White whales (*Delphinapterus leucas*) from three Alaskan stocks: Concentrations and patterns of persistent organochlorine contaminants in blubber

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ABSTRACT

White whale (*Delphinapterus leucas*) blubber samples from three of the five different Alaskan stocks, Cook Inlet ($n = 20$), Eastern Chukchi Sea ($n = 19$) and Eastern Beaufort Sea ($n = 2$), were analysed for levels and patterns of chemical contaminants. Blubber from these whales contained ΣPCBs, ΣDDTs, Σchlordanes, HCB, dieldrin, mirex, Σtoxaphene and ΣHCH, generally in concentration ranges similar to those found in white whales from the Canadian Arctic but lower than those in white whales from the highly contaminated St Lawrence River. Males from the Cook Inlet and Eastern Chukchi Sea stocks had higher mean concentrations of all contaminant groups than females of the same stock, a result attributable to the transfer of these organochlorine contaminants (OCs) from the mother to the calf during pregnancy and lactation. Principal component analysis of patterns of contaminants present in blubber showed that the Cook Inlet stock appeared to have identifiable contaminant patterns that allowed the stock to be distinguished from the others. Our results also showed that blubber from the three Alaskan stocks was a source of contaminant exposure for human subsistence consumers, but the health risks from consumption are currently unknown.

KEYWORDS: WHITE WHALE; ARCTIC; MONITORING; ORGANOCHLORINES; POLLUTANTS; POLLUTANT BURDEN

INTRODUCTION

The white or beluga whale (*Delphinapterus leucas*) is a small (up to 4.5m long), toothed cetacean (odontocete) that is circumpolar in distribution in the Arctic (e.g. see review in IWC, 1999c). Stock-dependent seasonal movements of these whales can be extensive. Some stocks migrate more than 2,500km, whereas others move relatively short distances between offshore and nearshore areas (Hazard, 1988). White whales are thought to winter along the ice edge and in ice free areas (i.e. polynyas) in offshore waters. In the spring, as the ice retreats, these whales generally move north, sometimes to nearshore areas (e.g. shallow bays and estuaries) to feed, molt and give birth to their young (Leatherwood and Reeves, 1983; Frost and Lowry, 1990). White whales feed at the top of the marine food web and are relatively long-lived (> 35 years). The diets of white whales vary, depending on the feeding areas of the individual stocks and the annual and seasonal variability in the abundance of suitable prey (Stewart and Stewart, 1989). Prey species include: various fish, crangonid shrimp, squid and octopus (Calkins, 1979; Seaman *et al*., 1982).

Based on the previous suggestions by Frost and Lowry (1990) and recent genetic evidence by O'Corry-Crowe *et al.* (1997), five Alaskan white whale stocks are recognised: (1) Cook Inlet; (2) Bristol Bay; (3) Eastern Bering Sea (Norton Sound); (4) Eastern Chukchi Sea; and (5) Eastern Beaufort Sea (Fig. 1). The Cook Inlet stock is a small, geographically isolated population (O'Corry-Crowe *et al.*, 1997) that may be found in Cook Inlet during all seasons and are occasionally seen as far east as Yakutat and as far west as the Shelikof Strait. Calkins (1979) postulated that movement out of Cook Inlet and into the relatively ice free Gulf of Alaska may occur during conditions of heavy ice in Cook Inlet. The other four stocks constitute the Bering Sea population and, although no obvious geographical barriers exist between these sub-populations, all were found to be genetically differentiated from each other (O'Corry-Crowe *et al.*, 1997). The Bristol Bay stock is the southernmost group of the Bering Sea population. The Eastern Bering Sea (Norton Sound) stock includes those whales occurring at the mouth of the Yukon River during the spring and summer. The Eastern Chukchi Sea stock includes animals of Kotzebue Sound, as well as those that occur at Kasegaluk Lagoon during the summer. The Eastern Beaufort Sea stock includes animals that migrate with the bowhead whale (*Balaena mysticetus*) during the latter's spring migration and that spend the summer at the mouth of the Mackenzie River and Amundsen Gulf (Moore *et al.*, 1993).

White whales from the St Lawrence River have been comparatively well-studied because reproductive impairment and population declines in this stock have been associated with exposure to high concentrations of industrial chemicals e.g. OCs and polycyclic aromatic hydrocarbons (PAHs) (Martineau *et al.*, 1994; 1999; Béland, 1996; Muir *et al.*, 1996). Biological effects that have been associated with the accumulation of environmental contaminants by the St Lawrence white whales include: transitional cell carcinoma in the urinary bladder (Martineau *et al.*, 1985), intestinal adenocarcinomas (Martineau *et al.*, 1995) and other tumors

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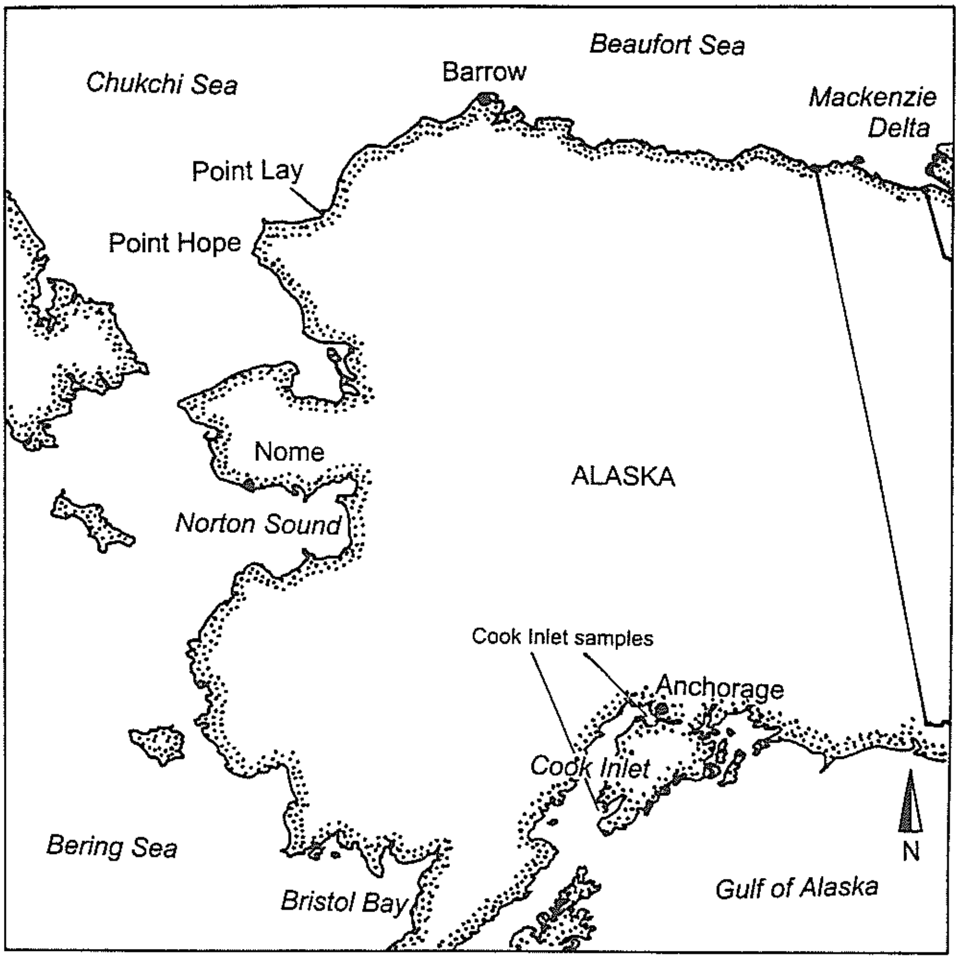

Fig. 1. Map of Alaska showing sampling locations of white whales in this study. Cook Inlet stock samples (depicted as diamonds) were collected in 1992-1996 from various locations in Cook Inlet ($n = 20$); Eastern Chukchi Sea stock samples were collected from Point Lay in 1990 and 1996 ($n = 19$); and Eastern Beaufort Sea stock was represented by samples collected from animals migrating past Point Hope in May, 1989 ($n = 2$).

(De Guise *et al.*, 1994b; Martineau *et al.*, 1994); adrenal hyperplastic and degenerative changes (Lair *et al.*, 1997), hermaphroditism (De Guise *et al.*, 1994a) and immune function alterations (Martineau *et al.*, 1994; De Guise *et al.*, 1996a; b). Alaskan white whales may also accumulate anthropogenic contaminants, especially during the summer when these whales are found in relatively populated areas, i.e. in near-shore coastal waters and far up major river systems. In general, Arctic white whales have lower concentrations of the various anthropogenic chemicals implicated in the effects shown by the St Lawrence white whales (Muir *et al.*, 1990b). However, there is little information about the long-term, chronic effects that environmental contaminants may have on these long-lived whales.

The white whale is an important subsistence food resource for Alaska native coastal villages (Freeman *et al.*, 1998). Approximately 30 coastal villages of the Arctic Ocean and Bering Sea, as well as communities located in Cook Inlet (northern estuary of the Gulf of Alaska), regularly take white whales for food. This animal is hunted primarily for its meat and maktaaq (epidermis and blubber, also spelled 'maktak'). These products are consumed locally and, in most cases, are also distributed to relatives and friends in inland villages who do not have direct access to this resource. White whales can accumulate relatively high concentrations of persistent lipophilic contaminants in lipid-rich tissues (e.g. blubber and liver) through trophic transfer (i.e. biomagnification). Although concentrations of OCs have generally been lower in Arctic white whales than in the animals from urban areas, e.g. the St Lawrence River (Béland, 1996; Muir *et al.*, 1996), the presence of these contaminants may be significant because white whale blubber provides high-fat food for the subsistence diet of Native populations.

Samples of white whale blubber from three of the five different Alaskan stocks (Eastern Beaufort Sea, Eastern Chukchi Sea and Cook Inlet) were analysed for concentrations and patterns of OC contaminants. These data were evaluated to assess how contaminant concentrations in white whales vary by stock and by gender. In addition, patterns of contaminants in blubber were evaluated to determine if distinct patterns were present that would allow resolution of each stock.

METHODS AND MATERIALS

Sample collection

Samples of white whale blubber were selected for analyses from aliquots of blubber specimens stored under cryogenic conditions in the US National Biomonitoring Specimen Bank at the National Institute of Standards and Technology (NIST). Protocols for specimen banking and cryogenic preparation of sample aliquots are described in Becker *et al.* (1997). The white whale specimens were originally collected by the Alaska Marine Mammal Tissue Archival Project (AMMTAP) in collaboration with Alaskan Native hunters, the North Slope Borough Department of Wildlife Management, the National Marine Fisheries Service

Western Alaska Field Office, and with the support of the Alaska Beluga Whale Committee. These collections were made following standard AMMTAP protocols as described in Becker *et al.* (1991).

Three white whale stocks are represented by the samples collected (Fig. 1): Cook Inlet stock samples were collected in 1992-1996 from various locations in Cook Inlet ($n = 20$); Eastern Chukchi Sea stock samples were collected from Point Lay in 1990 and 1996 ($n = 19$); and the Eastern Beaufort Sea stock was represented by samples collected from animals migrating past Point Hope in May 1989 ($n = 2$). Table 1 contains life history information about individual animals. Ages of the animals were determined based on the number of growth layer groups counted in a thin longitudinal section taken from the middle of the mandibular tooth using procedures described by Burns and Seaman (1986).

Sample analysis

The analyses of PCB congeners and chlorinated pesticides were performed at the National Marine Fisheries Service's Northwest Fisheries Science Center (NWFSC, Seattle, WA, USA), the National Institute of Standards and Technology (NIST, Gaithersburg, MD, USA) and the Department of Fisheries and Oceans (DFO, Winnipeg, Manitoba, Canada).

At the NWFSC, blubber samples were analysed for OCs and percentage lipid concentration following standard methods and quality assurance protocols (Krahn *et al.*, 1988; Sloan *et al.*, 1993). Briefly, samples of thawed tissue (1-3g) were extracted, following addition of internal standards, by maceration with sodium sulphate and methylene chloride. The methylene chloride extract was then filtered through a column of silica gel and alumina and concentrated for further

Table 1

White whale life history information by stock: gender, site of capture, age, length, date collected, comments and the laboratory that performed the analyses.[a]

Animal ID	Gender	Site of capture	Age[b]	Length (cm)	Date collected	Comments	Analytical laboratory[c]
Cook Inlet stock (n = 20)							
692-BLKA-015	M	Cook Inlet	8.5 yrs	374	06 Oct. 1992		NIST
692-BLKA-016	M	Cook Inlet	adult	472	23 Jul. 1994		NIST
692-BLKA-017	F	Cook Inlet	unknown	305	22 Jul. 1994		NWFSC
692-BLKA-018	M	Cook Inlet	unknown	305	23 Jul. 1994		NIST
692-BLKA-020	F	Cook Inlet	2 yrs	240	20 May 1995		NIST/NWFSC[d]
692-BLKA-021	M	Cook Inlet	10.5 yrs	409	03 Jun. 1995		NIST/NWFSC[d]
692-BLKA-022	F	Cook Inlet	10 yrs	360	09 May 1995		NIST/NWFSC[d]
692-BLKA-023	F	Cook Inlet	12.5 yrs	353.1	01 Jun. 1995		NIST/NWFSC[d]
692-BLKA-024	F	Cook Inlet	15 yrs	368	05 Jun. 1995	pregnant	NIST/NWFSC[d]
692-BLKA-025	F	Cook Inlet	foetus	142.5	05 Jun. 1995		NIST/NWFSC[d]
692-BLKA-026	M	Cook Inlet	adult	422	19 Jun. 1995		NIST/NWFSC[d]
692-BLKA-027	M	Cook Inlet	9 yrs	377	27 Jun. 1995		NIST/NWFSC[d]
692-BLKA-028	M	Cook Inlet	9 yrs	391	28 Jun. 1995		NIST/NWFSC[d]
692-BLKA-031	F	Upper Cook Inlet	adult	367	18 Jun. 1996	lactating	NWFSC[e]
692-BLKA-032	F	Upper Cook Inlet	adult	256	15 Jul. 1996		NWFSC[e]
692-BLKA-033	F	Upper Cook Inlet	adult	359	30 Jul. 1996	lactating	NWFSC[e]
692-BLKA-034	F	Point MacKenzie	adult	377	29 Aug. 1997		NWFSC[e]
692-BLKA-035	M	Chickaloon River	adult	415	07 Oct. 1996		NWFSC[e]
692-BLKA-036	M	Chickaloon River	adult	429	07 Oct. 1996		NWFSC[e]
692-BLKA-037	M	Chickaloon River	adult	367	07 Oct. 1996		NWFSC[e]
Eastern Beaufort Sea stock (n = 2)							
692-BLKA-001	F	Point Hope	8 yrs	342.9	26 May 1989		DFO
692-BLKA-002	F	Point Hope	4.5 yrs	309.9	25 May 1989		DFO
Eastern Chukchi Sea stock (n = 19)							
692-BLKA-005	M	Point Lay	15 yrs	394	11 Jul. 1990		DFO
692-BLKA-006	M	Point Lay	unknown	430	11 Jul. 1990		DFO
692-BLKA-007	F	Point Lay	22.5 yrs	363	11 Jul. 1990		DFO
692-BLKA-008	M	Point Lay	6.5 yrs	364	11 Jul. 1990		DFO
692-BLKA-009	M	Point Lay	6.5 yrs	348	11 Jul. 1990		DFO[f]
692-BLKA-010	M	Point Lay	11.5 yrs	400	11 Jul. 1990		DFO
692-BLKA-011	M	Point Lay	14 yrs	433	11 Jul. 1990		DFO
692-BLKA-012	F	Point Lay	27.5 yrs	375	11 Jul. 1990		DFO
692-BLKA-013	M	Point Lay	13 yrs	434	11 Jul. 1990		DFO
692-BLKA-014	F	Point Lay	11.5 yrs	351	11 Jul. 1990		DFO
692-BLKA-040	M	Point Lay	7 yrs	315	01 Jul. 1996		NWFSC
692-BLKA-041	F	Point Lay	6 yrs	322	01 Jul. 1996	lactating	NWFSC
692-BLKA-042	F	Point Lay	17 yrs	393	01 Jul. 1996	lactating	NWFSC[e]
692-BLKA-043	M	Point Lay	17.5 yrs	427	01 Jul. 1996		NWFSC
692-BLKA-045	M	Point Lay	12.5 yrs	420	01 Jul. 1996		NWFSC
692-BLKA-046	M	Point Lay	19 yrs	396	01 Jul. 1996		NWFSC
692-BLKA-047	F	Point Lay	16.5 yrs	333	01 Jul. 1996	lactating	NWFSC
692-BLKA-048	F	Point Lay	22 yrs	386	01 Jul. 1996	lactating	NWFSC
692-BLKA-049	F	Point Lay	8 yrs	333	01 Jul. 1996	lactating	NWFSC

[a] These samples were collected, in collaboration with other organisations, and maintained by the US National Biomonitoring Specimen Bank as described in Becker *et al.* (1997). [b] Ages were estimated by counting growth layer groups in a thin longitudinal section taken from the middle of the mandibular tooth. [c] Analyses performed by Department of Fisheries and Oceans, Canada (DFO); National Institute of Standards and Technology (NIST); and Northwest Fisheries Science Center (NWFSC). [d] Analysed once by NIST and once by NWFSC; analytical results are averaged in this paper. [e] Analysed in duplicate by the NWFSC; analytical results are averaged in this paper. [f] Analysed in triplicate by DFO; analytical results are averaged in this paper.

cleanup. High-performance liquid chromatography (HPLC) with a size-exclusion column was used to separate lipids and other biogenic material from a fraction containing the OCs. The OC fraction was analysed by capillary column gas chromatography (GC) equipped with an electron capture detector (ECD). Identification of individual OCs in selected samples was confirmed using GC-mass spectrometry. Quality assurance results (e.g. analyses of NIST SRM 1945, replicates and method blanks, surrogate recoveries) met laboratory criteria.

At the NIST, blubber samples were analysed for OCs and percentage lipid concentration as described previously (Schantz *et al.*, 1996). Briefly, the blubber (2-3g) was mixed with sodium sulphate (*ca* 100g), internal standards were added, and the mixture was extracted with methylene chloride by Soxhlet (18hr). The majority of the lipid and biogenic material were removed by size-exclusion chromatography and then normal-phase HPLC using an aminopropylsilane column was used to isolate two fractions (PCBs and lower polarity pesticides; more polar pesticides) that were analysed by GC/ECD. NIST SRMs 1588 (organics in cod liver oil) and 1945 (organics in whale blubber) were analysed with each set of blubber samples for quality control.

The DFO analyses of blubber were performed by methods described previously (Muir *et al.*, 1988; 1990a; Stern *et al.*, 1994). Samples of blubber (2-5g) were mixed with anhydrous sodium sulphate and extracted, following addition of internal standards, by ball-milling (30min) with hexane. The extract was allowed to stand for 4 hours and then centrifuged (1,000rpm). After evaporation of the solvent, the extract was chromatographed on an automated size-exclusion column to separate the OCs from the co-extracted lipids and then separated into three fractions on Florisil (PCBs/p,p'-DDE/mirex; toxaphene/chlordane/mirex; heptaclor epoxide and dieldrin) that were analysed by GC/ECD. NIST SRMs 1588 and 1945 were analysed with every 20 blubber samples for quality control.

All three laboratories participate in an annual inter-laboratory comparison exercise as part of the marine mammal quality assurance component of NMFS's Marine Mammal Health and Stranding Response Program. The results of these exercises have been in good agreement (Schantz *et al.*, 1996; Becker *et al.*, 1999). Also, any differences among the laboratories for specific analytes were much less than the final differences between white whale stocks using the databases from any of the three laboratories; therefore, combining databases and using the means for samples that had results from more than one laboratory for the same analyte, was justifiable. Several of the blubber samples were analysed by both NWFSC and NIST: the animal ID numbers were 692-BLKA-017, -020, -021, -022, -023, -024, -025, -026, -027, -028. The results of these analyses have been averaged. Other samples were analysed in replicate by one laboratory: 692-BLKA-009 was analysed in triplicate by DFO; and 692-BLKA-031, -032, -033, -034, -035, -042 were analysed in duplicate by NWFSC. The results for the replicate samples have been averaged.

The OCs are reported as follows: 'ΣPCBs' is calculated by first summing the concentrations of chlorobiphenyl congeners 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, 206 and 209 and then multiplying the sum by 2 as an estimate of total PCBs (Lauenstein *et al.*, 1993). 'ΣDDTs' is the sum of concentrations of o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT, p,p'-DDT. 'Σchlordanes' is the sum of concentrations of heptachlor, heptachlor epoxide, cis-chlordane, trans-chlordane, trans-nonachlor, cis-nonachlor, oxychlordane and nonaclor III. All concentrations given in this paper are in ng/g, wet weight, unless stated otherwise. The Σtoxaphene and ΣHCH (hexachlorocyclohexane) concentrations for samples in this paper were those reported in Becker *et al.* (1995; 1997).

Statistical analysis

White whale ages and blubber concentrations of OC analytes (wet weight basis; no normalisation or transformation) were grouped by stock and gender and then analysed using JMP software (SAS Institute, Inc., Cary, NC). The group means were analysed by ANOVA and differences among means were determined using the Tukey-Kramer HSD (honestly significant difference) test to compare all combinations of pairs of groups. White whale age was also plotted against analyte concentration for selected analytes and the 95% density ellipses were calculated. The calculated Pearson correlation coefficient approaches 1 as the relationship between age and analyte concentration approaches linearity. Statistical significance was set at $p = 0.05$.

For principal component analysis (PCA), analyte concentrations were normalised by dividing concentrations of each analyte by total OCs (sum of ΣPCBs, ΣDDTs, Σchlordanes, hexachlorobenzene (HCB), dieldrin and mirex). When PCA is used, the number of samples should exceed the number of variables, preferably by a factor of two. Due to the need to reduce the number of variables (33 variables and 41 samples), only those analytes that had significant differences between the groups as determined by the ANOVA test described above and with all values above the limit of detection, were used for the analysis. These analytes were chlorobiphenyl congeners (44, 101, 138, 170, 180 and 187), heptachlor epoxide, τ-HCH (lindane), trans-chlordane, cis-nonachlor, trans-nonachlor, oxychlordane, o,p'-DDE, p,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT and p,p'-DDT.

Human health calculations

Calculations of the allowable dose of contaminants in blubber were based on the Allowable Daily Intake (ADI) levels recommended by the Contaminants Toxicology Section, Food Directorate, Health Canada, Ottawa, as described by Jensen *et al.* (1997). Wet weight concentrations of contaminants in blubber were used for determining human exposure because tissue is consumed on a wet weight basis. The average body weight for a human consumer used in these calculations was 70kg. The ADI (µg/kg/day) × 70kg = allowable daily dose (µg/day for an adult). The allowable daily dose is then divided by mean tissue concentration (ng/g, wet weight, is converted to µg/g by dividing by 1,000) to give the allowable quantity of blubber (g) that can be consumed per day. The ADI (µg/kg/day) values used were: 1.0 for ΣPCBs, 20 for ΣDDTs, 0.05 for Σchlordanes, 0.27 for HCB, 0.10 for dieldrin, 0.07 for mirex, 0.20 for Σtoxaphene and 0.30 for ΣHCH (Jensen *et al.*, 1997).

RESULTS AND DISCUSSION

Blubber of white whales from Alaska contained ΣPCBs, ΣDDTs, Σchlordanes, HCB, dieldrin, mirex, Σtoxaphene and ΣHCH (Table 2), in concentration ranges similar to those found in white whales from the Canadian Arctic (Muir *et al.*, 1992; Norstrom and Muir, 1994) and much lower than those in white whales from the highly contaminated St

Table 2

Concentrations (mean ± SD and ranges (ng/g, wet weight)) of organochlorine compounds in blubber of Cook Inlet, Eastern Chukchi Sea and Eastern Beaufort Sea stocks of white whales.[a]

Stock:	Cook Inlet Stock (1992-97)		E. Chukchi Sea Stock (1990, 96)		E. Beaufort Sea Stock (1989)		E. Beaufort Sea Stock (1983, 87)	
Site & Reference:	Sites in Figure 1; this paper[b]		Pt. Lay; this paper[c]		Pt. Hope; this paper[d]		Mackenzie Bay; Muir *et al.*, (1990b)	
	Males (10)	Females (10)	Males (11)	Females (8)	Males (0)	Females (2)	Males (10)	Females (2)
ΣPCBs[e]	1,490 ± 700	790 ± 560	5,200 ± 900	1,500 ± 1,120		2,220	3,330 ± 850	1,230
	554 - 3,090	190 - 1,810	3,770 - 6,880	740 - 4,070		1,880 - 2,560	2,320 - 4,940	830 - 1,640
ΣDDTs[f]	1,350 ± 730	590 ± 450	3,630 ± 900	930 ± 850		1,240	2,200 ± 830	670
	340 - 2,910	110 - 1,410	2090 - 4,850	330 - 2,890		1,140 - 1,330	1,470 - 3,730	460 - 880
p,p'-DDE	820 ± 480	340 ± 260	2,100 ± 480	500 ± 500		650	1,030 ± 440	350
	140 - 1,780	58 - 830	1,240 - 2,800	140 - 1,640		610 - 690	150 - 1,760	190 - 520
ΣChlordanes[g]	560 ± 250	300 ± 220	2,420 ± 460	790 ± 610		1,300	1,750 ± 410	670
	360 - 1,110	60 - 680	1,900 - 3,260	300 - 2,150		1,080 - 1,530	1,280 - 2,560	440 - 890
HCB	220 ± 93	150 ± 130	810 ± 120	230 ± 280		570	590 ± 130	290
	78 - 400	30 - 460	520 - 950	60 - 840		230 - 900	400 - 780	160 - 410
Dieldrin	92 ± 47	57 ± 50	390 ± 86	120 ± 96		210	230 ± 50	100
	25 - 210	11 - 150	280 - 560	46 - 320		140 - 280	160 - 340	70 - 140
Mirex	13 ± 5.6	9.1 ± 3.7	63 ± 21	22 ± 6.6		17	40 ± 10	20
	4.0 - 20	3.7 - 14	28 - 100	15 - 35		14 - 20	20 - 60	10 - 30
ΣToxaphene[h]	2,380 ± 1,070	1,900 ± 690	4,200 ± 1,000	2,540 ± 1,700		3,060	3,830 ± 1,160	1,380
	950 - 4,320	40 - 2,600	3,090 - 5,380	500 - 4,640		2,640 - 3,480	2,550 - 6,620	1,120 - 1,630
ΣHCH[h]	210 ± 70	170 ± 50	330 ± 760	250 ± 120		380	230 ± 60	170
	80 - 310	100 - 250	270 - 480	80 - 360		290 - 460	140 - 320	170 - 170
Percent lipid	90 ± 1.4	89 ± 4.9	86 ± 6.3	89 ± 4.1		92	74.1 ± 10.0	81.7
	88 - 92	79 - 97	72 - 93	85 - 97		89 - 94	60.4 - 88.0	77.9 - 85.6
Age (n)	9.3 ± 0.9 (4)	9.9 ± 5.6 (4)	12.3 ± 4.5 (10)	16.4 ± 7.5 (8)		6.3	17 (2)	18 (1)
	8.5 - 10.5	2 - 15	6.5 - 19	6 - 27.5		4.5 - 8	13 - 20	

[a] Number of individuals is shown in the parentheses following "males" and "females". [b] Concentrations of OCs in certain Cook Inlet whales (7 males and 6 females) were summarized in Becker et al. (1997), but the results were not separated by gender; these animals are included in the totals given here. In addition, 10 of these 13 animals were also analysed by the NWFSC laboratory and the results from the two laboratories were averaged before being summarised for this table. [c] Concentrations of OCs in white whales (7 males and 3 females) reported by Becker *et al.* (1995) have been combined with analyses from animals collected later (1996) for this table. [d] Also reported in Becker *et al.* (1995). [e] ΣPCBs is the sum of concentrations of chlorinated biphenyl congeners 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, 206, and 209, multiplied by 2 as an estimate of total concentration of PCBs (Lauenstein *et al.* 1993). [f] ΣDDTs is the sum of concentrations of o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT and p,p'-DDT. [g] ΣChlordanes is the sum of concentrations of heptachlor, heptachlor epoxide, cis-chlordane, trans-chlordane, trans-nonachlor, cis-nonachlor, oxychlordane and nonaclor III. [h] Toxaphene and ΣHCH concentrations in this table for the Cook Inlet Stock (1992-97) are reported by Becker *et al.*, (1997) and for the E. Chukchi stock (1990, 1996) are reported by Becker *et al.*, (1995).

Lawrence River (Muir *et al.*, 1990b). For example, concentrations in the Alaskan stocks as a percentage of those in the St Lawrence stock reported in Muir *et al.* (1990b) were: ΣPCBs (2–7%), ΣDDTs (1–5%), Σchlordanes (8–37%), HCB (25–95%), dieldrin (10–42%) and mirex (1–6%). Within these ranges, the Cook Inlet stock generally had the lowest and the Eastern Beaufort Sea stock the highest concentrations compared to white whales from the St Lawrence River, a stock that is exhibiting serious pollution-related effects (Béland, 1996). However, it is necessary to take age and gender into consideration when making spatial or temporal comparisons of marine mammal species (Borrell and Aguilar, 1999).

Age is an important factor to consider in interpreting contaminant concentrations in marine mammals. In this paper, we have reliable age data for 28 of the animals (Tables 1 and 2). We found no statistically significant differences when the ages of white whales were compared by stock (location) and by gender. Using the available age data separated by gender and stock, we found males from both the Cook Inlet and Eastern Chukchi Sea stocks (Point Lay) showed positive correlations between age and concentrations of ΣPCBs, ΣDDTs, Σchlordanes and dieldrin ($r = 0.95$ to 0.99 and $p = 0.05$ to 0.01 for Cook Inlet; $r = 0.66$ to 0.81 and $p = 0.04$ to 0.005 for Eastern Chukchi Sea). The Cook Inlet males also showed positive correlations between age and concentrations of mirex ($r = 0.97$; $p = 0.03$) and the Point Lay males between age and concentrations of HCB ($r = 0.63$; $p = 0.05$). However, because there were only four Cook Inlet males with known ages (from 10 animals sampled) and the ages ranged narrowly from 8.5 to 10.5 years, the correlations with age could change if additional animals giving a greater range of ages were added to the dataset. Furthermore, the Eastern Chukchi Sea and Cook Inlet female white whales showed no correlations between age and contaminant concentrations; this observation is consistent with the transfer of contaminants to the calf during pregnancy and lactation (Martineau *et al.*, 1987; Muir *et al.*, 1990b). However, increasing OC concentrations in older females have been reported by Muir *et al.* for white whales (1996) and by Tanabe *et al.* (1986) for minke whales, possibly due to reduced parturition and lactation in older animals. Other studies report that trends with age can be variable for white whales, particularly the males. Muir *et al.* (1996) reported that concentrations of ΣDDTs, ΣPCBs, mirex and Σchlordanes were not correlated with ages of male white whales from the St Lawrence River, yet Martineau *et al.* (1987) found positive trends in ΣDDTs and ΣPCBs in both male and female white whales from the St Lawrence River. Male white whales from Greenland demonstrated no correlation of ΣDDTs and ΣPCBs with age (Stern *et al.*, 1992). Muir *et al.* (1996) suggest that the lack of correlation of OCs and age in male white whales may result from differences in diet of the older males compared to that of younger males.

Gender is another factor to consider when interpreting differences in OC concentrations among white whale stocks. We found that differences were evident when a comparison was made of contaminant concentrations in white whale blubber by stock and gender (Table 2 and Fig. 2). For example, the males of each stock had higher mean concentrations of all contaminant groups than the females of the same stock (Fig. 2). The males from the Eastern Chukchi Sea stock (Point Lay) showed the greatest difference in concentrations when compared to the females from the same stock; concentration ratios (male:female) ranged from 1.3 for ΣHCH to 3.9 for ΣDDTs (Table 3). Concentrations of ΣPCBs, ΣDDTs, Σchlordanes, HCB, dieldrin and mirex in males of the Eastern Chukchi Sea stock were significantly higher ($p < 0.05$) than those in females from the same stock (Fig. 2). The Cook Inlet stock had lower male:female concentration ratios for these contaminants than the Eastern Chukchi Sea stock, ranging from 1.2 for ΣHCH to 2.3 for the ΣDDTs (Table 3); none of the gender differences in mean concentrations were statistically significant (Fig. 2). The Eastern Beaufort Sea stock from Mackenzie Bay (Muir *et al.*, 1990b) had male:female concentration ratios of OCs that ranged from 1.4 for ΣHCH to 3.3 for ΣDDTs. These fall between the values for the Cook Inlet and Eastern Chukchi Sea stocks, except for Σtoxaphene where the Mackenzie Bay animals had the highest male:female ratios (Table 3).

The lower concentrations of certain OCs (e.g. PCBs, DDTs) in the blubber of sexually mature female white whales, compared to males of similar ages, is attributed to the transfer of these aromatic OCs from the mother to the calf during gestation and then lactation following birth (Martineau *et al.*, 1987; Muir *et al.*, 1990b). This transfer of OCs from the female to offspring is widely recognised in marine mammals and has been documented for a number of species (Tanabe *et al.*, 1982; Muir *et al.*, 1992; Aguilar and Borrell, 1994; Norstrom and Muir, 1994; Krahn *et al.*, 1997; Wade *et al.*, 1997). Certain classes of OCs (e.g. DDTs and PCBs) are readily transferred to offspring during pregnancy and lactation. For example, the reproductive transfer rate is higher for DDTs than for PCBs, so a larger proportion of the maternal body burden of DDTs is transferred to the offspring (Tanabe *et al.*, 1982; Aguilar and Borrell, 1994; Nakata *et al.*, 1995). This rate differential is reflected in a higher male:female ratio for DDTs than for other analytes (Table 3). In contrast, certain chlorinated aliphatic compounds (e.g. mirex, ΣHCH) appear to be less preferentially transferred during reproduction (Muir *et al.*, 1990b). Thus, the female retains a greater fraction of her body burden of chlorinated aliphatics and the male:female ratio is lower for these compounds than for the DDTs and PCBs. The transfer of a significant portion of the OC burden from a female white whale to her calf, particularly during sensitive portions of the foetal and neonatal life cycle phases, could result in serious health problems. For example, high concentrations of OCs in marine mammal tissues have been associated with immunosuppression, reproductive impairment and increased susceptibility to disease (Lahvis *et al.*, 1995; De Guise *et al.*,

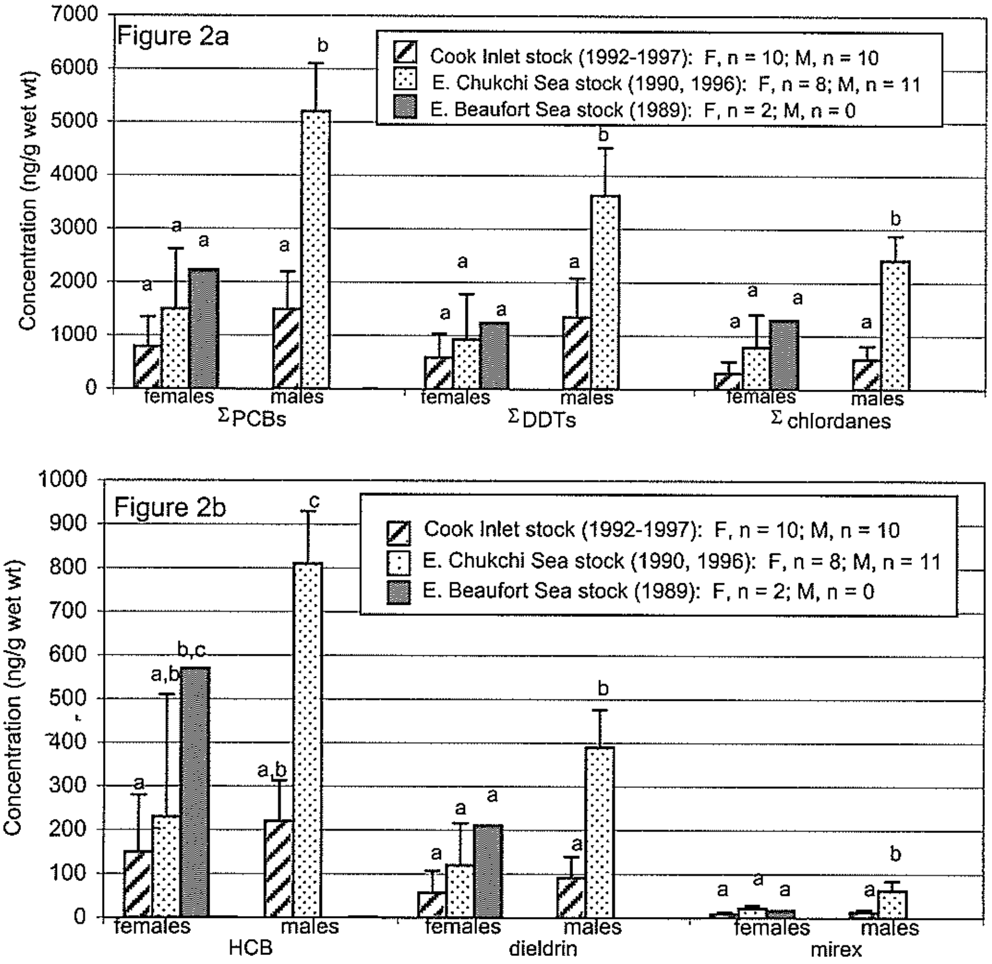

Fig. 2. Concentrations (mean ± SD) of organochlorine contaminants (OCs) in blubber of white whales grouped by sampling location and gender: (a) ΣPCBs, ΣDDTs, and Σchlordanes; (b) HCB, dieldrin and mirex. No significant differences in concentrations of an analyte were found among stocks that have the same letter above their bars; stocks that have different letters above their bars are significantly different from each other.

1996a; b; De Swart *et al.*, 1996; Kamrin and Ringer, 1996; O'Hara and Rice, 1996; Ross, 1996; Beckmen *et al.*, 1999).

Table 3
Ratios (male:female)[a] of organochlorine contaminants in blubber of Cook Inlet, E. Chukchi Sea and E. Beaufort Sea stocks of white whales.

	Cook Inlet Stock (1992-97)	E. Chukchi Sea Stock (1990, 1996)	E. Beaufort Sea Stock (1983, 1987)[b]
ΣPCBs	1.9	3.5	2.7
ΣDDTs	2.3	3.9	3.3
ΣChlordanes	1.9	3.1	2.6
HCB	1.5	3.5	2.0
Dieldrin	1.6	3.3	2.3
Mirex	1.4	2.9	2.0
ΣToxaphene	1.3	1.7	2.8
ΣHCH	1.2	1.3	1.4

[a] Ratios were calculated by dividing the mean concentration of a particular contaminant in males of a stock by the mean concentration of that analyte in females of the same stock. [b] from Muir *et al.*, (1990b).

Due to the gender differences described previously, separate comparisons of contaminant concentrations in white whales from different stocks should be made for male and female animals. For male Alaskan white whales, the highest mean concentrations of all analytes in blubber were found in animals from the Eastern Chukchi Sea stock (Point Lay; Table 2 and Fig. 2). Blubber of males from the Eastern Beaufort Sea stock had the next highest concentrations of all the contaminants (Table 2; Muir *et al.*, 1990b). The lowest concentrations were found in males from the Cook Inlet stock (Table 2 and Fig. 2). Making comparisons of contaminant concentrations among the female whales was less reliable since the reproductive status of several females is not known and only four females were collected from the Eastern Beaufort Sea stock (two in 1989 and two in 1983/1987). The analyte concentrations in blubber from female Alaskan white whales from the Eastern Chukchi Sea and the Eastern Beaufort Sea were similar to each other and to those for males from the Cook Inlet stock (Table 2 and Fig. 2). The female white whales from Cook Inlet had generally lower OC concentrations compared to females from the other stocks, but these concentrations were not significantly different (Fig. 2). It is somewhat surprising that the Cook Inlet stock has the lowest concentrations of contaminants among the three Alaskan stocks, because these animals reside in one of the most 'urban' areas of Alaska where anthropogenic contamination results from a relatively higher density of human residents and commercial activities. However, this isolated stock may be exposed to different sources of OCs than the other Alaskan stocks (Becker *et al.*, 1997). Threshold concentrations of contaminants that cause health effects in marine mammals are largely unknown and will need to be determined before the threat of contaminants to the health of these Alaskan white whale populations can be established with any degree of certainty(IWC, 1999a; b).

Ratios of certain contaminants can help to define possible sources or pathways of contaminants in marine mammals. For example, the ratio of p,p'-DDE to ΣDDTs in marine mammal tissues is often used to determine whether there has been recent use of the parent p,p'-DDT. Higher ratios of p,p'-DDE/ΣDDTs indicate an 'older' (metabolised) source and lower ratios point to a current input of p,p'-DDT(Aguilar, 1984). For the Alaskan stocks in this paper, the ratios were very similar and varied between 0.51 and 0.58 (Fig. 3a). These ratios are similar to those found for the Canadian Arctic (0.47-0.57), but are lower than found for the St Lawrence (0.56-0.66) (Muir *et al.*, 1990b; and Fig. 3a), indicating Arctic white whales may be exposed to a more recent input of p,p'-DDT. This finding is consistent with the results of Iwata *et al.* (1993) who reported a high ratio of p,p'-DDT/p,p'-DDE in air sampled in the polar regions, suggesting current DDT usage in some high-latitude countries near the polar regions.

The concentrations of Σchlordanes were lower in the blubber of the Cook Inlet stock than in the other Alaskan Arctic stocks of white whales (Table 2; Fig. 2). This is not surprising because the Cook Inlet animals had lower concentrations of all OCs. However, it also appears that the relative contribution of chlordane compounds to the total OC concentrations in Cook Inlet animals was also less, i.e. Σchlordanes might not be such an important contributor to the overall OC loads in the sub-Arctic Cook Inlet animals as they are in the Arctic white whale stocks. Ratios of Σchlordanes/ΣPCBs in the Cook Inlet stock, the two Alaskan Arctic stocks (Eastern Chukchi Sea and Eastern Beaufort Sea), two Canadian Arctic stocks (Hudson Bay and Jones Sound), and the St Lawrence Estuary stock are compared in Fig. 3b. The higher the ratio, the greater the relative contribution of Σchlordanes to the total OCs concentration. The Σchlordanes/ΣPCBs ratio varied widely among the white whale stocks, but was similar between male and female white whales of the same stock. Although the mean concentration of Σchlordanes in the blubber of the St Lawrence animals was reported by Muir *et al.* (1990b) to be two to three times higher than in the Canadian Arctic animals, the relative contribution of Σchlordanes to total OCs was actually lower in the St Lawrence animals (~0.1 as compared to ~0.8 for the Arctic stocks). The Σchlordanes/ΣPCBs ratios of the Alaskan Arctic white whales (Eastern Chukchi Sea and Eastern Beaufort Sea) and the Cook Inlet stock (~0.5 and ~0.4, respectively), suggest less relative contribution of this group of compounds to the total OC concentrations in the Alaska animals than that reported in the Canadian Arctic animals, with the lowest contribution occurring in the Cook Inlet stock. The differences in these ratios also suggests different sources of these compounds, which may be related to geographic and latitudinal differences in atmospheric transport patterns and processes, different feeding habits, or prey availability for these white whale stocks.

Of the three white whale stocks investigated in this study, only the Cook Inlet white whale stock is known to be declining in numbers, from 653 animals in 1994, to 347 animals in 1998 (Hobbs *et al.*, 1998). Subsistence hunters were taking up to 70 white whales each year, leading to a precipitous decline of this stock. Although there are many health effects that have been attributed to elevated levels of OC contaminants in white whales and in other species (De Guise *et al.*, 1996a; b; Kamrin and Ringer, 1996; O'Hara and Rice, 1996; Beckmen *et al.*, 1999), any contribution that contaminants may have made to the decline of the Cook Inlet stock is likely to be small because the Cook Inlet white whale stock has the lowest concentrations of OCs in blubber of the three Alaskan stocks studied. On the other hand, very little is known about the role that multiple stressors (e.g. stress of being hunted; exposure to bacteria, viruses, biotoxins and parasites; insufficient food; bioaccumulation of toxic chemicals; climate change) play in population declines. The interaction among stressors in a declining stock that is approaching a small number of individuals could potentially

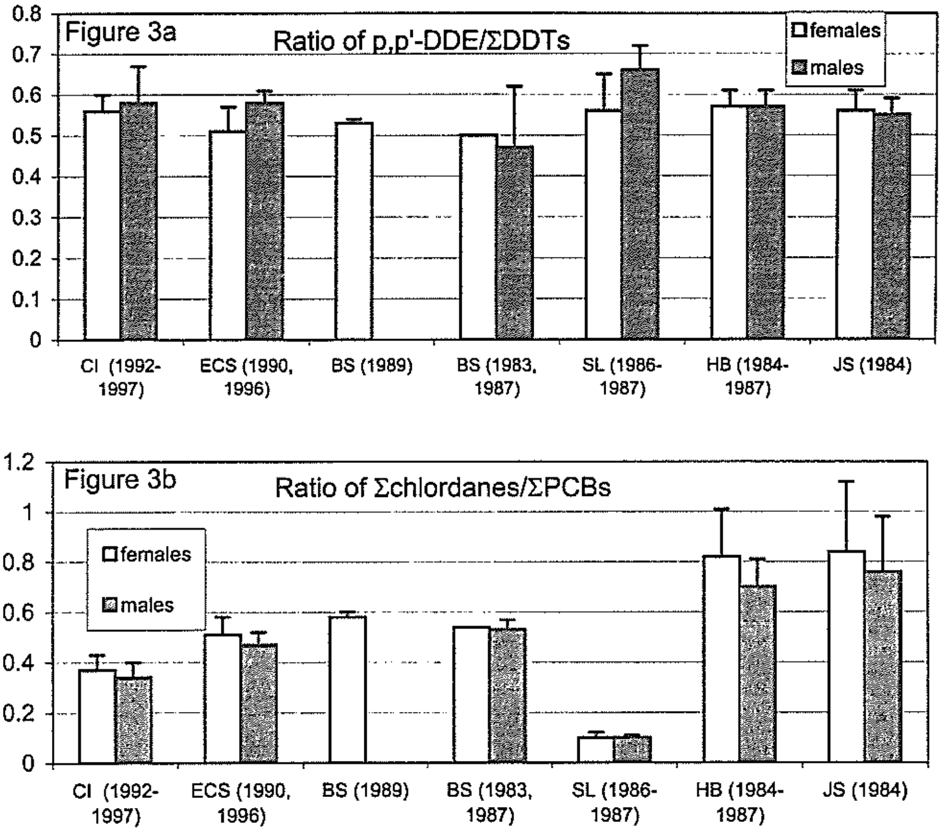

Fig. 3. Ratios of OCs (mean ± SD) in blubber of white whales grouped by sampling location and gender: (a) p,p'-DDE/ΣDDTs; (b) Σchlordanes/ΣPCBs. The Eastern Beaufort Sea (1989) animals are from Becker *et al.* (1995) and the Eastern Beaufort Sea (1983, 1987), St Lawrence, Hudson Bay and Jones Sound animals are from Muir *et al.* (1990b). Key: CI = Cook Inlet; ECS = E. Chukchi Sea; BS = Beaufort Sea; SL = St Lawrence; HB = Hudson Bay; JS = Jones Sound.

limit the ability of the stock to recover and, thus, have severe effects on the continued existence of the population. Therefore, the examination of other factors (e.g. parasite loads, incidence of disease, nutritional state and condition of animals), in addition to contaminant loads and loss of animals through hunting, should aid scientists in assessing the overall effects of anthropogenic activities on white whale populations.

Two of the white whale stocks in our study could be clearly distinguished by patterns of individual OC analytes as shown in a principal components analysis (PCA) plot in which concentration effects have been removed through normalisation to total OCs (Fig. 4). The Cook Inlet stock (upper plate) appears on the negative side of the PC1 axis and these animals are distinguished by higher loading values (lower plate) of the DDTs (except p,p'-DDT), trans-chlordane, a tetrachlorobiphenyl and a pentachlorobiphenyl. Although there is some overlap between the males and females of the Cook Inlet stock, these groups were mostly separated. The Alaskan Arctic stocks (Eastern Chukchi Sea, designated EC, and Eastern Beaufort Sea, designated EB) both appear on the positive side of PC1. The males and females of the Eastern Chukchi Sea stock were separated, except for the two oldest females (22.5 and 27.5 years) which were grouped with the males of that stock. This result might be expected because the cessation of parturition and lactation (senescence) in these older females can reduce the transfer of OC contaminants to the offspring. The Eastern Chukchi Sea females were distinguished by higher loading values of the hexa- through nonachlorobiphenyls and the Eastern Chukchi Sea males by higher loading values of the pesticides lindane and heptachlor epoxide. The Eastern Beaufort Sea females (Point Hope) were poorly resolved on the PCA plot from the Eastern Chukchi Sea males. However, there are only two Eastern Beaufort Sea samples; clearly, additional data are needed to establish whether the patterns from the Eastern Beaufort Sea and Eastern Chukchi Sea stocks can be resolved. A similar PCA plot for white whales from the St Lawrence and Canadian Arctic also showed resolution of the stocks (Muir *et al.*, 1996), but the group of OCs used in the their PCA plots was somewhat different from those in our study, therefore, the PCA loading factors that distinguished the stocks also differed. The PCA results indicated differences in contaminant accumulation, which likely reflects differences in habitat use and prey foraging among the stocks. Additional data are needed, particularly from the Alaskan stocks that were not represented (Bristol Bay and Eastern Bering Sea stocks) or were under-represented (Eastern Beaufort Sea), to provide a better understanding of the relationship between contaminant profiles and white whale stock structure, as well as increased knowledge about the health risks that contaminants pose to individual stocks.

Based on the ADI from the Canadian Northern Contaminants Program (Jensen *et al.*, 1997), the blubber of the white whale was assessed as a source of OCs to human consumers (Table 4). The results show that Σchlordanes in the Eastern Chukchi Sea stock blubber would pose the most restrictive consumption rate (2g/day) because this amount would equal the ADI. The ADI for Σchlordanes also limits consumption of the Eastern Beaufort Sea white whale

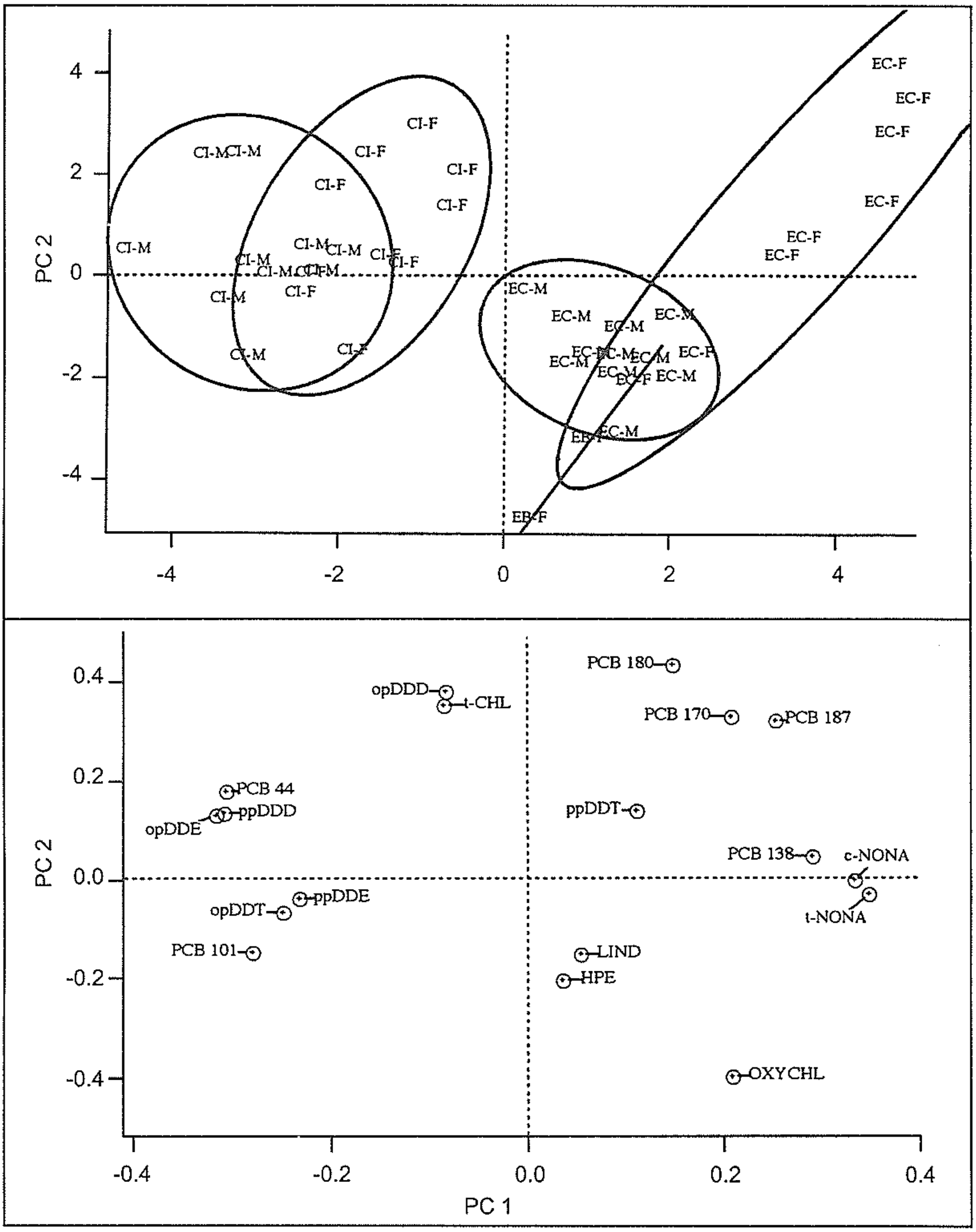

Fig. 4. Principlal components analysis plot for 41 beluga whales grouped by location-gender and 18 individual organochlorines. CI = Cook Inlet stock, EC = Eastern Chukchi Sea stock; EB = Eastern Beaufort Sea stock; —F = female and —M = male. Concentrations were normalised to total organochlorines. Ellipses are the bivariate normal 95% confidence intervals for each group. The loading plot (lower panel) shows the contributions of the individual contaminant to the principal component eigenvectors.

blubber to 3g/day and that Σtoxaphenes limits Cook Inlet blubber to 7g/day. The ADI represents a life-long daily exposure and a significant safety factor has been applied to make these safe and conservative estimates. In contrast, the quantity of blubber from other Alaskan marine mammal species needed to exceed the ADI is much higher than for the Alaskan white whale stocks. For example, up to 1,700–10,600g of walrus, narwahl and ringed seal blubber can be safely consumed on a daily basis before exceeding the ADI of Σchlordanes (the most restrictive value) (Jensen *et al.*, 1997). Furthermore, the FDA regulatory limits for contaminants in seafood are exceeded for ΣPCBs in blubber from the Eastern Chukchi Sea and Eastern Beaufort Sea stocks and for Σchlordanes in all three stocks (see Table 4). However, FDA levels were not developed for subsistence-based consumption patterns of marine mammals, so these standards may not be completely applicable. Although our results show that white whale blubber from the three Alaskan stocks is a source of OC exposure for subsistence consumers, the health risks from

Table 4

The allowable daily quantity (g/day) of white whale blubber that can be consumed by an adult, based on allowable daily intake (ADI; Jensen *et al.* 1997) and mean concentrations of the contaminants from Table 2.

			Stock mean tissue concentration (µg/g)[a]			Allowable blubber consumption (g/day)		
	ADI (µg/kg/day)	Allowed dose (µg/day) (ADI x 70 kg/adult)	Cook Inlet n = 20	E. Chukchi n = 19	E. Beaufort n = 2	Cook Inlet n = 20	E. Chukchi n = 19	E. Beaufort n = 2
ΣPCBs	1.0	70	1.14	3.64†	2.22†	61	19	32
ΣDDTs	20.0	1400	0.97	2.50	1.24	1,443	560	1,129
ΣChlordanes	0.05	3.5	0.40†	1.74†	1.30†	9	2	3
HCB	0.27	18.9	0.18	0.56	0.57	105	34	33
Dieldrin	0.10	7	0.07	0.27	0.21	95	26	33
Mirex	0.07	4.9	0.01	0.05	0.02	445	107	288
ΣToxaphene[b]	0.20	14	2.14	3.37	3.06	7	4	5
ΣHCH[b]	0.30	21	0.19	0.29	0.38	111	72	55

[a] Mean of tissue concentrations for all animals of the stock (males and females). † = mean concentration exceeds FDA regulatory limits which are (µg/g): ΣDDTs and toxaphene ≥ 5.0; ΣPCBs ≥ 2.0; Σchlordanes and dieldrin ≥ 0.3; mirex ≥ 0.1. [b] Mean tissue concentration obtained by averaging mean tissue concentrations (µg/g, wet wt) for males and females in Table 2 and dividing by 1,000.

consumption are currently unknown. More information is needed about the actual consumption rate of white whale blubber by Native populations and the resulting actual human exposure. For example, because the epidermis is eaten together with the blubber (maktaaq), the concentrations of OCs consumed would be lower than if only blubber were eaten. A more direct assessment of the quantity and frequency of consumption of maktaaq by Native populations could assist in a more accurate evaluation of the accumulation of OCs. Finally, the benefits (i.e. nutritional, cultural, spiritual) of maktaaq consumption by Native Alaskans should also be considered in any 'costs-benefits' analysis.

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REFERENCES

Aguilar, A. 1984. Relationship of DDE/tDDT in marine mammals to the chronology of DDT input into the ecosystem. *Can. J. Fish. Aquat. Sci.* 41:840-4.

Aguilar, A. and Borrell, A. 1994. Reproductive transfer and variation of body load of organochlorine pollutants with age in fin whales (*Balaenoptera physalus*). *Arch. Environ. Contam. Toxicol.* 27(4):546-54.

Becker, P.R., Wise, S.A., Koster, B.J. and Zeisler, R. 1991. *Alaska Marine Mammal Tissue Archival Project: Revised Collection Protocol.* National Institute of Standards and Technology, NISTIR 4529, Gaithersberg, Maryland. 33pp.

Becker, P., Mackey, E., Schantz, M., Greenberg, R., Koster, B., Wise, S. and Muir, D. 1995. *Concentrations of Chlorinated Hydrocarbons, Heavy Metals and Other Elements in Tissues Banked by the Alaska Marine Mammal Tissue Archival Project.* National Institute of Standards and Technology, NISTIR 5620, Gaithersberg, Maryland. 115pp.

Becker, P., Mackey, E., Demiralp, R., Schantz, M., Koster, B. and Wise, S. 1997. Concentrations of chlorinated hydrocarbons and trace elements in marine mammal tissues archived in the U.S. National Biomonitoring Specimen Bank. *Chemosphere* 34:2067-98.

Becker, P.R., Porter, B.J., Mackey, E.A., Schantz, M.M., Demiralp, R. and Wise, S.A. 1999. *National Marine Mammal Tissue Bank and Quality Assurance Program: Protocols, Inventory, and Analytical Results.* US Department of Commerce, NIST, NISTIR 6279, Gaithersberg, Maryland. 183pp.

Beckmen, K.B., Ylitalo, G.M., Towell, R.G., Krahn, M.M., O'Hara, T.M. and Blake, J.E. 1999. Factors affecting organochlorine contaminant concentrations in milk and blood of northern fur seal (*Callorhinus ursinus*) dams and pups from St. George Island, Alaska. *Sci. Total Environ.* 231:183-200.

Béland, P. 1996. The beluga whales of the St. Lawrence River. *Sci. Am.* 274:74-81.

Borrell, A. and Aguilar, A. 1999. A review of organochlorine and metal pollutants in marine mammals from Central and South America. *J. Cetacean Res. Manage. (special issue)* 1:195-207.

Burns, J.J. and Seaman, G.A. 1986. Investigations of belukha whales in western and northern Alaska. II. Biology and ecology. (Unpublished report). [Available from the Alaska Department of Fish and Game].

Calkins, D.G. 1979. Marine mammals of lower Cook Inlet and the potential for impact from Outer Continental Shelf oil and gas exploration, development and transport. Alaska Dept. Fish and Game. 89pp.

De Guise, S., Lagace, A. and Béland, P. 1994a. True hermaphroditism in a St. Lawrence beluga whale (*Delphinapterus leucas*). *J. Wildl. Dis.* 30(2):287-90.

De Guise, S., Lagacé, A. and Béland, P. 1994b. Tumors in St. Lawrence beluga whales (*Delphinapterus leucas*). *Vet. Pathol.* 31(4):444-9.

De Guise, S., Bernier, J., Defresue, M.M., Martineau, D., Béland, P. and Fournier, M. 1996a. Immune functions in beluga whales (*D. leucas*): evaluation of mitogen-induced blastic transformation of lymphocytes from peripheral blood, spleen and thymus. *Vet. Immunol. Immunopathol.* 50(1-2):117-26.

De Guise, S., Ross, P., Osterhaus, A., Martineau, D., Béland, P. and Fournier, M. 1996b. Immune functions in beluga whales (*Delphinapterus leucas*): Evaluation of natural killer cell activity. *Vet. Immunol. Immunopathol.* 58:345-54.

De Swart, R., Ross, P., Vos, J. and Osterhaus, A. 1996. Impaired immunity in harbour seals (*Phoca vitulina*) exposed to bioaccumulated environmental contaminants: Review of a long-term feeding study. *Environ. Health Perspect.* 103:62-72.

Freeman, M.M.R., Boboslovskaya, L., Caulfield, R.A., Egede, I., Krupnik, I.I. and Stevenson, M.G. 1998. *Inuit, Whaling and Sustainability*. Altamira Press, Walnut Creek, CA. 208pp.

Frost, K.J. and Lowry, L.F. 1990. Distribution, abundance and movements of beluga whales, *Delphinapterus leucas*, in coastal waters of western Alaska. *Can. Bull. Fish. Aquat. Sci.* 224:39-57.

Hazard, K. 1988. Beluga whale *Delphinapterus leucas*. pp. 195-235. *In:* J.W. Lentfer (ed.) *Selected Marine Mammals of Alaska. Species Accounts with Research and Management Recommendations*. US Marine Mammal Commission, Washington, DC. v+275pp.

Hobbs, R.C., Rugh, D.J. and DeMaster, D.P. 1998. Abundance of beluga whales in Cook Inlet, Alaska, 1994-1998. National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, Seattle, WA. (Unpublished). 14pp.

International Whaling Commission. 1999a. Planning workshop to develop a programme to investigate pollutant cause-effect relationships in cetaceans--Pollution 2000+. *J. Cetacean Res. Manage. (special issue)* 1:55-72.

International Whaling Commission. 1999b. Report of the IWC Workshop on Chemical Pollution and Cetaceans, March 1995, Bergen, Norway. *J. Cetacean Res. Manage. (special issue)* 1:1-42.

International Whaling Commission. 1999c. Report of the Scientific Committee. Annex I. Report of the Standing Sub-Committee on Small Cetaceans. *J. Cetacean Res. Manage. (Suppl.)* 1:211-25.

Iwata, H., Tanabe, S., Sakai, N. and Tatsukawa, R. 1993. Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of ocean on their global transport and fate. *Environ. Sci. Technol.* 27:1080-98.

Jensen, J., Adare, K. and Shearer, R. 1997. *Canadian Arctic Contaminants Assessment Report*. Department of Indian Affairs and Northern Development, Catalogue No. R72-260/1997E, ISBN 0-662-25704-9, Ottawa, Ontario, Canada. 460pp.

Kamrin, M. and Ringer, R. 1996. Toxicology implications of PCB residues in mammals. p. 494. *In:* W. Beyer, G. Heinz and A. Redmon-Norwood (eds.) *SETAC Special Publicaitons Series. Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations*. Lewis Publishers, Boca Raton, FL.

Krahn, M.M., Moore, L.K., Bogar, R.G., Wigren, C.A., Chan, S.L. and Brown, D.W. 1988. High-performance liquid chromatographic method for isolating organic contaminants from tissue and sediment extracts. *J. Chromatogr.* 437:161-75.

Krahn, M.M., Becker, P.R., Tilbury, K.L. and Stein, J.E. 1997. Organochlorine contaminants in blubber of four seal species: Integrating biomonitoring and specimen banking. *Chemosphere* 34:2109-.

Lahvis, G.P., Wells, R.S., Kvehl, D.W., Stewart, J.L., Rhinehart, H.L. and Via, C.S. 1995. Decreased in vitro humpback responses in free-ranging bottlenose dolphins (*Tursiops truncatus*) are associated with increased whole blood concentrations of polychlorinated biphenyls (PCBs) and o,p'-DDT; p-p'-DDE; and o,p'-DDE. *Environ. Health Perspect.* :In press.

Lair, S., Béland, P., De Guise, S. and Martineau, D. 1997. Adrenal hyperplastic and degenerative changes in beluga whales. *J. Wildl. Dis.* 33:430-7.

Lauenstein, G.G., Cantillo, A.Y. and Dolvin, S. 1993. NOAA National Status and Trends Program Development and Methods. Overview of Summary and Methods. p. 117. *In:* G.G. Lauenstein and A.Y. Cantillo (eds.) Vol. 1. *Sampling and Analytical Methods of the National Status and Trends Program, National Benthic Surveillance and Mussel Watch Projects 1984-1992*. US Dept. of Commerce, NOAA Technical Memorandum NOS ORCA 71.

Leatherwood, S. and Reeves, R.R. 1983. *The Sierra Club Handbook of Whales and Dolphins*. Sierra Club Books, San Francisco. xvii+302pp.

Martineau, D., Lagacé, A., Massé, R., Morin, M. and Béland, P. 1985. Transitional cell carcinoma of the urinary bladder in a beluga whale (*Delphinapterus leucas*). *Can. Vet. J. Res.* 26:297-302.

Martineau, D., Béland, P., Desjardins, C. and Lagacé, A. 1987. Levels of organochlorine chemicals in tissues of beluga whales (*Delphinapterus leucas*) from the St. Lawrence estuary, Quebec, Canada. *Arch. Environ. Contam. Toxicol.* 16:137-47.

Martineau, D., De Guise, S., Fournier, M., Shugart, L., Girard, C., Lagacé, A. and Béland, P. 1994. Pathology and toxicology of beluga whales from the St Lawrence estuary, Quebec, Canada - past, present and future. *Sci. Total Environ.* 154(2-3):201-15.

Martineau, D., Lair, S., De Guise, S. and Béland, P. 1995. Intestinal adenocarcinomas in two beluga whales (*Delphinapterus leucas*) from the Estuary of the St. Lawrence River. *Can. Vet. J. Res.* 36:563-5.

Martineau, D., De Guise, E., Pelletier, E., Shugart, L. and Béland, P. 1999. Cancer in beluga whales (*Delphinapterus leucas*) from the St. Lawrence Estuary, Quebec, Canada. *J. Cetacean Res. Manage. (special issue)* 1:249-65.

Moore, S.E., Clarke, J.T. and Johnson, M.M. 1993. Beluga distribution and movements offshore northern Alaska in spring and summer, 1980-84. *Rep. int. Whal. Commn* 43:375-86.

Muir, D.C.G., Simon, M. and Norstrom, R.J. 1988. Organochlorine contaminants in Arctic marine food chains - accumulation of specific polychlorinated biphenyls and chlordane-related compounds. *Environ. Sci. Technol.* 22(9):1071-9.

Muir, D.C.G., Ford, C.A., Grift, N.P., Metne, D.A. and Lockhart, W.L. 1990a. Geographic variation of chlorinated hydrocarbons in burbot (*Lota lota*) from remote lakes and rivers in Canada. *Arch. Environ. Contam. Toxicol.* 19:530-42.

Muir, D.C.G., Ford, C.A., Stewart, R.E.A., Smith, T.G., Addison, R.F., Zinck, M.E. and Béland, P. 1990b. Organochlorine contaminants in belugas, *Delphinapterus leucas*, from Canadian waters. *Can. Bull. Fish. Aquat. Sci.* 224:165-90.

Muir, D.C.G., Wagemann, R., Hargrave, B.T., Thomas, D.J., Peakall, D.B. and Norstrom, R.J. 1992. Arctic marine ecosystem contamination. *Sci. Total Environ.* 122:75-134.

Muir, D.C.G., Ford, C.A., Rosenberg, B., Norstrom, R.J., Simon, M. and Béland, P. 1996. Persistent organochlorines in beluga whales (*Delphinapterus leucas*) from the St. Lawrence River Estuary-I. Concentrations and patterns of specific PCBs, chlorinated pesticides and polychlorinated dibenzo-*p*-dioxins and dibenzofurans. *Environ. Pollut.* 93:219-34.

Nakata, H., Tanabe, S., Tatsukawa, R., Amano, M., Miyazaki, N. and Petrov, E. 1995. Persistent organochlorine residues and their accumulation kinetics in Baikal seals (*Phoca sibirica*) from Lake Baikal, Russia. *Environ. Sci. Technol.* 29:2877-85.

Norstrom, R.J. and Muir, D.C.G. 1994. Chlorinated hydrocarbon contaminants in Arctic marine mammals. *Sci. Total Environ.* 154(2-3):107-28.

O'Corry-Crowe, G., Suydam, R., Rosenberg, A., Frost, K. and Dizon, A.E. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale, *Delphinapterus leucas*, in the western Neartic revealed by mitochondrial DNA. *Mol. Ecol.* 6:955-70.

O'Hara, T. and Rice, C. 1996. Polychlorinated biphenyls. p. 219. *In:* A. Fairbrother, L.N. Locke and G.L. Hoff (eds.) *Noninfectious Diseases of Wildlife*. Iowa State University Press, Ames, Iowa.

Ross, P. 1996. Conatminant-induced immunotoxicity in harbour seals: Wildlife at risk? *Toxicology* 112:157-69.

Schantz, M.M., Porter, B.J., Wise, S.A., Segestro, M., Muir, D.C.G., Mossner, S., Ballschmiter, K. and Becker, P.R. 1996. Interlaboratory comparison study for PCB congeners and chlorinated pesticides in beluga whale blubber. *Chemosphere* 33:1369-90.

Seaman, G.A., Lowry, L.F. and Frost, K.J. 1982. Foods of belukha whales *Delphinapterus leucas* in Western Alaska. *Cetology* 44:1-19.

Sloan, C.A., Adams, N.G., Pearce, R.W., Brown, D.W. and Chan, S.L. 1993. Northwest Fisheries Science Center Organic Analytical Procedures. p. 182. *In:* G.G. Lauenstein and A.Y. Cantillo (eds.) *Sampling and Analytical Methods of the National Status and Trends Program: National Benthic Surveillance and Mussel Watch Projects 1984-1992*. NOAA Coastal Monitoring and Bioeffects Assessment Division, Office of Ocean Resources Conservation and Assessment, National Ocean Service, Silver Spring, Maryland.

Stern, G., Muir, D., Ford, C., Grift, N., Dewailly, E., Biddleman, T. and Walla, M. 1992. Isolation and identification of two major recalcitrant toxaphene congeners in aquatic biota. *Environ. Sci. Technol.* 26:1838-40.

Stern, G.A., Muir, D.C.G., Segstro, M.D., Dietz, R. and Heide-Jørgensen, M.P. 1994. PCB's and other organochlorine contaminants in white whales (*Delphinapterus leucas*) from West Greenland: variations with age and sex. *Medd. Grønl. Biosci.* 39:245-59.

Stewart, B.E. and Stewart, R.E.A. 1989. *Delphinapterus leucas*. *Mamm. Species* No. 336:1-8.

Tanabe, S., Tatsukawa, R., Maruyama, K. and Miyazaki, N. 1982. Transplacental transfer of PCBs and chlorinated pesticides from the pregnant striped dolphin (*Stenella coeruleoalba*) to her fetus. *Agric. Biol. Chem.* 46(5):1249-954.

Tanabe, S., Miura, S. and Tatsukawa, R. 1986. Variations of organochlorine residues with age and sex in Antarctic minke whales. *Mem. Natl Inst. Polar Res., Japan (Spec. Iss.)* 44:174-81.

Wade, T.L., Chambers, L., Gardinali, P.R., Sericano, J.L. and Jackson, T.J. 1997. Toxaphene, PCB, DDT, and chlordane analyses of beluga whale blubber. *Chemosphere* 34:1351-57.