ORGANOCHLORINE DYNAMICS IN FREE-RANGING POLAR BEARS AND THEIR CUBS

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Susan Carol Polischuk

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SUMMARY OF DISSERTATION

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by

Susan Polischuk

Department of Biology
University of Saskatchewan

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Examining Committee:

Dr. P.F. Flood	Dean, Dean's Designate, Chair College of Graduate Studies and Research
Dr. R.A.A. Morrall	Chair of Advisory Committee, Department of Biology
Dr. M.A. Ramsay	Supervisor, Department of Biology
Dr. R.J. Norstrom	Co-supervisor, Environment Canada, National Wildlife Research Centre
Dr. F.A. Leighton	Department of Veterinary Pathology
Dr. G.R. Bortolotti	Department of Biology

External Examiner:

Dr. G.D. Haffner
Department of Biological Sciences
University of Windsor
401 Sunset Avenue
Windsor, Ontario
N9B 3P4

Organochlorine dynamics in free-ranging polar bears and their cubs

Polar bears (*Ursus maritimus*) are top predators of the Arctic marine ecosystem, and as a consequence, accumulate relatively high burdens of organochlorine (OC) contaminants in their fat tissue. Extreme fluctuations in the mass of adipose tissue of polar bears occurs during seasonal and pregnancy fasts. Since the dynamics of OC compounds under such a regimen was unknown, my objective was to determine the change in concentrations and whole body burdens of OCs in polar bears handled sequentially during seasonal fasting and feeding, pregnancy, and the first two months of lactation. Total body burdens and adipose tissue, milk, and plasma concentrations were determined for chlorobenzenes (S-ClBzs), hexachlorocyclohexanes (S-HCHs), chlordanes (S-CHLORs), dichlorodiphenyl-trichloroethane compounds (S-DDTs) and polychlorinated biphenyls (S-PCBs).

During seasonal fasts; 1) mean body burdens of S-DDTs declined while burdens of S-ClBzs, S-CHLORs, and S-PCBs remained the same for most bears 2) OC concentrations in adipose tissue increased for S-ClBzs, S-CHLORs, and S-PCBs while plasma concentrations remained relatively constant 3) OC concentrations in adipose tissue and milk from females with cubs were correlated positively 4) OC body burdens of females with COYs correlated positively to those of their cubs. By contrast, OCs in adipose tissue of feeding bears remained relatively constant with little variation between captures.

During pregnancy fasts all OC body burdens declined, although the amount and percent decrease varied with OC compound. Whole body concentrations for mothers and cubs were similar for all OCs except for S-PCBs, where cubs had lower whole body concentrations than their mothers. Cubs in spring had 1.3X higher concentrations of S-ClBzs, S-HCHs, S-CHLORs, and S-PCBs in their adipose tissue than their mothers, while S-DDTs concentrations were similar. The

concentration of all OCs in the adipose tissue from nursing females in spring was correlated positively with OC concentrations in their milk. Females who lost their cubs between spring and fall had significantly higher mean OC concentrations in their milk in spring than did females who kept their cubs until fall.

The annual dynamics of OCs in the tissues of polar bears were variable and dependent on the bears' nutritional and reproductive status. Extreme fluctuations in OC concentrations occurred in adipose tissue depots but these changes did not necessarily reflect the total body burden dynamics of OC compounds. Except for S-DDTs, OC burdens in polar bears did not decline significantly during seasonal fasting whereas all burdens for OCs declined during pregnancy and early lactation. Organochlorine body burden changes during gestation and early lactation showed that females could transfer a significant burden to their young cubs.

BIOGRAPHICAL

January, 1967	Born in Simcoe, Ontario
November, 1992	B.Sc.(Honours, first-class standing), Lakehead University

HONOURS

University Graduate Scholarship, Univ. of Saskatchewan, Sept. 1994 to Sept. 1996
Isabel Lopez Memorial Scholarship, Univ. of Saskatchewan, Sept. 1996
Canadian Geographic Scholarship, Royal Canadian Geographical Society, April 1993
NSERC Graduate Scholarship, Univ. of Saskatchewan, Sept. 1992 to Aug. 1994
NSERC Undergraduate Award, Lakehead University, May-June1990 & 1991
Thunder Bay Field Naturalists Scholarship, Lakehead University, Sept.1991
Dr. L.D. Hawton Memorial Award, Lakehead University, Sept.1991
Canadian Federation of University Women Award, Lakehead University, Sept.1991
Bamfield Marine Station Scholarship, Univ. Victoria, June 1991

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Head of the Department of Biology
University of Saskatchewan
Saskatoon, Saskatchewan S7N 5E2

ABSTRACT

Polar bears (*Ursus maritimus*) are top predators of the Arctic marine ecosystem, and as a consequence, accumulate relatively high burdens of organochlorine (OC) contaminants in their fat tissue. Depending on their nutritional and reproductive status, polar bears undergo extreme annual fluctuations in their adipose tissue depots. I determined the dynamics of OCs in adipose tissue, milk, and plasma of polar bears during seasonal fasting and feeding, pregnancy, and the first two months of lactation. I collected tissue samples from free-ranging polar bears both before and after a period of fasting and feeding, and analyzed them for concentrations and total body burdens of chlorobenzenes (S-ClBzs), hexachlorocyclohexanes (S-HCHs), chlordanes (S-CHLORs), dichlorodiphenyl-trichloroethane compounds (S-DDTs) and polychlorinated biphenyls (S-PCBs). Logistical constraints necessitated sampling to be conducted in two different regions within the Canadian Arctic. Pregnant females, females with natal cubs in spring, and bears in summer and autumn were handled in the vicinity of Churchill, Manitoba. All of these bears were fasting at the time of handling. Bears during a period of feeding were handled on the sea ice in the vicinity of Resolute Bay, Northwest Territories.

During seasonal fasts, mean body burdens of S-DDTs declined by 50% while burdens of S-ClBzs, S-CHLORs, and S-PCBs remained the same for most bears. Generally, mean OC concentrations in adipose tissue increased by 30% for S-ClBzs and by 40% for S-CHLORs and S-PCBs while the plasma concentrations remained relatively constant. Females with high OC concentrations in their adipose tissue also had high concentrations in

their milk. The OC body burdens of females with COYs correlated positively to those of their cubs.

Adipose tissue concentrations of some specific OC compounds decreased during fasting whereas other compounds became concentrated. By contrast, specific OC compounds in adipose tissue of feeding bears remained relatively constant with little variation between captures. The relationship of OC compounds between mother and cub generally remained the same during fasting; some compounds were always higher in the cubs than mother and others the opposite.

Pregnant polar bears can maintain themselves on stored fat for eight months during which they undertake gestation and the first few months of lactation. The fate of stored lipophilic OCs during pregnancy and lactation in an animal that is fasting and the consequent OC dynamics in their young cubs is unknown. I determined total body burden (total body fat x OC concentration) and concentration change of OCs in female polar bears during pregnancy and the first 2-3 months of lactation. In March soon after den emergence, I also determined OC concentrations in adipose tissue and plasma from cubs. Organochlorine body burdens in seven female polar bears declined during gestation and the initial lactation period by 81% for S-DDTs, 64% for S-HCHs, 43% for S-ClBzs, 32% for S-CHLORs, and 23% for S-PCBs. Total declines in mean body burden of OCs were 70 mg for S-CHLORs, 56 mg for S-PCBs, 20 mg for S-DDTs, 14 mg for S-HCHs, and 7 mg for S-ClBzs. Lactation was estimated to account for 59%-66% of the decrease in S-PCBs and S-CHLORs burdens, 37%-49% for S-HCHs and S-ClBzs burdens, and 5% of the decrease for S-DDTs burdens. Total body burdens of OCs for cubs in spring were calculated to be 1-4% of pregnant

females and 3-7% of nursing mothers. Whole body concentrations for mothers and cubs were similar for all OCs except for S-PCBs, where cubs had lower whole body concentrations than their mothers. Because cubs are smaller and have a lower percentage of body fat than their mothers, they had higher concentrations of S-ClBzs, S-HCHs, S-CHLORs, and S-PCBs in their adipose tissue (3.1x, 3.0x, 2.3x, 1.3x higher, respectively). Cubs and mothers had similar concentrations of S-DDTs in their adipose tissue and plasma.

There was a positive relationship between the concentration of all OCs in adipose tissue and milk from females with young cubs. Females who lost their cubs had significantly higher mean OC concentrations in their milk in spring than did females who kept their cubs. The difference was 70% for S-PCBs, 60% for S-CHLORs, 58% for S-HCHs and S-ClBzs, and 49% for S-DDTs. This correlation between OC concentration in mother's milk and the subsequent survival of their cubs warrants further investigation. Cubs can receive a large influx of contaminants from their mother during their first year of life. This first year for the cub is a period of rapid growth and development that may be impaired with the presence of high OC loads.

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DEDICATION

I wish to dedicate this research, which comprised the last 7 years of my life and moulded me into the present, to my deceased grandmother, Freda Olive Bradt, and to the polar bear. Both individual and species had and have their fate dictated to them by the materialistic and selfish whims of society.

Inquisitive, curious, and gentle
She looks deep into my soul
I touch her paw
She touches my hand
And turns her nose
To smell the human odour
Which determines her fate
I look into her eyes
Wonder about her thoughts
And the life as a polar bear

Susan Polischuk

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α-HCH	alpha-hexachlorocyclohexane
β-HCH	beta-hexachlorocyclohexane
COYs	Cubs-of-the-year
DDD	1,1-dichloro-2,2-bis (*p*-chlorophenyl) ethylene
DDE	Dichlorodiphenyl dichloroethene
Fem/COYs	Females with cubs-of-the-year
Fem/YRLGs	Females with yearlings
HCB	Hexachlorobenzene
mg	milligrams
ng/g	nanograms per gram
PnClBz	Pentachlorobenzene
S-CHLORs	Sum of chlordane isomers
S-ClBzs	Sum of chlorobenzene isomers
S-DDTs	Sum of dichlorodiphenyl trichloroethane type compounds
S-HCHs	Sum of hexachlorocyclohexane isomers
S-PCBs	Sum of polychlorinated biphenyl congeners
TeClBz	1,2,4,5-tetrachlorobenzene
YRLGs	Yearling cubs

1. GENERAL INTRODUCTION

1.1. Arctic contamination

The Arctic is a circumpolar land and sea mass that encompasses several countries and cultures. In northern Europe and North America there are few cities and population centres within this huge region and disturbances due to direct human activities are few. Consequently, it is popularly thought that this region is pristine and relatively unaffected by human disturbances. Unfortunately, this is not the case. In Arctic Russia, there are certainly some large cities and very large disturbances due to human activities. For example, in this area there has been dumping of reactor cores, nuclear testing on Novaya Zemlya, and smelting in the Kola pennisula (Nilsson 1997).

Ecosystems in the Arctic are being continuously exposed to contamination from anthropogenically produced organochlorine (OC) compounds. The primary mode of OC contamination to the Arctic is by atmospheric transport and to a lesser extent by oceanic currents and rivers flowing into the Arctic (MacDonald and Bewers 1996). A net transport of OCs occurs from warmer to colder regions (Ottar 1981) due to the increased fractionation and cold condensation of low volatility compounds in polar regions (Wania and Mackay 1993). Certain OCs (e.g. some PCB and chlordane compounds) are especially transferred from air to ocean as both become colder with higher latitudes (Iwata *et al.* 1993). Unlike transport by ocean currents, which can take years or even decades, atmospheric transport

of chlorinated compounds occurs in days (MacDonald and Bewers 1996).

Although considerable investigation of OC contamination has been carried out in the Arctic, most studies have focussed on monitoring residue levels in organisms and the long range transport of specific chemicals (Patton *et al.* 1989, Barrie *et al.* 1992, Muir *et al.* 1992a, MacDonald and Bewers 1996). The impact and fate of these contaminants is less well understood. Although we are aware of the extent of OC contamination in the Arctic, we do not know yet the dynamics of OCs within individual organisms or whether these contaminants are causing deleterious effects on animals and humans occupying the area.

High trophic-level organisms in the Arctic marine ecosystem, such as polar bears, may be particularly vulnerable to fat-soluble contaminants because of their low diversity of prey items and the long length of the food chain that supports them (MacDonald and Bewers 1996). My research constitutes the first effort to determine the fate of OC compounds in the tissues of a top-level mammalian predator, the polar bear (*Ursus maritimus*), which undergoes extreme annual fluctuations in adipose tissue.

1.2. Characteristics of organochlorine contaminants

Organochlorines are chlorinated hydrocarbons. These compounds have a wide range of physicochemical properties that determine their transport pathways, redistribution, and partitioning in the environment. For organisms, the octanol-water partition coefficient (K_{ow}), water solubility, and the structural characteristic of the compound can determine the extent of the chemical's bioaccumulation (Carey *et al.* 1998).

For species higher in the food chain, exposure to OC compounds occurs mainly

through food (Thomann 1981, Braune and Norstrom 1989, Muir *et al.* 1992, Suedel *et al.* 1994). As a result, uptake from the gastrointestinal tract is the primary process influencing an organism's actual exposure while blood is the mechanism whereby OCs are transported to the various tissues (Opperhuizen *et al.* 1985, Niimi and Oliver 1988). Bioaccumulation of halogenated hydrocarbons in mammals occurs in adipose tissue, blubber, liver, bone marrow, and brain tissue (Tanabe *et al.* 1981, Mossner *et al.* 1992). Mammals can either rid their bodies of OCs through metabolism or excretion. The liver is the primary site for metabolism, which is highly stereospecific, of chlorinated aromatic hydrocarbons for most vertebrates (Sijm *et al.* 1993). Excretion of unchanged OC compounds and metabolites can occur through feces, bile, urine, lactation, or through partitioning into gut contents (Rozman *et al.* 1981).

Laboratory studies have been used typically to assess the effects of OC compounds on organisms. Areas of research have addressed questions on mortality, reproduction, development, growth, neurology, immunology, and endocrinology (Carey *et al.* 1998). The response of the organism to OCs has been dependent on the magnitude and duration of exposure, the potency of the chemical, the tolerance of the organism, and the interactive effects of other chemicals or stressors (Carey *et al.* 1998). For most wildlife species, the effects and responses of OCs is unknown.

The characteristics of OCs, such as their persistence, affinity for fat, and toxicity, makes them potentially hazardous to wildlife. In addition, wildlife may influence their risk to OC contamination by the amount of lipid they ingest or accrue, their longevity, preferred habitat, lactation period, food-web structure and position (Bremle *et al.* 1997).

1.2.1. Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) are stable organic compounds that were used widely in many industrial processes (Eisler 1986, Tanabe 1988, Peterle 1991). There are 209 possible congeners of PCBs (Eisler 1986, Peterle 1991). Because of their stability and lack of reactivity, PCBs have been used in a wide array of industrial products including plasticizers, paints, dielectric fluids, waxes, and paper manufacturing (Amdur *et al.* 1991).

Only after worldwide use of PCBs did the toxicity and persistence of these compounds in the environment become evident. From 1930 to 1975, the total North American production of PCBs was estimated at 570×10^6 kg, with an additional import of 1.4×10^6 kg from Europe (Buckley 1982). Polychlorinated biphenyls have now been found globally in the tissues of mammals (Born *et al.* 1981, Martineau *et al.* 1987, Focardi *et al.* 1995, Mason *et al.* 1992, Miles *et al.* 1992, Muir *et al.* 1992*a*, 1992*b*, Norstrom *et al.* 1988, 1990, 1992, Kamrin and Ringer 1994). Not all of the congeners are equally worrisome. Depending on the congener's degree of chlorination and substitution pattern, the more persistent the PCB compound and, consequently, the greater the concern for toxicological effects (Eisler 1986, Sawhney 1986, Schiefer and Buzik 1990).

Even though PCBs have been banned in several developed countries, over 70% of the total worldwide production is still in use today (Buckley 1982). Recently, Russia has admitted that they still manufacture PCBs. In North America, approximately 95% of the total mass of PCBs produced or imported between 1930 and 1975 is either still in use today, in landfill sites, or is circulating in the environment (Buckley 1982). Marquenie and Reijnders (1989) calculated that only 1% of the world production of PCBs has reached the

oceans and so the marine environment is still at risk from future OC contamination.

Although the bioaccumulation and magnification mechanisms are not completely understood, PCB levels tend to increase proportionally with the trophic level and metabolic rate of the target organism (Masse *et al.* 1986). Metabolic rate, growth, lipid deposition, and reproduction control the food requirements of an organism and thus, the rate of contaminant uptake (Carey *et al.* 1998). Adverse effects of PCB contamination on mammalian reproduction tend to be manifested through consumption of contaminated food (Tanabe *et al.* 1993). Food is the only important source of exposure for mammals.

PCBs have been associated with impaired reproduction in mink (*Mustela vison*; Restum *et al.* 1998), growth and behavioural abnormalities in rats and mice (Collins and Capen 1980, Rosin and Martin 1981), and immunosuppression in bottlenose dolphins (*Tursiops truncatus*; Lahvis *et al.* 1995). Although the mechanisms by which PCB compounds can affect reproduction is unknown (Fuller and Hobson 1986), very low concentrations of these compounds have the ability to bring about deleterious developmental changes during critical embryonic, fetal, and early postnatal stages (Colborn and Smolen 1996). Young may suffer different health consequences than adults exposed to the same chemicals (Myers and Colborn 1991).

1.2.2. Hexachlorobenzene and hexachlorocyclohexanes

Hexachlorobenzene (HCB) and hexachlorocyclohexanes (HCHs) are highly stable in the environment and tend to accumulate in food chains. Hexachlorobenzene was used as a seed dressing to prevent fungal disease on grains, and was discontinued in most countries

in the 1970s. Hexachlorbenzene continues to be released into the environment as a byproduct and contaminant of many other chlorinated solvents (Toppari *et al.* 1996). β-hexachlorocyclohexane (β-HCH) is a byproduct in the manufacture of lindane, an insecticide, and has been found in the air and oceans as the most persistent HCH isomer. Bioaccumulation of β-HCH has taken place in invertebrates, fish, birds, humans and in mammals where the compound is stored in adipose tissue (Toppari *et al.* 1996).

Certain isomers of HCHs have been shown to cause central nervous system (Sahoo and Chainy 1998), reproductive and endocrine damage (Willett *et al.* 1998). Exposure of female mink to lindane during conception showed a decrease in reproductive efficiency when they were subsequently mated, leading to a 60% reduction in the number of kits born (Beard and Rawlings 1998). In addition, small quantities of β-HCH released from adipose tissue during fasting were sufficient to stimulate estrogen target tissues in mice (Bigsby *et al.* 1997).

1.2.3. DDT and DDE

Although the use of DDT as an insecticide in developed countries is now severely restricted, it is still being used extensively in some developing countries (Voldner and Li 1995). Global usage of DDT is estimated to be greater this decade than in the 1970s when it was banned in North America (Lindstrom *et al.* 1995). The DDT metabolite, DDE, is more persistent than the parent compound and readily accumulates in the food chain (Toppari *et al.* 1996). DDE has been shown to have estrogenic qualities and to act as an androgen antagonist which may affect the development of young animals either pre- or post-

natally (Dewailly *et al.* 1994, Kelce *et al.* 1995, Patlak 1996).

1.2.4. Chlordanes

Chlordane and heptachlor are insecticides that were once widely used in the United States, but now the use of chlordane is suspended and that of heptachlor is restricted. Technical chlordane contains a mixture of various chlordane isomers. Oxychlordane and heptachlor epoxide are the most persistent metabolites of technical chlordane (Toppari *et al.* 1996). Chlordanes are chlorinated cyclodienes that are now recognized as environmentally persistent and among the more toxic pesticides (Thomas and Colborn 1992).

These pesticides induce hepatic microsomal cytochrome P-450 (CYP) activity, and induce the monooxygenases which hydroxylate testosterone (Haake *et al.* 1987). In polar bears, chlordane (mainly the metabolite oxychlordane) has been shown to induce CYP2B enzymatic activity (Letcher *et al.* 1996). Polar bear hepatic microsomes also metabolized testosterone to a variety of oxidative products by induction of CYP3A and CYP2B enzymatic activity (Bandiera *et al.* 1995). Chlordane has been shown to affect spermatogenesis and cause degenerative changes in testicular tissue in mice (Balash *et al.* 1987).

1.3. Polar bears as biomonitors

Biomonitors are a species that are selected by humans to act as a representative indicator of environmental health. For monitoring Arctic contamination, the biomonitor would supply knowledge of the circumpolar distribution and temporal trends in

concentrations of OCs and would therefore, determine the sources and potential significance of these contaminants to arctic marine and maritime wildlife and humans (Norstrom *et al.* 1998).

Polar bears have been used as biomonitors to determine the prevalence and variation of persistent contaminants in the Arctic since the early 1970s (Bowes and Jonkel 1975, Norstrom *et al.* 1988, Norstrom and Muir 1994, Norstrom *et al.* 1998). Organochlorine concentrations in polar bear adipose tissue are given in Table 1.1. Polar bears were used as biomonitors primarily for four reasons (Norstrom *et al.* 1998). First, polar bears are found throughout the circumpolar basin; therefore, contaminant levels could be monitored in one species throughout the entire Arctic. Second, polar bears are philopatric and there is little exchange among populations. Third, the polar bear is the top predator of the Arctic marine ecosystem which is advantageous for OC monitoring for two reasons: 1) polar bears have relatively high longevity and low fecundity rates and 2) since organochlorines biomagnify at each level of the food chain, contaminant levels can be easily detected by instrumentation at higher concentrations. The third reason is because of the bears' feeding ecology. Polar bears feed primarily on ringed seals (*Phoca hispida*) and to a lesser extent on bearded seals (*Erignathus barbatus*) (Stirling and McEwan 1975). Therefore, most bears throughout the entire Arctic will have a similar food source that would facilitate comparison of contaminant profiles among different populations of bears.

1.3.1 Influence of the polar bear's feeding habits to OC contamination

Polar bears feed primarily on ringed seals and often prefer to consume the blubber,

Table 1.1 Organochlorine concentrations in polar bear (*Ursus maritimus*) adipose tissue (μg/g) based on lipid weight (lw) or wet weight (ww) from 1969 to 1994.

Year	Location	lw/ww	S-PCBs	S-CHLORs	S-DDTs	S-HCHs	S-ClBzs	Reference
1969	Western Hudson Bay	lw	1.9 - 4.5	0.6 - 1.9	0.39 - 2.03	0.12 - 0.38	0.09 - 0.15	(Norstrom *et al.* 1988)
1968-1972	Canadian Arctic and Subarctic	lw	0.2 - 80.6	-	0.03 - 4.56	-	-	(Bowes and Jonkel 1975)
1982-1984	Western Hudson Bay	lw	3.2 - 8.3	1.8 - 7.1	0.12 - 1.19	0.30 - 0.87	0.19 - 0.40	(Norstrom *et al.* 1988)
1978-1989	Svalbard, Norway	ww	2.9 - 90.0	-	0.1 - 3.4 (DDE)	0.05 - 1.5 (HCB)	-	(Norheim *et al.* 1992)
1990-1994	Svalbard, Norway	lw	4.8 - 80.3	0.1 - 8.3	0.02 - 1.82 (DDE)	0.03 - 1.5	-	(Bernhoft *et al.* 1997)
1989-1993	Circumpolar countries	lw	2.8 - 24.3	0.7 - 4.6	0.05 - 0.56	-	-	(Norstrom *et al.* 1998)

where lipophilic OCs concentrate (Stirling and McEwan 1975). Polar bears experience dramatic seasonal variation in food availability (Ramsay and Stirling 1988, Ramsay and Hobson 1991) with relatively brief periods of hyperphagia coupled with, at least in some populations, lengthy periods when foods are unavailable. The body mass of individual polar bears can more than triple during hyperphagic periods and adipose tissue may then constitute more than 50% of total body mass (Atkinson and Ramsay 1995). For most of the remaining year, polar bears from Churchill, Manitoba feed little and undergo lengthy fasts (Ramsay and Hobson 1991, Atkinson and Ramsay 1995). After extended fasting, adipose tissue depots may be reduced to less than 10% of body mass (Pond *et al.* 1992). The polar bear's high trophic status (Hobson and Welch 1992) coupled with its unique feeding ecology makes it particularly susceptible to OC contamination. The dynamics of OCs under such fluctuations of body fat reserves are virtually unknown, as most species investigated do not have a similar nutritional regimen.

Organochlorine compounds accumulate in lipophilic tissues and total body burdens are presumably affected by past and present nutritional status of the animal. Usually, biological data from mammals, such as body condition, are unknown (Augilar 1985, Aguilar and Borrell 1994). A novel approach in my research was to determine the change in body composition of each animal (percent body fat and lean body mass) during different nutritional stages and, subsequently, to determine the changes in total body burden of the contaminant. Previous contaminant studies on free-ranging animals have generally used cross-sectional sampling, animals captured on one occasion. Organochlorine concentrations and body burdens in mammals handled sequentially under different feeding regimes are unknown.

1.3.2. Influence of the polar bear's reproductive biology to OC contamination

Pregnant female polar bears from Churchill, MB can maintain themselves on stored fat, which can be up to 50% of their body mass, for eight months or more, during which they undergo post-implantation gestation and the first 2-3 months of lactation (Atkinson and Ramsay 1995). These females do not have access to any food during this period, and rely entirely on their adipose tissue reserves. The fate of stored lipophilic OCs during these fasts, while also undertaking gestation and lactation, is unknown.

When cubs-of-the-year (COYs) emerge with their mothers from maternity dens during March and April, they are about 3 months old and have been completely dependent on mother's milk for nutrition since birth. Polar bear cubs are born in a notably altricial state and experience a lengthy period of lactation (Ramsay and Dunbrack 1986). Polar bear milk has a high lipid content (approximately 30%) compared to other terrestrial species (Cook *et al.* 1970, Jenness *et al.* 1972) and during the mother's fasting period is formed entirely from her lipid and protein reserves. Any OCs found in cubs at the time of den emergence, therefore, must have been transferred from the mother *in utero* or via milk, since no other food sources are available to cubs at the den site. Soon after emergence from the den, families move onto the sea ice where they can hunt for seals. Cubs continue to nurse until weaning (at approximately 2 years), but lipid content and volume of milk per day decreases during the lactation period (Derocher *et al.* 1993), and solid food makes up an increasing proportion of the diet (Polischuk *et al.* in review).

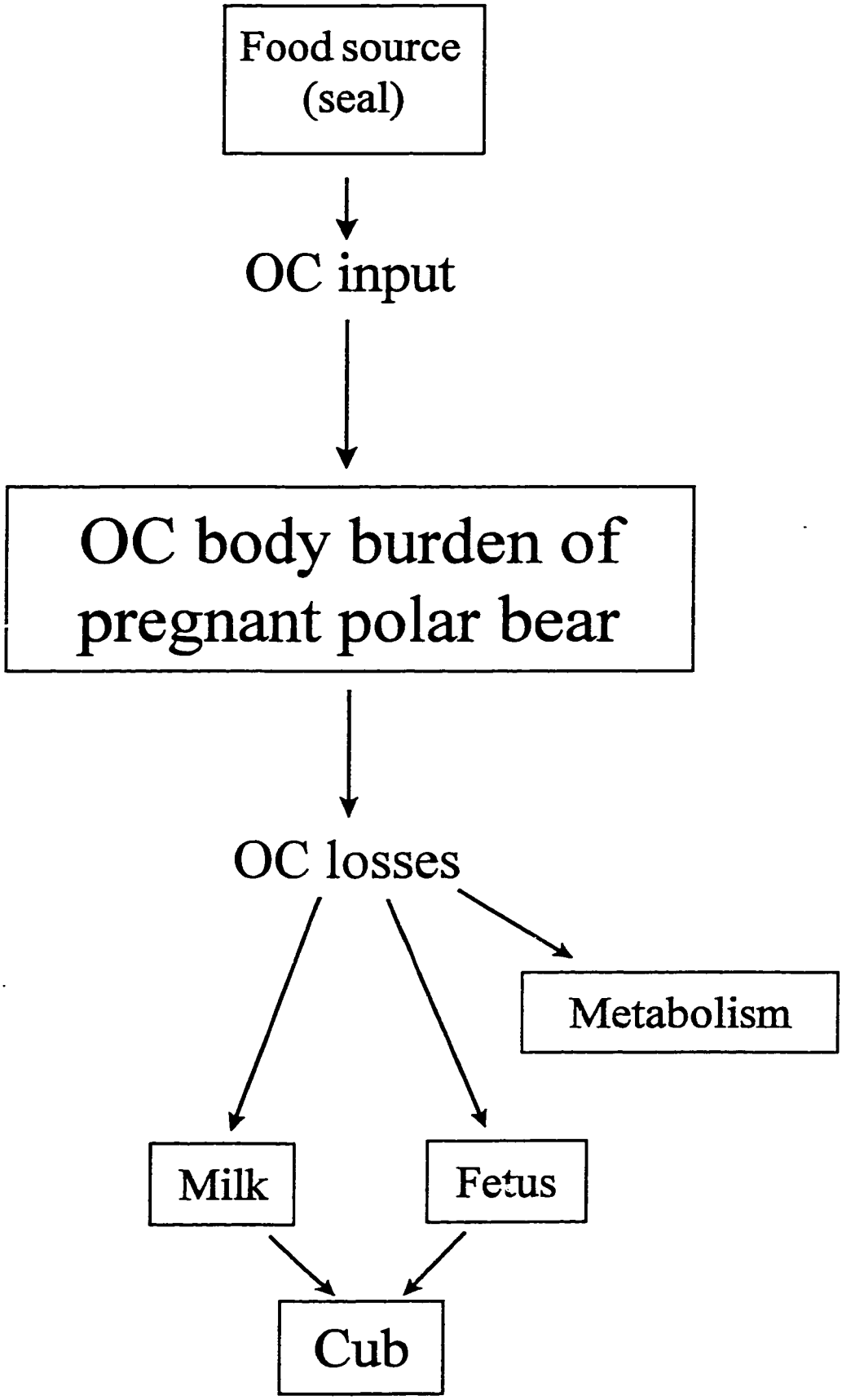
By determining the change in total body burden of OCs during gestation and

lactation, estimates of reproductive transfer of contaminants by females can be calculated. The total OC body burden of a pregnant female would have been attained by consumption of seals prior to embryonic implantation and her subsequent pregnancy (Fig. 1.1). During gestation, parturition, and early lactation, OC burden losses could be incurred via metabolism, lactation, and transfer to fetus (Fig. 1.1). Since fasting female polar bears rely almost exclusively on their fat stores while denning to avoid net catabolism of protein and net production of urine (Lundberg *et al.* 1976, Nelson 1980), loss of OCs via feces and urine during this period would likely not occur. Lactation provides a mechanism whereby a significant burden of OCs can be transferred from one generation to the next (Tanabe and Tatsukawa 1991). Cubs-of-the-year in spring receive a relatively higher OC burden from their mother than older yearling cubs (Polischuk *et al.* 1995) because COYs have a higher absolute milk consumption than yearlings (Arnould and Ramsay 1994). A major transfer of OC contaminants in milk from mother to young, therefore, may occur at a crucial point in the growth and development of young polar bear cubs.

1.4. Study objectives and chapter organization

Since OC contaminants are lipophilic and accumulate in adipose tissue, I wanted to determine how the bears' nutritional and reproductive status influenced their contaminant loads. The body condition of polar bears can vary widely during seasonal fasting periods and how this influences body burdens and concentrations of OCs is unknown. My first objective was to determine how fasting influenced total body burdens and concentrations of OCs in adipose tissue, plasma and milk (Chapter 2).

Figure 1.1. Routes of inputs and losses of organochlorine (OC) contaminants to the total OC body burden of pregnant polar bears.


Food source
(seal)
OC input
OC body burden of
pregnant polar bear
OC losses
Metabolism
Milk
Fetus
Cub

Having established the dynamics of the various groups of OC compounds in fasting bears, my second objective was to look at specific OCs in tissues of bears that had undergone changes in mass due to fat mobilization or deposition. By monitoring bears during a period of fasting and feeding, I established patterns of excretion or accretion of individual compounds in adipose tissue, plasma, and milk (Chapter 3). In Chapter 3, I also present longitudinal OC data on polar bears that had been captured sequentially on more than two occasions over a 4-year period.

Since pregnant females have the largest change in adipose tissue depots, my third objective was to investigate the dynamics of OC concentrations and body burdens in polar bears during pregnancy and the initial period of lactation. In Chapter 4, I examine the body burden loss of OCs by the mother and the subsequent transfer of contaminants to her natal cubs via lactation. By determining the amount of OCs transferred from mother to cubs, I established the relative exposure of OCs to cubs.

2. EFFECT OF SEASONAL FASTING ON ORGANOCHLORINE CONCENTRATIONS AND BODY BURDENS IN POLAR BEARS (*Ursus maritimus*)

2.1 Abstract

Polar bears have relatively high concentrations of lipophilic organochlorines (OCs) in their adipose tissues and the fate of these compounds during a seasonal fast is unknown. To investigate OC dynamics in the tissues of free-ranging polar bears, I collected samples of adipose tissue, plasma, and milk in summer near the beginning of fasting and in fall after 3-4 months of fasting. These tissues were analysed for the sum of chlorobenzenes (S-ClBzs), hexachlorocyclohexanes (S-HCHs), chlordanes (S-CHLORs), dichlorodiphenyl-trichloroethane compounds (S-DDTs) and polychlorinated biphenyls (S-PCBs). The body composition of all bears and their total body burdens of OCs were determined before and after fasting. The mean proportion of body mass lost as fat during fasting varied with status: females with yearlings (Fem/YRLGs) 62%, males 48%, females with cubs-of-the-year (Fem/COYs) 43%, yearling cubs (YRLGs) 43%, and cubs-of-the-year (COYs) 18%. Decreases in body mass during fasting ranged from 0.5 kg/day for yearlings to 0.9 kg/day for adult males. Body burdens of S-DDTs declined for most bears during fasting (12 - 194 μg/day) whereas the burden changes of other OCs varied with the bear status and also

among individuals. For example, males decreased their body burdens of S-CHLORs by 3100 ± 4284 μg/day during fasting while other classes did not change. Fat mass changes in COYs were significantly correlated with changes in their body burdens for all OCs, while this correlation was generally not evident for other classes. The OC body burdens of Fem/COYs were related to their body fat percentages as were the OC burdens of their cubs. Whereas the concentrations of S-DDTs in adipose tissue declined for most bears, the concentrations of the more chlorinated compounds increased. Concentrations of OCs in milk were higher than in mothers' adipose tissues, but were closely correlated.

2.2 Introduction

Polar bears are carnivores that occupy the top niche of the arctic marine food chain (Hobson and Welch 1992), and consequently, are exposed to the bioaccumulation and biomagnification of environmental contaminants (Norstrom *et al.* 1998). The fate of these compounds is unknown, but could be affected by dietary patterns. Polar bears feed primarily on ringed seals and often prefer to consume blubber (Stirling and McEwan 1975), where lipophilic organochlorines (OCs) concentrate. Polar bears experience dramatic seasonal variation in food availability (Ramsay and Stirling 1988, Ramsay and Hobson 1991) with relatively brief periods of hyperphagia coupled with, at least in some populations, lengthy periods when foods are unavailable. The body mass of individual polar bears can more than triple during hyperphagic periods and adipose tissue may then constitute more than 50% of total body mass (Atkinson and Ramsay 1995). For much of the remaining year, polar bears feed little and undergo lengthy fasts (Ramsay and Hobson 1991, Atkinson and Ramsay

1995). After extended fasting, adipose tissue depots may be reduced to less than 10% of body mass (Pond *et al.* 1992). Polar bears have evolved physiological and biochemical means to be one of the most proficient terrestrial mammals at undertaking extended fasts (Ramsay *et al.* 1991).

Their high trophic status (Hobson and Welch 1992) coupled with the large annual fluctuations in adipose tissue stores make them, among terrestrial mammals, particularly prone to OC contamination. The dynamics of OC compounds under such dramatic fluctuations of body fat reserves is virtually unknown, as most species investigated in toxicological studies to date do not have a similar nutritional regimen.

Organochlorine compounds accumulate in lipophilic tissues and total body burdens are presumably affected by the past and present nutritional and reproductive status of the animal. Contaminant studies on free-ranging animals have generally reported on the concentration of compounds from an animal tissue sampled only once. Additional biological data from study organisms, such as nutritional status and body composition, are usually unknown (Aguilar and Borrell 1994). Thus, whole body burden dynamics of OCs cannot be determined.

I studied the population of polar bears located in western Hudson Bay, Canada that live near the southern limits of the species' range. These bears come ashore each year when the ice melts in summer (July-August) and remain on land for 4-5 months until the Bay re-freezes (Ramsay and Stirling 1988). During their stay on land the bears fast and deplete their large adipose reserves that were accumulated prior to coming ashore.

For my first objective, I estimated the total body burden of OCs for all bears handled

and assessed body burden changes during fasting for animals handled sequentially. Second, I determined the effects of seasonal fasting on OC concentrations in adipose tissue, plasma, and milk collected from the animals. Third, I compared the relationship between OC body burdens and OC concentrations in adipose tissue to determine which reflected the best measure of contamination.

2.3 Methods

2.3.1 Field study

Polar bear plasma, milk, and adipose tissue samples were collected in the vicinity of Churchill, Manitoba (57°00' to 58°50' N, 92°25' to 94°15' W) during summer (July-August) and fall (September-November) of 1992-1996. Polar bears were immobilized from a helicopter using well-established methods (Stirling *et al.* 1989). Each adult female captured in summer was fitted with a radio-collar (Telonics Inc., Mesa, AZ) and adult males were fitted with ear-radios (Holohill Ltd., Woodlawn, ON) to allow relocation in fall. All bears handled were assigned a unique identifying number for subsequent identification when recaptured, which was applied as a tattoo to the upper lips and on matching ear tags. A vestigial premolar tooth was extracted from bears older than one year for age determination (Calvert and Ramsay 1998). Standard body measurements and mass were taken on all bears captured. Body composition (percent body fat and lean body mass) was determined by ^{2}H dilution for all bears handled (Farley and Robbins 1994, Atkinson and Ramsay 1995). Up to 80% of adipose tissue from adult polar bears is superficial and thus readily accessible (Pond *et al.* 1992). Adipose tissue (0.6cm x 1.0 cm, 200 mg) was obtained under anaesthesia by

superficial biopsy from the subcutaneous depot at the base of the tail, approximately 15 cm lateral to the midline (Ramsay *et al.* 1992). Blood samples were collected in heparinized vacutainer tubes via jugular catheterization. Blood was kept cool until centrifugation, when plasma was removed and frozen immediately at -20°C. Milk samples were collected by administering 1.0 ml oxytocin via the jugular catheter and palpating the teats. All samples were stored in individually pre-cleaned vials (rinsed three times each with acetone and *n*-hexane), sealed, and frozen at -20°C.

2.3.2 Laboratory analysis and statistics

Organochlorines in adipose tissue, milk and plasma were extracted and separated from methylsulphone metabolites and lipids (see Letcher *et al.* 1995 for separating methylsulphone metabolites from OC compounds). The subcutaneous adipose tissue portion (approximately 100-200 mg) of the biopsy was clipped off the skin into a tared, chemically cleaned scintillation vial and weighed. Approximately 1 g of sodium sulfate was added and mixed with the fat using a spatula. The mixture was weighed accurately and allowed to stand for 0.5 h before addition of 3 ml of 1:1 dichloromethane/*n*-hexane (DCM/hexane). The vial was swirled and allowed to stand for 0.5 h. The supernatant was removed and the mixture washed twice with 3 ml of 1:1 DCM/hexane. The vial was heated for 0.5 h at 100°C to drive off solvents and re-weighed to determine extractable lipid weight. The percent extractable lipid was determined by dividing the lipid weight of the sample by its wet weight. The majority of lipid removal was accomplished by gel-permeation chromatography and chromatography on 33% KOH/silica gel. Organochlorines were separated from

methylsulphone metabolites by chromatography on 1.2% water-deactivated Florisil.

Milk (3 g) was prepared by adding 3 ml of potassium oxalate and 3 ml of methanol. The potassium oxalate solution (0.1g/ml) was prepared by dissolving 10 g of ground potassium oxalate into 100 ml of distilled, deionized, *n*-hexane-washed water. The milk solution was mixed by using a vortex machine and then allowed to stand for 0.5 h. Lipids were extracted from milk by adding 6 ml of diethyl ether and 6 ml of *n*-hexane, vortexed and centrifuged. The supernatant was transferred to a flask and the extraction procedure was repeated twice. Hexane (15 ml) was added to the flask and the volume was reduced to approximately 1 ml by using a rotary evaporator. The residual was transferred to a 15 ml graduated centrifuge tube and adjusted to 10 ml with 1:1 DCM/*n*-hexane. One ml was removed for lipid determination and placed in a pre-weighed aluminum (Al) dish. The Al dish was heated for 0.5 h at 100°C to drive off solvents and re-weighed. The percent extractable lipid was determined by dividing the lipid weight of the sample by its wet weight. Milk fat (approximately 150 mg) was carried through the same OC separation procedure used for adipose tissue biopsies.

Plasma (6-7 ml) was weighed into a 50 ml screw top centrifuge tube and diluted with similar volumes (6-7 ml) each of *n*-hexane (washed with doubly-distilled water) and methanol. The mixture was vortexed and allowed to stand for 0.5 h. Lipids were extracted from plasma by adding 10 ml of 1:1 methyl tertbutyl ether (MTBE)/*n*-hexane, vortexed and centrifuged, and then allowed to stand for 0.5 h for phase separation to occur. The organic phase was removed and placed in a flask. The extraction procedure was repeated twice. The volume of the organic phase was reduced by using a rotary evaporator to approximately

1 ml, and then transferred to a graduated centrifuge tube and adjusted to 5 ml with *n*-hexane. The percent extractable lipid was determined by removing 0.5 ml of the mixture by pipette that was placed in a pre-weighed Al dish. The Al dish was heated for 0.5 h at 100°C to drive off solvents and re-weighed. The percent extractable lipid was determined by dividing the lipid weight of the sample by its wet weight. Plasma lipid was then carried through the same OC separation procedure used for adipose tissue biopsies and milk.

Adipose tissue, milk, and plasma were analysed for chlorobenzenes (ClBzs), hexachlorocyclohexanes (HCHs), chlordanes (CHLORs), DDTs, and polychlorinated biphenyl (PCBs). Organochlorines were determined in a single fraction by gas chromatography with a mass selective detector (GC/MSD) using a characterized polar bear adipose tissue extract as a secondary standard (Norstrom *et al.* 1998). Instrumentation consisted of a HP 5987B GC/MSD in the EI mode (70eV) equipped with a DB-5 capillary column (J & W Scientific Inc., 30-m x 0.25-mm i.d., 0.25-µm film thickness). All injections were 3 µl in the splitless mode with helium as the carrier gas. The initial temperature of 100°C was held for 3 min, then programmed to rise at 20°C/min to 180°C, and 3°C/min to 300°C. Injections port, transfer line, and ion source temperatures were 270°C, 300°C, and 300°C, respectively (Norstrom *et al.* 1998).

Adipose biopsy, milk, and plasma samples were spiked with 20 µl of a fully ^{13}C-labelled standard mixture of tetra- (2.5 ng/µl), penta- (2.5 ng/µl), and hexachlorobenzene (2.5 ng/µl), and CB-28 (2.0 ng/µl), CB-52 (2.0 ng/µl), CB-118 (2.1 ng/µl), CB-153 (2.1 ng/µl), CB-180 (2.0 ng/µl), and CB-194 (2.1 ng/µl) for percent recovery determination. All data were corrected to 100% recovery based on ^{13}C-labelled percent recovery results.

Correction factors were determined from a regression plot based on retention times and ^{13}C-labelled percent recovery results. The higher chlorinated ^{13}C-labelled PCBs had longer retention times and tended to have similar percent recoveries. Therefore, for these PCBs, the mean of the ^{13}C-labelled percent recovery results were determined and used as the correction factor. Just prior to GC/MSD analysis, 5µl of PCB-154 normalization standard was added. PCB-154 does not occur naturally in polar bear adipose tissue (Norstrom *et al.* 1988).

The sum of chlorobenzene compounds (S-ClBzs) is reported as the total of 1,2,4,5 tetrachlorobenzene (TeClBz), pentachlorobenzene (PnClBz), and hexachlorobenzene (HCB). The two isomers of hexachlorocyclohexane, α-HCH and β-HCH, are reported as the S-HCHs. The sum of chlordane compounds (S-CHLORs) includes 11 chlordane-related compounds that are found in polar bear tissue (Norstrom *et al.* 1998). Oxychlordane, heptachlor epoxide, trans-nonachlor, and MC-6 account for over 80% of the total sum of chlordanes. The sum of DDT related compounds (S-DDTs) include *pp*'DDE, *pp*'DDD, *pp*'DDT, with pp'DDE accounting for greater than 88% of the total sum. The sum of polychlorinated biphenyls is given as the sum of the 22 congeners that can be detected in polar bear tissues. Seven congeners account for greater than 80% of the total PCB congeners; PCB-99, PCB-153, PCB-138/163, PCB-180, and PCB-170. Adipose tissue and milk OC concentrations were determined based on lipid weight whereas plasma concentrations were based on wet weight.

Total body burdens of OC contaminants were calculated on all bears for which body composition was determined. Total body burden of OC was estimated by:

Total body fat (kg) x OC concentration (mg/kg, lipid weight)

Total body fat was determined as the difference between total body mass (weight of bear) and lean body mass (calculated from ^{2}H-dilutions) (Farley and Robbins 1992). Body burden changes during fasting were determined for all polar bears handled sequentially. Organochlorine concentrations were assumed to be similar for all adipose tissue depots. Norstrom (pers. comm.) found that organochlorine concentrations were similar for different adipose depot sites from polar bears.

Data were analysed using STATISTICA software (© 1997 StatSoft, Inc.). Wilcoxon Matched Paired Tests were used on all data where there were sequential samples collected. Pearson Product-Moment Correlations were used to determine relationships between two measured variables. A t-test was used to determine whether there was a significant difference in the milk lipid between summer and fall. All tests were considered significant at $p<0.05$.

2.4 Results

Mean percent of extractable lipids by weight in adipose tissue, plasma, and milk were as follows: adipose tissue 81.3 ± 7.9% ($n = 216$), plasma 0.09 ± 0.09% ($n = 192$), and milk 27.2 ± 8.6% ($n = 60$), respectively. Mean percent recoveries of ^{13}C-labelled internal standards for adipose tissue, plasma, and milk are given in Table 2.1.

2.4.1 Body composition changes

All bears that were handled sequentially lost total body mass during their seasonal

Table 2.1. Mean (±SD) percent recoveries of ^{13}C-labelled internal standards for adipose tissue, plasma, and milk from polar bears, Churchill, MB, and Resolute Bay, NWT.

^{13}C-standard	Adipose tissue $n = 198$	Plasma $n = 166$	Milk $n = 60$
^{13}C-TeClBz	61 ± 11	48 ± 9	57 ± 13
^{13}C-PnClBz	69 ± 10	52 ± 11	65 ± 15
^{13}C-HCB	86 ± 22	68 ± 13	76 ± 17
^{13}C-PCB-28	79 ± 11	55 ± 13	76 ± 11
^{13}C-PCB-52	80 ± 11	52 ± 14	77 ± 14
^{13}C-PCB-118	81 ± 11	47 ± 14	77 ± 12
^{13}C-PCB-153	81 ± 10	46 ± 13	77 ± 11
^{13}C-PCB-180	80 ± 11	46 ± 12	79 ± 13
^{13}C-PCB-194	80 ± 13	45 ± 15	75 ± 12

fast from summer to fall (Table 2.2). Of this mass loss, all bears lost lean mass and all, except for three cubs, lost body fat between sequential handlings. Two COYs and one YRLG gained body fat from summer to fall; 2.7 kg, 3.0 kg, and 4.9 kg, respectively. Cubs-of-the-year had the lowest proportion (18%) and Fem/YRLGs had the greatest proportion (62%) of mass loss as fat during the on-land period (Table 2.2). Mean percent body fat before and after fasting for each group is shown in Table 2.2. Note that COYs are consuming milk from their mothers during this period whereas mothers of YRLGs usually cease lactation as the fast progresses (October - November).

2.4.2 Changes in body burden of organochlorines

Total body burdens of S-DDTs generally decreased for all bears whereas there was no change in burdens of S-ClBzs and S-PCBs (Table 2.3). Whole body burden concentrations of OCs were determined for all bears captured in summer and in fall. Females with COYs, COYs, and YRLGs had higher body concentrations of S-CHLORs and S-PCBs after a period of fasting compared to the start of their fast (Table 2.4). Whole body concentrations of S-CHLORs in males decreased by half during fasting. Generally, COYs and YRLGs had the highest burdens per mass for S-ClBzs, S-CHLORs and S-PCBs, while COYs had the largest increase in their burden per mass of S-CHLORs and S-PCBs during the fasting period (Table 2.4). The body burden of S-DDTs in bears that were handled sequentially generally decreased during fasting (Table 2.4). Mean changes of OC body burdens per day in polar bears handled sequentially are given in Table 2.5. Notably, the body burden of S-CHLORs in males decreased by 3100 μg/day.

Table 2.2. Mean (± SD) change (δ) in total body mass, lean body mass, and body fat mass of females with cubs-of-the-year (Fem/COYs), females with yearlings (Fem/YRLGs), COYs, YRLGs, and male polar bears handled sequentially during a seasonal fast, Churchill, MB. The male group includes both sub-adult and adult bears. Mean (± SD) percent body fat before and after a fasting period and the proportion of mass loss as fat are shown for each group.

Status	*n*	Fasting period (days)	δ Mass (kg)	δ Lean body mass (kg)	δ Body fat (kg)	Percent body fat		Proportion mass loss as fat (%)
						before fasting	after fasting	
Fem/COYs	9	60 ± 14	-45 ± 22	-22 ± 9	-24 ± 19	29 ± 8	24 ± 6	43 ± 30
Fem/YRLGs	7	48 ± 25	-34 ± 28	-15 ± 16	-19 ± 13	29 ± 4	25 ± 4	62 ± 19
COYs	12	59 ± 13	-9 ± 5	-6 ± 2	-3 ± 6	24 ± 7	23 ± 4	18 ± 47
YRLGs	9	47 ± 23	-20 ± 9	-12 ± 9	-8 ± 6	29 ± 4	28 ± 4	43 ± 34
Males	10	68 ± 22	-65 ± 37	-34 ± 24	-32 ± 23	28 ± 9	23 ± 7	48 ± 25

Table 2.3. Mean (± SD) total body burden (mg) of organochlorines (OCs) in females with cubs-of-the-year (Fem/COYs), females with yearlings (Fem/YRLGs), COYs, YRLGs, and subadult and adult males (Males) handled sequentially in summer before fasting and in fall after fasting for 3-4 months. Asterisks designate significant differences between total burdens in summer and in fall (Wilcoxon Matched Pairs Test, *p<0.10, **p<0.05, ***p<0.005).

	n	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Fem/COYs	9					
before fast		7 ± 4	12 ± 9*	127 ± 76	14 ± 11**	142 ± 91
after fast		6 ± 3	9 ± 8	126 ± 74	7 ± 7	140 ± 86
Fem/YRLGs	7					
before fast		7 ± 2	10 ± 4	137 ± 45	15 ± 9**	150 ± 51
after fast		7 ± 2	8 ± 3	112 ± 32	8 ± 3	152 ± 62
COYs	12					
before fast		4 ± 2	4 ± 3***	70 ± 47*	3 ± 3***	62 ± 40
after fast		4 ± 3	3 ± 3	80 ± 63	2 ± 3	71 ± 51
YRLGs	9					
before fast		7 ± 5	8 ± 7	137 ± 76	9 ± 6	150 ± 70
after fast		7 ± 6	8 ± 9	151 ± 96	8 ± 9	160 ± 88
Males	10					
before fast		15 ± 13	25 ± 32**	371 ± 323**	26 ± 25***	277 ± 125
after fast		13 ± 11	10 ± 7	124 ± 58	12 ± 16	247 ± 185

Table 2.4. Mean (± SD) body burden (mg) of organochlorines (OCs) per mass (kg) in females with cubs-of-the-year (Fem/COYs), females with yearlings (Fem/YRLGs), COYs, YRLGs, and subadult and adult males (Males) handled sequentially in summer before fasting and in fall after fasting for 3-4 months. Asterisks designate significant differences of burden/mass (mg/kg) between summer and fall (Wilcoxon Matched Pairs Test, *p<0.10, **p<0.05, ***p<0.005).

	n	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Fem/COYs	9					
before fast		32 ± 16	52 ± 33	551 ± 307**	60 ± 46**	618 ± 367**
after fast		35 ± 16	46 ± 36	684 ± 352	38 ± 35	758 ± 403
Fem/YRLGs	7					
before fast		33 ± 14	49 ± 23	672 ± 332	69 ± 33**	724 ± 321
after fast		36 ± 12	43 ± 16	635 ± 234	45 ± 14	829 ± 280
COYs	12					
before fast		57 ± 31	59 ± 42**	1074 ± 698**	48 ± 52***	958 ± 585**
after fast		62 ± 47	48 ± 46	1430 ± 1078	31 ± 54	1276 ± 872
YRLGs	9					
before fast		53 ± 26*	60 ± 41	1024 ± 458**	67 ± 33	1125 ± 432**
after fast		62 ± 36	65 ± 65	1299 ± 602	62 ± 63	1389 ± 530
Males	10					
before fast		43 ± 25	65 ± 49**	1048 ± 656**	70 ± 40***	847 ± 215
after fast		46 ± 27	36 ± 15	501 ± 248	37 ± 33	911 ± 432

Table 2.5. Mean (± SD) change of organochlorine (OC) body burdens (μg/day) in polar bears handled sequentially during a seasonal fast, Churchill, MB. Declines of OC burdens per day are highlighted in bold.

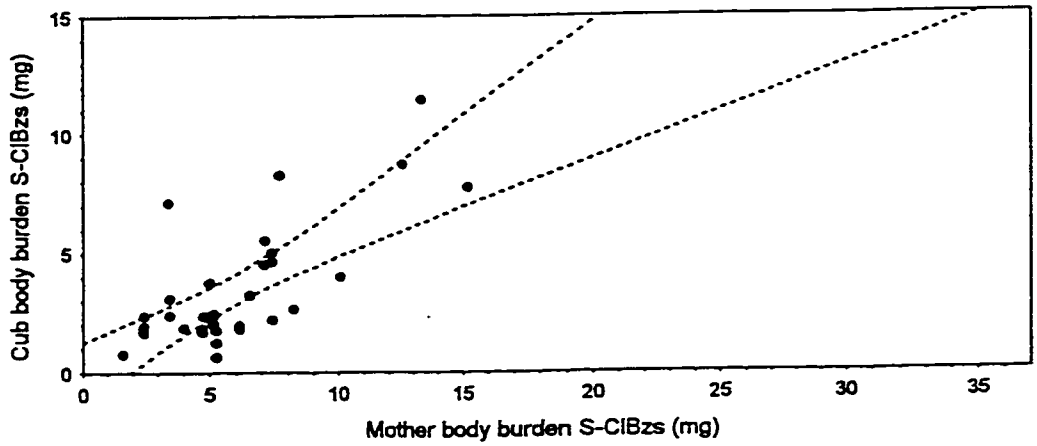
Status	*n*	δ S-ClBzs	δ S-HCHs	δ S-CHLORs	δ S-DDTs	δ S-PCBs
Fem/COYS	9	**-11 ± 35**	**-48 ± 75**	2175 ± 3045	**-120 ± 113**	41 ± 734
Fem/YRLGs	7	**-4 ± 26**	**-31 ± 42**	**-270 ± 597**	**-91 ± 89**	**-22 ± 599**
COYs	12	**-2 ± 18**	**-13 ± 15**	124 ± 324	**-16 ± 17**	110 ± 274
YRLGs	9	4 ± 22	1 ± 49	199 ± 453	**-12 ± 77**	150 ± 465
Males	10	**-32 ± 73**	**-205 ± 410**	**-3100 ± 4284**	**-194 ± 143**	**-462± 1499**

The body burdens of females with COYs correlated positively with those of their cubs (COYs) in both summer and fall for all OCs (Pearson Correlation $n = 33$: S-ClBzs r = 0.73, p = 0.000001; S-HCHs r = 0.87, p = 0.0000001; S-CHLORs r = 0.78, p = 0.0000001; S-DDTs r = 0.90, p = 0.0000001; S-PCBs r = 0.79, p = 0.0000001; see Fig. 2.1a-e). There was no correlation between the body burdens of females with YRLGs and those of their cubs (YRLGs) for S-ClBzs, S-DDTs, and S-PCBs while there was a significant correlation for S-HCHs and S-CHLORs (Pearson Correlation, $n = 18$: S-ClBzs r = -0.03, p = 0.91, S-DDTs r = 0.27, p = 0.27; S-PCBs r = 0.34, p = 0.17; S-HCHs r = 0.53, p = 0.02; S-CHLORs r = 0.65, p = 0.003).

Change in body fat was significantly correlated with change in OC body burdens for COYs during the fasting period (Pearson Correlation $p<0.05$; Table 2.6). Generally, this correlation was not evident for other categories of bears (Table 2.6). The percent body fat of females with COYs in summer and fall was correlated with the female's contaminant body burdens for all OCs (Pearson Correlation, $n = 24$: S-ClBzs r = 0.78, p = 0.000006; S-HCHs r = 0.72, p = 0.00008; S-CHLORs r = 0.58, p = 0.0031; S-DDTs r = 0.69, p = 0.0002; S-PCBs r = 0.48, p = 0.0168; see Figs. 2.2a-e) whereas this relationship did not hold true for females with YRLGs (Pearson Correlation, $n = 17$: S-ClBzs r = 0.14, p = 0.60; S-HCHs r = 0.17, p = 0.51; S-CHLORs r = -0.09, p = 0.72; S-DDTs r = 0.47, p = 0.07; S-PCBs r = -1.11, p = 0.67). The percent body fat of subadult and adult males correlated with total body burden of S-HCHs, S-CHLORs, and S-DDTs but not of S-ClBzs and S-PCBs (Pearson Correlation $p<0.05$, $n = 22$: S-ClBzs r = 0.42; S-HCHs r = 0.73; S-CHLORs r = 0.44; S-DDTs r = 0.50; S-PCBs r = 0.41).

Figure 2.1a-e. Correlation (r) between organochlorine body burdens (mg) for female polar bears with cubs-of-the-year (COYs) and their cubs in summer and fall from Churchill, Manitoba, Canada (1992-1996). Dashed lines indicate 95% confidence interval. Correlation coefficients for OCs are as follows: S-ClBzs $r = 0.73$, S-HCHs $r = 0.87$, S-CHLORs $r = 0.78$, S-DDTs $r = 0.90$, S-PCBs $r = 0.79$.

1a.


Cub body burden S-ClBzs (mg)
Mother body burden S-ClBzs (mg)
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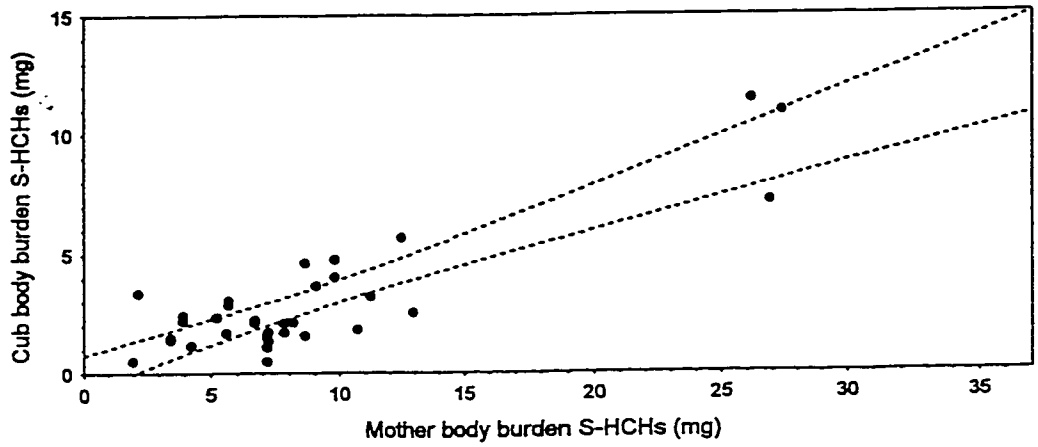
5
10
15
20
25
30
35

1b.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Mother body burden S-HCHs (mg)
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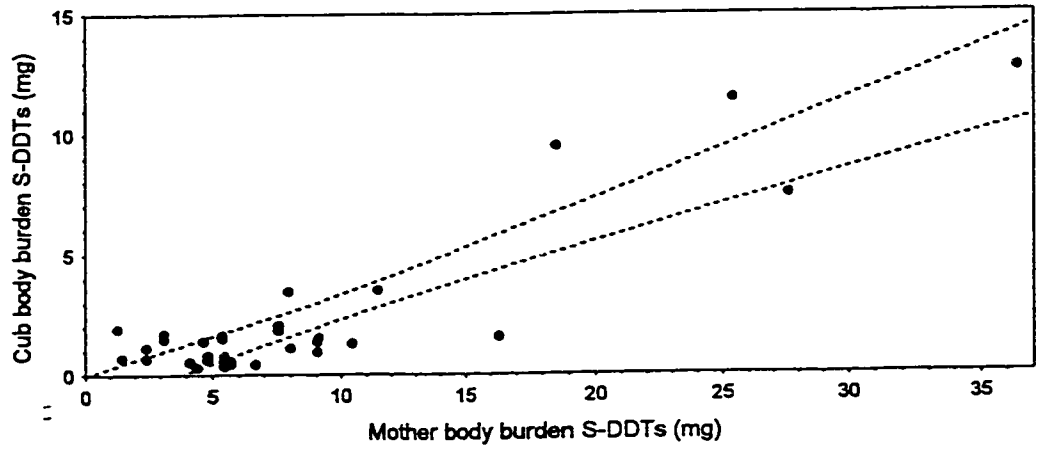
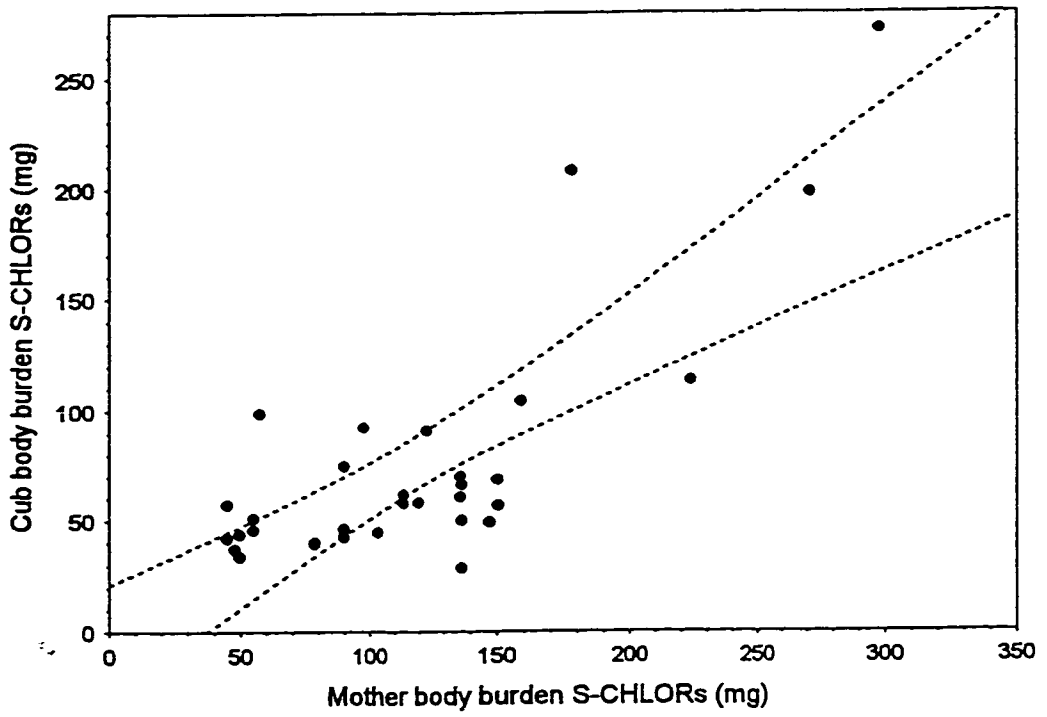
5
10
15
20
25
30
35

1c.


Cub body burden S-DDTs (mg)
Mother body burden S-DDTs (mg)
0
5
10
15
20
25
30
35

1d.


Cub body burden S-CHLORs (mg)
0
50
100
150
200
250
0
50
100
150
200
250
300
350
Mother body burden S-CHLORs (mg)

1e.

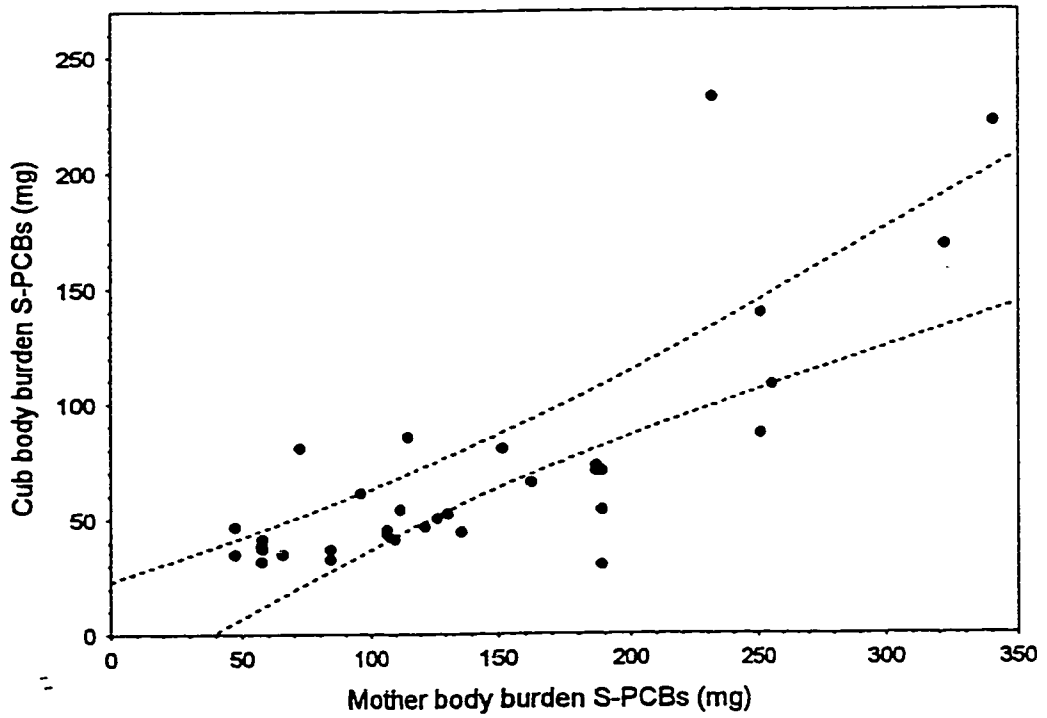
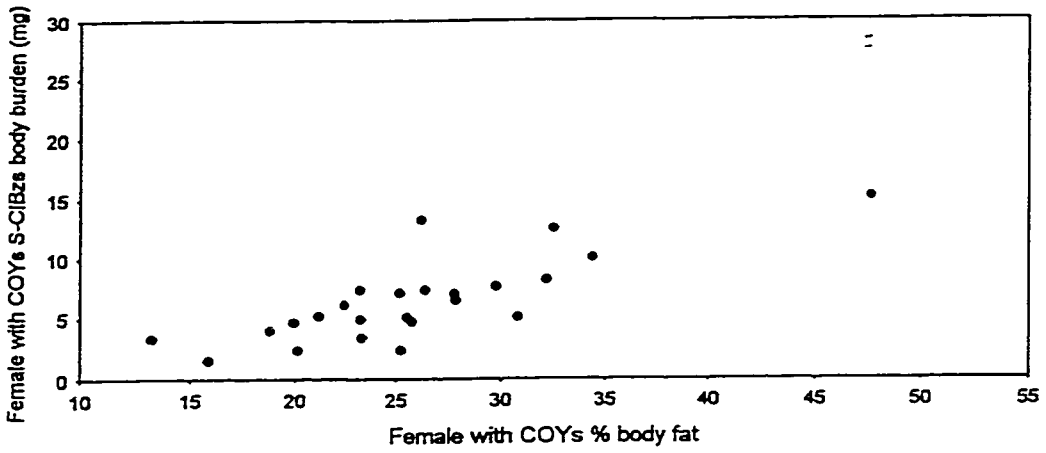

Cub body burden S-PCBs (mg)
0
50
100
150
200
250
0
50
100
150
200
250
300
350
Mother body burden S-PCBs (mg)

Table 2.6. Correlation coefficients (*r*) for change in fat mass (mg/day) and change in individual organochlorine burdens (mg/day) for polar bears captured during a period of fasting, Churchill, MB. Asterisk and bold type designate significant correlations between change in fat mass and change in body burden (Pearson Correlation $p<0.05$).

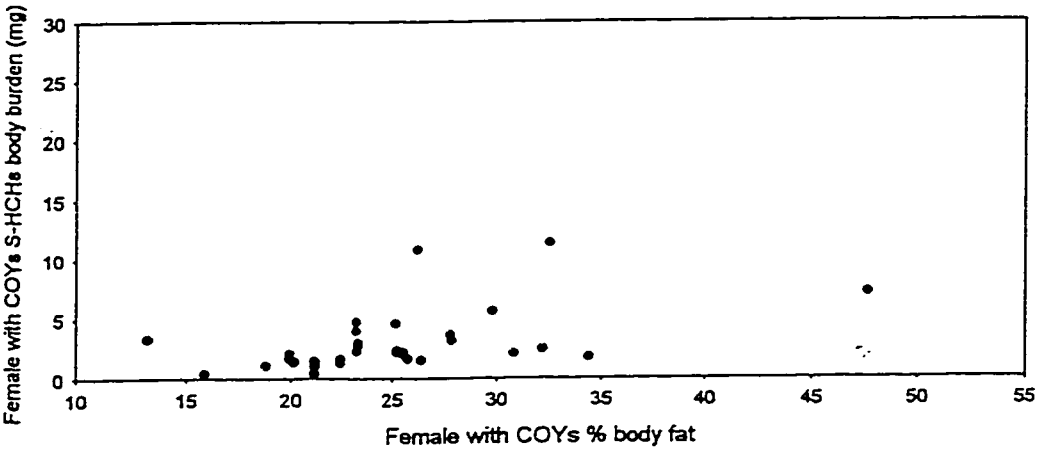
Status	*n*	S-ClBzs	p-value	S-HCHs	p-value	S-CHLORs	p-value	S-DDTs	p-value	S-PCBs	p-value
Fem/COYS	9	0.60	0.09	0.53	0.14	-0.19	0.63	***0.73**	**0.02**	0.66	0.06
Fem/YRLGs	7	-0.56	0.19	-0.39	0.38	-0.11	0.81	0.02	0.97	-0.51	0.24
COYs	12	***0.69**	**0.02**	***0.86**	**0.0003**	***0.69**	**0.01**	***0.78**	**0.003**	***0.82**	**0.001**
YRLGs	9	-0.25	0.52	-0.31	0.42	-0.23	0.55	-0.40	0.28	-0.24	0.53
Males	10	0.59	0.07	-0.07	0.85	0.38	0.27	***0.81**	**0.004**	-0.19	0.60

Figure 2.2a-e. Organochlorine body burdens (mg) and percent body fat for female polar bears with COYs in summer and fall from Churchill, Manitoba, Canada (1992-1996).

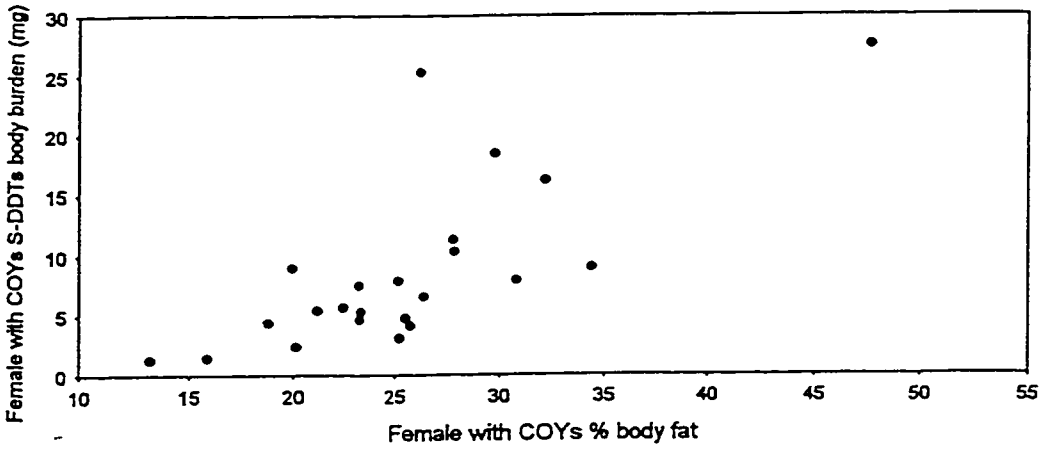
2a.


Female with COYs S-ClBzs body burden (mg)
0
5
10
15
20
25
30
10
15
20
25
30
35
40
45
50
55
Female with COYs % body fat

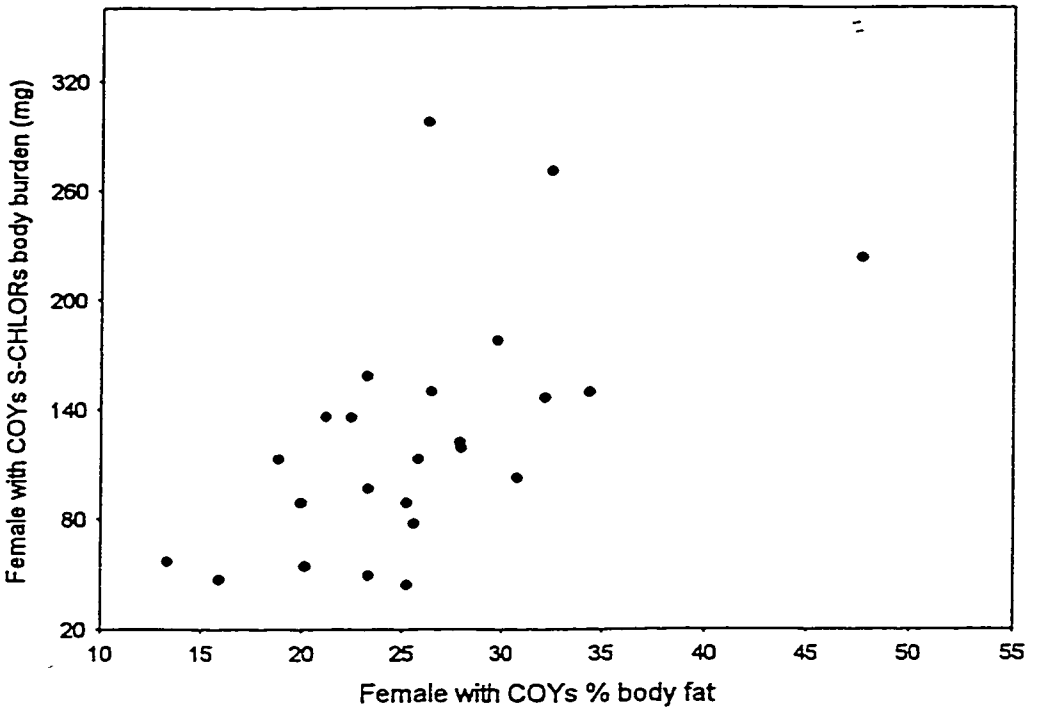
2b.


Female with COYs S-HCHs body burden (mg)
0
5
10
15
20
25
30
10
15
20
25
30
35
40
45
50
55
Female with COYs % body fat

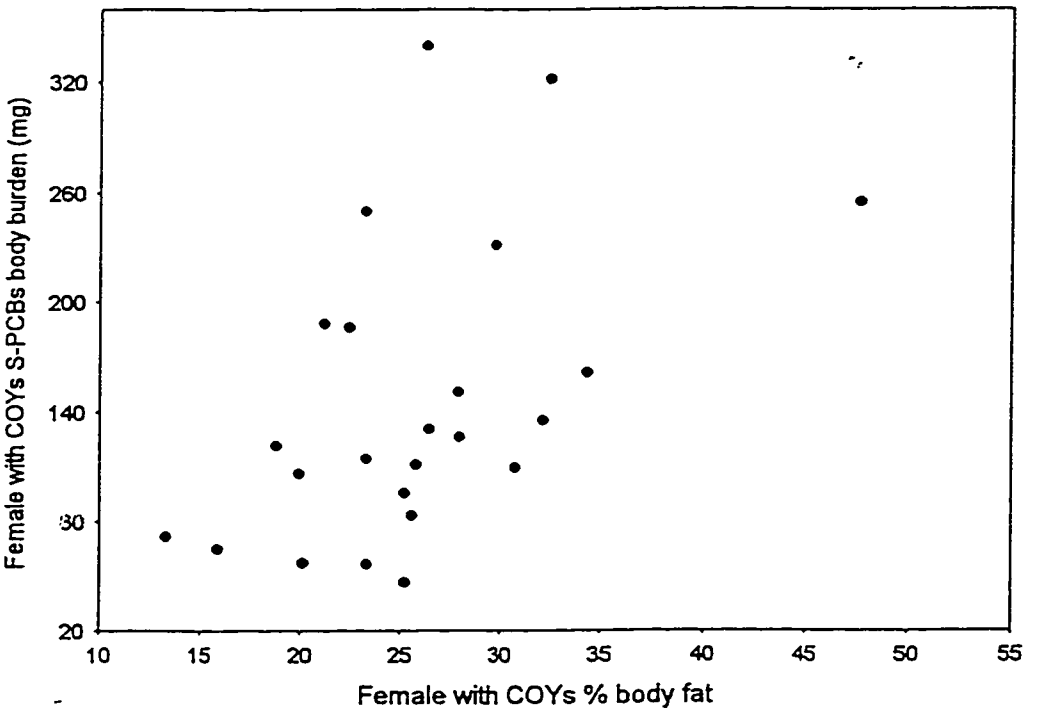
2c.


Female with COYs S-DDTs body burden (mg)
0
5
10
15
20
25
30
10
15
20
25
30
35
40
45
50
55
Female with COYs % body fat

2d.


Female with COYs S-CHLORs body burden (mg)
320
260
200
140
80
20
10
15
20
25
30
35
40
45
50
55
Female with COYs % body fat

2e.


Female with COYs S-PCBs body burden (mg)
320
260
200
140
30
20
10
15
20
25
30
35
40
45
50
55
Female with COYs % body fat

2.4.3. Changes in tissue concentration of organochlorines

2.4.3.1. Adipose tissue

The concentrations of S-ClBzs, S-CHLORs, and S-PCBs in adipose tissue generally increased in bears handled sequentially during fasting, whereas concentrations of S-HCHs and S-DDTs remained the same or decreased, respectively (Wilcoxon Matched Pairs Test: Fem/COYs $n = 9$, S-CLBzs $p = 0.008$, S-HCHs $p = 0.95$, S-CHLORs $p = 0.008$, S-DDTs $p = 0.02$, S-PCBs $p = 0.008$; Fem/YRLGs $n = 7$, S-CLBzs $p = 0.09$, S-HCHs $p = 0.74$, S-CHLORs $p = 0.24$, S-DDTs $p = 0.09$, S-PCBs $p = 0.03$; COYs $n = 12$, S-CLBzs $p = 0.58$, S-HCHs $p = 0.002$, S-CHLORs $p = 0.003$, S-DDTs $p = 0.002$, S-PCBs $p = 0.002$; YRLGs $n = 9$, S-CLBzs $p = 0.008$, S-HCHs $p = 0.77$, S-CHLORs $p = 0.008$, S-DDTs $p = 0.37$, S-PCBs $p = 0.008$; Males $n = 10$, S-CLBzs $p = 0.07$, S-HCHs $p = 0.33$, S-CHLORs $p = 0.09$, S-DDTs $p = 0.007$, S-PCBs $p = 0.11$; see Table 2.7). The mean change in OC concentration in adipose tissue for each class during fasting is given in Table 2.8.

2.4.3.2 Plasma

Changes in plasma OC concentrations were less common than in adipose tissue (Table 2.9). The concentration of S-DDTs in plasma from males and YRLGs decreased and the concentration of S-CHLORs in plasma from Fem/COYs increased during fasting, whereas for most other classes OC concentrations in plasma remained the same (Wilcoxon Matched Pairs: Fem/COYs $n = 8$, S-CLBzs $p = 0.26$, S-HCHs $p = 0.58$, S-CHLORs $p = 0.04$, S-DDTs $p = 0.78$, S-PCBs $p = 0.07$; Fem/YRLGs $n = 5$, S-CLBzs $p = 0.89$, S-HCHs $p = 0.22$, S-CHLORs $p = 0.69$, S-DDTs $p = 0.14$, S-PCBs $p = 0.69$; COYs $n = 12$, S-CLBzs

Table 2.7. Mean (± SD) organochlorine (OC) concentrations (μg/kg, lipid wt) in adipose tissue from females with cubs-of-the-year (Fem/COYs), females with yearlings (Fem/YRLGs), COYs, YRLGs, and subadult and adult males (Males) in summer before fasting and in fall after 3-4 months of fasting. Significant changes in adipose tissue OC concentrations for polar bears captured sequentially during their on-land seasonal fast are designated with an asterisk * $p<0.10$, ** $p<0.05$, *** $p<0.005$, Wilcoxon Matched Pairs Test).

	n	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Fem/COYs	9					
before fast		105 ± 37**	171 ± 80	1835 ± 812**	196 ± 125**	2063 ± 1002**
after fast		143 ± 53	183 ± 130	2820 ± 1211	149 ± 128	3163 ± 1486
Fem/YRLGs	7					
before fast		116 ± 61*	177 ± 101	2406 ± 1443	244 ± 128*	2601 ± 1419**
after fast		149 ± 62	182 ± 83	2723 ± 1353	189 ± 69	3476 ± 1445
COYs	12					
before fast		239 ± 112	249 ± 159***	4717 ± 2901***	196 ± 199***	4261 ± 2573***
after fast		261 ± 168	201 ± 166	6123 ± 3965	128 ± 201	5508 ± 3289
YRLGs	9					
before fast		177 ± 67**	197 ± 108	3506 ± 1323**	223 ± 94	3876 ± 1389**
after fast		224 ± 119	229 ± 217	4798 ± 2135	221 ± 212	5158 ± 1989
Males	10					
before fast		149 ± 72*	240 ± 156*	4145 ± 2558*	238 ± 102**	3409 ± 1540
after fast		186 ± 103	146 ± 52	2155 ± 1186	149 ± 134	3975 ± 1872

Table 2.8. Mean (± SD) change (x) in OC concentrations in adipose tissue for polar bears handled sequentially during a period of fasting. Mean decreases in concentration are given in bold-type.

Status	*n*	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Fem/COYS	9	1.4 ± 0.1	1.0 ± 0.3	1.6 ± 0.2	**0.8 ± 0.2**	1.6 ± 0.3
Fem/YRLGs	7	1.4 ± 0.6	1.1 ± 0.5	1.3 ± 0.3	**0.9 ± 0.4**	1.5 ± 0.6
COYs	12	1.1 ± 0.2	**0.8 ± 0.2**	1.3 ± 0.2	**0.6 ± 0.2**	1.3 ± 0.1
YRLGs	9	1.2 ± 0.2	1.0 ± 0.3	1.4 ± 0.2	**0.9 ± 0.5**	1.3 ± 0.2
Males	10	1.2 ± 0.6	0.8 ± 0.5	**0.9 ± 0.8**	**0.6 ± 0.3**	1.3 ± 0.6

Table 2.9. Mean (± SD) organochlorine (OC) concentrations (μg/kg, wet wt) in plasma from females with cubs-of-the-year (Fem/COYs), females with yearlings (Fem/YRLGs), COYs, YRLGs, and subadult and adult males (Males) in summer before fasting and in fall after 3-4 months of fasting. Significant changes in adipose tissue OC concentrations for polar bears captured sequentially during their on-land seasonal fast are designated with an asterisk * $p<0.10$, ** $p<0.05$, *** $p<0.005$, Wilcoxon Matched Pairs Test).

	n	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Fem/COYs	8					
before fast		1.4 ± 0.7	4.0 ± 3.1	14.9 ± 9.0**	3.1 ± 3.4	22.0 ± 19.7*
after fast		1.6 ± 0.8	3.8 ± 3.1	21.6 ± 9.8	5.7 ± 10.5	31.0 ± 24.8
Fem/YRLGs	5					
before fast		2.2 ± 0.7	4.5 ± 2.3	23.4 ± 15.7	2.3 ± 0.7	28.6 ± 21.8
after fast		2.2 ± 0.3	2.7 ± 1.0	25.2 ± 13.8	1.4 ± 0.5	30.9 ± 16.3
COYs	12					
before fast		3.3 ± 1.5*	5.3 ± 4.2	49.6 ± 30.7*	2.5 ± 2.1	48.8 ± 28.8
after fast		2.9 ± 1.6	3.9 ± 3.2	38.4 ± 20.0	3.3 ± 6.3	45.1 ± 25.9
YRLGs	7					
before fast		4.1 ± 2.6**	8.5 ± 6.2	38.0 ± 17.6	4.3 ± 2.8**	41.6 ± 20.8
after fast		3.8 ± 2.3	3.2 ± 1.5	41.4 ± 29.5	1.9 ± 1.1	41.6 ± 28.3
Males	10					
before fast		2.7 ± 1.1	3.1 ± 1.7	17.0 ± 10.7	2.1 ± 1.9**	23.2 ± 15.6*
after fast		2.6 ± 1.3	2.6 ± 2.0	21.0 ± 14.3	0.8 ± 0.6	42.7 ± 46.3

p = 0.07, S-HCHs p = 0.12, S-CHLORs p = 0.10, S-DDTs p = 0.18, S-PCBs p = 0.24; YRLGs n = 7, S-CLBzs p = 0.40, S-HCHs p = 0.04, S-CHLORs p = 0.74, S-DDTs p = 0.03, S-PCBs p = 0.74; Males n = 10, S-CLBzs p = 0.88, S-HCHs p = 0.44, S-CHLORs p = 0.14, S-DDTs p = 0.03, S-PCBs p = 0.07). Plasma concentrations correlated positively with adipose tissue concentrations for S-ClBzs, S-CHLORs, and S-PCBs (Pearson Correlation $p<0.05$, n = 113; r = 0.35, r = 0.53, and r = 0.35, respectively), but showed no significant relationship for S-HCHs and S-DDTs (Pearson Correlation n = 113; r = -0.04 and r = 0.01, respectively).

2.4.3.3 Milk

For females with COYs handled sequentially, the levels of S-CHLORs and S-PCBs in milk increased during fasting (Wilcoxon Matched Pairs n = 7: S-ClBzs p = 0.09; S-HCHs p = 0.50; S-CHLORs p = 0.02; S-DDTs p = 0.87; S-PCBs p = 0.02) while females with YRLGs did not have any significant changes in milk OC concentrations during fasting (Wilcoxon Matched Pairs n = 3: S-ClBzs p = 1.00; S-HCHs p = 0.11; S-CHLORs p = 0.59; S-DDTs p = 0.11; S-PCBs p = 0.59 (Table 2.10).

Organochlorine concentrations in milk were correlated positively with adipose tissue concentrations for each bear (Pearson Correlation $p<0.05$, n = 33: S-ClBzs r = 0.34; S-HCHs r = 0.52; S-CHLORs r = 0.57; S-DDTs r = 0.43; S-PCBs r = 0.42). There was no correlation between the mother's OC concentrations in milk and body burdens (Pearson Correlation, n = 32: S-ClBzs r = 0.30; S-HCHs r = 0.33; S-CHLORs r = 0.31; S-DDTs r = 0.34; S-PCBs r = 0.14). However, the OC concentrations in milk from mothers with COYs

Table 2.10. Mean (± SD) organochlorine (OC) concentrations (μg/kg, lipid wt) in milk from females with cubs-of-the-year (Fem/COYs) and females with yearlings (Fem/YRLGs). Significant changes in adipose tissue OC concentrations for polar bears captured sequentially during their on-land seasonal fast are designated with an asterisk * $p<0.10$, ** $p<0.05$, *** $p<0.005$, Wilcoxon Matched Pairs Test).

	n	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Fem/COYs	7					
before fast		236 ± 118*	276 ± 92	2607 ± 500**	141 ± 32	1960 ± 380 **
after fast		348 ± 188	368 ± 251	4547 ± 1737	143 ± 118	3575 ± 1053
Fem/YRLGs	3					
before fast		462 ± 126	683 ± 316	4709 ± 1243	409 ± 226	4392 ± 1482
after fast		375 ± 195	326 ± 335	5243 ± 4537	197 ± 104	5124 ± 4700

correlated with her cub's adipose tissue concentrations for the following OCs: S-HCHs r = 0.66, S-CHLORs r = 0.80; YRLGs n = 9, S-CHLORs r = 0.88 (n = 21, Pearson Correlations all $p<0.05$).

2.4.4 Lactational transfer of OCs during fasting

Estimated daily milk yields of female polar bears with COYs during the summer ice-free period in western Hudson Bay was 680g/day (Arnould and Ramsay 1994). The percent lipid in milk significantly decreased during the fasting period, from 27.6 % ± 5.0% to 18.1% ± 12.3% ($t = 2.26$, $df = 19$, $p<0.05$) while milk OC concentrations increased (Table 2.10). Therefore, I calculated the total amount of OCs transferred by mothers to their cubs during fasting as follows

$$B_m = \sum_{n=1}^{n=d} k \times l(n) \times C_{OC}(n)$$

where B_m is the burden loss that occurred via milk transfer (mg), d is the number of days between captures, k is the daily milk yield, l is the percent lipid in milk, and C_{OC} is the concentration of the organochlorine in milk (mg/kg, lipid wt). The estimated OC burden transferred through lactation during the fasting period was 2.6 ± 1.7 mg for S-ClBzs, 2.6 ± 1.1 mg for S-HCHs, 30.5 ± 12.9 mg for S-CHLORs, 1.2 ± 0.7 mg for S-DDTs, and 22.8 ± 9.7 mg for S-PCBs.

2.5 Discussion

Tissue concentrations and body burdens of OCs varied among bears during fasting between summer and fall. Even within the same group, the concentrations and body burdens of some OCs in bears were extremely variable. Several factors could be influencing the dynamics of OC compounds, such as nutritional condition of the animal (*e.g.*, percent body fat) at the beginning of fasting. The nutritional condition of polar bears during fasting presumably dictates how they use body reserves to meet their daily energy requirements. Bears that have a high percent body fat at the start of their fast will likely use their adipose tissue depots as their primary source of energy, whereas bears that are leaner will access relatively more of their protein mass for energy (Atkinson *et al.* 1996, Polischuk *et al.* in review). The dynamics of OC mobilization, therefore, will be influenced by whether the bear is primarily using its adipose tissue or protein mass as an energy source.

Nutritional condition influences the concentrations and burdens for all OCs (except for S-DDTs which significantly declined) during fasting. Other factors that can affect body concentrations and burdens after a fast are the initial OC concentration in tissues, the initial OC body burden, the length and timing of a recent lactation bout (Rogan *et al.* 1986), the lipid content of milk (Pomeroy *et al.* 1996), and the length of a fast prior to sampling. One datum I could not know was exactly how long the bears had been fasting prior to initial capture.

2.5.1 Comparison of adipose and plasma concentrations with body burden

The "concentration" of some OC compounds was highly dependent on the nutritional

status of the bear. Fatter bears had lower OC concentrations than did leaner bears. Whole body concentrations (calculated as the body burden of an OC divided by its body mass) yielded similar results. Total body burdens, however, were not dependent on nutritional status and showed whether compounds were being metabolized or excreted without metabolism.

Since the dynamics of OC concentrations and burdens during fasting were influenced by the nutritional and reproductive status of the bear, handling individuals sequentially was very useful to access the effects of fasting. Bears handled sequentially during fasting from summer to fall generally showed increased concentrations of S-ClBzs, S-CHLORs, and S-PCBs in adipose tissue, which resulted in there being no change in OC body burdens for these compounds (note, however, that S-CHLORs for adult males did not follow this trend). Apparently, polar bears were not able to significantly rid their bodies of these OCs as lipid reserves were depleted during a seasonal fast, indicating that the half-life of these compounds is relatively long. By contrast, S-DDTs concentrations decreased in adipose tissue during fasting which resulted in decreased body burdens. Polar bears during their seasonal fast significantly decreased their body burden of S-DDTs within 3-4 months, suggesting that they were able to metabolize S-DDTs as readily as their adipose lipid.

Since S-DDTs do not increase in concentration over time in tissues of polar bears, they appear to have an ability to readily metabolize S-DDTs (Norstrom *et al.* 1988) which is unlike seals and bats (Clark and Prouty 1976). Muir *et al.* (1988) speculated that the low biomagnification factor of DDE in polar bears was indicative of metabolism. Biomagnification refers to a process by which the tissue concentrations of chemical residues

increase as these materials pass up the food chain through two or more trophic levels (Macek *et al.* 1979)

When body burdens did not change during a fast (e.g., for S-ClBzs, S-CHLORs, and S-PCBs), plasma concentrations of these compounds were correlated positively with adipose tissue levels, whereas, when burdens declined (e.g., for S-HCHs in COYs and S-DDTs), there was no correlation.

In both Canadian and Svalbard populations, male polar bears have been shown to have lower concentrations of S-CHLORs than females (Norstrom and Muir 1994, Bernhoft *et al.* 1997). My data show that male polar bears, unlike females, decreased their body burdens of S-CHLORs while fasting, presumably by metabolizing them. The inter-sexual difference in excretion capabilities of chlordane compounds during a period of fasting indicates that there are probably differences in structure-related metabolism of chlordane compounds rather than differences in source of chlordane (*e.g.*, hunting locations for seals, feeding on different age-classes of seals or different parts of seal). The mechanism by which males are able to effectively decrease their body burdens of chlordanes is unknown but may be related to male-specific CYP450s or to a higher induction (or inducibility) of specific enzymes, although sex differences in CYP450 capabilities has not been shown for other species.

In polar bears, metabolism of Ah-receptor active xenobiotic chemicals is directly proportional to the CYP1A content in their liver (Letcher *et al.* 1996). Total ortho-PCB and total chlordane compounds (mainly oxychlordane) have been shown to be the major contributors to CYP2B induction (Letcher *et al.* 1996). CYP1A and CYP2B contents are

therefore good indicators of CHC exposure in polar bear liver.

2.5.2 Comparison of adipose and milk concentrations with body burden

As mothers depleted their adipose reserves during fasting, chlorinated OC compounds (S-CHLORs and S-PCBs) became more concentrated. The concentration of these OCs also increased significantly in the milk of females with COYs as the milk lipid levels declined during the same period. A similar pattern of PCBs rise in milk is seen in women losing mass during lactation (Ramos *et al.* 1997).

All OC body burdens in females (except for the S-DDTs) did not change during fasting. My interpretation of these results is that there was not a significant amount of OCs transferred via lactation. This conclusion is supported by the lack of an increase in cub OC burdens during the same period. The composition of polar bear milk, particularly fat content, changes through lactation for fasting bears (Derocher *et al.* 1993). The lipid content of milk decreased during fasting which would also decrease the partitioning of OCs from adipose tissue lipid to milk lipid. Skaare and Polder (1990) found a significant downward trend in PCB residue levels with a decrease in milk fat.

Even though I took into account the variation in milk lipid content to estimate OC transfer via lactation, my calculations for the amount of OCs transferred from mother to cub were greater (e.g., S-CHLORs and S-PCBs) than the actual burden changes that occurred in the cubs. The cubs, therefore, may have had a lower daily milk intake during fall than that estimated by Arnould and Ramsay (1994) for the summer period. Another explanation could be that the cubs were metabolizing or excreting all compounds that were ingested during the

on-land period. Since the cubs are feeding, clearance by biliary excretion or partitioning into gut contents may be occurring and could account for the discrepancy in the mass balance between cubs and lactational transfer.

When the mother's fat mass and milk lipid content decreased during fasting, the burden of OCs transferred was non-detectable. During feeding, however, the fat mass of the mother and the milk lipid content of her milk is relatively constant (Derocher *et al.* 1993). Whether there is a significant transfer of OCs via lactation during feeding periods is unknown.

Pregnant females consume more seals (Stirling and Øritsland 1995) in the years they conceive to attain large adipose reserves to carry them through a successful pregnancy. The contaminant loads ingested are stored in their adipose tissue. The subsequent correlation between OC body burdens in mothers and their young cubs (see Fig. 2.1) suggests that females passed their contaminant burdens directly to their cubs via lactation. After a year of lactation, however, this correlation no longer held for most OCs.

2.5.3 Implications for young cubs

There appeared to be no significant net transfer of OC compounds from mothers to cubs during the periods of lactation that I monitored. Although I found the adipose tissue concentrations of the more chlorinated compounds increased during the on-land period, the body burdens of all OCs did not increase. Actually, the body burden of S-HCHs and S-DDTs decreased in COYs during fasting.

Although COYs during the seasonal fasting period do not appear to be at risk to OC

contamination, these fasting polar bear cubs are growing and at the same time losing body mass (Arnould and Ramsay 1994). Geyer *et al.* (1993) found that there was a direct positive correlation with LC_{50} of OCs and percent body fat. The early neonatal period (2-4 months) for polar bears cubs is a period where they have very little body fat (4-15%). Young animals with low levels of total body lipids could possibly be sensitive to the toxic effects of OCs since young do not have excess adipose reserves in which to sequester the compounds.

The long-term consequences of OC exposure during fasting in early life are little known in mammals and our studies were not directed to answering such questions. In mammalian species, postnatal functional alterations are the most sensitive adverse developmental effects of OCs (Peterson *et al.* 1993). These include effects on the male reproductive system of rats and object-learning behaviour in monkeys (Peterson *et al.* 1993). In humans, Inuit infants who consumed milk with high OC concentrations (111 μg/L) had depressed immune function (Reece 1987) and higher infection rates (10- to 15- fold greater) than infants who consumed milk with low OC concentrations (28 μg/L; Dewailly *et al.* 1989). At present, such reproductive, behaviour, and immune effects are not evident in polar bears.

3. ORGANOCHLORINE CONCENTRATION AND COMPOSITIONAL CHANGE IN SEQUENTIALLY HANDLED POLAR BEARS (*Ursus maritimus*)

3.1. Abstract

I captured polar bears in Churchill, MB during a period of fasting and in Resolute Bay, NWT during a period of feeding to determine the dynamics of OC compounds. From these animals, I collected adipose tissue, plasma, and milk samples, before and after periods of fasting and feeding, and analyzed them for chlorobenzenes (S-ClBzs), hexachlorocyclohexanes (S-HCHs), chlordanes (S-CHLORs), dichlorodiphenyl-trichlorethane compounds (S-DDTs), and polychlorinated biphenyls (S-PCBs). During fasting, changes in the composition of OC compounds in adipose tissue were generally similar for all bears except for changes in composition of chlordane compounds for male polar bears. Unlike females and cubs, the amount of oxychlordane in adipose tissue of males significantly decreased during fasting. In milk, the proportion of lesser chlorinated biphenyls (CBs) generally decreased during fasting, whereas the proportion of higher chlorinated CBs increased. Compositional changes of OCs in milk during fasting were similar to the changes that occurred in cub adipose tissue during the same period. Females who subsequently lost their COYs had significantly higher mean OC concentrations in their milk in spring than did females who kept their COYs (S-PCBs 70% higher, S-CHLORs 60% higher, S-HCHs 58%

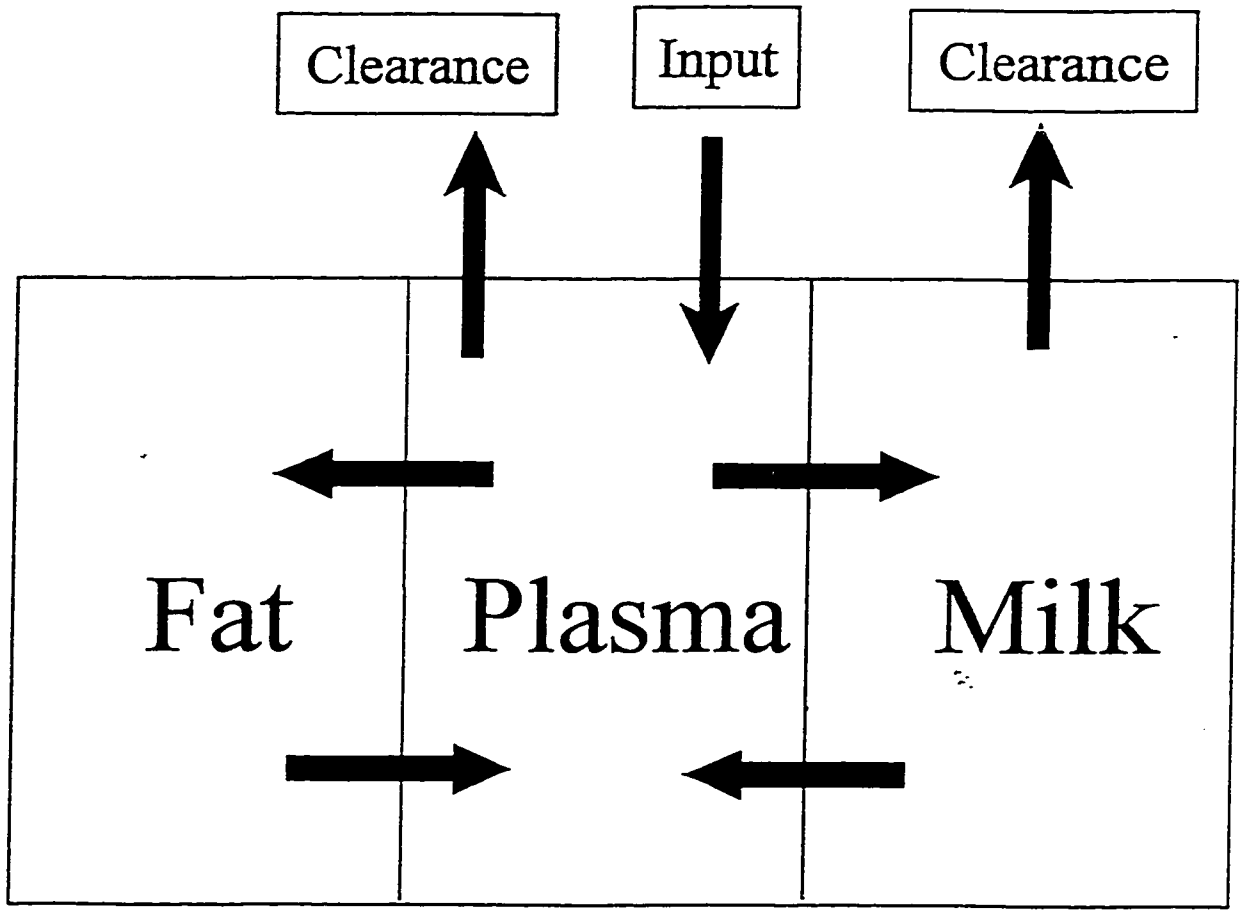
higher, S-ClBzs 58% higher, and S-DDTs 49% higher).

3.2 Introduction

As carnivores occupying the top niche of a five-level Arctic marine food web (Hobson and Welch 1992), polar bears bioaccumulate organochlorine (OC) contaminants (Norstrom *et al.* 1988, Norstrom and Muir 1994, Norstrom *et al.* 1998). They feed primarily on ringed seals, often consuming preferentially the blubber (Stirling and McEwan 1975) where lipophilic OCs concentrate. Polar bears can experience dramatic seasonal variation in food availability (Ramsay and Stirling 1988, Ramsay and Hobson 1991) alternating between relatively brief periods of hyperphagia during seal pupping and relatively lengthy periods when their foods are unavailable. The body mass of individual polar bears can more than triple during the hyperphagic periods and adipose tissue may then constitute more than 50% of total body mass (Atkinson and Ramsay 1995). For most of the remaining year, polar bears feed little and undergo lengthy fasts (Ramsay and Hobson 1991, Atkinson and Ramsay 1995). After extended fasting, adipose tissue depots may be reduced to less than 10% of body mass (Pond *et al.* 1992). The dynamics of OC compounds under such fluctuations of body fat reserves is unknown for any mammalian species.

My first objective was to determine whether OC concentrations and composition in adipose tissue, plasma, and milk changed in polar bears sampled sequentially during periods of feeding and fasting. The relationship of OCs with these three tissues is as follows. During feeding, bears consumed OCs that were transported by blood to adipose tissue. For lactating females, these OCs in blood could also be directly mobilized into milk (Fig. 3.1). During

Figure 3.1. Movement of organochlorine compounds between adipose tissue, plasma, and milk.


Clearance
Input
Clearance
Fat
Plasma
Milk

fasting, stored OCs in adipose tissue could be mobilized in blood and also transported into milk (Fig. 3.1). My second objective was to determine whether fasting influenced the lactational transfer of specific OC compounds. I particularly wanted to assess whether there was a differential change in the OC transfer profile when mothers were nutritionally stressed. My third objective was to show the variability of OC concentrations in tissues from the same bears sampled over periods longer than a single season. A bear's nutritional state, age, reproductive status and prior history could influence its OC concentrations at a given sampling period. The longitudinal sampling of females allowed me to determine whether OC levels in mothers were correlated with cub survival.

3.3 Methods

3.3.1 Field study

Polar bears from two populations were sampled from 1992-1996 when their feeding patterns differed. The polar bears living in western Hudson Bay, Canada, in the vicinity of Churchill, Manitoba (57°00' to 58°50' N, 92°25' to 94°15' W) were sampled during their lengthy fasting period. These bears come ashore when the ice melts in summer (July-August) and remain on land for 4-5 months until the bay re-freezes (Ramsay and Stirling 1988). During their stay on land polar bears fast and use their large adipose reserves, which they accumulated prior to coming ashore, to meet their energy requirements. Polar bears in the vicinity of Resolute Bay, NWT (74°00' to 76°50' N, 88°00' to101°00' W) were sampled on the sea-ice in spring (April-May) during the period of peak feeding. These bears gain

mass, or at least maintain their mass, in comparison to Churchill bears that lose mass from summer to fall.

Polar bears were immobilized from a helicopter using well-established methods (Stirling *et al.* 1989). Adult females were fitted with a VHF radio-collar (Telonics Inc., Mesa, AZ) and adult males were fitted with VHF ear radio transmitters (Holohill Ltd., Woodlawn, ON) so I could relocate and recapture them. In Churchill, bears were recaptured after a 1-3 month fasting period between July and November. In Resolute, bears were recaptured after 1 month (April and May) during which time they had access to seals. All bears handled were marked with uniquely numbered ear tags and matching lip tattoos for subsequent identification. A vestigial premolar tooth was extracted from bears older than one year for age determination (Calvert and Ramsay 1998). Standard body measurements were taken and mass determined for all bears captured (Stirling *et al.* 1977).

Bears from Churchill and Resolute Bay were categorized by status: i) females with cubs, which includes females with cubs-of-the-year (COYs) and females with yearling (YRLG) cubs, ii) cubs-of the year, iii) yearling cubs, iv) and males, which includes both subadults and adults.

Two sequential adipose tissue samples were collected at Churchill from 9 females with COYs, 7 females with YRLGs, 12 COYs, 10 YRLGs, and 10 males. In addition, sequential milk samples were also collected from 9 females (7 with COYs, 2 with YRLGs) and plasma samples were collected from 48 bears (8 females with COYs, 6 females with YRLGs, 12 COYs, 12 YRLGs, and 10 males). Polar bears that were captured sequentially

at Churchill for body burden determination (Chapter 2) are also included as part of the Churchill sample for this chapter (Chapter 3). From Resolute I collected i) sequential adipose tissue samples from 2 females with COYs, 1 female with YRLGs, 2 YRLGs, and 4 males ii) sequential milk samples from 2 females with COYs, 1 female with YRLGs and iii) sequential plasma samples from 2 females with COYs, 1 female with YRLGs, 3 COYs, 2 YRLGs, and 4 males.

Up to 80% of adipose tissue from adult polar bears is superficial and thus readily accessible (Pond *et al.* 1992). Adipose tissue was obtained under anaesthesia by superficial biopsy (0.6cm x 1.0 cm, 200 mg) from the subcutaneous depot at the base of the tail, approximately 15 cm lateral to the midline (Ramsay *et al.* 1992). Blood samples were collected in heparinized vacutainer tubes via jugular catheterization. Blood was kept cool until centrifugation when plasma was removed and frozen immediately at -20°C. Milk samples were collected by administering 1.0 ml oxytocin via the jugular catheter followed by palpation of the teats. All samples were stored in individually pre-cleaned vials (rinsed three times each with acetone and *n*-hexane), sealed, and frozen at -20°C.

3.3.2 Laboratory analysis and statistics

See 2.3.2 for methodology used for organochlorine analyses.

Data were analysed using STATISTICA software (© 1997 StatSoft, Inc.). The Wilcoxon Matched Paired Test was used to determine if there was a significant difference between samples collected sequentially. An ANOVA was used to test whether there were

differences in OC concentration and composition among different groups of bears. If a significant difference was found, then a Tukey Honest Significant Difference Test for unequal N (Spjotvoll/Stoline Test) was used to assess specifically which groups of bears were different. A Wilcoxon Mann-Whitney Test for small samples was calculated manually according to Siegel and Castellan (1988) and was used to determine whether there were differences in the parameters measured for females who lost and kept their cubs. All tests were considered significant at $p<0.05$.

3.4 Results

3.4.1 Fasting and feeding bears

3.4.1.1 Body mass changes

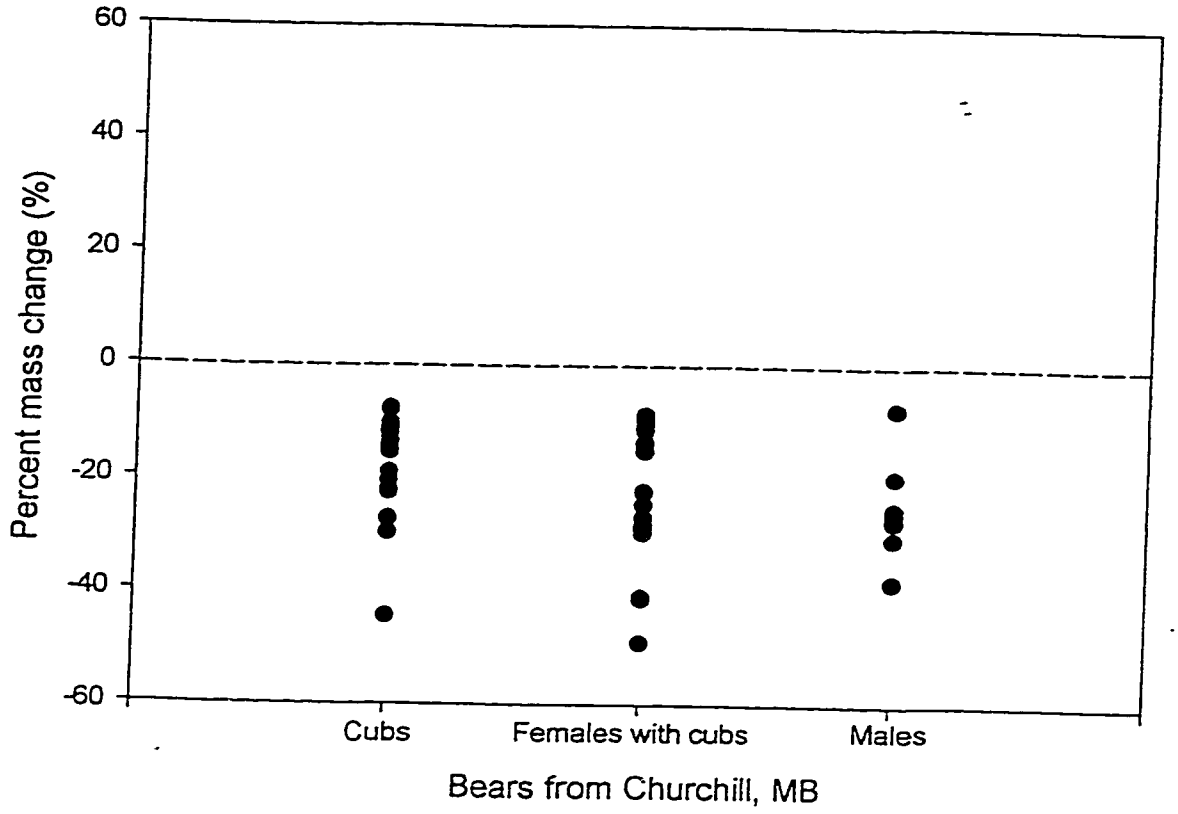
All bears from Churchill lost body mass over the sampling period. Bears from Resolute Bay lost, maintained, or increased their body mass (Figs. 3.2a & b). From Churchill, males and females with cubs had greater mass loss per day than COYs (Tukey, $p = 0.01$ and 0.0002, respectively; see Table 3.1). Unlike males who lost mass, females and cubs from Resolute gained mass over the sampling period (Tukey, females $p = 0.005$, COYs $p = 0.0007$, YRLGs $p = 0.025$; see Table 3.1).

3.4.1.2 Changes in organochlorine concentration

I did not detect a difference in the sum of organochlorine (S-OC) concentrations in adipose tissue, plasma, and milk for females with cubs, COYs, yearlings and males from

Figure 3.2a & b. Percent body mass change in cubs, females with cubs, and male polar bears from a) Churchill, MB, during a period of fasting (58 ± 20 days) and from b) Resolute Bay, NWT, during a period of feeding (28 ± 3 days).

2a.


60
40
20
0
-20
-40
-60
Percent mass change (%)
Cubs
Females with cubs
Males
Bears from Churchill, MB

2b.

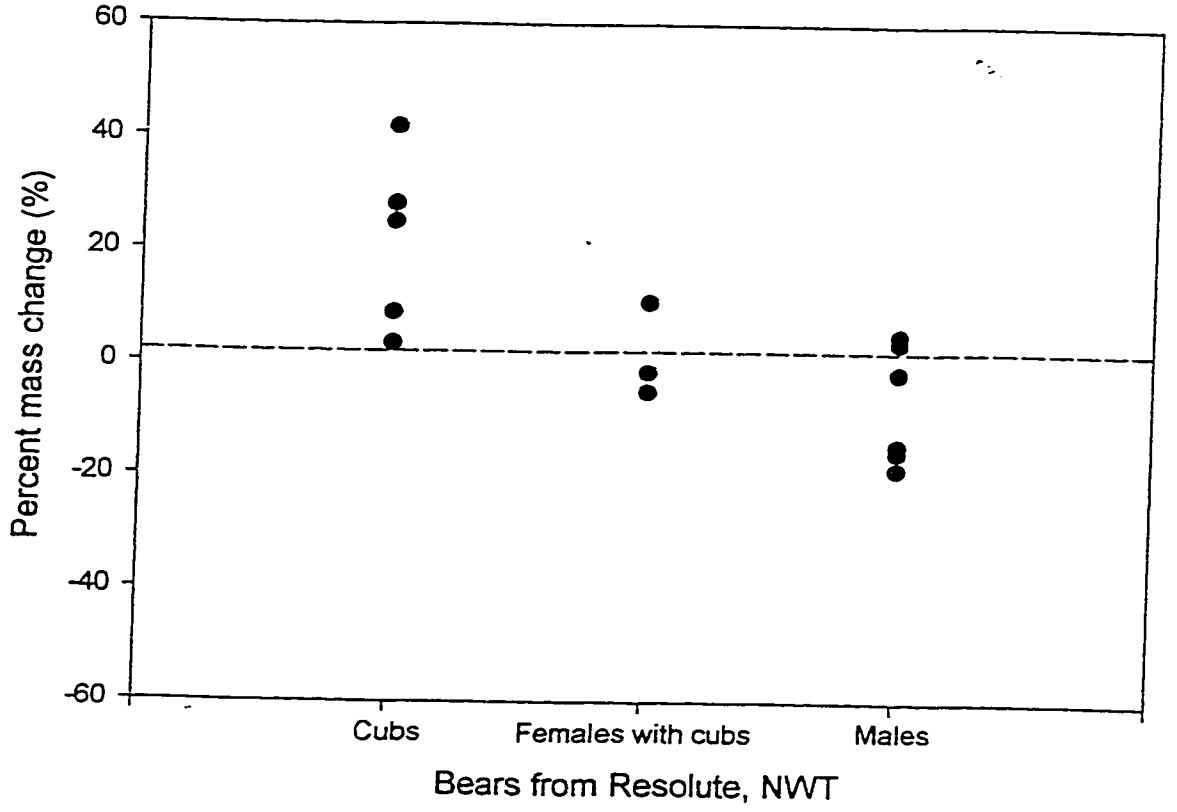

60
40
20
0
-20
-40
-60
Percent mass change (%)
Cubs
Females with cubs
Males
Bears from Resolute, NWT

Table 3.1. Mean (± SD) body mass changes per day for polar bears fasting in Churchill, MB from summer (July-September) to fall (October-November) and for bears feeding in Resolute Bay, NWT from April to May.

	Change in body mass per day (kg/day)			
	Churchill		Resolute	
No. days between sampling	58 ± 20		28 ± 3	
	n		*n*	
Females with cubs	15	-0.72 ± 0.26	3	0.07 ± 0.44
Cubs-of-the-year	12	-0.15 ± 0.09	3	0.27 ± 0.06
Yearlings	9	-0.45 ± 0.10	2	0.13 ± 0.08
Subadult & adult males	12	-0.94 ± 0.32	4	-1.12 ± 1.20

Resolute Bay between the two capture periods (Appendix A). In comparison, S-OC concentrations in adipose tissue, plasma, and milk did change between captures for most status groups of polar bears from Churchill (Table 3.2, see also Appendix A). The concentration of S-CHLORs in adipose tissue from females with cubs, COYs, and YRLGs increased by approximately 30% after a period of fasting whereas, there was no change for males. Similarly, there was no change in the concentration of S-PCBs in adipose tissue from males whereas there was an increase for females and cubs by 43% and 29%, respectively. The concentration of S-DDTs in adipose tissue decreased during fasting for all bears, with percent decreases ranging from 23-50%. Concentrations of S-ClBzs in both adipose tissue and milk increased by about 30% whereas increases in S-CHLORs and S-PCBs were greater for milk than adipose tissue by 35% and 18%, respectively. Generally, the concentrations of S-ClBzs, S-CHLORs, and S-PCBs in tissues tended to increased while that of S-DDTs decreased between captures.

3.4.1.3 Composition of organochlorine classes

A few compounds generally comprised a large proportion of their OC class. Appendix A shows the percentage that each compound made up of the total sum of each OC class. The compositions of OCs in adipose tissue, in plasma and in milk were similar for bears from Churchill and Resolute Bay, except for S-HCHs. Similar to the isomeric proportions of S-HCHs in ringed seal blubber from Hudson Bay (Cameron *et al.* 1997), polar bears from NE Manitoba had a greater percentage of α-HCH in adipose tissue (49-

Table 3.2. Organochlorine concentration (ng/g) and composition (%) changes in adipose tissue (AD), plasma (PL), and milk (MI) from females with cubs, subadult and adult males, COYs, and yearling cubs during a seasonal fast (58 ± 20 days), Churchill, MB. Significant changes between captures are designated with + for increases and - for decreases (Wilcoxon Matched Pairs Test, + or - $p<0.10$, ++ or -- $p<0.05$, +++ or --- $p<0.005$). A blank space indicates that there were no changes in concentration or composition after a period of fasting.

	Females with cubs			Males		COYs		Yearlings	
	AD	PL	MI	AD	PL	AD	PL	AD	PL
n	16	14	9	10	10	12	12	10	12
S-ClBzs (ng/g)	+++		++	+			-	++	
(%)									
1,2,4,5-TeClBz	+++					++	+		
PnClBz	---		-		--	---	--	-	
HCB	--								
S-HCHs (ng/g)							---		
								--	
(%)									
α-HCH	---				-	---			
β-HCH	+++				+	+++			
S-CHLORs (ng/g)	+++	++	+++			+++	-		++
(%)									
Compound C	-			++				--	
Photoheptachlor				++					-
Heptachlor epoxide				++		---		---	
Oxychlordane	++			--	++	+++		++	
U4				++		++		++	
C5				+					
C3				++					
C4				++					

Table 3.2 contd:

MC-6	–			++					
Trans-nonachlor		-	-	–	-	—	—		–
U2			++	++					–
S-DDTs (ng/g)	–			–	–	—			–
(%)									
*p,p'*DDE								-	
*p,p'*DDD				–					
*p,p'*DDT					++				
S-PCBs (ng/g)	+++	++	+++		+	+++		++	
(%)									
PCB-47/48	–		–	–		–			
PCB-74	—		–	–		—			–
PCB-56/60			—					–	
PCB-99			-						
PCB-85	—		–		-	—		-	-
PCB-149	—			–		–			
PCB-118	—	–	–	–	—	—	–	-	–
PCB-146	—					—	–	-	–
PCB-153	+++		++		++	+++	+	++	
PCB-105	–					++			
PCB-137		–							
PCB-138/163	–		–			—		-	–
PCB-187	—	–			–	—			–
PCB-183		—		++		-	–		-
PCB-156			-					++	
PCB-157				–		–			
PCB-180	+++	++	++		+	++	+		
PCB-170	+++		++		+	+++	++		
PCB-195						–			
PCB-194	++								
PCB-206									
PCB-209									

84%), plasma (54-65%), and milk (83-87%) compared to bears from Resolute who had a greater amount of β-HCH in their tissues (adipose tissue, 52-81%; plasma, 44-78%; milk, 54-65%). Tetrachlorobenzene comprised the largest percentage of S-ClBzs in adipose tissue (49-73%), plasma (52-75%), and milk (57-68%) for bears from Churchill and Resolute. Oxychlordane comprised the largest percentage of S-CHLORs with means ranging from 39-68% for all tissues in both feeding and fasting bears. The isomer *p,p'*DDE was the most prevalent of S-DDTs in adipose tissue and milk for all bears (75-93%). For both feeding and fasting bears, PCB-153 comprised the largest percentage of S-PCBs with means ranging from 31-50% for all tissues while the sum of four other PCB congeners (PCB-99, PCB-138/163, PCB-180, PCB-170) comprised between 40-49% of S-PCBs. The 17 other congeners assayed made up only a small fraction of the total PCB load.

3.4.1.4 Changes in organochlorine composition

Compositional changes of OCs in tissues occurred for most bears from Churchill whereas I could not detect similar changes in bears from Resolute Bay. From Resolute, I had small sample sizes (n = 3) which may have biassed the results. Adipose tissue in males from Resolute Bay did show composition changes in α-HCH, β-HCH, U4, PCB-47/48, PCB-74, PCB-138/163, PCB-180, and PCB-170 (Table 3.2, see also Appendix A). Letcher *et al.* (1998) has shown significant metabolism of PCBs taken up from seals in the Resolute bear population.

There were significant changes between captures in the OC composition in tissues

of bears from Churchill. Generally, when changes in composition occurred they were small and similar among tissues and groups of bears (Figs. 3.3a-e and Table 3.2). One notable exception is with the chlordane compounds. Whereas the adipose tissue of males showed significant changes in every chlordane compound, this was not the case for the other groups. In particular, the amount of oxychlordane in male polar bears decreased in their tissues while fasting (Figs. 3.3c).

The composition of compounds in milk was relatively constant for all OCs except for S-PCBs. Congeners PCB-153 and PCB-180 showed the largest increase. In this group, about 40% of the congeners changed in proportion over the sampling period (Fig. 3.3b).

3.4.2 Relationship of OC compounds between mothers and cubs during fasting

The composition of each compound class in adipose tissue from cubs relative to their mothers did not change after a period of fasting (Table 3.3). Cubs always had greater amounts of 1,2,4,5-TeClBz, most chlordane compounds, *p,p'*DDE, PCB-47/48, PCB-99, PCB-153, and PCB-157 in their adipose tissue than their mothers. For the remaining compounds, cubs always had lower amounts than their mothers.

3.4.3 Change in the ratio of OCs in mothers' adipose tissue and milk during fasting

For most OCs, the ratio of each compound between mother's milk and adipose tissue did not change significantly during fasting (Wilcoxon Matched Pairs Test, $p>0.05$) except increases in HCB, PCB-183, PCB-180, PCB-170, and decreases in 1,2,4,5-TeClBz, PCB-

Figure 3.3a-e. Change in percent composition of specific OCs in adipose tissue from females with cubs (Fig. 3.3a), subadult and adult males (Fig. 3.3b), cubs-of-the-year (Fig. 3.3c), and yearling cubs (Fig.3.3d) during fasting, Churchill, MB. Compositional changes in milk from females with cubs during fasting is also shown (Fig. 3.3e). Significant changes in specific OCs composition are designated with an asterisk (Wilcoxon Matched Pairs Test, $p<0.05$).

a.
Female with cubs - adipose tissue
Change in percent composition
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
TeCIBc
PnCIBz
HCB
a-HCH
b-HCH
Comp C
Photo
HepEp
Oxychl
U-4
C-5
C-3
C-4
MC-6
t-Non
U-2
DDE
DDD
DDT
PCB47/48
PCB 74
PCB56/60
PCB 99
PCB 85
PCB149
PCB118
PCB146
PCB153
PCB105
PCB137
PCB138/163
PCB187
PCB183
PCB156
PCB157
PCB180
PCB170
PCB195
PCB194
PCB206
PCB209

b.
Males - adipose tissue
Change in percent composition
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-34
PnClBz
HCB
a-HCH
b-HCH
Comp C
Photo
HepEp
Oxychl
U-4
C-5
C-3
C-4
MC-6
t-Non
U-2
DDE
DDD
DDT
PCB47/48
PCB 74
PCB56/60
PCB 99
PCB 85
PCB149
PCB118
PCB146
PCB153
PCB105
PCB137
PCB138/163
PCB187
PCB183
PCB156
PCB157
PCB180
PCB170
PCB195
PCB194
PCB206
PCB209

C.
Cubs-of-the-year - adipose tissue
Change in percent composition
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
TeClBc
PnClBz
HCB
a-HCH
b-HCH
Comp C
Photo
HepEp
Oxychl
U-4
C-5
C-3
C-4
MC-6
t-Non
U-2
DDE
DDD
DDT
PCB47/48
PCB 74
PCB56/60
PCB 99
PCB 85
PCB149
PCB118
PCB146
PCB153
PCB105
PCB137
PCB138/163
PCB187
PCB183
PCB156
PCB157
PCB180
PCB170
PCB195
PCB194
PCB206
PCB209

d.
Yearling cubs - adipose tissue
Change in percent composition
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
TeClBc
PnClBz
HCB
a-HCH
b-HCH
Comp C
Photo
HepEp
Oxychl
U-4
C-5
C-3
C-4
MC-6
t-Non
U-2
DDE
DDD
DDT
PCB47/48
PCB 74
PCB56/60
PCB 99
PCB 85
PCB149
PCB118
PCB146
PCB153
PCB105
PCB137
PCB138/163
PCB187
PCB183
PCB156
PCB157
PCB180
PCB170
PCB195
PCB194
PCB206
PCB209
*
*
*
*

e.
Females with cubs - milk
Change in percent composition
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
TeClBc
PnClBz
HCB
a-HCH
b-HCH
Comp C
Photo
HepEp
Oxychl
U-4
C-5
C-3
C-4
MC-6
t-Non
U-2
DDE
DDD
DDT
PCB47/48
PCB 74
PCB56/60
PCB 99
PCB 85
PCB149
PCB118
PCB146
PCB153
PCB105
PCB137
PCB138/163
PCB187
PCB183
PCB156
PCB157
PCB180
PCB170
PCB195
PCB194
PCB206
PCB209
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Table 3.3. Relationship of OC compounds in cub-of-the-year adipose tissue relative to their mother's. Mother and cub family groups were sampled in summer (August) and in fall (September to November) after a period of fasting, Churchill, MB. Significant differences were designated as follows; + cubs had higher amount of OC compound than their mother, - cubs had lower amount of OC compound than their mother (Wilcoxon Matched Pairs Test $p<0.05$). Blanks designate when mothers and cubs had similar OC composition. Sample sizes for mother-cub pairs were $n = 13$ for summer and $n = 21$ for fall.

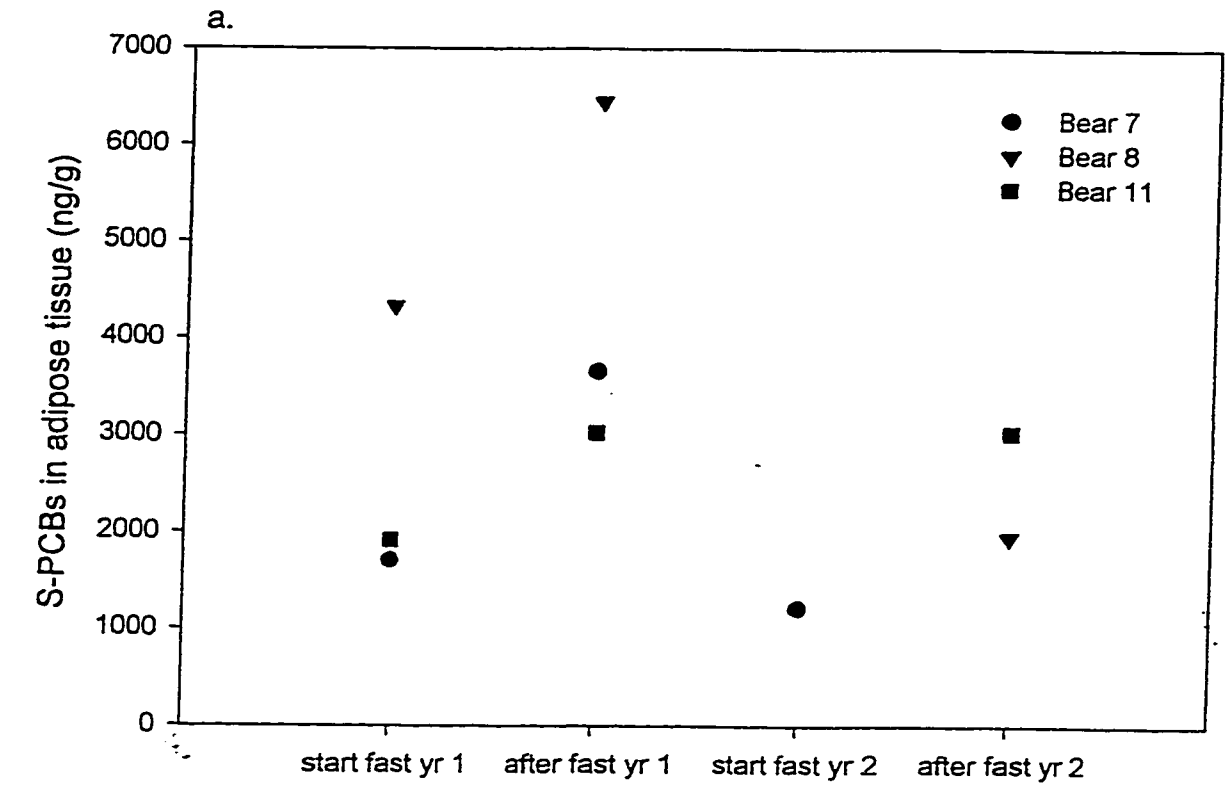
	Summer	Fall		Summer	Fall
S-ClBzs	+	+	S-PCBs	+	+
1,2,4,5 TeClBz	+	+	PCB-47/48	+	+
PnClBz	-	-	PCB-56/60	-	
HCB	-	-	PCB-74	-	-
			PCB-99	+	+
S-HCHs	+		PCB-85		
α-HCH	-	-	PCB-149	-	-
β-HCH	+	+	PCB-118	-	-
			PCB-146	-	-
S-CHLORs	+	+	PCB-153	+	+
Compound C	+	+	PCB-105		+
Photoheptachlor	+	+	PCB-137	+	+
Heptachlor epoxide			PCB-138/163		
Oxychlordane	+	+	PCB-187	-	-
U4	+	+	PCB-183	-	-
C5	+	+	PCB-156		+
C3	+	+	PCB-157	+	+
C4	+	+	PCB-180	-	-
MC-6	-	-	PCB-170	-	-
Trans-nonachlor	-	-	PCB-194	-	-
U2	-	-	PCB-195	-	-
			PCB-206	-	-
S-DDTs			PCB-209	-	-
*p,p'*DDE	+	+			
*p,p'*DDD	-				
*p,p'*DDT	-	-			

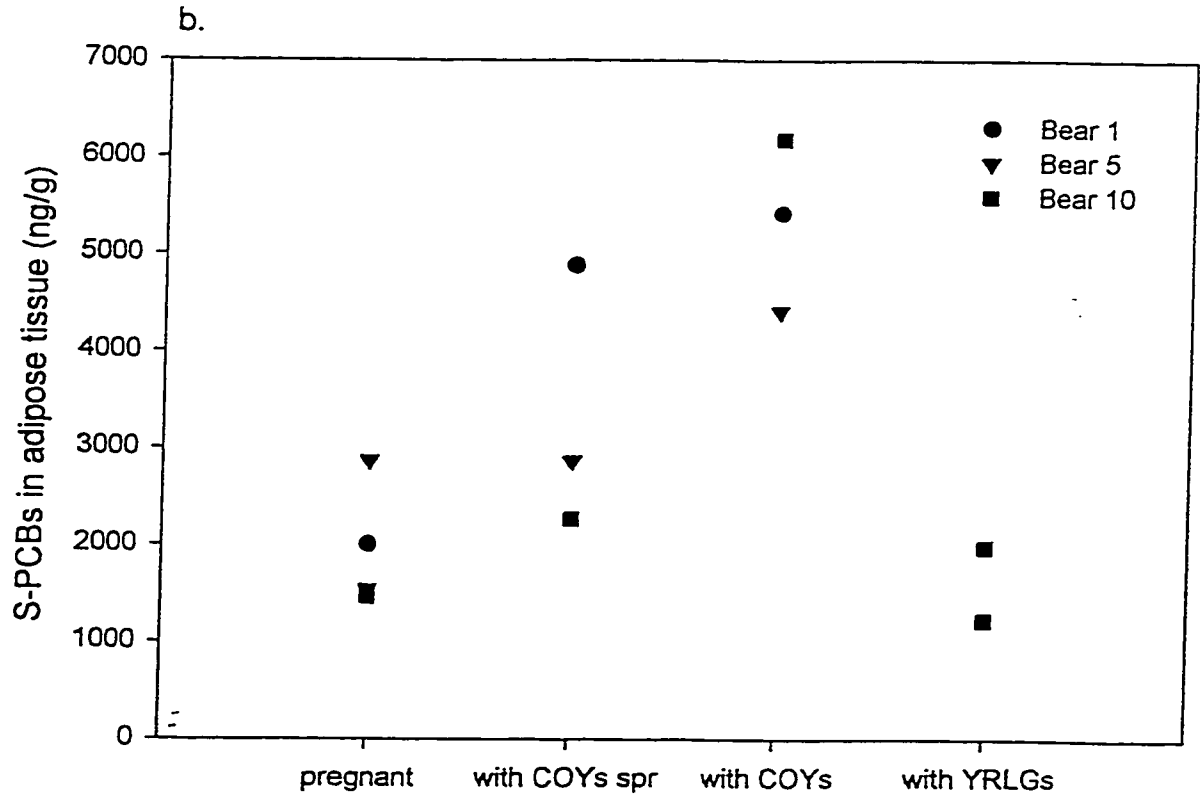
137, and PCB-209 (Wilcoxon Matched Pairs Test, $p<0.05$).

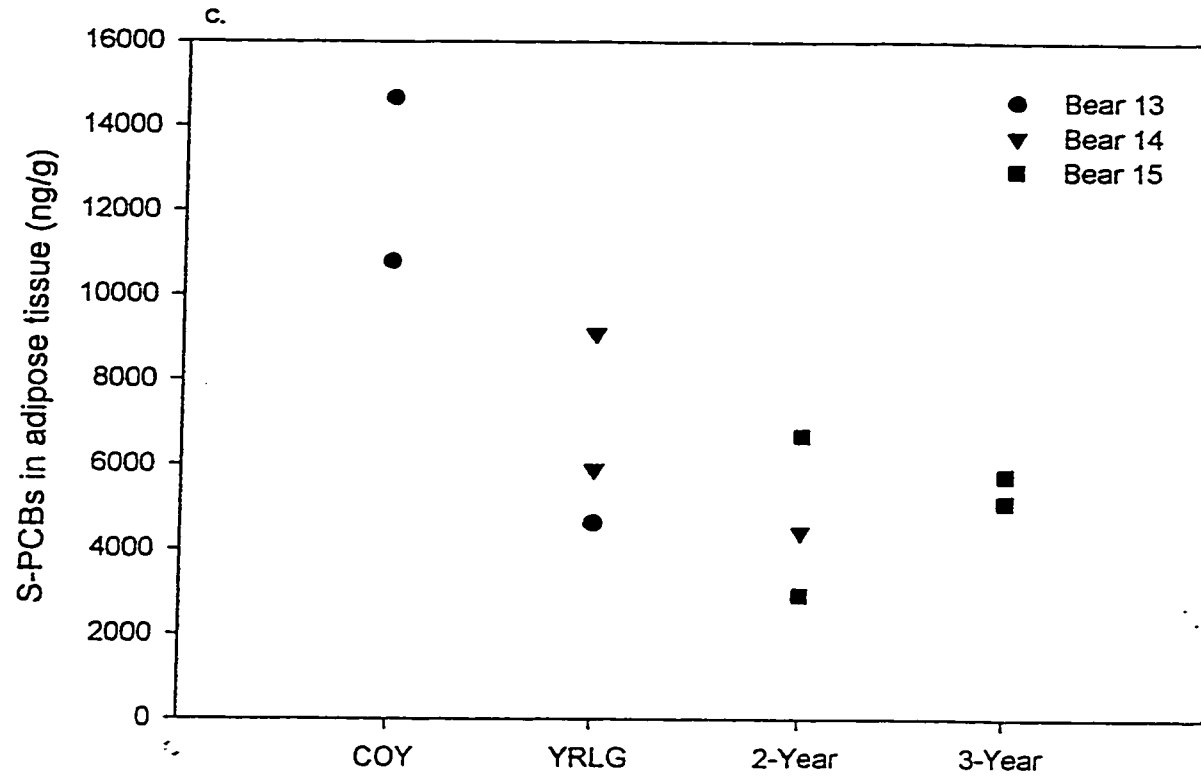
3.4.4 OC profile of individual bears between seasons

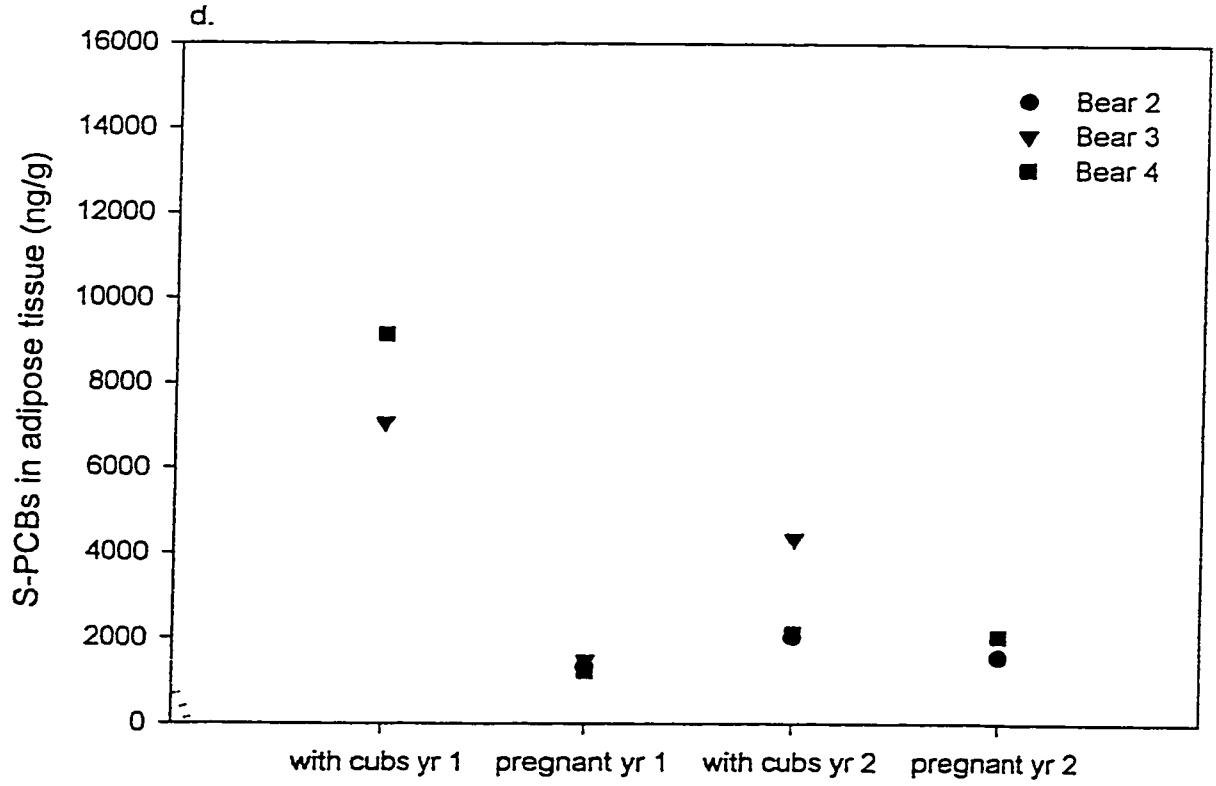
Sixteen bears were handled on more than two occasions over a 4-year period (Appendix B). Organochlorine concentrations in adipose tissue, plasma, and milk from each bear were generally different at each capture. Factors that changed between each capture were body condition, feeding status, age, reproductive status and previous reproductive history. For most bears, when the amount of adipose tissue (percent body fat) declined during fasting, there was an increase in OC concentration similar to that seen in bears undergoing intra-seasonal fasts. For example, S-PCBs increased in the adipose tissue of Bears 7, 8 and 11 during their seasonal fasts (August to November; Fig. 3.4a). Some females (Bears 1, 5 & 10) at different reproductive stages (e.g., pregnant *vs.* with COYs in spring or fall *vs.* with yearlings) showed a three to five-fold difference in their OC concentrations in adipose tissue (Fig. 3.4b). A cub showed a dramatic decrease in her adipose tissue and plasma OC concentrations between her first and second year (Bear 13; Fig. 3.4c). Similarly, another cub showed a marked decrease in adipose tissue and plasma OC concentrations between his second and third year (Bear 14) whereas a subadult in his third and fourth year had less variation in concentrations (Bear 15; Fig. 3.4c). Females who become pregnant in subsequent years had greater OC concentrations in their adipose tissue and milk in spring on their first capture than on their second capture the following year (Bears 2, 3 & 4; Fig. 3.4d). Organochlorine concentrations were highly variable with

Figure 3.4a-d. Concentrations of S-PCBs in adipose tissue (ng/g, lipid wt) from polar bears captured on more than two occasions. Differences in S-PCBs concentrations in adipose tissue vary a) during seasonal fasting b) with different reproductive status c) with age and d) with previous reproductive history. Bears 7, 8, and 11 are females undergoing a seasonal fast from August to November. Bears 1, 5, and 10 are pregnant in August and are with young cubs in March. Bears 13, 14, and 15 are growing cubs at different ages. Bears 2, 3, and 4 are females that have been pregnant in two consecutive years.


a.
S-PCBs in adipose tissue (ng/g)
7000
6000
5000
4000
3000
2000
1000
0
Bear 7
Bear 8
Bear 11
start fast yr 1
after fast yr 1
start fast yr 2
after fast yr 2


b.
S-PCBs in adipose tissue (ng/g)
7000
6000
5000
4000
3000
2000
1000
0
Bear 1
Bear 5
Bear 10
pregnant
with COYs spr
with COYs
with YRLGs


c.
16000
14000
12000
10000
8000
6000
4000
2000
0
S-PCBs in adipose tissue (ng/g)
Bear 13
Bear 14
Bear 15
COY
YRLG
2-Year
3-Year


d.
16000
14000
12000
10000
8000
6000
4000
2000
0
S-PCBs in adipose tissue (ng/g)
Bear 2
Bear 3
Bear 4
with cubs yr 1
pregnant yr 1
with cubs yr 2
pregnant yr 2

differences in feeding status, age, and reproductive history.

I captured three adult females with COYs in spring and again the following summer when they were all pregnant (Bear 2, Bear 3, and Bear 4). These females must have lost their cubs sometime between March and August (Appendix B). I also handled two females in spring that were still lactating but were without cubs. Since these females were still producing milk, I presumed they had recently lost their cubs. I also captured three females with COYs in spring who I later captured in fall with their cubs (Bear 1, Bear 4, and Bear 10).

Organochlorine concentrations in milk were significantly higher in females that lost their cubs in the first year compared with those that did not lose cubs (Wilcoxon-Mann-Whitney Test for small samples, $p < 0.0179$: S-PCBs 70% higher, S-CHLORs 60% higher, S-HCHs 58% higher, S-ClBzs 58% higher, and S-DDTs 49% higher; see Fig.3.5). The mean mass of cubs that did not survive was also lower than that of cubs that did survive (Wilcoxon-Mann-Whitney Test for small samples, $p = 0.03$; see Table 3.4). Nonetheless, there was no difference in the proportion of lipid in milk of the two groups of females, nor was there any difference in the body mass or fat mass in either summer or spring between the mother's who lost their cubs and those that did not (see Table 3.4).

3.5 Discussion

3.5.1 Influence of nutritional state on OC compound residues

The concentration of OCs in the tissues of polar bears varied with the bear's

Figure 3.5. Mean (± SD) organochlorine concentrations in milk (ng/g, lipid wt) from female polar bears in spring who subsequently lost their cubs ($n = 5$) and from females who kept their cubs from spring to fall ($n = 3$). Asterisk designates significant differences (Wilcoxon Mann-Whitney Test for small samples $p<0.05$).

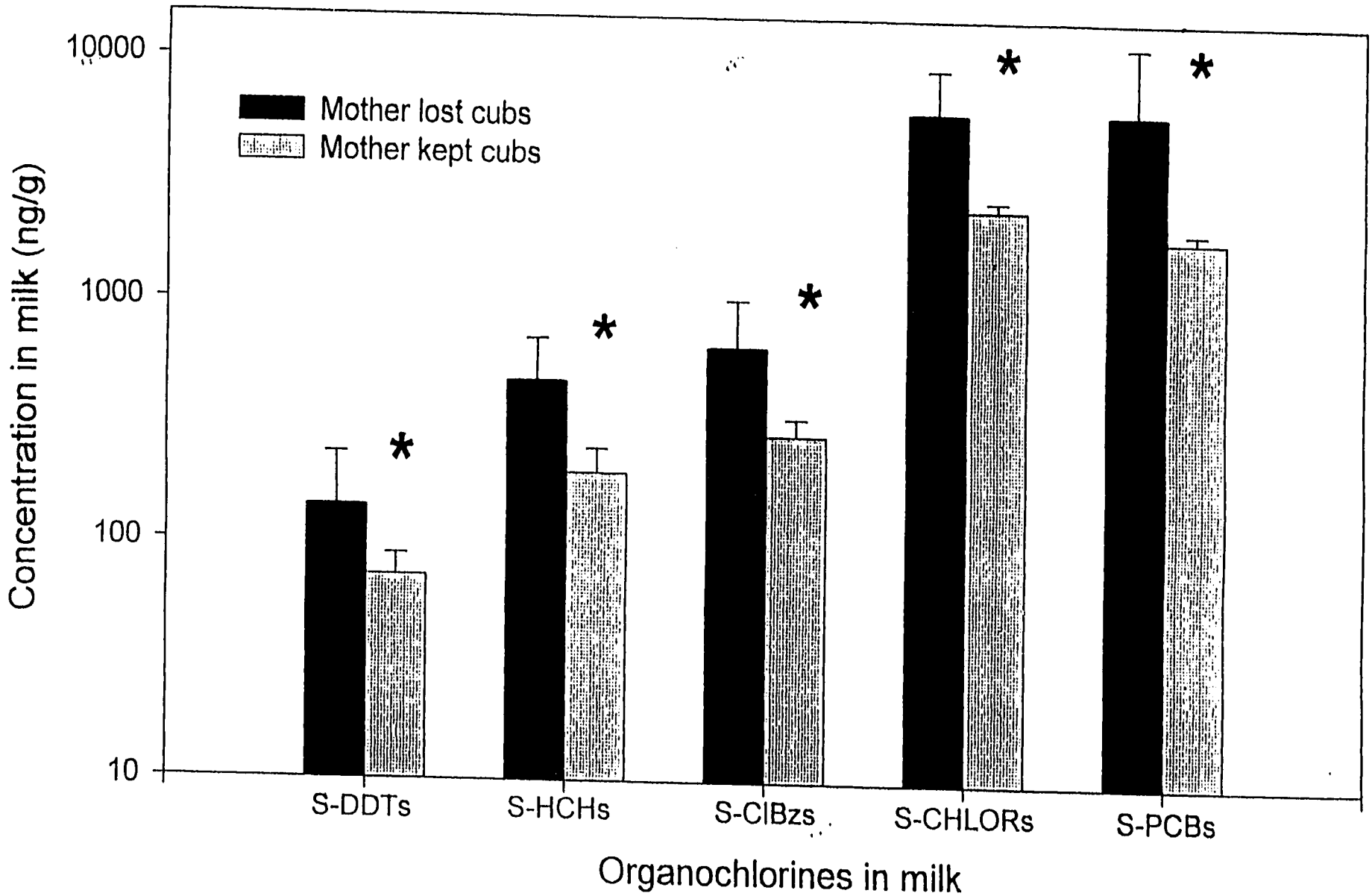

10000
1000
100
10
Concentration in milk (ng/g)
Mother lost cubs
Mother kept cubs
*
*
*
*
*
S-DDTs
S-HCHs
S-ClBzs
S-CHLORs
S-PCBs
Organochlorines in milk

Table 3.4. Mean (± SD) mass of cubs-of-the-year (COYs) in spring, percent lipid in milk in spring, body mass and fat mass when pregnant in summer and with cubs in spring of females who subsequently kept their cubs until fall ($n = 3$) or lost their cubs before fall ($n = 5$), Churchill, MB. The two groups of females were analyzed to determine significant differences (Wilcoxon-Mann-Whitney Test for small samples, $p<0.05$).

	Females who kept their cubs	*n*	Females who lost their cubs	*n*	P-value
Mass (kg) of COYs in spring	12.4 ± 0.9	5	10.7 ± 1.4	5	0.03
Lipid in milk (%)	28.6 ± 4.8	5	21.4 ± 9.7	3	0.13
Body mass (kg) when pregnant in summer	320 ± 36	3	353 ± 15	3	0.35
Body mass (kg) with cubs in spring	180 ± 5	4	193 ± 36	3	0.06
Fat mass (kg) when pregnant in summer	140 ± 22	3	148 ± 9	3	0.50
Fat mass (kg) with cubs in spring	57 ± 7	3	57 ± 11	3	0.50

nutritional status. Animals that were fasting displayed distinct shifts in the concentration and compound specificity of their OC burden, whereas feeding animals showed little variation in OC concentrations and composition.

Concentrations of S-ClBzs, S-CHLORs, and S-PCBs generally increased during fasting while S-HCHs and S-DDTs remained the same or decreased. Unlike the other OCs, HCHs and DDTs have been shown to be readily metabolized in the mammalian liver that might account for their observed decline during fasting (Carey *et al.* 1998).

The concentration of some PCB congeners (notably PCB-153, PCB-170, and PCB-180) did not decline during fasting and, presumably, were not easily metabolized or excreted. They all had similar chlorination properties (chlorination at two *ortho* positions 2,2'; two *para* positions 4, 4'; and at one *meta* position 5). The less chlorinated compounds, in contrast, declined as a proportion of the total OC concentration.

In all fasting polar bears the concentration of *t*-nonachlor declined. At the same time, the concentration of oxychlordane increased in all bears, except in adult and subadult males where oxychlordane levels declined. These observations imply that the *t*-nonachlor is being converted to oxychlordane in most of the bears (Tashiro and Matsumura 1978). The fact that only males were able to significantly decrease their total body burden of S-CHLORs (see Chapter 2) may be a direct result of males metabolizing or excreting oxychlordane.

3.5.2 Transfer of organochlorines to cubs in fasting bears

The composition of S-PCBs in milk altered slightly (e.g., changes of 0.1% - 3.3% as

a proportion of the total) while mothers fasted. The proportion of tetra-, penta-, and hexa-chlorobiphenyls (CBs) decreased while that of some other hexa- and hepta-CBs increased. The adipose tissue of COYs showed parallel changes. In contrast, the adipose tissue of yearling cubs did not show similar changes, probably because they were not as reliant on their mother's milk as COYs (Arnould and Ramsay 1994). Although these slight compound-specific changes of OCs in mother's milk and cub adipose tissue occurred during fasting, the relative relationship of these compounds in the adipose tissue of mother and cub remained the same.

3.5.3 Variability of organochlorine concentrations in bears tracked over multi-seasons

Considerable variation in the OC concentrations of body tissues (i.e., 1- to7-fold differences between sequential handlings) were noted in bears handled over multiple seasons. Over the sampling interval the age, nutritional status, nutritional history, reproductive status, and reproductive history of the bears changed. Although age and the reproductive status of polar bears have been factored into analyses of geographical patterns of OC concentrations used for biomonitoring purposes (Norstrom *et al.* 1998), the bears' recent nutritional and reproductive histories may also be important confounding variables for OC concentrations in most populations. Thus, data comparing lipophilic contaminant loads from geographically distinct polar bears populations should be collected at similar times in the annual reproductive cycle and at comparable times in the nutritional regimen of the bears in order for the comparison of OC concentrations to be valid among years.

3.5.4 Organochlorine levels in milk and cub survival

The concentration and compound-specific variations of OCs during different nutritional and reproductive stages of the bears' yearly or life cycle may predispose them to potentially deleterious effects of OC contamination. Multiple handlings of mothers with cubs allowed me to track the contaminant loading of individual females through time and the subsequent survival of their cubs. This research is the first time that higher OC concentrations in polar bear milk have been correlated with cub mortality. Females who lost their cubs had significantly higher mean OC concentrations in their milk in the period soon after den emergence than did females who kept their cubs. I don't know what might account for the higher OC loads in some females. Animals in both groups (i.e., relatively high and low OC concentrations in their milk) were similar in age and body condition. Since my samples sizes were small and the results only correlational, I can only suggest that OC contamination may play a role in cub survival in some polar bear populations. Given the potentially vulnerable position of polar bears to environmental contamination by lipophilic OCs, however, the observed mortality trend warrants further investigation.

4. ORGANOCHLORINE BODY BURDENS IN FEMALE POLAR BEARS (*Ursus maritimus*) DECLINE DURING PREGNANCY AND LACTATION

4.1 Abstract

I determined the total body burden and concentrations of OCs in individual female polar bears in NE Manitoba handled during pregnancy in summer and again the following spring after the first 2-3 months of nursing their newborns. Organochlorine concentrations in adipose tissue and plasma were also determined for cubs, soon after the time of den emergence from both NE Manitoba and the Arctic archipelago, near Resolute NWT. Organochlorine body burdens in seven female polar bears declined during gestation and the initial lactation period, although the amount and percent decrease varied with OC compound and individual bear. In descending order, the mean percent decreases in body burdens were S-DDTs (81%) > S-HCHs (64%) > S-ClBzs (43%) > S-CHLORs (32%) > S-PCBs (23%), while the mean declines in amount of OCs were S-CHLORs (70 mg) > S-PCBs (56 mg) > S-DDTs (20 mg) > S-HCHs (14 mg) > S-ClBzs (7 mg). Lactation was estimated to account for 59-66% of the decrease in S-PCBs and S-CHLORs burdens, 37-49% for S-HCHs and S-ClBzs burdens, and 5% for S-DDTs burdens. Total body burdens of OCs for cubs in spring were calculated to be 1-4% of the burden of pregnant females and 3-7% of the burden of females in spring. Whole body concentrations of OCs were similar for females and cubs

except for S-PCBs, where cubs had lower whole body concentrations than mothers. Cubs had higher mean concentrations of S-ClBzs, S-HCHs, S-CHLORs, and S-PCBs in adipose tissue (53%, 36%, 47%, and 11% higher, respectively) than their mothers whereas concentrations of S-DDTs were similar. Organochlorine composition of S-CHLORs, S-DDTs, and S-PCBs varied with reproductive status whereas the composition of S-ClBzs and S-HCHs were similar. Concentrations of all OCs in adipose tissue from adult females in spring were correlated positively with those in their milk. Thus, cubs can receive a large influx of contaminants via milk during the initial lactation period which might influence various developmental processes at a critical stage of growth.

4.2 Introduction

Faunas in the Arctic have been chronically exposed to organochlorine (OC) contamination for many decades (Bowes and Jonkel 1975, Muir *et al.* 1988, Muir *et al.* 1992*a*, 1992*b*, Macdonald and Bewers 1996). For some OC compounds, this phenomenon is due to a net transport from warmer to colder regions (Ottar 1981) which encourages increased fractionation and cold condensation of low volatility compounds in polar regions (Wania and Mackay 1993) and increased net transfer of PCBs and chlordanes from air to ocean as both become colder with increasing latitude (Iwata *et al.* 1993).

Because of their distribution and trophic status, polar bears have been used as biomonitors to determine prevalence and variation of persistent contaminants in the Arctic (Bowes and Jonkel 1975, Norstrom *et al.* 1988, Norstrom and Muir 1994, Norstrom *et al.*

1998). The feeding ecology and maternal investment strategies of polar bears also make them of interest from the perspective of contaminant impacts. Polar bears are at the top of a lengthy marine food chain (Hobson and Welch 1992) and, as a consequence, can bioaccumulate high concentrations of OC contaminants in their adipose tissue. Polar bears feed primarily on ringed seals and often prefer to consume the blubber (Stirling and McEwan 1975), where lipophilic OCs concentrate. Because sea ice conditions in the Arctic vary seasonally, polar bears' access to seals is also seasonally limited. During a relatively short period of hyperphagia, polar bears accrue massive fat depots that are then mobilized during relatively long periods of fasting. Rare among terrestrial mammals, pregnant female polar bears maintain themselves on stored fat, which can be up to 50% of their body mass at the start of their fast, for eight months or more during which they undergo post-implantation gestation and the first 2-3 months of lactation (Atkinson and Ramsay 1995). The fate of stored lipophilic OCs during these fasts is unknown but could be predicted using kinetic models.

When cubs-of-the-year (COYs) emerge with their mothers from maternity dens during March and April, they are about 3 months old and have been completely dependent on mother's milk for nutrition since birth. At parturition, polar bears are in a strikingly undeveloped state and obtain a higher proportion of their early nutrients from milk than do most eutherian mammals (Ramsay and Dunbrack 1986). Polar bear milk has a high lipid content (i.e., approximately 30%) compared to other terrestrial species (Cook *et al.* 1970, Jenness *et al.* 1972) and during the mother's fasting period is formed entirely from her lipid

and protein reserves. Any OCs found in cubs at the time of den emergence, therefore, must have been transferred from the mother *in utero* or via milk since no other food sources are available at the den site. Soon after emergence from the den, families move onto the sea ice where they gain access to seals. Cubs stay with their mothers and continue to nurse until weaning, which is around two years (Ramsay and Stirling 1988). Lipid content and volume of milk decreases during the lactation period (Derocher *et al.*1993) and solid food makes up an increasing proportion of their diet (Polischuk *et al.* in review). Cubs-of-the-year in spring receive a relatively higher OC burden from their mother than older yearling cubs (Polischuk *et al.* 1995) because COYs have a higher absolute milk consumption than yearlings (Arnould and Ramsay 1994).

Lactation provides a mechanism whereby large quantities of OCs can be transferred from one generation to the next (Tanabe and Tatsukawa 1991). Therefore, major transfer of OC contaminants from mother to young may occur at a crucial point in the growth and development of polar bear cubs.

I had three objectives in my study. First, I determined the changes in the total body burden of OCs during pregnancy and the initial lactation period in fasting female polar bears (see Fig. 1.1). Changes in OC body burdens of adult females during pregnancy and lactation represent the maximum cub exposure level during foetal and early post-natal development. Second, I estimated the burden of OCs transferred from the mother during early lactation and the subsequent OC burdens in the cubs. Third, I determined the concentration and composition of OCs in adipose tissue, plasma, and milk from pregnant females in summer

and from mothers and cubs in spring (see Fig. 3.1). Since the females are fasting throughout the sampling period, differences in the OC composition of tissues from pregnant and nursing females and their cubs should reflect the transfer, metabolism, and excretion history of these compounds.

4.3 Methods

4.3.1 Field study

Tissue samples were collected from polar bears in the vicinity of Churchill, Manitoba (57°00' to 58°50' N, 92°25' to 94°15' W) and Resolute Bay, Northwest Territories (74°00' to 76°50' N, 88°00' to101°00' W) from 1992-1996. In Churchill, pregnant females were captured from August 3 and October 7 and females with cubs in spring were captured between March 2 and March 17. In Resolute Bay, females with cubs in spring were handled between April 16 and May 24. From Churchill, I collected adipose tissue from 46 bears (12 pregnant females, 17 mothers, and 17 cubs), 18 milk samples, and 31 plasma samples (11 pregnant females, 14 mothers, and 6 cubs). From Resolute, I collected adipose tissue from 13 bears (6 mothers and 7 cubs), 8 milk samples, and 19 plasma samples (7 mothers and 12 cubs).

Polar bears were immobilized from a helicopter using well-established methods (Stirling *et al.* 1989). Seven pregnant females captured in summer were fitted with a radio-collar (Telonics Inc., Mesa, AZ) and recaptured with cubs the following spring as they emerged from their dens. All bears handled were marked with uniquely numbered ear tags

and matching lip tattoos for subsequent identification when recaptured. A vestigial premolar tooth was extracted from bears older than one year for age determination (Calvert and Ramsay 1998). Standard body measurements (straight-line-length, head length, and zygomatic width) and mass were taken from all bears captured.

Isotope (^{2}H) dilution, based on a two compartment model in which body mass is comprised of fat and fat-free or lean body mass (Farley and Robbins 1994, Atkinson and Ramsay 1995), was used to determine body composition for pregnant females and females in spring. Body composition was determined for 58 bears (12 pregnant females, 22 mothers, 24 cubs). Seven of the twelve pregnant females were also subsequently resampled in spring at the time of den emergence when they had cubs. Body composition was not determined on cubs in spring because I deemed the cubs too tiny for invasive manipulations and for being anaesthetized for the necessarily long period. The body composition of cubs was instead determined by bioelectrical impedance analysis (BIA) (Farley and Robbins 1994).

Up to 80% of adipose tissue from adult polar bears is superficial and thus readily accessible (Pond *et al.* 1992). Adipose tissue (0.6cm x 1.0 cm, 200 mg) was obtained under anaesthesia by superficial biopsy from the subcutaneous depot at the base of the tail, approximately 15 cm lateral to the midline (Ramsay *et al.* 1992). Blood samples were collected in heparinized vacutainer tubes via jugular catheterization. Blood was kept cool until centrifugation when plasma was removed and frozen immediately at -20°C. Milk samples were collected by administering 1.0 ml oxytocin via the jugular catheter and palpation of the teats. All samples were stored in individually pre-cleaned vials (rinsed three

times each with acetone and *n*-hexane), sealed, and frozen at -20°C.

4.3.2 Laboratory analysis and statistics

See section 2.3.2 for description of laboratory analyses and total body burden calculation.

Data were analysed using STATISTICA software (© 1997 StatSoft, Inc.). The Wilcoxon Matched Paired Test was used to determine if there was a significant difference between samples collected sequentially. An ANOVA was used to test whether there were differences in OC concentration and composition among different groups of bears. If a significant difference was found, then a Tukey Honest Significant Difference Test for unequal N (Spjotvoll/Stoline Test) was used to assess specifically which groups of bears were different. Pearson Product-Moment Correlations were used to determine relationships between two measured variables. A t-test was used to determine whether there was a significant difference between two samples that had the same variance. All tests were considered significant at $p<0.05$.

4.4 Results

The mean percent of extractable lipids for adipose tissue ($n = 59$), milk ($n = 26$), and plasma ($n = 50$) were 82.8 ± 10.5, 30.3 ± 6.8, and 0.1 ± 0.1, respectively.

All pregnant bears were captured in the vicinity of Churchill, MB while about 70% of the females (15/22) and their cubs (17/24) in spring were also captured in the Churchill

area. The remaining females and their cubs were captured in the vicinity of Resolute Bay, NWT.

The composition of the various OC compound classes was similar in polar bear tissues from Churchill and Resolute Bay except for α-HCH and β-HCH. Bears from Churchill had a greater percent of α-HCH (75% ± 13%) than β-HCH (25% ± 13%) in their tissues compared to bears from Resolute who had a larger proportion of β-HCH (65% ± 13 %) than α-HCH (35% ± 13 %) (ANOVA: $F_{11,23}$=54.0, $p<0.00005$).

4.4.1 Mass and percent body fat

Pregnant females had a greater mass and percent body fat compared to females with cubs in spring (Table 4.1). Mass and percent body fat are also given for cubs-of-the-year in Table 4.1.

4.4.2 Organochlorine dynamics

4.4.2.1 Chlorobenzenes

Pregnant females had lower concentrations of S-ClBzs in plasma ($t = -3.52$, $df = 30$, $p<0.005$) and adipose tissue ($t = 2.86$, $df = 33$, $p<0.05$) than did females in spring, while cubs in spring had higher S-ClBzs concentrations than did their mothers (Tukey $p<0.0005$; Table 4.2).

The mean body burdens of S-ClBzs for females in spring were 45% lower than that of pregnant females (Table 4.3). Cubs in spring had mean body burdens of S-ClBzs that

Table 4.1. Mean (± SD) mass (kg) and percent body fat (%) of pregnant female polar bears in summer, females with cubs-of-the-year (COYs) in spring, and COYs in spring. Seven of the bears were captured in Churchill, MB, as pregnant and then again in spring with cubs. All pregnant bears were captured in the vicinity of Churchill, MB. Most of the females and their cubs in spring also were captured in the Churchill area (15/22 and 17/24, respectively). The remaining females and cubs were captured in the vicinity of Resolute Bay, NWT.

Status	*n*	Mass (kg)	Body fat (%)
Pregnant	12	317 ± 39	40 ± 6
Females with cubs-of-the-year	22	162 ± 25	23 ± 9
Cubs-of-the year	24	14 ± 3	11 ± 8

Table 4.2. Mean (± SD) OC concentrations (μg/kg) in plasma (wet wt), adipose tissue (lipid wt) and milk (lipid wt) from pregnant polar bears, females with cubs-of-the-year (Fem/COYs) and cubs-of-the-year (COYs) in spring. Seven of the pregnant females also were recaptured in the spring with COYs. Asterisks designate significant differences between pregnant females and Fem/COYs, and between COYs and Fem/COYs (Tukey *p<0.05, **p<0.005, ***p<0.0005) for adipose tissue and plasma.

Tissue	Status	*n*	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Adipose	pregnant	12	110 ± 40*	178 ± 92	1743 ± 652	220 ± 91***	1817 ± 712*
	Fem/COYs	23	167 ± 63	167 ± 74	3085 ± 1496	110 ± 65	3866 ± 2172
	COYs	24	520 ± 323***	501 ± 432**	7012 ± 3440***	137 ± 85	5201 ± 2394*
Plasma	pregnant	11	1.6 ± 0.6**	2.2 ± 0.6	13.0 ± 2.2*	2.8 ± 2.7	16.9 ± 7.6
	Fem/COYs	21	3.3 ± 1.5	3.8 ± 1.5	29.5 ± 12.5	1.7 ± 1.1	31.0 ± 15.3
	COYs	18	9.7 ± 4.2***	8.7 ± 3.9***	75.4 ± 22.2***	2.0 ± 1.0	75.4 ± 26.0***
Milk	Fem/COYs	26	299 ± 110	387 ± 181	3804 ± 1427	87 ± 40	2576 ± 1011

Table 4.3. Percentage (± SD) of 1,2,4,5 tetrachlorobenzene (TeClBz), pentachlorobenzene (PnClBz), and hexachlorobenzene (HCB) of S-ClBzs in adipose tissue, plasma, and milk from pregnant female polar bears, females with cubs-of-the-year (Fem/COYs) and cubs-of-the-year (COYs) in spring. There were no significant differences in congener proportions between pregnant females and Fem/COYs in spring or between COYs and Fem/COYs in spring (Tukey $p>0.05$).

Tissue	Status	*n*	TeClBz (%)	PnClBz (%)	HCB (%)
Adipose	pregnant	12	51.3 ± 8.3	16.5 ± 3.1	32.1 ± 10.0
	Fem/COYs	23	55.6 ± 7.7	17.1 ± 4.0	27.4 ± 8.9
	COYs	24	56.5 ± 9.8	16.5 ± 4.0	27.0 ± 12.3
Plasma	pregnant	11	42.7 ± 17.7	20.2 ± 5.6	37.1 ± 17.2
	Fem/COYs	21	49.9 ± 14.5	18.3 ± 3.6	31.8 ± 14.4
	COYs	18	57.8 ± 6.0	18.5 ± 2.1	23.7 ± 5.8
Milk	Fem/COYs	26	58.4 ± 8.5	17.2 ± 4.4	24.4 ± 7.6

were 4.1% of the burden of pregnant females and 7.3% of the burden of females in spring (Table 4.3). Pregnant females, females in spring and cubs had similar whole body concentrations (Table 4.3). The concentration of S-ClBzs in milk was positively related to the concentrations in adipose tissue from females in spring ($r^2 = 0.51$, $p<0.0005$; Fig.4.1). Adipose tissue concentrations of S-ClBzs in cubs were not related to concentrations in their mother's milk ($r^2 = 0.06$, $p = 0.23$).

1,2,4,5-TeClBz comprised about 50% of S-ClBzs, while PnClBz and HCB made up the remainder (Table 4.4). Adipose and plasma S-ClBzs profiles were similar for pregnant females, mothers and cubs in spring. Milk from females with cubs in spring, however, had a higher proportion of 1,2,4,5-TeClBz than that of plasma (Tukey $p<0.05$; Table 4.4).

4.4.2.2 Hexachlorocyclohexanes

Pregnant females and females with cubs had similar concentrations of S-HCHs in their adipose tissue and also in their plasma (Table 4.2). Cubs in spring had higher concentrations of S-HCHs than did mothers for both adipose tissue and plasma (Table 4.2).

The isomeric composition of S-HCHs in adipose tissue and in plasma were similar for pregnant females and females with cubs (Table 4.5). Cubs from Resolute had lower amounts of α-HCH and greater amounts of β-HCH in their plasma than that of mothers in spring (Tukey $p<0.05$; Table 4.5), however, this was not evident for mothers and cubs in spring from Churchill.

The proportion of α-HCH and β-HCH in adipose tissue from Churchill females was

Figure 4.1. Organochlorine concentrations (ng/g, lipid wt) in adipose tissue and milk from females with cubs in spring, Churchill, MB and Resolute Bay, NWT (S-ClBzs $r^2 = 0.51$, S-HCHs $r^2 = 0.71$, S-CHLORs $r^2 = 0.51$, S-DDTs $r^2 = 0.77$, S-PCBs $r^2 = 0.69$, $p<0.0005$).

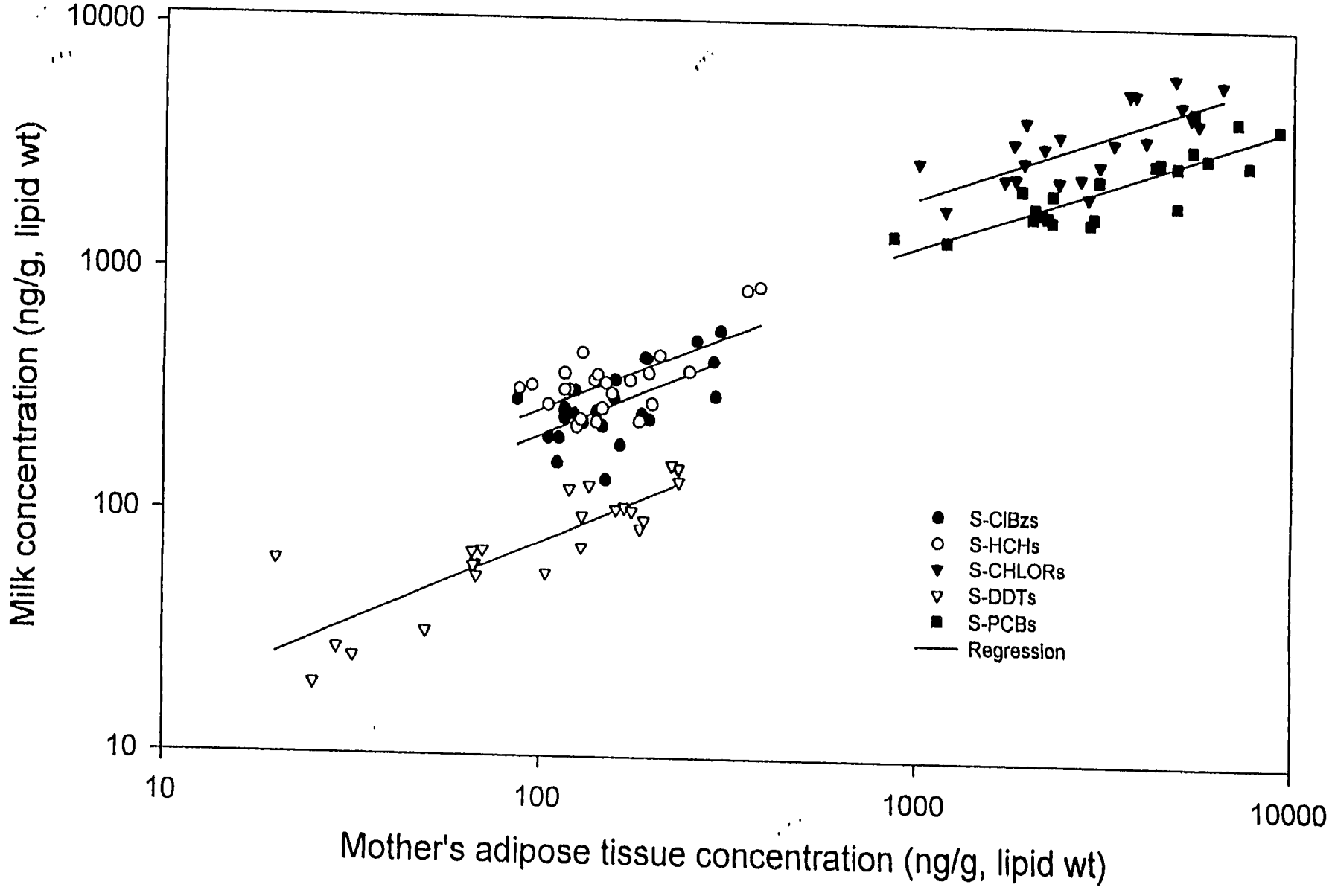

10000
1000
100
10
Milk concentration (ng/g, lipid wt)
10
100
1000
10000
Mother's adipose tissue concentration (ng/g, lipid wt)
S-ClBzs
S-HCHs
S-CHLORs
S-DDTs
S-PCBs
Regression

Table 4.4. Mean (± SD) body burden (mg) and whole body concentrations (mg/kg) of organochlorines (OCs) in pregnant females, mothers and cubs in spring. Body burdens for each group differ significantly from one another for all OCs (ANOVA $p<0.0005$). Seven of the females were captured as pregnant and again with cubs in spring. Asterisks designate significant differences of in whole body concentrations between pregnant females and mothers, and cubs and mothers in spring (Tukey *$p<0.05$, ***$p<0.0005$).

	n	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Body burdens (mg)						
Pregnant	11	14.8 ± 6.1	22.7 ± 9.6	226.2 ± 68.3	27.5 ± 10.7	236.1 ± 79.2
Mothers	11	8.2 ± 2.4	8.1 ± 3.6	153.3 ± 46.7	6.0 ± 2.6	190.1 ± 65.1
Cubs	9	0.6 ± 0.4	0.3 ± 0.1	7.3 ± 3.7	0.2 ± 0.1	5.7 ± 3.0
Whole body concentrations (mg/kg)						
Pregnant	11	0.05 ± 0.02	0.07 ± 0.04	0.73 ± 0.25	0.09 ± 0.04***	0.76 ± 0.29*
Mothers	11	0.05 ± 0.02	0.05 ± 0.02	0.89 ± 0.29	0.03 ± 0.01	1.10 ± 0.37
Cubs	9	0.04 ± 0.03	0.02 ± 0.01	0.58 ± 0.31	0.02 ± 0.01	0.45 ± 0.25***

Table 4.5. Proportion of α-HCH and β-HCH in adipose tissue, plasma, and milk from pregnant females, females with cubs-of-the-year (Fem/COYs) and cubs-of-the-year (COYs) in spring, Churchill, MB and Resolute Bay, NWT. Asterisks designate significant difference between Fem/COYs and COYs in spring (Tukey ***p<0.0005).

		Churchill			Resolute		
Tissue	Status	*n*	α-HCH (%)	β-HCH (%)	*n*	α-HCH (%)	β-HCH (%)
Adipose	pregnant	12	87.8 ± 7.9	12.2 ± 7.9	-	-	-
	Fem/COYs	17	85.9 ± 10.4	14.1 ± 10.4	6	39.3 ± 9.5	60.7 ± 9.5
	COYs	17	78.6 ± 14.2	21.4 ± 14.2	7	18.8 ± 4.4*	81.2 ± 4.4*
Plasma	pregnant	11	70.9 ± 11.8	29.1 ± 11.8	-	-	-
	Fem/COYs	14	67.5 ± 9.5	32.5 ± 9.5	7	45.8 ± 9.4	54.2 ± 9.4
	COYs	6	59.2 ± 6.8	40.8 ± 6.8	12	29.5 ± 8.8	70.5 ± 8.8
Milk	Fem/COYs	18	71.0 ± 8.1	29.0 ± 8.1	8	43.0 ± 9.3	57.0 ± 9.3

significantly different from that of their plasma and milk (Tukey $p<0.005$ for all comparisons). In contrast, Resolute females had similar proportions of α-HCH and β-HCH in their adipose tissue, plasma, and milk. The isomeric composition of S-HCHs in milk from mothers and in adipose tissue from cubs in spring from Churchill were similar (Tukey $p = 0.52$), but were significantly different for Resolute bears (Tukey $p<0.0005$).

The mean body burden of S-HCHs for females in spring was 64% lower than that of pregnant females (Table 4.3). Cubs in spring had total body burdens of S-HCHs that were only 1.3% and 3.7% of burdens found in pregnant females and females in spring, respectively (Table 4.3). Pregnant females, females and cubs in spring had similar whole body concentrations. There was a positive relationship between the concentration of S-HCHs in mother's milk and her adipose tissue ($r^2 = 0.71$, $p<0.0005$; Fig. 4.1). The concentration of S-HCHs in the adipose tissue of cubs was not related to that of their mother's milk ($r^2 = 0.04$, $p = 0.36$).

4.4.2.3 Chlordanes

Cubs had mean S-CHLORs concentrations in adipose tissue that were more than twice that of their mothers' when nursing or when pregnant (Tukey $p<0.0005$; Table 4.2). S-CHLORs concentrations in the plasma of pregnant females were about half that of nursing females (Tukey $p<0.05$; Table 4.2).

Oxychlordane comprised the largest percentage of S-CHLORs for all three groups. Four chlordane compounds (heptachlor epoxide, oxychlordane, MC-6, and *trans*-nonachlor)

comprised about 80% of all chlordanes (Table 4.6). Seven other chlordane-related compounds (Compound C, Photoheptachlor, U-4, C-5, C-3, C-4, U-2) ranged individually between 0.3 to 5.4% of S-CHLORs. The percentage of heptachlor epoxide in plasma and adipose tissue was similar for both pregnant females and females in spring (Tukey $p = 0.41$ and 0.31, respectively). Cubs in spring had a higher percent of heptachlor epoxide in their adipose tissue than their mothers at the same time (Tukey $p<0.05$), while the percentage of heptachlor epoxide in plasma was similar for both groups (Tukey $p = 0.51$; Table 4.6). The percentage of MC-6 in plasma was similar for all three groups ($F = 1.94$, $df = 47$, $p = 0.16$; Table 4.6), but cubs had a lower proportion in their adipose tissue than did females in spring (Tukey $p<0.0005$). Pregnant females had a higher percentage of *t*-nonachlor in adipose tissue and plasma than did nursing females (Tukey $p<0.05$) while cubs had a lower proportion in their plasma than did nursing females (Tukey $p<0.005$).

The composition of chlordane compounds was different in tissues from each status group of bears. Pregnant females had a higher proportion of *t*-nonachlor and a lower proportion of heptachlor epoxide in their adipose tissue than in their plasma (Tukey $p<0.05$ and $p<0.005$, respectively), while the proportions of oxychlordane and MC-6 in adipose and plasma were similar (Tukey $p = 0.99$ and $p = 1.0$, respectively). Nursing females had a higher proportion of oxychlordane in their milk compared to their plasma (Tukey $p<0.005$), while the proportion in adipose tissue and plasma was similar (Tukey $p = 0.12$). Adipose tissue and milk from nursing females had a lower proportion of heptachlor epoxide than did their plasma (Tukey $p<0.0005$). Cubs had similar proportions of oxychlordane, heptachlor

Table 4.6. The percent S-CHLORs made up of heptachlor epoxide, oxychlordane, MC-6, and *trans*-nonachlor in adipose tissue, plasma, and milk from pregnant female polar bears, females with cubs-of-the-year (Fem/COYs) and cubs-of-the-year (COYs) in spring. Asterisks designate significant differences between pregnant females and Fem/COYs or between COYs and Fem/COYs (Tukey * $p<0.05$, ** $p<0.005$, *** $p<0.0005$).

Tissue	Status	*n*	Oxychlordane (%)	Heptachlor Epoxide (%)	MC-6 (%)	*t*-nonachlor (%)	Total % of S-CHLORs
Adipose	pregnant	12	54.2 ± 2.0***	9.3 ± 1.5	8.0 ± 1.4	10.8 ± 4.1***	82.3
	Fem/COYs	23	60.8 ± 4.4	8.5 ± 1.2	8.4 ± 2.0	5.3 ± 4.0	83.0
	COYs	24	63.2 ± 2.7*	9.5 ± 1.4*	5.9 ± 1.4***	3.9 ± 1.6	82.5
Plasma	pregnant	11	52.4 ± 5.3*	12.0 ± 2.3	8.6 ± 6.8	6.6 ± 1.7*	79.6
	Fem/COYs	21	57.0 ± 4.4	11.0 ± 2.0	6.7 ± 1.6	4.8 ± 1.8	79.5
	COYs	18	60.4 ± 2.9*	10.2 ± 1.5	6.0 ± 1.5	2.8 ± 1.6**	79.4
Milk	Fem/COYs	26	62.3 ± 6.7	7.8 ± 1.6	7.4 ± 3.0	5.6 ± 3.4	83.1

epoxide, MC-6, and *t*-nonachlor in their adipose tissue and plasma (Tukey p = 0.67, 0.92, 1.0, and 0.97, respectively).

Nursing females had body burdens of S-CHLORs that were 32% lower than those of pregnant females (Table 4.3). Cubs had body burdens of S-CHLORs that were only 3.2% the body burdens of pregnant females and 4.8% that of nursing females (Table 4.3). Pregnant females, mothers, and their cubs all had similar whole body concentrations of S-CHLORs (Table 4.3). The concentration of S-CHLORs in mother's milk in spring was related positively to the concentration in her adipose tissue ($r^2 = 0.57$, $p < 0.0005$; Fig.4.1). There was no relationship between the concentration of S-CHLORs in the adipose tissue of cubs with the concentrations in the milk they were consuming ($r^2 = 0.09$, $p = 0.14$).

4.4.2.4 DDTs

The concentration of S-DDTs in plasma was similar for pregnant females, nursing females and their cubs ($F = 1.68$, $df = 47$, $p = 0.198$; Table 4.2). Pregnant females had higher concentrations of S-DDTs in adipose tissue than did females in spring (Tukey $p<0.005$), while females with cubs had similar concentrations of S-DDTs in adipose tissue to that of their cubs (Tukey p = 0.46; Table 4.2).

All three status groups of bears had a higher proportion of *pp*'DDE in adipose tissue than in plasma, and higher proportions of *pp*'DDD in their plasma than in their adipose tissue (Tukey $p<0.05$ for all comparisons). Cubs had a lower percentage of *pp*'DDT in their adipose tissue than did their mothers (Tukey $p<0.05$; Table 4.7).

Table 4.7. The proportion of *pp*'DDE, *pp*'DDD, and *pp*'DDT in adipose tissue, plasma, and milk from pregnant female polar bears, females with cubs-of-the-year (Fem/COYs) and cubs-of-the-year (COYs) in spring. Asterisk designates significant difference between Fem/COYs and COYs (Tukey * $p<0.05$).

Tissue	Status	*n*	*pp*'DDE (%)	*pp*'DDD (%)	*pp*'DDT (%)
Adipose	pregnant	12	87.9 ± 9.3	5.5 ± 8.0	6.6 ± 2.1
	Fem/COYs	23	89.3 ± 7.5	1.7 ± 2.6	9.0 ± 6.8
	COYs	24	93.8 ± 4.8	1.2 ± 1.5	5.0 ± 5.0*
Plasma	pregnant	11	66.0 ± 15.8	23.9 ± 19.3	10.1 ± 6.8
	Fem/COYs	21	66.9 ± 23.5	26.8 ± 24.3	6.3 ± 8.8
	COYs	18	61.3 ± 23.3	35.8 ± 22.0	2.9 ± 3.9
Milk	Fem/COYs	26	87.2 ± 10.6	6.6 ± 9.7	6.2 ± 3.8

Nursing females had body burdens of S-DDTs that were 79% lower than that of pregnant females (Table 4.3). Cubs had S-DDTs body burdens that were 0.7% of that of pregnant females and 3.3% that of nursing mothers (Table 4.3). Pregnant females had significantly greater whole body concentrations than did nursing females (Table 4.3). The concentration of S-DDTs in mother's milk was related positively to her adipose tissue concentrations ($r^2 = 0.77$, $p<0.0005$; Fig. 4.1) and to those of her cubs ($r^2 = 0.57$, $p<0.0005$).

4.4.2.5 Polychlorinated biphenyls

Cubs in spring had greater S-PCBs concentrations in both plasma and adipose tissue than mothers in spring (Tukey $p<0.05$; Table 4.2). Females in spring had significantly greater concentrations of S-PCBs in adipose tissue and plasma compared to pregnant females (Tukey $p<0.05$; Table 4.2).

Five congeners (PCB-99, PCB-138/163, PCB-153, PCB-180, PCB -170) comprised over 78% of S-PCBs while the remaining 17 congeners comprised individually only 0.01 to 4.1% (Table 4.8). Cubs in spring had higher proportions of PCB-99 in their adipose tissue and plasma than did their mothers (Tukey $p<0.0005$). Pregnant females had lower proportions of PCB-153 in adipose tissue than did nursing females (Tukey $p<0.005$), while proportions in plasma were similar for the two groups (Tukey $p = 0.07$). Cubs in spring had significantly higher proportions of PCB-153 in their plasma compared to that of their mothers (Tukey $p<0.0005$), while cubs and mothers had similar proportions in adipose

Table 4.8. Percent of various congeners of PCBs making up the bulk of S-PCBs in adipose tissue, plasma, and milk from pregnant female polar bears, females with cubs-of-the-year (Fem/COYs) and cubs-of-the-year (COYs) in spring. Asterisks designate significant differences between pregnant females and Fem/COYs, or between COYs and Fem/COYs (Tukey * $p<0.05$,** $p<0.005$, *** $p<0.0005$).

Tissue	Status	*n*	PCB-99 (%)	PCB-138/163 (%)	PCB-153 (%)	PCB-180 (%)	PCB-170/190 (%)	% of total S-PCBs
Adipose	pregnant	12	10.1 ± 1.1	8.0 ± 1.4	39.9 ± 4.4**	14.9 ± 1.4**	5.1 ± 0.7*	78.0
	Fem/COYs	23	9.9 ± 0.8	9.8 ± 1.1	43.8 ± 2.3	16.6 ± 1.4	6.1 ± 1.1	86.2
	COYs	24	15.3 ± 1.3***	10.4 ± 1.0	45.7 ± 3.4	10.5 ± 1.1***	4.5 ± 0.9***	86.4
Plasma	pregnant	11	9.5 ± 2.5	11.0 ± 2.2	32.6 ± 5.1	12.0 ± 5.5*	5.2 ± 1.6	70.3
	Fem/COYs	21	11.0 ± 2.0	10.9 ± 2.1	37.3 ± 6.1	15.2 ± 3.8	6.2 ± 1.8	80.6
	COYs	18	13.8 ± 1.1***	10.8 ± 1.3	43.3 ± 2.7***	12.7 ± 1.6	6.1 ± 0.9	86.7
Milk	Fem/COYs	26	15.4 ± 2.0	11.2 ± 1.3	46.5 ± 1.8	10.3 ± 2.1	4.5 ± 1.1	87.9

tissue. Pregnant females had lower proportions of PCB-180 in adipose tissue and plasma than did nursing females (Tukey $p<0.005$ and $p<0.05$, respectively). Cubs in spring had lower proportions of PCB-180 in adipose tissue compared to their mothers (Tukey $p<0.0005$). Pregnant females and cubs both had lower proportions of PCB-170 in adipose tissue compared to that of females in spring (Tukey $p<0.05$ and $p<0.0005$, respectively).

The composition of congeners varied in tissues for some status groups of bears. Both pregnant and nursing females had a higher proportion of PCB-153 in their adipose tissue than in their plasma (Tukey $p<0.0005$ for both comparisons). Milk had a higher proportion of PCB-99 than did the adipose and plasma from nursing mothers (Tukey $p<0.0005$). Milk also had a higher proportion of PCB-138/163 (Tukey $p<0.05$), and a lower proportion of PCB-180 (Tukey $p<0.0005$) and PCB-170 (Tukey $p<0.0005$) than did the adipose tissue from nursing mothers. Cubs in spring had similar proportions of PCB-99, PCB 138/163, PCB-153, and PCB-180 in their adipose tissue and plasma (Tukey $p = 0.08$, 0.96, 0.47, 0.13, respectively), and a lower proportion of PCB-170 in adipose tissue relative to plasma (Tukey $p<0.005$).

Nursing females had 19% lower body burdens of S-PCBs did pregnant females (Table 4.3). Cubs in spring had total body burdens of S-PCBs that were 2.4% and 3.0% those of pregnant females and nursing females, respectively (Table 4.3). Pregnant females and cubs had significantly lower whole body concentrations of S-PCBs than did females in spring (Table 4.3). The concentration of S-PCBs in milk was related positively to the concentrations in adipose tissue of mothers ($r^2 = 0.69$, $p<0.0005$; Fig. 4.1). Cub adipose

tissue concentrations of S-PCBs were not related to concentrations in their mother's milk ($r^2 = 0.05$, $p = 0.27$).

4.4.3 Ratio of organochlorines in cub and mother tissues

Cubs in spring had higher concentrations of OCs in their adipose tissue compared to their mothers. In particular, the ratio of cub / mother adipose tissue concentrations were greater for S-ClBzs (2.5 ± 0.6), S-CHLORs (2.3 ± 0.7), and S-HCHs (2.2 ±0.7) compared to S-PCBs (1.3 ± 0.3) and S-DDTs (1.1 ± 0.2; see Fig. 4.2). Likewise, the ratio of the mother's milk/adipose tissue concentrations were also greater for S-HCHs (2.3 ±0.7), S-ClBzs (1.8 ± 0.5), and S-CHLORs (1.2 ± 0.7) compared to S-DDTs (0.8 ± 0.2) and S-PCBs (0.7 ± 0.2); see Fig. 4.3).

4.4.4 Sequential sampling of adult female polar bears

The mean number of days between sampling seven female polar bears as pregnant and then again with cubs in spring was 188 ± 22 days. I assumed that cubs were born in mid-December (Derocher *et al.* 1992), therefore, the mean number of days of lactation prior to sampling was 81 ± 6 days.

The total body mass of the seven females handled sequentially declined 43 ± 5% and total fat mass declined 42 ± 3% (Table 4.9). The proportion of mass loss as fat ranged between 55-66% (Fig. 4.4). The total fat mass loss per day did not correlate with OC body burden loss per day (S-ClBzs r = 0.17, S-HCHs r = 0.00, S-CHLORs r = -0.16, S-DDTs r

Figure 4.2. Ratio of organochlorine concentrations in cub's adipose tissue relative to their mother's adipose tissue concentrations in spring at the time of den emergence, Churchill, MB and Resolute Bay, NWT. Cubs would have been nursing for approximately 3–4 months. Mothers with two cubs are shown as one family group.

Ratio of OC concentration cub adipose tissue : mother's adipose tissue
Family group
S-ClBzs
S-HCHs
S-CHLORs
S-DDTs
S-PCBs
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 4.3. Ratio of organochlorine concentrations in mother's milk relative to her adipose tissue concentrations in spring at the time of den emergence, Churchill, MB and Resolute Bay, NWT.

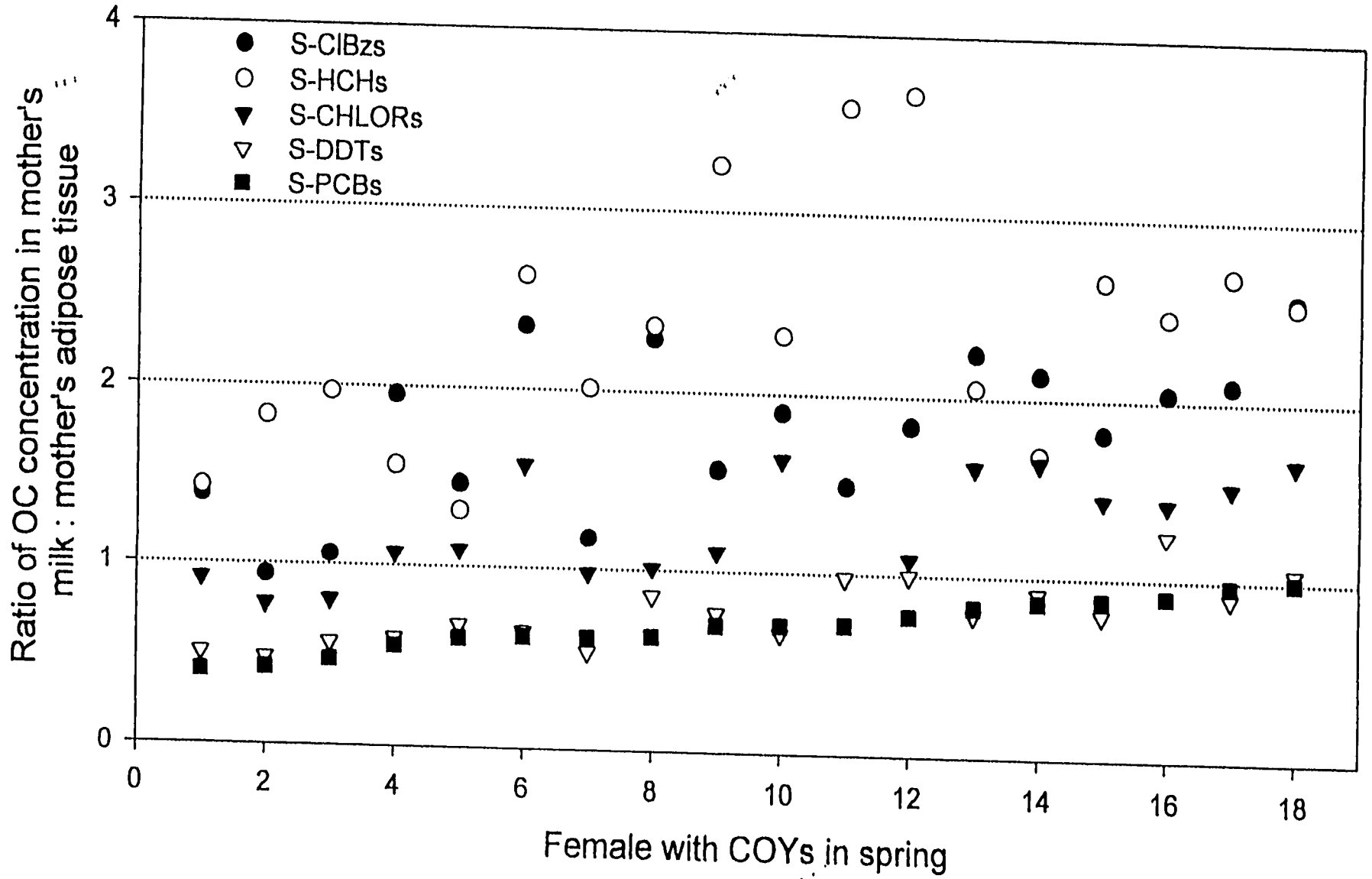
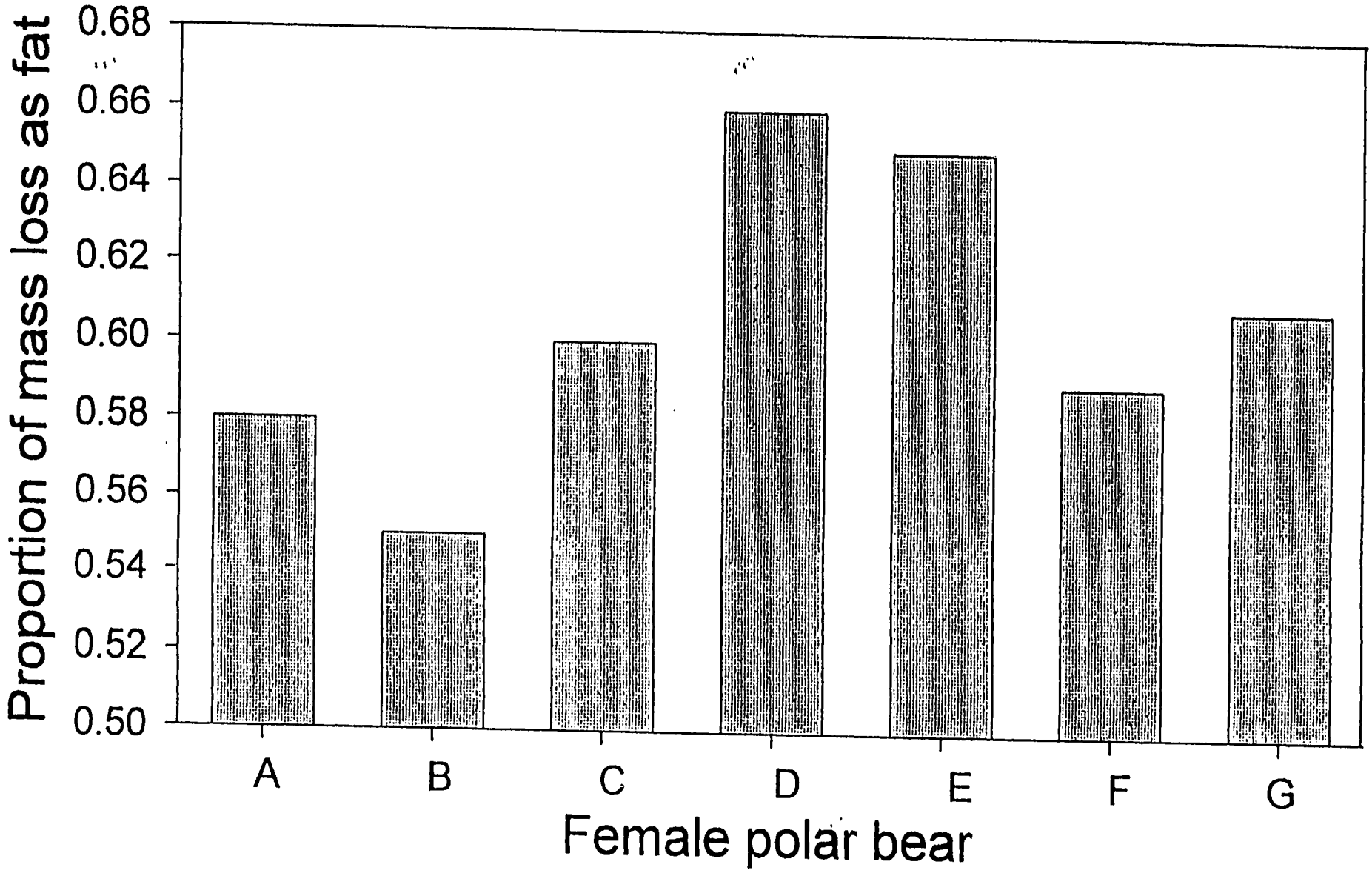

S-ClBzs
S-HCHs
S-CHLORs
S-DDTs
S-PCBs
Ratio of OC concentration in mother's milk : mother's adipose tissue
Female with COYs in spring
0
1
2
3
4
0
2
4
6
8
10
12
14
16
18

Table 4.9. Number of days between captures, body mass (kg) and percent body fat (%) for seven female polar bears handled sequentially as pregnant and again with cubs in spring, Churchill, MB. The number of cubs each female had at the time of capture, the cub's mass, and the estimated length of time they had been nursing when captured are also presented. Female polar bears did not have access to seals during the sampling period.

Bear	No. days between captures	Mass (kg)		Body fat (%)		No. cubs	Mass (kg) of cubs	No. days cubs nursing
		pregnant	with cubs	pregnant	with cubs			
A	148	283	171	41	24	2	10.0, 10.2	78
B	165	245	139	37	24	2	9.0, 9.0	90
C	192	281	182	42	34	1	12.5	75
D	195	352	184	46	33	2	13.5, 11.5	78
E	200	364	217	43	28	1	13.2	85
F	205	343	179	41	25	2	11.0, 10.7	85
G	208	326	175	43	28	2	12.5, 11.5	76

Figure 4.4. Proportion of body mass loss as fat for seven female polar bears handled sequentially during pregnancy and the initial lactation period, Churchill, MB.


Proportion of mass loss as fat
0.68
0.66
0.64
0.62
0.60
0.58
0.56
0.54
0.52
0.50
A
B
C
D
E
F
G
Female polar bear

= -0.02, and S-PCBs r = -0.14 (S-ClBzs r = -0.36, S-HCHs r = -0.21, S-CHLORs r = 0.11, S-DDTs r = 0.18, and S-PCBs r = -0.02).

Changes of OC concentrations in adipose tissue and plasma between gestation and early lactation periods showed inter-individual variation (Tables 4.10 & 4.11). Generally, concentrations in adipose tissue increased for S-PCBs, S-CHLORs, and S-ClBzs by 2.0X, 1.9X, and 1.5X, respectively; remained the same for S-HCHs; and decreased by 0.6X for S-DDTs. For plasma, concentrations increased by 2.0X for S-HCHs, 1.9X for S-CHLORs and for S-DDTs, 1.6X for S-ClBzs, and 1.5X for S-PCBs. The proportional change in OC concentrations in adipose tissue during gestation and early lactation did not correlate with the proportional change in percent body fat over the same period (S-ClBzs r = 0.03, S-HCHs r = 0.05, S-CHLORs r = 0.27, S-DDTs r = 0.01, and S-PCBs r = 0.34) or total fat mass loss (S-ClBzs r = -0.36, S-HCHs r = -0.21, S-CHLORs r = 0.11, S-DDTs r = 0.18, and S-PCBs r = -0.02).

The OC body burdens in female polar bears declined during gestation and the early lactation period, although the amount and proportional decrease varied with OC compound and individual bear (Table 4.12). In descending order, the proportional decrease in body burdens were S-DDTs (75 ± 8%) > S-HCHs (61 ± 8%) > S-ClBzs (45 ± 12%) > S-CHLORs (29 ± 20%) > S-PCBs (24 ± 16%), while the actual burden losses were S-CHLORs (71 ± 57 mg) > S-PCBs (56 ± 34 mg) > S-DDTs (20 ± 8 mg) > S-HCHs (14 ± 7 mg) > S-ClBzs (7 ± 2 mg).

The composition of OC compounds in adipose tissue and plasma changed during

Table 4.10. Organochlorine concentrations in adipose tissue (ng/g, lipid wt) from seven female polar bears handled when pregnant and again with cubs in spring, Churchill, MB. Female polar bears did not have access to seals during the sampling period.

Bear	when pregnant					with cubs in spring				
	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
A	134	352	2608	252	3095	192	381	6836	163	7068
B	176	358	2901	353	2848	259	352	4783	86	5417
C	85	98	990	98	1238	130	105	1791	68	2127
D	110	130	1382	254	2000	149	125	2814	184	4877
E	97	135	1208	162	1340	123	119	1676	67	2040
F	76	97	1192	151	1500	146	116	3298	129	4360
G	91	91	2047	134	1464	112	88	2331	71	2266

Table 4.11. Organochlorine (OC) concentrations in plasma (ng/g, wet wt) from seven female polar bears handled when pregnant and again with cubs in spring, Churchill, MB. For Bear B and F with cubs in spring, there were no measurements (n.m.) for OC concentrations in plasma. Female polar bears did not have access to seals during the sampling period.

Bear	when pregnant					with cubs in spring				
	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
A	1.9	2.6	16.3	2.1	24.9	3.7	3.0	33.2	3.0	36.6
B	1.9	1.3	13.0	2.0	8.0	n.m.	n.m.	n.m.	n.m.	n.m.
C	1.5	1.9	11.3	0.5	10.8	1.2	1.5	10.5	0.6	11.0
D	1.6	2.7	14.3	2.1	21.2	3.2	2.9	32.3	1.7	31.9
E	0.2	1.0	10.9	0.6	14.0	0.4	4.9	24.4	3.6	25.9
F	1.7	2.2	13.3	1.5	13.9	n.m.	n.m.	n.m.	n.m.	n.m.
G	1.0	1.7	14.1	9.8	25.9	1.2	3.4	31.6	2.8	48.5

Table 4.12 Total body burden (mg) of organochlorines in seven female polar bears handled when pregnant and again with cubs in spring, Churchill, MB.

Bear	when pregnant					with cubs in spring				
	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
A	15.6	40.9	303.3	29.3	359.9	7.9	15.7	263.1	6.7	291.2
B	16.1	32.8	266.3	32.4	261.4	8.6	11.7	158.8	2.9	179.8
C	10.1	11.5	117.3	11.6	146.6	7.9	6.4	109.2	4.1	129.7
D	17.9	21.2	225.6	41.5	326.7	9.1	7.6	172.2	11.3	298.5
E	15.1	21.0	187.2	25.2	207.5	7.4	7.2	100.5	4.0	122.4
F	10.7	13.8	169.3	21.5	213.0	6.5	5.2	146.8	5.7	194.0
G	12.6	12.6	284.1	18.6	203.2	5.4	4.3	112.8	3.4	109.7

pregnancy and the first three months of lactation (Table 4.13). In particular, the percentage of TeClBz, β-HCH, oxychlordane, U2, PCB-153, and PCB-137 increased while PnClBz, HCB, α-HCH, *trans*-nonachlor, PCB-47/48, PCB-74, PCB-149, PCB-118, PCB-146, PCB-105, PCB-187, PCB-183, and PCB-195 decreased in adipose tissue. These changes in compound composition were almost identical to changes in OC composition that occurred in females with cubs undergoing a seasonal fast (Chapter 3).

The concentration of OCs in adipose tissue were higher in cubs in spring relative to their mothers for S-ClBzs (53 ± 10%), S-HCHs (36 ± 9%), S-CHLORs (47 ± 4%), and S-PCBs (11 ± 8%). The concentration of S-DDTs in adipose tissue from these mothers and cubs in spring was similar.

4.4.5 Estimation of OC burden transferred during lactation

For Churchill bears only, cubs had been suckling for approximately 84 ± 5 days (assuming cubs were born in mid-December) when they were captured in spring. The mean mass of these cubs at the time of den emergence was 12.2 ± 2.5 kg. Since the mean mass of cubs at birth is approximately 700g (Uspenski, from Stirling 1989), polar bear cubs gained approximately 137 g/day. In comparison, black bear and grizzly bear cubs gained significantly less mass per day than polar bear cubs (Table 4.14). Polar bear milk was higher in gross energy per gram than that of black and grizzly bears (Table 4.14). Based on actual mass and milk intake measurements for black bear and grizzly bear cubs from birth until the time of den emergence, milk intake per unit of metabolic body mass ($kg^{0.75}$) averaged 298

Table 4.13. Concentration (ng/g) and composition of organochlorine (OC) compounds in adipose tissue (lipid wt) and plasma (wet wt) from female polar bears handled as pregnant and again in spring at the time of den emergence with cubs-of-the-year (COYs), Churchill, MB. Significant changes between captures are designated with * for increased change and - for decreased change (Wilcoxon Matched Pairs, * $p<0.10$, ** $p<0.05$, *** $p<0.005$). Concentrations and compositions of OCs in milk from females in spring are also given.

	Pregnant females		Females with COYs in spring	
	Adipose	Plasma	Adipose	Plasma
n	8	7	8	7
S-ClBzs (ng/g)	105 ± 34	1 ± 1	152 ± 50**	2 ± 1*
(%)				
1,2,4,5-TeClBz	53 ± 6	40 ± 19	58 ± 6**	42 ± 21
PnClBz	17 ± 2	22 ± 6	16 ± 3--	19 ± 4
HCB	30 ± 6	38 ± 18	27 ± 7--	39 ± 21
S-HCHs (ng/g)	177 ± 112	2 ± 1	184 ± 116	4 ± 2**
(%)				
α-HCH	92 ± 6	67 ± 13	88 ± 10--	67 ± 13
β-HCH	8 ± 6	33 ± 13	12 ± 10**	33 ± 13

Table 4.13 contd:

S-CHLORs (ng/g)	1711 ± 717	13 ± 2	3178 ± 1630**	24 ± 9**
(%)				
Compound C	1.1 ± 0.2	3.9 ± 4.4	1.1 ± 0.1	2.1 ± 1.6--
Photoheptachlor	2.4 ± 0.7	2.7 ± 1.4	2.4 ± 0.4	3.3 ± 1.0
Heptachlor epoxide	9.3 ± 1.9	11.4 ± 2.5	9.2 ± 0.9	11.3 ± 1.4
Oxychlordane	54.4 ± 2.3	52.0 ± 6.6	58.8 ± 6.3**	56.3 ± 1.8
U4	4.0 ± 1.1	6.5 ± 4.2	4.6 ± 1.8*	4.8 ± 0.4
C5	5.0 ± 3.1	2.1 ± 0.7	3.8 ± 2.7-	2.1 ± 0.6
C3	1.3 ± 0.4	1.3 ± 0.6	1.4 ± 0.3	1.6 ± 0.3
C4	2.1 ± 0.6	1.4 ± 0.3	1.6 ± 0.4	1.6 ± 0.5
MC-6	7.8 ± 1.5	10.2 ± 8.4	7.1 ± 1.9-	7.6 ± 2.3
Trans-nonachlor	10.1 ± 4.9	7.0 ± 1.8	7.5 ± 5.7--	6.3 ± 1.7
U2	2.4 ± 0.5	1.6 ± 2.0	2.6 ± 0.5**	3.0 ± 1.9*
S-DDTs (ng/g)	214 ± 90	3 ± 3	125 ± 63--	2 ± 1
(%)				
*p,p'*DDE	90 ± 10	67 ± 17	91 ± 5	69 ± 23
*p,p'*DDD	5 ± 9	23 ± 20	2 ± 4	18 ± 22
*p,p'*DDT	6 ± 2	10 ± 7	7 ± 5	13 ± 12
S-PCBs (ng/g)	1878 ± 714	18 ± 6	3877 ± 1846**	27 ± 13**
(%)				
PCB-47/48	0.6 ± 0.1	0.8 ± 0.3	0.6 ± 0.1--	0.8 ± 0.3
PCB-74	1.2 ± 0.4	2.3 ± 1.8	0.8 ± 0.4--	1.5 ± 1.6-
PCB-56/60	0.1 ± 0.1	1.1 ± 1.5	0.1 ± 0.1	0.8 ± 1.1
PCB-99	9.6 ± 0.8	8.4 ± 1.4	9.8 ± 0.4	10.3 ± 1.9*

Table 4.13 contd:

PCB-85	0.8 ± 0.4	1.7 ± 1.7	0.6 ± 0.2	1.5 ± 1.5
PCB-149	0.2 ± 0.1	0.4 ± 0.9	0.1 ± 0.1--	0.4 ± 0.8
PCB-118	2.5 ± 0.5	2.7 ± 0.9	1.7 ± 0.5--	2.4 ± 0.8
PCB-146	2.3 ± 1.1	1.1 ± 0.7	1.5 ± 0.8--	1.1 ± 0.4
PCB-153	39.5 ± 4.8	32.2 ± 5.9	42.9 ± 3.2**	32.7 ± 8.3
PCB-105	0.8 ± 0.2	1.3 ± 1.0	0.5 ± 0.2--	1.6 ± 1.9
PCB-137	0.5 ± 0.3	1.0 ± 1.5	0.7 ± 0.3**	0.9 ± 0.3
PCB-138/163	9.7 ± 1.4	10.5 ± 2.0	9.5 ± 0.7	11.1 ± 2.7
PCB-187	1.8 ± 1.0	3.4 ± 3.4	1.2 ± 0.8--	3.2 ± 3.1
PCB-183	3.2 ± 2.1	0.8 ± 0.6	2.1 ± 1.5--	0.9 ± 0.7
PCB-156	2.0 ± 1.3	0.9 ± 0.7	1.4 ± 0.9-	0.9 ± 0.4
PCB-157	0.4 ± 0.2	0.2 ± 0.2	0.5 ± 0.2	0.4 ± 0.4
PCB-180	15.3 ± 1.4	14.7 ± 4.0	16.3 ± 1.7	17.1 ± 5.6**
PCB-170	5.3 ± 0.5	5.6 ± 1.9	5.8 ± 0.9*	6.8 ± 2.0*
PCB-195	0.3 ± 0.2	6.3 ± 6.3	0.2 ± 0.2--	2.8 ± 3.6
PCB-194	2.5 ± 0.7	4.7 ± 3.0	2.8 ± 0.7	2.5 ± 1.5
PCB-206	0.4 ± 0.2	0.05 ± 0.1	0.3 ± 0.3	0.1 ± 0.1
PCB-209	0.9 ± 0.3	0.03 ± 0.1	0.7 ± 0.6	0.1 ± 0.2

Table 4.14. Growth and milk intake parameters for black bear, grizzly bear, and polar bear cubs from birth until the time of den emergence.

	Black bear[a]	Grizzly bear[a]	Polar bear
n cubs	3 litters	3 litters	32
No. days from birth to time of den emergence	~ 60	~60	84 ± 5
Mass (kg) at time of den emergence	2.6 ± 0.5	5.1 ± 0.8	12.2 ± 2.5
Growth rate (g/day)	49 ± 9	98 ± 22	137 ± 32
kcal/g/milk	2.4	2.3	4.0[b]
Milk intake/cub (g/day)	185 ± 89	353 ± 54	301 ± 35[c]
Total milk intake/cub[c] (kg)	9.7	17.0	23.1 ± 3.9

[a] from Farley and Robbins (1995)

[b] from Derocher and *et al.* (1993), $n = 31$

[c] based on 298 kcal/day/kg$^{0.75}$ (Farley and Robbins 1995)

± 67 kcal/day for both species (Farley and Robbins 1995). I assumed that this value would be similar for polar bear cubs and therefore, calculated total milk intake for polar bear cubs according to the following equation;

$$TMI = \frac{\sum_{i=1}^{i=n} m(i)^{0.75} \times 298}{k}$$

where *TMI* is total milk intake (g), *n* is the number of days from the birth of the cub to the time of capture, *m* is the mass of cub on day *i* (kg), and *k* is the gross energy content of the mother's milk (kcal/g).

Once total milk intake was determined for each cub, I then calculated the total OC burden loss that occurred via lactation for each mother according to the following equation;

$$B_m = \sum_{c=1}^{c=n} TMI \times l \times C_{OC}$$

where B_m is the burden loss that occurred via milk transfer (mg), *n* is the number of cubs, *TMI* is the total milk intake for each cub (kg), *l* is the percent lipid in milk, and C_{OC} is the concentration of the organochlorine in milk (mg/kg, lipid wt).

The total body burden loss and lactational transfer of OCs during gestation and the initial lactation period for the seven females handled sequentially are given in Table 4.15.

Table 4.15. Total organochlorine (OC) body burden loss (mg) and estimated OC burden transferred via milk (mg) during gestation and the first 3 months of lactation for seven females captured sequentially, Churchill, MB. The percent OC body burden loss via lactation is also given. Organochlorine body burdens were determined for 21 cubs in spring soon after den emergence, Churchill, MB.

	S-ClBzs	S-HCHs	S-CHLORs	S-DDTs	S-PCBs
Total body burden loss (mg)	6.5 ± 2.4	13.7 ± 7.3	70.0 ± 56.6	20.3 ± 8.2	56.1 ± 33.5
Lactational transfer (mg)	2.9 ± 1.7	4.8 ± 3.2	40.9 ± 25.0	0.9 ± 0.4	29.9 ± 17.2
Percent burden loss via lactation (%)	49 ± 25	37 ± 18	66 ± 37	5 ± 2	59 ± 32
Cub body burden (mg)	0.6 ± 0.3	0.4 ± 0.2	9.0 ± 5.7	0.2 ± 0.1	6.9 ± 4.4

Between 37%-66% of the female's burden of S-ClBzs, S-HCHs, S-CHLORs and S-PCBs was transferred during lactation, while only 5% of the female's S-DDTs burden was transferred via milk (Table 4.15). The body burdens of OCs for 4 cubs from 3 of the 7 females handled sequentially were lower than the estimated burden that was transferred via lactation. The OC burdens for these 4 cubs were identical to mean burdens for all cubs captured at the time of den emergence from Churchill, MB (Table 4.15). Body composition was determined using BIA for 9 cubs. Based on the BIA data for body composition of cubs, I estimated that cubs had approximately 12% body fat that is similar to the value of 8% that Pond *et al.* (1992) reported. Cub had higher burdens of S-CHLORs and S-PCBs than that of S-ClBzs, S-HCHs, and S-DDTs (Table 4.15). Cubs with higher burdens of one OC generally had higher burdens for all compounds. Cub burdens of S-ClBzs, S-HCHs, S-CHLORs, and S-PCBs were highly correlated with each other (Pearson-Product $n = 25$, $p<0.05$) whereas, burdens of S-DDTs did not correlate with the other OC burdens (Fig.4.5).

4.4.6 Correlation between OCs and cub measurements

There were significant negative correlations between DDE concentrations in adipose tissue and cub weight, and PCB-118 concentrations in adipose tissue with head length and zygomatic width (Pearson-Product $n = 25$, $p<0.05$; Figs. 4.6a-c).

Figure 4.5. Organochlorine body burdens for cubs in spring at the time of den emergence, Churchill, MB, and Resolute Bay, NWT.

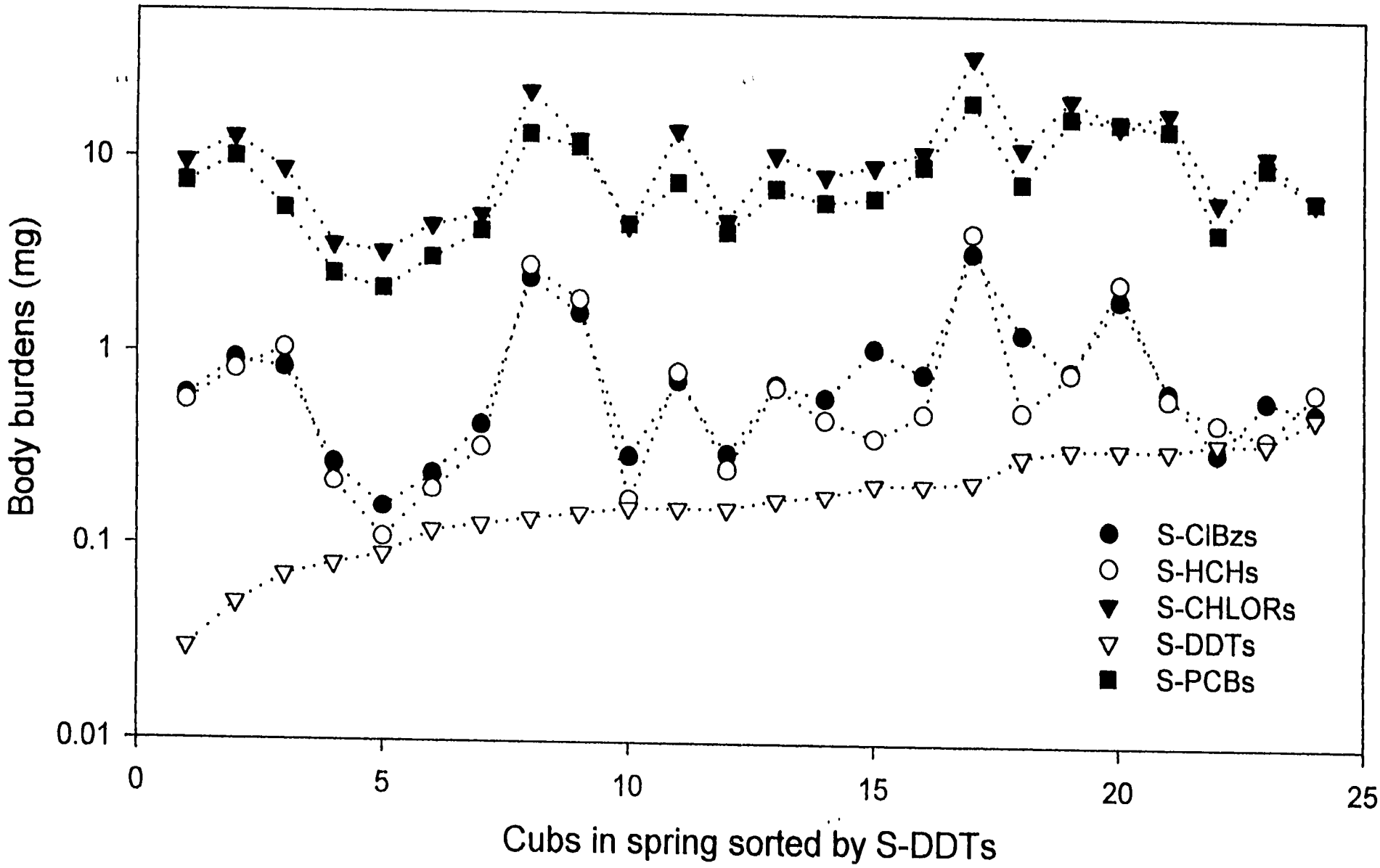
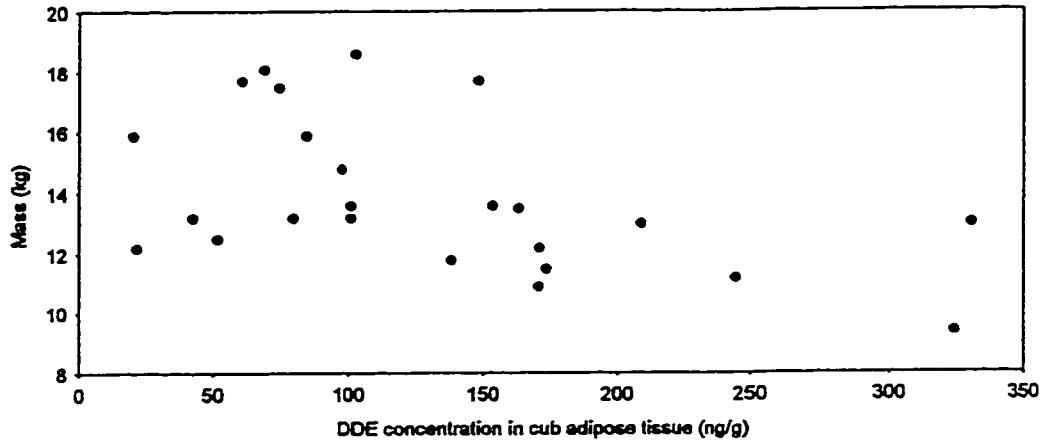
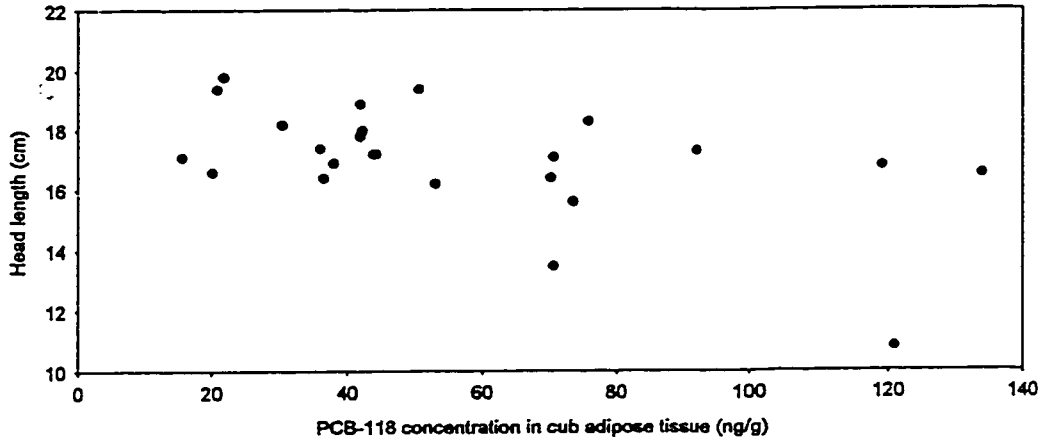

Body burdens (mg)
10
1
0.1
0.01
0
5
10
15
20
25
Cubs in spring sorted by S-DDTs
S-ClBzs
S-HCHs
S-CHLORs
S-DDTs
S-PCBs

Figure 4.6a-c. Correlation (r) between DDE concentrations (ng/g, lipid wt) and body weight (kg), PCB-118 concentrations (ng/g, lipid wt) and head length (cm), and PCB-118 concentrations (ng/g, lipid wt) and zygomatic width (cm) of cubs in spring, Churchill, MB, and Resolute Bay, NWT (Pearson-Product r = -0.50, r = -0.53, and r = -0.41, respectively, $p<0.05$).

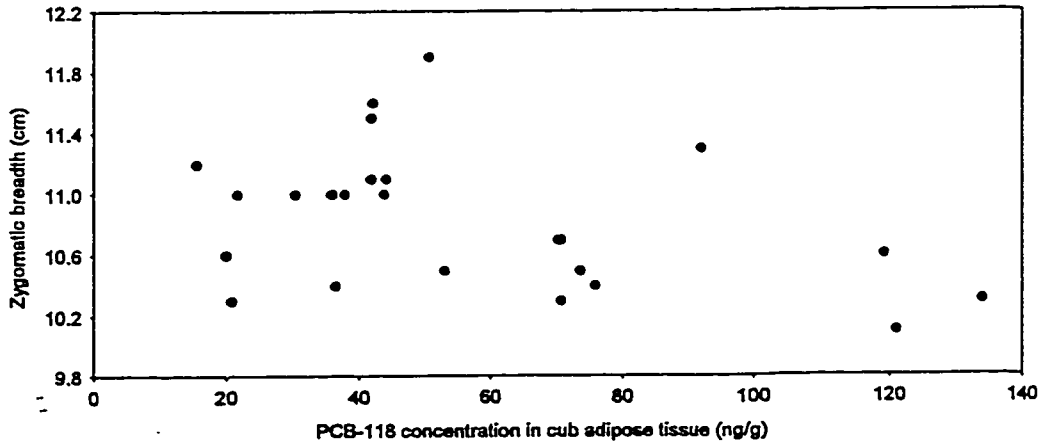
6a.


Mass (kg)
20
18
16
14
12
10
8
0
50
100
150
200
250
300
350
DDE concentration in cub adipose tissue (ng/g)

6b.


Head length (cm)
22
20
18
16
14
12
10
0
20
40
60
80
100
120
140
PCB-118 concentration in cub adipose tissue (ng/g)

6c.


Zygomatic breadth (cm)
12.2
11.8
11.4
11.0
10.6
10.2
9.8
0
20
40
60
80
100
120
140
PCB-118 concentration in cub adipose tissue (ng/g)

4.5 Discussion

4.5.1 Organochlorine transfer during pregnancy and early lactation

Trans-placental transfer of OCs is minor compared to lactational transfer, at least in all mammalian species that have been investigated (Allen and Barsotti 1977, Clark and Lamont 1976, Addison and Brodie 1977 & 1987, Tanabe *et al.* 1981). That fact, coupled with the relatively small size of neonates in bears, suggests that most inter-generational OC transfer in polar bears occur after birth. By about 3 months post-partum, when I sampled the families, the females had unloaded a relatively large proportion of their OC burden to their cubs. The more soluble (low K_{ow}) compounds (S-ClBzs and S-HCHs) were more selectively transferred from adipose tissue to cub via milk. Approximately 170 mg of OCs (approximately 0.9 mg/kg) were transferred from female polar bears to their cubs. This value is significantly higher than the transfer rates to young that Aguilar and Borrell (1994) calculated for female fin whales (*Balaenoptera physalus*); 200-1000 mg of PCBs (approximately 0.01-0.03 mg/kg) and 300-1500 mg of DDTs (approximately 0.01-0.04 mg/kg). Polar bear mothers with relatively high OC concentrations in their adipose tissue also had relatively high body burdens and milk concentrations. This is the same pattern that Borrell *et al.* (1995) reported for long-finned pilot whales (*Globicephala melas*).

The body burdens of all measured OCs in polar bear cubs in spring were approximately 17 mg (1.5 mg/kg). This value was somewhat higher than Addison and Stobo (1993) reported for grey seal (*Halichoerus grypus*) neonates (0.03 - 0.05 mg/kg) and post-weaning (12 - 16 days old) pups (0.45 - 1.01 mg/kg) but somewhat lower than Tanabe *et al.*

(1982) reported for striped dolphin calves (*Stenella coeruleoalba*): PCBs (4.9-11.3 mg/kg), DDTs (5.9 - 10.8 mg/kg), and HCHs (0.5 mg/kg).

The OC body burdens of polar bear litters were approximately1 - 4% that of their mothers when pregnant and 3 - 8% of when their mothers were nursing. These mother / young proportions are similar to the DDTs and PCBs burdens in fin whales (i.e., 9 - 27% and 3 - 14%, respectively) reported by Aguilar and Borrell (1994). The total transfer of OCs from mother to cub in polar bears, calculated from milk transfer rates and milk contaminant loads, is about an order of magnitude greater than what was determined to be in the tissues of the cubs. The fate of these missing OCs is not known but according to my model. Unless my assumptions used in calculating the transfer rates are incorrect, the OCs in cubs were, presumably, excreted or metabolized by them. The very low body fat of cubs would tend to enhance the possibility of partitioning into fecal contents, and possible biliary excretion could be occurring.

4.5.2 OC dynamics in pregnant females and mothers

During the 8 months of pregnancy and lactation when female polar bears are fasting and mobilizing adipose tissue, stored OCs are, presumably, also mobilized and then re-sequestered or excreted. The movement of some OCs is controlled by thermodynamic equilibrium among the various lipid pools, with blood acting as a transport medium. There is also strong evidence that some PCB metabolites and oxychlordane are selectively stored in the liver (Letcher 1996). The rate at which steady state is achieved can occur quickly for

OCs , on the order of days or hours (Carey *et al.* 1998). When the lipid pool size is reduced, such as when bears catabolize their adipose tissue, the local OC concentration in adipocytes can increase. If OCs levels in one lipid pool get out of equilibrium with the rest, the OCs can be redistributed to allow a return to a steady state of relative equivalence among pools (Carey *et al.* 1998).

Lactational elimination of OCs, especially S-CHLORs and S-PCBs, was a major excretory route for female polar bears, similar to that seen in cetaceans and pinnipeds; *e.g.*, Arctic beluga whales *Delphinapterus leucus* (Muir *et al.* 1990); Baikal seals *Phoca sibirica* (Nakata *et al.* 1995); and ringed seals *Phoca hispida* (Addison *et al.* 1986, Muir *et al.* 1988).

The adipose tissue concentrations for S-ClBzs, S-CHLORs, and S-PCBs increased in females during their pregnancy / nursing fast although the total body burdens of each declined. During the same period, the adipose tissue concentration of the S-DDTs decreased and that of the S-HCHs remained the same while their burdens also declined.

In general, there were no significant changes in the compound-specific composition of OCs found in nursing females compared with when they were pregnant, even though OC concentrations changed by 2- to 4-fold over this period. Variation in the mobility of some individual compounds was, however, evident. For example, the proportion of PCB-180 and PCB-170 within the S-PCBs increased in mothers during gestation and lactation, whereas they were found in a lower proportion in cubs, suggesting that both compounds were not easily transferred *in utero* or via lactation. Heptachloro-PCBs, such as PCB-180 and PCB-170, are more highly chlorinated and do not appear to redistribute as readily as the less

chlorinated PCBs.

The relative proportions of oxychlordane and PCB-153 in cubs were higher than or similar to those of their mothers, indicating that these compounds were readily transferred to cubs. The congener, PCB-153, was also easily transferred during lactation in rats (Gallenberg and Vodicinik 1987). This may occur because the plasma/fat partition coefficient tends to be somewhat higher for the less chlorinated compounds, making them more readily available for incorporation into milk fats (Carey *et al.* 1998).

Trans-nonachlor was found in lower proportions in mothers than in pregnant females while oxychlordane rose as a proportion of S-CHLORs over the same period. These patterns of change might be accounted for by the determination that *t*-nonachlor can be metabolized to oxychlordane (Tashiro and Matsumura 1978).

4.5.3 OC dynamics in mothers and cubs

As cubs were captured soon after the time of den emergence, they did not have access to alternative food sources. Therefore, OCs found in the cub must have been obtained from their mothers or *in utero*, primarily via lactational transfer. Most of the burden that mothers lost could be accounted for by milk transfer (S-CHLORs, 66%; S-PCBs, 59%; S-ClBzs, 49%; S-HCHs, 37%). This is similar to the pattern seen in many marine mammals. Up to 95% of the mother's OC burden in grey seals and striped dolphins are transferred to the neonate during lactation (Addison and Brodie 1987, Tanabe 1988).

In contrast to most of the OCs I monitored, lactation was not a major excretory route

for S-DDTs even though mothers had significant body burden losses. Females must have metabolized most of their S-DDTs burden prior to lactation. I have shown previously that non-pregnant / non-lactating polar bears undergoing a seasonal fast can significantly decrease their body burdens of S-DDTs within a 2-3 month period (see Chapter 2). Unlike most of the OCs monitored, where cubs had higher concentrations of S-ClBzs, S-HCHs, S-CHLORS, and S-PCBs in adipose tissue and plasma than did their mothers, the concentrations of S-DDTs in mothers and cub adipose tissue were similar. Thus, like their mothers, cubs may have been able to metabolize or excrete DDTs at a much higher rate than they could the other OCs.

Whole-body concentrations of OCs for mothers and cubs were similar for S-ClBzs, S-HCHs, S-CHLORs and S-DDTs, but cubs had significantly lower concentrations for S-PCBs. Since none of my other data would support cubs being able to metabolize significant amounts of PCBs, their relative absence in cub adipose tissue suggests that PCBs were not transferred as readily from mother to cub as were the other OCs.

While there was no selective transfer of S-ClBzs and S-HCHs compounds, the relative proportion of S-CHLORs and S-PCBs compounds varied between mothers and cubs. Like mink (Crum *et al.* 1993), higher proportions of heptachlor epoxide and oxychlordane were found in the adipose tissue of cubs than in that of their mothers. Similarly, cub adipose tissue had lower proportions of MC-6, PCB-180 and PCB-170 than did the milk or adipose tissue of their mothers. Thus, some of the OCs monitored showed compound-specific transfer between mother and cub.

4.5.4 OC dynamics and lipid composition of tissues

If chlorinated biphenyls (CBs) are free to migrate between different tissues within an animal, it is assumed that there should be a similar distribution pattern between individual congeners in all tissues (Boon *et al.* 1992). However, Jenssen *et al.* (1996) found different patterns of CB distribution within tissues of neonatal grey seal pups which they related to variations in the capacity of the tissue and lipid composition among sites. Similarly, differences in lipid composition and amounts of circulating triacylglycerols during pregnancy and lactation in mice were proposed as factors for differential PCB mobilization rates (Gallenberg and Vodicnik 1987).

Guitart *et al.* (1996) found a direct relationship between fatty acid composition and OC concentrations in the tissues of striped dolphins (*S. coeruleoalba*). The lipid composition of polar bear tissues may, therefore, affect the distributional pattern of OC compounds. The fatty acid compositions of polar bear adipose depots, however, are uniform (Pond *et al.* 1992) and similar to the composition found in milk (Cook *et al.* 1970). Unlike adipose tissue and milk, the fatty acid composition of plasma consists of a high proportion of phospholipids (Kaduce *et al.* 1981). The inter-tissue differences in proportions of some DDT compounds that I observed between plasma and both adipose tissue and milk might be explicable via differences in fatty acid composition of the tissues.

4.5.5 Implications

Organochlorine concentrations in the adipose tissue of young cubs were higher,

relative to their mothers, probably due to their substantially lower percentage of body fat. Geyer *et al.* (1993) found a direct inverse relationship between percent body fat and LC_{50} for lipophilic chemicals (i.e., the lower the percent body fat the lower the LC_{50}). A greater proportion of body fat, thus, serves as a 'protective reservoir' against the toxic effects of lipophilic persistent chlorinated compounds (Geyer *et al.* 1993). Unlike young seals and whales, newborn polar bear cubs, with relatively small adipose tissue depots, do not have such a 'protective reservoir' for sequestering the OC burdens they receive from their mothers. Since the first few months of lactation coincides with a period of particularly rapid growth and development for young bear cubs, a large influx of contaminants during this time may influence various developmental pathways (Ross *et al.* 1995, Tilson *et al.* 1990, Jansen *et al.* 1993).

The immunosuppressive potential of OCs has been well established in laboratory animals (Vos *et al.* 1988), but the effects of OCs on immune function in free-ranging mammals and their young is limited. Suppression of natural killer (NK) cell activity and specific T-cell responses occurred in harbour seals (*Phoca vitulina*) who were fed contaminated herring (DeSwart *et al.* 1996). Perinatal exposure to chlordane has been shown to adversely affect the fetus and induce long lasting and subtle effects on immune function, such as suppressed cell-mediated immunity (Spyker-Cranmer *et al.* 1982, Johnson *et al.* 1986). Chemically-induced immunosuppression of young polar bear cubs, therefore, could cause an increased susceptibility to infection and disease.

Since developing young are more sensitive to effects of chemicals than adults (Myers

and Colborn 1991, Colborn *et al.* 1993, Bearer 1995), polar bear cubs in spring would be most susceptible to the effects of OC contamination. Maternal exposure *in utero* and during lactation, as well as the possibility of increased body residues during multi-generational exposure, may contribute to reduced growth and fertility (McCoy *et al.* 1995). I found a correlation between two morphological parameters, head length and zygomatic breadth, with PCB-118 levels; and body mass with DDE levels. These correlations do not imply a cause-effect relationship but I suggest that their presence may warrant further investigation. Smaller head circumferences and lower birth weights in newborn human infants were correlated with increased OC exposure (Fein *et al.* 1984, Rylander *et al.* 1995).

Metabolites, such as methylsulfone-PCB and -DDE and hydroxy-PCBs, can be detected in tissues of polar bears (Sandau and Norstrom 1996, Letcher *et al.* 1998). A negative correlation between Vitamin A (retinol) and total PCBs in plasma of Svalbard polar bears has been shown in a recent Norwegian report (Skaare *et al.* 1994).

If chemical stresses were effecting polar bear populations, these stresses would not occur uniformly, and would occur as low frequency, random, and stochastic events (Fox 1995). Therefore, I would probably not be able to detect mild effects of OC contamination in young cubs. Alternatively, if OC body burdens were causing serious implications for body functioning processes and were detrimental to cub health, then I would expect to see a decline in the cub survival rate in polar bear populations. Since cub survival rate has declined in the Churchill population (Derocher and Stirling 1992), future research should focus on whether OC contamination is a factor.

5. GENERAL DISCUSSION

The data set presented in this thesis contains some of the most important and comprehensive information ever to be gathered on the dynamics of organochlorines in a wild mammal (or any kind of biota) living in its natural environment. Organochlorine dynamics in other wild species are not likely to be studies with this intensity and thoroughness. One of the most valuable contributions comes from the availability of proximate composition data from sequentially sampled bears during fasting. This allows us to view, for the first time, of how fasting effects metabolism and clearance of several important classes of organochlorine chemicals in a mammal, including the influence of gender and reproductive status. These data illustrate clearly the high degree of "variability" that can occur in contaminate burdens of a species.

5.1. Seasonal and pregnancy fasts

Polar bears accumulate huge adipose tissue depots during times of food surplus to carry them through periods of fasting. Obligate fasting in polar bears occurs primarily for two reasons; 1) when food is unaccessible, such as when bears are forced on land due to the melting of the ice and 2) during pregnancy and the initial stages of lactation when females are in dens. I will refer to these two types of obligate fasts as seasonal fasts and pregnancy fasts.

Even though the duration of the seasonal fasts I monitored in lactating females was shorter (3-4 months) than for pregnancy fasts (7-8 months), the relative changes in OC concentration and compound-specific composition in adipose tissue was almost identical for both. However, changes in the body burden of OCs were different for females undergoing pregnancy fasts than those undergoing seasonal fasts. Body burdens for all OCs declined during gestation and early lactation (i.e., during the pregnancy fast) whereas only the S-DDTs burden decreased for lactating females during their summer/autumn fast (seasonal fast). Since some compound-specific OC changes occurred in the adipose tissue of lactating females, females may have been able to metabolize some OC compounds but, since there was no significant decline in their total body burden, there was no substantial excretion of any OCs. In contrast, pregnant females were able to metabolize and excrete a significant proportion of their OC body burden during gestation and the early post-natal period.

5.2 Relevance of OC concentration variation to scientists and managers

I examined the dynamics of OCs during the annual cycle of feeding and fasting in polar bears, which included the time of gestation and the initial stages of lactation. In doing so, I have illustrated that OC compounds can be highly labile and that this labiality can vary with reproductive status (*e.g.* females with cub, COYs, yearlings, males), nutritional state, age, and previous reproductive history. Individual bears sampled repeatedly over a 4-year period displayed a 1- to 7-fold variation in OC concentrations.

Such large ranges in OC concentrations from the same bears has implications for scientists and managers who might wish to use polar bears as biomonitors for Arctic

contamination. Sampling of tissues should be standardized to the same time of year and stratified by reproductive classes if valid comparisons are to be made among years and geographic regions. Since OC concentrations are highly dependent on the condition of the bears, all other things being equal, animals will tend to have lower concentrations in years of food abundance than in years when food is less plentiful. Similarly, if sampling in one region occurs, for example, at a time of hyperphagia while in another region the sampling occurs after a lengthy fast, calculated differences in OC tissue loads may not reflect the real differences that exist between the populations.

There may be other limitation to the use of polar bears as biomonitors for general Arctic contamination. First, the metabolic capability of polar bears is not representative of other species in the Arctic. Polar bears can apparently metabolize S-DDTs and a number of PCB congeners that accumulate in other species. Second, polar bears undergo huge fluctuations in body fat reserves which is not indicative of the nutritional regimen of most other species inhabiting the Arctic. This "boom and bust" feeding pattern, however, do make polar bears a good model to study the dynamics of OCs in an animal that accrues huge adipose tissue depots (with associated stored OCs) and then later mobilize those stores.

5.3 Transfer of OC contaminants to cubs

During the first few months of lactation there was a significant decline in the mother's body burden of OCs through excretion of OC compounds to their cubs. During seasonal fasting in summer and autumn, however, the body burdens of lactating females did not change appreciably. Although their milk contains OC contaminants, the lipid

composition of the milk declines throughout those fasts as does the volume of milk transferred. The early neonatal period, therefore, may be when polar bear cubs are most at risk for OC exposure. That is also a period in their lives when rapid development and growth occurs. For example, cubs grew an average of 22-fold or more between birth and the time when they were first sampled in spring. This is also a time when their diet is exclusively milk. Neonatal cubs also do not have large fat reserves into which they can sequester OC contaminants.

5.3. Effects of OC contamination

Different species have variable responses when exposed to the same level of OC contamination (Peterson *et al.* 1993). In mammals, OCs have been shown to affect reproduction (Aulerich and Ringer 1977, Lione 1988, Addison 1989, Beland *et al.*1993, Arnold *et al.* 1995, Heaton *et al.* 1995), immune function (Lahvis *et al.* 1995, Tryphonas 1995), endocrine systems (Pluim *et al.*1993, Feeley 1995), behaviour (Golub and Jacobson 1995, Fiedler *et al.* 1996), and development (Rice *et al.* 1996). While several studies have focussed on the effects of individual OC compounds, research on their combined toxicological effects in wildlife is limited (Sullivan 1993, Kavlock *et al.* 1996).

I have shown that newborn polar bear cubs whose mothers had high OC levels in their milk were less likely to survive their next year of life than were cubs from mothers with lower OC levels in their milk (Chapter 3). While my data are only correlational, this may be some of the first evidence of deleterious effects of OCs on bears. Wiig *et al.* (1998) have implicated OC estrogenic mimics in their recent report on pseudohermaphrodism in polar

bears.

5.4 Future direction of contaminant research in polar bears

Polar bear cubs may be especially sensitive to organochlorine exposure because they are born in a notably altricial state and rely heavily on milk intake during a critical early period of growth and development (Ramsay and Dunbrack 1986). Polar bear cubs are exposed *in utero* and, especially, postnatally to relatively high OC contaminant loads (Polischuk *et al.* 1995, Chapter 4). The greatest impact of these contaminants may be occurring during the early months of post-natal development when cubs may be dying before they are even sampled. Special attention to early post-natal survival might be warranted.

Although polar bears have long been known to have relatively high OC burdens (Bowes and Jonkel 1975, Norstrom and Muir 1994, Norstrom *et al.* 1988, Norstrom *et al.* 1998), there has been no attempt to determine whether these contaminants have had any negative effect on the bear's immune system, its endocrine system, its neural system, or its reproduction. Scientists at the University of Montreal are currently completing a preliminary immunotoxicological study and Norwegian researchers will be completing a more extensive immunotoxicological project on polar bears this year (A. Derocher, pers. comm.).

Organochlorines have recently been shown to mimic endogenous estrogen and androgen hormones (Arnold *et al.* 1996, Guillette *et al.* 1996) and may be responsible for a recent decrease in human male fertility and reproductive health in humans (Bush *et al.* 1986, Skakkebaek and Meyer 1996). The effects seen in human males have included decreased semen quality (Carlsen *et al.* 1992, Auger *et al.* 1995), a doubling in frequency

of undescended testis (Chilvers *et al.* 1984), and an increased incidence of testicular cancer (Adami *et al.* 1994). Males may be especially susceptible to chemically induced mutations since sperm production involves mitotic and meiotic division of cells throughout the male's reproductive life (Sullivan and Barlow 1976). Exposure of young to OCs *in utero* and during lactation (Allen and Barsotti 1977, Masuda *et al.* 1979, You *et al.* 1998) can influence the neonate's reproductive capacity as adults (Sager *et al.* 1987 & 1991, Lundkvist 1990). Their high trophic level and their lengthy period of post-natal development when they are entirely dependent on lipid-rich milk may make male polar bears especially susceptible to reproductive anomalies. This notwithstanding, there are essentially no investigations of what constitutes a normal physiological status in the reproductive performance of polar bears. Even large-scale effects could be passing unnoticed in wild polar bear populations.

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APPENDIX A:

Concentration and composition of organochlorine compounds in adipose tissue, plasma, and milk from polar bears captured sequentially from Churchill, MB and Resolute Bay, NWT.

Table A1. Mean (±SD) sum of organochlorine (S-OC) concentrations and compound composition (%) in adipose tissue (ng/g lipid wt), plasma (ng/g wet wt), and milk (ng/g lipid wt) from female polar bears with cubs captured sequentially during a period of fasting, Churchill, MB. Mean number of days between captures is 60 ± 20. Significant differences in concentration and compound composition between captures are designated with an asterisk (*) for increases and with a hyphen (-) for decreases (Wilcoxon Matched Pairs, *p<0.10, **p<0.05, ***p<0.005). Subscript letters indicate significant differences bewteen groups of bears; c = cubs-of-the-year, y = yearlings, and m = males (Tukey p<0.05).

	Churchill, MB (Fasting)					
	Capture 1			Capture 2		
	Adipose	Plasma	Milk	Adipose	Plasma	Milk
n	16	14	9	16	14	9
S-ClBzs (ng/g)	110 ± 47	$_{c,y}$2 ± 1	270 ± 123	146 ± 55***	2 ± 1	378 ± 176**
(%)						
1,2,4,5-TeClBz	58 ± 7	54 ± 11	68 ± 10	61 ± 5***	52 ± 18	67 ± 12
PnClBz	16 ± 2	18 ± 9	13 ± 5	$_{c}$15 ± 2---	17 ± 4	12 ± 5-
HCB	25 ± 6	28 ± 8	19 ± 5	24 ± 6--	32 ± 15	21 ± 8

Table A1 contd:

S-HCHs (ng/g)	174 ± 87	4 ± 3	336 ± 175	182 ± 108	4 ± 3	395 ± 242
(%)						
α-HCH	$_{c,m}$84 ± 9	62 ± 20	87 ± 9	$_{c,m}$79 ± 11^{---}	65 ± 17	83 ± 12
β-HCH	$_{c,m}$16 ± 9	38 ± 20	13 ± 9	$_{c,m}$21 ± 11***	35 ± 17	17 ± 12
S-CHLORs (ng/g)	$_{c}$2063 ± 1114	$_{c}$18 ± 11	2978 ± 1043	$_{c}$2810 ± 1149***	23 ± 11**	5100 ± 2440***
(%)						
Compound C	1.7 ± 2.7	7.3 ± 6.7	1.0 ± 0.1	1.0 ± 0.3^{-}	5.5 ± 4.3	1.2 ± 0.5
Photoheptachlor	2.2 ± 0.5	3.2 ± 1.3	2.4 ± 0.3	$_{c,m}$2.2 ± 0.6	2.9 ± 0.8	2.4 ± 0.4
Heptachlor epoxide	8.7 ± 1.2	9.8 ± 3.7	9.0 ± 1.5	9.0 ± 2.3	$_{m}$9.3 ± 2.3	9.2 ± 1.4
Oxychlordane	$_{m}$57.1 ± 5.8	47.4 ± 13.6	60.2 ± 7.1	58.8 ± 10.8**	51.0 ± 12.0	61.2 ± 5.0
U4	4.1 ± 1.4	12.1 ± 14.2	3.3 ± 0.9	$_{m}$4.1 ± 1.4	11.2 ± 12.0	3.6 ± 0.7
C5	2.3 ± 2.4	1.8 ± 1.2	1.8 ± 0.2	1.9 ± 1.2	1.6 ± 1.1	1.8 ± 0.2
C3	$_{c,m}$1.1 ± 0.2	$_{c,m}$ 1.0 ± 0.3	1.3 ± 0.5	$_{c,m}$1.2 ± 0.3	$_{m}$1.2 ± 0.4	1.3 ± 0.3

Table A1 contd:

C4	1.6 ± 0.4	1.4 ± 0.5	2.1 ± 1.0	$_{m}$1.5 ± 0.4	$_{m}$1.3 ± 0.4	1.8 ± 0.8
MC-6	$_{c,m}$8.4 ± 1.3	7.0 ± 2.7	10.2 ± 5.1	$_{c}$9.2 ± 2.8	6.8 ± 2.0	9.7 ± 3.8
Trans-nonachlor	$_{c,m,y}$10.4 ± 3.8	5.0 ± 1.5	6.8 ± 2.2	$_{c}$8.6 ± 4.0^{--}	4.5 ± 1.6^{-}	5.6 ± 1.6^{-}
U2	2.4 ± 0.6	4.0 ± 2.3	1.8 ± 0.5	2.6 ± 0.9	4.7 ± 5.3	2.1 ± 0.6**
S-DDTs (ng/g)	217 ± 124	3 ± 3	229 ± 178	167 ± 105^{--}	4 ± 8	167 ± 114
(%)						
*p,p'*DDE	90 ± 6	62 ± 15	82 ± 16	88 ± 10	56 ± 20	81 ± 24
*p,p'*DDD	3 ± 4	30 ± 17	13 ± 17	5 ± 9	35 ± 22	15 ± 15
*p,p'*DDT	$_{c,m}$7 ± 3	8 ± 10	5 ± 2	7 ± 2	10 ± 13	4 ± 2
S-PCBs (ng/g)	$_{c}$2299 ± 1190	$_{c}$24 ± 19	2333 ± 1186	3282 ± 1411***	33 ± 22**	4328 ± 2455***
(%)						
PCB-47/48	0.7 ± 0.1	3.7 ± 7.8	1.0 ± 0.2	0.6 ± 0.1^{--}	2.9 ± 5.3	0.8 ± 0.2^{--}
PCB-74	0.9 ± 0.5	6.0 ± 5.6	1.3 ± 0.4	0.7 ± 0.4^{---}	5.1 ± 4.2	0.9 ± 0.4^{--}

Table A1 contd:

PCB-56/60	0.1 ± 0.1	2.0 ± 3.6	0.6 ± 1.0	0.1 ± 0.1^{---}	3.6 ± 8.8	0.4 ± 0.9
PCB-99	$_{c,y}$9.9 ± 0.9	$_{c}$9.8 ± 2.0	14.2 ± 2.6	$_{c,y}$9.9 ± 0.9	$_{c}$9.3 ± 1.9	12.5 ± 1.4^{-}
PCB-85	0.7 ± 0.1	1.9 ± 2.5	1.2 ± 0.5	0.6 ± 0.2^{---}	1.2 ± 1.2	0.8 ± 0.2^{--}
PCB-149	$_{c}$0.1 ± 0.1	0.4 ± 0.8	0.1 ± 0.04	$_{c}$0.1 ± 0.04^{---}	0.2 ± 0.3	0.04 ± 0.03
PCB-118	$_{c,m,y}$2.0 ± 0.6	$_{c}$1.8 ± 0.8	2.5 ± 0.7	$_{c,y}$1.5 ± 0.5^{---}	$_{c}$1.3 ± 0.7^{--}	1.4 ± 0.4^{--}
PCB-146	$_{c,m}$1.6 ± 0.7	$_{c}$1.1 ± 0.4	0.9 ± 0.5	$_{c}$1.2 ± 0.4^{---}	$_{c}$0.9 ± 0.5	0.9 ± 0.2
PCB-153	$_{c,m,y}$40.7 ± 2.9	31.0 ± 9.9	42.9 ± 5.5	$_{c,y}$42.1 ± 2.9***	33.9 ± 8.9	46.2 ± 1.5**
PCB-105	0.6 ± 0.1	0.7 ± 0.1	0.7 ± 0.3	0.5 ± 0.1^{--}	0.6 ± 0.2	0.6 ± 0.2
PCB-137	0.9 ± 0.2	1.5 ± 0.7	1.7 ± 1.4	0.8 ± 0.2	1.1 ± 0.6^{--}	0.9 ± 0.3
PCB-138/163	$_{m}$10.8 ± 1.0	10.1 ± 3.1	12.7 ± 1.6	$_{m}$10.2 ± 1.0^{--}	9.5 ± 2.4	10.9 ± 1.3^{--}
PCB-187	1.1 ± 0.7	$_{c}$2.4 ± 1.5	0.3 ± 0.1	$_{c}$0.7 ± 0.4^{---}	$_{c}$1.5 ± 0.8^{--}	0.3 ± 0.2
PCB-183	1.6 ± 1.5	1.4 ± 1.1	0.6 ± 0.1	1.2 ± 0.8^{---}	1.3 ± 0.7	0.7 ± 0.1**
PCB-156	1.1 ± 0.9	1.2 ± 0.7	1.0 ± 0.2	0.9 ± 0.5	1.0 ± 0.6	1.0 ± 0.2^{-}

Table A1 contd:

PCB-157	$_{m}$0.4 ± 0.1	0.5 ± 0.8	0.6 ± 0.3	$_{c,m,y}$0.3 ± 0.1	0.4 ± 0.4	0.4 ± 0.2
PCB-180	$_{c,y}$16.5 ± 1.7	13.0 ± 4.9	11.7 ± 1.8	$_{c,y}$17.6 ± 1.8***	14.8 ± 5.4**	14.1 ± 1.2**
PCB-170	$_{m}$5.3 ± 0.7	5.8 ± 2.2	4.2 ± 0.8	$_{m}$5.6 ± 0.6***	$_{m}$5.5 ± 1.4	4.9 ± 0.4**
PCB-195	0.3 ± 0.2	1.4 ± 1.8	0.3 ± 0.1	$_{m}$0.3 ± 0.1	1.5 ± 1.8	0.3 ± 0.4
PCB-194	$_{c,y}$3.2 ± 0.6	2.6 ± 1.3	1.3 ± 0.3	$_{c,y}$3.5 ± 0.9**	2.6 ± 1.6	1.5 ± 0.7
PCB-206	$_{c,m,y}$0.6 ± 0.2	0.9 ± 1.8	0.2 ± 0.1	$_{c,m,y}$ 0.7 ± 0.4	1.3 ± 2.2	0.3 ± 0.1
PCB-209	$_{c,m,y}$0.9 ± 0.8	0.8 ± 2.2	0.1 ± 0.1	1.1 ± 0.9	0.5 ± 1.6	0.1 ± 0.1

Table A2. Mean (±SD) sum of organochlorine (S-OC) concentrations and compound composition (%) in adipose tissue (ng/g lipid wt), plasma (ng/g wet wt), and milk (ng/g lipid wt) from female polar bears with cubs captured sequentially during a period of feeding, Resolute Bay, NWT. Mean number of days between captures is 28 ± 5. Significant differences in concentration and compound composition between captures are designated with an asterisk (*) for increases and with a hyphen (-) for decreases (Wilcoxon Matched Pairs, *p<0.10, **p<0.05, ***p<0.005). Subscript letters indicate significant differences between groups of bears; c = cubs-of-the-year, y = yearlings, and m = males (Tukey p<0.05).

	Resolute Bay, NWT (Feeding period)					
	Capture 1			Capture 2		
	Adipose	Plasma	Milk	Adipose	Plasma	Milk
n	3	3	3	3	3	3
S-ClBzs (ng/g)	137 ± 51	$_{c}$4 ± 1	329 ± 103	122 ± 21	3 ± 0.5	247 ± 36
(%)						
1,2,4,5-TeClBz	$_{m}$57 ± 3	54 ± 5	57 ± 2	57 ± 3	54 ± 3	58 ± 1
PnClBz	20 ± 4	19 ± 1	20 ± 2	19 ± 5	20 ± 3	19 ± 3
HCB	$_{m}$23 ± 3	27 ± 4	23 ± 4	$_{m}$24 ± 3	27 ± 2	23 ± 3

Table A2 contd:

S-HCHs (ng/g)	133 ± 34	c3 ± 0.3	347 ± 24	152 ± 40	4 ± 2	328 ± 60
(%)						
α-HCH	35 ± 6	47 ± 10	35 ± 10	48 ± 5	m56 ± 7	46 ± 6
β-HCH	65 ± 6	53 ± 10	65 ± 10	52 ± 5	m44 ± 7	54 ± 6
S-CHLORs (ng/g)	2006 ± 1505	c24 ± 7	3671 ± 1985	1565 ± 372	c20 ± 3	2927 ± 1362
(%)						
Compound C	1.6 ± 0.4	2.1 ± 0.6	1.8 ± 0.3	1.7 ± 0.3	3.2 ± 1.4	1.7 ± 0.3
Photoheptachlor	m3.0 ± 0.8	4.7 ± 1.1	4.5 ± 0.5	3.3 ± 0.1	4.9 ± 1.3	4.6 ± 0.5
Heptachlor epoxide	7.0 ± 0.9	10.0 ± 0.7	7.6 ± 0.7	7.2 ± 0.4	9.9 ± 1.0	7.7 ± 0.8
Oxychlordane	m63.5 ± 1.9	60.7 ± 1.3	65.9 ± 1.5	m63.3 ± 1.9	59.1 ± 8.1	66.0 ± 3.1
U4	m4.5 ± 0.3	4.7 ± 0.6	4.4 ± 0.1	4.5 ± 0.3	6.4 ± 3.7	4.3 ± 0.3
C5	2.0 ± 0.6	2.2 ± 0.3	1.9 ± 0.9	2.0 ± 0.7	1.9 ± 0.2	1.7 ± 0.7
C3	m1.3 ± 0.5	1.5 ± 0.4	1.7 ± 0.2	1.2 ± 0.3	1.3 ± 0.3	1.4 ± 0.2
C4	m1.5 ± 0.4	1.9 ± 0.6	1.9 ± 0.2	m1.4 ± 0.2	1.4 ± 0.4	1.7 ± 0.3

Table A2 contd:

MC-6	8.8 ± 2.4	6.1 ± 1.2	5.8 ± 1.1	8.8 ± 0.8	6.4 ± 0.8	6.0 ± 0.1
Trans-nonachlor	4.9 ± 1.5	3.5 ± 0.4	3.1 ± 0.4	4.3 ± 1.6	3.1 ± 1.5	3.4 ± 1.5
U2	2.0 ± 0.4	2.5 ± 0.7	1.4 ± 0.3	2.3 ± 0.7	2.4 ± 0.6	1.4 ± 0.1
S-DDTs (ng/g)	39 ± 17	1 ± 0.2	42 ± 18	67 ± 47	2 ± 1	84 ± 51
(%)						
*p,p'*DDE	77 ± 4	55 ± 28	75 ± 13	47 ± 16	56 ± 20	81 ± 4
*p,p'*DDD	1 ± 1	45 ± 28	14 ± 16	47 ± 21	35 ± 22	6 ± 3
*p,p'*DDT	22 ± 3	0 ± 10	11 ± 3	6 ± 6	10 ± 13	13 ± 6
S-PCBs (ng/g)	2288 ± 2247	24 ± 9	1892 ± 922	1722 ± 475	17 ± 3	1639 ± 648
(%)						
PCB-47/48	0.7 ± 0.1	1.3 ± 0.5	1.1 ± 0.1	0.8 ± 0.7	2.9 ± 5.3	1.0 ± 0.1
PCB-74	0.8 ± 0.4	3.1 ± 2.7	1.4 ± 0.3	6.0 ± 3.6	5.1 ± 4.2	1.4 ± 0.4
PCB-56/60	0.02 ± 0.3	0.1 ± 0.2	0.3 ± 0.3	0.9 ± 1.5	3.6 ± 8.8	0.2 ± 0.1
PCB-99	9.4 ± 1.0	10.4 ± 1.1	14.7 ± 1.1	9.6 ± 1.5	9.3 ± 1.9	13.9 ± 1.8

Table A2 contd:

PCB-85	0.4 ± 0.1	2.4 ± 2.9	0.7 ± 0.1	1.8 ± 1.4	1.2 ± 1.2	0.6 ± 0.1
PCB-149	0.02 ± 0.04	0.0 ± 0.0	0.04 ± 0.02	0.4 ± 0.6	0.2 ± 0.3	0.1 ± 0.03
PCB-118	1.7 ± 1.0	1.6 ± 0.7	2.2 ± 1.0	1.5 ± 0.6	1.3 ± 0.7	1.8 ± 0.7
PCB-146	1.0 ± 0.2	0.7 ± 0.1	0.9 ± 0.2	0.9 ± 0.3	0.9 ± 0.5	0.9 ± 0.4
PCB-153	43.5 ± 1.9	40.0 ± 4.1	47.4 ± 1.4	38.3 ± 1.3	33.9 ± 8.9	47.3 ± 1.5
PCB-105	0.5 ± 0.4	0.5 ± 0.04	0.5 ± 0.04	0.6 ± 0.1	0.6 ± 0.2	0.5 ± 0.02
PCB-137	0.9 ± 0.2	1.3 ± 0.7	1.0 ± 0.1	1.4 ± 0.5	1.1 ± 0.6	$_{m}$1.0 ± 0.1
PCB-138/163	9.8 ± 1.4	9.6 ± 1.2	10.0 ± 1.3	9.6 ± 1.4	9.5 ± 2.4	10.2 ± 1.7
PCB-187	$_{m}$0.7 ± 0.1	1.5 ± 0.5	0.2 ± 0.1	1.6 ± 0.7	1.5 ± 0.8	0.3 ± 0.2
PCB-183	$_{m,y}$1.0 ± 0.1	0.9 ± 0.9	0.6 ± 0.2	0.8 ± 0.7	1.3 ± 0.7	0.6 ± 0.1
PCB-156	1.1 ± 0.3	1.1 ± 0.4	1.3 ± 0.1	1.2 ± 0.2	1.0 ± 0.6	1.2 ± 0.2
PCB-157	0.6 ± 0.2	0.5 ± 0.5	0.6 ± 0.1	0.5 ± 0.5	0.4 ± 0.4	0.5 ± 0.1
PCB-180	$_{m,y}$16.4 ± 1.7	15.1 ± 2.8	10.9 ± 1.0	14.3 ± 2.2	14.8 ± 5.4	11.8 ± 1.6

Table A2 continued:

PCB-170	7.0 ± 1.1	6.4 ± 1.7	5.1 ± 0.6	5.9 ± 0.8	5.5 ± 1.4	5.4 ± 1.0
PCB-195	1.0 ± 1.1	0.8 ± 0.5	0.1 ± 0.03	1.0 ± 0.3	1.5 ± 1.8	0.1 ± 0.03
PCB-194	3.0 ± 0.5	2.2 ± 1.4	1.0 ± 0.1	3.2 ± 0.3	2.6 ± 1.6	1.1 ± 0.3
PCB-206	0.3 ± 0.3	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	1.3 ± 2.2	0.1 ± 0.01
PCB-209	0.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 1.6	0.0 ± 0.0

Table A3. Mean (±SD) sum of organochlorine (S-OC) concentrations and compound composition (%) in adipose tissue (ng/g lipid wt) and and plasma (ng/g wet wt) from subadult and adult males captured sequentially during a period of fasting, Churchill, MB (mean number of days between captures is 59 ± 26) and during a period when they had access to seals, Resolute Bay, NWT (mean number of days between captures is 28 ± 5). Significant differences in concentration and compound composition between captures are designated with an asterisk (*) for increases and with a hyphen (-) for decreases (Wilcoxon Matched Pairs, *p<0.10, **p<0.05, ***p<0.005). Subscript letters indicate significant differences between groups of bears; f = females with cubs, c = cubs-of-the-year, and y = yearling cubs (Tukey p<0.05).

	Churchill, MB (Fasting)				Resolute Bay, NWT (access to seals)			
	Capture 1		Capture 2		Capture 1		Capture 2	
	Adipose	Plasma	Adipose	Plasma	Adipose	Plasma	Adipose	Plasma
n	10	10	10	10	4	4	4	4
S-ClBzs (ng/g)	168 ± 103	3 ± 1	186 ± 103*	3 ± 1	251 ± 124	$_{c}$7 ± 4	277 ± 142	8 ± 5
(%)								
1,2,4,5-TeClBz	$_{c,y}$49 ± 15	55 ± 17	$_{c}$54 ± 18	64 ± 17	$_{f}$71 ± 8	72 ± 9	73 ± 8	75 ± 6
PnClBz	21 ± 16	15 ± 5	14 ± 6	13 ± 4	18 ± 5	14 ± 4	18 ± 5	16 ± 4

Table A3 contd:

HCB	29 ± 16	30 ± 15	32 ± 20	24 ± 18	f,y11 ± 3	14 ± 6	f,y10 ± 3	10 ± 2
S-HCHs (ng/g)	254 ± 150	y3 ± 2	306 ± 513	3 ± 2	324 ± 165	6 ± 3	333 ± 169	8 ± 5
(%)								
α-HCH	f62 ± 20	62 ± 11	f55 ± 13	51 ± 19⁻	19 ± 11	35 ± 6	25 ± 21	f22 ± 8⁻
β-HCH	f38 ± 20	38 ± 11	f45 ± 13	49 ± 19*	81 ± 11	65 ± 6	75 ± 21	f78 ± 8*
S-CHLORs (ng/g)	c4109 ± 2486	c17 ± 10	c3429 ± 1514	21 ± 14	814 ± 841	c10 ± 7	710 ± 460	c12 ± 14
(%)								
Compound C	0.8 ± 0.5	2.8 ± 2.4	1.4 ± 0.5**	2.2 ± 1.4	2.5 ± 0.5	5.4 ± 1.0	2.9 ± 0.9	4.9 ± 0.7
Photoheptachlor	c1.9 ± 1.3	4.5 ± 1.6	f,y3.1 ± 0.5**	3.6 ± 0.5	f4.9 ± 0.5	6.7 ± 2.0	4.8 ± 1.2	6.3 ± 4.2
Heptachlor epoxide	7.1 ± 3.5	13.2 ± 3.3	10.5 ± 1.7**	f,c13.9 ± 3.5	6.8 ± 1.3	9.0 ± 2.5	7.4 ± 0.8	8.3 ± 2.2
Oxychlordane	f68.0 ± 15.0	49.0 ± 9.5	c,y50.0 ± 9.7⁻⁻	52.2 ± 7.7**	f,y40.2 ± 5.7	46.3 ± 6.9	f,y39.0 ± 7.9	41.7 ± 2.7
U4	4.4 ± 2.1	6.5 ± 2.1	f,y6.8 ± 2.0**	6.9 ± 3.1	f9.7 ± 2.8	7.4 ± 2.1	11.9 ± 5.3	9.7 ± 2.0*
C5	0.9 ± 0.6	2.0 ± 1.6	1.3 ± 0.6*	1.4 ± 0.4	1.1 ± 0.5	2.3 ± 1.8	m0.7 ± 0.4	2.6 ± 1.6

Table A3 contd:

C3	$_{f}$1.8 ± 1.1	^{f}2.4 ± 0.9	$_{c,f,y}$2.8 ± 0.9**	$_{f,y}$2.6 ± 1.2	$_{f}$3.5 ± 0.8	4.1 ± 1.7	3.8 ± 1.1	4.8 ± 1.0
C4	2.0 ± 1.4	2.0 ± 0.5	$_{c,f,y}$2.9 ± 1.2**	$_{c,f,y}$2.1 ± 0.5	$_{f,y}$4.4 ± 0.4	3.7 ± 1.9	$_{f,y}$4.7 ± 1.5	4.4 ± 1.3
MC-6	$_{f,y}$4.8 ± 2.5	6.5 ± 1.4	7.5 ± 1.7**	6.3 ± 0.7	$_{y}$12.3 ± 1.5	6.8 ± 0.5	$_{y}$10.3 ± 1.2	6.9 ± 1.5
Trans-nonachlor	$_{f}$6.6 ± 3.4	$_{c}$9.1 ± 9.0	$_{c,y}$10.6 ± 6.4^{--}	6.5 ± 4.2^{-}	$_{y}$7.9 ± 3.1	3.8 ± 1.0	$_{y}$7.4 ± 2.6	$_{c}$4.7 ± 1.2
U2	1.8 ± 1.4	1.9 ± 0.9	3.0 ± 2.5**	2.3 ± 0.6	$_{f,y}$6.8 ± 1.9	4.4 ± 3.8	7.0 ± 2.9	5.7 ± 4.7
S-DDTs (ng/g)	235 ± 103	2 ± 2	149 ± 134^{--}	1 ± 1^{--}	55 ± 59	1 ± 0.4	48 ± 22	1 ± 1
(%)								
*p,p'*DDE	92 ± 3	76 ± 16	90 ± 6	76 ± 13	80 ± 7	47 ± 10	82 ± 4	50 ± 22
*p,p'*DDD	4 ± 2	16 ± 19	3 ± 2^{--}	$_{c}$10 ± 11	5 ± 3	48 ± 14	5 ± 2	42 ± 23
*p,p'*DDT	$_{f}$4 ± 1	7 ± 5	7 ± 7	14 ± 8**	15 ± 7	4 ± 5	13 ± 3	7 ± 6
S-PCBs (ng/g)	3409 ± 1540	$_{c}$23 ± 16	3975 ± 1872	43 ± 40*	3702 ± 1514	$_{c}$30 ± 14	4576 ± 2221	44 ± 22
(%)								
PCB-47/48	$_{c}$0.5 ± 0.3	0.9 ± 0.5	$_{c,y}$0.5 ± 0.3	1.0 ± 0.3	0.4 ± 0.2	0.9 ± 0.3	0.3 ± 0.2	0.6 ± 0.3^{-}
PCB-74	0.6 ± 0.3	1.9 ± 2.6	0.4 ± 0.2^{--}	1.2 ± 1.4	$_{f}$0.2 ± 0.1	1.8 ± 0.5	0.2 ± 0.1	1.1 ± 0.4^{-}

Table A3 contd:

PCB-56/60	0.1 ± 0.1	0.2 ± 0.3	0.03 ± 0.03^{--}	0.2 ± 0.4	0.1 ± 0.04	0.0 ± 0.0	0.05 ± 0.04	0.3 ± 0.2
PCB-99	$_{c,y}$9.6 ± 2.6	10.4 ± 3.1	$_{c,y}$9.0 ± 2.9	10.8 ± 2.4	$_{y}$7.2 ± 2.4	9.1 ± 3.0	6.8 ± 1.8	8.5 ± 3.0
PCB-85	0.5 ± 0.2	1.0 ± 0.6	0.5 ± 0.2	0.8 ± 0.3^{-}	0.2 ± 0.1	1.3 ± 1.2	0.2 ± 0.2	0.4 ± 0.1
PCB-149	0.1 ± 0.1	0.5 ± 0.9	0.05 ± 0.04^{--}	0.2 ± 0.1	0.04 ± 0.03	0.1 ± 0.1	0.03 ± 0.03	0.0 ± 0.0
PCB-118	$_{f}$1.4 ± 0.6	1.8 ± 0.9	1.0 ± 0.5^{--}	1.0 ± 0.6^{---}	0.7 ± 0.3	1.1 ± 0.5	0.7 ± 0.6	0.6 ± 0.2
PCB-146	$_{f}$0.9 ± 0.3	1.0 ± 0.5	0.9 ± 0.2	0.9 ± 0.3	0.7 ± 0.2	1.2 ± 0.9	0.6 ± 0.2	0.6 ± 0.3
PCB-153	$_{c,f,y}$44.9 ± 2.3	37.2 ± 8.1	45.5 ± 6.4	40.8 ± 4.8**	42.2 ± 4.1	37.5 ± 7.0	40.9 ± 4.3	39.6 ± 4.0
PCB-105	0.5 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	0.6 ± 0.1	$_{y}$0.5 ± 0.1	0.4 ± 0.3	0.4 ± 0.05	0.5 ± 0.1
PCB-137	0.8 ± 0.2	1.2 ± 0.8	$_{c,y}$0.7 ± 0.1	0.9 ± 0.2	0.7 ± 0.2	1.2 ± 0.7	$_{f,y}$0.6 ± 0.1	0.9 ± 0.2
PCB-138/163	$_{f}$8.8 ± 2.3	9.0 ± 2.6	$_{f}$8.5 ± 2.5	8.2 ± 2.6	6.6 ± 1.8	7.6 ± 2.0	5.6 ± 1.7	6.7 ± 1.8^{-}
PCB-187	0.6 ± 0.2	1.8 ± 1.1	0.5 ± 0.1	1.1 ± 0.6^{--}	$_{f}$0.3 ± 0.1	1.2 ± 1.0	0.3 ± 0.1	0.6 ± 0.1
PCB-183	0.7 ± 0.2	1.2 ± 0.8	0.6 ± 0.2	0.7 ± 0.3^{-}	$_{y}$0.6 ± 0.1	1.3 ± 1.5	0.5 ± 0.1	0.6 ± 0.4
PCB-156	0.9 ± 0.2	1.1 ± 0.6	0.9 ± 0.2	0.9 ± 0.4	1.2 ± 0.2	1.8 ± 1.0	1.1 ± 0.2	1.3 ± 0.5

Table A3 contd:

PCB-157	$_{c,f,y}$0.6 ± 0.1	0.7 ± 0.4	$_{c,f}$0.5 ± 0.1^{--}	0.8 ± 0.3	0.9 ± 0.2	1.4 ± 0.5	0.8 ± 0.2	1.1 ± 0.4
PCB-180	$_{c,y}$17.1 ± 3.5	15.4 ± 4.2	$_{c,y}$17.3 ± 3.7	17.0 ± 3.9*	$_{f}$21.5 ± 4.4	17.3 ± 3.5	$_{y}$22.9 ± 3.7	19.5 ± 3.4*
PCB-170	$_{c,f,y}$7.4 ± 2.2	7.6 ± 2.7	$_{c,f,y}$7.6 ± 2.4	$_{c,f}$8.7 ± 3.0*	$_{y}$11.4 ± 2.9	9.9 ± 2.9	11.9 ± 3.0	11.0 ± 3.1*
PCB-195	$_{c,y}$0.7 ± 0.6	3.5 ± 3.7	$_{c,f,y}$0.7 ± 0.6	1.5 ± 0.9^{--}	0.3 ± 0.2	1.7 ± 0.9	0.2 ± 0.2	2.5 ± 2.7
PCB-194	$_{c,y}$2.6 ± 1.3	2.9 ± 2.0	$_{c,y}$2.7 ± 1.6	2.6 ± 1.5	3.9 ± 1.6	3.4 ± 2.3	4.9 ± 2.2	3.6 ± 1.5
PCB-206	$_{c,f,y}$0.4 ± 0.2	0.1 ± 0.1	$_{f}$0.4 ± 0.2	0.1 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0
PCB-209	$_{f}$0.3 ± 0.3	0.0 ± 0.0	1.2 ± 2.4	0.03 ± 0.1	0.1 ± 0.2	0.0 ± 0.0	0.4 ± 0.4	0.0 ± 0.0

Table A4. Mean (±SD) sum of organochlorine (S-OC) concentrations and compound composition (%) in adipose tissue (ng/g lipid wt) and and plasma (ng/g wet wt) from cubs-of-the-year captured sequentially during a period of mass loss (fasting period), Churchill, MB (mean number of days between captures is 60 ± 20) and during a period of mass gain (feeding period), Resolute Bay, NWT (mean number of days between captures is 28 ± 5). Significant differences in concentration and compound composition between captures are designated with an asterisk (*) for increases and with a hyphen (-) for decreases (Wilcoxon Matched Pairs, *p<0.10, **p<0.05, ***p<0.005). Subscript letters indicate significant differences between groups of bears; f = females with cubs, y = yearlings, and m = males (Tukey p<0.05).

	Churchill, MB (Fasting)				Resolute Bay, NWT (access to seals)	
	Capture 1		Capture 2		Capture 1	Capture 2
	Adipose	Plasma	Adipose	Plasma	Plasma	Plasma
n	12	12	12	12	3	3
S-ClBzs (ng/g)	$_{f}$239 ± 112	$_{f}$3 ± 2	261 ± 168	3 ± 2^{-}	$_{f,m,y}$13 ± 5	11 ± 2
(%)						
1,2,4,5-TeClBz	$_{f}$68 ± 7	59 ± 13	$_{m}$69 ± 7**	63 ± 13*	60 ± 6	64 ± 3
PnClBz	14 ± 7	16 ± 7	$_{f}$11 ± 2^{---}	13 ± 4^{--}	19 ± 2	18 ± 1
HCB	19 ± 7	24 ± 7	19 ± 6	24 ± 9	21 ± 5	18 ± 4

Table A4 contd:

S-HCHs (ng/g)	249 ± 159	5 ± 4	201 ± 166^{---}	4 ± 3	$_{f}$10 ± 4	9 ± 3
(%)						
α-HCH	$_{f}$61 ± 17	54 ± 14	$_{f,y}$49 ± 19^{---}	58 ± 13	25 ± 5	32 ± 2
β-HCH	$_{f}$40 ± 17	46 ± 14	$_{f,y}$51 ± 19***	42 ± 13	75 ± 5	68 ± 2
S-CHLORs (ng/g)	$_{f}$4668 ± 2874	$_{f,m}$49 ± 30	$_{f,m}$6059 ± 3929***	38 ± 20^{-}	$_{f,m}$80 ± 8	$_{f,m}$71 ± 14
(%)						
Compound C	1.1 ± 0.2	3.9 ± 3.0	1.1 ± 0.2	3.3 ± 2.9	1.9 ± 0.3	1.9 ± 0.2
Photoheptachlor	$_{m}$2.8 ± 0.3	3.6 ± 0.6	$_{f}$2.7 ± 0.3	3.4 ± 0.7	5.2 ± 1.3	6.0 ± 0.4
Heptachlor epoxide	9.1 ± 1.0	10.1 ± 2.5	8.6 ± 1.0^{---}	$_{m}$10.5 ± 3.3	10.2 ± 0.8	10.5 ± 0.3
Oxychlordane	64.0 ± 3.7	54.7 ± 12.5	$_{m}$65.8 ± 3.8***	55.5 ± 12.5	61.1± 2.7	60.6 ± 0.7
U4	5.2 ± 0.8	9.2 ± 10.1	5.3 ± 0.9**	10.3 ± 9.0	5.0 ± 0.7	5.6 ± 0.1
C5	1.9 ± 0.4	1.6 ± 0.5	1.8 ± 0.4	1.5 ± 0.3	2.9 ± 0.7	3.0 ± 0.2
C3	$_{f}$1.9 ± 0.3	$_{f}$1.8 ± 0.5	$_{f,m}$2.0 ± 0.3	1.8 ± 0.5	2.3 ± 0.6	2.3 ± 0.6
C4	1.7 ± 0.4	1.5 ± 0.8	$_{m}$1.7 ± 0.4	$_{m}$1.1 ± 0.4	1.9 ± 0.5	1.8 ± 0.3
MC-6	$_{f}$6.1 ± 1.4	6.0 ± 1.7	$_{f}$6.0 ± 1.6	5.9 ± 1.9	5.8 ± 1.4	4.7 ± 0.9

Table A4 contd:

Trans-nonachlor	$_{f}$4.4 ± 1.6	$_{m}$3.4 ± 1.9	$_{f, m}$3.2 ± 1.3^{---}	$_{m}$2.2 ± 1.7^{---}	2.2 ± 0.2	1.5 ± 0.1
U2	1.7 ± 0.4	4.1 ± 5.2	1.8 ± 0.4	4.4 ± 5.5	1.4 ± 0.3	2.0 ± 0.9
S-DDTs (ng/g)	196 ± 199	2 ± 2	128 ± 201^{---}	3 ± 6	1 ± 0.4	2 ± 0.5
(%)						
p,p'DDE	93 ± 5	68 ± 18	92 ± 9	55 ± 24^{-}	68 ± 9	63 ± 14
p,p'DDD	3 ± 4	24 ± 17	4 ± 8	$_{m}$37 ± 25	32 ± 9	31 ± 14
p,p'DDT	$_{f}$4 ± 1	8 ± 11	4 ± 2	8 ± 10	0 ± 0	6 ± 6
S-PCBs (ng/g)	$_{f}$258 ± 2564	$_{f,m}$56 ± 33	5505 ± 3279***	45 ± 26	$_{f,m,y}$75 ± 12	71 ± 15
(%)						
PCB-47/48	$_{m}$0.8 ± 0.1	4.9 ± 3.8	$_{m}$0.7 ± 0.1^{--}	2.4 ± 2.8	1.3 ± 0.2	1.3 ± 0.1
PCB-74	0.7 ± 0.1	3.1 ± 2.8	0.5 ± 0.1^{---}	3.9 ± 3.9	1.0 ± 0.4	1.4 ± 0.7
PCB-56/60	0.1 ± 0.1	1.3 ± 2.5	0.1 ± 0.1^{--}	2.0 ± 4.3	0.2 ± 0.2	0.2 ± 0.3
PCB-99	$_{f,m,y}$14.9 ± 0.7	$_{f}$12.9 ± 3.5	$_{f,m,y}$14.6 ± 0.9	$_{f}$12.0 ± 2.7	14.5 ± 1.2	14.3 ± 0.7
PCB-85	0.7 ± 0.2	1.4 ± 0.9	0.6 ± 0.2^{---}	1.1± 1.0^{-}	0.9 ± 0.1	0.7 ± 0.1

Table A4 contd:

PCB-149	$_{f}$0.1 ± 0.03	0.1 ± 0.3	$_{f}$0.03 ± 0.02^{---}	0.1 ± 0.3	0.1 ± 0.1	0.0 ± 0.0
PCB-118	$_{f}$1.2 ± 0.3	$_{f}$1.0 ± 0.5	$_{f}$ 0.7 ± 0.2^{---}	$_{f}$0.6 ± 0.4^{--}	0.7 ± 0.4	0.4 ± 0.2
PCB-146	$_{f}$0.9 ± 0.2	$_{f}$1.0 ± 0.3	$_{f}$0.7 ± 0.1^{---}	$_{f}$0.4 ± 0.3^{--}	0.6 ± 0.1	0.6 ± 0.1
PCB-153	$_{f,m}$48.5 ± 1.2	37.4 ± 9.7	$_{f}$49.7 ± 1.2***	39.7 ± 7.4*	43.0 ± 3.9	44.9 ± 3.0
PCB-105	0.5 ± 0.1	0.6 ± 0.2	0.6 ± 0.2**	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.1
PCB-137	1.0 ± 0.2	1.1 ± 0.3	$_{m}$0.9 ± 0.2	1.1 ± 0.3	1.0 ± 0.5	1.0 ± 0.3
PCB-138/163	10.3 ± 0.5	9.9 ± 2.3	9.5 ± 0.8^{---}	8.9 ± 1.6^{-}	9.6 ± 1.9	10.0 ± 0.2
PCB-187	0.4 ± 0.2	$_{f}$0.8 ± 0.6	$_{f}$0.3 ± 0.1^{---}	$_{f}$0.6 ± 0.4	0.5 ± 0.2	0.7 ± 0.4
PCB-183	0.7 ± 0.5	1.1 ± 1.0	0.6 ± 0.3^{--}	0.9 ± 0.6	0.7 ± 0.04	0.8 ± 0.2
PCB-156	1.0 ± 0.2	0.9 ± 0.4	0.9 ± 0.2	1.1 ± 0.7**	1.1 ± 0.2	0.9 ± 0.1
PCB-157	$_{m}$0.5 ± 0.1	1.4 ± 3.1	$_{f,y}$0.5 ± 0.04^{--}	0.6 ± 0.5	0.8 ± 0.2	0.8 ± 0.1
PCB-180	$_{f,m}$11.8 ± 0.9	11.2 ± 3.7	$_{f,m}$12.5 ± 0.9**	12.8 ± 5.0*	13.6 ± 2.5	12.3 ± 1.2
PCB-170	$_{m}$4.8 ± 0.4	6.0 ± 2.3	$_{m}$5.1 ± 0.4***	6.9 ± 2.4 **	7.2 ± 0.8	6.2 ± 0.9

Table A4 contd:

PCB-195	$_{m}$0.1 ± 0.1	0.7 ± 0.9	$_{m}$0.1 ± 0.04	0.9 ± 0.9	0,4 ± 0.3	0.7 ± 0.3
PCB-194	$_{f,m}$1.1 ± 0.3	2.4 ± 3.0	$_{f,m}$1.2 ± 0.2	1.4 ± 0.9	1.8 ± 0.6	1.7 ± 0.8
PCB-206	$_{f,m}$0.1 ± 0.1	0.6 ± 1.1	$_{f}$0.1 ± 0.1	1.2 ± 2.2	0.6 ± 0.7	0.3 ± 0.5
PCB-209	$_{f}$0.1 ± 0.1	0.6 ± 2.1	0.03 ± 0.1	0.8 ± 2.7	0.0 ± 0.0	0.0 ± 0.0

Table A5. Mean (±SD) sum of organochlorine (S-OC) concentrations and compound composition (%) in adipose tissue (ng/g lipid wt) and and plasma (ng/g wet wt) from yearlings captured sequentially during a period of mass loss (fasting period), Churchill, MB (mean number of days between captures is 60 ± 20) and during a period of mass gain (feeding period), Resolute Bay, NWT (mean number of days between captures is 28 ± 5). Significant differences in concentration and compound composition between captures are designated with an asterisk (*) for increases and with a hyphen (-) for decreases (Wilcoxon Matched Pairs, *p<0.10, **p<0.05, ***p<0.005). Wilcoxon matched pairs test would not be run on feeding bears since sample size was $n = 2$. Subscript letters indicate significant differences between groups of bears; f = females with cubs, c = cubs-of-the-year, m = males (Tukey p<0.05).

	Churchill, MB (Fasting)				Resolute Bay, NWT (access to seals)			
	Capture 1		Capture 2		Capture 1		Capture 2	
	Adipose	Plasma	Adipose	Plasma	Adipose	Plasma	Adipose	Plasma
n	10	12	10	12	2	2	2	2
S-ClBzs (ng/g)	181 ± 65	$_f$4 ± 3	217 ± 114**	4 ± 2	343 ± 42	$_c$8 ± 1	181 ± 104	7 ± 1
(%)								
1,2,4,5-TeClBz	$_m$64 ± 4	58 ± 10	64 ± 4	58 ± 9	66 ± 3	55 ± 3	68 ± 3	64 ± 5
PnClBz	14 ± 2	20 ± 11	13 ± 2⁻	15 ± 5	14 ± 1	16 ± 0.2	11 ± 0.3	14 ± 1

Table A5 contd:

HCB	22 ± 4	23 ± 7	23 ± 4	27 ± 5	$_{m}$20 ± 2	29 ± 3	$_{m}$20 ± 3	22 ± 5
S-HCHs (ng/g)	196 ± 102	$_{m}$8 ± 6	224 ± 205	3 ± 1^{--}	360 ± 53	7 ± 0.1	217 ± 140	7 ± 0.1
(%)								
α-HCH	$_{c}$69 ± 20	56 ± 24	$_{c}$67 ± 18	63 ± 8	19 ± 0.3	37 ± 1	20 ± 8	31 ± 9
β-HCH	31 ± 20	43 ± 24	$_{c}$33 ± 18	37 ± 8	81 ± 0.3	63 ± 1	80 ± 8	69 ± 9
S-CHLORs (ng/g)	3285 ± 1368	37 ± 16	4409 ± 2271**	41 ± 29	2812 ± 333	44 ± 6	1802 ± 861	50 ± 23
(%)								
Compound C	1.3 ± 0.3	4.7 ± 3.4	1.2 ± 0.2^{--}	3.3 ± 2.8	1.7 ± 0.04	2.0 ± 0.1	1.7 ± 0.03	2.1 ± 0.2
Photoheptachlor	2.6 ± 0.6	3.5 ± 0.9	$_{m}$2.6 ± 0.6^{-}	3.2 ± 1.0	4.2 ± 0.1	5.2 ± 0.04	3.8 ± 0.4	5.4 ± 0.3
Heptachlor epoxide	8.8 ± 0.9	10.5 ± 2.4	8.6 ± 0.9^{---}	11.0 ± 2.3	7.5 ± 0.02	9.7 ± 0.4	7.6 ± 0.4	10.0 ± 0.9
Oxychlordane	61.6 ± 2.8	56.9 ± 3.5	$_{m}$63.1 ± 3.2**	59.9 ± 5.6	$_{m}$63.2 ± 0.3	63.4 ± 0.7	$_{m}$64.2 ± 0.9	62.1 ± 2.4
U4	4.9 ± 0.7	4.9 ± 2.5	$_{m}$4.8 ± 0.7**	5.3 ± 0.8	5.2 ± 0.4	4.9 ± 0.02	5.1 ± 0.4	4.7 ± 0.4
C5	2.0 ± 1.3	1.7 ± 0.5	2.0 ± 1.2	1.6 ± 0.8	2.0 ± 0.1	2.7 ± 0.1	$_{m}$3.1 ± 1.1	2.9 ± 0.1
C3	1.8 ± 0.5	1.8 ± 0.5	$_{m}$1.8 ± 0.5	$_{m}$1.6 ± 0.4	2.7 ± 0.7	2.2 ± 0.1	2.8 ± 0.7	2.7 ± 0.6

Table A5 contd:

C4	1.7 ± 0.2	1.2 ± 0.2	$_{m}$1.7 ± 0.3	$_{m}$1.1 ± 0.4	$_{m}$2.0 ± 0.01	1.8 ± 0.1	$_{m}$1.8 ± 0.3	1.8 ± 0.1
MC-6	$_{m}$7.2 ± 1.1	6.7 ± 2.3	7.2 ± 1.4	6.8 ± 2.1	$_{m}$7.0 ± 0.03	5.0 ± 0.6	$_{m}$5.8 ± 0.01	5.0 ± 0.2
Trans-nonachlor	$_{f}$6.0 ± 1.9	4.2 ± 0.8	$_{m}$5.1 ± 1.6^{--}	4.2 ± 3.2	$_{m}$2.4 ± 0.03	1.3 ± 0.1	$_{m}$1.8 ± 0.3	2.1 ± 0.6
U2	2.1 ± 0.4	3.9 ± 3.3	2.1 ± 0.4	2.1 ± 1.3^{--}	$_{m}$2.2 ± 0.2	1.6 ± 0.4	2.1 ± 0.8	1.2 ± 0.3
S-DDTs (ng/g)	203 ± 108	4 ± 3	201 ± 209	2 ± 1^{--}	30 ± 6	1 ± 0.1	29 ± 8	2 ± 0.3
(%)								
p,p'DDE	89 ± 6	64 ± 19	91 ± 3	67 ± 24	79 ± 2	30 ± 6	80 ± 0.3	62 ± 2
p,p'DDD	5 ± 6	30 ± 23	3 ± 3	29 ± 25	3 ± 1	70 ± 6	4 ± 1	29 ± 1
p,p'DDT	6 ± 2	6 ± 6	6 ± 2	4 ± 6	18 ± 3	0 ± 0	17 ± 1	9 ± 2
S-PCBs (ng/g)	3680 ± 1449	42 ± 21	4747 ± 2273**	42 ± 28	2895 ± 435	35 ± 9	2336 ± 1220	36 ± 11
(%)								
PCB-47/48	0.7 ± 0.1	1.1 ± 0.4	$_{m}$0.7 ± 0.2	1.0 ± 0.3	0.7 ± 0.1	1.2 ± 0.1	0.5 ± 0.01	1.0 ± 0.2
PCB-74	0.6 ± 0.2	3.1 ± 2.7	0.5 ± 0.2	2.3 ± 2.6^{--}	0.7 ± 0.1	2.8 ± 0.03	0.6 ± 0.1	2.0 ± 0.2
PCB-56/60	0.1 ± 0.1	1.0 ± 1.5	0.1 ± 0.1	0.5 ± 0.8	0.04 ± 0.1	0.2 ± 0.2	0.04 ± 0.1	0.2 ± 0.1

Table A5 contd:

PCB-99	$_{c,f,m}$12.2 ± 0.8	11.8 ± 2.0	$_{c,f,m}$12.3 ± 0.7	12.3 ± 2.9	$_{m}$11.8 ± 0.3	13.2 ± 1.0	9.5 ± 0.3	13.4 ± 0.3
PCB-85	0.7 ± 0.2	1.4 ± 1.0	0.6 ± 0.1^{-}	0.9 ± 0.3	0.4 ± 0.04	0.6 ± 0.04	0.3 ± 0.05	0.5 ± 0.1
PCB-149	0.1 ± 0.1	0.3 ± 0.4	0.1 ± 0.2	0.4 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
PCB-118	$_{f}$1.1 ± 0.4	1.5 ± 0.3	$_{f}$0.9 ± 0.4^{-}	0.9 ± 0.3^{--}	1.1 ± 0.2	0.9 ± 0.1	0.4 ± 0.1	0.8 ± 0.2
PCB-146	1.1 ± 0.5	1.0 ± 0.1	1.0 ± 0.5^{-}	0.8 ± 0.2^{--}	0.7 ± 0.01	0.6 ± 0.1	0.4 ± 0.01	0.6 ± 0.1
PCB-153	$_{c,f,m}$48.0 ± 2.0	37.2 ± 6.4	$_{f}$48.4 ± 2.0**	41.2 ± 5.2	48.6 ± 1.0	45.0 ± 0.7	45.4 ± 1.9	46.5 ± 3.2
PCB-105	0.6 ± 0.2	0.6 ± 0.1	0.6 ± 0.2	0.6 ± 0.1	$_{m}$0.6 ± 0.01	0.5 ± 0.04	0.5 ± 0.02	0.5 ± 0.1
PCB-137	1.0 ± 0.1	1.0 ± 0.3	$_{m}$1.0 ± 0.1	1.3 ± 0.3	0.9 ± 0.05	1.2 ± 0.2	1.0 ± 0.04	$_{m}$1.1 ± 0.3
PCB-138/163	9.8 ± 1.3	10.8 ± 1.5	9.5 ± 1.3^{--}	11.3 ± 1.7	7.7 ± 0.1	9.5 ± 0.4	5.7 ± 0.1	8.6 ± 0.8
PCB-187	0.7 ± 0.5	2.0 ± 1.3	0.7 ± 0.6	1.0 ± 0.8^{--}	0.4 ± 0.2	0.5 ± 0.1	0.5 ± 0.01	0.8 ± 0.5
PCB-183	1.0 ± 1.0	1.1 ± 0.8	1.0 ± 1.0^{-}	1.1 ± 0.5	$_{f}$0.5 ± 0.02	0.7 ± 0.03	1.0 ± 0.6	0.7 ± 0.2
PCB-156	0.9 ± 0.6	0.6 ± 0.3	0.9 ± 0.6	0.8 ± 0.2	1.3 ± 0.1	1.2 ± 0.2	1.3 ± 0.01	0.6 ± 0.1
PCB-157	$_{m}$0.5 ± 0.1	0.5 ± 0.5	$_{c,f,m}$0.5 ± 0.2	0.5 ± 0.4	0.7 ± 0.2	0.7 ± 0.1	0.8 ± 0.1	1.1 ± 0.2

Table A5 contd:

PCB-180	$_{c,f,m}$13.7 ± 1.2	12.1 ± 2.0	$_{f,m}$13.8 ± 1.4	13.2 ± 4.2	$_{f}$13.2 ± 0.1	11.8 ± 0.2	15.6 ± 1.1	$_{m}$12.7 ± 1.7
PCB-170	$_{m}$5.4 ± 0.8	5.2 ± 0.8	$_{m}$5.5 ± 0.8	$_{m}$5.6 ± 1.4	$_{m}$6.2 ± 0.1	6.5 ± 0.3	7.0 ± 0.3	6.6 ± 0.6
PCB-195	$_{m}$0.2 ± 0.2	4.1 ± 5.4	$_{m}$0.2 ± 0.1	1.2 ± 1.1	3.2 ± 0.7	0.8 ± 0.1	7.0 ± 3.0	0.4 ± 0.1
PCB-194	$_{f,m}$1.4 ± 0.2	2.1 ± 0.9	$_{f,m}$1.4 ± 0.2	2.0 ± 1.5	1.3 ± 0.2	1.4 ± 0.1	2.3 ± 0.4	1.5 ± 0.6
PCB-206	$_{f,m}$0.2 ± 0.3	0.4 ± 0.8	$_{f}$0.2 ± 0.1	0.9 ± 1.5	0.0 ± 0.0	0.8 ± 1.1	0.3 ± 0.5	0.3 ± 0.4
PCB-209	$_{f}$0.3 ± 0.4	1.3 ± 2.6	0.1 ± 0.2	0.3 ± 0.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

APPENDIX B:

Organochlorine concentrations in adipose tissue, plasma, and milk from polar bears handled on more than two occasions from Churchill, MB and Resolute Bay, NWT (1992-1996).

Table B1. Organochlorine concentrations in adipose tissue (ng/g, lipid wt), plasma (ng/g, wet wt), and milk (ng/g, lipid wt) from polar bears handled on 2-5 occasions within 1-2 years. Bears 1-15 were sampled from Churchill, MB and Bear #16 was sampled from Resolute Bay, NWT. Percent body fat (%BF), age, month and year of sampling, and status are given for all bears: fem/coy/s = females with cubs-of-the-year in spring at the time of den emergence, fem/coy = females with cubs-of-the-year, fem/yrlg = females with yearling cubs, coys = cubs-of-the-year, yrlg = yearling cubs, 2-yr = two-year old cub, and males. Organochlorine compounds include S-ClBzs (ClB), S-HCHs (HCH), S-Chlordanes (CHL), S-DDTs (DDT), and S-PCBs (PCB).

Status	Age (yrs)	Capture date	BF (%)	Adipose					Plasma					Milk				
				ClB	HCH	CHL	DDT	PCB	ClB	HCH	CHL	DDT	PCB	ClB	HCH	CHL	DDT	PCB
Bear 1																		
pregnant	9	Aug 93	46	110	130	1395	254	2000	1.6	2.7	14.5	2.1	21.2	-	-	-	-	-
fem/coy/s	10	Mar 94	33	149	125	2830	184	4877	3.2	2.9	32.9	1.7	31.9	140	228	2238	89	2075
fem/coy	10	Oct 94	21	149	205	3922	156	5419	1.7	2.5	19.3	0.4	14.6	105	129	1310	211	1676
Bear 2																		
pregnant	15	Aug 93	43	97	136	1222	162	1340	0.2	1.0	11.0	0.6	14.0	-	-	-	-	-
fem/coy/s	16	Mar 94	28	123	119	1690	67	2040	0.4	4.9	24.6	3.6	25.9	257	323	2662	60	1980
pregnant	16	Aug 94	44	192	175	1868	230	1562	2.4	2.3	11.4	0.8	6.4	-	-	-	-	-

Table B1 contd:

Bear 3																		
pregnant	7	Oct 92	41	134	352	2636	252	3095	1.9	2.6	16.3	2.1	24.9	-	-	-	-	-
fem/coy/s	8	Mar 93	24	192	381	6439	163	7068	3.7	3.0	33.2	3.0	36.7	440	901	6555	139	4631
pregnant	8	Aug 93	41	76	97	1205	151	1500	1.7	2.2	13.7	1.5	13.9	-	-	-	-	-
fem/coy/s	9	Mar 94	25	146	116	3310	129	4360	-	-	-	-	-	230	378	3758	99	3072
Bear 4																		
fem/coy/s	7	Mar 93	-	292	194	5557	129	9140	-	-	-	-	-	309	382	4576	73	4348
pregnant	7	Aug 93	42	85	98	1002	98	1231	1.5	1.9	11.6	0.5	10.8	-	-	-	-	-
fem/coy/s	8	Mar 94	34	130	105	1807	68	2127	1.2	1.5	10.6	0.6	11.0	237	280	2651	55	1876
fem/coy	8	Aug 94	28	106	182	1940	169	2056	2.6	4.4	11.4	1.6	13.5	122	138	1108	224	6004
Bear 5																		
fem/coy	6	Oct 92	30	146	237	3392	353	4416	9.1	17.6	29.2	4.7	42.0	114	231	1678	656	2249
pregnant	7	Aug 93	39	125	232	2525	383	2867	2.5	2.7	16.2	3.7	28.8	-	-	-	-	-
pregnant	9	Aug 95	-	74	160	1374	306	1540	1.8	3.1	10.3	2.4	18.9	-	-	-	-	-
fem/coy/s	10	Mar 96	-	111	183	2368	233	2865	2.5	3.7	16.7	2.1	20.3	163	241	2593	158	1737
Bear 6																		
fem/coy/s	11	Mar 93	-	299	249	4992	175	5869	-	-	-	-	-	586	391	5395	105	3266
fem/coy	11	Aug 93	48	120	212	1768	218	2019	0.3	0.4	1.5	0.3	2.0	392	295	2367	155	1538
fem/coy	11	Oct 93	34	156	166	2323	141	2512	0.4	0.4	1.8	0.3	2.1	727	260	4253	89	3063
Bear 7																		
fem/coy	11	Aug 93	25	127	154	1601	141	1709	0.3	0.4	1.3	0.2	1.7	421	194	2261	71	1419
fem/coy	11	Oct 93	13	172	110	2890	65	3656	0.4	0.7	27.0	0.7	23.8	368	159	3049	27	2366
pregnant	12	Aug 94	34	79	135	1570	156	1217	-	-	-	-	-	-	-	-	-	-

Table B1 contd:

Bear 8																		
fem/coy	21	Sep 92	32	168	351	3639	489	4328	2.7	2.8	86.8	2.8	64.6	190	462	3691	154	2517
fem/coy	21	Oct 92	26	252	518	5633	481	6446	-	-	-	-	-	412	863	8366	247	5644
fem/yrlg	22	Oct 93	29	123	117	1796	141	1952	-	-	-	-	-	354	323	4373	94	2407
Bear 9																		
fem/coy	21	Nov 94	19	145	154	4108	160	4404	2.8	3.3	37.6	1.0	41.9	259	256	4230	55	3033
fem/yrlg	22	Aug 95	-	86	133	1704	196	1521	1.8	3.2	17.0	1.4	13.6	170	237	2033	170	1385
Bear 10																		
fem/yrlg	16	Oct 92	33	83	74	1457	84	1224	2.6	7.2	12.7	2.2	14.2	607	962	5364	149	5209
fem/yrlg	16	Nov 92	28	138	117	2490	131	1975	2.0	2.0	11.2	1.0	11.9	159	0	1351	85	1425
pregnant	17	Aug 93	43	91	91	2070	134	1464	1.0	1.7	14.3	9.8	25.9	-	-	-	-	-
fem/coy/s	18	Mar 94	28	112	88	2356	71	2266	1.2	3.4	31.0	2.8	48.5	205	324	2592	71	1758
fem/coy	18	Oct 94	23	182	241	3917	186	6182	-	-	-	-	-	252	262	4386	602	4827
Bear 11																		
fem/yrlg	17	Oct 92	28	120	167	2107	148	1914	-	-	-	-	-	-	-	-	-	-
fem/yrlg	17	Nov 92	23	178	223	3157	179	3023	2.1	4.5	17.9	1.3	15.8	-	-	-	-	-
fem/coy	19	Oct 94	16	73	90	2201	68	3022	2.2	6.7	36.1	3.0	60.9	-	-	-	-	-
Bear 12																		
fem/yrlg	24	Sep 92	26	239	368	5481	464	5128	2.2	2.1	50.9	3.5	66.4	380	784	5487	535	5286
fem/yrlg	24	Oct 92	20	259	329	4966	243	5675	2.6	1.7	44.9	1.0	45.0	538	669	10227	216	10412
fem/coy/s	26	Mar 94	22	157	149	3635	159	4398	3.4	2.4	44.2	1.7	64.5	299	346	5977	106	3131

Table B1 contd:

Bear 13																		
coy	0	Sep 92	25	559	734	12725	814	10795	5.2	4.3	117.4	3.8	109.3	-	-	-	-	-
coy	0	Oct 92	26	760	724	18054	761	14667	6.4	3.5	55.1	1.7	78.0	-	-	-	-	-
yrlg	1	Oct 93	25	215	133	5053	147	4627	6.5	6.0	60.8	2.0	91.9	-	-	-	-	-
Bear 14																		
yrlg	1	Sep 92	34	339	460	6067	396	5901	3.9	2.0	46.7	2.6	53.7	-	-	-	-	-
yrlg	1	Oct 92	29	508	772	9522	758	9092	5.1	2.6	70.8	2.9	83.3	-	-	-	-	-
2-yr	2	Oct 93	24	167	142	3654	178	4433	3.0	5.1	27.2	1.7	22.0	-	-	-	-	-
Bear 15																		
male	2	Jul 93	24	129	200	1961	246	2927	1.9	2.8	16.5	0.8	12.5	-	-	-	-	-
male	2	Oct 93	23	150	150	3727	72	6680	1.1	0.7	34.7	0.5	52.6	-	-	-	-	-
male	3	Oct 94	16	158	158	7512	100	5111	2.4	1.9	23.8	0.4	21.5	-	-	-	-	-
male	3	Nov 94	15	145	145	3571	81	5754	3.1	2.3	33.0	0.8	50.6	-	-	-	-	-
Bear 16																		
male	20	Apr 95	-	153	178	257	14	2329	3.9	2.9	7.7	0.7	18.9	-	-	-	-	-
male	20	May 95	-	477	502	1338	78	4897	5.2	4.5	4.6	0.7	29.3	-	-	-	-	-
male	21	May 96	-	125	180	259	44	1927	3.7	4.2	5.7	1.3	28.3	-	-	-	-	-