectable concentration were set to half the respective detection limit. The repeatability of the assays was tested by running samples in duplicates, and readings with a coefficient of variation > 15% were excluded from the final data set. The range limit of 15% was set according to the laboratory’s quality assurance and control routine. Thus, from a total of 83 captured birds, 10 birds from Sørhamna and 7 birds...
from Evjebukta were removed from further analyses, for a remaining total of 66 birds.

In each kit, two human serum controls (Immunoassay Plus Control level 2, Biorad Laboratories, Liquichek and Lyphochek, Bio-Rad Laboratories, Hercules, CA, USA) were also assayed to test for repeatability. Results were in the acceptance range of the kits and met the laboratory’s established requirements for precision.

Data analyses. Statistical analyses were carried out using the statistical packages Statistica, version 6 (StatSoft 2002), and SAS, release 6.09 (SAS Institute, Cary, NC, USA). Statistical significance was set at \( p \leq 0.05 \). Data were analyzed for normality by Shapiro-Wilk’s W-test and the Kolmogorov-Smirnov and Lilliefors test (Zar 1999). Variables that did not approximate the normal distribution were \( \log_{10} \) transformed.

Because body condition in avian species may influence OC levels (e.g., Henríksen et al. 1998), TH levels (e.g., McNabb 2000), and other biologic parameters such as reproductive success (e.g., Saether 1997), adjusting for body condition was necessary. A single measure of body size (body size index) was obtained using principal component analysis (Hair et al. 1998). The body size index of glaucous gulls, which was expressed by the scores on the first principal component (PC1), was extracted from two morphologic measurements: wing length and total head and bill length (Henríksen et al. 2000). The body condition of an individual was defined as the residuals obtained when body mass was regressed against the body size index, that is, the difference between the observed body mass and the mass predicted from the body size index (Green 2001). The body size index and body condition were calculated separately for each sex because the glaucous gull is sexually dimorphic (Gillchrist 2001; Lewenskiold 1964).

General linear models (GLMs) were used to analyze the effect of any combinations of categorical and continuous variables (StatSoft 2002). Following Rothman (1990), \( p \)-values were not adjusted despite the use of multiple comparisons. The Levene’s test (StatSoft 2002) was computed to test for homogeneity of variance. Backward elimination (Zar 1999) was used to select the variables in the model that contributed significantly to the variation of OC and TH levels and TH ratios in the whole model, which included the following variables: sex, breeding colony, extractable plasma fat percentage, day of capture, and body condition. Day of capture refers to the day in the incubation period (1–30 days) when the birds were captured. Because timing in the reproductive cycle plays a major role in the natural oscillations of circulating hormones, correlations (coefficients) between TH and OC levels were adjusted for day of capture in the incubation period. Likewise, OC levels (ww basis) were corrected for plasma fat content because of their lipophilic properties, using extractable plasma fat (percent of whole blood; Hebert and Keenleyside 1995). Correlations are expressed using the Pearson correlation coefficient (\( r \)).

Results

Organochlorines. The \( \Sigma \)PCB concentration in this study ranged from 31.9 to 1,927 ng/g ww (Table 1) and accounted for 76% of the total OC fraction for both sexes. The most abundant PCBs were PCB-153, PCB-138, and PCB-180, making up 57% of the PCB fraction. Levels of OCs (all compounds) were on average 42% (range, 17–77%) higher in males than in females, but the difference was nonsignificant for HCB and oxychlordane (Table 2). Levels of HCB, \( \rho \rho \rho \)-DDE, and \( \Sigma \)PCB were higher in birds from the breeding colony Evjebukta than in birds from Sørhamna (Table 2). The effect of breeding colony on the variation of these OCs was stronger than the effect of sex in the whole model including day of capture and extractable plasma fat percentage. Body condition did not influence the variation of OC levels.

Thyroid hormones. Levels of circulating \( \text{FT}_{4} \) and \( \text{TT}_{3} \) were 28% higher in males than in females. Levels of \( \text{TT}_{4} \) were lower in males than in females, 26% for \( \text{FT}_{4} \) and 16% for \( \text{TT}_{4} \), although not significant for \( \text{FT}_{4} \) (Table 2 and 3). Concurrently, males had 37 and 44% lower \( \text{FT}_{3} : \text{FT}_{4} \) and \( \text{TT}_{3} : \text{TT}_{4} \) ratios, respectively, than did females. The total free \( \text{T}_{4} \) and \( \text{T} \) ratios did not differ significantly between sexes (Table 2).

From a population-wide perspective, the levels of \( \text{FT}_{3} \) and \( \text{TT}_{3} \) were higher in birds from the breeding colony at Evjebukta compared with birds from Sørhamna, whereas levels of FT4 and TT4 were lower in birds from Evjebukta, although not significant for FT4 (Table 2). The \( \text{FT}_{3} : \text{FT}_{4} \) and \( \text{TT}_{3} : \text{TT}_{4} \) ratios were lower in birds from Evjebukta compared with birds from Sørhamna. The ratios of total to free \( \text{T}_{4} \) and \( \text{T} \) did not differ between the breeding colonies (Table 2). The effect of breeding colony on the variation of \( \text{FT}_{3} \), \( \text{TT}_{4} \), and \( \text{TT}_{3} : \text{TT}_{4} \) was stronger than the effect of sex in the whole model including day of capture. Body condition and extractable plasma fat percentage did not influence the variation of TH levels and TH ratios.

Relationships. In females, no correlation was found between OC and TH concentrations and thyroid ratios. However, in males, negative correlations were found between the \( \text{FT}_{3} : \text{FT}_{4} \) and \( \text{TT}_{3} : \text{TT}_{4} \) ratios and most OCs quantified (Table 4, Figure 2). Negative relationships were also found between \( \text{FT}_{3} \) and \( \text{TT}_{3} \) and OCs, although these were statistically significant for HCB and oxychlordane only (Pearson \( r \geq –0.37, p \leq 0.043 \); Figure 3). Additionally, there was a trend for increasing \( \text{FT}_{3} \) and \( \text{TT}_{3} \) levels with increasing OC levels, although not significant. The most prominent negative correlations were found between the \( \text{TT}_{3} : \text{TT}_{4} \), HCB, and oxychlordane, and the three \textit{mono-ortho} PCBs (congeners 118, 114, and 105; Pearson \( r \leq –0.43, p \leq 0.017 \); Table 4). Levels of HCB, which made up only 3.4% of the total OC fraction in males, accounted for 20.6% of the variation of \( \text{TT}_{3} : \text{TT}_{4} \) ratio in the whole model (\( p \leq 0.012 \)). The effect of breeding colony on the variation of \( \text{TT}_{3} : \text{TT}_{4} \) in males was inhibited by the effect of HCB in the same model (GLM; \( F_{32} = 0.00, p = 0.99 \)). Furthermore, negative relationships were found in males between \( \text{TT}_{3} : \text{FT}_{3} \) and OCs, although this was statistically significant for oxychlordane only (\( r = –0.40, p = 0.026 \)). No association was
The levels of T3 were within the range previously reported for other adult precocial species, whereas this study on glaucous gulls were in the lower range compared with a less-exposed colony. This indicates that the glaucous gull is susceptible to changes in TH homeostasis mediated by exposure to halogenated organic contaminants in the Barents Sea food chain.

The levels of circulating T3 reported in this study on glaucous gulls were in the lower end of the range previously reported for other adult precocial species, whereas the levels of T4 were within the range previously reported for these species (ASTIER 1980; McNABB 2000). Furthermore, blood levels of the OCs quantified in this study were comparable with previously reported blood levels in glaucous gulls breeding at Bear Island, and the levels were higher in males compared with females, which also is in accordance with the same studies (BUSTNES et al. 2000, 2001a, 2001b, 2002, 2003a).

The T4:T3 ratio measured in incubating females may be explained partly by excretion of OCs deposited in the egg yolk during egg formation (BARGAR et al. 2001; INGEBRIGTSEN et al. 1984; NORSTROM et al. 1986).

### Interverbreeding colony comparison.

In line with findings by BUSTNES et al. (2000), glaucous gulls breeding in the colony Evjebuksa had higher blood levels of OCs than those from Sorhamna for both males and females. In an attempt to compare TH levels between individuals with various degrees of contamination, it was necessary to perform an interbreeding colony comparison to control for potential confounding factors that may influence TH levels, that is, sex, age, activity, body condition, and diet (1 availability; e.g., McNABB 1992, 2000). Because sex, date of capture in the incubation, and body condition were controlled for in the statistical models, the age of the birds was assumed to be similarly distributed between the two colonies. However, activity and diet, associated with the glaucous gulls’ specialization in terms of feeding strategy, is known to differ between these two breeding colonies (BUSTNES et al. 2000). Food items included in the diet of glaucous gulls, which are selected at different trophic levels in the food chain, differ in their contaminant burden (BORGÅ et al. 2001; SAGERUP et al. 2002) and a complex array of constituents such as iodine, an essential component of THs (e.g., McNABB 1992). The T3:T4 ratio is known to be altered by changing iodine availability where high iodine favors T4 formation (increasing T3:T4 ratio), and low iodine favors T3 formation (decreasing T3:T4 ratio; McNABB 1992). However, studies on fish-eating birds such as the herring gull (Larus argentatus) from the Great Lakes in North America have provided strong evidence that hypothyroidism in this species was due to lack of iodine deficiency but to exposure to halogenated organic contaminants, although the disruptive mechanisms suggested were speculative (FOX 1993; McNABB and FOX 2003; MOCCIA et al. 1986). Based on these results, and because marine environments (e.g., the Barents Sea) are documented to be rich in iodine compared with freshwater environments (e.g., the Great Lakes; FOX 1993; PEAKALL 1992), iodine deficiency is not likely to occur in glaucous gulls breeding at Bear Island. Therefore, even though it cannot be completely disregarded, the difference in diet between individuals in the two breeding colonies is not likely to affect levels of circulating or stored THs.

### Relations between OCs and THs.

In males, no correlation was found between OC and TH concentrations and thyroid hormone ratios. In males, however, several negative correlations were found showing decreasing plasma T3 levels and T3:T4 ratios with increasing blood levels of most OCs quantified. In males, HCB and oxochlordane seemed to have a particularly negative effect on the T3:T4 ratio and on the circulating levels of T3. HCB and oxochlordane accounted for a minimal proportion (< 3.4%) of the total OC fraction. In an experimental study, PISAREV et al. (1990) found that the T4:T3 ratio was significantly lower in birds exposed to HCB than in control birds.

### Abbreviations.

- OC: organochlorine
- TH: thyroid hormone
- T3, FT3, T4, FT4: circulating levels of T3 and T4
- T3:T4, FT3:FT4: thyroid hormone ratios
- FT3:FT4: free T3 and free T4
- T3:FT3: T3 concentration divided by FT3 concentration

### Table 2. Results from analyses of covariance (GLM, type III) testing the difference in blood levels of organochlorines (log10 ng/g ww), plasma levels of thyroid hormones (μmol/L) and thyroid ratios (log10 mole ratio) between two breeding colonies of glaucous gulls (Larus hyperboreus) at Bear Island.

| Breeding colony | Sex | Whole model |
|-----------------|-----|-------------|
|                 | df  | Value | p-Value |
| HCB             | 1, 61 | 23.86 | <0.00001 |
| p,p’-DDE        | 1, 61 | 11.37 | 0.001 |
| Oxychlordane    | 1, 61 | 2.04 | 0.158 |
| ΣPCB (14)       | 1, 61 | 6.00 | 0.017 |
| Total T3        | 1, 62 | 8.47 | 0.005 |
| Total T4        | 1, 62 | 7.05 | 0.007 |
| Free T3         | 1, 62 | 1.15 | 0.267 |
| Free T4         | 1, 62 | 4.52 | 0.037 |
| Total T3:free T4 | 1, 62 | 0.45 | 0.502 |
| Total T4:free T4 | 1, 62 | 2.76 | 0.101 |
| Total T3:Total T4 | 1, 62 | 3.98 | 0.050 |
| Total T4:Total T4 | 1, 62 | 8.69 | 0.005 |

### Table 3. Concentrations of free (μmol/L) and total (nmol/L) T3 and T4 and T3:FT3, T4:FT4, T3:TT4, T4:TT4 and FT3:FT4 ratios (mole ratio) for male and female glaucous gulls (Larus hyperboreus) breeding at Bear Island.

| Females (n = 34) | Males (n = 32) |
|------------------|----------------|
|                  | Mean ± SD | Range | Median | Mean ± SD | Range | Median |
| Free T3          | 3.32 ± 1.32 | 1.25–5.9 | 3.15 | 4.32 ± 1.75 | 1.50–9.3 | 4.00 |
| Total T3         | 3.02 ± 1.02 | 1.38–5.25 | 2.69 | 3.86 ± 1.20 | 1.80–7.63 | 3.92 |
| Free T4          | 36.7 ± 12.7 | 11.4–65.1 | 36.7 | 27.1 ± 9.3 | 14.4–51.4 | 26.7 |
| Total T4         | 34.3 ± 13.4 | 1.61–56.5 | 37.9 | 28.9 ± 11.6 | 16.1–62.6 | 28.1 |
| Total T3:Free T4 | 0.92 ± 0.27 | 0.11–1.32 | 0.97 | 1.07 ± 0.29 | 0.11–1.56 | 1.02 |
| Total T4:Free T4 | 0.93 ± 0.17 | 0.68–1.43 | 0.94 | 0.94 ± 0.16 | 0.67–1.34 | 0.93 |
| Total T3:T4      | 13.1 ± 7.85 | 0.54–41.0 | 13.6 | 8.25 ± 4.70 | 0.54–26.7 | 8.04 |
| Free T3:Free T4  | 12.9 ± 7.68 | 2.79–40.7 | 11.8 | 7.18 ± 3.98 | 1.94–21.4 | 5.72 |
observed a 25% reduction of serum levels of T4 in rats exposed to a relatively high dose of HCB, whereas the levels of T3 were not significantly affected. Moreover, in glaucous gulls breeding at Bear Island, it has been documented that HCB had the strongest correlating effect on feather asymmetry and reproductive parameters, whereas oxychlordane was negatively correlated with survival probability (Bustnes et al. 2002, 2003b); these studies have argued that HCB and oxychlordane were the OCs that possibly produced most stress in glaucous gulls. However, because the blood levels of many lipophilic halogenated organic contaminants are intercorrelated, the contribution or causative agent(s) to TH depletion in this species might not necessarily have been detected here.

Because dose–response toxicologic experiments were not performed between male and female glaucous gulls, the associations observed here between THs and OCs in males only cannot be explained from a sex-specific perspective, although they may lead to speculation toward that eventualty.

Potential mechanisms of disruption. Because the negative associations reported in this study do not allow the demonstration of causality of TH depletion in glaucous gulls, extrapolations of laboratory results from other vertebrate species are necessary to suggest potential mechanisms of disruption, although these mechanisms remain speculative.

Based on experimental studies, our findings could support the mechanism involving the interference of contaminants with TH plasma carrier proteins (e.g., Brouwer et al. 1986, 1998). Because of structural resemblance to THs, certain halogenated organic contaminants, and especially some OH-PCBs, may disturb circulating TH levels by competing for binding sites on their transport proteins. Instances of binding affinity of PCBs, OH-PCBs, PCDDs, and polychlorinated dibenzofurans to the T4 transport protein TTR have been reported in a number of studies (Brouwer 1989; Brouwer and van den Berg 1986; Brouwer et al. 1986; Lans et al. 1994; Letcher et al. 2000; van den Berg et al. 1991). The displacement of T4 from TTR is presumed to facilitate the excretion of the free T4 fraction in urine or bile, thereby decreasing circulating total T4 levels (Brouwer et al. 1986; Lans et al. 1994). Recent analyses have revealed the presence of several major OH-PCBs and methyl sulfone metabolites of PCBs in plasma of glaucous gulls breeding at Bear Island (Verreault J., unpublished data).

The laboratory studies cited here have generally been performed in rodents, in which TTR is the principal T4 carrier protein in the plasma (McNab 1992; Retefoff et al. 1970). The situation in birds may be different. Most of the T4 in birds is associated with the plasma-carrier protein albumin, which has low-affinity binding sites with little specificity for T4 or T3 (McNab 2000; Merryman and Buckles 1998a). As yet, exceedingly few studies have been performed on competition between halogenated organic contaminants, especially compounds such as HCB and oxychlordane, and THs for binding sites on TTR and albumin in avian species. Other possible mechanisms for contaminant-induced modulation of thyroid functions and T4 turnover have been reported in diverse reviews (e.g., Leatherland 2000; McNab and Fox 2003; Peakall 1992).

Conclusions

In this study, we report an association between high blood levels of halogenated organic contaminants and alteration of circulating TH levels in glaucous gulls breeding at Bear Island. Because THs play an important role in initiating/regularing development, reproduction, and behavior, and because certain contaminants may decrease directly or indirectly the levels of THs through diverse mechanisms, high levels of contaminants may contribute to distortion of these physiologic functions in this species. Moreover, we suggest that alteration of TH levels in glaucous gulls, beyond the limits of homeostatic compensation, may lead to decreased basal metabolic rate, which in turn may alter lipid metabolism and sensitivity to cold temperature. The death of breeding glaucous gulls observed early in the chick period at Bear Island (Bakken V and Størm H, personal communication) could be attributed to these adverse effects and to stressors associated with high-energy investment in parent birds during the incubation period.

The associations reported in this study showed that contaminant-mediated thyrotoxicity may affect male glaucous gulls more particularly, indicating a possible sex-specific response of thyroid functions to the action of halogenated organic contaminants. There is as yet no clear evidence that irreversible physiologic effects, normally linked to hypothroidism during avian development, manifest in the glaucous gull, and further studies are required. Presumable exposure to current blood levels of OCs or other type of contaminants may possibly be insufficient to overwhelm the mechanisms of TH homeostasis in this species.

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