Concentrations of persistent organic pollutanst (POPs) in minke whales (*Balaenoptera acutorostrata*) from Icelandic waters.

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Summary
The legacy POPs PCBs (#28, 31, 52, 101, 105, 118, 138, 153, 156, 170 and 180), DDTs (p,p'-DDE, p,p'-DDD, p,p'-DDT, and o,p'-DDT), HCHs (α-, β-, and γ-HCH), HCB, Chlordanes (trans-nonachlor, α-chlordane, γ-chlordane, and oxychlordane), toxaphenes (26, 50, and 62), and dieldrin were analysed in blubber, biopsies, muscle tissue, and livers of 25 minke whales from Icelandic waters. Additionally, PBDEs (47, 99 and 100) were analysed in these tissues. The animals selected for this study represented the areas north and south of Iceland, equal sex ratios from both areas and as large a length span as was possible. Also, dioxins and dioxin-like PCBs were analysed in samples of ventral grooves from 5 males.

The relative contribution of the various organic contaminants classes is similar in blubber and muscle while the distribution in livers differ fromt that of blubber and muscle. Notable is the lower contribution of Toxaphenes in the livers and higher contribution of HCB, Dieldrin and HCHs. No significant difference was found in the pattern of PCBs between the four tissues examined. Biopsies reflect the liver but not the blubber core and muscle as regards ratios of DDE to total DDTs and oxychlordane to total Chlordanes. However, the biopsies do not reflect ratios of DDTs to PCB7 in blubber core, liver or muscle. Biopsies reflect blubber and muscle but not the liver as regards ratio of γ-HCH to total HCHs and as regards Tox-26 to total Toxaphenes.

No difference was found in levels of any the contaminants analysed between areas north and south of Iceland where liver, blubber and muscle were studied. Levels of organic contaminants in blubber and muscle were not affected by either sex or length. However, levels in livers were higher in males in the case of β-HCH, PCB52, PCB138, and PCB153 and increased with length for Tox-62, α-chlordane, PCB138, and PCB 153. Other contaminants in livers were not affected by either sex or length.

From studies on levels of organic contaminants in minke whales worldwide, it may be concluded that the pattern of the legacy POPs and PBDEs in the blubber of Icelandic minke whales is different than that found in other minke whale stocks of the North-Atlantic and very different than that of the N-Pacific and Antarctic.

It may be concluded that biopsies are strictly speaking only applicable to four compounds in the blubber (HCB, β-HCH, p,p'-DDT, o,p'-DDT, and Tox-26) where there is a 1:1 relationship while biopsies give a good idea of the levels of other POPs in the whole blubber core. However, it is not generally possible to predict the levels of organic contaminants in muscle or livers by their levels in biopsies with the exception of p,p'-DDT in muscle tissue. Further studies are needed to explore if the relationships found in this study may be valid in time for the Icelandic stock or for other stocks of minke whales.

Introduction

The common minke whale (*Balaenoptera acutorostrata*) is the most abundant baleen whale species in the Icelandic continental shelf area. Like other baleen whales, minke whales are migratory animals spending the summer at relatively high latitude feeding areas and the winters at lower latitude breeding areas (Horwood, 1990). Minke whales are found all around the North Atlantic during summer, from Canada to the North Sea, Svalbard and to Novaya Zemlya region of the western Russian arctic (Hobbs *et al*., 2003). Minke whales are also found in the Pacific and in the Antarctic although as a different species there (*Balaenoptera bonaerensis)*. This renders them a suitable species to monitor pollutants in a comparable way across vast marine areas of the earth but marine mammals have often been used for detecting both spatial and temporal trends in organic pollutants (Aguilar *et al*., 2002; Borrell and Reijnders, 1999). Various studies have used differences in levels of contaminants to identify different stocks of marine mammals (Hobbs *et al*., 2003) even on a small geographical scale using sums of DDTs and PCBs as well as ratios of DDE to total DDTs and ratios of DDTs to PCBs (Aguilar *et al*., 1993). The use of biopsies have been discussed as a tool for monitoring contaminants in marine mammals and some validation trials have been carried out (Gautier *et al*., 1997a; Gautier *et al*., 1997b).

The objectives of this study were to examine whether there was a difference between minke populations within Icelandic water with respect to organic contaminants, to see if the Icelandic stock differed from other minke whale stocks in the North Atlantic, as well as in the Antarctic and N-Pacific, and finally to validate biopsies for monitoring organic pollutants in the Icelandic minke whale stock.

The study is a part of a wide ranging research programme on the biology and feeding ecology of minke whales in Icelandic waters (Marine Research Institute 2003).

Materials and methods

Sampling

Sampling of minke whales for organic contaminants took place in the years 2003 and 2004 (SC/F13/SP1). The animals selected for this study represented the areas north and south of Iceland (see SC/F13/SP2), equal sex ratios from both areas and as large a length span as was possible. Samples were taken of meat, blubber, blubber biopsies (1,5 cm deep into the blubber) and liver. Sampling took place at D4, see Figure 1. The samples of meat were taken underneath the blubber sample while samples of livers were taken from the middle of the liver. The samples of ventral grooves were taken at V1, Figure 1. The size of each sample was about 1 kg, packed in two plastic bags, sample marking in the outer bag. Both blubber and meat were frozen at -20°C until the samples were preapared for analysis.

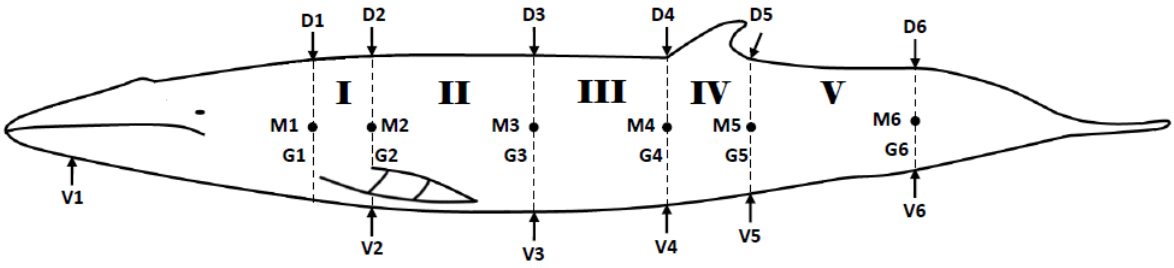

Figure 1. Sampling for organic contaminants were taken at D4 (Figure from SC/F13/SP8)

Sample preparation

The samples were thawed and blubber core taken from the middle of easch sample. Great care was taken to include the whole core of the blubber from skin to muscle where the core was of the same diameter through the blubber. The samples were homogenized in a mixer (steel bowl adn knives) at low temperatures to ensure that no fat separation took place due to heating. The mixer was cleaned with soap and water and after that with acetone and ample amounts of water. After thawing, slices of meat were taken from all sides of the meat samples before they were minced in a mincing machine (steel bowl and knives) and since the samples were also used for trace elements the cleaning was done by acetone and water after which the bowl and knives were washed with a mixture of 2% Na_2EDTA/2% Na_3citrate and finally with ample amounts of water. The livers were prepared in the same manner as the meat samples.

Analysis

The legacy POPs PCBs (#28, 31, 52, 101, 105, 118, 138, 153, 156, 170 and 180), DDTs (p,p'-DDE, p,p'-DDD, p,p'-DDT, and o,p'-DDT), , HCHs (α-, β-, and γ-HCH), HCB, chlordanes (trans-nonachlor, α-chlordane, γ-chlordane, and oxychlordane), toxaphenes (26, 50, and 62), and dieldrin were analysed in blubber, biopsies, muscle tissue, and livers. PCB7 includes the sum of PCBs #28, 52, 101, 118, 138, 153, and 180.
Additionally, PBDEs (47, 99 and 100) were analysed in these tissues. Dioxins (the 15 polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), Table 1, and 12 dioxin-like PCBs (the 4 mono-ortho PCBs and the 8 mono-ortho PCBs: DL-PCBs), see Table 1, were analysed in samples of ventral grooves from 5 males.

Table 1. List of the PCDD/Fs and DL-PCBs anlysed in five minke whale males

Dioxins	Dioxin-like PCBs (DL-PCBs)
2,3,7,8 TCDF	Non-ortho PCBs
1,2,3,7,8 PeCDDF	PCB-77
2,3,4,7,8 PeCDF	PCB-81
1,2,3,4,7,8 HxDCF	PCB-126
1,2,3,6,7,8 HxCDF	PCB-169
2,3,4,6,7,8 HxCDF	
1,2,3,7,8,9 HxCDF	Mono-ortho PCBs
1,2,3,4,6,7,8 HpCDF	PCB-105
1,2,3,4,7,8,9 HpCDF	PCB-114
OCDF	PCB-118
2,3,7,8 TCDD	PCB-123
1,2,3,7,8 PeCDD	PCB-156
1,2,3,4,7,8 HxCDD	PCB-157
1,2,3,6,7,8 HxCDD	PCB-167
1,2,3,7,8,9 HxCDD	PVB-189
1,2,3,4,6,7,8 HpCDD	
OCDD	

The analysis of the legacy POPs was carried out at the Department of Pharmacaology and Toxicology, University of Iceland, while the analysis of PCDD/Fs and DL-PCBs was provided by NILU, Norway.

Results and discussions

Table 2 contains the data on legacy POPs and PBDEs.

Table 2. Levels of POPs in tissues of Icelandic minke whales.

	Liver µg/kg wet weight			**Blubber biopsy µg/kg wet weight**			**Blubber, whole core µg/kg wet weight**			**Muscle µg/kg wet weight**		
n	Mean 25	Min	Max	Mean 24	Min	Max	Mean 24	Min	Max	Mean 25	Min	Max
Fat, %	4.3	2.6	6.7	77	62	87	73	46	97	7.1	0.9	18.3
PCB28	<0.07	<0.07	0.2	2	1	4	1	<0.4	3	0.2	<0.4	0.7
PCB31	<0.05	<0.05	0.1	2	0	5	0	<0.2	0	0.1	<0.2	0.1
PCB52	1.3	0.1	3.5	50	14	128	39	10	84	2.7	0.4	8.2
PCB101	1.3	0.4	3.2	53	19	134	39	11	85	2.9	0.4	9.2
PCB105	0.1	0.0	0.3	5	2	8	6	1	9	0.3	0.0	1.3
PCB118	1.8	0.7	5.0	77	22	199	56	14	118	3.2	0.4	9.7
PCB138	2.5	0.7	8.4	139	38	516	91	18	284	4.4	0.5	17.3
PCB153	3.2	0.9	11.6	197	52	838	135	31	461	6.7	0.8	26.8
PCB156	0.1	0.0	0.4	8	2	21	5	1	13	0.3	0.0	0.9
PCB170	0.3	0.1	1.2	21	7	82	15	3	46	0.6	0.1	2.7
PCB180	0.9	0.2	3.4	54	18	215	39	9	134	1.6	0.2	6.9
HCB	5.1	1.8	11.3	82	24	246	73	20	219	7.8	0.9	27.4
α-HCH	0.3	0.1	0.9	6	2	11	6	2	11	0.8	0.1	3.0
β-HCH	1.8	0.4	3.9	11	2	29	10	2	25	0.8	0.2	3.2
γ-HCH	0.04	0.01	0.16	1.76	0.21	3.24	1.82	0.45	3.76	0.24	0.03	1.00
p,p'-DDE	10.2	2.2	37.3	549	128	1871	356	67	955	17.4	1.9	65.2
p,p'-DDD	2.9	0.2	8.1	129	39	389	99	29	258	6.9	1.0	21.8
p,p'-DDT	0.2	0.0	0.9	23	6	85	23	7	56	1.6	0.2	6.9
o,p'-DDT	0.3	0.1	1.2	46	4	151	39	7	96	2.0	0.2	8.4
transnonachlor	3.7	0.8	14.2	265	57	999	188	38	652	11.3	1.2	37.7
α-chlordan	0.8	0.2	2.3	31	9	48	24	8	49	2.0	0.2	9.1
γ-chlordan	0.2	0.1	0.5	11	4	29	9	3	19	0.7	0.1	2.2
oxychlordan	0.7	0.2	1.7	50	12	160	38	8	104	2.6	0.3	7.9
Tox-26	2.8	0.5	9.4	180	51	522	134	34	335	8.6	1.0	28.8
Tox-50	2.5	0.1	15.8	332	92	1148	253	75	741	16.3	1.8	57.7
Tox-62	0.1	0.0	0.3	51	10	174	47	16	113	3.4	0.2	19.0
PBDE-47	0.56	0.20	1.29	26.51	9.91	58.00	19.41	4.91	43.12	1.30	0.23	3.81
PBDE-99	0.11	0.03	0.28	5.43	2.13	13.46	4.04	0.99	13.74	0.23	0.02	0.76
PBDE-100	0.06	0.02	0.11	2.70	1.05	6.21	2.03	0.71	5.79	0.13	0.02	0.38
Dieldrin	7.3	2.3	19.5	239	37	619	168	35	396	14.1	3.4	43.7

Table 3 contains data on dioxins, dioxin-like PCBs, and PCB7 in ventral grooves of five males.

Table 3. Levels of PCDD/Fs, DL-PCBs, and PCB7 in ventral groove samples of five minke whale males from 2003. Lengths varied between 6.8 and 8.4 m.

Chemical parameter	Unit	Mean	Min	Max
PCDD/Fs	pg WHO-TEQ/g ww	0,37	0,2	0,61
DL-PCBs	pg WHO-TEQ/g ww	13,2	4,1	18,9
PCB7	µg/kg ww	269	98	376
Fat, %		49,3	34,4	60,3

Relative contribution of classes of compounds

The relative contribution of different compound classes is similar in muscle and blubber, Figure 2, while there is a marked difference between blubber and liver, Figure 3. It is seen that in muscle and blubber, DDTs, Toxaphenes and PCBs are of highest contribution while Toxaphenes are at relatively low levels in livers. The livers on the other hand are relatively higher in HCB and HCHs than the blubber, Figure 3. PCBs, DDTs, Chlordaens, and PBDEs are at similar relative level in all three types of tissues. Although similar, the blubber and muscle differ significantly in relative contribution in all but Toxaphenes, Chlordanes and PBDEs (two-sided t-test; $p<0.05$). The relative contribution of the various classes of compounds in biopsies and blubber is very similar although there is a significant difference in Toxaphenes and HCHs (two-sided t-test; $p<0.05$).

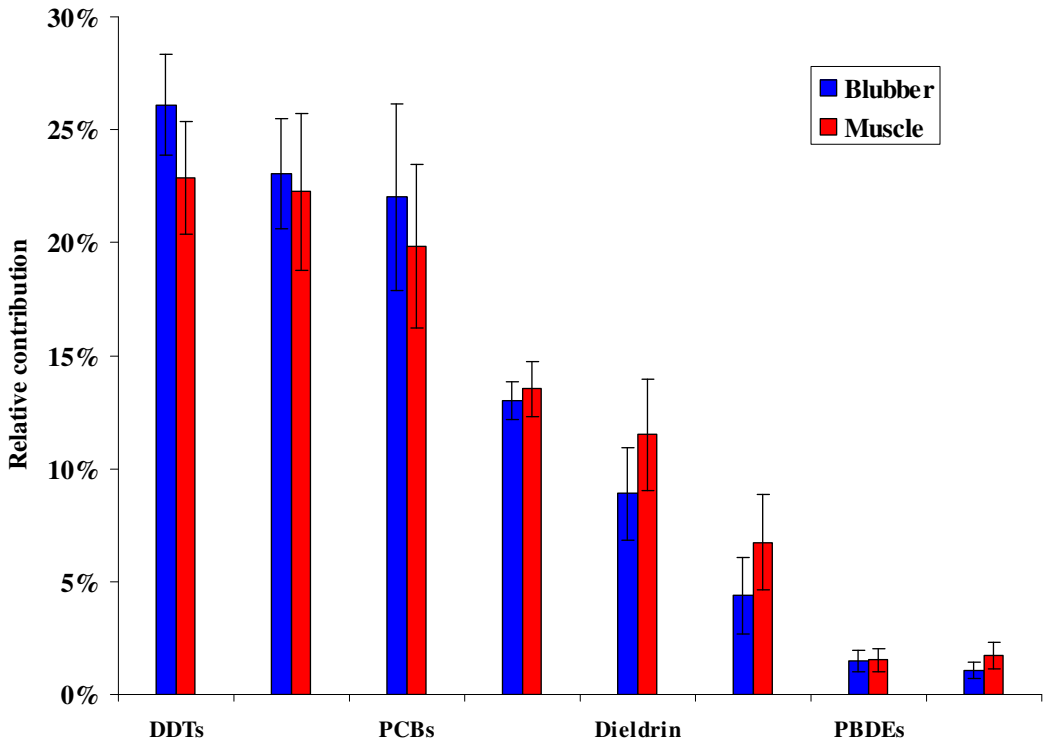

Figure 2. Relative contribution of the various classes of organic contaminants in blubber and muscle of Icelandic minke whales. The bars of each column represents one standard deviation where n=23 for blubber and n = 25 for muscle.

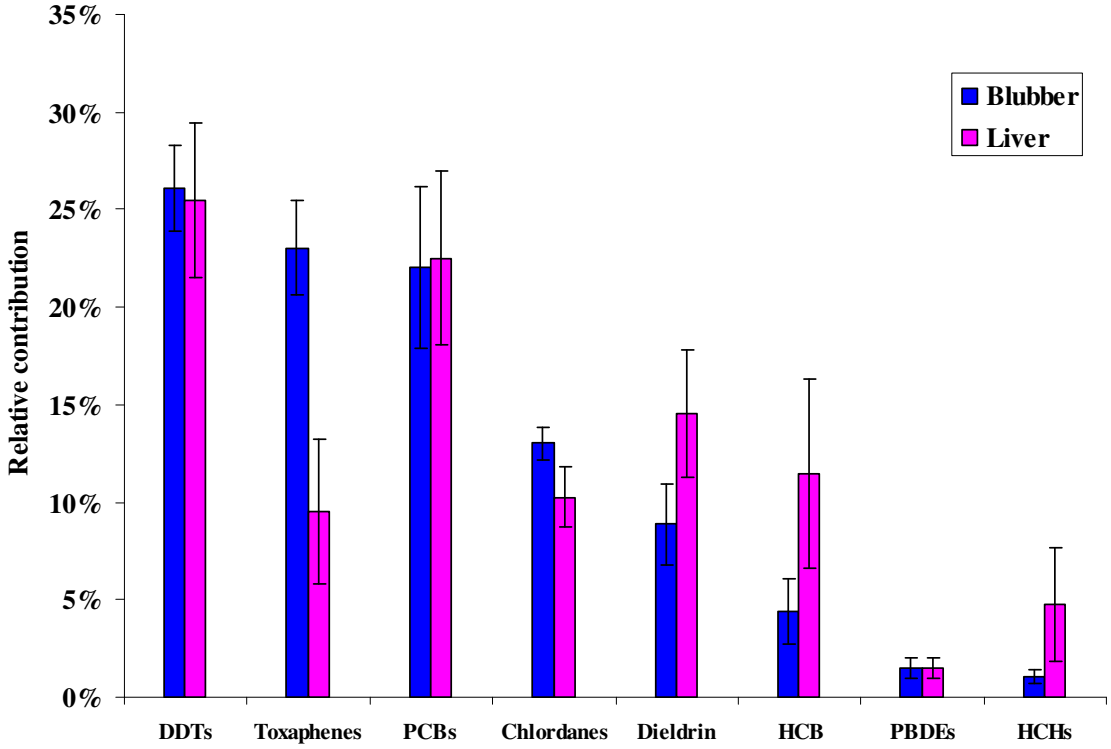

Figure 3. Relative contribution of the various classes of organic contaminants in blubber and liver of Icelandic minke whales. The bars of each column represents one standard deviation where n=23 for blubber and n = 25 for liver.

No significant difference was found in the pattern of PCBs between the four tissues examined. The ratio of DDE to total DDTs was, however, significantly higher in liver than both blubber and muscle tissue (paired two sided t-test; $p<0.05$), possibly reflectin metabolims of the DDTs to DDE in the liver (Borrell, 1993). Furthermore, there was not a significant difference between this ratio in liver and the biopsy samples (paired two-sided t-test; $p>0.05$). Additionally, oxychlordane, the main metabolite of many chlordanes, was at a higher ratio to total Chlordanes in blubber and muscle than in the liver (paired two sided t-test; $p<0.05$) but liver and biopsy did not show a significant difference (paired two sided t-test; $p>0.05$). The ratio of DDTs to PCB7 in livers was not significantly different from this ratio in blubber core or muscle tissue (paired two sided t-test; $p>0.05$) while this ratio was lower in biopsies than in the liver (paired two sided t-tes; $p<0.05$). Thus, biopsies differ in this respect from both blubber core and muscle as regards DDTs, Chlordanes, and ratio of DDTs to PCB7. γ-HCH, the most toxic component of the HCHs, was at a much lower rato to total HCHs in livers than in blubber core, biopsies, and muscle tissue (paired one-sided t-test; $p<0.05$), also suggesting degradation of γ-HCH in the liver. Finally, Toaxaphene congener 26 was at a much higher ratio in livers than in blubber core, muscle tissue, and biopsies (paired two sided t-test; $p<0.05$).

Effect of sex, length, and area within Icelandic waters

Sampling of minke whales for the study of organic and inorganic contaminants provided 12 animals from south of Iceland (5 males and 7 females) and 13 animals north of Iceland (5 males and 7 females). The variation in length of both sexes were similar, 5.0-8.6 m for females and 5.1-8.5 m for males. The sample size is limited but when log-transformed levels

on lipid weight basis were linearly regressed on sex, area and length, no significant difference in any of the 32 compounds in Table 2 was found for the blubber and muscle samples ($p>0.05$). However, in livers, area never had an effect while length had significant effect ($p<0.05$) in the case of Tox-62, α-chlordane, PCB138, and PCB 153, *i.e.* these compunds incfreased with length. These two PCBs are also the highest of the 11 PCBs analysed. Additionally, the levels of β-HCH, PCB52, PCB138, and PCB153 had significantly higher levels in males than females ($p<0.05$). No assessment could be done on PCBs 28 and 52 in livers because of too many nondetects for these two congeners. It is to be expected that levels increase with age/length and that females have lower levels than males due to maternal transfer through calving and lactation (Aguilar and Borrell, 1988; Aguilar *et al*., 1999). However, this appears to manifest itself only in livers of minke whales in Icelandic waters and only in few compounds.

Comparisons with other minke whale populations

PCBs, DL-PCBs, and PCDD/Fs

Comparisons of levels between studies is often hampered by the use of sum parameters since these sums may represent different compounds from one study to another. This is for example the case of the PCBs, which are usually expressed as a sum of PCBs but not necessarily the same PCBs in all studies. PCBs (PCB7) were found to be similar in Icelandic minke whale blubber as the levels found in minke whales from the NW-Pacific and the Barents Sea while they were lower than those found in the North Sea, Figure 4. The relative distribution of the 7 PCBs were almost the same in the blubber of both Icelandic and the NW-Pacific minke whales. Furthermore, data on PCBs in male minke whales from the Antarctic from the years 1984-1993, expressed as a sort of total PCBs, were lower by far than the levels shown in Figure 4 (Aono *et al*., 1997).

Similar pattern between Iceland, Barents Sea and North Sea was also seen for DL-PCBs in ventral gooves, similar levels were found in minke whales from the Barents Sea but lower than those found in the North Sea, Figure 5.

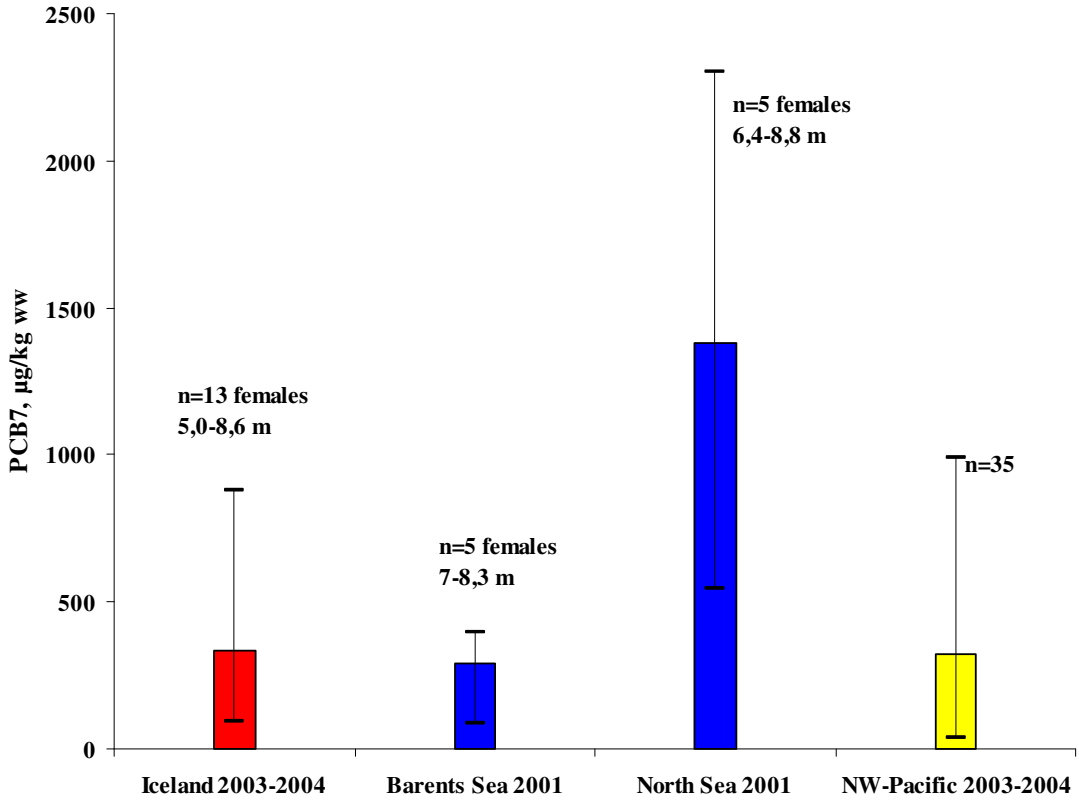

Figure 4. PCB7 (µg/kg wet weight (ww)), mean values, in blubber of minke whales from four areas. The vertical bars show minima and maxima in the results. The data for minke whales from the Barens Sea and North Sea derive from Utne-Skåre *et al.* (2001) while the data on minke whales from the NW-Pacific derive from Fujita *et al.* (2008).

Dioxins in ventral grooves of the Icelandic minke whales were somewhat lower than those found in Barents Sea and much lower than those found in the North Sea, Figure 6.

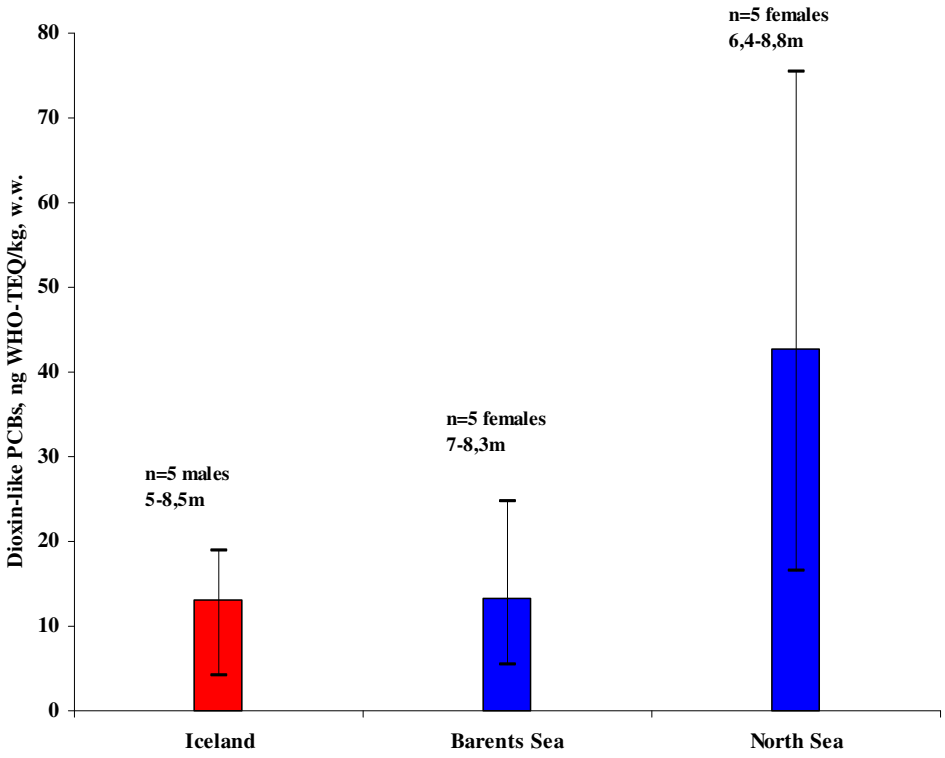

Figure 5. Dioxin-like PCBs, mean values on a wet weight basis, in ventral grooves of minke whales from three different areas. The bars of each column represent minima and maxima of the levels. The data for the Barents Sea and the North Sea derive from Utne-Skåre *et al.* (2001).

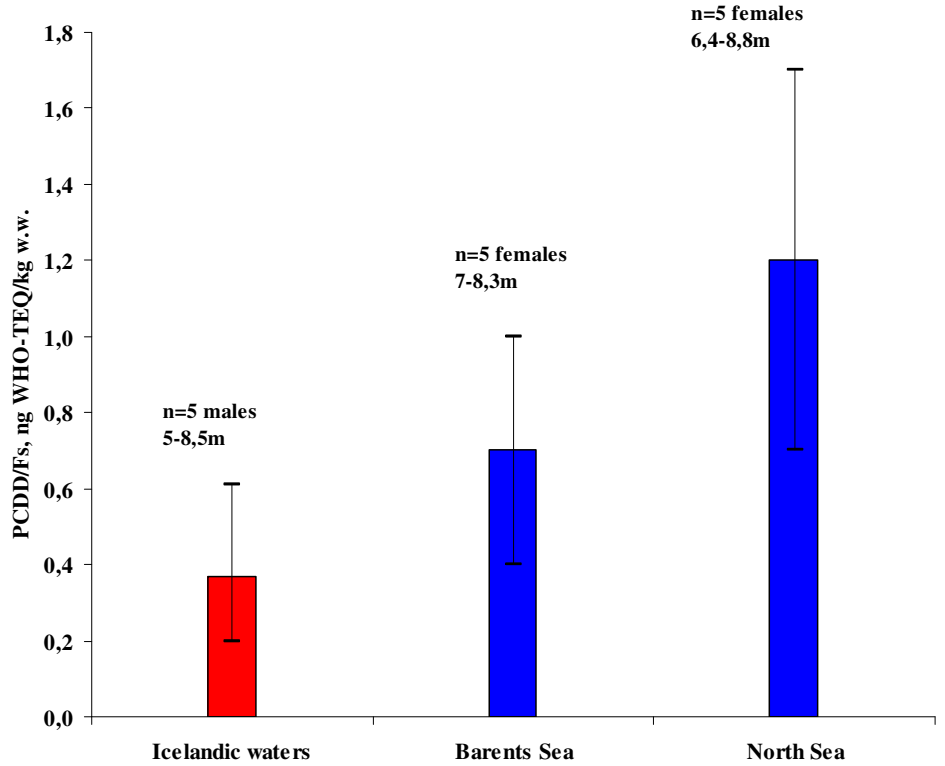

Figure 6. Dioxins, mean values on a wet weight basis, in ventral grooves of minke whales from three different areas. The bars of each column represent minima and maxima of the levels. The data for the Barents Sea and the North Sea derive from Utne-Skåre *et al.* (2001).

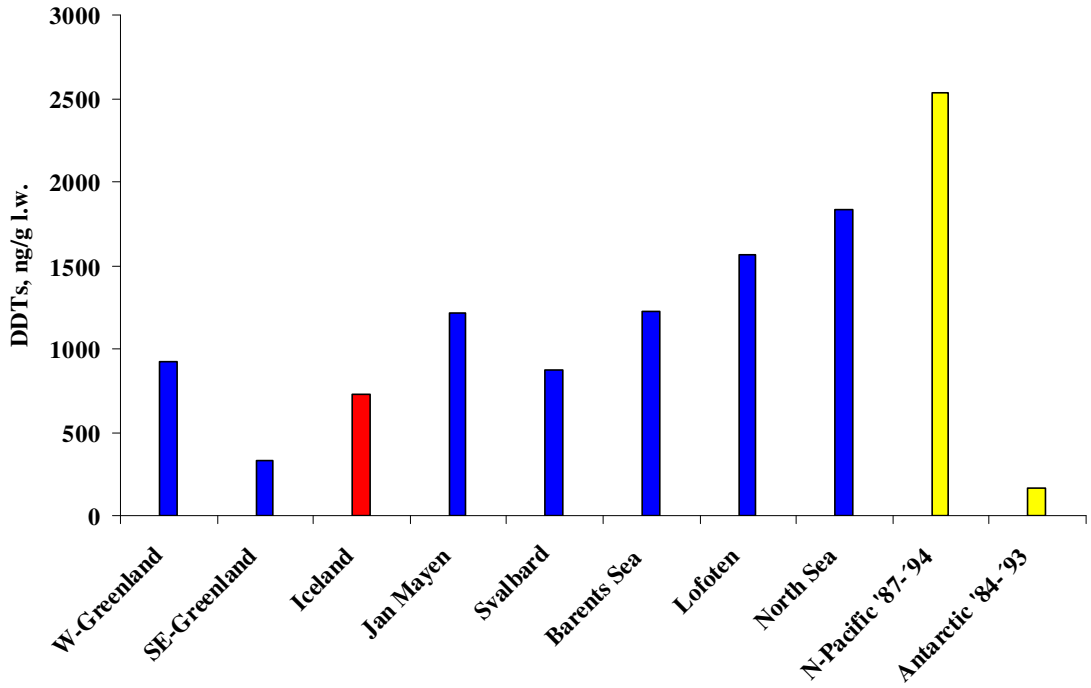

Figure 7. DDTs (sum of p,p'-DDT, p,p'-DDD, and p,p'-DDE), mean values on a lipid weight basis, in blubber of minke whales from different areas. The blue column data derive from Hobbs *et al.* (2003) while the data for N-Pacific and Antarctic are from Aono *et al.* (1997).

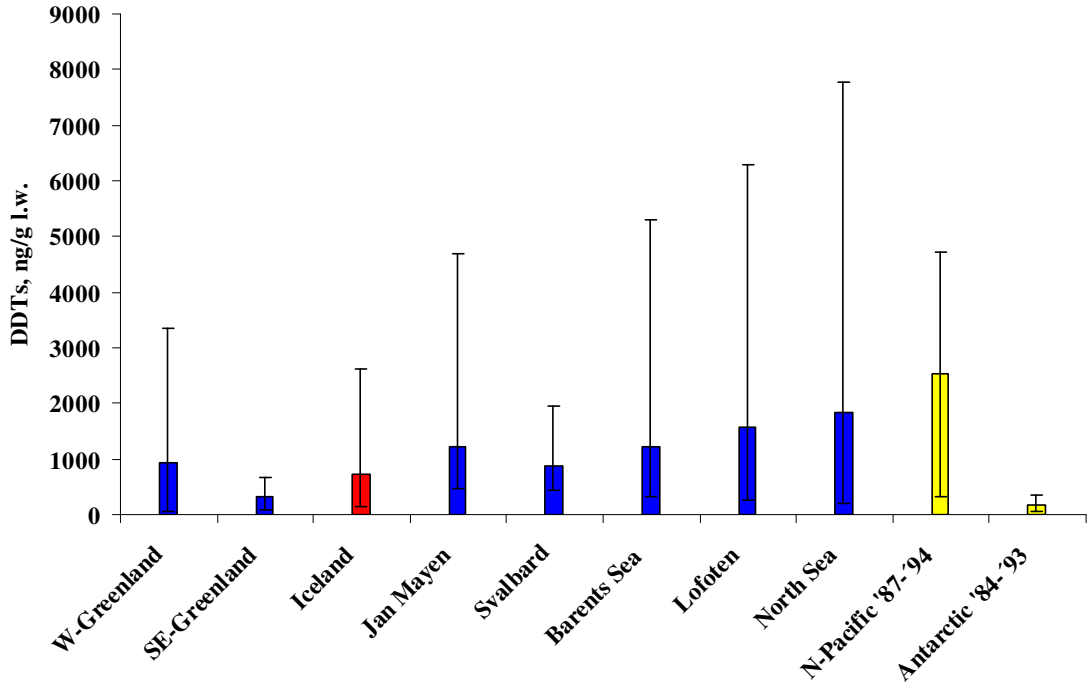

Figure 8. DDTs (sum of p,p'-DDT, p,p'-DDD, and p,p'-DDE), mean values on a lipid weight basis, in blubber of minke whales from different areas. The bars of each column represent minima and maxima of the levels. The blue column data derive from Hobbs *et al.* (2003) while the data for N-Pacific and Antarctic are from Aono *et al.* (1997).

The levels of DDTs in blubber tissue of the Icelandic minke whale were similar to the levels found in blubber of minke whales from the Barents sea (Hobbs *et al*., 2003) but lower than the levels found in the N-Pacific (Aono *et al*., 1997). However, the levels of DDTs in the Antarctic minke whale (Aono *et al*., 1997) are much lower than those found in minke whales from Icelandic waters, Figure 7. Similar DDT-levels were found in minke whale in Korean coastal waters as found in SE-Greenland (Moon *et al*., 2010). It is to be noted that the variation within each area is considerable, Figure 8.

HCB is found in similar levels in blubber of minke whales from the North Atlantic, N-Pacific and the Antarctic, Figure 9 (Hobbs *et al*., 2003; Aono *et al*., 1997). The mean and median values on HCB in blubber of minke whales caught in the area between North-Norway (Finnmark) and Svalbard in 1992 were in the higher range of the values seen in Figure 9 (Kleivane and Utne-Skåre, 1998). Therefore, a decrease in HCB is indicated in this area between 1992 and 1998, the year the animals were captured in the study of Hobbs *et al.* (2003). Similar HCB-levels were found in minke whale in Korean coastal waters as found in SE-Greenland (Moon *et al*., 2010). However, a considerable variation is found in the data of HCB, Figure 10.

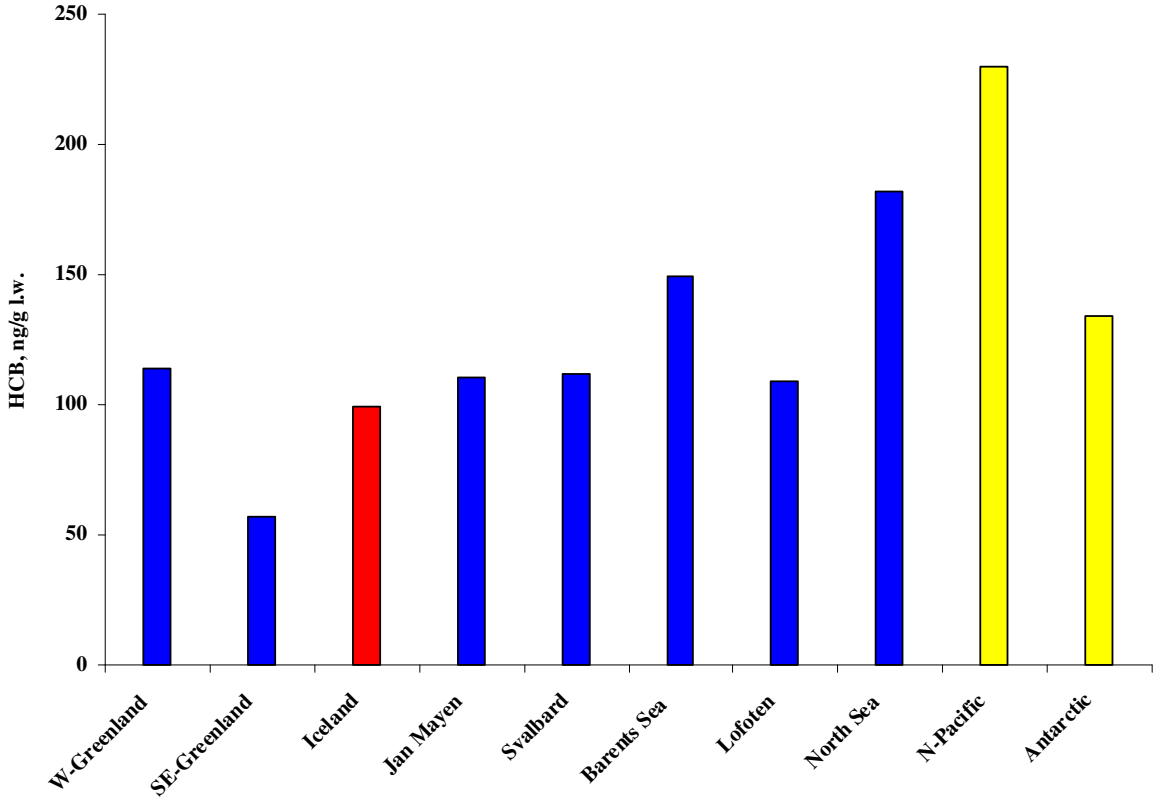

Figure 9. HCB, mean values on a lipid weight basis, in blubber of minke whales from different areas. The bars of each column represent minima and maxima of the levels. The bars of each column represent minima and maxima of the levels. The blue column data derive from Hobbs *et al.* (2003) while the data for N-Pacific and Antarctic are from Aono *et al.* (1997).

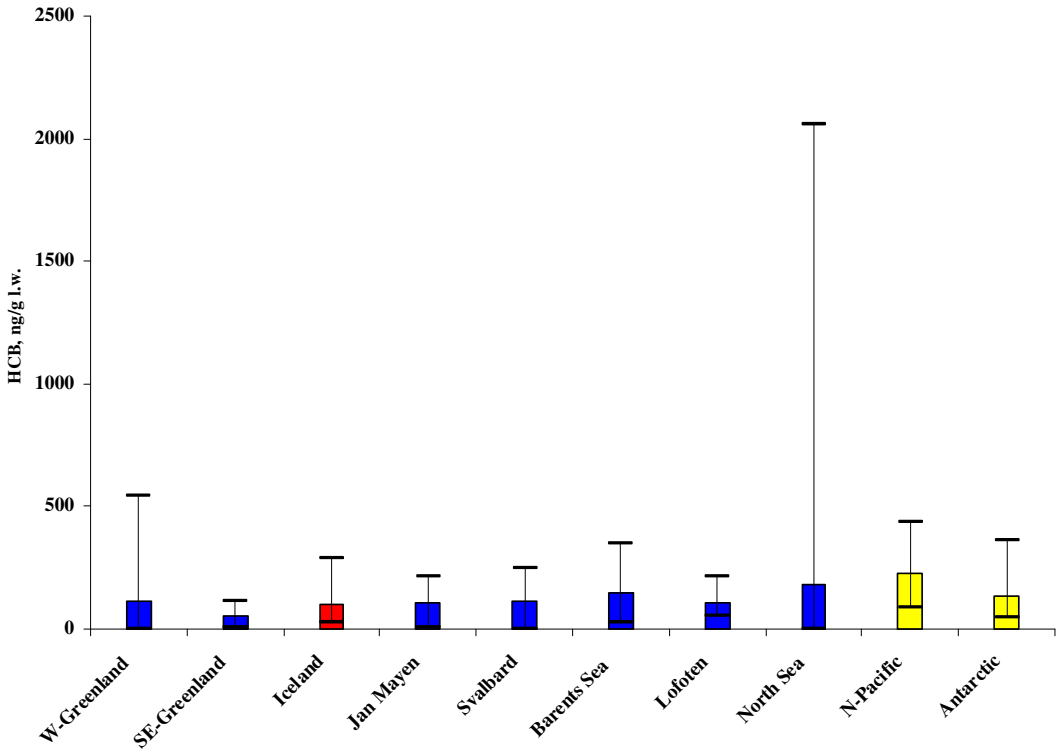

Figure 9. HCB, mean values on a lipid weight basis, in blubber of minke whales from different areas. The bars of each column represent minima and maxima of the levels. The blue column data derive from Hobbs *et al.* (2003) while the data for N-Pacific and Antarctic are from Aono *et al.* (1997).

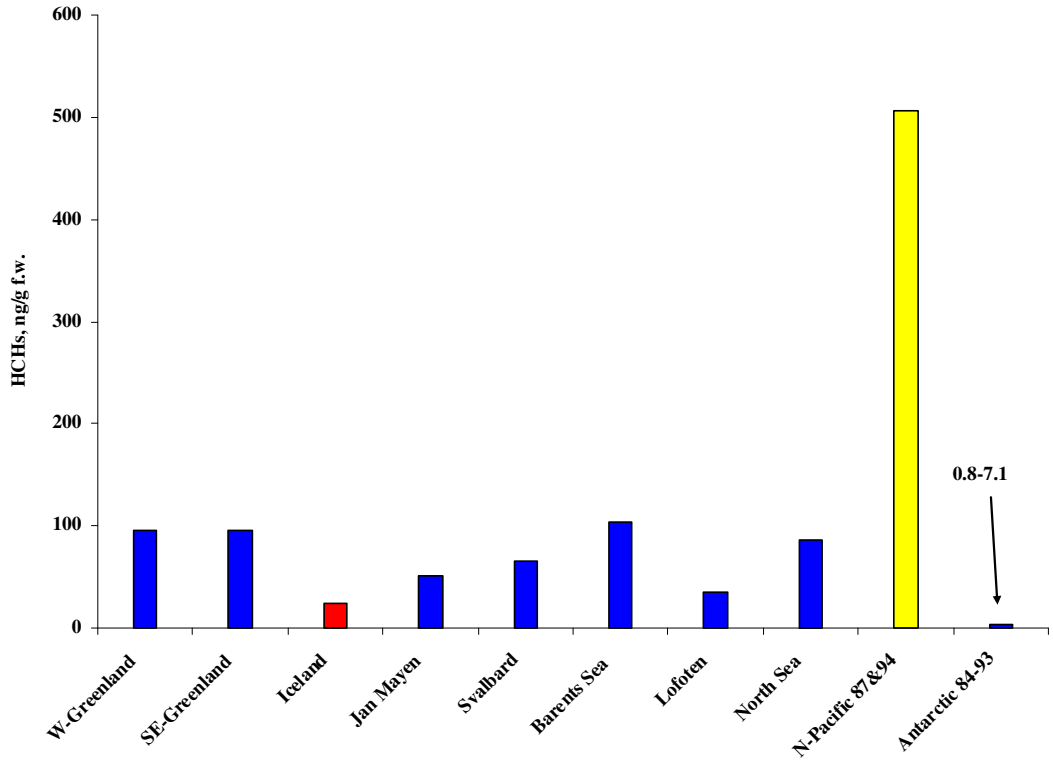

Figure 10. HCHs (sum of α-, β-, and γ-HCH), mean values on a lipid weight basis, in blubber of minke whales from different areas. The blue column data derive from Hobbs *et al.* (2003) while the data for N-Pacific and Antarctic are from Aono *et al.* (1997).

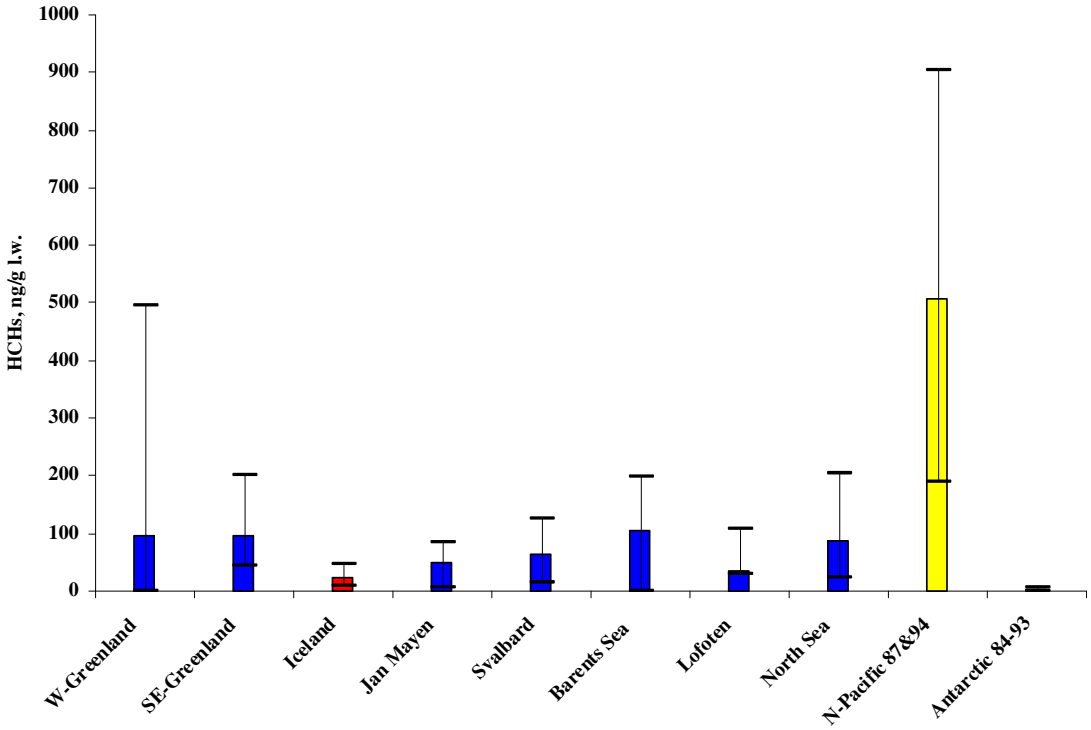

Figure 11. HCHs (sum of α-, β-, and γ-HCH), mean values on a lipid weight basis, in blubber of minke whales from different areas. The bars of each column represent minima and maxima of the levels. The blue column data derive from Hobbs *et al.* (2003) while the data for N-Pacific and Antarctic are from Aono *et al.* (1997).

HCHs are at low levels in the blubber of Icelandic minke whales, equal to the lowest found in the North Atlantic but much higher than the levels found in blubber of the Antarctic minke whales (Hobbs *et al*., 2003). However, levels of HCHs in blubber of minke whales from the N-Pacific (Aono *et al*., 1997) are much higher than those found in the N-Atlantic. Similar values as in the Barents Sea were found in minke whales caught in 1992 between Svalbard and N-Norway (Kleivane and Utne-Skåre, 1998). Similar HCH-levels were found in minke whale in Korean coastal waters as found in W-Greenland (Moon *et al*., 2010). However, considerable variation is in the data, Figure 11.

Levels of Dieldrin is on average low in blubber of the minke whales from Icelandic waters, Figure 12. As for othe organochlorines, the variation in data is great, Figure 13.

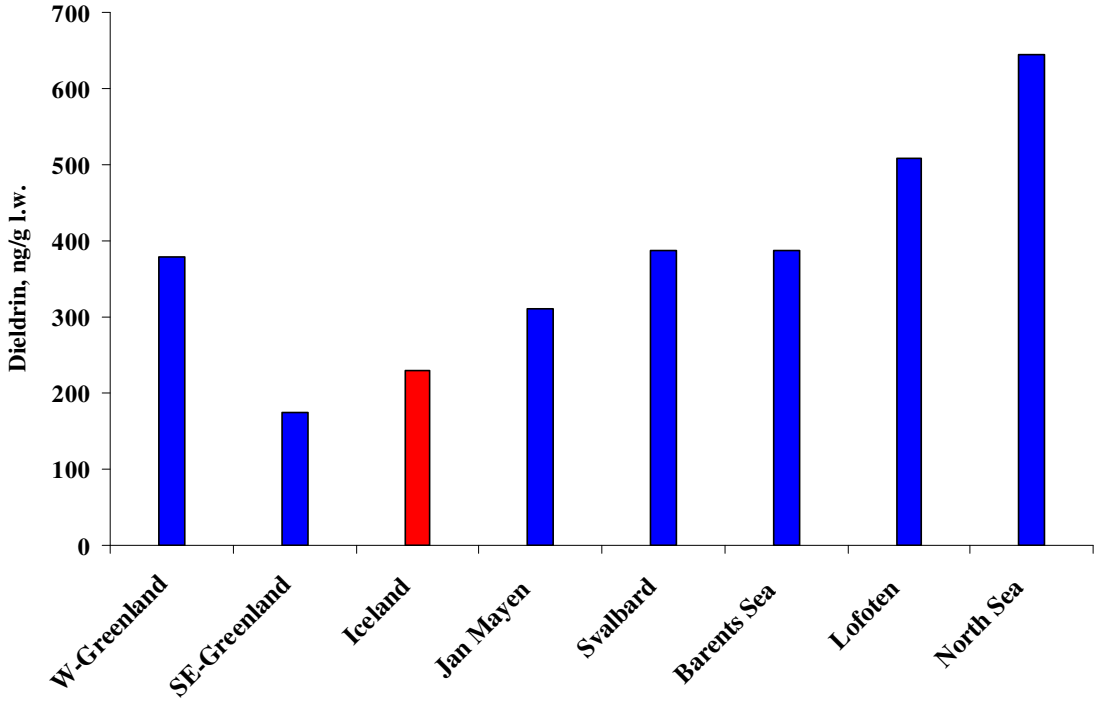

Figure 12. Dieldrin, mean values on a lipid weight basis, in blubber of minke whales from different areas. The blue column data derive from Hobbs *et al.* (2003).

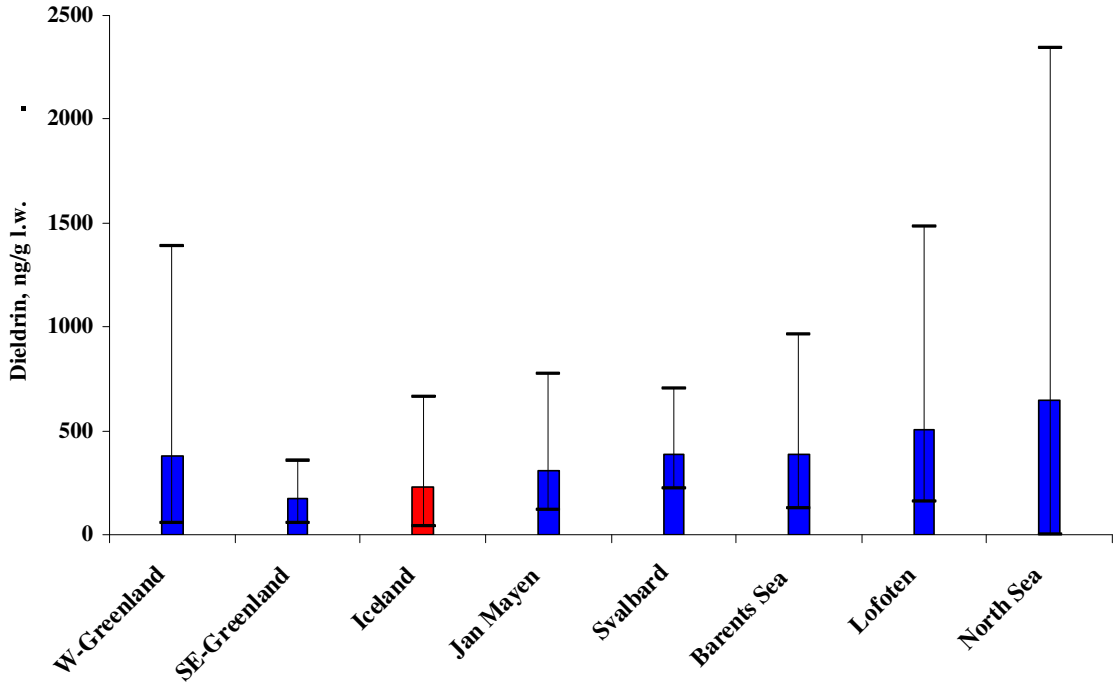

Figure 13. Dieldrin, mean values on a lipid weight basis, in blubber of minke whales from different areas. The bars of each column represent minima and maxima of the levels. The blue column data derive from Hobbs *et al.* (2003).

Toxaphenes, unlike other organic contaminants studied, are at higher levels in the blubber of Icelandic minke whales than in blubber of other minke whale populations in the N-Atlantic (Gouteux *et al*., 2008), where levels are lowest in SE and SW of Greenland, Figure 14, although variation in the data is high, Figure 15. The spatial trend in N-Atlantic minke whale blubber indicates long range transport of toxaphenes from the southwest. Furthermore, data on Toxaphenes in muscle tissue from minke whales from Icelandic waters and pooled samples from Barents Sea and Svalbard (15 and 16 animals in a pool) in May-June 1998 (Frydenlund and Øvervoll, 2002) showed similar results as found in this study, being 254 and 1403 ng/g l.w. in the Norwegian minke whales while the lavels ranged 137-1647 ng/g l.w. in the Icelandic minke whales. Two pooled samples from the North Sea May-June 1998 were similar to those of Barenst Sea and Svalbard or 787 and 1144 ng/g l.w. (Frydenlund and Øvervoll, 2002).

It proved difficult to find comparable data for the Chlordanes since different compounds are found in the various studes on minke whales. However, the mean level and range found in the blubber of the Icelandic minke whales are well below the levels found in minke whales between North of Norway and Svalbard in 1992 (Kleivane and Utne-Skåre, 1998) while they are considerably above the levels of Chlordanes found in minke whales in the coastal waters of Korea (Moon *et al*., 2010).

The data of this study together with those of SC/F13/SP24, where a selection of PBDE congeners were analysed in pooled blubber samples of minke whales as well as several other marine mammals from the N-Atlantic, reveal that the levels found in minke whale blubbers from Norway, SW-Greenland, and Iceland were 82–389 ng/g lipid weight, 50–170 ng/g lipid weight and 64–111 ng/g lipid weight, respectively (sum of 10 congeners). These levels were slightly lower compared to minke whales caught off the Korean coast (Moon *et al*., 2010).

Therefore, it may be concluded that the pattern of the legacy POPs in the blubber of Icelandic minke whales is different than that found in other minke whale populations of the North-Atlantic and very different than that of the N-Pacific and Antarctic.

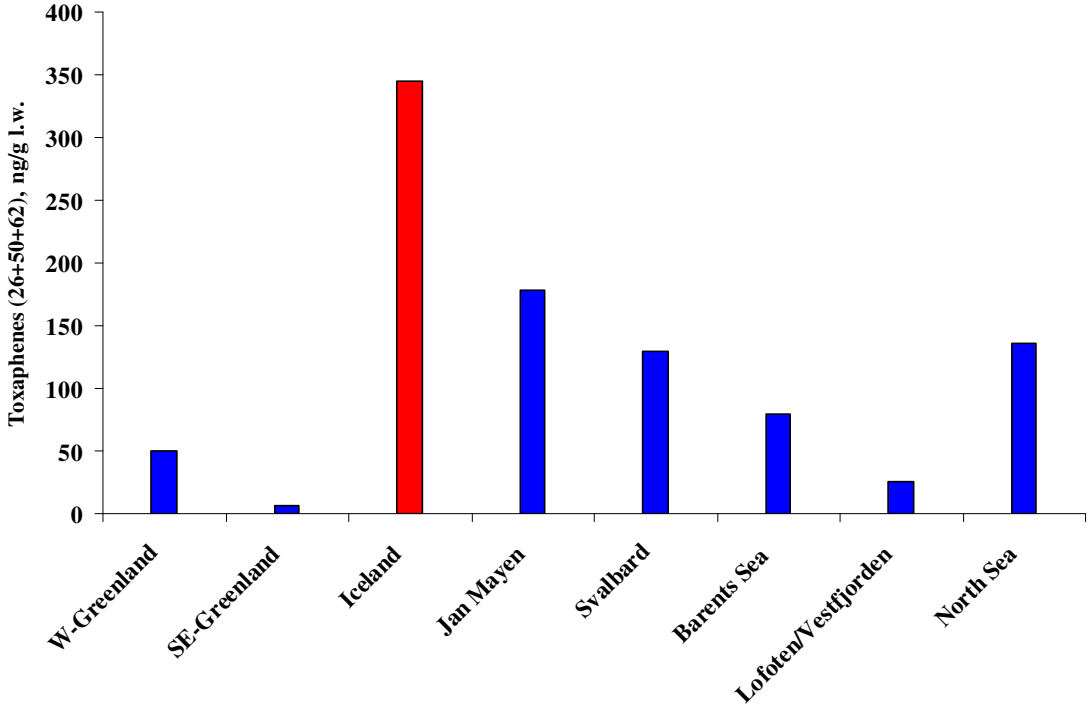

Figure 14. Toxaphenes (sum of 26, 50, and 62), mean values on a lipid weight basis, in blubber of minke whales from different areas. The blue column data derive from Gouteux *et al.* (2008).

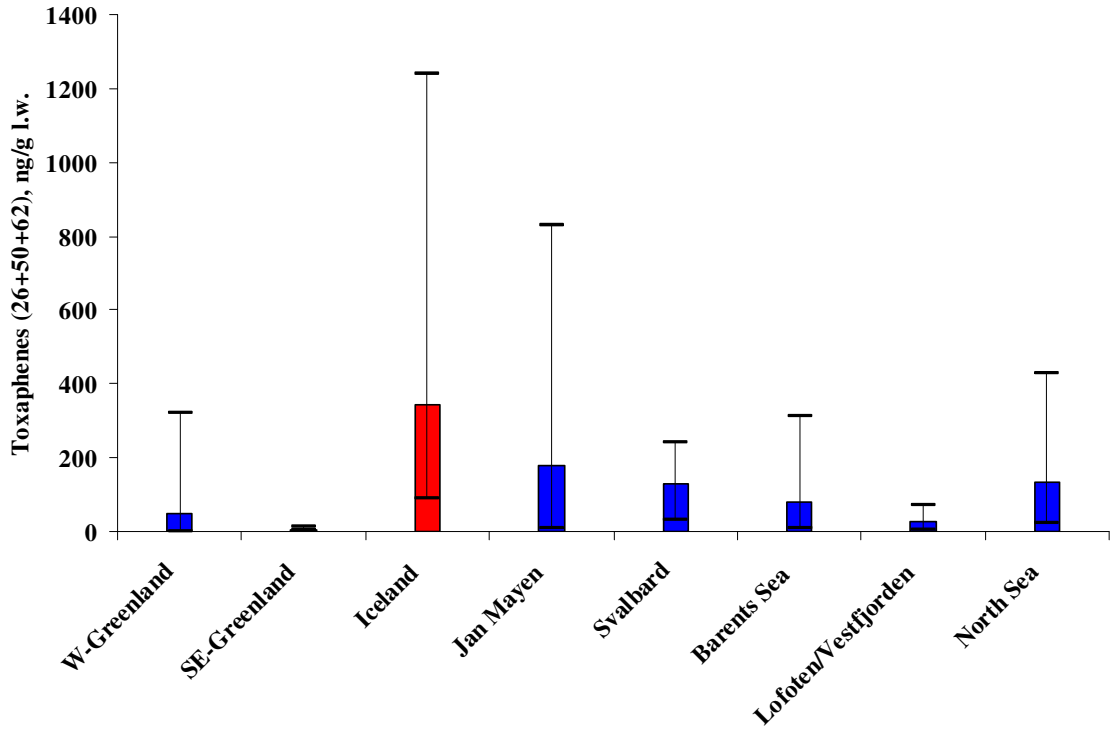

Figure 15. Toxaphenes (sum of 26, 50, and 62), mean values on a lipid weight basis, in blubber of minke whales from different areas. The bars of each column represent minima and maxima of the levels. The blue column data derive from Gouteux *et al.* (2008).

Biopsies

The relationship between contaminant burden in blubber core (D4), muscle tissue (D4), and livers with that of the biopsy (1.5 cm deep blubber sample at D4), was studied by way of linear regression. The log-transformation of data did not show any improvement in correlation coefficients and therefore the data were compared after normalising to lipid weight basis. Additionally, when the intercept of the regression line was not significantly different from zero ($p>0.05$), regression through origin was carried out and therby the coefficient of dermination increased. Table 4 shows the result of these correlations studies.

Table 4. Results of linear regresssion of levels in biopsy on levels in blubber core, muscle, and liver on lipid weight basis (n=23). The line ws regressed through origin when the intercept was not significantly different from zero ($p>0.05$). b is the slope and a is the intercept.

Compound	**Blubber core**			**Muscle tissue**			**Liver tissue**		
	r	b	a	r	b	a	r	b	a
PCB28	0.879	1.36	0.84	**	-	-	0.989	1.84	***
PCB31	**	-	-	**	-	-	**	-	-
PCB52	0.993	1.22	***	0.930	1.54	***	0.895	2.44	***
PCB101	0.992	1.26	***	0.944	1.60	***	0.851	3.78	-34.7
PCB105	0.969	0.88	***	**	-	-	0.586	1.19	3.74
PCB118	0.993	1.30	***	0.913	2.10	***	0.806	4.28	-57.4
PCB138	0.994	1.30	***	0.931	2.67	***	0.868	4.90	-69.7
PCB153	0.993	1.26	***	0.912	2.65	***	0.875	5.74	-116
PCB156	0.952	1.09*	3.35	0.931	2.77	***	0.942	3.90	***
PCB170	0.995	1.24	***	0.930	2.89	***	0.947	4.24	***
PCB180	0.994	1.16	***	0.930	2.90	***	0.941	4.08	***
S7PCB*	0.995	1.27	***	0.921	2.34	***	0.860	4.93	-366
HCB	0.995	1.05*	***	0.964	0.84	***	0.901	0.68	22.0
α-HCH	0.995	0.93	***	0.977	0.63	***	0.852	0.92*	1.68
β-HCH	0.983	0.99*	***	0.948	0.86	***	0.459	0.15	7.80
γ-HCH	0.992	0.91	***	0.968	0.67	***	0.724	1.05*	1.47
p,p'-DDE	0.995	1.40	***	0.883	2.72	***	0.915	3.84	***
p,p'-DDD	0.930	1.21	***	0.864	1.56	***	0.841	2.70	***
p,p'-DDT	0.960	0.94*	***	0.843	0.97*	***	**	-	-
o,p'-DDT	0.978	1.06*	***	0.705	1.81	***	**	-	-
***trans*-nonachlor**	0.994	1.29	***	0.890	2.07	***	0.892	5.06	***
α-chlordane	0.992	1.18	***	0.726	0.93	15.1	0.647	1.07*	21.4
γ-chlordane	0.992	1.14	***	0.917	1.39	***	0.904	2.80	***
oxychlordane	0.984	1.36	-8.7	0.916	1.63	***	0.923	4.36	***
Tox-26	0.994	1.24	***	0.881	1.80	***	0.870	3.93	***
Tox-50	0.987	1.33	-53	0.832	1.72	***	**	-	-
Tox-62	0.963	1.01*	***	**	-	-	**	-	-
PBDE-47	0.988	1.27	***	0.967	1.64	***	0.966	2.77	***
PBDE-99	0.984	1.17	***	0.769	1.22*	2.33	0.945	2.85	***
PBDE-100	0.981	1.18	***	0.728	1.10*	1.38	0.951	2.84	***
Dieldrin	0.996	1.28	***	0.961	1.43	***	0.961	1.95	***

*The slope is not significantly different from unity ($p>0.05$)

**Correlation coefficient is not significant ($p>0.05$).

***Regression through origin since intercept was not significantly different from zero ($p>0.05$)

The correlation between blubber and blubber biopsies is very good and in four cases is there a 1:1 relationship between levels in biopsy and levels in the whole blubber core, namely HCB, β-HCH , p,p'-DDT, o,p'-DDT, and Tox-26. The slope is equal to one in the case of PCB156 but the intercept is non-zero. Otherwise, the biopsies show generally higher levels than the whole blubber core (14-40%) with the exception of PCB105, α-HCH, and γ-HCH, where the level in biopsy is about 90% of the levels in the blubber core. Differences in organic contaminants between strata in the blubber have been observed in marine mammals (Auguilar and Borrell, 1991; Aguilar *et al*., 1999). Therefore, strictly speaking, the biopsy is a good measure of HCB, β-HCH , p,p'-DDT, o,p'-DDT, and Tox-26 in the blubber core while the biopsy gives a good idea of the levels in the other contaminants analysed.
The corelation between blubber biopsy and muscle tissue is generally fairly good although not as good as for the blubber core as was to be expected but only in one case is there a 1:1 relationship*, i.e.* for p,p'-DDT. Except for all the three HCHs and α-chlordane, which have significantly lower levels than the biopsy, the levels in lipids of the biopsy are higher or up to three times higher than in the lipids of the muscle tissue.
The correlations for the liver are similar to or worse than for the muscle tissue and in none of the compounds is there a 1:1 relationship between blubber biopsy and liver, the relationships generally showing great vraiability but alway is there a higher or up to five times higher levels in biopsy lipids than in the liver lipids.
It may therefore be concluded that biopsies are strictly speaking only applicable to four compounds in the blubber (HCB, β-HCH, p,p'-DDT, o,p'-DDT, and Tox-26) where there is a 1:1 relationship while biopsies give a good idea of the levels of other POPs in the whole blubber core. However, it is not generally possible to predict the levels of organic contaminants in muscle or livers by their levels in biopsies with the exception of p,p'-DDT in muscle tissue. Further studies are needed to explore if the relationships found in this study may be valid in time for the Icelandic stock or for other stocks of minke whales.

Conclusions

The relative contribution of the various organic contaminants classes is similar in blubber and muscle while the distribution in livers differ fromt that of blubber and muscle. No significant difference was found in the pattern of PCBs between the four tissues examined. Biopsies reflect the liver but not the blubber core and muscle as regards ratios of DDE to total DDTs and oxychlordane to total Chlordanes. However, the biopsies do not reflect ratios of DDTs to PCB7 in blubber core, liver or muscle. Biopsies reflect blubber and muscle but not the liver as regards ratio of γ-HCH to total HCHs and as regards Tox-26 to total Toxaphenes.

No difference was found in levels of any the contaminants analysed between areas north and south of Iceland where liver, blubber and muscle were studied. Levels of organic contaminants in blubber and muscle were not affected by either sex or length. However, levels in livers were higher in males in the case of β-HCH, PCB52, PCB138, and PCB153 and increased with length for Tox-62, α-chlordane, PCB138, and PCB153. Other contaminants in livers were not affected by either sex or length.

From studies on levels of organic contaminants in minke whales worldwide, it may be concluded that the pattern of the legacy POPs and PBDEs in the blubber of Icelandic minke whales is different than that found in other minke whale stocks of the North-Atlantic and very different than that of the N-Pacific and Antarctic.

It may be concluded that biopsies are strictly speaking only applicable to four compounds in the blubber (HCB, β-HCH, p,p'-DDT, o,p'-DDT, and Tox-26) where there is a 1:1 relationship while biopsies give a good idea of the levels of other POPs in the whole blubber core. However, it is not generally possible to predict the levels of organic contaminants in muscle or livers by their levels in biopsies with the exception of p,p'-DDT in muscle tissue. Further studies are needed to explore if the relationships found in this study may be valid in time for the Icelandic stock or for other stocks of minke whales.

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