ELSEVIER

Environmental Pollution 103 (1998) 153–158

ENVIRONMENTAL
POLLUTION

Seasonal fluctuations of organochlorine levels in the common eider (*Somateria mollissima*) in Iceland

K. Olafsdottir[a,*], K. Skirnisson[b], G. Gylfadottir[a], T. Johannesson[a]

[a]*Department of Pharmacology, University of Iceland, POB 8216, IS-128 Reykjavik, Iceland*
[b]*Institute for Experimental Pathology, Keldur, University of Iceland, IS-112 Reykjavik, Iceland*

Received 4 November 1997; accepted 8 July 1998

Abstract

Breast muscle of 55 common eiders (*Somateria mollissima*) and liver samples of 12 birds, caught at Skerjafjörður in SW-Iceland in February, May, June and November 1993 were analysed for organochlorine contamination (10–30 different congeners of PCBs, pp′-DDT, -DDE, -DDD, HCB, α-, β-, and γ-HCH). The levels of the contaminants were similar in both tissues and were at their lowest in February. A substantial increase (up to 10-fold) in the levels of all substances was observed in June, in the females, which at that point had lost about one-third of their late winter body weight. The increase may be due to relocation to other tissues of organochlorines stored in the shrinking bodyfat. During this period the birds must be vulnerable to the toxic effects of these chemicals as they can transiently reach high concentrations in the blood. The levels found were similar or higher than those recently reported for eiders from Spitsbergen, the NWT of Canada and Frans Josefs Land of Russia, especially the levels of PCBs.

Keywords: Common eiders; *Somateria mollissima*; Organochlorines; Seasonal changes; Iceland

1. Introduction

Early investigations of organochlorine pollution in Icelandic wildlife (Bengtson and Södergren, 1974; Skaftason and Johannesson, 1982) revealed very low levels as was expected for a low-industrial environment. Despite very limited local sources of organochlorines (OCs), recent evidence has, however, suggested that a part of Icelandic wildlife is now contaminated with polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT)-metabolites and hexachlorobenzene (HCB) at surprisingly high levels at the top of the food chain (Olafsdottir et al., 1995; Klobes et al., 1998). These persistent chemicals have been globally transported in the atmosphere as well as via ocean currents and have been detected in even the most pristine ecosystems of the world (Goldberg, 1975; Norheim and Kjos-Hansen, 1984; Dewailly et al., 1989; Hargrave, 1992; Thomas et al., 1992). We found that while no OCs could be detected in the ptarmigan (*Lagopus mutus*), a seed-eating terrestrial bird, the Icelandic gyrfalcon (*Falco rusticolus*), a top predator, was heavily contaminated, especially the older birds.

To further investigate the extent of OC contamination in Icelandic wildlife we have now conducted a study on the common eider (*Somateria mollissima*), a sedentary duck feeding mainly on bentonic molluscs. It is widely distributed and abundant along coastal Iceland and breeds in approximately 400 colonies which range in size from dozens to thousands of pairs (Snæbjörnsson, 1996). Females gain weight due to increased food consumption in late winter, up to three times the normal amount in order to lay down fat reserves for the incubation period. During this time the males actively defend an area around the mates.

During incubation in May the females starve and loose about one-third of their weights. The males, however, leave the breeding colonies when the incubation has started. Although the Icelandic common eider population is regarded as healthy, local mortalities have been observed, both among adults and ducklings (Skirnisson, 1997). This phenomenon has raised questions regarding the effects of exposure to environmental contaminants on resistance to infectious diseases.

* Corresponding author. Tel.: +354-5680866; fax: +354-5680872; e-mail: stinaola@hi.is

0269-7491/98/$—see front matter
PII: S0269-7491(98)00132-8

The aim of our study was to gather information on environmental contaminants in the common eider. This is a part of an extensive study on the condition of the common eider in Iceland, which started in 1993.

2. Materials and methods

2.1. Samples

Breast muscles of 55 birds and liver samples of 12 birds, shot on four sampling dates during 1993 in Skerjafjörður, a few kilometres south of the island's largest urban area, were examined. Numbers, mean weights and weight ranges of the birds are shown in Table 1. Immediately after collection the birds were weighed, measured, sexed and divided into first winters (juveniles) and adults. Samples of breast muscle and liver were wrapped into aluminium foil and stored frozen until analysed.

2.2. Analysis

Extraction and cleanup of the samples was done basically according to the method of Jensen et al. (1983) as described (Olafsdottir et al., 1995). α-, β-, γ-HCH, HCB, and the DDT metabolites dichlorodiphenyl dichloroethene (pp′-DDE) and dichlorodiphenyl dichloroethane (pp′-DDD), and 10 congeners of PCB (Nos. 28, 31, 52, 101, 105, 118, 138, 153, 156, 180) were analysed in breast muscle of all birds and in the liver of 12 birds. Other 20 PCB congeners (Nos. 18, 33, 47, 66, 74, 99, 110, 114, 122, 128, 141, 157, 167, 170, 183, 187, 189, 194, 206, 209) were analysed in the breast muscle of 8 birds to enable a better estimation of the total amount of PCBs present. On average the sum of PCBs Nos. 118 + 138 + 153 + 180 was 68% of the total sum of the 30 different PCBs. The total amount of PCBs in the other birds was therefore estimated to be the sum of the four congeners divided by 0.68. However, the total amount of PCBs is inevitably somewhat higher since so many congeners were not quantified.

The individual PCB congeners and pesticides were determined by gas chromatography against standard curves made from the corresponding individual standards and an internal standard (1,2,3,4-tetrachloronaphthalene) from Promochem, Wesel, Germany or Accustandard, USA. An HP5890 gas chromatograph with an HP Ultra-2 (25 m, 0.20 mm i.d., 0.33 μm film thickness) capillary column, and an HP5970 mass selective detector (MSD) or with DB1701 (60 m, 0.25 mm i.d., 0.25 μm film) and ECD were used. By MSD the chemicals were detected by single ion monitoring (4 ions for each chemical or congener) and quantified from ion chromatograms of the single most abundant ion. Carrier gas was He (25 cm/s), splitless injection of 3 min, injector temp. 270°C, MSD-interphase 290°C. Temperature program: 85°C for 2 min, 30°C/min to 185°C, hold for 30 min, 2°C/min to 250°C, 7°C/min to 290°C, hold for 2 min. The conditions for the ECD were the same except for the temperature program: 85°C for 2 min, 30°C/min to 210°C, hold for 22 min, 2°C/min to 260°C, 3°C/min to 290°C, hold for 10 min. The limit of quantification was at least 1 μg/kg for the pesticides and the individual PCB congeners.

2.2.1. Statistics

When enough data-points were available for testing, normality was met (Kolmogorov–Smirnoff) for most of the data. Significant differences between means in Tables 3 and 4, were found by ANOVA and the Bonferroni post-test, using Instat, version 2.01 for Macintosh computers. Occasionally, the Student's t-test and the Mann–Whitney test were used to test differences between sampling groups, as indicated in the text. All tests were unpaired and two-tailed. For all statistical tests a p-value >0.05 was considered to be not significant.

2.3. Results

PCBs, pp′-DDE and HCB were found in all tissues investigated, and only β-HCH at low levels in the birds caught in June (<1 ng/g). The levels of pp′-DDD usually represented about 5–10% of ΣDDT. The relative composition of 30 different PCB congeners in the breast muscle of eight eider ducks is shown in Fig. 1. The four most abundant congeners were PCB 153

Table 1
Physical characteristics of the common eiders (*Somateria mollissima*)

1993	Females			Males		
Date caught	*n*	Mean wt (g)	Range (g)	*n*	Mean wt (g)	Range (g)
Feb. 10	10	2006	1655–2250	10[a]	2124	1920–2350
May 11	7	2154	1750–2450	7	1881	1780–2100
June 24	5	1399	1240–1620	8	1873	1750–2125
Nov. 2	4[b]	1875	1770–1940	4	2048	1860–2250

[a] Three were first winters.
[b] One was a first winter.

(30 ± 1%), PCB 138 (17 ± 1%), PCB 118 (11 ± 0.3%) and PCB 180 (10 ± 0.5%), with PCBs 187, 128, 170, 105 and 99 next in that order with 3–6% each.

All four first winters had reached the average weight of the adult birds. The three first winter birds from February had higher levels of OCs than the average adult (Table 2) although not significantly higher levels of PCBs (Student's *t*-test, $p = 0.18$; Mann–Whitney, $p = 0.83$) and DDTs (Student's *t*-test, $p = 0.22$; Mann–Whitney, $p = 0.67$). The HCB levels, however, were significantly higher (Students *t*-test, $p = 0.0084$; Mann–Whitney, $p = 0.0167$) in these three first winters and they were therefore not included in the sample with the adults. The single first winter bird from November had much lower levels of all contaminants than the average adult and was also excluded from the data to reduce variation in the sample.

Table 2
Levels of organochlorines in breast muscle of first winter common eiders (*Somateria mollissima*) from SW-Iceland [ng/g ww with the range in parentheses (ng/g extractable fat in italics)] [a]

Date 1993	Number	ΣPCB	ΣDDT	HCB
Feb. 10	3	121	20.4	3.46
		(84.7–184)	(9.1–37.4)	(2.17–5.98)
		3440	*562*	*96.1*
Nov. 2	1	21.2	2.60	1.08
		375	*46.0*	*19.2*

[a] Numbers for February are means.

The levels of ΣPCB, ΣDDT and HCB found in breast muscle of both sexes of adult common eiders at four different dates during 1993 are shown in Table 3. The levels of the contaminants in the common eiders were at their lowest in February, but a very substantial increase occurred in the levels of these OCs from May to June in the females which at that point had lost about one third of their body weight. Increased levels were also observed in the males but these were not significant. The June levels were found to be significantly higher than the May and February levels in the females (see Table 3 for details).

Very similar levels of the OCs were found in breast muscle and liver at each sampling period as seen in Table 4. The correlation coefficient, *r*, for ΣPCB was 0.66, $p = 0.026$; for DDT $r = 0.78$, $p = 0.0047$ and for HCB $r = 0.63$, $p = 0.038$, confirming the association between the two tissues. The same dramatic increase occurred in both tissues during the nesting period, although the levels were more variable in the muscle.

The levels of PCBs were about 5–10 times greater than the levels of ΣDDT and about 50–100 times greater than the levels of HCB. As seen in Fig. 2, a good correlation ($r = 0.92$) was found between ΣDDT and ΣPCB in the breast muscle of all 55 birds but the correlation was not as good between HCB and ΣPCB ($r = 0.76$).

Table 3
Levels of organochlorines in breast muscle of adult female (f) and male (m) common eiders (*Somateria mollissima*) from SW-Iceland [ng/g ww (ng/g extractable fat)] [a]

Date 1993	Number		% Extr. fat		ΣPCB[b]		ΣDDT		HCB	
	f	m	f	m	f[c]	m	f[c]	m	f[c]	m[f]
Feb. 10	10	7	2.67	2.97	77.0	90.7	10.3	13.1	0.85	0.77
					(2680)	(3060)	(400)	(441)	(31.4)	(26.1)
May 11	7	7	4.26	3.14	80.7	100	17.1	24.7	2.36	3.43
					(1720)	(3260)	(380)	(853)	(56.2)	(122)
June 24	5	8	1.42	2.36	247[d]	182	44.4[d]	36.2	4.07[d]	4.46
					(17 900[e])	(6740)	(3340[e])	(1254)	(299[e])	(169[g])
Nov. 2	3	4	3.09	3.94	146	181	19.6	21.8	1.93	1.66
					(2200)	(3960)	(296)	(482)	(36.8)	(35.5)

Differences between sexes were significant (ANOVA, $p < 0.0001$) for ΣPCB and ΣDDT in May and in June (Bonferroni $p < 0.01$), when expressed on fat basis, but not for HCB. No significant differences were found for males ww (ANOVA: $p = 0.46$ for ΣPCB and ΣDDT, $p = 0.088$ for HCB, nor for males expressed on fat basis for ΣPCB (ANOVA: $p = 0.044$, but $p > 0.05$ by Bonferroni and ΣDDT (ANOVA: $p = 0.075$).

[a] Numbers are means for the indicated number of samples.

[b] ΣPCB = (118 + 153 + 138 + 180)/0.68.

[c] Significant differences (ANOVA, $p = 0.0029$, 0.0043, 0.0003 for ww for ΣPCB, ΣDDT and HCB, respectively, and $p < 0.0001$ for extr. fat for all).

[d] Significantly different from Feb. and May (Bonferroni $p < 0.01$ and $p < 0.05$, respectively).

[e] Significantly different from Feb., May and Nov. (Bonferroni $p < 0.01$).

[f] Significant differences (ANOVA, $p = 0.0059$).

[g] Significantly different from Feb. (Bonferroni $p < 0.05$).

Table 4
Levels of organochlorines in breast muscle and liver of adult common eiders (*Somateria mollissima*) from SW-Iceland

Date 1993			ΣPCB[b]		ΣDDT		HCB	
	n[a]		Muscle[c]	Liver[d]	Muscle[c]	Liver[d]	Muscle[c]	Liver[d]
Feb. 10	3	a	97.5	90.1	11.0	17.4	0.58	0.66
		b	(85.4–111)	(78.0–99.3)	(10.0–12.2)	(8.05–26.8)	(0.25–0.83)	(0.52–0.75)
		c	2850	2560	436	488	21.3	19.0
May 11	4	a	58.9	66.6	17.9	23.1	2.02	1.96
		b	(13.6–109)	(58.4–85.7)	(2.99–36.4)	(14.0–35.6)	(0.53–3.97)	(1.39–2.48)
		c	2070	1630	567	520	63.9	45.8
June 24	4	a	252	207[e]	50.9	47.4[f]	6.46	6.90[e]
		b	(77.0–688)	(164–253)	(7.74–144)	(31.8–72.4)	(0.59–14.9)	(4.35–11.8)
		c	8900[g]	5300[e]	1710[h]	1220[e]	249[g]	178[e]
Nov. 2	7	a	169	n.a.	21.2	n.a.	1.93	n.a.
		b	(21.2–404)		(5.40–49.0)		(0.34–3.85)	
		c	3260		409		38.8	

Both tissues were from the same individual and differences between tissues were not significant (ANOVA). n.a., not analyzed.

[a] Numbers are means of n number of data, a = ng/g ww; b = range in ng/g ww; c = ng/g extr. fat.

[b] ΣPCB = (118 + 153 + 138 + 180)/0.68.

[c] Significant differences when expressed per extr. fat (ANOVA, $p = 0.01$ for ΣPCB, $p = 0.04$ for ΣDDT and $p = 0.0001$ for HCB). No significant differences for ww (ANOVA, $p = 0.42$ for ΣPCBs, $p = 0.36$ for ΣDDTs, $p = 0.062$ for HCB).

[d] Significant differences (ANOVA, $p = 0.0005/0.0004$ for ΣPCB, $p = 0.03/0.01$ for ΣDDT and $p = 0.01/0.0095$ for HCB when expressed per ww/extr. fat, respectively).

[e] Significantly different from Feb. and May (Bonferroni $p < 0.01$ for ΣPCB, $p < 0.05$ for ΣDDT and HCB).

[f] Significantly different from Feb. not May (Bonferroni $p < 0.05$).

[g] Significantly different from Feb., May and Nov. (Bonferroni $p < 0.05$ for ΣPCB, $p < 0.01$ for HCB).

[h] Significantly different from Nov. (Bonferroni $p < 0.05$).

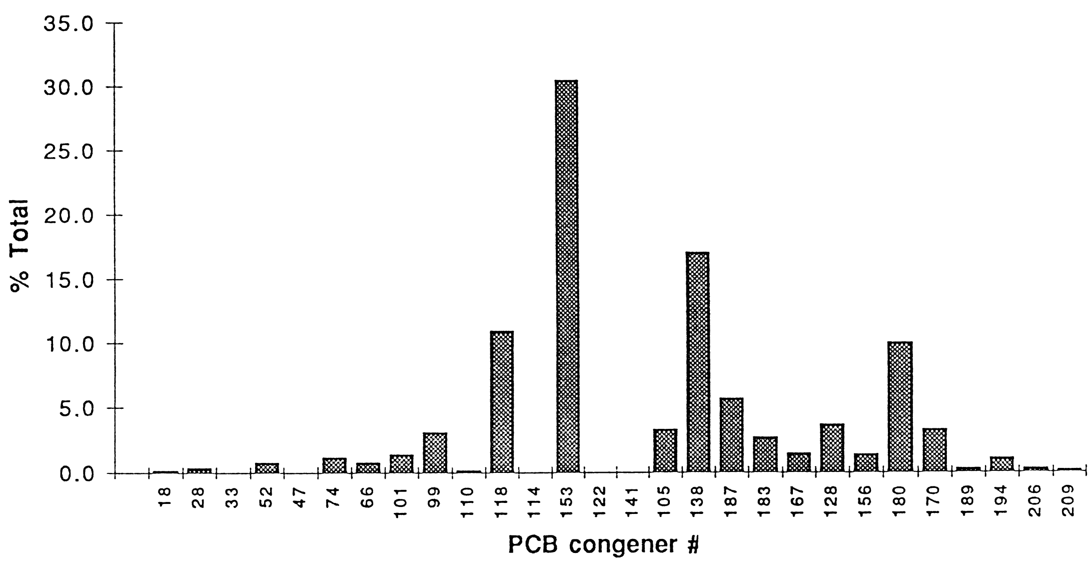

Fig. 1. The mean relative proportion of 28 different PCB congeners in eight common eiders (*Somateria mollissima*) from SW-Iceland.

2.4. Discussion

PCBs appear to be the most abundant OC contamination in Iceland. The total levels of PCBs in the common eider were at least 100-fold lower than what we observed in the gyrfalcon in 13–18-month-old birds (Olafsdottir et al., 1995) thus indicating that the trophic level of a species outweighs the fact that the common eider belongs to a more contaminated foodchain. The relative composition of PCB congeners in the breast muscle of the common eider was very similar to what has been reported from Spitsbergen (Savinova et al.,

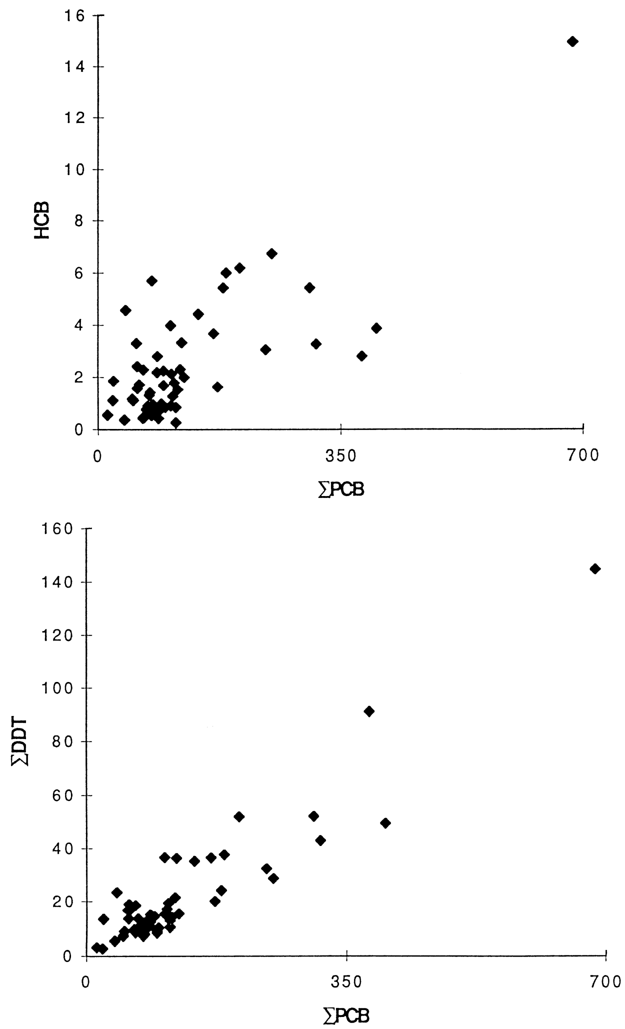

Fig. 2. The correlation between ΣDDT and ΣPCB (bottom) and HCB and ΣPCB (top) in 55 common eiders (*Somateria mollissima*) from SW-Iceland (ng/g wet weight).

1995) indicating the metabolic specificity of this species. Very low levels were found of the lower chlorinated PCBs; the pattern was dominated by penta-, hexa- and heptachlorobipenyls. The PCB/DDT and the PCB/HCB ratios were in the range of 4–8 and 30–170, respectively, which are similar to the ratios we observed in Icelandic gyrfalcons (4–6 and 70–220, respectively, Olafsdottir et al., 1995). Gyrfalcons consume mainly terrestrial birds (mainly ptarmigan, *Lagopus mutus*, and waterfowl) (Nielsen and Cade, 1990). Common eiders, however, feed mainly on marine bivalves and gastropods (Skirnisson et al., 1996). Since these two species belong to different foodchains, these similarities are difficult to explain except by a common source, most likely long range airborne transport (Iwata et al., 1993; Pacyna, 1995).

The only OC insecticide used in Iceland to any extent in the past was Lindane, or γ-HCH. It has been estimated that during 1950–1986 approximately 16 tonnes were used in the campaign against ectoparasites, mainly on sheep. However, the only HCH found in the eiders was the β-isomer, the environmentally most persistent HCH (Steinwandter and Schlüter, 1978), most likely because of long range airborne transport.

The correlation between ΣDDT and ΣPCB suggests a common source of these contaminants, making the possibility of a local source for one or the other unlikely. The lower correlation between HCB and ΣPCB, however, indicates the possibility of a different source for HCB as suggested by Vetter et al. (1995). A very similar trend was seen in the Icelandic gyrfalcon (Olafsdottir et al., 1995).

The increased levels of OCs during nesting in May and June in the female, occurred concomitantly with an appreciable loss of tissue lipids and body weight. The most probable explanation for the fluctuation of OC levels is the relocation of OCs from the rapidly diminishing adipose tissue to lipids in other tissues in the body. During this time the birds are possibly exposed to high concentrations of OCs as they are released into the bloodstream (Wiemeyer and Cromartie, 1981; Walker, 1990) and birds with very high body burdens have been found dead with typical symptoms of OC poisoning (convulsions) at times of low fat depots (Gabrielsen et al., 1995). Although severe toxic effects are unlikely at the levels found in the Icelandic common eider (Stickel et al., 1984a, b), elevated levels of OCs can possibly lower the birds resistance to infectious disease as discussed by Whiteley and Yuill (1991). The loss of OCs to the eggs by the females is not substantial according to our data, since the differences between the sexes were only significantly different in May and June when expressed on a fat basis.

The higher levels in the three first winters from February (all males) could possibly be explained by different origin of these birds, i.e. they may have come from another area. Although the common eiders in Iceland are mostly sedentary, birds originating from eastern Greenland are often found in Iceland during the winter, especially the young birds. The very low levels in the first winter bird from November, on the other hand, despite having reached adult weight, can also be explained by different origin or simply by having had less time for bioaccumulation of these persistent chemicals.

Very few studies are available on OC contamination in eider ducks. At Spitsbergen in May 1980, Norheim and Kjos-Hansen (1984) found 11 ± 14 ng/g pp′-DDE, 2 ± 2 ng/g HCB and < 100 ng/g PCB in 9 livers of eider ducks which are similar to the levels we report. In the same area, Mehlum and Daelemans (1995) in July 1990 found 40 (10–150) ng/g PCB in livers of 9 adult females. One year later Savinova et al. (1995) found 24.3 (0.8–54.3) ng/g PCB, 9.7 (0.5–18.2) ng/g ΣDDT and 4.1 (0.3–7.3) ng/g HCB in livers of four adult eiders. These are lower levels than what we have found except for HCB. The same investigators found even lower levels (ΣPCB 2.8 ng/g) in five first winter eiders at Frans Josefs Land of Russia. In artic Canada, levels of 5–19 ng/g ΣPCB, 5–17 ng/g ΣDDT and 2–6 ng/g ΣCBz were found in breast muscle of eiders (Braune, 1994), which are an order of magnitude lower for PCBs than we found but similar to the levels for DDTs and HCB.

Our results indicate that PCB levels are high in SW-Iceland compared to arctic areas. The seasonal fluctuation in the OC levels most likely also occur in other nesting birds in this region and can have detrimental effects, at least when levels are high, as in the top predators.

Acknowledgements

The authors wish to thank Arnor Th. Sigfusson at the Icelandic Institute of Natural History and Sigurdur Sigurdarson at the Institute for Experimental Pathology, Keldur, University of Iceland, for their help with the collection of the birds and Kristinn H. Skarphedinsson at the Icelandic Institute of Natural History for his invaluable discussion on the behavior of birds in Iceland. Thanks are also due to Magnus Johannsson at the Department of Pharmacology University of Iceland for his help with the statistics.

References

Bengtson, S.-A., Södergren, A., 1974. DDT and PCB residues in airborne fallout and animals in Iceland. Ambio 3, 84–86.

Braune, B., 1994. Trends and effects of environmental contaminants in Arctic seabirds, waterfowl, and other wildlife. I. Contaminants in waterfowl: Native Harvest in NWT. Synopsis of research conducted under the northern contaminants program. Environmental studies no. 72:305-311. Indian and Northern Affairs, Ottawa, Canada.

Dewailly, E., Nantel, A., Weber, J.-P., Mayer, F., 1989. High levels of PCBs in breast milk of Inuit women from Artic Quebec. Bull. Environ. Contam. Toxicol. 43, 641–646.

Gabrielsen, G.W., Skaare, J.U., Polder, A., Bakken, V., 1995. Chlorinated hydrocarbons in glaucous gulls (*Larus hyperboreus*) in the southern part of Svalbard. Sci. Total Environ. 160/161, 337–346.

Goldberg, E., 1975. Synthetic organohalides in the sea. Proc. R. Soc. Lond. B 189, 277–289.

Hargrave, B.T., 1992. Organochlorine pesticides and polychlorinated biphenyls in the Artic ocean food web. Arch. Environ. Contam. Toxicol. 22, 41–54.

Iwata, H., Tanabe, S., Sakal, N., Tatsukawa, R., 1993. Distribution of persistent organochlorines in the oceanic air and surface seawater and role of ocean on their global transport and fate. Environ. Sci. Technol. 27, 1080–1098.

Jensen, S., Reutergårdh, L., Janson, B., 1983. Analytical methods for measuring organochlorines and methyl mercury by gas chromatography. FAO/SIDA Manual of methods in aquatic environment research. Part 9. Analysis of metals and organochlorines in fish. FAO Fish Tech. Pap. 212, 21–333.

Klobes, U., Vetter, W., Glotz, D., Luckas, B., Skirnisson, K., Hersteinsson, P., 1998. Levels and enantiomeric ratios of chlorinated hydrocarbons in livers of Arctic fox (*Alopex lagopus*) and adipose tissue and liver of a polar bear (*Ursus maritimus*) sampled in Iceland. Intern. J., Environ. Anal. Chem. 69, 67–68.

Mehlum, F., Daelemans, F.F., 1995. PCBs in Arctic seabirds from the Svalbard region. Sci. Total Environ. 160/161, 441–446.

Nielsen, O.K., Cade, T.J., 1990. Seasonal changes in food habits of Gyrfalcons in NE-Iceland. Ornis Scandinavica 21, 202–211.

Norheim, G., Kjos-Hansen, B., 1984. Persistent chlorinated hydrocarbons and mercury in birds caught off the coast of Spitsbergen. Environ. Poll. 33, 143–152.

Olafsdottir, K., Petersen, Æ., Thordardottir, S., Johannesson, T., 1995. Organochlorine residues in Gyrfalcons (*Falco rusticolus*) in Iceland. Bull. Environ. Contam. Toxicol. 55, 382–389.

Pacyna, J.M., 1995. The origin of Arctic air pollutants: lessons learned and future research. Sci. Total Environ. 160/161, 39–53.

Savinova, T.N., Poldner, A., Gabrielsen, G.W., Skaare, J.U., 1995. Chlorinated hydrocarbons from the Barents Sea area. Sci. Total Environ. 160/161, 497–504.

Skaftason, J., Johannesson, T., 1982. Organochlorine compounds in Icelandic lake trout and salmon fry: local and global sources of contamination. Acta Pharmacol. Toxicol. 51, 397–400.

Skirnisson, K., 1997. Mortality associated with renal and intestinal coccidiosis in juvenile eiders in Iceland. Parassitology 39, 325–330.

Skirnisson, K., Sigurdarson, S., Bambir, S.H., Sigfússon, A.TH., 1996. Seasonal changes of the food consumption and condition of the common eider in Iceland. Bull. Scand. Soc. Parasitol. 6, 127–128 (abstract).

Snæbjörnsson, A., 1996. Eider Husbandry in Iceland. Bliki 17,55–63 (in Icelandic, with an English summary).

Steinwandter, H., Schlüter, H., 1978. Experiments on lindane metabolism in plants. IV. A kinetic investigation. Bull. Environ. Contam. Toxicol. 20, 174–179.

Stickel, W.H., Stickel, L.F., Dyrland, R., Hughes, D.L., 1984. DDE in birds: lethal residues and loss rates. Arch. Environ. Contam. Toxicol. 13, 1–6.

Stickel, W.H., Stickel, L.F., Dyrland, R., Hughes, D.L., 1984. Arochlor 1254® residues in birds: lethal levels and loss rates. Arch. Environ. Contam. Toxicol. 13, 7–13.

Thomas, D.J., Tracey, B., Marshall, H., Norstrom, R.J., 1992. Arctic terrestrial ecosystem contamination. Sci. Total Environ. 122, 135–164.

Vetter, W., Hummert, K., Luckas, B., Skirnisson, K., 1995. Organochlorine residues in two seal species from western Iceland. Sci. Total Environ. 170, 159–164.

Walker, C.H., 1990. Persistent pollutants in fish-eating seabirds—bioaccumulation, metabolism and effects. Aquatic Toxicol. 17, 293–324.

Wiemeyer, S.N., Cromartie, E., 1981. Relationship between brain and carcass organochlorine residues in ospreys. Bull. Environ. Contam. Toxicol. 27, 499–505.

Whiteley, P.L., Yuill, T.M., 1991. Interactions of environmental contaminants and infectious disease in avian species. Acta Congr. Int. Orn. 20, 2338–2342.