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Intra- and inter-species differences in persistent organic contaminants in the blubber of blue whales and humpback whales from the Gulf of St. Lawrence, Canada

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Abstract

Biopsy samples of blubber from adult male and female blue whales, and from female and young-of-the-year humpback whales were collected during the summers of 1992–1999 in the Gulf of St. Lawrence, Canada. In blue whales, concentrations of 25 PCB congeners, DDT and metabolites and several other organochlorine compounds were present at higher concentrations in the blubber of males relative to females; reflecting maternal transfer of these persistent contaminants from females into young. Sex-related differences in concentrations were not observed with less persistent contaminants, such as HCHs. In humpback whale samples, there were no significant differences in the concentrations of PCBs and organochlorine compounds in the blubber of females and calves. These data indicate that calves quickly bioaccumulate contaminants by transplacental and lactational routes to concentrations that are in equilibrium with females. In comparisons between contaminant concentrations and patterns in the blubber of female blue and humpback whales, there were no significant differences in concentrations, but the proportions of some PCB congeners, HCH isomers, and DDT and its metabolites were different in the two baleen whale species. These may reflect differences in the diet of the two species, since fish comprise a large part of the diet of humpback whales and blue whales feed exclusively on euphausiid crustaceans (i.e. krill).

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1. Introduction

Marine mammals accumulate high concentrations of persistent contaminants because they have high lipid contents, and they may also metabolize these compounds more slowly than birds and terrestrial mammals (Boon, Oostingh, van der Meer, Theo, & Hillebrand, 1994; Kawai, Fukushima, Miyazaki, & Tatsukawa, 1988; Tanabe, Watanabe, Kan, & Tatsukawa, 1988). Several studies on contaminant levels in beluga whales (*Delphinapterus leucus*) from the estuary of the St. Lawrence River have shown that these odontocete whales are highly contaminated with persistent organic compounds (Metcalfe, Metcalfe, Ray, Paterson, & Koenig, 1999; Muir, Ford, Rosenberg, Norstrom, Simon, & B eland, 1996). We previously analyzed persistent contaminants in blubber biopsies from four species of balaenopterid whales from the Gulf of St. Lawrence and reported concentrations of PCBs and organochlorine pesticides that were one to two orders of magnitude lower than concentrations in beluga whales from the estuary (Gauthier, Metcalfe, & Sears, 1997a).

This study was conducted by analyzing blubber biopsies collected from live whales. The biopsy sampling technique involves firing a sampling device into the subcutaneous blubber of the whale and removing a small sample (Gauthier, Metcalfe, & Sears, 1997b). Blubber biopsies provide a representative sample for determining concentrations and patterns of persistent contaminants in the blubber of balaenopterid whales, provided that the data are lipid normalized (Gauthier et al., 1997b). In this study, we collected biopsy samples during the summers of 1992–1999 from mature male and female blue whales, and from female and young-of-the-year (i.e. calves) humpback whales.

The source of persistent contaminants in balaenopterid whales from the Gulf of St. Lawrence is the invertebrates and fish they consume while occupying their summer range. Balaenopterid whales with summer ranges in the northwest Atlantic fast, at least partially, during their migration and winter stay in their calving grounds in the Caribbean (Lockyer & Brown, 1981). However, there is evidence that some blue whales feed year-round in the north Atlantic (R. Sears, personal communication). Blue whales feed exclusively on krill, while humpback whales feed heavily on small fish. In this study, we compared the concentrations and patterns of persistent contaminants in blubber biopsies from female blue and humpback whales to determine whether there are differences that can be related to the diets of these two species.

In marine mammals, there are often differences in the concentrations of contaminants in males and females due to the maternal transfer of contaminants from females into young. Sex-related differences in the concentrations of PCBs and DDT have been observed previously in fin whales from the eastern north Atlantic (Aguilar & Borrell, 1988), fin whales from the Mediterranean (Marsili & Focardi, 1996), and right whales (*Eubalaena glacialis*) from the north Atlantic (Weisbrod, Shea, Moore, & Stegeman, 2000a; Woodley, Brown, Kraus, & Gaskin, 1991). In this study, we evaluated whether there were similar sex-related differences in persistent contaminants in blubber biopsies from male and female blue whales from the Gulf region, with a focus on expanding these analyses to include other classes of organochlorine compounds (e.g. HCB, HCHs, chlordanes).

Limited data from marine mammals indicate that persistent contaminants partition from the body of females through the placenta into the developing fetus (Gauthier, Pelletier, Brochu, Moore, Metcalfe, & Béland, 1998; Tanabe, Tatsukawa, Maruyama, & Miyazaki, 1982; Weisbrod, Shea, Moore, & Stegeman, 2000b). Contaminants also partition from the female into maternal milk, which is consumed by the young prior to weaning. In a study of lactating grey seals (*Halichoerus grypus*), Addison and Brodie (1987) concluded that there are barriers to the partitioning of PCBs and DDT compounds from the blubber into circulatory lipids, and from the circulatory lipids to milk lipids. In this study, we hypothesized that similar partitioning processes may produce differences in the patterns and concentrations of contaminants in humpback calves relative to female whales. Few data are available on the levels and patterns of persistent contaminants in the young of cetaceans. However, a contaminant model that predicts concentrations of PCBs in beluga whales indicates that the concentrations accumulated in beluga calves prior to weaning will be similar to concentrations in the mother (Hickie, Mackay, & De Koenig, 1999). In this study, we analyzed persistent contaminants in blubber biopsies from humpback females and calves to determine whether there are differences in the concentrations and patterns of these compounds in females and their young.

2. Methods

Blubber biopsy samples were collected from live blue and humpback whales while they occupied their summer feeding range on the north shore of the Gulf of St. Lawrence (Fig. 1). Biopsies were collected as described previously (Gauthier et al., 1997b) by firing a biopsy dart with a crossbow into the dorsal region of the whale, then retrieving the dart for collection of blubber and skin samples. For blue whales, samples from 38 male and 27 female whales were selected for analysis from biopsies collected over the period from the summer of 1992 to the summer of 1997. For one of the female blue whales sampled in the summer of 1997, it was possible to collect a biopsy from her male calf. For humpback whales, samples from 12 females and 13 calves were selected for analysis from biopsies collected over the period from the summer of 1993 to the summer of 1999. Because of ongoing monitoring of the balaenopterid whale populations in the region, it was possible to determine that there were no multiple biopsies collected from single individuals over the sampling period. It was difficult to collect biopsies simultaneously from cow-calf pairs of humpback whales, due to avoidance of the sampling boat after collection of the calf biopsy. Therefore, samples were collected from only two cow-calf pairs. All other comparisons were between humpback calves and females that were not matched. However, all female humpbacks sampled were mature individuals with a reproductive history of at least one calf.

Blubber from the biopsy samples was prepared for analysis as described by Metcalfe and Metcalfe (1997). Briefly, blubber samples of <1 g were mixed and ground with sodium sulfate and packed into a glass column for extraction into 50:50 dichloromethane/hexane using a cold-column extraction procedure. The lipids were

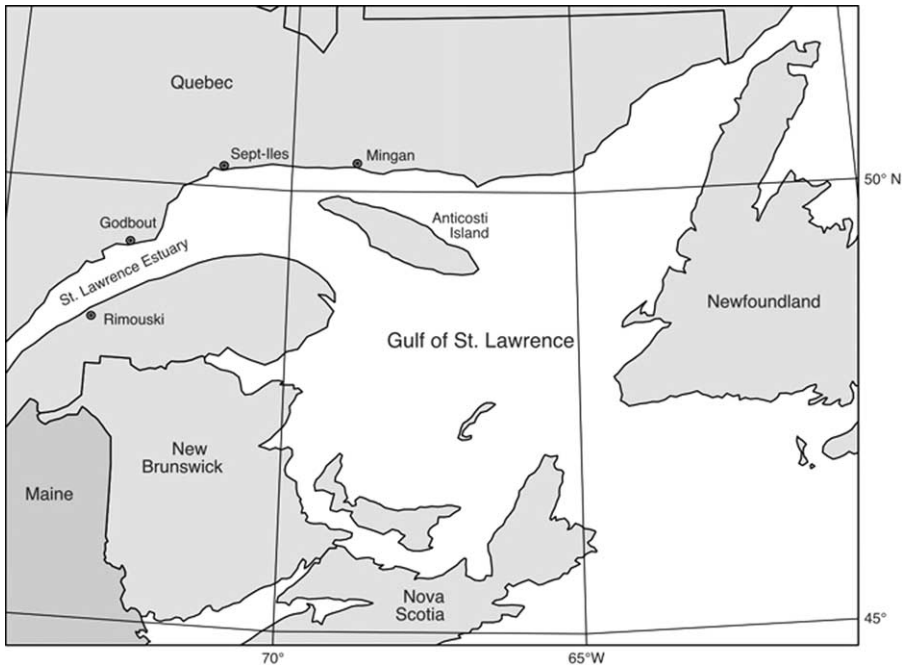


Fig. 1. Map of the northwest region of the Gulf of St. Lawrence showing the range over which biopsy samples were collected from humpback and blue whales during the summers of 1992–1999.

removed from the extracts by gel-permeation chromatography (GPC) and the lipid fraction was collected for gravimetric analysis of the lipid content of the sample. The GPC fraction containing contaminants was subfractionated by silica-gel column chromatography to yield Fraction A that contained primarily PCB congeners and some DDE, and Fraction B that contained the rest of the DDE and the majority of the organochlorine analytes.

Samples were analyzed for 25 PCB congeners with IUPAC numbers 18, 31, 44, 47, 49, 52, 66, 87, 99, 101, 105, 110, 118, 119, 138, 149, 151, 153, 156, 170, 180, 194, 195, 199, 209. The samples were also analyzed for a range of organochlorine compounds, including *p,p'*-DDT, DDE and DDD, HCB, α -HCH, β -HCH, γ -HCH and δ -HCH, *trans*- and *cis*-chlordane, *trans*- and *cis*-nonachlor, heptachlor and heptachlor epoxide, aldrin, dieldrin, endrin and endrin aldehyde, methoxychlor and mirex. The samples were analyzed by gas chromatography with an electron capture detector (GC–ECD), as described previously (Metcalfe & Metcalfe, 1997). The Limits of Detection (LODs), calculated according to Keith, Crummett, Deegan, Libby, Taylor, and Wentler (1983) were between 0.3 and 1.0 ng/ml for PCB congeners, between 0.6 and 1.0 ng/ml for DDT and metabolites and between 0.3 and 0.6 ng/ml for all other organochlorine analytes. Procedural blanks and a National Institute for Standards and Testing (NIST) cod liver oil reference material (SRM 1588) were analyzed for quality control/quality assurance purposes.

The total PCB concentration was calculated as the sum of all PCB congeners and the total DDT concentration was calculated as the sum of p,p'-DDT, DDE and DDD. The total HCH concentration was calculated as the sum of the four HCH isomers. Total chlordane was calculated as the sum of *trans*- and *cis*-chlordane and *trans*- and *cis*-nonachlor. However, only *trans*- and *cis*-chlordane were analyzed in samples from humpback whales. Among samples of blue whales, 10 of 27 females and 16 of 38 males were analyzed for only *trans*- and *cis*-chlordane. All analyte concentrations were lipid normalized, since our previous studies showed that this is required to generate contaminant concentrations that are representative of all layers within the subcutaneous blubber mantle of baleenopterid whales (Gauthier et al., 1997b).

Means and standard deviations about the mean were calculated for lipid-normalized concentrations of contaminants, and these data are presented for reference in all figures. However, there was no homogeneity of variance for contaminant concentrations among the intraspecies and interspecies sample groups. Log-transformations were successful in normalizing these data. Differences in the concentrations of analytes in sample groups were tested for by Student's *t*-test and analysis of variance (ANOVA) using log-transformed data ($\alpha=0.05$). These analyses were conducted with Excel software (Microsoft '97). Intra and interspecies differences in the concentrations and patterns of contaminants were tested for by principal components analysis (PCA) using log-transformed data for the lipid-normalized concentrations of selected individual PCB congeners and DDT compounds, or using log-transformed data on the lipid-normalized concentrations of total PCBs, total HCHs, DDE, DDD and DDT. All PCA analyses were conducted with Systat software.

3. Results

3.1. Blue whales

A range of PCBs and organochlorine contaminants were detected in blubber biopsies from blue whales (Table 1). Among organochlorine compounds, concentrations of heptachlor and aldrin were generally below detection limits, although these compounds were detected in a few samples taken from male blue whales. However, heptachlor epoxide was present in all biopsy samples. Concentrations of endrin, endrin aldehyde, methoxychlor and γ -HCH were usually very low or below detection limits. The classes of compounds present in the highest concentrations were DDT and its metabolites, PCBs, HCHs, chlordanes, HCB and Mirex.

As shown in Fig. 2a, there was considerable variation in the concentrations of total DDT and total PCB in blue whales of both sexes. This is to be expected when sampling animals of different ages, and in the case of females, different reproductive histories. However, statistical analysis showed that the lipid-normalized concentrations of total DDT and total PCB were significantly lower in the blubber of females relative to males. Although there was a similar trend for HCB and total chlordanes (Table 1), the differences between sexes were not statistically significant. No sex-related differences

Table 1

Mean and standard deviations about the mean of concentrations ($\mu\text{g/g}$ lipid) of PCBs and organochlorine compounds in blubber biopsies collected from humpback whales (females and calves) and blue whales (males, females, single calf) in the Gulf of St. Lawrence from 1992 to 1999

Analyte	Humpback whales				Blue whales				
	Calves		Females		Males		Females		Calf
	Mean <i>n</i> = 13	S.D.	Mean <i>n</i> = 12	S.D.	Mean <i>n</i> = 38	S.D.	Mean <i>n</i> = 27	S.D.	<i>n</i> = 1
<i>PCB congeners</i>									
18	ND	ND	ND	ND	7.8	5.1	4.6	3.2	ND
31	ND	ND	ND	ND	5.4	2.0	43.5	–	ND
52	157.1	110.5	103.5	86.0	219.2	119.1	90.6	53.6	84.4
49	28.8	7.9	19.6	8.2	17.9	7.5	13.0	8.1	15.3
47	25.9	11.2	18.5	9.6	23.7	11.3	11.1	9.0	ND
44	23.2	9.3	16.0	8.2	16.0	10.4	15.8	10.1	ND
66	33.5	–	ND	ND	71.0	57.1	19.0	31.0	ND
101	102.8	56.2	75.2	46.8	146.7	58.8	82.1	38.5	65.8
99	ND	ND	303.3	–	129.5	82.8	57.6	37.3	ND
119	ND	ND	ND	ND	38.1	51.5	17.5	33.4	ND
87	28.1	10.4	20.0	10.2	24.4	7.8	18.5	11.2	16.9
110	64.9	31.8	43.0	27.6	47.8	19.2	55.1	53.9	66.5
118	135.5	82.6	107.1	77.0	202.0	96.9	94.7	41.6	80.4
149	98.1	76.3	76.6	71.2	194.9	99.9	100.9	46.2	64.8
151	ND	ND	ND	ND	312.9	130.6	271.8	31.4	ND
153	207.0	112.2	148.8	101.6	291.5	140.3	161.8	64.0	124.2
105	35.4	14.3	23.7	13.7	49.8	69.8	17.8	16.0	23.9
156	7.4	5.3	10.5	7.1	14.6	7.4	6.3	4.1	5.0
138	190.5	95.0	165.8	101.4	292.6	139.5	158.1	60.3	132.8
180	62.5	46.5	58.4	47.9	166.4	86.6	90.6	34.9	49.0
170	16.9	12.2	18.8	14.3	56.8	30.6	31.4	14.3	12.3
199	15.2	18.2	15.3	14.8	52.0	29.8	30.9	13.8	6.0
195	12.2	–	ND	ND	7.5	5.0	4.0	2.4	ND
194	12.0	15.7	12.6	10.0	28.0	16.4	15.8	8.9	3.1
209	ND	ND	ND	ND	5.4	4.5	3.0	3.0	ND
Total PCBs	1137.5	654.4	897.2	596.0	2017.9	912.3	1220.2	671.8	750.4
<i>Organochlorines</i>									
α HCH	75.4	40.4	75.6	36.7	42.6	15.0	38.7	18.2	56.5
β HCH	34.0	13.5	41.3	12.2	27.9	20.7	15.8	8.7	45.5
γ HCH	20.5	12.6	24.3	21.6	14.6	11.0	12.9	11.8	22.5
δ HCH	4.0	3.5	3.5	2.4	8.5	11.9	9.7	12.0	3.8
Total HCH	105.1	50.0	108.1	51.7	70.0	33.7	62.1	33.2	128.3
HCb	172.2	120.9	153.0	99.8	225.8	322.6	90.0	32.9	101.3
Heptachlor	ND	ND	ND	ND	2.1	1.0	ND	–	ND
Hept. Epoxide	25.4	17.5	33.2	16.5	137.4	216.1	88.4	152.7	24.2
Aldrin	ND	ND	ND	ND	0.8	0.4	–	–	ND
Dieldrin	363.4	224.8	347.7	169.7	353.7	190.6	201.1	102.8	249.8
Endrin	12.0	8.1	ND	ND	12.7	10.4	3.3	3.4	ND
DDE	1037.6	1106.6	812.2	958.2	1978.9	1588.3	832.4	666.3	511.5

(continued on next page)

Table 1 (continued)

	Humpback whales				Blue whales				
	Calves		Females		Males		Females		Calf
	Mean <i>n</i> = 13	S.D.	Mean <i>n</i> = 12	S.D.	Mean <i>n</i> = 38	S.D.	Mean <i>n</i> = 27	S.D.	<i>n</i> = 1
DDD	286.5	200.9	225.6	165.2	551.9	303.3	215.2	138.0	235.8
DDT	170.5	268.9	84.4	197.1	887.6	580.0	306.6	234.6	203.0
Total DDT	1481.5	1501.4	1122.2	1255.8	3418.4	2144.5	1354.3	958.8	950.3
Mirex	6.4	3.8	7.2	3.9	10.0	4.8	6.9	3.1	ND
<i>trans</i> -Chlordane	55.6	31.2	41.3	24.3	42.9	13.9	29.4	12.7	56.4
<i>cis</i> -Chlordane	6.4	5.1	5.6	4.1	6.6	3.8	8.3	8.8	2.9
<i>trans</i> -Nonachlor	NA	NA	NA	NA	95.6	72.9	44.9	43.4	NA
<i>cis</i> -Nonachlor	NA	NA	NA	NA	335.9	269.6	55.4	55.9	NA
Total chlordane	NA	NA	NA	NA	260.6	323.1	112.6	88.6	NA
Endrin aldehyde	20.3	16.9	14.3	10.0	19.1	4.6	439.2	378.8	ND
Methoxychlor	4.9	0.0	4.8	2.2	44.6	46.1	17.3	13.5	8.3

ND = Not detected; NA = Not analyzed.

were observed for concentrations of HCH compounds, mirex, heptachlor epoxide, endrin aldehyde and methoxychlor (Table 1).

PCA supported the conclusions described above. Total PCB, total HCH, DDT, DDD and DDE concentrations (lipid-normalized, log-transformed) in blue whales were used to ordinate these samples. With the exception of total HCH, all contaminants used in the ordination were strongly correlated to the first principal component axis (Fig. 3). Blubber biopsies from male blue whales had consistently higher scores on the first principal component axis relative to females; demonstrating higher concentrations of total PCBs, DDT, DDD and DDE. There was little difference in scores on the second principal component axis (Fig. 3). Since this axis is strongly correlated with total HCH concentrations, there appeared to be little difference in HCH concentrations in male and female blue whales.

The lower concentration of contaminants in females probably reflects the loss of these hydrophobic compounds through maternal transfer to young. This indicates that calves of blue whales may be exposed to PCBs and organochlorines as a result of maternal transfer through transplacental routes and lactation. The contaminant data from a single blue whale calf (Table 1) shows that lipid normalized concentrations of total PCB, total HCH, total DDT and HCB were 750.4, 128.3, 950.3 and 101.3 ng/g, respectively. Although these are data from a single animal, the concentrations in the calf are within the same range as the mean concentrations in the female blue whales.

The patterns of PCB congeners and organochlorine compounds can provide insights into the rates of metabolism and elimination of these compounds. Fig. 4a shows the proportions (%) of individual PCB congeners in male and female blue whales. There is relatively high variability in the proportions of some congeners. However, in general, it appears that the pattern of PCB congeners is the same in the blubber of both males and females; with the possible exception of a lower

proportion of congener 31 in males. Similarly, the relative proportions (%) of DDT and its metabolites are consistent among both sexes of blue whale (Fig. 5a). The data on the proportions of HCH isomers and chlordanes compounds in male and female blue whales show similar trends.

3.2. Humpback whales

The classes of compounds present in humpback whales were the same as those observed in blue whales (Table 1), with DDT and its metabolites, PCBs, HCHs, *cis*- and *trans*-chlordanes, HCB and Mirex present in the highest concentrations. As

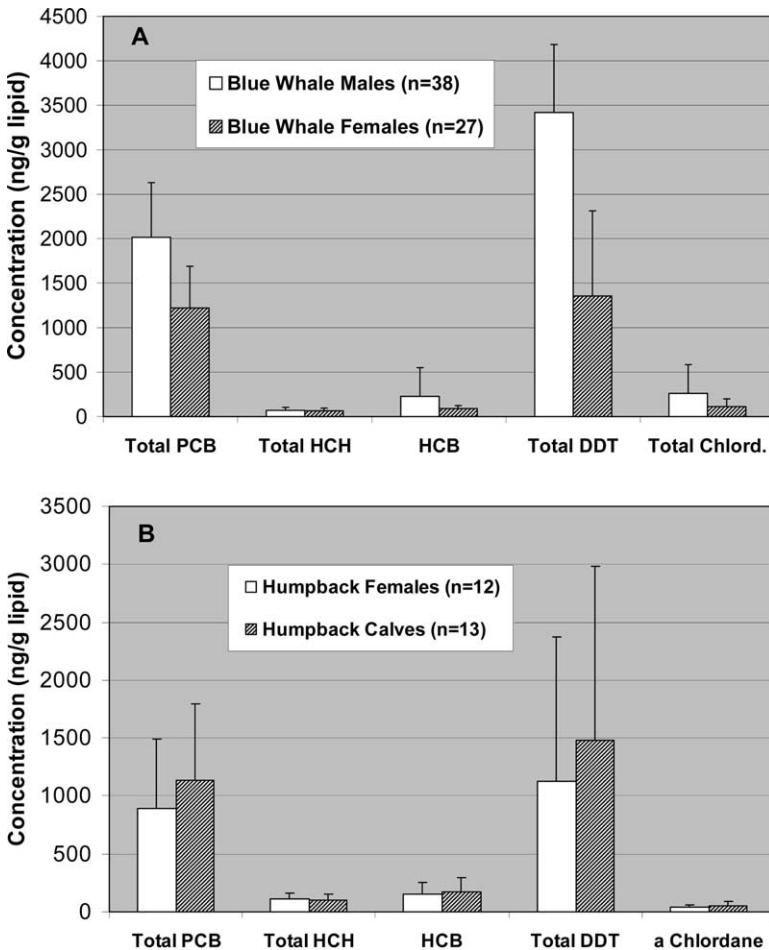


Fig. 2. Mean concentrations (\pm S.D.) in ng/g lipid of total PCBs and classes of organochlorine compounds in blubber biopsies from: (a) Blue whales (males and females). Note for the data on total chlordanes (*cis* and *trans* chlordanes and nonachlor), the sample size was 17 females and 22 males; (b) Humpback whales (females and calves). Note that only *trans* and *cis* chlordanes were analyzed (a chlordanes).

shown in Fig. 2b, there was considerable variation in the concentrations of total DDT and total PCB in humpback females and calves. Statistical analysis showed that the lipid-normalized concentrations of total PCBs and all classes of organochlorines compounds were not significantly different in the females and the calves. PCA supported these observations. Total PCB, total HCH, DDT, DDD and DDE concentrations (lipid-normalized, log-transformed) were used to ordinate data for females and calves. This ordination did not separate the samples; demonstrating that the concentrations of these analytes were very similar in the humpback calves and adult females.

The data on the proportions (%) of PCB congeners in blubber biopsy samples from humpback females and calves (Fig. 4b) indicate that the patterns of PCB contamination are the same in the adult females and the young animals. Similar patterns were observed in humpback females and calves for the relative proportions of DDT and metabolites (Fig. 5b), as well as the proportions of HCH isomers.

3.3. Humpback vs. blue whales

There were no significant differences in the lipid-normalized concentrations of PCBs and organochlorine contaminants in the blubber biopsies from female humpback whales and blue whales. Therefore, it appears that the females of these two baleenopterid species accumulate similar concentrations of persistent contaminants, despite their differences in diet and possibly, other biological characteristics (e.g. metabolism, blubber thickness). However, a comparison of patterns of DDT and metabolites in female blue whales and humpback whales (Fig. 5) shows that DDT is

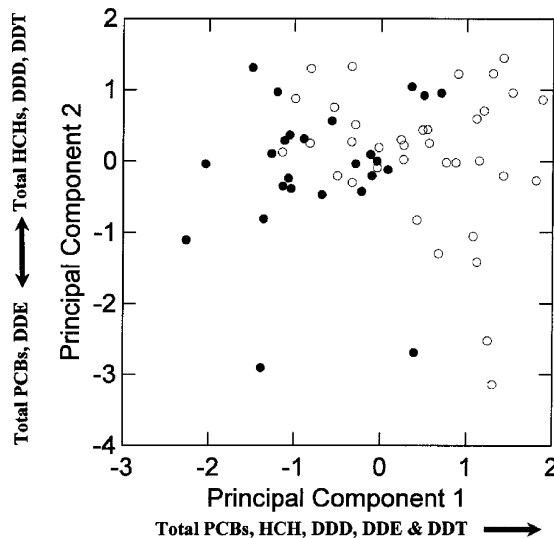


Fig. 3. Principal components ordination of total PCBs, total HCH, DDT, DDD and DDE concentrations in blubber biopsy samples collected from male ($n=38$) and female ($n=27$) blue whales. Female and male whales are represented by the shaded and open circles, respectively.

present in higher proportions in the female blue whales. Thus, the patterns of persistent compounds vary between the two species. This trend is also seen with PCB congener patterns (Fig. 4), where female blue whales have detectable concentrations of congeners 18, 31, 66, 118 and 151, but these congeners are below detection limits in female humpback whales. Female blue whales also had higher proportions of some of the more highly chlorinated PCBs, such as congeners 170, 180, 194 and 199.

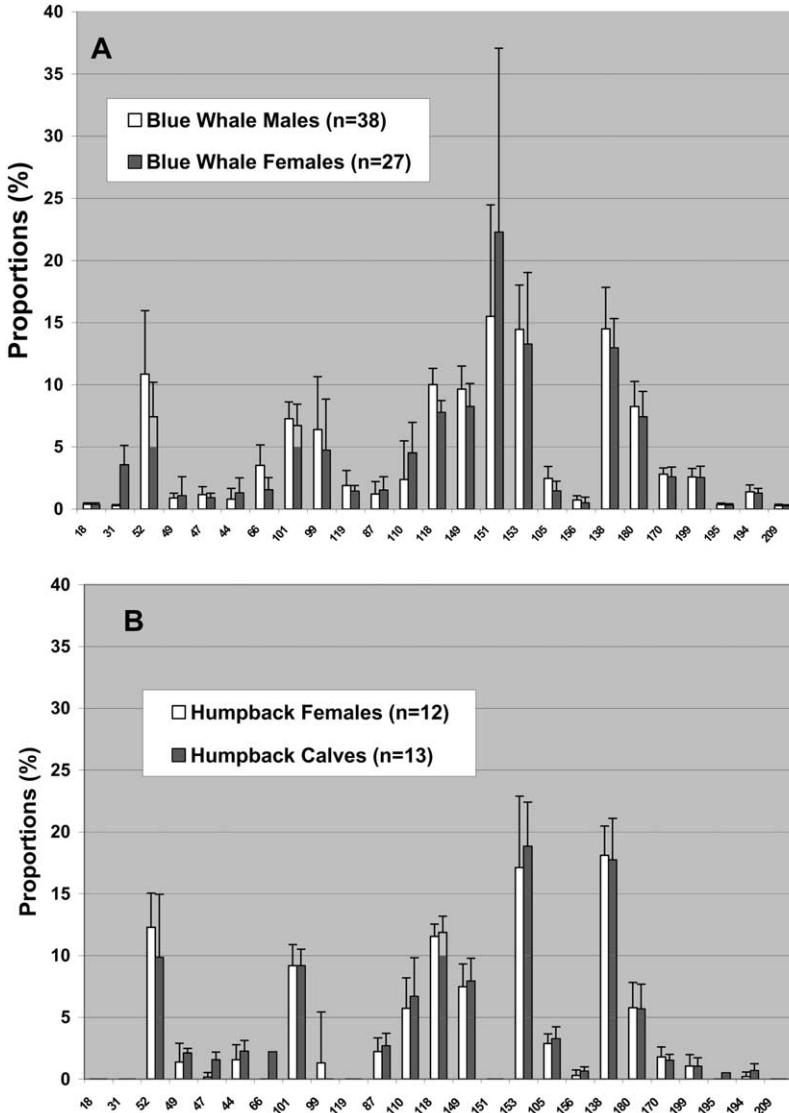


Fig. 4. Mean proportions (\pm S.D.) of PCB congeners in blubber biopsies from: (a) Blue whales (males and females); (b) Humpback whales (females and calves).

PCA of selected PCB congeners, DDT, DDD and DDE was able to provide an ordination of all blue whales (males, females, single calf) and all humpback whales (females and calves). Data on lipid-normalized concentrations of PCB congeners 170, 180, 194, 195, 199 and 209 were selected for PCA, based upon the high principal component loadings of these six congeners. All PCB congeners and DDT were positively correlated with the first principal component axis, with DDE and DDE being moderately negatively correlated with this axis. The second axis provided ordination of data based primarily upon differences in lipid-normalized concentrations of DDT, DDD and DDE. Both DDT and DDD were strongly negatively correlated with the second axis, while DDE was highly positively correlated with this axis. Much of the ordination was due to the greater proportions of highly chlorinated PCB congeners and DDT in blue whales (Fig. 6). Humpback females and their calves had higher proportions of the DDT metabolites, DDD and DDE. It is

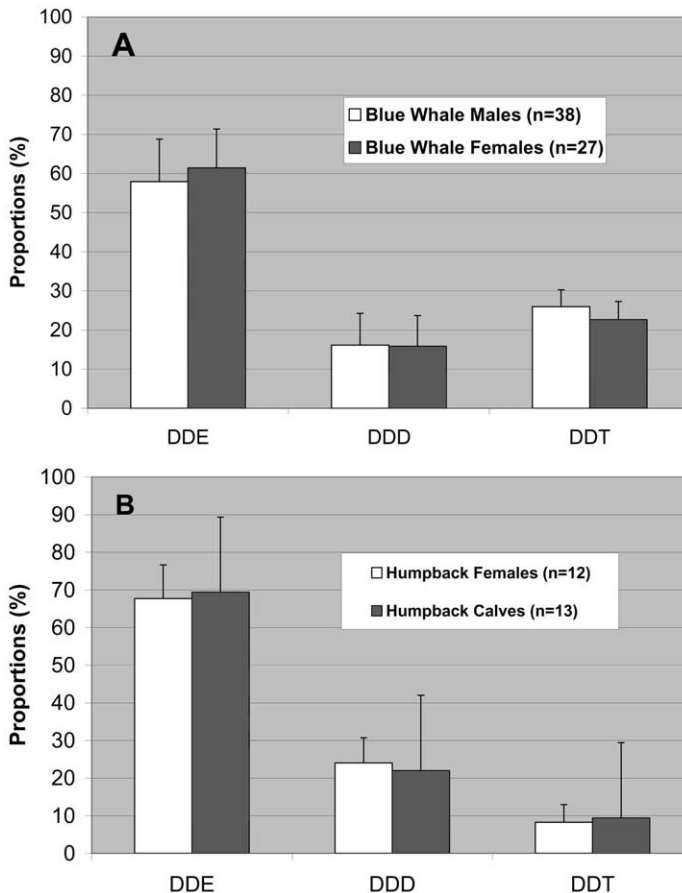


Fig. 5. Mean proportions (\pm SD) of DDT and its metabolites in blubber biopsies from: (a) blue whales (males and females); (b) Humpback whales (females and calves).

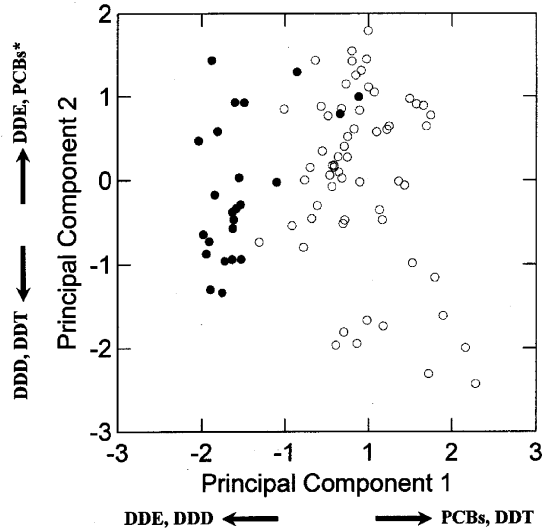


Fig. 6. Principal components ordination of selected PCB congeners, DDT, DDD and DDE in blubber biopsy samples from humpback whales ($n=25$ females and calves) and blue whales ($n=68$ females, males and single calf). Humpback and blue whales are represented by the shaded and open circles, respectively.

interesting to note that there was considerable variation in the ordination of blue whale samples along the second principal component axis (Fig. 6), indicating that there are variations in the proportions of DDT and metabolites in individual blue whales. However, these differences did not appear to be related to the sex of the animal.

4. Discussion

The concentrations of PCBs and organochlorine compounds reported for blubber biopsies of blue whales and humpback whales in this study were similar to those reported earlier by Gauthier et al. (1997a) for biopsies collected from these species in 1990–1992 in the Gulf of St. Lawrence. However, in the earlier study, analysis of inter-species differences in contaminant patterns was hampered by the small number of biopsies collected from blue whales (i.e. $n=6$). However, this earlier study did show a trend of higher proportions of DDT and lower proportions of DDE and DDD in the blubber biopsies from blue whales, relative to humpback, minke and fin whales from the region (Gauthier et al., 1997a). In this more recent study, there were clear differences in the patterns of contaminants in the blubber of female blue and humpback whales. However, there was considerable variation in contaminant levels among the study populations, which is to be expected when animals differ in age and, in the case of females, reproductive history. Unfortunately, it was not possible

to determine the age of the animals in this study because they were biopsied as free-swimming individuals.

Diet is the most obvious difference between humpback and blue whales that could explain inter-species differences in the contaminant data. Blue whales feed exclusively on krill (Breton, 1986), while humpback whales feed heavily on small fish (Borobia, Gearing, Simard, Gearing, & Béland, 1996; Weisbrod et al., 2000b). The different patterns of PCB congeners and DDT metabolites in blue and humpback whales could reflect differences in the patterns of these contaminants in fish and krill. Although there are no data on contaminants in krill from the Gulf of St. Lawrence, data from zooplankton collected off the coast of Newfoundland (Ray, Paranjape, Koenig, Paterson, Metcalfe, & Metcalfe, 1999) indicate that several of the PCB congeners exclusively detected in blue whales (e.g. 18, 31, 66 and 151) and DDT were present in high proportions in zooplankton. However, it cannot be ruled out that the two species of whale differ in their capacity for metabolizing PCBs, DDT and other organochlorine compounds. Weisbrod (1998) reported different concentrations and patterns of PCBs and organochlorines in white-sided dolphins (*Lagenorhynchus acutus*) and pilot whales (*Globicephala melas*) from the Gulf of Maine, even though these odontocete species feed at the same trophic level. Inter-species differences in the metabolism of persistent contaminants could also explain the differences in patterns in the two baleenopteric whale species sampled in this study. Sex-related differences in contaminant metabolism could also affect contaminant patterns in marine mammals.

Among blue whales, there were differences in the concentrations of PCBs and DDT compounds in the blubber of males and females, but no differences in the patterns of these compounds. Higher concentrations of persistent contaminants have been observed in the males of several species of odontocete whales (Martineau et al., 1987; Muir et al., 1996; Ross, Ellis, Ikonomou, Barrett-Lennard, & Addison, 2000; Subramanian, Tanabe, & Tatsukawa, 1988; Weisbrod et al., 2000b). Among baleen whales, Aguilar and Borrell (1988) reported higher concentrations of PCBs and organochlorines in the blubber of male fin whales from the northeast Atlantic. Higher concentrations of PCBs and DDT compounds were also observed in male fin whales from the Mediterranean (Marsili and Focardi, 1996), and in male right whales (*Eubalaena glacialis*) from the north Atlantic (Weisbrod et al., 2000a; Woodley et al., 1991). Oddly, Gauthier et al. (1997a) did not find any significant sex-related differences in the concentrations of contaminants in blubber biopsies from baleenopteric whales sampled in the Gulf of St. Lawrence; although the high variability in contaminant concentrations may have contributed to this result. In the present study, there were sex-related differences in the concentrations of PCBs and DDT compounds, but this trend was not observed for several other organochlorine contaminants, such as HCB, HCHs, and the metabolites of hexachlorocyclodiene pesticides (e.g. endrin aldehyde, heptachlor epoxide). It appears that several less persistent compounds do not show the same high degree of loss from female whales as observed for more persistent PCBs and DDT compounds.

It is generally accepted that maternal transfer of hydrophobic contaminants in marine mammals reduces the concentrations of these compounds in females relative

to males. However, it cannot be ruled out that differences in metabolism of contaminants among males and females contribute to this pattern, as Letcher et al. (2000) reported sex-related differences in the levels of methylsulfone metabolites of PCBs and DDT in male and female beluga whales from the Arctic. In the present study, the patterns of contaminants in the blubber of male and female blue whales were similar. This indicates that the proportions of contaminants in the blubber of females relative to males are unaffected by differences in metabolism or by the transport of contaminants out of the whale via transplacental or lactational routes. These results are not consistent with the observations of Subramanian et al. (1988), who suggested that lesser chlorinated PCB congeners were preferentially eliminated from female Dall's porpoise (*Phocoenoides dalli*) through lactational transfer.

The data presented in this study on the levels and patterns of PCBs and organochlorine compounds in the blubber of a blue whale calf and 13 humpback whale calves is the first detailed report of the levels of persistent contaminants in the blubber of young balaenopterid whales. Gauthier et al. (1997a) previously reported the concentrations of persistent contaminants in blubber biopsies from two humpback calves from the Gulf of St. Lawrence. The data from this present study indicate that PCB congeners and organochlorine compounds are present in the blubber of whale calves in concentrations and proportions that are similar to the blubber of the females.

It appears that the partitioning of contaminants from the blubber of the female whale and transport across the placental barrier and into maternal milk, followed by uptake and contaminant distribution in the young whale does not change the proportions of contaminants in the blubber of the calf relative to the blubber of the adult female. Unfortunately, only a limited number of cow-calf pairs were sampled simultaneously in this study (i.e. one blue whale cow-calf pair; two humpback cow-calf pairs). However, even this limited sample size showed that the concentrations and proportions of PCBs, DDT and metabolites and other organochlorines were similar in females and offspring (data not shown). Addison and Brodie (1987) observed differences in the concentrations of organochlorines in the blubber, serum and milk of lactating grey seals and concluded from these differences that there are barriers to the partitioning of PCBs and DDT compounds from the blubber into circulatory lipids, and from the circulatory lipids to milk lipids. The whale data in this study indicate that, if differential partitioning of contaminants between body compartments occurs, this does not alter the final contaminant patterns in the blubber of the calves relative to the females.

The most important finding in this study was that the concentrations of contaminants in the blubber of young-of-the-year animals were consistent with the concentrations in the blubber of the female whales. The only source of these contaminants in the humpback and blue whale calves was maternal transfer, as they had not yet been weaned at the time of sampling. It appears, therefore, that bioaccumulation via transplacental and lactational transfer is sufficient to establish an equilibrium in contaminant levels between females and their calves. A model of PCB accumulation in beluga whales over their life history (Hickie et al., 1999) predicts that concentrations of these compounds will quickly rise in the calf to the level in the

beluga cow, and will then decline post-weaning. The observations in this study are consistent with this predictive model.

Overall, these data indicate that the patterns of persistent contaminants in the blubber of baleen whales are remarkably consistent; indicating that metabolic transformation, and transplacental and lactational partitioning have little effect on the relative proportions of these contaminants in blubber. Concentrations of PCBs and organochlorine compounds in the blubber of calves were as high as the concentrations in adult animals. This trend has significance for all cetaceans. In whales or dolphins in which concentrations of contaminants are very high, such as the St. Lawrence beluga (Muir et al., 1996) and the Pacific killer whale (Ross et al., 2000), the sensitive early life stages of these animals may be exposed to toxicologically significant concentrations of contaminants.

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