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Accumulation of Persistent Organic Pollutants in Terrestrial Vegetation from the Canadian Rocky Mountains

Deborah A. Davidson B.Sc.

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"Water, soil, and the earth's green mantle of plants make up the world that supports the animal life of the earth. Although modern man seldom remembers the fact, he could not exist without the plants that harness the sun's energy and manufacture the basic foodstuffs he depends upon for life. ... The earth's vegetation is part of a web of life in which there are intimate and essential relations between plants and the earth, between plants and other plants, between plants and animals. Sometimes we have no choice but to disturb these relationships, but we should do so thoughtfully, with full awareness that what we do may have consequences remote in time and place."

- Rachel Carson, *Silent Spring*, 1962.

ABSTRACT

This thesis examines the accumulation of persistent organochlorine compounds in Canadian mountain environments through the sampling of air and coniferous vegetation along a 1430-meter elevation gradient in the Canadian Rocky Mountains. Results showed that lower temperatures encountered in high altitudes favor the accumulation of chemicals with higher volatility in vegetation. Air concentrations further suggest that the reason for this accumulation in elevated areas is increased atmospheric deposition from distant sources and not from temperature-induced revolatilization from local terrestrial surfaces. Seasonal decreases in plant concentrations indicate evaporative processes, and volatilization from vegetation was confirmed by calculated fugacity gradients. However, volatilization contributes very little to air concentrations and the subsequent fractionation upslope, which appears to be dominated by long-range transport. Multivariate analysis revealed that, in addition to cooler temperatures, other environmental conditions common to mountain ecosystems, such as elevated precipitation and lower pressure, promote chemical deposition onto vegetation.

RÉSUMÉ

Cette thèse fournit l'examen en l'amasse des polluants organiques persistants dans les montagnes. Les échantillons de feuillage des conifères et de l'air ont été ramassé de sept sites couvrants une élévation de 1430 mètres en les montagnes Rocheuses du Canada et ont été analyzé pour la présence des polluants chlorinés. Cette étude à révélée que les températures basses présentes aux altitudes hautes favorisent l'amasse de certains polluants. Ces observations ont été confirmées par les résultats d'un modèle de fugacité. Les polluants dans l'air qui travers vers l'ouest, avant d'arriver aux montagnes Rocheuses, déposent aux surfaces terrestres au côte de l'ouest. L'évaporation de ces polluants de la végétation contribu peu aux concentrations dans l'air ou à la distribution le long des pentes des montagnes. Niveaux dans l'air suggèrent que l'amasse est dominée par le transport atmosphérique à l'origine des régions de loin et n'est pas causée par l'évaporation du terrain local.

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GLOSSARY OF ACRONYMS, SYMBOLS, AND ABBREVIATIONS

A	surface area of vegetation (m^2)
ANOVA	analysis of variance
B	diffusivity in air ($m^2 \cdot h^{-1}$)
C	chemical concentration ($mol \cdot m^{-3}$)
CB	chlorobenzene
dC/dt	observed chemical flux ($ng \cdot g^{-1}$ lipid $\cdot day^{-1}$)
dC_L/dt	growth-corrected flux ($ng \cdot g^{-1}$ lipid $\cdot day^{-1}$)
d_L/dt	seasonal change in lipid content (g lipid $\cdot$g needle^{-1} $\cdot day^{-1}$)
dM/dt	predicted flux ($pmol \cdot g^{-1} \cdot day^{-1}$)
D	intermedia D-value ($mol \cdot Pa^{-1} \cdot h^{-1}$)
DBB	dibromobenzene
DCB	dichlorobenzene
DCM	dichloromethane
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DEP	dependent variable
EM	expectation-maximization
f	fugacity (Pa)
H	Henry's law constant ($Pa \cdot m^3 \cdot mol^{-1}$)
H_T	T-adjusted H ($Pa \cdot m^3 \cdot mol^{-1}$)
HCB	hexachlorobenzene
HCH	hexachlorocyclohexane
IND	independent variable
IUPAC	International Union of Pure and Applied Chemistry
K	partition coefficient
l	length of pine fascicle (m)
L	lipid fraction of wet weight ($m^3 \cdot m^{-3}$)
m	molecular mass ($g \cdot mol^{-1}$)
masl	meters above sea level
M	amount of chemical (mol)
MDL	method detection limit ($pg \cdot g^{-1}$ dry weight)
MS_B	mean square between groups
MS_W	mean square within groups
NLET	National Laboratory for Environmental Testing
OC	organochlorine
OCN	octachloronaphthalene
PAH	polycyclic aromatic hydrocarbon
PC	principal component
PCA	principal component analysis
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-*p*-dioxin
PCDF	polychlorinated dibenzofuran
POP	persistent organic pollutant
P_L	subcooled liquid vapor pressure (Pa)
PUF	polyurethane foam
q	boundary layer thickness (m)
r	radius of pine fascicle
R	gas constant ($Pa \cdot m^3 \cdot mol^{-1} \cdot K^{-1}$)
R_I	intraclass correlation coefficient
SD	standard deviation
SE	standard error
SVOC	semivolatile organic compound
t	time (h)
T	temperature (K)
T_H	T at which H was measured (K)
TBB	tribromobenzene
TTBB	tetrabromobenzene
U	mass transfer coefficient ($m \cdot h^{-1}$)
V	volume (m^3)
V	wind speed ($m \cdot s^{-1}$)
VOC	volatile organic compound
Z	fugacity capacity ($mol \cdot m^{-3} \cdot Pa^{-1}$)
Δ_1	minor diameter of spruce needle (m)
Δ_2	major diameter of spruce needle (m)
ΔH	enthalpy of phase change ($J \cdot mol^{-1}$)
ΔH_{VAP}	enthalpy of vaporization ($J \cdot mol^{-1}$)
ΔS	entropy of phase change ($J \cdot mol^{-1} \cdot K^{-1}$)
λ	length of spruce needle (m)
ΣPCB	sum of all PCB congeners

Subscripts

A	air/atmosphere
EXP	experimental
L	lipid
O	octanol
PRED	predicted
R	rain
V	vegetation
W	water

1.0 GENERAL INTRODUCTION

The control of persistent organic pollutants (POPs) is an ongoing issue for environmentalists and regulatory agencies. Rachel Carson (1962) highlighted the dangers surrounding the use of harmful chemicals when she recounted numerous examples of the damaging effects of pesticides in her book *Silent Spring*. Pollutants are those substances that are present in the environment due, in part, to human activities, and that are capable of exerting harmful effects on living systems (Moriarty 1999). Persistence, the tendency to accumulate in lipid-rich tissues, and the ability to travel great distances through the atmosphere are characteristic of POPs, which include organochlorine (OC) insecticides and polychlorinated biphenyls (PCBs). The potential threat posed by these compounds to human and environmental health has led many regulatory agencies to restrict or ban the use, sale, and production of certain POPs.

Despite limitations imposed regarding their usage, several POPs are presently ubiquitous in the environment. Detection of OCs and PCBs in remote, polar regions, where emission sources are minimal or nonexistent, demonstrates their omnipresence and has prompted many interested parties to examine the global implications of pollution. It is now evident that certain chemicals discharged in warm, temperate regions are able to migrate to higher latitudes where deposition onto Earth's surfaces occurs due to cooler temperatures (Wania and Mackay 1993a).

Chemical transfer from the atmosphere to various environmental compartments, including water, snow, soil, and vegetation, is accomplished through particle deposition, rain and snow scavenging events, and gaseous partitioning between the air and terrestrial surfaces. Vegetation is a potentially large atmospheric sink for lipophilic organic compounds. It covers approximately 80% of terrestrial surface, and its surface area can be up to 14 times larger than the land on which it grows (Simonich and Hites 1994b). Chemical accumulation in plants is important because, not only do pollutant levels in plant foliage provide an indication of their atmospheric levels, but vegetation is also the prime energy source in many ecosystems and it determines, to some extent, the physical structure of areas inhabited by living organisms (Moriarty 1999). Furthermore, plants provide a vector through which pollutants can enter the terrestrial food chain and become incorporated into both animal and human diets (Böhme et al. 1999).

It follows that areas with low temperatures that are rich in vegetation are susceptible to an enrichment of certain POPs. It is conceivable that these patterns of accumulation are manifested in mountain regions that

exhibit cooler temperatures at higher elevations, such as the Canadian Rocky Mountains. To fully comprehend the processes and subsequent implications of global POP transport, we must first define and understand the characteristics of pollutants, possible mechanisms of accumulation, and the physical environment of interest.

1.1 RESEARCH OBJECTIVES

This project was undertaken to determine the extent to which POPs accumulate in elevated areas using vegetation growing at various altitudes as an indicator of environmental contamination. To accomplish this objective, I examined concentrations of OC pesticides and PCBs in coniferous needles and in air sampled from the Canadian Rocky Mountains. Levels of these compounds in vegetation sampled along a transect from interior British Columbia to the western side of the Rocky Mountain range were also measured. The sites chosen for this study are outlined in Figure 1.1 and in Table 1.1. Daily variations in plant concentrations of POPs were also examined. Beyond providing an indication of pollutant concentrations in air and vegetation in these areas, the generated data sets were used to test the following hypotheses:

1. Levels of OC pesticides and PCBs in vegetation will increase with elevation due to increased deposition and limited volatilization at higher altitudes as a result of cooler temperatures. This relationship will be strongest for semivolatile compounds, or those chemicals with vapor pressures between 0.01 Pa and 1.0 Pa. This hypothesis was tested in Chapter 2.0 by examining the dependence of analyte concentrations on site elevation.
2. Lower temperatures will favor atmospheric deposition of POPs to vegetation, resulting in higher plant concentrations and lower air concentrations. This hypothesis was tested in Chapter 3.0 by analyzing the temperature-dependence of analyte concentrations in samples of vegetation and air, as well as the vegetation-air partition coefficient.
3. Species of vegetation will exhibit different concentrations of OC pesticides and PCBs due to differences in lipid content and surface area. Species differences were explored in Chapter 3.0 and further examined using the fugacity-based model in Chapter 5.0.
4. Vegetation samples from the Rocky Mountains will contain higher levels of OC pesticides and PCBs than will samples from the British Columbia interior. It is proposed that, as air travels from the west over parts of British Columbia to the Rocky Mountains, wet and vapor phase deposition will be more significant at

higher altitudes in the Rocky Mountains than the interior due to cooler temperatures. This hypothesis was tested in Chapter 3.0 by examining trends in analyte concentration along a longitudinal transect.

5. Daily fluctuations in temperature will result in diurnal cycling of relatively volatile compounds between vegetation and air. Plant concentrations will be higher in early morning compared to the afternoon when volatilization peaks as temperature reaches its daily maximum. This hypothesis was investigated in Chapter 3.0.
6. Temperature will not be the sole predictor of OC pesticide and PCB concentrations in vegetation from the Canadian Rocky Mountains, as many environmental and physical factors can contribute to chemical accumulation in plant tissue. The interaction between analyte concentrations and various independent variables, such as precipitation, relative humidity, and plant lipid content (all of which may promote atmospheric deposition onto vegetation), was examined in Chapter 4.0 through principal component and canonical correlation analysis.

Furthermore, the evaluation of a fugacity-based model helped to explain observed trends in the field study. Predicted rates of chemical exchange between vegetation and both the atmosphere and rain were compared for the selected sites. This model, developed in Chapter 5.0, was used to test the following hypotheses:

1. Deposition from rain and air onto vegetation will dominate chemical exchange at higher altitudes, while volatilization from vegetation will be favored at lower elevations.
2. Species will display unique exchange tendencies due to different properties of plant foliage.

Finally, to assess vegetation's capacity to store POPs in elevated regions, the fugacity capacities of coniferous needles were determined experimentally at different temperatures. The following predictions were evaluated in Chapter 6.0.

1. The storage ability of vegetation will be higher at lower temperatures, promoting absorption by and accumulation in plant tissue.
2. Fugacity capacities will differ between species as properties such as lipid content and surface area vary among vegetation types and are major determinants of chemical uptake in plants.

Information regarding chemical deposition in remote, cooler regions such as the Canadian Rocky Mountains will assist in the development of future regulations governing contaminant emissions.

Recommendations for the replacement of those pollutants that persist in the atmosphere and that are capable of long-range transport should be given due consideration. Research on long-range transport of contaminants should demonstrate to governing bodies the importance of predicting the long-term effects of chemical use, emission, and exposure prior to policy implementation. This is of particular importance to inhabitants of remote areas who do not reap the benefits of such chemicals but suffer the unfortunate consequences of their use and misuse. Long-range transport of persistent pollutants may be a health risk to remote communities other than northern populations. It is expected that this research will reveal the potential exposure to POP emissions incurred by people living at high altitudes. For instance, elevated regions such as Denver, CO, USA, and Banff, AB, Canada, may be subject to global distillation and fractionation and subsequent enrichment of POPs in their environments.

1.2 ORGANOCHLORINE INSECTICIDES

Pesticide application is a century-old exercise, but the pesticide industry flourished only after World War II as a result of improved economic conditions in many industrialized countries. Early pesticides and most modern OC insecticides are non-systemic, contact, or surface pesticides that are designed to remain on the exterior of the plant. Conversely, systemic pesticides are able to penetrate plant tissue and enter the vascular system (Cremlyn 1978). Three main families of OC insecticides include hexachlorocyclohexane (HCH), dichlorodiphenyltrichloroethane (DDT), and chlorinated cyclodienes. The polychlorinated camphenes, or toxaphenes, are also a major class of OC insecticide, but will not be a focus of this thesis. Organochlorine insecticides consist of one or more chlorinated carbocyclic rings (Figure 1.2). At room temperature, most OC insecticides are waxy solids that are stable and resistant to both biodegradation and ultraviolet radiation due to the abundance of inactive carbon-carbon, carbon-hydrogen, and carbon-chlorine bonds (Hassall 1982). These lipophilic compounds tend to accumulate in the fatty tissues of birds, fish, and mammals (Cremlyn 1978).

Ziedler was the first to prepare DDT in 1874 (Ayres and Hellier 1998). However, Müller only discovered its insecticidal properties in 1939, after which Geigy put it on the market in 1942 (Hassall 1982). India produced 7000 tons of DDT in 1991 alone (Ayres and Hellier 1998). It was one of most widely used insecticides that was produced extensively during WW II, and is made from benzene and trichoroacetaldehyde in the presence of sulfuric acid (de March et al. 1998). The technical mixture consists of 80% *p-p'*-DDT, 20% *o,p'*-DDT, and trace amounts of *o,o'*-DDT, but only *p,p'*-DDT is insecticidal. Its principal metabolite,

dichlorodiphenyldichloroethylene (DDE), is produced via enzymatic dehydrochlorination, and is metabolized in birds and mammals to a water-soluble carboxylic acid (Brooks 1974a, Ayres and Hellier 1998). Another metabolite, dichlorodiphenyldichloroethane (DDD), is produced by reductive chlorination in microsomes, dead tissues, and microorganisms, and has also been marketed as an insecticide (Hassall 1982). The primary use of DDT is in the control of disease carrying insects (Brooks 1974a). Its use was restricted in the U.S. in 1973 and in the U.K. in 1984 (Ayres and Hellier 1998), and Canada soon followed with a ban in 1985 (de March et al. 1998). This insecticide has a half-life of eight years, but its metabolite DDE may persist for over ten years (Hassall 1982). The parent compound is estrogenic in birds and rats (Cremlyn 1978) and is a strong neurotoxin (Hassall 1982). The metabolites 3-methylsulfonyl-DDE and *o,p'*-DDD are toxic to cells in the human adrenal cortex (Lindhe et al. 2002). A relative of DDT, methoxychlor has been used in the control of beetles (Hassall 1982) and is metabolized via oxidative demethylation (Cremlyn 1978).

Faraday first prepared HCH in 1825 (Ayres and Hellier 1978). The γ-isomer, commonly known as lindane, was isolated in 1912 by van der Linden (Cremlyn 1978). It is prepared through the reaction of benzene with chlorine under ultraviolet light (Cremlyn 1978). The technical mixture, used in WW II, consists of 70% α-HCH and 15% γ-HCH. India produced 20,000 tons of γ-HCH in 1991, and 10 million tons of technical HCH were produced worldwide before 1992 (Ayres and Hellier 1998). Eight isomers exist, including α-HCH and δ-HCH, which are less toxic than γ-HCH, and β-HCH and ε-HCH, which are relatively inert (Hassall 1982). However, γ-HCH, a carcinogen, is the only insecticidal isomer. Dehydrochlorination of HCH in basic solution produces lower chlorinated benzenes (Cremlyn 1978). It is converted to chlorophenol in animals (Ayres and Hellier 1998) and to pentachlorocyclohexene in insects (Cremlyn 1978), while γ-HCH degrades to α-HCH through photolysis (Ockenden et al. 1998b). This pesticide has been used in fumigation (Brooks 1974a) and in the control of soil organisms (Cremlyn 1978). Technical HCH was restricted around 1970 in Canada and the U.S., while γ-HCH is the only form of HCH currently used in North America, Japan, and Europe. China continues to use technical HCH on lumber, seeds, fruits, and vegetables (de March et al. 1998).

In 1893, Lorentz first synthesized hexachlorobenzene (HCB), which is produced from ferric chloride and benzene (Ayres and Hellier 1998). It is a by-product of pesticide and lower-chlorinated benzene production (de March et al. 1998). Japan produced 300,000 kg of HCB in 1977 and it has been used as a fungicidal fumigant for cereals and as a precursor to pesticides such as pentachlorophenol (Ayres and Hellier

1998). Canada implemented restrictions on its use in 1976 (de March et al. 1998) as it has been shown to be a carcinogen (Ayres and Hellier 1998).

Chlordane was discovered in 1945 (Ayres and Hellier 1998) and has chlordene as its precursor (de March et al. 1998). The technical mixture consists of 26 compounds, 25% of which is γ-(*trans*)chlordane (Ayres and Hellier 1998), although it can contain up to 120 compounds, including α-(*cis*)chlordane, heptachlor, and nonachlor (Hassall 1982). Its principal metabolite is oxychlordane and the α-isomer is more toxic than the γ-isomer (Hassall 1982). It has been used as a fumigant, as a seed dressing, and in termite control (de March et al. 1998). In 1987, its use was restricted in Canada (de March et al. 1998), and it is currently banned in many European countries (Ayres and Hellier 1998). It is carcinogenic and causes liver and kidney damage (Ayres and Hellier 1998).

Velsicol was the first company to manufacture heptachlor. The technical mixture consists of 72% heptachlor and 22% γ-chlordane (Ayres and Hellier 1998). Like chlordane, its precursor is also chlordene (de March et al. 1998). It is converted to its epoxide, a more toxic compound, in plants, animals, and insects (Cremlyn 1978). Now a known carcinogen, it has been used for ant and termite control and as a soil fumigant, and has a half-life in soil of one year (Ayres and Hellier 1998).

Dieldrin is formed by the epoxidation of aldrin (Hassall 1982), a highly toxic chemical used as a pesticide and banned in the U.S. in the 1980's. It is the most powerful human carcinogen of all OC pesticides and is metabolized in mammals to water-soluble, excretable compounds (Ayres and Hellier 1998). It has been used as a seed dressing and a wood preservative, as well as in cattle and sheep dips (Brooks 1974a). Its use is restricted in the U.K. and the U.S. for termite control (Ayres and Hellier 1998) and was restricted in Canada in 1987 (de March et al. 1998).

Hoechst was the first company to market endosulfan (Ayres and Hellier 1998), and 57,000 tons have been used worldwide since the 1950's (de March et al. 1998). The technical mixture consists of 66% α-endosulfan and 34% β-endosulfan. It is rapidly hydrolyzed in mammals to a diol and sulfur dioxide, and is known to be teratogenic (Ayres and Hellier 1998). It has been applied to vegetables, rice, cereals, and fruit (Ayres and Hellier 1998) and has been used in the control of moths, beetles, and termites (Hassall 1982). Its use was restricted in Canada in 1998 for commercial pest control (de March et al. 1998).

The Hyman Company introduced endrin to the market in 1951. Its precursor, isodrin, is also insecticidal, but was never sold as a pesticide (Brooks 1974a). This neurotoxin has been banned in most developed countries, but it is still used in Third World nations (Ayres and Hellier 1998).

Organochlorine insecticides generally attack the nervous, respiratory, or digestive systems of the targeted pest (Brooks 1974a, Hassall 1982). Unfortunately, many strains of insects have become resistant to the effects of certain insecticides, making it necessary to intensify application or to develop more toxic alternatives (Cremlyn 1978). Consequently, OC pesticides have contaminated many environmental compartments resulting in widespread exposure. Animal effects resulting from exposure to OC pollutants include weakened immunity, tumor promotion, and impaired reproduction (de March et al. 1998).

1.3 POLYCHLORINATED BIPHENYLS

The chlorination of biphenyl in the presence of ferric chloride produces 209 different PCB congeners (Ayres and Hellier 1998). In 1929, Monsanto began industrial PCB production, most commonly as Aroclor® mixtures 1242 and 1254, containing 42% and 54% chlorine by weight, respectively. In addition to the Aroclor® trade name, PCBs have been sold under the identifiers Kanechlor®, Phenochlor®, and Clophen® (de March et al. 1998, Ayres and Hellier 1998). World PCB production reached 50,000 tons in 1971 (Cremlyn 1978). The U.S. ceased production of PCBs in 1976 and a worldwide ban soon followed (Ayres and Hellier 1998). Throughout this thesis, individual PCB congeners will be identified with their corresponding International Union of Pure and Applied Chemistry (IUPAC) number.

Their inertness, thermal stability, and dielectric properties, as well as their resistance to oxidation, acids, and bases, make PCBs useful in many industrial applications (Hutzinger et al. 1974). They have been employed as dielectric fluids in capacitors and transformers, as fire retardants, as plasticizers in adhesives, and as industrial fluids in hydraulic systems, gas turbines, and vacuum pumps. Other uses include heat transfer applications, textiles, surface coatings, sealants, carbonless copy paper, wax polishes, sealing compounds, synthetic rubber, paints, and inks (Hutzinger et al. 1974, Cremlyn 1978, Ayres and Hellier 1998).

Due to their lipophilic properties and resistance to degradation, PCBs have a high tendency to biomagnify through food chains, which can ultimately lead to liver damage in higher animals. Higher chlorinated PCBs with five or more chlorine atoms are more persistent and accumulate in lipid-rich tissues to a

greater extent than lower chlorinated PCBs, which are more easily hydroxylated and excreted by fish and mammals (Hutzinger et al. 1974, Ayres and Hellier 1998).

1.4 GLOBAL TRANSPORT OF PERSISTENT POLLUTANTS

Several POPs including OC pesticides and PCBs have been detected in remote environments once thought to be free of contaminants (de March et al. 1998 and references therein). Chlorinated compounds, including PCBs and HCH, have been reported in air and rain over the North Pacific Ocean (Atlas and Giam 1981). At mid-latitudes, winds carry pollutants from Europe and Asia over the Pacific Ocean and further west to North America (Wilkening et al. 2000). Researchers have also documented contamination of arctic air and water (Stern et al. 1997, Cotham and Bidleman 1991, Bailey et al. 2000, Hung et al. 2001a, Patton et al. 1991). Furthermore, arctic fish and wildlife are not immune to the effects of long-range POP transport, as demonstrated by the detection of PCBs in seals (Muir et al. 2000) and other northern biota (de March et al. 1998).

Research has unveiled trends in POP concentrations with latitude. For instance, Agrell et al. (1999) found an inverse relationship between atmospheric levels of PCBs and latitude in the Baltic Sea region that was strongest for more volatile congeners. Simonich and Hites (1995a) discovered a latitudinal gradient for levels of several semivolatile OC compounds in tree bark, with higher concentrations occurring at higher latitudes. Calamari et al. (1991) also observed similar results in various types of plant material. Model estimations confirm these observations, indicating that compounds of intermediate volatility are more prone to long-range transport and subsequent accumulation in polar regions (Strand and Hov 1996, Wania and Mackay 1993b, Wania and Mackay 1995, Wania and Mackay 1999, Wania et al. 1999). Detectable or elevated concentrations of selected POPs in colder regions suggest that a compound's physical and chemical properties along with environmental factors govern global chemical distribution more than source proximity and transport mechanisms (Wania and Mackay 1993a). Based on these observed and modeled trends, Wania and Mackay (1993a, 1996) have detailed a theory of global fractionation.

Several events occur that contribute to this phenomenon (Figure 1.3). "Cold condensation" refers to the tendency for airborne chemicals to condense onto terrestrial and aquatic surfaces at low temperatures. This process is further enhanced by increased adsorption of vapors to particles at lower temperatures (Wania and Mackay 1995). The term "condensation" normally implies a saturated or supersaturated medium, but in this

case it refers to the partitioning from a gaseous to a nongaseous phase (Wania and Mackay 1996). "Global distillation" describes chemical transfer from warm regions dominated by evaporative processes to regions where cold condensation is favored. This process depends on chemical changes that result from temperature variations. Similarly, "global fractionation" results in variable accumulation of chemical along a latitudinal gradient caused by different volatilization and deposition rates for compounds with dissimilar chemical and physical properties, again arising from a temperature gradient. Confounding this process is the "retention effect", in which certain compounds are more strongly retained by environmental compartments, such as water and soil, based on their chemical characteristics. As a result, global distillation may not be immediate (Wania and Mackay 1995). Relating these processes on a smaller scale is the "grasshopper effect", which involves short cycles of evaporation, atmospheric transport, and condensation at lower temperatures that normally coincide with seasonal temperature changes (Wania and Mackay 1996). These processes, combined with cold temperatures and the unique ecosystem of polar environments, have given rise to the accumulation of semivolatile compounds in arctic regions. Chemical persistence in the Arctic is further enhanced by a lack of biological activity and sunlight (Wania and Mackay 1993a).

Certain chemicals are more susceptible than others to this global migration. Highly volatile compounds with vapor pressures above 1.0 Pa are not likely to partition out of the gaseous phase, while less volatile compounds with vapor pressures below 0.001 Pa are not likely to escape into the gaseous phase (Wania and Mackay 1996). Semivolatile compounds, with vapor pressures between 0.01 and 1.0 Pa, have relatively high mobility and are volatile enough to undergo long-range transport, but still have a tendency to condense at colder temperatures observed, for instance, in the Arctic. Chemicals that preferentially accumulate in mid-latitudes normally have vapor pressures between 0.001 and 0.01 Pa and have relatively low mobility. Most OC pesticides and PCBs fall within the latter two categories, and are thus likely to participate in global distillation and fractionation (Wania and Mackay 1996).

These theories illustrate that chemicals know no boundaries, as cold, remote regions are susceptible to pollution from all areas of the world. When airborne pollutants reach these environments, they condense onto water, soil, and vegetation, and become part of the ecosystem, threatening environmental and human health. The importance of vegetation in the global fate of POPs has not been well documented and needs to be addressed in future research endeavors.

1.5 CHEMICAL ACCUMULATION IN PLANTS

Vegetation acts as a source of entry for pollutants into terrestrial food chains. Many variables influence pollutant uptake in plants, such as physical-chemical properties of the compound, environmental parameters, and plant characteristics. Chemical properties of interest include vapor pressure, molecular weight, water solubility, temperature of condensation, and the octanol-air partition coefficient (K_{OA}). Temperature, soil composition, and wind velocity are important environmental variables, while surface area, lipid content, and root-type are significant plant characteristics important in the accumulation process (Paterson et al. 1990).

Passive processes of diffusion and convection appear to be the major routes of chemical accumulation in plants (Schwarz and Jones 1997). Uptake can take place either through the root or through aerial parts of the plant. Gases are exchanged more readily through the leaf while dissolved substances are selectively absorbed through the root (Hartley and Graham-Bryce 1980).

The principle barrier to aerial uptake in plants is the cuticle. This non-cellular structure covers the foliage, stem, and any hairs, or trichomes, found on the plant. A thin coating of cuticular wax also lines the stomatal cavities (Hartley and Graham-Bryce 1980). For airborne chemicals to enter the plant, nonvolatile compounds must penetrate the cuticle, whereas volatile chemicals can enter through the stomata (Schwartz and Jones 1997).

The cuticular membrane is permeable to water and certain chemicals (Cremlyn 1978). It consists of insoluble polymeric cutins, which act as a skeleton for the cuticle, and soluble waxes, which are further classified into epicuticular wax found on the surface and cuticular wax embedded in the plant matrix (Holloway 1982). A very thin layer of wax and microcrystals makes up the outermost layer of the cuticle (Hassall 1982). Soluble waxes are composed of *n*-alkanes, alcohols, carboxylic esters, and straight chain saturated ketones, and may contain other aliphatic and terpenoid elements. A layer of cutin lies beneath the outer layer of wax, and consists of a cross-linked condensation polymer of fatty acids, dibasic acids, and hydroxy carboxylic acids. Closely associated with the cutin layer is a cutinized layer of cellulose fastened to the foliage epidermis through a layer of pectin (Hartley and Graham-Bryce 1980). The cuticle may also contain enzymes and carbohydrates (Schwartz and Jones 1997).

The composition and structure of the cuticle can vary among species and throughout the plant's lifetime (Kramer and Kozlowski 1979, Hartley and Graham-Bryce 1980, Holloway 1982). Plants growing in shady areas tend to have thinner cuticles than those exposed to bright sun. Furthermore, colder seasons elicit higher lipid contents in vegetation than summer months, but this observation is believed to be a result of internal metabolism rather than environmental conditions (Kramer and Kozlowski 1979).

Volatile airborne chemicals can be taken up by vegetation through stomata, which are specialized openings in the leaf surface that link the outside environment to the inner air-filled cavities of the plant. A pair of guard cells regulates the opening and closing of these apertures. Guard cells create a gap between them when they are turgid, opening the stomata, while flaccid cells block the aperture. The degree to which stomata are open controls the transpiration rate and the oxygen-carbon dioxide exchange rate. Guard cells do not allow entry of aqueous or detergent solutions through stomata, but they may permit penetration of oily liquids that can damage the stomatal lining (Hartley and Graham-Bryce 1980, Hassall 1982).

The phloem and xylem are plant translocation systems responsible for the transport of water and dissolved substances such as sucrose, mineral ions, nitrate, and amino acids. The phloem transports metabolites against their concentration gradient from photosynthetic compartments to growing regions, a process regulated by sieve tubes. Plasmodesmata are linked with the phloem and connect the protoplasm of adjacent cells, forming a continuous system between the phloem and intracellular components, called the symplast (Hartley and Graham-Bryce 1980).

Transpiration involves transport through the xylem system from the roots to the outer leaf and is driven by the evaporation of water at the leaf surface. This process is accelerated at higher ambient temperatures. The xylem forms a continuous system with intercellular pectinacious fluid called the apoplast. The plasmalemma is a semipermeable membrane that separates the apoplast from the symplast (Hartley and Graham-Bryce 1980). The symplast is composed of living plant tissue while the apoplast includes all nonliving portions (Boersma et al. 1988).

For translocation in the apoplast to occur, a compound must enter the free space, that is the first phase involved in root uptake in which chemical diffuses rapidly. It then must traverse the endodermis (a layer of closely packed cells on the interior of the cortex) to enter the xylem and travel with the water moving in response to transpiration. To be translocated in this aqueous system, the compound must be somewhat water-

soluble and sufficiently hydrophilic as not to partition into fatty structures encountered during transport, but somewhat lipophilic so that it can penetrate the endodermis (Hartley and Graham-Bryce 1980).

Guttation is a process by which involatile solutes are excreted through specialized openings called hydathodes in leaf margins of herbaceous plants. Hydathodes are most likely insignificant in chemical uptake (Hartley and Graham-Bryce 1980). Conversely, trichomes, or hairs, on the foliage exterior may play a significant role in chemical uptake from liquids in that they can form a grid that traps aqueous solutions on the foliage (Hassall 1982).

Although they are non-systemic in action, OC insecticides are able to penetrate plants to some degree (Brooks 1974b). These chemicals are capable of traveling through the atmosphere and partitioning to vegetation in areas around the world. As a result, POPs have been detected in foliage from all parts of the globe, including tropical regions and remote, colder regions such as the Antarctica Peninsula (Calamari et al. 1995, Ockenden et al. 1998a, Thomas et al. 1998).

Pesticide degradation and transformation may occur once absorbed into vegetation. In plants, endrin is transformed into endrin ketone and aldrin into dieldrin. In these cases, the metabolites are more stable and more persistent than their parent insecticides. Lindane, which degrades more rapidly than α-HCH, is converted to five products, including 1,2,4-trichlorobenzene and γ-pentachlorocyclohexene. Both DDD and DDE occur in plants as degradation products of DDT. Endosulfan sulfate and its ether have been detected in foliage following application of endosulfan (Brooks 1974b). Also, PCBs, particularly the heavier and more persistent congeners, can accumulate in the cuticle, but are not transported into the plant where degradation is more likely (Puri et al. 1997).

Chemical accumulation in vegetation depends on properties of the compound, various environmental variables, such as wind speed and temperature, and the plant's storage capacity. Variation in contaminant storage abilities among plant species has been documented and can often be explained by plant lipid content (Simonich and Hites 1994b). Conversely, Ockenden et al. (1998b) determined that plant components other than lipid influence accumulation of PCBs in grass. Investigation into the chemical partitioning behavior between the atmosphere and vegetation will contribute to our understanding into the global distribution of pollutants and the importance of vegetation as a chemical sink.

One important pathway through which POPs accumulate in vegetation is by atmospheric deposition. A high degree of mobility and a tendency to adhere to dust particles contribute to the global atmospheric transport of chlorinated hydrocarbons. Thus, pesticides and PCBs are present in air worldwide, even in remote communities. Airborne chemicals can then partition into and contaminate various environmental compartments, such as water, soil, sediment, and vegetation.

McLachlan (1999) describes three primary mechanisms by which atmospheric pollutants deposit onto plants. The first is gaseous deposition and is determined by the equilibrium fugacity gradient, or chemical potential, between the atmosphere and vegetation. When the transfer of chemical from the gas phase to vegetation is slow, equilibrium may not be reached during the plant's lifetime and gaseous deposition becomes kinetically limited. The second mechanism is particle-bound deposition and is further subdivided into wet and dry varieties. Wet deposition of dissolved chemical is the third method of deposition but is of little relevance in the fate analysis of hydrophobic compounds such as OC pesticides and PCBs (McLachlan 1999).

Particle-bound deposition is related to the properties of airborne compounds that are distributed between the gaseous and particle-bound phases. Vapor pressure and total suspended particle concentration are determinants of the vapor-to-particle ratio (Bidleman 1988). Recent studies have revealed that K_{OA} is a good predictor of gas to aerosol partitioning (Finizio et al. 1997). The Henry's law constant (H), an indication of a compound's air-water partitioning behavior, influences the wet deposition of particles. Particle-bound fractions of chemicals with high H values are scavenged by precipitation, whereas wet deposition of dissolved chemical dominates for compounds with low H values. Dry deposition onto vegetation depends on particle size, with both the largest and smallest particles settling at the greatest velocities. Larger particles tend to adsorb onto vegetation due to gravitational forces whereas Brownian motion – the continuous random movement of smaller particles in a fluid medium – governs deposition of smaller particles (Bidleman 1988).

Not only is vegetation selective in adsorption of specific chemicals from the atmosphere, certain parts of the plant are more susceptible to accumulation of these compounds. Plant foliage is more important in the adsorption of airborne compounds than the aboveground stem and twigs (Riederer 1990). Buckley (1982) reported higher PCB concentrations in plant leaves than in the stems and flowers of several species. Also, semivolatile chemicals such as γ-HCH, dieldrin, and DDT remain in tree bark due to their slow migration into wood (Trapp et al. 2001). Contamination of plant foliage by non-polar compounds with low volatility is

accomplished primarily through atmospheric deposition (Bacci et al. 1990b). Uptake of gas phase OC pesticides from the air has been found to be the primary mechanism for contamination of plant foliage following introduction of pesticides into the plant soil (Bacci and Gaggi 1986). Barrows et al. (1969) reported similar results when comparing dieldrin concentrations in field and greenhouse plants. Furthermore, Calamari et al. (1991) reported a linear relationship between plant and atmospheric concentrations of OC compounds, indicating a direct chemical exchange between these two phases.

In some studies, vegetation concentrations may be underestimated since the cutin polymer may not be completely extractable with solvent and may also act as a lipid, storing hydrophobic compounds (Ockenden et al. 1998b). Furthermore, Strachan et al. (1994) found that the factor used as a basis for concentration calculations, including surface area, dry weight, and wet weight, did not affect reported pollutant levels. Differences did exist when concentrations were based on the wax cuticle versus the needle interior, which were extracted and analyzed separately. However, concentrations in this study are expressed in terms of extractable lipids only, so a lipid-normalized concentration should be fairly accurate in order to determine temperature trends in POP accumulation.

Although it is believed that vapor phase compounds contribute the most to plant concentrations of these chemicals, particulate matter can also adhere to the waxy cuticle of plant foliage (Eriksson et al. 1989). However, adsorption from the vapor phase is a much faster process than particle phase deposition (Reischl et al. 1989) and gaseous chemicals can accumulate in epicuticular wax as well as interior lipids, whereas particle-bound compounds should only adsorb onto wax (Kylin 1996).

It is evident that vegetation has an enormous capacity to store lipophilic, semivolatile, gas phase compounds. Consequently, concentrations of these chemicals in vegetation compared to those in air are so high that increases in plant concentrations are only observed after extended periods of exposure, enabling the plant to encounter adequate amounts of air and chemical. As a result, the limiting factor in the accumulation of airborne chemical is its transport to the plant surface (Kömp and McLachlan 1997a). McLachlan and Horstmann (1998) estimated that the capacity for a spruce canopy to filter vapor phase organic compounds with log K_{OA} less than nine is expended during the lifetime of spruce foliage. This also explains observations that chemical concentrations in plant foliage continue to increase over time (Thomas et al. 1984, Kylin et al. 1994, Strachan et al. 1994, Tolls and McLachlan 1994).

1.6 THE CANADIAN ROCKY MOUNTAINS

High altitudes, cool temperatures, proximity to the Pacific Ocean, elevated levels of precipitation and snowfall, northern latitude, and an abundance of both coniferous vegetation and open water bodies all contribute to the susceptibility of the Canadian Rocky Mountains to contamination from global sources. The potential for mountain regions to retain semivolatile OC pesticides and PCBs has been demonstrated by Blais et al. (1998) who discovered that concentrations of many of these compounds in snowpacks from the Canadian Rocky Mountains were positively correlated with site elevation. Detection of chlorobornanes in Rocky Mountain lakes has been attributed to long-range transport (Donald et al. 1998). Furthermore, stream budgets in the Canadian Rocky Mountains indicate that only a small portion of POPs deposited in rain reaches stream water (Blais et al. 2001a). Thus the majority of the POPs inventory in this region is either volatilized or stored in terrestrial vegetation and soil.

The Canadian Rocky Mountains are bounded in the East by the Interior Plains, in the West by the Rocky Mountain Trench, in the North by the Liard River, and in the South by Maria's Pass in Montana. At 1450 km long and 150 km wide, they span an area of 180,000 km^2. Traveling from east to west, one first encounters the foothills, located between the prairies and the mountains, then the front ranges on the eastern front, the main ranges, and finally the western ranges. The Canadian Rocky Mountains are further divided into northern, central, and southern regions (Gadd 1995).

Daily and seasonal variations in climatic conditions exist throughout various parts of the Rocky Mountains. The climate is characteristic of inland or continental climate in which the rainfall is average and there is a wide range of temperatures throughout the year compared to coastal areas. The western slope of the Rocky Mountains is generally warmer and wetter than the eastern slope, particularly during winter. Shading created by the mountains causes the eastern slope to receive sunshine early in the day when air temperatures are low. South-facing slopes are warmer and drier than north-facing slopes due to the low angle of the sun (Gadd 1995).

Air temperature drops 0.7°C for every 100-meter gain in elevation, but can be as much as 1.0°C for air forced to higher elevations. A temperature inversion can occur during winter when cold air from high-pressure arctic air arising from the prairies becomes trapped in the valley, while air above the valley remains a few degrees warmer. Most of the precipitation in the valley falls during summer, whereas winter months bring

the majority of the high-altitude precipitation, mainly in the form of snow. The heaviest snow accumulation of all the ecological zones occurs in the cool and damp subalpine zone (Gadd 1995).

Winds generally originate from the southwest, but easterly winds from the prairies tend to occur in early summer and during cold snaps in the middle of winter. As these easterly winds move up the mountain slope, the air expands and cools, condensing into clouds and creating cloudy and rainy conditions on the western slope. In winter, easterly winds produce a constant precipitation of tiny ice crystals. A few times each winter a warm wind from the east called a Chinook encounters the eastern slope foothills of the mountain range. This phenomenon can cause the temperature on the ground to rise as much as 30°C in a few hours (Gadd 1995).

Orographic weather is a daily cycle of weather events created by upslope activity, or orographic lifting. Days begin with clear mornings while clouds emerge over the summit around mid-morning bringing afternoon thunderstorms followed by clear nights. Cold lows cause warm air to rise and cool quickly with increasing elevation, producing intense thunderstorms and cold rain. Consistent clearing of the skies tends to occur around mid-day throughout the year (Gadd 1995).

Forests on the eastern and western slopes form the montane ecological communities at lower elevations while alpine zones appear at higher altitudes above treeline. The eastern slope montane forest consists primarily of lodgepole pine, white spruce, and aspen, as well as buffaloberry, juniper, cinquefoil, and wild rose. Douglas fir can be found in the eastern valleys and foothills. Similar species of plant are found on the western montane slope, along with Columbia lily and western larch. The subalpine zone, located between montane and alpine communities, is heavily forested with fir and Engelmann spruce and contains shorter trees growing at higher elevations. At treeline, temperatures are warm enough to allow only tiny amounts of foliage to grow. Summer growth is sufficient to replace winter loss, and the ground thaws just long enough for vegetation to collect a year's supply of moisture and minerals. At the south end of the Rocky Mountains, treeline is at 3600 meters above sea level (masl) while it is as low as 1500 masl at the north end (Gadd 1995).

Vegetation found in the Rocky Mountains consists mostly of evergreen trees. Lodgepole pine (*Pinus contorta*) is found primarily in montane regions and is the most abundant species of vegetation in these areas (Gadd 1995). The species *Pinus contorta* actually has two varieties; lodgepole pine is an inland tree found in Yukon and interior British Columbia through to western Alberta, while shore pine is found along the Pacific

coast (Farrar 1995). The name lodgepole comes from its use as teepee poles and the species name *contorta* originates from its first sightings in California where the tree trunks were twisted (Gadd 1995). Lodgepole pine is also known as both Rocky Mountain lodgepole pine and black pine (Farrar 1995). It is the only pine in the Canadian Rocky Mountains with needles grouped by two. Its bark is brown with many fine scales and reaches heights between five and twenty meters (Gadd 1995).

Found in the subalpine zone, whitebark pine (*Pinus albicaulis*) is not a common species of the Canadian Rocky Mountains. Mature trees normally do not exceed ten meters in height and have a brown, scaly bark, while young specimens have gray, smooth bark. Needles are found in bunches of five. Also known as scrub pine, it is the oldest known species of the Canadian Rocky Mountains. It grows most often in rocky areas from 1000 masl to the treeline in the mountains of British Columbia and Alberta, most often in rocky areas (Gadd 1995, Farrar 1995).

Engelmann spruce (*Picea engelmannii*), and white spruce (*Picea glauca*) are the most common spruce species found in the Canadian Rocky Mountains. Engelmann spruce trees reach twenty to thirty meters in height and have a brown, shreddy bark. Cross-sections of the prickly needles are square while the lengths of the needles reach between one and two centimeters. Engelmann spruce grows higher on the mountain than white spruce, usually in subalpine zones and tends to be sparse in the north (Gadd 1995). This spruce is found in the interior mountains of British Columbia and eastern parts of Alberta, and spreads south to the U.S. It is also known as mountain spruce, Colombian spruce, silver spruce, and white spruce. Engelmann spruce tends to form part of the treeline and usually grows on mountain slopes between 1000 and 2000 masl, whereas it normally grows along streams at lower elevations (Farrar 1995).

More common at lower elevations, white spruce is similar in size and shape to Engelmann spruce and grows throughout the Rocky Mountains (Gadd 1995). It is often found at the arctic treeline and is also known as cat spruce, skunk spruce, pasture spruce, and Canadian spruce. Forests throughout Canada are host to this tree with the exception of the pacific coast, but it is most common in northern forests (Farrar 1995).

Table 1.1 Altitude, latitude, and longitude of sampling sites.

The last four sites correspond to those in the BC interior chosen for the examination of trends along a longitudinal transect.

Site	Altitude (masl)	Latitude (°N)	Longitude (°W)
Bow Lake	1975	51°40'	116°25'
Donald Station	770	51°30'	117°10'
Dixon Dam	948	52°03'	114°19'
Lower Kananaskis Lake	1667	50°40'	115°10'
Rock Isle	2200	51°04'	115°47'
Sundre	1115	51°48'	114°38'
Vermilion Lakes	1380	51°10'	115°34'
Wapta Lake	1590	51°26'	116°11'
Kamloops	350	50°39'	120°24'
Kelowna	430	49°50'	119°29'
Revelstoke	500	51°02'	118°12'
Salmon Arm	530	50°41'	119°18'

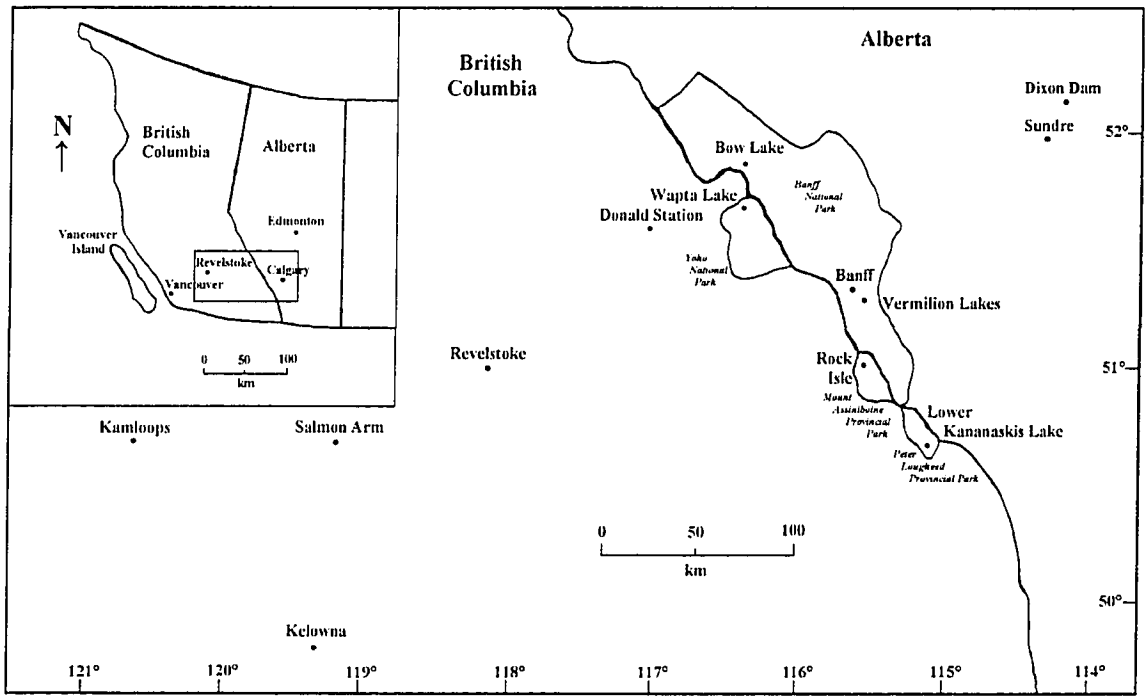
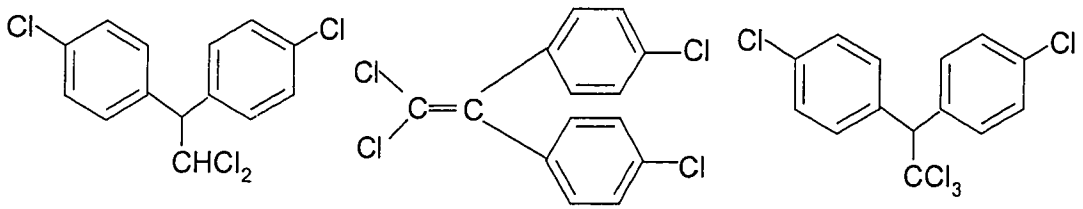
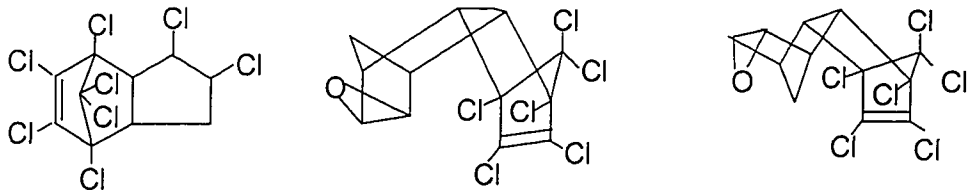


Figure 1.1 Sampling sites in Alberta and British Columbia.

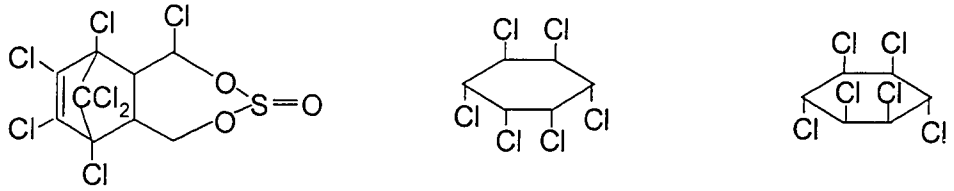
Major cities are represented for reference. Vegetation was collected from Wapta Lake, Vermilion Lakes, Rock Isle, and Dixon Dam, as well as from Revelstoke, Kamloops, Salmon Arm, and Kelowna for transect analysis. Air was sampled at Sundre, and both air and vegetation were sampled at Bow Lake, Donald Station, and Lower Kananaskis Lake.



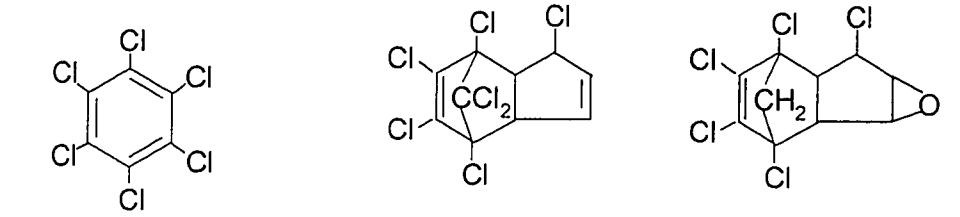
DDE **DDE** **DDT**



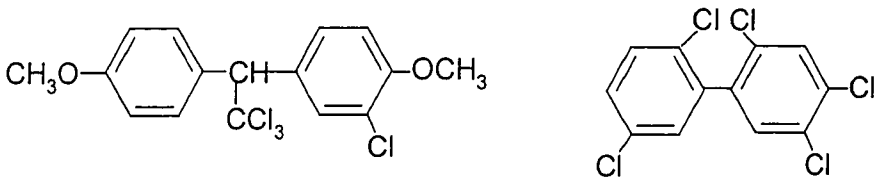
Chlordane **Dieldrin** **Endrin**



Endosulfan **α-HCH** **γ-HCH**



Hexachlorobenzene **Heptachlor** **Heptachlor Epoxide**



Methoxychlor

PCB 101
(2,2',4,5,5'-pentachlorobiphenyl)

Figure 1.2 Structures of selected organochlorine pollutants

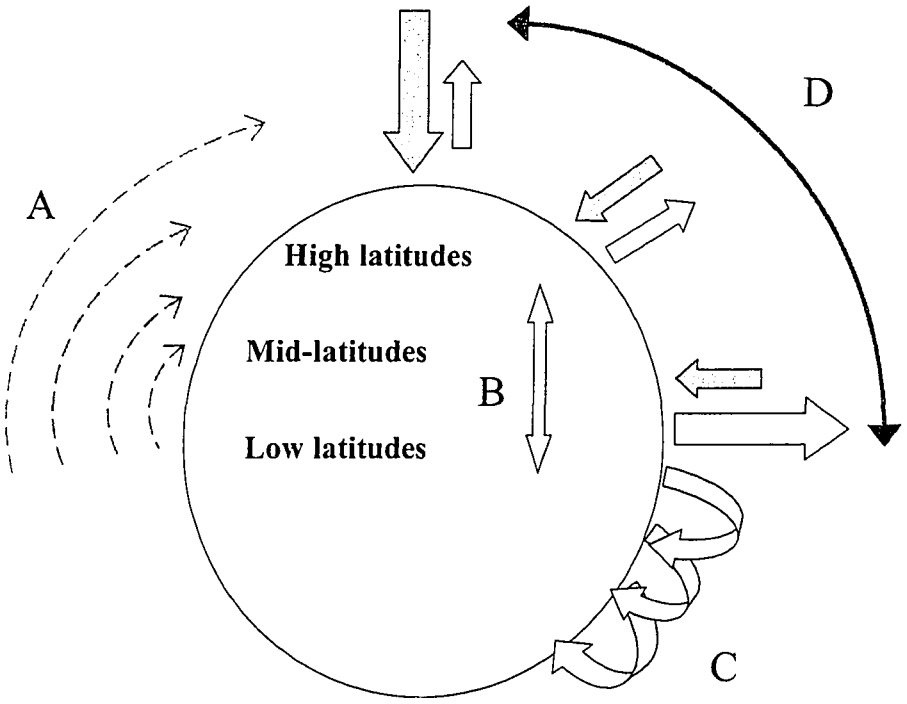


Figure 1.3 Events in the global transport of POPs.

A. Global fractionation – compounds of varying mobility migrate at different rates; B. Long-range oceanic transport; C. The grasshopper effect; D. Long-range atmospheric transport. At low latitudes, the evaporation rate exceeds the deposition rate, and some compounds are retained and possibly degraded. Evaporation and deposition at mid-latitudes are governed by seasonal temperature variations. Deposition is more significant at high latitudes, where minimal evaporation occurs (adapted from Wania and Mackay 1996).

2.0 OROGRAPHIC COLD-TRAPPING OF PERSISTENT ORGANIC POLLUTANTS BY VEGETATION IN MOUNTAINS OF WESTERN CANADA

2.1 ABSTRACT

Persistent organic pollutants, such as organochlorine pesticides and polychlorinated biphenyls, are progressively distilled toward cold environments. High mountain environments are generally cold with high precipitation, and are often located near emission areas, yet the role of mountain vegetation as orographic 'cold traps' is unknown for these chemicals. In this study, the enrichment of persistent organic pollutants in mountainous regions was investigated by collecting 230 vegetation samples from seven sites spanning an elevation of 1430 meters in the Canadian Rocky Mountains. Concentrations of several organochlorines increased significantly with site elevation, with higher increases for more volatile compounds. Back trajectories revealed that air masses arriving at these sites originate from over Asia and the Pacific Ocean. Results from this study demonstrate that alpine ecosystems accumulate these chemicals to the same degree that is observed in polar environments that are known to receive contaminants from distant sources.

2.2 INTRODUCTION

Regions, such as the Arctic, that are characterized by cold climates are susceptible to the enrichment of some persistent organic pollutants (POPs) through a global fractionation of persistent, semivolatile airborne chemicals (Wania and Mackay 1993a). Persistent compounds prone to global transport and temperature-induced deposition are typically those with subcooled liquid vapor pressures between 0.01 Pa and 1.0 Pa at 25°C and include several organochlorine (OC) compounds and polychlorinated biphenyls (PCBs) (Wania and Mackay 1996). Soil and vegetation are potential reservoirs for these chemicals, and are vectors through which persistent chemicals may enter terrestrial food chains (Böhme et al. 1999). As a result, they can accumulate in northern food chains to levels that sometimes exceed human consumption guidelines (Kidd et al. 1995).

Investigations of POP concentrations in various media have shown a latitudinal gradient in the concentrations of many semivolatile compounds. It has been demonstrated that levels of α-hexachlorocyclohexane (α-HCH), γ-HCH, hexachlorobenzene (HCB), and pentachloroanisole in bark samples increase significantly with latitude (Simonich and Hites 1995a). With the exception of high-altitude regions, negligible concentrations of HCB have been reported in plants from tropical countries, with increasing levels in colder areas at higher latitudes (Calamari et al. 1991). Similar relationships have been observed for dichlorodiphenyltrichloroethane (DDT) in fish from the Alps (Hofer et al. 2001) and for polycyclic aromatic

hydrocarbons (PAHs) in fish from Europe (Escartín and Porte 1999). Air concentrations of semivolatile POPs show an inverse relationship with latitude (Agrell et al. 1999), particularly for heavier, less volatile compounds. As contaminated air masses move to colder, higher latitudes, certain compounds preferentially condense and partition to soil, vegetation, and water due to a lowering of vapor pressure at lower temperatures.

Chemical distillation towards colder regions can occur in mountainous areas, where temperatures decrease as elevation increases. In the Canadian Rocky Mountains, concentrations of many OC compounds in snowpacks have been positively correlated with site elevation (Blais et al. 1998), and similar trends have been observed for chlorobornanes in fish (Donald et al. 1998). Because only a small portion of POPs deposited by rain in this area reaches stream water (Blais et al. 2001a), most of the POPs inventory in the western Canadian mountains, resulting from precipitation and gas phase deposition, is likely stored in terrestrial vegetation and soil. It is hypothesized that cold temperatures at higher elevations promote the deposition and accumulation of POPs, particularly the more volatile compounds with physical properties that are more sensitive to temperature-induced changes. A large data set of OC pesticide and PCB concentrations in vegetation from the Canadian Rocky Mountains was compiled to determine altitudinal trends and to test our hypothesis.

2.3 METHODS

2.3.1 Sample Collection

New growth of Engelmann spruce (*Picea engelmannii*; n=74), white spruce (*Picea glauca*; n=54), lodgepole pine (*Pinus contorta*; n=86), and whitebark pine (*Pinus albicaulis*; n=16) needles were collected throughout the summers of 1999 and 2000 from seven sites in the Canadian Rocky Mountains (Figure 1.3 in Chapter 1.0, Table 2.1). Needles were taken at heights between five and seven feet and removed from outer whorls of the tree with a clean pair of scissors. Samples were wrapped in clean aluminum foil, stored in resealable plastic bags, and sent to the University of Ottawa, Ottawa, ON, Canada, in an insulated cooler containing dry ice for storage at -20°C until extraction. Hourly temperature data were collected at each site using HOBO® Temp data loggers and BoxCar® Pro software, version 3.51 (Onset Computer Corporation, Bourne, MA, USA).

2.3.2 Chemicals

All solvents used for sample extraction were pesticide grade. Omnisolv® acetone, hexane, dichloromethane (DCM), and water were manufactured by EM Science-Merck KGaA (Darmstadt, Germany)

while Optima iso-octane was obtained from Fisher Scientific (Fair Lawn, NJ, USA). Omnisolv® water was stored at –4°C. Glassware was rinsed with ACS grade acetone and hexane (BDH Inc., Toronto, ON, Canada).

Anhydrous granular sodium sulfate (ACS Grade, BDH Inc., Toronto, ON, Canada) and Florisil® PR grade 60/100 mesh (Supelco, Bellefonte, PA, USA) were activated in a muffle furnace at 600°C for 6 hours and stored at 130°C. Glass wool (VWR Scientific, West Chester, PA, USA) was cleaned with DCM in an ultrasonic cleaner (Aquasonic 75D, VWR Scientific, West Chester, PA, USA) for 30 minutes and then stored at 130°C.

All field surrogates, lab surrogates, and pure standards used at the University of Ottawa were obtained from the National Laboratory for Environmental Testing (NLET) in Burlington, ON, Canada. Field surrogates contained 1,3,5-tribromobenzene (1,3,5-TBB), 1,2,4,5-tetrabromobenzene (1,2,4,5-TTBB), and δ-hexachlorocyclohexane (δ-HCH) at approximately 100 pg $\cdot \mu l^{-1}$ in methanol. Laboratory OC surrogates included 1,3-dibromobenzene (1,3-DBB) and endrin ketone, and laboratory PCB surrogates contained PCB 30 and PCB 204 at approximately 50 pg $\cdot \mu l^{-1}$ in iso-octane. Octachloronaphthalene (OCN), at approximately 50 pg $\cdot \mu l^{-1}$ in iso-octane, was also used as a laboratory surrogate. Lab surrogates were diluted ten-fold with iso-octane at the University of Ottawa before use. Mirex, used as an internal standard at the University of Ottawa, was obtained from Ultra Scientific (North Kingstown, RI, USA) at 100 ng $\cdot \mu l^{-1}$ in methanol, and further diluted to 2000 pg $\cdot \mu l^{-1}$ in iso-octane at the University of Ottawa. Pure reference standard solutions were used for instrument calibration, recovery evaluation, and analyte identification and quantification.

2.3.3 Extraction

A 5 gram subsample of needles removed from the twig was placed in a clean 40 ml amber glass vial with an open-top phenolic screw cap and a polytetrafluoroethylene/silicone septum (Supelco, Bellefonte, PA, USA). Each subsample was spiked with field surrogates and sonicated for 30 minutes in a 20:80 mixture of acetone:hexane covering the vegetation in an ultrasonic cleaner (Aquasonic Model 75D, VWR Scientific Products, West Chester, PA, USA). The solvent was decanted and placed into a clean separatory funnel, which allowed for removal of water and emulsion through liquid-liquid extraction with Omnisolv® water. The liquid-liquid extraction was performed in triplicate before the extract was further dried with sodium sulfate. The extract was then evaporated down to a few milliliters using a rotary evaporator (Bücchi Rotovapor-R, Switzerland) with a water bath at 30°C. Following lipid determination (see below), the extract was

concentrated to 2 ml with a gentle stream of ultra high purity nitrogen (Praxair, Mississauga, ON, Canada) using a Reacti-Therm evaporating unit and heating module (Pierce, Rockford, IL, USA) kept at 30°C.

After spiking with laboratory surrogates, the extract was cleaned up and fractionated on a Florisil® column packed as follows: glass wool, 8 g of 1.2% deactivated Florisil®, 1g sodium sulfate. Florisil® was deactivated by vortexing 7.9 g of the magnesium silicate adsorbent with 96 µl of Omnisolv® water for two hours. The packed column was pre-rinsed with 50 ml hexane that was drained to the top of the column before exposing the sodium sulfate to the air, and the eluate was discarded. The extract was placed on top of the column and allowed to pass through the column prior to fractionation. Fraction 1 (37 ml hexane) contained HCH, heptachlor, HCB, dichlorodiphenyldichloroethylene (DDE), DDT, and PCBs; fraction 2 (38 ml of a 15:85 mixture of DCM:hexane) contained HCH, chlordane, and dichlorodiphenyldichloroethane (DDD); and fraction 3 (52 ml DCM) contained endosulfan, dieldrin, endrin, heptachlor epoxide, and methoxychlor. Fractions were drained to the top of the column, solvent-exchanged into iso-octane, and evaporated down to approximately 0.5 ml by rotary evaporation followed by nitrogen blow-down. Mirex was added as an internal standard and the extract was topped up to 1 ml with iso-octane. Each fraction was stored in a clear 2 ml borosilicate glass vial (Autosampler LOVials, Kimble Glass Inc., Vineland, NJ, USA) sealed with a solid polytetrafluoroethylene lined cap (Supelco, Bellefonte, PA, USA) and stored at -20°C until analysis.

The moisture and lipid content of each sample were determined so that concentrations could be normalized to either lipid weight or dry weight, as desired. Prior to the first nitrogen evaporation, the extract was topped up to 12 ml with hexane and a 10% aliquot of the extract was placed in a pre-weighed, 50 ml aluminum weigh dish (VWR Scientific, West Chester, PA, USA). After drying in a dessicator for several days, the dish was re-weighed and the percent lipid of vegetation fresh weight was calculated. For moisture determination, a 2 gram subsample was weighed into a 40 ml amber glass vial, dried at 95°C for 24 hours, and re-weighed, and the percent moisture was calculated.

2.3.4 Analytical

Vegetation extracts were analyzed by a Hewlett Packard 6890 gas chromatograph equipped with a split/splitless injector, a 30 m x 250 µm i.d. HP-5 capillary column (5% phenyl, 95% dimethylpolysiloxane) with a 0.25 µm thickness, and a ^{63}Ni electron capture detector. One microliter of extract was injected in the splitless mode with an initial injector temperature of 250°C. Helium was used as the carrier gas and nitrogen

as the make-up gas. The temperature program conditions were 80°C held for two minutes, ramped at 10°C per minute to 110°C, then at 3°C per minute to 280°C and held for five minutes. The detector temperature was 350°C.

Chromatographic analysis and quantification of sample extracts were performed using HP Chemstation software (Rev. A.06.03, Hewlett Packard, Palo Alto, CA, USA). Sample extracts were screened for 16 OC pesticides and 130 PCB congeners, some of which coeluted to give 92 peaks. Analytes were considered present if the sample peak and its corresponding reference peak eluted within a retention time window of 0.04 minutes. A five-point calibration curve was prepared using reference standards between 1.9 and 530 pg $\cdot\mu l^{-1}$ for OCs and between 1.78 and 721 pg $\cdot\mu l^{-1}$ for PCBs. Calibration was based on a linear curve forced through the origin with linear weighting to all five points. The coefficients of determination for all calibration curves were 0.99 or higher. Mid-level standards for the OC pesticides and PCBs were analyzed at intervals throughout the sample analysis and used to recalibrate the instrument after every 15 injections. Sample peak quantification was based on the relative response of the internal standard against the target analytes. Data analysis was performed using either SYSTAT, version 9.01 (SPSS Inc., Chicago, IL, USA) or SPSS for Windows Student Version, release 9.0.1 (SPSS Inc., Chicago, IL, USA).

2.3.5 Quality Control

Aluminum foil used for storage of vegetation samples was rinsed with ACS grade acetone and hexane before heating for 12 hours at 200°C. All glassware used at the University of Ottawa was washed with industrial grade detergent, rinsed in triplicate with tap water followed by deionized water, rinsed with ACS grade acetone and hexane, and heated for 12 hours at 200°C. Glass Pasteur pipettes (VWR Scientific, West Chester, PA, USA) used for transfer of solvents and sample extracts were also heated for 12 hours at 200°C. To monitor potential laboratory contamination, procedural blanks were processed after every ten vegetation extractions. All data were blank-corrected prior to analysis by subtracting the mean blank concentration from the extract concentration and corrected for loss of analyte in the 10% aliquot used for lipid determination. For the PCBs, the sample concentration of each congener was adjusted for its detection in blank samples prior to grouping congeners in homologue groups.

Field surrogates were recovered with 83.5±0.8% efficiency, while the recovery of OC and PCB laboratory surrogates were 104.1±1.3% and 109.4±0.7%, respectively. Blanks contained detectable levels of

α-HCH, HCB, heptachlor epoxide, α-endosulfan, α-chlordane, dieldrin, *p,p'*-DDE, and endrin at 16.9±1.1%, 64.2±8.2%, 1.0±0.3%, 15.8±1.9%, 1.1±0.2%, 7.2±1.2%, 1.6±0.1%, 138.2±35.7%, respectively, of levels in vegetation samples. Several PCB congeners were detected in blank samples, accounting for 53.0±8.4% of ΣPCB in tissue sample extracts. The high mean blank levels relative to sample concentrations were caused by a few samples with low levels of the analyte, and not by large concentrations detected in the blanks.

2.3.6 Back Trajectories

Five day back trajectories were computed for the sampling area for July 2000 at pressures of 850, 725, and 500 mbar using a Lagrangian model based on meteorological data objectively analyzed every six hours. Descriptions of the methods used to compile these trajectories can be found in Cheng et al. (1998) and McDonald et al. (1996).

2.4 RESULTS AND DISCUSSION

The most ubiquitous compounds present in the vegetation were α-HCH, γ-HCH, and HCB, occurring in over 97% of the samples. Heptachlor epoxide and methoxychlor were the most concentrated OC pesticides detected, with respective mean concentrations of 50±17 ng $\cdot g^{-1}$ lipid and 32±15 ng $\cdot g^{-1}$ lipid (error estimates represent the standard error of the mean). Average concentrations of *p,p'*-DDD and *p,p'*-DDT were 0.48±0.15 ng $\cdot g^{-1}$ lipid and 0.98±0.23 ng $\cdot g^{-1}$ lipid, making these compounds the most dilute of the OC pesticides detected.

Levels of endosulfan and HCB detected in this study were comparable to those reported for vegetation samples collected from northern Russia and Alaska (Simonich and Hites 1995a). Levels of DDT were also comparable to those reported in northern Norway, and dieldrin concentrations were within the range detected in vegetation from northern Russia (Simonich and Hites 1995a). These northern areas have been investigated for years as potential sinks for global sources of POPs.

The most prevalent PCB congeners were those with four and five chlorine atoms, while the lighter (mono- and dichlorinated) and heavier (nona- and decachlorinated) congeners were uncommon. Total PCB burdens reached levels as high as 312±19 ng $\cdot g^{-1}$ lipid, with nonachlorinated congeners showing the lowest concentrations at 0.75±0.28 ng $\cdot g^{-1}$ lipid and tetrachlorinated congeners the highest at 144±10 ng $\cdot g^{-1}$ lipid.

To examine the potential for POP distillation in this mountain region, the log of the analyte concentrations in vegetation were correlated with altitude. Concentrations were expressed on a lipid-weight

basis to minimize the effects of species differences (Simonich and Hites 1994b). The average lipid content of the vegetation samples was 0.60%, with a standard error of the mean of only 0.03%, indicating that lipid contents were relatively similar among species. Several of the more volatile OC pesticides correlated significantly with altitude, while others were inversely related to elevation (Table 2.2, Figure 2.1). Concentrations of PCB homologue groups did not increase significantly with elevation. Linear regression between temperature and elevation revealed a drop of 5°C for every 1000-meter rise. Neither lipid content nor moisture content in vegetation was correlated with elevation.

The relatively volatile γ-HCH, commonly known as lindane, showed an inverse relationship with elevation, likely due to application of this pesticide at low altitudes in nearby southern Alberta and British Columbia, as this compound was still used in Canada at the time of sampling (Bidleman 1999, www.nrtee-trnee.ca/eng/programs/Current_Programs/Health/LINDANE_e.htm). An inverse relationship between ΣHCH concentration in spruce needles and altitude was also reported in Austria, and was caused by the proximity of low altitude sites to agriculture where γ-HCH is applied (Weiss et al. 2000).

Vapor pressure was a significant indicator of the slope for the relationship between OC pesticide concentration and altitude ($R^2 = 0.255$, $p<0.05$), indicating that concentrations of more volatile compounds increase more with elevation than those with lower volatility (Figure 2.2).

$$\text{Slope} = 1.506\text{x}10^{-3} \cdot \text{Vapor Pressure} - 1.53\text{x}10^{-4} \qquad (2.1)$$

The dependence was stronger when the outlier γ-chlordane was omitted, yet the correlation was still significant at the 95% confidence level when all OC pesticides were included. Relatively high slopes were observed for the less volatile methoxychlor and *o,p'*-DDT. These compounds were detected primarily in those samples taken from 1380 meters above sea level (masl) and higher; thus results may have been affected by low concentrations that approached detection limits. However, the magnitude of the slope was not dependent on the concentration of analyte detected in the vegetation samples (Figure 2.3). Thus, the relative increase in chemical concentration with elevation for different compounds is due to their physical and chemical properties, such as vapor pressure, and not their levels in the environment.

Ratios of both α-HCH to γ-HCH and DDT to DDE can be used as indicators of contaminant source age (Calamari et al. 1991, de March et al. 1998). A high α/γ-HCH ratio suggests older or more distant sources because α-HCH is no longer used in North America and the γ-isomer can be photolytically degraded to α-HCH

(Calamari et al. 1991). Furthermore, γ-HCH is more water-soluble than α-HCH, making it more prone to removal from air through precipitation or by deposition onto water (Law et al. 2001). However, because the γ-isomer continues to be applied in this study area, the calculated α/γ-HCH ratio is not an adequate indicator of age, but may still signify distant sources. The average α/γ-HCH ratio in this study was 2.04±0.14 and reached as high as 19 in one sample from Rock Isle, the most elevated site. Levels of γ-HCH were highest in vegetation collected from Dixon Dam, a site near farming activity where application of this compound continues. The ratio of α-HCH to γ-HCH increased significantly with elevation (Pearson's $r = 0.292$, $p<0.001$), indicating that higher sites are receiving more distant sources of this compound, possibly because of lower air pressures that are less restrictive to air movement. Ratios of α-HCH to γ-HCH in lakes increase with latitude, indicating long-range transport of aged HCH to northern lakes (Law et al. 2001). Once transported to colder regions, the α-HCH isomer is less likely to be transported elsewhere due to the low temperatures that hinder its evaporation (Law et al. 2001).

Low DDT/DDE ratios indicate aged sources because DDT is converted primarily to DDE (de March et al. 1998). When both DDT and DDE were detected in vegetation samples, ratios ranged from 0.05 to 3.8, with a mean of 1.88±0.22, suggesting recent sources of DDT to this region. All but four of the 20 extracts that contained both DDT and its metabolite were sampled from Vermilion Lakes at 1380 masl. The distribution of species was fairly uniform across study sites with samples of pine and spruce collected at each elevation, except for Dixon Dam at which spruce foliage dominated the samples (Table 2.1). It is not clear why DDT was detected most frequently at Vermilion Lakes. This site is on the eastern slope of the Rocky Mountains, along with most of the other sites, and is located at mid-altitude. The parent isomer *p,p'*-DDT was detected only in samples from Rock Isle, Vermilion Lakes, and Wapta Lake collected during July and August of the 1999 sampling season. Because most of the *p,p'*-DDT was detected at a certain time of the year, it is possible that air masses arriving to the region at this time passed predominantly over Vermilion Lakes and preferentially deposited to vegetation in this region.

Given the relatively low ratios reported previously throughout North America and Europe compared to other parts of the world (Table 2.3), the bulk of the DDT present in the Rocky Mountains is likely arising from continued application of the parent DDT isomers in Asia, Africa, and South America. Arctic air shows higher levels of total DDT when air masses reaching the arctic have lingered over Asia (Bailey et al. 2000). It

has also been shown that North America receives pollutants from Eurasia via mid-latitude westerly winds that travel over the Pacific Ocean (Wilkening et al. 2000). Five-day back trajectories for air masses arriving at the sampling area for the summer months of 2000 reveal that air masses are originating over the Pacific Ocean and as far west as Asia (Figure 2.4). Donald et al. (1998) performed five-day back trajectories from Bow Lake at 700 mbar for 1990, 1991, and 1992. The back-trajectories revealed that air arriving at Bow Lake originated from the Pacific and Arctic Oceans 60% of the time, while the United States, Canada, and Siberia were sources 21%, 11%, and 8% of the time, respectively.

Higher sites are also more likely to receive air masses from farther distances than lower sites due to lower pressures that accommodate the movement of air masses (Figure 2.4). Furthermore, lower sites also tend to receive air from the east to a greater extent than higher sites, although the bulk of the air masses are still arriving from the west. Cotham and Bidleman (1991) showed that HCB and dieldrin are evaporating from the Arctic Ocean, and air over the North Pacific Ocean has been shown to be contaminated with POPs (Wilkening et al. 2000). Chlorinated hydrocarbons, which are transported to oceans primarily through atmospheric transport (Harvey and Steinhauer 1974), can evaporate fairly rapidly from water resulting in short half-lives in this medium (Mackay and Wolkoff 1973). Thus, Asia and the Pacific Ocean are possible suppliers of fresh DDT to this region arriving via long-range transport.

2.5 CONCLUSIONS

Enrichment of persistent chemicals in vegetation from the Canadian Rocky Mountains suggests that cold condensation and fractionation are occurring, for some volatile chemicals, in elevated areas and are not exclusive to remote, polar environments. The sampling sites in this study cover an area of approximately 45,000 km^2, but span only two degrees in latitude and four degrees in longitude. Thus mountain environments provide the conditions necessary to observe true chemical fractionation on a small scale where terrestrial and aquatic ecosystems are exposed to the same regional sources and global air masses, possibly arising from Asia via the Pacific Ocean. Fractionation observed previously in global studies (Simonich and Hites 1995a, Calamari et al. 1991) might have been influenced by dissimilarities in POP emissions between both countries and continents where regulations, restrictions, and economic conditions vary greatly. In light of these discoveries, it is evident that alpine ecosystems warrant similar attention provided to arctic environments when it comes to POP transport and possible bioaccumulation in food webs.

Table 2.1 Species of vegetation sampled in the Rocky Mountains.

Number of samples for each species collected at each site and elevation. Species included Engelmann spruce (ES), white spruce (WS), lodgepole pine (LP), and whitebark pine (WP).

Site	Altitude (masl)	Year	Dates (mm/dd)	ES	WS	LP	WP
Donald Station	770	1999	06/10 – 08/19	2	10	8	
Dixon Dam	948	2000	04/22 – 08/01		12	2	
Vermilion Lakes	1380	1999	06/11 – 08/19		12	8	
		2000	04/18 – 08/08	2	12	14	
Wapta Lake	1590	1999	06/05 – 08/11	6	6	6	
		2000	04/19 – 08/08	14		14	
Lower Kananaskis Lake	1667	2000	05/02 – 08/07	12		12	
Bow Lake	1975	1999	06/04 – 08/11	12		8	
		2000	04/25 – 07/27	8		12	
Rock Isle	2200	1999	06/25 – 08/18	12			10
		2000	06/17 – 08/16	6	2	2	6

Table 2.2 Results for the correlation between POP concentration and altitude.

Pearson's correlation coefficients (r), slopes for the lines of best fit (m), and sample size used for the correlation (n) are shown for the correlation between the log concentration (ng $\cdot g^{-1}$ lipid) and site elevation (masl). Values for the sub-cooled liquid vapor pressure (P_L) at 25°C were obtained from Mackay et al. (2000), with the exception of heptachlor epoxide, which was quoted from Howard (1991). Compounds are listed in order of decreasing vapor pressure from highest to lowest volatility, with a range of vapor pressures presented for all PCB congeners. The four most volatile compounds show significant increases in plant concentration with elevation. *Correlation was significant at the 95% confidence level.

Compound	r	m	n	P_L (Pa)
β-Endosulfan	0.259*	3.24×10^{-4}	56	3.94×10^{-1}
Heptachlor	0.303*	3.50×10^{-4}	104	2.67×10^{-1}
HCB	0.169*	2.40×10^{-4}	224	2.45×10^{-1}
α-HCH	0.213*	1.73×10^{-4}	229	1.00×10^{-1}
γ-HCH	-0.189*	-1.68×10^{-4}	223	2.74×10^{-2}
Dieldrin	-0.148	-1.22×10^{-4}	38	1.60×10^{-2}
α-Endosulfan	0.050	7.20×10^{-5}	144	8.00×10^{-3}
p,p'-DDE	0.052	5.74×10^{-5}	111	3.72×10^{-3}
γ-Chlordane	-0.513*	-1.13×10^{-3}	19	2.65×10^{-3}
α-Chlordane	-0.199	-2.99×10^{-4}	50	2.65×10^{-3}
Heptachlor Epoxide	-0.225	-3.20×10^{-4}	66	2.56×10^{-3}
Endrin	-0.025	-3.33×10^{-5}	50	1.32×10^{-3}
p,p'-DDD	-0.502	-3.05×10^{-4}	11	6.93×10^{-4}
Methoxychlor	0.129	1.89×10^{-4}	24	5.46×10^{-4}
o,p'-DDT	0.154	2.79×10^{-4}	23	1.72×10^{-4}
p,p'-DDT	-0.104	-1.15×10^{-4}	25	1.35×10^{-4}
ΣPCBs	-0.046	-4.52×10^{-5}	230	$3 \times 10^{-5} - 2.5$

Table 2.3 Global distribution of DDT/DDE ratios.

Ratios of DDT/DDE measured in vegetation and air from the literature compared to this study. The error estimate represents the standard error of the mean. a. Calamari et al. (1995); b. Tremolada et al. (1993); c. Calamari et al. (1991); d. Calamari et al. (1994); e. this study, f. Halsall et al. (1998); g. Cortes et al. (1998); h. Jantunen et al. (2000); i. McConnell et al. (1996); j. Alegria et al. (2000).

Medium	Geographic Region	Location	Ratio DDT/DDE	Reference
Vegetation	Africa	Burkina Faso	10.22	a
		Sierra Leone	7.83	b
		Ghana	6.67	c
		Benin	5.10	c
		Guinea	4.57	c
		Ivory Coast	2.06	c
		Kenya	0.95	c
	Asia	Nepal	7.37	c
		India	3.76	a
		Jordan	0.98	a
		Indonesia	2.15	a
		Japan	1.27	a
	Europe	Italy	1.63	d
		Netherlands	1.15	d
		Greece	0.76	a
		Austria	0.63	d
		Finland	0.50	d
		Czech	0.41	d
	Canada	**Rocky Mountains**	**1.88 ± 0.22**	**e**
	Mexico	Mexico	5.38	a
	Central America	Guatemala	2.64	c
	South America	Venezuela	9.27	c
	South America	Chile	1.09	a
Air	Canada	Alert	0.33	f
	Canada	Tagish	0.31	f
	Russia	Dunai	0.39	f
	USA/Canada	Great Lakes	0.60	g
	USA	Alabama	0.71	h
	Russia	Irkutsk	2.50	i
		Lake Baikal	1.20	i
	Central America	Belize	2.30	j

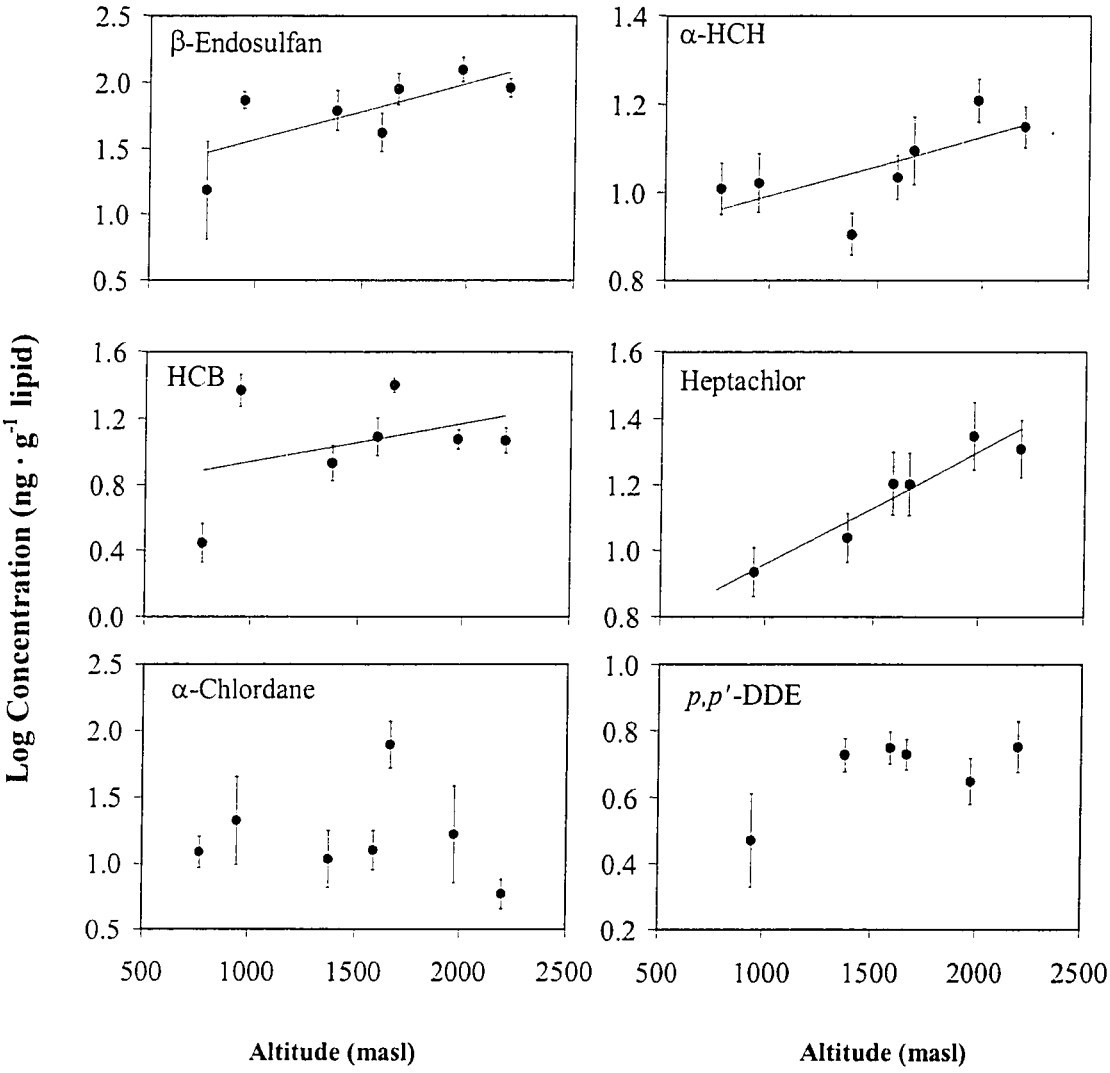


Figure 2.1 Correlations between POP concentrations in vegetation and altitude.

Points represent the mean concentration (ng $\cdot g^{-1}$ lipid) at each elevation (masl) and error bars represent the standard error. Lines of best fit were drawn if analyses revealed a significant correlation between the original concentrations and elevation, as in Table 2.2. Samples in which analytes were not detected were omitted from analyses and mean calculations, giving rise to the following sample sizes for each site: Donald Station, n=20; Dixon Dam, n=14, Vermilion Lakes, n=48; Lower Kananaskis Lakes, n=46 Wapta Lake, n=24, Bow Lake, n=40; Rock Isle, n=38.

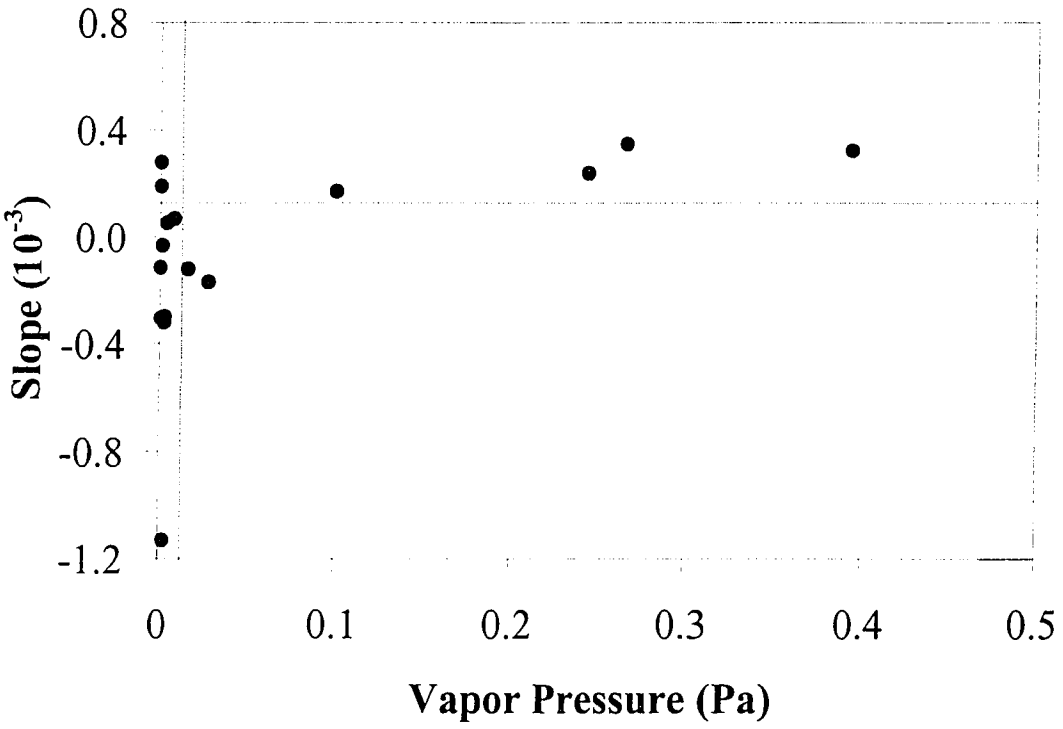


Figure 2.2 Change in concentration with elevation as it relates to volatility.

The slope of the regression line for the relationship between analyte concentration (ng $\cdot g^{-1}$ lipid) and site elevation (masl) is plotted against analyte vapor pressure (Pa). Persistent compounds prone to temperature-induced deposition are typically those with subcooled liquid vapor pressures between 0.01 (vertical dashed line) and 1.0 Pa at 25°C. Points above the horizontal dashed line and with vapor pressures greater than 0.01 Pa represent positive slopes that were significantly different from zero at the 95% confidence level (Table 2.2). As discussed in the text, methoxychlor and *o,p'*-DDT showed high slopes in relation to their volatility, and make up the two points above the horizontal dashed line with vapor pressures below 0.01 Pa. The outlier, γ-chlordane, had a very highly negative slope of -1.13×10^{-3}.

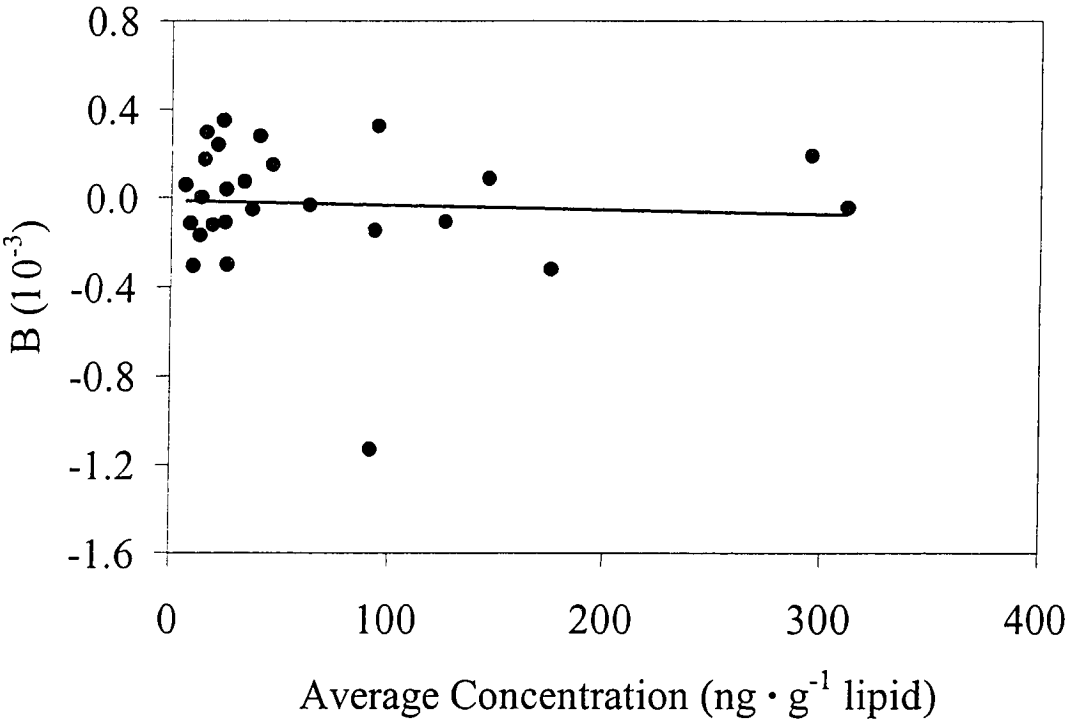


Figure 2.3 Effect of analyte concentration on the distillation upslope.

The slope for the regression of analyte concentration versus elevation (B) is plotted against the average concentration in the vegetation samples (ng ·g^{-1} lipid).

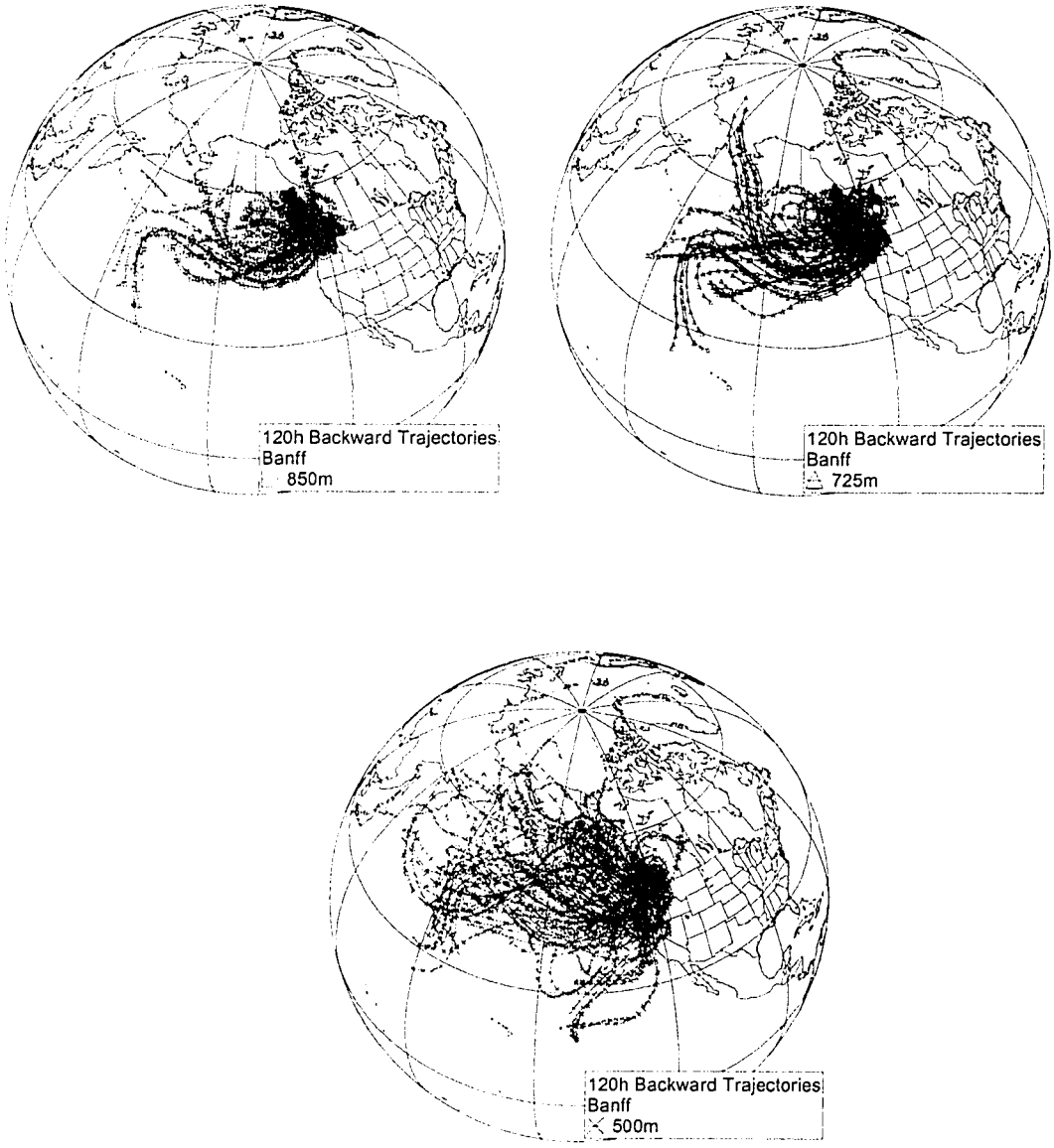


Figure 2.4 Back trajectories for the sampling area.

Five-day back trajectories were computed every six hours using a Lagrangian model at 850 mbar, 725 mbar, and 500 mbar for Banff, Alberta, a central point in the study area.

3.0 VEGETATION-ATMOSPHERE EXCHANGE OF SEMIVOLATILE ORGANIC COMPOUNDS IN THE CANADIAN ROCKY MOUNTAINS

3.1 ABSTRACT

The exchange of chlorinated organic pollutants between air and vegetation in cold, mountain environments was investigated through the extraction of coniferous vegetation and high-volume air samples collected from the Canadian Rocky Mountains during the summers of 1999 and 2000. Concentrations of several compounds in vegetation increased as temperatures decreased, whereas atmospheric concentrations were not related to temperature. Daily cycling of these compounds between air and vegetation as a result of diurnal temperature changes was not observed. Compared to concentrations in vegetation from the Canadian Rocky Mountains, plant samples from low altitudes in British Columbia showed higher pollutant levels. Chemical partitioning between vegetation and air was not correlated with temperature, indicating that air contamination is governed by long-range transport and not by local revolatilization events. Based on these observations, both temperature-induced deposition at higher altitudes and long-range atmospheric transport influence chemical accumulation in vegetation at higher altitudes in the Canadian Rocky Mountains.

3.2 INTRODUCTION

Vegetation assists in cleansing the atmosphere by removing organic pollutants through the absorption of vapors and the scavenging of chemical particulates from the air (Thomas et al. 1998). The tendency for vegetation to retain semivolatile organic compounds (SVOCs) is particularly important in heavily forested areas such as northern Canada. Forests can intercept gaseous airborne chemicals traveling north before they reach higher latitudes where colder temperatures favor their condensation and deposition (McLachlan and Horstmann 1998). Soil can also act as a significant sink for SVOCs (Weiss 2000). However, most atmospherically derived compounds are trapped by vegetation rather than by soil due to the greater total surface area of plant foliage compared to ground area (Kerler and Schönherr 1988). While translocation of some compounds from the soil to plant foliage can occur, hydrophobic compounds such as organochlorine (OC) pesticides and polychlorinated biphenyls (PCBs) generally contaminate aerial parts of the plant through atmospheric deposition (Trapp et al. 1990). Chlorinated hydrocarbons are soluble in fatty acids and aromatic compounds, such as terpenes and etheric oils, and accumulate most readily in bark and coniferous needles that contain an abundance of these lipophilic substances (Thomas et al. 1984).

This study was conducted to examine the tendency for coniferous vegetation in the Canadian Rocky Mountains to retain SVOCs. Coniferous needles can grow on the tree for several years, and, provided chemical volatility is low enough, these plant species can adsorb and accumulate airborne lipophilic compounds throughout their lifetime (Kylin 1996). Semivolatile pesticides are introduced into the environment via revolatilization following application, initial scatter upon application, and wind erosion of soil. They can then travel to cold regions in a matter of days, where they are more resistant to breakdown than in temperate climates where pesticides are commonly applied (Weiss 2000). The persistent and bioaccumulative nature of OC compounds may permit them to remain in a cycle of volatilization and deposition between vegetation, soil, and the air for up to 20 years (Thomas et al. 1984). If such cycles are occurring in the Canadian Rocky Mountains, alpine and subalpine ecosystems may be continuously exposed to certain hazardous chemicals. Characterizing the chemical accumulation in vegetation is crucial to identifying the risk for humans and wildlife arising from exposure through this essential link in the food chain (McGrady and Maggard 1993).

3.3 METHODS

3.3.1 Sample Collection

Vegetation samples were collected as described in Chapter 2.0 from the locations indicated in Table 1.1 in Chapter 1.0, with the exception of Sundre, where air only was sampled. Vegetation samples were also collected along a longitudinal transect in British Columbia from Kamloops to Revelstoke in mid-July, 2000. To ascertain if daily cycling of POPs occurs between air and vegetation, diurnal samples were collected in early morning (n=12) and late afternoon (n=12) on three separate occasions at Bow Lake.

Air was sampled using a high-volume air sampler (Andersen Instruments Inc., Smyrna, GA, USA) placed at Bow Lake and Donald Station in 1999 and at Bow Lake, Sundre, and Lower Kananaskis Lake in 2000. Air samplers were run for a period of four days during the 1999 sampling season and for two days during the summer of 2000, coinciding with vegetation sampling, during which a total of about 2500 m^3 of air was sampled. Vapor phase compounds were collected on two 7.5 cm x 6.4 cm diameter polyurethane foam (PUF) filters placed in series. The filters were collected every two weeks, at which time they were placed in clean, airtight aluminum containers. Samples from the 1999 season were sent to the National Laboratory for Environmental Testing (NLET) in Burlington, ON, Canada, while samples from the 2000 season were sent to

the University of Ottawa, Ottawa, ON, Canada for extraction. Filters were shipped in an insulated cooler containing dry ice and stored at -20°C at the laboratory until extraction.

Meteorological data were collected throughout the sampling periods from nearby weather stations operated by Environment Canada; Parks Canada; the University of Alberta, Edmonton, AB, Canada; and the University of Calgary, Calgary, AB, Canada. Data included ambient temperature, relative humidity, barometric pressure, precipitation, wind speed, and wind direction. Hourly temperature data were also collected at each site using HOBO® Temp data loggers and BoxCar® Pro software for Windows, version 3.51 (Onset Computer Corporation, Bourne, MA, USA).

3.3.2 Chemicals

Chemicals used for extraction of vegetation samples and the air PUF filters from the 2000 season were described in Chapter 2.0. Silica (70/230 mesh, J.T. Baker, Phillipsburg, NJ, USA) was heated at 350°C for 16 hours prior to use and stored in an airtight container in a dessicator. Copper used for sulfur removal at NLET was washed with 10% nitric acid, rinsed with deionized water and methanol, and stored under methanol in a glass jar with a polytetrafluoroethylene lined lid at -4°C. Field surrogates used at NLET for the 1999 air PUF filters included 1,3,5-tribromobenzene (1,3,5-TBB) at 5 pg $\cdot \mu l^{-1}$ and octachloronaphthalene (OCN) at 20 pg $\cdot \mu l^{-1}$.

3.3.3 Experimental

Vegetation samples were extracted as described in Chapter 2.0. Air PUF filters sent to NLET were spiked with 1,3,5-TBB and OCN and Soxhlet extracted for 24 hours in hexane. The extract was then dried with sodium sulfate, solvent-exchanged into iso-octane, and evaporated down to 1 ml using rotary evaporation followed by nitrogen blow-down. The extract was then cleaned up on a silica gel column pre-rinsed with hexane that consisted of glass frit, 20 cm of silica, and 1 cm of sodium sulfate. Fraction 1 (50 ml hexane) contained hexachlorobenzene (HCB), heptachlor, dichlorodiphenyldichloroethylene (DDE), and PCBs, while fraction 2 (50 ml of 1:1 dichloromethane:hexane) contained hexachlorocyclohexane (HCH), heptachlor epoxide, endosulfan, dieldrin, endrin, methoxychlor, dichlorodiphenyldichloroethane (DDD), and dichlorodiphenyltrichloroethane (DDT). Extracts were copper cleaned prior to analysis to remove any sulfur present in the sample. Each fraction was solvent-exchanged into iso-octane and evaporated to a final volume of 1 ml.

Air PUF filters extracted at the University of Ottawa were spiked with field surrogates and PCB lab surrogates prior to Soxhlet extraction in dichloromethane for 6 to 16 hours. The extract was dried with sodium sulfate and concentrated in hexane to approximately 1 ml using a Turbovap II (Zymark, Hopkinton, MA, USA) with the water bath at 35°C and the nitrogen pressure between 12 and 15 psi. The extract was spiked with lab OC surrogates and OCN, and cleaned up using the same column chromatography method described for vegetation extracts. Each fraction was solvent-exchanged into iso-octane and concentrated to 0.5 ml using the Turbovap II with a nitrogen pressure between 12 and 15 psi and a water bath temperature of 55°C for fraction 1, 45°C for fraction 2, and 35°C for fraction 3. Mirex was added as an internal standard and each fraction was topped up to 1 ml with iso-octane. The extracts were then transferred to 2 ml glass vials and stored at -20°C until analysis.

3.3.4 Analytical

Vegetation and the 1999 air PUF filter extracts were analyzed by gas chromatography as described in Chapter 2.0. Air PUF filters extracted at NLET were injected on a Hewlett Packard 5890 Series II gas chromatograph equipped with a split/splitless injector, a 30 m x 250 μm i.d. DB-5 capillary column with a 0.25 μm thickness, and a ^{63}Ni electron capture detector. The injector temperature was 220°C and was operated in the splitless mode. Helium was used as the carrier gas at a constant flow of 1 ml $\cdot min^{-1}$ with nitrogen as the make-up gas. The temperature program conditions were 80°C held for 2 minutes, and ramped at 4°C per minute to 280°C and held for 5 minutes. The detector temperature was 350°C.

For conciseness, results reported for PCBs are presented as the sums of homologue groups. These include monochlorinated (1, 3), dichlorinated (4+10, 6, 7+9, 8+5, 12+13, 15+17), trichlorinated (18, 19, 22, 24+27, 16+32, 54+29, 25, 26, 50+31+28, 33+20+53), tetrachlorinated (40, 43, 44, 45, 46, 48+47, 49, 51, 52, 56+60, 59+42, 63, 64+41+71, 66+95, 70+76+98, 74, 87+81, 91+55), pentachlorinated (82, 83, 84, 85, 92, 97, 99, 100, 101, 110, 114, 118, 119, 147+107, 157+200, 176+130), hexachlorinated (128, 129, 133, 134+131, 135+144, 136, 137, 138+163, 141+179, 146, 149, 151, 153+132+105, 158, 167), heptachlorinated (170+190, 172, 173, 174, 175, 177, 178, 180, 183, 185, 187+182, 189, 191, 193, 202+171+156), octachlorinated (194, 197, 198, 199, 201, 203+196, 205, 206+195), nonachlorinated (207, 208), and decachlorinated (209) PCBs. Addition signs indicate coeluting congeners. When two coeluting congeners spanned more than one

homologue group, the congeners were added to the lower homologue, or to the majority or middle homologue group in the case of three coeluting PCBs. Concentrations of all congeners were summed to give ΣPCB.

3.3.5 Quality Control

The method detection limit (MDL) for the vegetation matrix was determined as described in Eaton et al. (1995). Pure reference standards were added to a subsample of vegetation at a concentration near the estimated MDL, which was based on the smallest peak that could be detected using the analytical software, and ranged from 0.5 to 3.0 pg $\cdot \mu l^{-1}$. Following sonication, seven portions of the extract were processed through the entire method and analyzed. The MDL was calculated as

$$MDL = 1.94 \cdot SD \qquad (3.1)$$

where 1.94 is the t-value in the one-sided t-distribution for six degrees of freedom at the 95% confidence level, and SD is the standard deviation of the mean for the seven replicate analyses.

To monitor potential laboratory contamination, procedural blanks were processed after every ten vegetation extractions. The laboratory at NLET processed two lab blanks while the University of Ottawa processed two lab blanks and two solvent blanks during the PUF filter extractions. All data were blank-corrected prior to analysis by subtracting the mean blank concentration from the extract concentration.

3.4 RESULTS AND DISCUSSION

The calculated MDL and the percentage of samples that showed analyte concentrations greater than the detection limit are listed in Table 3.1.A high proportion of some chemicals had concentrations in vegetation below the MDL. To retain maximum possible information for characterization of trends, means, and statistical analysis, samples with concentrations lower than the MDL were left unchanged (Stern et al. 1997). After correcting for analytes detected in blank samples, surrogate recoveries for vegetation samples were generally greater than 70% for field surrogates and better than 90% for lab surrogates. Efficiencies of the air PUF extractions were comparable to those for vegetation extractions and were considered satisfactory; therefore data were not corrected for surrogate recoveries.

3.4.1 Vegetation Concentrations

Concentrations of several analytes in vegetation decreased as temperatures rose (Table 3.2, Figure 3.1). Temperature was calculated as an average for five days prior to sampling to eliminate the effect of extreme conditions (Simonich and Hites 1994b). Semivolatile compounds with subcooled liquid vapor

pressures (P_L) between 0.01 Pa and 1.0 Pa have relatively high mobility and are volatile enough to undergo long-range transport, but still tend to condense at colder temperatures observed, for instance, in the Arctic (Wania and Mackay 1996). Thus, as temperatures fall with elevation, compounds with P_L in this range are most likely to condense and deposit onto vegetation at high altitudes. These include α-HCH (P_L= 0.1 Pa), HCB (P_L= 0.245 Pa), and β-endosulfan (P_L= 0.394 Pa), all of which had levels in vegetation that correlated inversely with temperature in this study. Heptachlor (P_L= 0.267 Pa) concentrations also showed a weak inverse relationship with temperature, although not statistically significant. Levels of some of the less volatile compounds also decreased significantly with temperature, namely methoxychlor (P_L= 0.000546 Pa), α-endosulfan (P_L= 0.008 Pa) and decachlorinated PCBs. The most prevalent PCB congeners in vegetation, those having four to six chlorine atoms, as well as the ΣPCB group, displayed a significant relationship with temperature. Several of these trends are consistent with the theory of global fractionation (Wania and Mackay 1993a) that predicts migration of SVOCs to remote, colder regions resulting in temperature-dependent cycling of such compounds between air and Earth's surfaces. Conversely, less volatile compounds accumulate close to their source and thus show no or little relationship with temperature. Activities involving the production or use of PCBs and most of the OC pesticides examined in this study have been banned or severely restricted in Canada and the U.S. Presence of these chemicals in vegetation from the Canadian Rocky Mountains thus signifies either recent sources arriving by long-range transport or chemical recycling between contaminated environmental compartments such as soil, vegetation, and water.

Thomas et al. (1984) found that various plant species from Sweden contained between two and five times lower levels of γ-HCH than α-HCH. In our study, average levels of γ-HCH were only slightly lower than those of α-HCH, most likely due to the continued application of this pesticide in surrounding, low-lying areas near the sampling region. Presence of the α-isomer is probably the result of long-range atmospheric transport from Asia, the biggest consumer of technical HCH consisting of 70% α-HCH and 15% γ-HCH (Ayres and Hellier 1998). Higher levels of α-HCH in water from higher latitudes have been reported (Jantunen and Bidleman 1998), which is consistent with our observations that levels of α-HCH are higher in plant foliage from higher elevations, providing support for the theory that this compound is progressively distilled toward colder climates.

HCB tends to remain in the atmosphere for long periods of time (Calamari et al. 1991), making it prone to long-range transport and global distillation. Furthermore, it has been shown that HCB has a high plant-membrane permeance (Kerler and Schönherr 1988) and is thus readily absorbed by vegetation. Negligible HCB concentrations in plant tissue have been observed in tropical areas, while higher levels of this compound are reported in vegetation from colder regions of the globe (Calamari et al. 1991). Similarly, a significant inverse relationship was found in this study between HCB concentrations in vegetation from the Canadian Rocky Mountains and temperature.

Concentrations of the relatively volatile heptachlor were not significantly correlated with temperature (Table 3.2). This compound is oxidized in the atmosphere to the persistent and bioaccumulative heptachlor epoxide (Bidleman et al. 1998a). However, it has been shown that heptachlor epoxide in ambient air in the southern U.S. and in the Great Lakes region originates not from atmospheric heptachlor, but primarily from epoxidation of heptachlor by soil microbes and subsequent evaporation to the air (Bidleman et al. 1998b). Heptachlor is more volatile than heptachlor epoxide (P_L= 0.00256 Pa), and was detected in nearly twice as many vegetation samples as the metabolite. Heptachlor is likely preferentially deposited to soil and vegetation at higher altitudes. In the soil, it is then converted to heptachlor epoxide, which evaporates more readily at warmer temperatures, resulting in the upward trend in heptachlor epoxide concentrations and the downward trend in heptachlor concentrations with temperature. Conversely, higher levels of heptachlor epoxide have been reported in water from higher latitudes (Jantunen and Bidleman 1998), but heptachlor epoxide is ten times more water-soluble than its parent heptachlor, and thus would have an increased tendency to accumulate in northern waters.

In this study, α-endosulfan was detected in nearly three times as many vegetation samples as β-endosulfan, and concentrations of both isomers were significantly related to temperature (Table 3.2). Similarly, Jantunen and Bidleman (1998) found that levels of both isomers in water were lower in ice-covered regions than in areas of lower latitude. This insecticide is still approved for use in Canada, the U.S., and Europe (de March et al. 1998). The most abundant form in the atmosphere is the α-isomer, and although it is resistant to photolysis in water (Burgoyne and Hites 1993), β-endosulfan is more persistent (Hoff et al. 1992a).

Reductive dechlorination of *o,p'*-DDT occurs in some plant species (Garrison et al. 2000), which may account for its limited detection in vegetation in this study compared to the metabolites of DDT (Table 3.2).

Due to the relatively low volatility of the DDT compounds and metabolites, no relationship with temperature was observed here for plant DDT concentrations, since they tend to remain close to their source of emission. This is consistent with global concentrations in vegetation (Calamari et al. 1991).

PCB congeners with fewer than four chlorine atoms tend to condense at temperatures below 0°C (Wania and Mackay 1996). Average monthly temperatures for sites in this study were above this threshold, providing conditions more favorable for the deposition of tetrachlorinated and heavier PCBs. Congeners with more than five chlorine substituents are the most toxic (Thomas et al. 1984), and these compounds were consistently detected in this study, occurring in more than half the samples analyzed.

3.4.2 Temporal Trends

Ambient temperature at each site correlated significantly with Julian day, and concentrations of several compounds in vegetation decreased throughout the season (Table 3.3, Figure 3.2), suggesting that warming effects occurring throughout the summer season favor chemical volatilization from plant foliage. However, growth of vegetation can confound field experiments examining uptake from the air by increasing the apparent exposure time, resulting in enhanced removal of compounds from the air by the plant during spring and summer when active growth is at a maximum (Thomas et al. 1998). As vegetation grows, the dilution effect would decrease apparent OC concentrations at warmer temperatures (Wagrowski and Hites 1998). Pine needles tend to grow until the late summer of the year in which they emerge (Jensen et al 1992, Ockenden et al. 1998b). While in the growth stage, plant concentrations could be a function of the growth rate or the constitution of the cuticle as opposed to atmospheric conditions (Jensen et al 1992). Although plant lipid content increased significantly throughout the summer season (Pearson's $r = 0.284$, $p<0.01$) at a rate of 3.42×10^{-5} g lipid $\cdot g^{-1}$ needle $\cdot day^{-1}$, dilution due to increased lipid content was insignificant, lowering the apparent volatilization rate by only 1.86%.

Using an independent samples t-test and an alpha level of 0.05, the analyte concentrations in vegetation in 1999 were compared to those in 2000. Concentrations of heptachlor epoxide, *p,p'*-DDT, and the pentachlorinated, heptachlorinated, and nonachlorinated PCBs were elevated in 1999 compared to 2000. Levels of HCB, heptachlor, γ-chlordane, α-chlordane, α-endosulfan, β-endosulfan, *p,p'*-DDD, *p,p'*-DDE, endrin, and the dichlorinated, trichlorinated, tetrachlorinated, hexachlorinated, and decachlorinated PCBs as well as ΣPCB were higher in 2000 than in 1999.

3.4.3 Air Concentrations

Several factors influence atmospheric concentrations of pesticides, including the time, location, and amount of source emissions, the stability and velocity of long-range air masses, and ambient temperature (Burgoyne and Hites 1993). Atmospheric concentrations that are controlled by volatilization from terrestrial and aquatic surfaces should be strongly related to temperature (Hoff et al. 1992b). Octachlorinated PCBs and *p,p'*-DDT were the only compounds whose concentrations in air were significantly correlated with temperature in this study (Table 3.4). A significant inverse relationship was observed for HCB levels in air, when warmer temperatures are expected to favor higher air concentrations due to increased volatilization from terrestrial surfaces. A flattening of the slope in the relationship between air concentrations and temperature indicates a dominant contribution from long-range transport to atmospheric contamination, whereas a steep slope represents local air-surface exchange (Hoff et al. 1998). Observations from this study indicate that POP concentrations in Canadian Rocky Mountain air are not governed by temperature-dependent volatilization from environmental compartments, but may be due to recent local sources or inputs from long-range transport.

The most prevalent OC compound in arctic air is HCH, while HCB is a fairly ubiquitous compound in the northern atmosphere and shows little spatial variability (Patton et al. 1991). Similarly, the most ubiquitous compounds in air from this study were α-HCH and HCB. Generally, temperature often explains only a small portion of the variability in α-HCH air concentrations, whereas levels of γ-HCH and PCBs tend to be more strongly correlated with temperature (Wania et al. 1998). Long-range transport contributes more significantly to air concentrations of α-HCH than local revolatilization from vegetation and soil because it remains in air for long periods of time. During long-range transport, degradation of gas phase compounds can occur either by photolysis or through reactions with hydroxyl radicals. Hydroxyl radicals are normally diminished at colder temperatures (Bailey et al. 2000), which would lead to lower degradation rates at higher altitudes. However, high altitudes tend to receive higher levels of ultraviolet radiation, which may promote both photolysis and hydroxyl radical formation.

Concentrations of PCBs in arctic air are dominated by the more volatile congeners that are more prone to migration to northern latitudes than heavier PCBs (Ockenden et al. 1998c, Patton et al. 1991). Levels of lower chlorinated PCBs generally relate inversely to temperature, while levels of heavier PCBs show positive correlations (Stern et al. 1997, Agrell et al. 1999). Low correlation coefficients imply that long-range

transport is influencing concentrations in arctic air (Hung et al. 2001a). The more volatile trichlorinated and tetrachlorinated PCBs dominated the PCB profile in air from the Canadian Rocky Mountains and all homologue groups showed low coefficients of determination for the regression of air concentration versus temperature (Table 3.4), indicating that new sources of PCBs may continue to arrive in the area.

Temperature-dependent fractionation of PCBs is enhanced by faster degradation of lower chlorinated congeners via hydroxyl radicals (Anderson and Hites 1996). Again, these radicals are less abundant at colder temperatures (Haugen et al. 1998), which would hinder PCB fractionation in air at colder, higher altitudes. Relative contributions of each homologue group to the total PCB concentration in air samples collected from the Canadian Rocky Mountains remained constant with temperature, indicating that fractionation of these compounds in air was not occurring.

Since PCB production has been banned for several decades in North America, atmospheric PCB concentrations result from recycling between environmental compartments rather than from fresh emissions (Ockenden et al. 1998c). However, concentrations of only the octachlorinated homologue group were related to temperature in this study (Table 3.4). Concentrations of PCBs in U.K. air are declining over the past 20 years (Anderson and Hites 1996), while levels in arctic air have not decreased over the past five years of monitoring (Hung et al. 2001a), indicating that the arctic may still be acting as a sink for persistent pollutants volatilizing from warmer, lower latitudes. It is possible that the Canadian Rocky Mountains are also acting as a continuous sink for these compounds, accounting for the lack of temperature dependence in air concentrations of PCBs as they continue to arrive in the area via long-range transport following evaporation from distant, warmer sites. A gradual migration northward of PCBs has been shown in sediment cores, resulting from delayed deposition in lake sediments in the far north (Blais and Muir 2001).

3.4.4 Vegetation-Air Partitioning

When chemical partitioning between two phases reaches a state of equilibrium, a partition coefficient can be calculated to assess the relative importance of each phase in the fate of that chemical. The pseudo partition coefficient between air and vegetation, C_V/C_A, was calculated as the ratio of the plant concentration (C_V) to the atmospheric concentration (C_A). The true partition coefficient, K_{VA}, cannot be estimated since concentrations in the two phases were measured in a changing environment under non-equilibrium conditions

(Wania and Mackay 1993a). The pseudo partition coefficients of a few compounds were correlated with temperature (Table 3.5).

The concentration ratio also correlated with log K_{OA}. The correlation between temperature-corrected log K_{OA} and the log C_V/C_A for all compounds excluding heptachlor, in the entire sample set (n=545) was significant at the 99.9% confidence level with a slope of 0.489 and R^2=0.217 (Figure 3.3). Heptachlor has a high Henry's law constant (H), which made its K_{OA} relatively low compared to its concentration ratio. The K_{OA} values were calculated and corrected for temperature at the time of sampling using the following equation from Harner et al. (2000):

$$K_{OA} = K_{OW} \cdot R \cdot T \cdot H^{-1} \qquad (3.2)$$

where K_{OW} is the octanol-water partition coefficient, R is the universal gas constant (Pa $\cdot m^3 \cdot mol^{-1} \cdot K^{-1}$), T is temperature (K), and H is the Henry's law constant (Pa $\cdot m^3 \cdot mol^{-1}$). When the plot of the log concentration ratio versus log K_{OA} was constructed for each species, both slopes were similar to the one obtained when all samples were analyzed together. This indicates that there is little difference between the species in terms of vegetation-air partitioning in this area.

A straight line for the plot of the log K_{VA} versus log K_{OA} indicates that partitioning has reached equilibrium where fugacities between the two phases are equal (Mackay and Paterson 1981, McLachlan et al. 1995), and that lipophilic components of the plant are governing chemical uptake (Ockenden et al. 1998b). However, given the variability in air concentrations and fluctuations in temperature, it is unlikely that a stable partitioning equilibrium is ever achieved between vegetation and air (Morosini et al. 1993), particularly in this study. Slopes different from unity imply either that plant components other than lipid may be responsible for chemical partitioning between air and vegetation, or that octanol does not act as an adequate surrogate for plant lipids. Slopes greater than unity suggest that plant compartments responsible for chemical storage have a higher lipophilic nature than octanol (Kömp and McLachlan 1997b). Slopes less than one have been reported in many studies (Thomas et al. 1998, Ockenden et al. 1998b, Kömp and McLachlan 1997a, Kömp and McLachlan 1997b), whereas Hiatt (1999) reported a slope near one. Furthermore, air concentrations of polycyclic aromatic hydrocarbons (PAHs) calculated from K_{OA} tend to underestimate actual atmospheric levels (Tremolada et al. 1996), indicating that octanol is not necessarily a good predictor of the chemical accumulation behavior in vegetation. The slope of 0.489 observed here suggests either that equilibrium has not

been achieved between air and vegetation or that octanol is not representative of the plant storage compartment.

Values of K_{VA} are very sensitive to temperature fluctuations and can vary highly under environmental conditions. However, in non-equilibrated systems, plant pollutant levels will not be affected by changes in K_{VA} caused by variable temperature, unless the compound is highly volatile (Kömp and McLachlan 1997a), due to the enormous storage capacity of vegetation for compounds with high K_{OA}, which explains our observations (Table 3.5). Compounds with high K_{OA} values shift from a state of equilibrium to non-equilibrium conditions at higher temperatures than do compounds with low K_{OA} (McLachlan et al. 1995). In laboratory experiments, vegetation has reached equilibrium with PCBs in air after ten days to two weeks of exposure (Thomas et al. 1998, Tolls and McLachlan 1994) or after as little as 30 to 70 seconds (Kömp and McLachlan 1997a). However, the time to equilibrium likely differs among compounds and plant species, with longer equilibration times for less volatile compounds (Weiss 2000). In the field, it was shown that equilibrium was not reached between air and lipid-filled semipermeable membrane devices within three months (Ockenden et al. 1998a), and equilibrium between air and vegetation was not reached within three weeks of exposure to SVOCs (Bakker et al. 1999). Compared to a deciduous forest, it is expected that more compounds would reach equilibrium in a coniferous forest due to a longer exposure time to the air, but lower gaseous deposition velocities to coniferous vegetation oppose this effect (Wania and Mackay 1993a). In fact, conifer needles may never attain equilibrium with the air in their lifetime due to air-side resistance (Kylin 1996, Ockenden et al. 1998b).

Compounds whose equilibrium K_{VA} values are highly temperature dependent have high enthalpies of phase change between the two compartments involved in the transfer process. Variations in the enthalpy of phase change between vegetation and air affect the plant storage capacity (Kömp and McLachlan 1997b). Growth rates and atmospheric levels may also compound the temperature-dependent partitioning between vegetation and air (Ockenden et al. 1998b).

Several researchers have observed inverse relationships between temperature and K_{VA} for OC compounds in the laboratory (Kömp and McLachlan 1997b) and in the field (Ockenden et al. 1998b, Wagrowski and Hites 1998, Simonich and Hites 1994a). Results from this study show the opposite trend in significant correlations between log C_V/C_A and temperature (Table 3.5), possibly indicating a lack of equilibrium between the two phases. The additional lack of temperature dependence in atmospheric

concentrations (Table 3.4) suggests that air is acting as a continuous contaminant source to this area. Subsequent deposition onto vegetation, a significant sink, is favored at colder temperatures resulting in elevated plant concentrations.

With decreasing temperatures, this slope increases due to the strong temperature-dependence of K_{VA}, particularly for heavier compounds (Kömp and McLachlan 1997a, 1997b). At low K_{OA} values, partitioning behavior begins to vary widely among species because concentrations in plants exposed to the same air masses are controlled by K_{VA}. Accumulation of compounds with higher K_{OA} values in plants is limited by the amount of air that contacts the plant because of the plant's high storage capacity for these chemicals (Kömp and McLachlan 1997a). This is further evidence for the inconsistent behavior of chemicals in the plant-air partitioning process.

Böhme et al. (1999) found considerable variability in K_{VA} among species for OC compounds that undergo equilibrium partitioning while little variation was observed for those compounds that tend to undergo kinetically limited or particle bound deposition. This indicates that interspecies variability in the plant uptake of SVOCs is due to properties of the chemical as opposed to plant characteristics. Furthermore, the quality, not the quantity, of the plant storage compartment seems to be an important factor in the uptake of SVOCs by plants, because no relationship was observed between K_{VA} and plant lipid content (Böhme et al. 1999).

3.4.5 Species Differences

Regression analysis revealed that neither lipid content nor water content of the vegetation samples correlated significantly with elevation. One-way analyses of variance (ANOVA) with three and 226 degrees of freedom for between-groups and within-groups analysis, respectively, were performed to compare lipid content, water content, and analyte concentrations among the four species of vegetation. Results showed that there were significant differences for the factor of species with respect to lipid content ($F = 3.775$) and concentrations of α-HCH ($F = 7.605$), γ-HCH ($F = 5.611$), and dieldrin ($F = 2.688$) when expressed on a lipid-weight basis. Tukey post-hoc analysis showed that whitebark pine contains a higher proportion of lipid than lodgepole pine. Furthermore, levels of α-HCH were higher in Engelmann spruce than in the other three species; γ-HCH concentrations were higher in white spruce than in Engelmann spruce and lodgepole pine; and samples of Engelmann spruce showed higher levels of dieldrin than did lodgepole pine. However, caution must be exercised when interpreting differences in analyte concentrations among species since the group sizes are

not equal, and the assumption of equality of variances was not met for many parameters based on the Levene test. Furthermore, the distribution of species collected was not uniform across all sample sites and local events may be confounding species differences.

Higher proportions of lipid did not result in consistently elevated levels of OCs or PCBs, indicating that other factors such as surface area may also be important in the uptake of airborne chemicals by plants in this area. Higher surface roughness and a greater density of leaf hairs enhance adsorption of airborne chemicals to plant foliage (Bakker et al. 1999). Tree foliage generally has a higher proportion of lipid than grass (Meharg et al. 1998), making it more able to adsorb and retain lipophilic compounds. Species of spruce exhibiting different behavior in the uptake of DDE from the air differed only slightly in their fugacity capacities due to different lipid contents (Hauk et al. 1994). A ten-fold difference in PCB concentrations among 18 species of vegetation has been reported (Buckley 1982). Conversely, similar PAH concentrations were observed in several grass species due to similar storage compartment characteristics (Smith et al. 2001), as have levels of chlorinated hydrocarbons in two pine species (Gaggi and Bacci 1985).

Vegetation collected in this study consisted of newly emerged needles; thus, concentrations of OC pesticides and PCBs in plant foliage in this study reflected recent atmospheric deposition, allowing interpretation of concurrent air samples and eliminating the confounding factors of age and exposure to particular air masses. Younger, more lipid-rich pine samples have shown higher concentrations of lighter congeners than lichen, which has a larger surface area (Ockenden et al. 1998b). The longer life of lichen allowed it to accumulate heavier congeners after the lighter compounds had achieved equilibrium with air.

Species differences in lipid contents, surface areas, and growth rates result in different accumulation behavior, which can make the estimation of atmospheric concentrations from plant concentrations difficult (Ockenden et al. 1998b). When investigating the potential for vegetation to adsorb and retain airborne lipophilic chemicals, it may be more prudent to examine vegetation characteristics on a larger scale, such as swards of grass species or forests of coniferous trees, as opposed to the individual morphology of the plant (Smith et al. 2001). This will provide a broader understanding of the ability of a certain geographical region to retain SVOCs.

3.4.6 Diurnal Cycling

Lipid-based analyte concentrations in vegetation samples collected diurnally on three occasions at Bow Lake were analyzed using paired-samples t-tests that revealed little differences in analyte concentrations between samples collected in the early morning and those collected in the afternoon. The average afternoon temperature of 16.6°C was significantly higher than the average morning temperature of 4°C ($p<0.001$). However, only levels of decachlorinated PCBs and ΣPCB showed differences between the two sampling times, with afternoon concentrations being higher than levels detected in early-morning samples.

A temperature-dependent diurnal cycling for POP concentrations in England air was stronger for banned compounds than for those chemicals currently used, with afternoon levels being higher than early morning levels (Lee et al. 2000). Hung et al. (2001b) observed diurnal cycling of PCBs in grass as a result of rapid exchange between the air and the surface storage compartment of the vegetation. Conifer needles, however, contain more lipid and achieve equilibrium with the air much slower than grasses (Kylin 1996). The lack of a diurnal trend in this study is likely due to the slow kinetics in plant uptake of airborne pollutants, which would make the eight-hour time difference between sampling occasions too small to observe significant volatilization. For instance, Hiatt (1999) estimated that vegetation would continue to accumulate volatile chemical from the air for two hours after it was introduced into the atmosphere. Several researchers have also noted the nearly unlimited capacity that vegetation has, particularly coniferous foliage, for lipophilic compounds (Thomas et al. 1984, Kylin et al. 1994, Tolls and McLachlan 1994).

3.4.7 Longitudinal Transect Trends

Temperature ($R^2 = 0.387$, $p<0.001$) and concentrations of several compounds were significantly correlated with longitude, indicating that temperatures are generally warmer and concentrations higher in the valley toward the west compared to the Rocky Mountains (Table 3.6). Levels of α-HCH were fairly constant along the longitudinal transect. Conversely, concentrations of γ-HCH decreased from the Rocky Mountains to the western plains due to the increased use of this compound in Alberta and Saskatchewan to the east of the Rocky Mountains, compared to the western province of British Columbia (David Donald, personal communication). Blais et al. (1998) showed the opposite trend in PCB concentrations in snowpacks. These trends likely arise from the scavenging of certain compounds, such as heptachlor epoxide, endosulfan, and DDT, by vegetation along the west coast from trans-Pacific air masses before the air masses reach the colder

Rocky Mountains (Wilkening et al. 2000). This explanation was supported in Chapter 2.0 by analyzing five-day back trajectories for the sample area.

3.4.8 Effects of Species Differences and Detection Limits on Observed Trends

Further analysis was performed to confirm that species differences and varying detection limits among analytes were not affecting observed trends in vegetation concentrations of POPs in the Canadian Rocky Mountains. The standard error (SE) for the regression of analyte concentration in vegetation against temperature for the 16 OC pesticides and the nine homologue groups for PCBs were compared for two groups, one representing the species of pine, the other representing spruce. A significant correlation (Pearson's $r = 0.477$, $p<0.05$) was observed between SE for each species (Figure 3.4), indicating that each species contributes equally to the error associated with observed trends. Thus, species differences do not affect the observed temperature trends in analyte concentrations on a lipid-weight basis, and the grouping of all species in the analysis is acceptable.

The importance of both sample size and MDL on the temperature-dependence of plant concentrations was assessed by correlating the MDL with the SE for the regression of analyte concentration versus temperature (Figure 3.5). This correlation showed no relationship (Pearson's $r = 0.085$). Furthermore, smaller sample sizes are expected for compounds with larger detection limits, but the data show the opposite (Figure 3.5), with sample size being significantly correlated with MDL (Pearson's $r = 0.407$, $p<0.05$). Thus, the observed trends are a product of environmental forcing and are not a result of larger sample sizes associated with lower MDLs.

3.5 CONCLUSIONS

Results from this study suggest that lower temperatures encountered in high altitude areas are favoring accumulation of certain SVOCs in terrestrial vegetation. Air concentrations and diurnal vegetation samples suggest that the reason for this enhanced accumulation in elevated areas is increased atmospheric deposition from continual sources in contaminated air masses and not from local revolatilization from vegetation, soil, and water. Examination of longitudinal trends indicate that western vegetation in British Columbia may be acting as a filter for airborne lipophilic contaminants arriving via air masses traveling over the Pacific Ocean before reaching the Rocky Mountains. Air masses originating in Eurasia can travel to the

Pacific Ocean basin and eventually reach North America on mid-latitude westerly winds within five to ten days (Wilkening et al. 2000).

The fact that POP concentrations in vegetation decreased over the summer is proof that volatilization from plant material is occurring. However, air concentrations were not temperature-dependent, indicating that levels of these compounds in air are not governed by the local revolatilization from vegetation. Therefore, sources from recent emissions or from evaporation from soil and vegetation in warmer, distant areas arriving to the area via long-range atmospheric transport influence POP accumulation in vegetation at higher altitudes in the Canadian Rocky Mountains.

Table 3.1 Analyte method detection limits.

The method detection limit (MDL) was calculated from replicate analyses of seven portions of a single extraction, as described in the text, and is presented as pg $\cdot g^{-1}$ needle dry weight. The percentage of samples that contained compounds higher than the MDL are presented for the mountain, longitudinal transect, and diurnal samples.

	MDL (pg $\cdot g^{-1}$ dry weight)	%		
		Mountain	Transect	Diurnal
OC Compound				
α-HCH	31.64	94.8	80.0	95.8
γ-HCH	10.61	97.0	60.0	100.0
HCB	9.24	96.1	85.0	100.0
Heptachlor	7.30	45.2	0.0	0.0
Heptachlor Epoxide	222.04	22.2	75.0	41.7
Dieldrin	54.52	13.9	20.0	8.3
Endrin	17.15	20.9	10.0	4.2
α-Chlordane	26.38	18.3	25.0	41.7
γ-Chlordane	300.55	3.0	10.0	0.0
α-Endosulfan	172.12	40.4	60.0	8.3
β-Endosulfan	93.92	23.5	80.0	8.3
o,p'-DDT	59.47	5.2	10.0	4.2
p,p'-DDT	93.43	6.1	65.0	16.7
p,p'-DDE	32.64	33.5	70.0	4.2
p,p'-DDD	200.96	0.0	0.0	0.0
Methoxychlor	390.34	10.0	0.0	0.0
PCB Homologue				
Dichlorinated	378.06	2.2	5.0	0.0
Trichlorinated	758.15	5.2	10.0	0.0
Tetrachlorinated	887.02	55.7	85.0	29.2
Pentachlorinated	1315.15	3.9	20.0	0.0
Hexachlorinated	1097.10	9.1	40.0	0.0
Heptachlorinated	1605.16	2.6	5.0	0.0
Octachlorinated	785.02	4.8	0.0	0.0
Nonachlorinated	117.74	3.9	0.0	0.0
Decachlorinated	39.09	11.3	10.0	29.2
ΣPCB	6982.50	8.3	20.0	0.0

Table 3.2 Temperature-dependence of POP concentrations in vegetation.

Parameters are presented for the regression of log analyte concentration in vegetation (ng $\cdot g^{-1}$ lipid) against temperature (°C). Slope and intercept are for the line of regression, R^2 is the coefficient of determination, SE is the standard error of the estimate associated with the coefficient of determination, and df represents degrees of freedom. Temperature was taken as the average for the five days prior to sampling. * ANOVA revealed that the slope was significantly different from zero ($p < 0.05$); ** $p < 0.01$; *** $p < 0.001$.

OC Compound	Slope	Intercept	R^2	SE	df
α-HCH	-2.12×10^{-2}***	1.24	0.089	0.317	228
γ-HCH	6.87×10^{-3}	0.87	0.007	0.373	222
HCB	-2.14×10^{-2}*	1.22	0.028	0.591	223
Methoxychlor	-5.01×10^{-2}*	2.40	0.188	0.544	24
Heptachlor	-3.32×10^{-3}	1.21	0.002	0.395	103
Heptachlor Epoxide	5.62×10^{-3}	1.68	0.001	0.628	65
α-Chlordane	-2.53×10^{-2}	1.25	0.042	0.596	49
γ-Chlordane	6.28×10^{-2}	0.83	0.159	0.712	18
α-Endosulfan	-2.65×10^{-2}**	1.50	0.049	0.553	143
β-Endosulfan	-4.29×10^{-2}**	2.18	0.177	0.440	55
Endrin	4.50×10^{-3}	1.35	0.001	0.544	49
Dieldrin	3.18×10^{-3}	1.13	0.001	0.353	37
p,p'-DDD	2.70×10^{-3}	0.92	0.004	0.251	10
p,p'-DDE	-9.22×10^{-3}	0.80	0.024	0.270	110
o,p'-DDT	-1.31×10^{-2}	0.98	0.010	0.564	22
p,p'-DDT	-1.58×10^{-2}	0.93	0.021	0.388	25
PCB Homologue					
Dichlorinated	-8.46×10^{-3}	1.67	0.005	0.674	16
Trichlorinated	-1.25×10^{-2}	1.55	0.021	0.433	103
Tetrachlorinated	-1.97×10^{-2}**	2.10	0.033	0.499	225
Pentachlorinated	-1.51×10^{-2}*	1.40	0.021	0.480	202
Hexachlorinated	-1.62×10^{-2}*	1.90	0.026	0.486	172
Heptachlorinated	-3.91×10^{-3}	1.18	0.002	0.425	158
Octachlorinated	-7.71×10^{-3}	1.20	0.006	0.472	157
Nonachlorinated	-3.31×10^{-2}	1.40	0.227	0.294	10
Decachlorinated	-4.80×10^{-2}*	1.30	0.157	0.425	32
ΣPCB	-1.75×10^{-2}**	2.47	0.036	0.425	229

Table 3.3 Temporal changes in POP concentrations in vegetation.

Parameters are presented for the regression of log analyte concentration in vegetation (ng $\cdot g^{-1}$ lipid) against Julian day. Slope and intercept are for the line of regression, R^2 is the coefficient of determination, SE is the standard error of the estimate associated with the coefficient of determination, and df represents the degrees of freedom. * ANOVA revealed that the slope was significantly different from zero ($p < 0.05$); ** $p < 0.01$; *** $p < 0.001$.

OC Compound	Slope	Intercept	R^2	SE	df
α-HCH	-1.79×10^{-3}**	1.38	0.036	0.326	228
γ-HCH	-7.05×10^{-4}	1.05	0.004	0.373	222
HCB	-4.60×10^{-3}***	1.87	0.073	0.577	223
Methoxychlor	-4.72×10^{-3}	2.85	0.060	0.586	24
Heptachlor	2.18×10^{-3}*	0.81	0.044	0.387	103
Heptachlor Epoxide	1.31×10^{-3}	1.49	0.003	0.627	65
α-Chlordane	-6.95×10^{-3}**	2.24	0.175	0.553	49
γ-Chlordane	-9.89×10^{-4}	1.39	0.002	0.776	18
α-Endosulfan	-5.76×10^{-3}***	2.30	0.123	0.531	143
β-Endosulfan	-5.66×10^{-3}**	2.80	0.195	0.435	55
Endrin	2.23×10^{-3}	0.99	0.021	0.539	49
Dieldrin	2.76×10^{-4}	1.10	0.001	0.354	37
p,p'-DDD	-5.84×10^{-4}	1.04	0.013	0.249	10
p,p'-DDE	-1.02×10^{-3}	0.90	0.019	0.271	110
o,p'-DDT	-7.19×10^{-3}*	2.09	0.195	0.509	22
p,p'-DDT	-3.34×10^{-3}	1.441	0.031	0.385	25
PCB Homologue					
Dichlorinated	-4.51×10^{-3}	2.32	0.071	0.651	16
Trichlorinated	-7.46×10^{-4}	1.57	0.004	0.436	103
Tetrachlorinated	-2.50×10^{-3}**	2.38	0.030	0.499	225
Pentachlorinated	-1.34×10^{-3}	1.51	0.009	0.483	202
Hexachlorinated	-5.44×10^{-3}***	2.71	0.165	0.450	172
Heptachlorinated	-1.07×10^{-3}	1.34	0.007	0.423	158
Octachlorinated	-2.25×10^{-3}*	1.53	0.029	0.466	157
Nonachlorinated	-3.86×10^{-3}	1.82	0.139	0.310	10
Decachlorinated	-4.64×10^{-3}*	1.67	0.133	0.431	32
ΣPCB	-4.05×10^{-3}***	3.05	0.109	0.408	229

Table 3.4 Temperature-dependence of POP concentrations in air.

Parameters are presented for the regression of log analyte concentration in air (pg $\cdot m^{-3}$) against temperature (°C). Slope and intercept are for the line of regression, R^2 is the coefficient of determination, SE is the standard error of the estimate associated with the coefficient of determination, and df represents the degrees of freedom. Temperature was taken as the average for the five days prior to sampling. * ANOVA revealed that the slope was significantly different from zero ($p < 0.05$).

OC Compound	Slope	Intercept	R^2	SE	df
α-HCH	1.06×10^{-2}	1.05	0.011	0.525	22
γ-HCH	2.16×10^{-2}	0.33	0.020	0.830	17
HCB	-2.42×10^{-2}*	1.43	0.207	0.253	22
Methoxychlor	2.13×10^{-2}	-0.17	0.000	0.847	20
Heptachlor	-4.68×10^{-2}	-0.27	0.137	0.469	10
Heptachlor Epoxide	-6.05×10^{-3}	0.17	0.008	0.367	16
α-Chlordane	9.01×10^{-2}	0.18	0.015	0.498	10
γ-Chlordane	1.08×10^{-2}	-0.13	0.011	0.582	14
α-Endosulfan	5.82×10^{-3}	1.38	0.006	0.421	20
β-Endosulfan	3.24×10^{-2}	-0.40	0.042	0.825	20
Endrin	-1.33×10^{-2}	-0.56	0.029	0.411	10
Dieldrin	8.17×10^{-4}	0.04	0.000	0.411	21
p,p'-DDD	1.99×10^{-2}	-0.57	0.024	0.782	16
p,p'-DDE	3.40×10^{-2}	-0.45	0.137	0.445	17
o,p'-DDT	1.48×10^{-2}	-0.21	0.015	0.632	22
p,p'-DDT	3.46×10^{-2}*	-0.18	0.278	0.312	17
PCB Homologue					
Monochlorinated	8.11×10^{-3}	0.67	0.004	0.601	18
Dichlorinated	7.70×10^{-3}	0.86	0.005	0.599	22
Trichlorinated	1.78×10^{-2}	0.92	0.021	0.660	22
Tetrachlorinated	-3.01×10^{-3}	1.34	0.001	0.566	22
Pentachlorinated	-8.19×10^{-3}	0.85	0.003	0.865	22
Hexachlorinated	4.28×10^{-3}	0.78	0.002	0.568	22
Heptachlorinated	2.97×10^{-2}	0.28	0.051	0.689	22
Octachlorinated	5.24×10^{-2}*	-1.02	0.176	0.586	21
Nonachlorinated	-2.91×10^{-2}	-1.51	0.076	0.648	5
ΣPCB	3.21×10^{-3}	1.85	0.001	0.567	22

Table 3.5 Temperature-dependence of the vegetation-air partition coefficient.

Parameters are presented for the regression of log pseudo partition coefficient between vegetation and air, C_V/C_A ($m^3 \cdot g^{-1} \cdot$ lipid) against temperature (°C). Slope and intercept are for the line of regression, R^2 is the coefficient of determination, SE is the standard error of the estimate associated with the coefficient of determination, and df represents the degrees of freedom. Temperature was taken as the average for the five days prior to sampling. * ANOVA revealed that the slope was significantly different from zero ($p < 0.05$); ** $p < 0.01$.

OC Compound	Slope	Intercept	R^2	SE	df
α-HCH	2.78×10^{-2}	2.56	0.031	0.585	77
γ-HCH	5.36×10^{-2}	2.69	0.057	0.753	61
HCB	2.42×10^{-2}	2.53	0.034	0.490	76
Methoxychlor	1.15×10^{-1}	3.96	0.294	0.954	4
Heptachlor	7.54×10^{-2}*	4.00	0.254	0.560	20
Heptachlor Epoxide	-4.64×10^{-2}	5.25	0.093	0.502	17
α-Chlordane	4.73×10^{-2}	3.41	0.147	0.641	5
α-Endosulfan	7.03×10^{-2}**	2.09	0.246	0.462	39
β-Endosulfan	1.04×10^{-2}	4.68	0.002	0.839	15
Endrin	2.86×10^{-2}	4.44	0.001	0.836	4
Dieldrin	3.85×10^{-2}	3.84	0.081	0.545	20
p,p'-DDE	1.16×10^{-1}*	2.34	0.304	0.653	17
PCB Homologue					
Dichlorinated	5.00×10^{-2}	2.69	0.190	0.570	5
Trichlorinated	1.87×10^{-2}	2.49	0.015	0.603	38
Tetrachlorinated	-8.95×10^{-3}	3.61	0.005	0.500	76
Pentachlorinated	-5.25×10^{-2}	3.90	0.042	0.936	65
Hexachlorinated	2.60×10^{-3}	3.53	0.000	0.562	53
Heptachlorinated	-4.17×10^{-3}	3.55	0.001	0.643	47
Octachlorinated	-4.54×10^{-3}	4.38	0.001	0.682	47
ΣPCB	-1.89×10^{-3}	3.36	0.000	0.484	77

Table 3.6 Longitudinal trends in POP concentrations in vegetation.

Parameters are presented for the regression of log analyte concentration in vegetation (ng $\cdot g^{-1}$ $\cdot$lipid) against longitude (°W). Slope and intercept are for the line of regression, R^2 is the coefficient of determination, SE is the standard error of the estimate associated with the coefficient of determination, and df represents the degrees of freedom. Temperature was taken as the average for the five days prior to sampling. * ANOVA revealed that the slope was significantly different from zero ($p < 0.05$); ** $p < 0.01$; *** $p < 0.001$.

OC Compound	Slope	Intercept	R^2	SE	df
α-HCH	4.27×10^{-3}	0.65	0.001	0.350	40
γ-HCH	-1.85×10^{-2}	3.05	0.007	0.398	34
HCB	-9.43×10^{-2}*	12.42	0.130	0.466	40
Heptachlor Epoxide	8.15×10^{-2}	-7.30	0.034	0.554	15
α-Chlordane	2.23×10^{-1}*	-24.70	0.616	0.487	8
α-Endosulfan	1.40×10^{-1}**	-14.59	0.350	0.377	29
β-Endosulfan	8.12×10^{-2}**	-7.32	0.272	0.257	25
Endrin	1.12×10^{-1}	-11.26	0.106	0.407	13
Dieldrin	3.87×10^{-2}	-3.39	0.107	0.224	6
p,p'-DDE	2.32×10^{-1}***	-26.12	0.651	0.337	31
p,p'-DDT	2.87×10^{-1}**	-32.43	0.662	0.174	12
PCB Homologue					
Dichlorinated	1.86×10^{-1}	-20.56	0.353	0.369	10
Trichlorinated	9.42×10^{-2}*	-9.54	0.170	0.388	33
Tetrachlorinated	8.66×10^{-2}*	-7.84	0.136	0.417	41
Pentachlorinated	2.90×10^{-1}***	-32.50	0.567	0.480	35
Hexachlorinated	1.06×10^{-1}**	-10.32	0.255	0.347	41
Heptachlorinated	1.68×10^{-1}**	-18.42	0.369	0.445	26
Octachlorinated	7.18×10^{-2}	-7.13	0.123	0.356	26
Decachlorinated	6.73×10^{-2}	-6.99	0.054	0.532	7
ΣPCB	1.26×10^{-1}***	-12.03	0.431	0.276	41

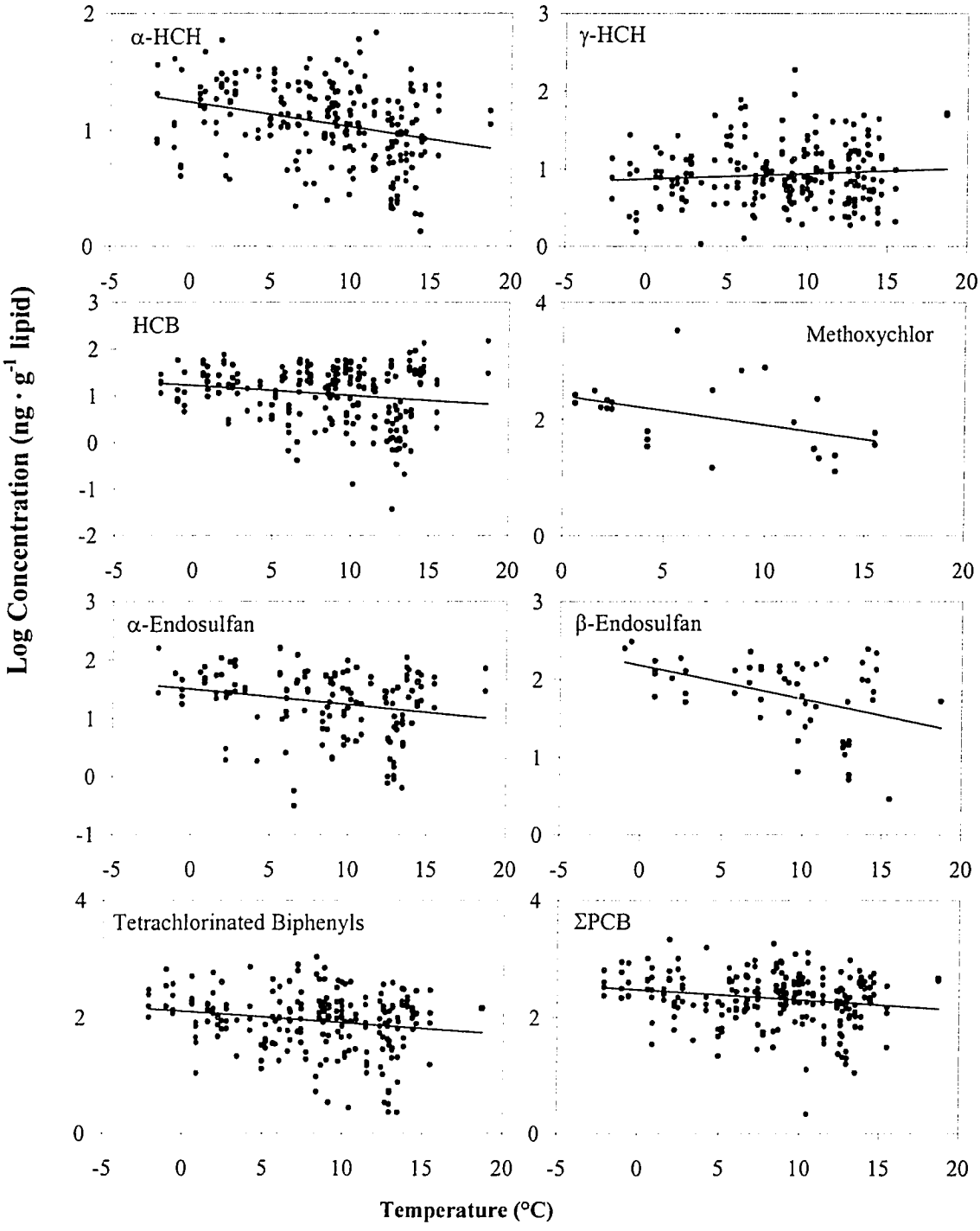


Figure 3.1 Temperature-dependence of selected OC compounds in vegetation.

The line of best fit is drawn for the relationship between log analyte concentration (ng · g^{-1} lipid) and temperature (°C).

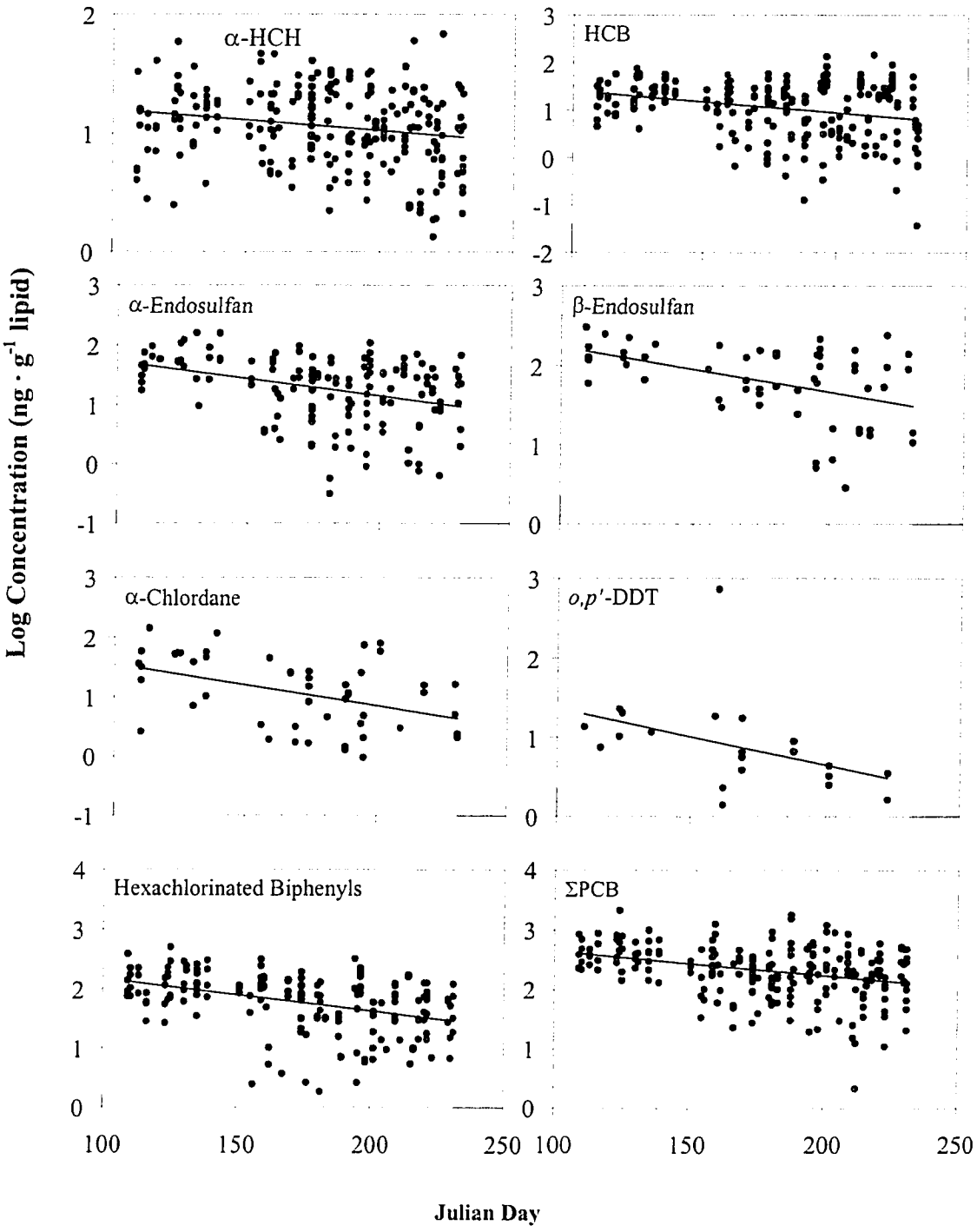


Figure 3.2 Seasonal changes for selected OC compounds in vegetation.

The line of best fit is drawn for the relationship between log analyte concentration (ng $\cdot g^{-1}$ lipid) and Julian day, representing the months of May to September.

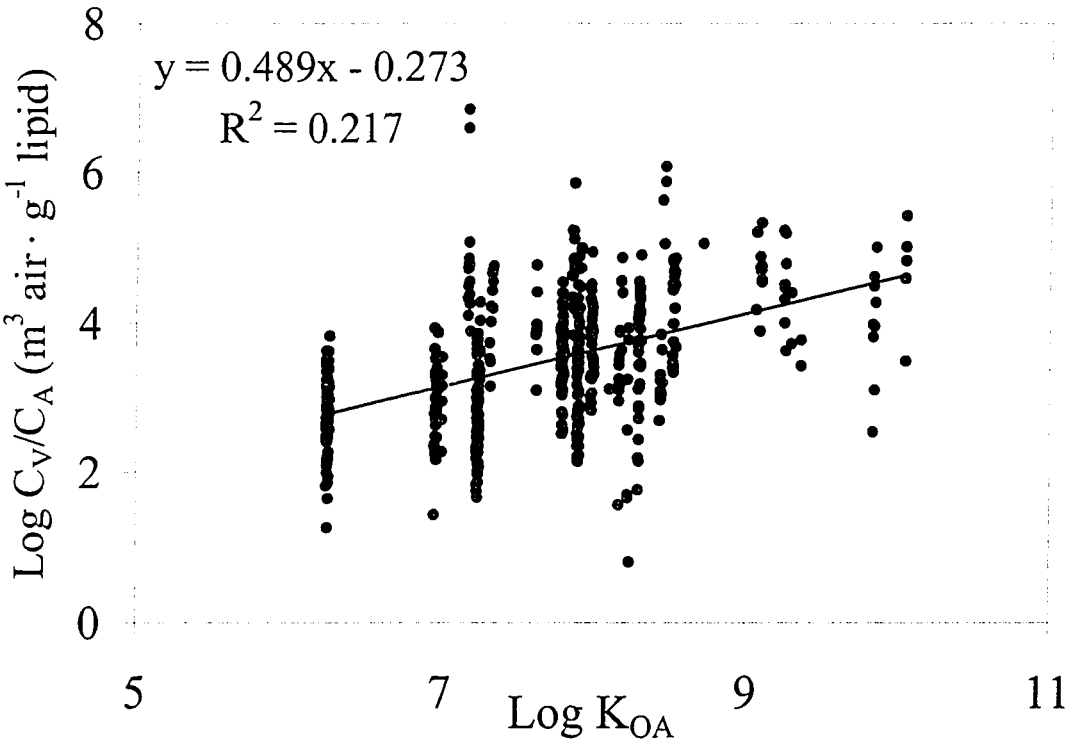


Figure 3.3 Relationship between the vegetation-air partition coefficient and K_{OA}.

The line of best fit is drawn for the correlation between the log concentration ratio, C_V/C_A (m^3 air $\cdot g^{-1}$ lipid), and the log octanol-air partition coefficient, K_{OA}, corrected for sampling temperature from the equation $K_{OA} = K_{OW} \cdot R \cdot T \cdot H^{-1}$ (Harner et al. 2000)

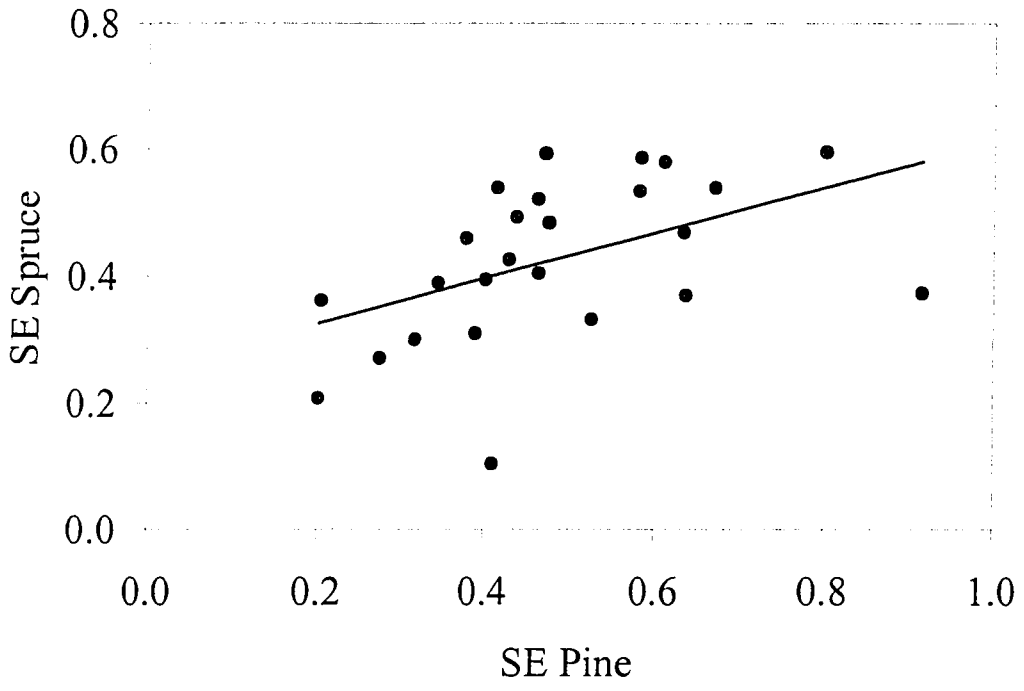


Figure 3.4 Effect of species differences on temperature trends.

Correlation between the standard errors associated with the coefficient of determination (SE) for the regression of analyte concentration in vegetation versus temperature for species of spruce and pine.

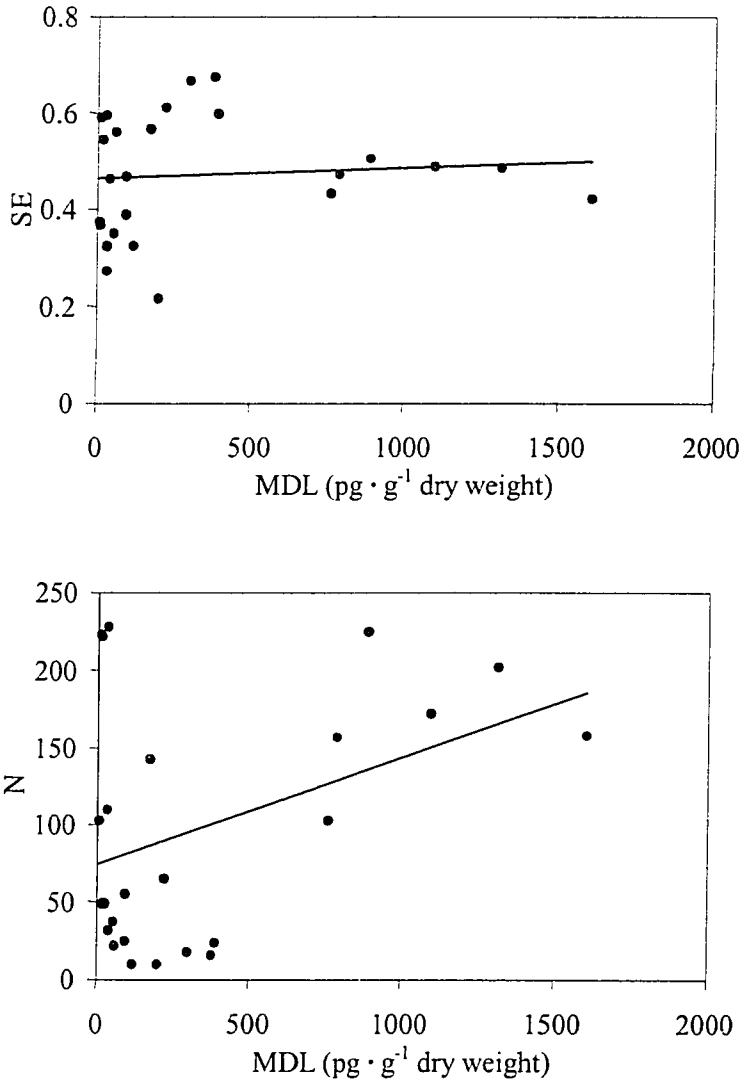


Figure 3.5 Effect of MDL on sample size and the observed tmperature trends.

The standard error associated with the coefficient of determination (SE) for the regressions of analyte concentration in vegetation versus temperature, and the sample size (N) for these regressions, are plotted against the method detection limit, MDL (pg $\cdot g^{-1}$ dry weight).

4.0 INFLUENCE OF ENVIRONMENTAL AND PHYSICAL FACTORS ON THE CONTAMINATION OF VEGETATION FROM THE CANADIAN ROCKY MOUNTAINS

4.1 ABSTRACT

Several factors influence the chemical uptake by vegetation. Multivariate analysis was performed on data, including organochlorine pollutant concentrations in vegetation and meteorological information from the Canadian Rocky Mountains, to describe the relationship between environmental conditions and chemical accumulation in plants in this region. Principal component analysis reduced the number of independent variables from twelve to five, and the number of dependent variables from 26 to nine. The set of independent variables was characterized by high loadings for precipitation, relative humidity, site elevation, and pressure on the same component, while Julian day, temperature, and percent moisture of vegetation loaded highly on another. Wind speed and wind direction were characterized together on a third component, and both site longitude and percent lipid of vegetation were each described by their own components. Trends in the classification of analyte concentrations on their respective principal components were not related to volatility or other chemical properties. Using the principal components as variables in canonical correlation analysis revealed that levels of several PCB congeners and hexachlorobenzene were related to altitude, precipitation, relative humidity, temperature, barometric pressure, Julian day, and vegetation percent moisture. From this analysis, it is evident that several factors in addition to temperature affect the accumulation process of certain organochlorine compounds in vegetation.

4.2 INTRODUCTION

Several factors affect the accumulation of semivolatile pollutants in vegetation and other environmental compartments. These factors include temperature, wind speed, rainfall, humidity, and physical properties of the compartment. Using regression analysis, Burgoyne and Hites (1993) showed that temperature was a more important predictor of atmospheric levels of α-endosulfan than wind speed and wind direction. Hiatt (1999) reported that calm conditions with low wind speeds favor the retention of volatile compounds by vegetation. Conversely, high wind speed was reported to be an important contributor to the overall flux of organochlorine (OC) compounds to Lake Baikal in Russia (McConnell et al. 1996). Furthermore, weak, nonsignificant relationships were observed between pasture polychlorinated biphenyl (PCB) concentrations and cumulative rainfall, average temperature, and run of wind, indicating that other factors, such as exposure

time, are controlling levels of these compounds in grass (Thomas et al. 1998). Thus, these factors may act alone or in combination with other variables to create a complex process that can be difficult to understand.

For the transfer of airborne compounds to vegetation, the limiting factor on plant concentrations is likely the rate of supply from the air (McLachlan 1996). While high wind speeds may result in a greater supply of contaminant, longer exposure time to the same air mass would provide vegetation showing slow uptake kinetics with adequate time to encounter enough contaminant for significant changes in plant concentrations to occur. The importance of various meteorological and physical factors in the accumulation of persistent organic pollutants (POPs) accumulation thus depends on the medium of interest.

A field study conducted in the Canadian Rocky Mountains during the summers of 1999 and 2000 resulted in the compilation of concentrations for 16 OC pesticides and several PCBs in four species of coniferous vegetation for a sample size of 230. With such a large data set and numerous dependent and independent variables, analyzing relationships among variables would contribute to the characterization of chemical fate in mountainous regions. To do so, multivariate data analysis was performed to investigate the relationships between these variables and to determine the important environmental conditions that promote POP accumulation in vegetation at high altitudes.

4.3 PROCEDURE

Analyte concentrations in vegetation and meteorological data were compiled as described in Chapter 2.0. Values for wind speed, wind direction, precipitation, relative humidity, barometric pressure, and temperature for the five days prior to sampling were averaged to eliminate daily variations. While 230 vegetation samples provide information on chemical concentrations, some meteorological data, such as precipitation, wind velocity, relative humidity, and barometric pressure, were not available for some sites at certain times of the season. In order to retain maximum power and utilize data from all samples, an expectation-maximization (EM) algorithm that replaces missing observations was performed on the original data using SYSTAT, version 9.01 (SPSS Inc., Chicago, IL, USA). This procedure uses a general maximum likelihood approach and all available data to obtain plausible estimates for missing values through an iterative procedure with prediction and estimation steps. It is used to treat situations where data are missing at random, when the variables themselves do not manipulate the process responsible for the missing values. In the prediction step, the algorithm predicts the contribution of any missing values to the sample sufficient statistics,

while in the estimation step the predicted sufficient statistics are used to compute a revised estimate of the parameters. The calculation alternates between these two steps until stable values for the estimates are obtained (Gittins 1985, Johnson and Wichern 1998).

With the exception of Julian day, latitude, longitude and altitude, variables were log transformed and each zero value replaced with a near-zero value of 0.001 to retain the maximum amount of data. The EM algorithm was then performed using the Pearson correlation matrix, the t-normal distribution, 20 iterations, and a convergence of 0.001. The significance of Little's MCAR test statistic (693.772, df = 223, $p<0.001$) indicated that the missing values were not random but instead depended on variables in the analysis. This is likely a result of missing meteorological data for specific times at specific sites, thus the variables 'altitude' and 'Julian day' may be influencing the randomness of the missing data. Estimated values were calculated for pressure (n=142), relative humidity (n=122), precipitation (n=120), wind speed (n=94), and wind direction (n=124).

Principal component analysis (PCA) followed by varimax rotation was then applied separately to the sets of dependent and independent variables to reduce data dimension. With 12 independent variables and 26 dependent variables, the variable/sample ratio is quite high at 0.17, considering the desired ratio lies between 0.025 and 0.05 (Gittins 1985). High variable/sample ratios exaggerate the strength of the canonical correlation and diminish the applicability of the results to prediction and modeling exercises (Gittins 1985). The first five principal components (PCs) of the set of 12 independent variables had eigenvalues greater than one and explained 81.2% of the variance (Table 4.1). Nine PCs with eigenvalues greater than one were retained for further analyses from the set of 26 dependent variables, explaining 63.6% of the variance (Table 4.2). The variable/sample ratio now becomes 0.06, which is still fairly large but closer to the recommended values.

For canonical correlation, new variables were created by multiplying standardized data values by the unrotated PC factor coefficients. Canonical correlation was performed to reveal the relationship between these two sets of newly created variables, one set of independent and one set of dependent parameters. In canonical correlation, the covariance between two sets of variables is emphasized, generating a sample space that corresponds to each variable set. The sample spaces are rotated such that they represent linear transformations of each variable set where the correlation, called the canonical correlation, between the two new variables, or canonical variates, is maximized. Furthermore, the analysis is performed under the constraint that the within-

set correlation is zero, or that no pair of canonical variates is correlated with any other (Gittins 1985). This analysis produced three significant sets of correlations (Table 4.3).

Assumptions of PCA and canonical correlation include independence of observations, multivariate normality, and equality of covariance matrices. The independence of observations was assessed by testing the significance of the intraclass correlation, R_I, calculated as follows:

$$R_I = [MS_B - MS_W] \cdot [MS_B + (n-1)\, MS_W]^{-1} \quad (4.1)$$

where MS_B is the mean square between groups, MS_W is the mean square within groups, and n is the sample size. Multivariate normality was tested by calculating Mahalanobis distances between concentrations at each site from the mean concentration of the sample and plotting them against their chi-square approximation. This plot gives a straight line if the data are multivariate normal. Furthermore, a box test for equality of covariance matrices was performed, in which the Box's M value is calculated using the determinant of each group covariance matrix and the pooled covariance matrix. The significance of this value is then tested with a chi-square distribution.

The original, unmodified data satisfied the condition of independence, but failed to meet the criteria of normality and equality of covariance (Box Test: $\chi^2 = 16{,}763.465$, df = 1260, $p<0.001$). The modified data set, with missing observations estimated by the EM algorithm, satisfied the assumption of equality of covariance matrices ($\chi^2 = 83.273$, df = 1260), but the variables 'pressure' and 'precipitation' showed non-independence of observations and the data were still not multivariate normal. However, PCA and canonical correlation are carried out in this study for descriptive purposes only, thus no tightly specified distributional assumptions are necessary (Gittins 1985).

4.4 RESULTS AND DISCUSSION

The rotated components for the set of independent variables (Table 4.1) indicate that average precipitation, relative humidity, altitude, and barometric pressure load strongly on the first PC, while Julian day, temperature, and percent moisture of vegetation load highly on the second PC. The third PC had high loadings for wind speed and wind direction and the fourth was represented by site latitude only. Site longitude loaded highly and percent lipid of vegetation loaded moderately on the fifth PC. For the set of dependent variables (Table 4.2), ΣPCB, tetrachlorinated, hexachlorinated, and trichlorinated PCBs, along with hexachlorobenzene (HCB) and heptachlor loaded highly on the first PC, while *p,p'*-

dichlorodiphenyltrichloroethane (*p,p'*-DDT), *o,p'*-DDT, and α-endosulfan loaded highly on the second. The third PC represented γ-chlordane and dichlorinated PCBs, while heptachlorinated, nonachlorinated, and octachlorinated PCBs loaded strongly on the fourth PC. Endrin, β-endosulfan, *p,p'*-dichlorodiphenyldichloroethane (*p,p'*-DDD), and *p,p'*-dichlorodiphenyldichloroethylene (*p,p'*-DDE) loaded highly on the fifth PC, and HCH dominated the sixth PC. The seventh PC contained methoxychlor and dieldrin, while the eighth included the pentachlorinated PCBs. Finally, α-chlordane loaded highly, while the decachlorinated PCBs and heptachlor epoxide both loaded moderately, on the last PC. The loadings for the first two sets of components are plotted in Figure 4.1 for the illustration of several groupings.

Precipitation was determined to be a dominant source of HCB and PCBs to Bow Lake, AB, Canada (Blais et al. 2001b). Bennett et al. (1998) noted that wet deposition is negligible in the contamination of vegetation since water is likely swept off the plant before it is able to penetrate the plant surface. However, Jordan (1977) found that the herbicide glyphosate was twice as toxic when the relative humidity was 100% compared to 40% regardless of temperature. Moreover, the target was more susceptible to the toxin at 32°C than at 22°C at a constant humidity of 40%, whereas the plant showed no difference in response to the herbicide with temperature at 100% relative humidity. This indicates that higher humidity favors the adsorption of certain chemicals into vegetation. This may apply to the POPs investigated here, although the water solubility of glyphosate (12 g $\cdot L^{-1}$) is much higher than those of OC compounds such as γ-HCH (200 mg $\cdot L^{-1}$), endosulfan (0.3 mg $\cdot L^{-1}$), and HCB (6.2 μg $\cdot L^{-1}$) (Ayres and Hellier 1998).

Forested and nonforested areas are expected to receive similar contaminant burdens through wet deposition. An exception to this would be high altitude areas where orographic fog regularly forms (Horstmann and McLachlan 1998). Weiss et al. (2000) reported higher levels of organic compounds in spruce needles and humus samples from high elevations than from low altitude sites, but temperature alone was not the most important factor in this observation. The high altitude sites are also characterized by high wind speeds, heightened precipitation, and orographic fog, as well as the interception by elevated areas of air masses traveling long distances, all of which increase the deposition of airborne pollutants to terrestrial surfaces.

In our analyses, the first component for the independent variable set represented three important meteorological conditions that are related to altitude, which also loaded highly on this component (Table 4.1). Precipitation and relative humidity are generally higher at higher elevations, while barometric pressure drops

as elevation increases. Temperature was related more strongly to Julian day than to altitude, as these both loaded highly on the second component along with percent moisture of vegetation. Wind velocity and latitude were relatively independent of the other variables, with each variable described by its own component, while longitude and percent lipid of vegetation were grouped together on the last component.

For analyte concentrations, rotated loadings showed little relationship to chemical properties such as volatility, although the HCH isomers, the DDT parent compounds, and the DDT metabolites were grouped together on their respective components. The decachlorinated PCBs and heptachlor epoxide were difficult to classify because they both contained relatively small component loadings. Studies investigating chemicals in air (Stern et al. 1997), plants (Thomas et al. 1984), and ringed seals (Muir et al. 2000) have used PCA to extrapolate trends in pollutant concentrations. Compounds that load highly on the same PC are similar in their deposition and atmospheric transport behavior or in their accumulation processes in environmental compartments (Thomas et al. 1984).

In canonical correlation analysis, the magnitude and the sign of canonical loadings indicate the direction and relative contribution of each variable to the canonical correlation coefficient, while redundancies represent the degree to which the variance within a set of variables is explained by a canonical variate (Gittins 1985). The first dependent PC was highly correlated to the first canonical variate, which was also negatively correlated to the first and second independent PCs (Table 4.4). With respect to the original variables, levels of HCB, trichlorinated, tetrachlorinated, hexachlorinated, and heptachlorinated PCBs, as well as ΣPCB, were all affected by altitude, pressure, relative humidity, precipitation, temperature, Julian day, and vegetation percent moisture. The HCH compounds represented by the sixth dependent PC was also related to the first independent PC, represented by the third set of canonical variates, signifying increasing HCH levels with increasing altitude, precipitation, and humidity and with decreasing pressure.

In the second set of canonical variates, the fourth, fifth, and seventh dependent PCs were moderately correlated with the fourth independent PC, representing latitude. Compounds represented in this correlation include *p,p'*-DDD, endrin, β-endosulfan, *p,p'*-DDE, methoxychlor, and dieldrin. The sampling sites cover only two degrees of latitude, and the correlations were only moderate, so little weight should be placed on these relationships, which may simply be a manifestation of site-specific emissions and accumulations.

The second, third, eighth, and ninth dependent PCs were not significantly correlated with any variate as only the first three pairs of variates were significant. Compounds represented by these components included *p,p'*-DDT, *o,p'*-DDT, α-endosulfan, γ-chlordane, α-chlordane, heptachlor epoxide, and dichlorinated, pentachlorinated, and decachlorinated PCBs. The lack of meteorological effects on concentrations of the above may be explained by the low volatility and limited number of samples with detectable levels of most of these compounds.

Moreover, wind velocity, longitude, and plant lipid content, represented by the third and fifth independent components, had little effect on vegetation concentrations of the analytes examined. Only the nonsignificant pairs of variates, variates four and five, were related to the third independent variable, wind velocity. The dependent PCs that correspond to these variates include the fourth, representing the heptachlorinated, octachlorinated, and nonachlorinated PCBs, and the eighth, representing the pentachlorinated PCBs. The dependence on wind velocity, although non-significant, for the plant concentrations of these PCB homologues may be a result of certain PCBs being delivered to the study sites via the same air masses originating from a common source.

Canonical correlations were moderately high and significant, but redundancies were low; therefore there may be other variables besides those measured, such as emissions, air concentrations, and chemical properties, contributing to or governing POP uptake by vegetation. In-cloud scavenging events may also contribute to the atmospheric deposition of semivolatile compounds in high altitude areas (Blais et al. 1998). There is a need to monitor chemical usage globally and to understand the synergistic influence of environmental factors to properly describe and characterize plant accumulation of POPs in mountain regions.

4.5 CONCLUSIONS

In addition to temperature, several factors, particularly precipitation, relative humidity, and barometric pressure, affect the accumulation process of several compounds in vegetation. The high loadings on the first PC for these independent variables, accounting for 28% of the variance in the independent set of variables, was a major determinant of the concentrations of many POPs in plant foliage. However, relative humidity, pressure, and precipitation all correlated highly with elevation, which continues to be a major factor in the accumulation of chemicals in terrestrial vegetation. Additional variables not measured in this study are likely important to this process as well, demonstrating that stricter reporting guidelines for chemical sale and usage

are needed, as are more universally accepted values for physical and chemical properties of POPs. It thus becomes essential that we characterize the behavior of such chemicals in the environment using the greatest possible collection of pertinent information applicable to their fate. The meteorology of mountain ecosystems should not be ignored in this process. Furthermore, human and wildlife exposure to POPs is often a result of either direct or indirect consumption of vegetation (Paterson and Mackay 1994), so the potential for plant material to accumulate and retain these chemicals must not be overlooked.

Table 4.1 Principal component loadings for the set of independent variables.

Principal component loadings are varimax rotated and the proportion of variance explained by each component is indicated. Components were retained if their eigenvalues exceeded one. With the exception of altitude, latitude, longitude, and Julian day, all variables were log transformed prior to analysis.

Independent Variable	Principal Component				
	1	2	3	4	5
Precipitation (mm)	0.867	-0.071	0.001	0.144	0.005
Relative Humidity (%)	0.800	0.015	0.411	0.125	0.141
Altitude (masl)	0.785	-0.043	-0.334	-0.428	0.051
Pressure (kPa)	-0.674	-0.067	0.112	-0.168	-0.628
Julian Day	0.155	0.901	0.181	-0.123	0.066
Temperature (°C)	-0.469	0.800	0.090	0.018	-0.181
Moisture (%)	-0.076	0.660	-0.226	0.276	0.299
Wind Speed ($m \cdot s^{-1}$)	-0.258	-0.159	-0.825	-0.168	-0.061
Wind Direction (°N)	0.419	0.027	-0.713	0.094	-0.165
Latitude (°N)	0.110	-0.000	0.065	0.950	0.072
Longitude (°W)	-0.006	0.044	0.155	0.064	0.918
Lipid (%)	0.258	0.450	0.211	-0.108	0.463
Percent Variance	28.08	21.26	13.07	10.02	8.75

Table 4.2 Principal component loadings for the set of dependent variables.

Principal component loadings are varimax rotated and the proportion of variance explained by each component is indicated. Components were retained if their eigenvalues exceeded one. Concentrations were expressed in pg $\cdot g^{-1}$ lipid and log transformed prior to analysis. PCB homologue groups are abbreviated to the prefix describing the degree of chlorination.

Dependent Variable	Principal Component								
	1	2	3	4	5	6	7	8	9
ΣPCB	0.897	0.112	0.083	0.180	0.052	0.085	0.034	0.054	0.027
Tetrachlorinated	0.818	0.004	0.058	0.044	-0.126	0.065	-0.069	0.179	0.073
Hexachlorinated	0.785	0.069	0.005	-0.048	0.221	-0.050	-0.049	-0.249	0.179
HCB	0.582	-0.186	0.140	-0.431	0.183	0.140	-0.173	-0.075	-0.002
Trichlorinated	0.577	-0.127	0.170	-0.107	0.318	-0.142	0.304	-0.154	-0.288
Heptachlor	0.575	-0.194	0.085	-0.145	0.500	-0.183	0.003	-0.159	-0.091
p,p'-DDT	-0.235	0.757	-0.100	0.056	-0.074	0.001	-0.123	0.124	-0.055
o,p'-DDT	0.083	0.601	0.453	0.021	0.013	0.074	0.134	0.193	0.137
α-Endosulfan	0.313	0.519	-0.097	-0.076	-0.049	0.081	-0.005	-0.167	0.407
γ-Chlordane	0.018	-0.013	0.704	-0.063	-0.014	-0.085	-0.088	-0.026	0.006
Dichlorinated	0.237	-0.004	0.644	0.067	0.134	0.071	0.147	0.114	-0.081
Heptachlorinated	-0.075	0.182	-0.071	0.645	0.033	0.238	-0.034	0.069	0.030
Nonachlorinated	-0.094	-0.208	0.174	0.622	-0.124	-0.084	-0.053	0.077	0.112
Octachlorinated	0.280	-0.012	-0.077	0.606	0.264	-0.102	0.011	-0.053	-0.102
p,p'-DDD	-0.004	0.056	0.027	0.148	0.696	0.195	0.020	-0.046	-0.028
Endrin	0.098	-0.231	0.128	0.016	0.598	-0.031	-0.175	-0.052	0.261
β-Endosulfan	0.179	0.025	-0.314	-0.055	0.552	-0.046	0.332	0.283	0.128
p,p'-DDE	0.306	0.429	0.200	-0.152	0.517	-0.038	0.011	0.118	0.000
γ-HCH	-0.052	0.056	-0.085	0.192	-0.073	0.764	0.045	-0.090	0.041
α-HCH	0.150	-0.006	0.090	-0.243	0.228	0.704	-0.175	0.129	-0.027
Methoxychlor	0.035	-0.020	-0.017	-0.025	0.021	0.149	-0.700	0.077	0.075
Dieldrin	-0.079	-0.306	0.034	-0.249	-0.009	0.321	0.553	0.151	0.195
Pentachlorinated	-0.054	0.161	0.142	0.124	0.046	0.028	-0.042	0.823	-0.182
α-Chlordane	0.041	0.061	-0.020	0.066	0.135	0.016	-0.005	-0.089	0.825
Decachlorinated	0.024	0.163	0.307	0.195	0.188	0.255	0.352	-0.385	-0.278
Heptachlor Epoxide	-0.389	0.232	-0.084	0.042	-0.311	0.051	0.300	0.347	0.106
Percent Variance	18.06	8.54	6.48	6.18	5.98	5.22	4.82	4.38	3.90

Table 4.3 Results from canonical correlation analysis.

Correlation analysis was performed between the sets of independent and dependent principal component variables. Canonical correlation between each pair of canonical variates, the probability (p) from the Bartlett test of residual correlations, and the redundancies describing the variance in the entire set of independent variates accounted for by each dependent variates are reported.

Canonical Pair	Canonical Correlation	p	Redundancies
1	0.681	0.000	0.052
2	0.429	0.000	0.020
3	0.332	0.002	0.012
4	0.246	0.107	0.007
5	0.140	0.492	0.002

Table 4.4 Canonical loadings for the five canonical variates.

Canonical loadings of each variable were calculated using retained principal components for the five canonical variates. Variables include the independent (IND) and dependent (DEP) principal components (PC) outlined in Tables 4.1 and 4.2. Loadings represent correlations either between each dependent variable and the variate for the dependent variable set, or between the independent variable and the variate for the independent variable set. Note that the canonical correlation between each pair of canonical variates is a maximum.

Variable	Canonical Variate				
	1	2	3	4	5
Dependent Set					
PC-IND1	-0.614	-0.355	0.681	0.137	0.120
PC-IND2	-0.767	0.310	-0.477	-0.295	0.025
PC-IND3	-0.056	0.234	-0.183	0.737	0.604
PC-IND4	0.029	-0.786	-0.418	-0.191	0.414
PC-IND5	0.171	0.326	0.319	-0.560	0.670
Independent Set					
PC-DEP1	0.920	0.109	-0.153	-0.107	0.148
PC-DEP2	0.077	0.276	0.218	0.311	0.054
PC-DEP3	-0.111	-0.222	-0.021	0.066	-0.281
PC-DEP4	-0.008	0.571	-0.333	0.474	-0.396
PC-DEP5	-0.001	0.582	0.444	-0.388	0.110
PC-DEP6	0.041	-0.036	0.652	-0.082	-0.336
PC-DEP7	0.248	-0.421	0.231	0.335	0.125
PC-DEP8	-0.222	0.139	0.092	0.340	0.759
PC-DEP9	0.153	-0.024	0.364	0.527	-0.152

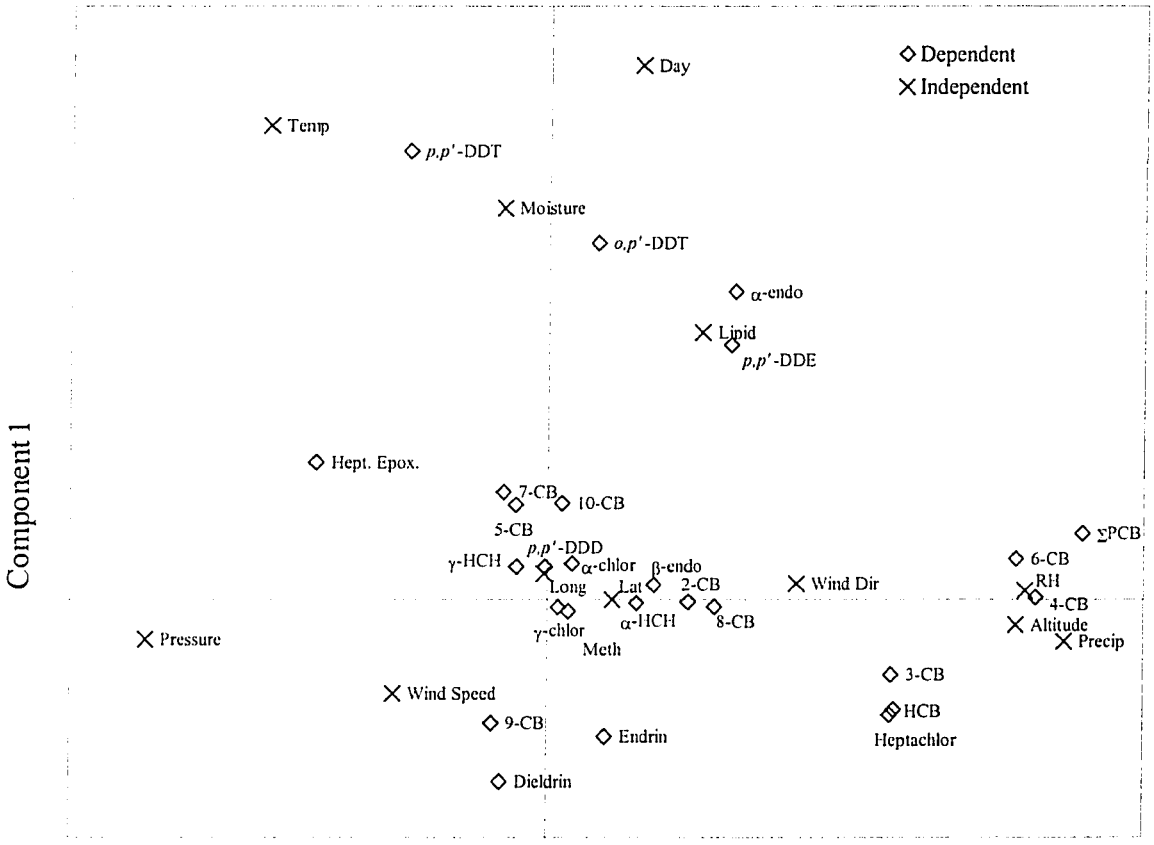


Figure 4.1 Plot of the first and second component loadings from PCA.

Data points represent the component loadings for the first two principal components of the set of independent and dependent variables.

5.0 MODELING THE ACCUMULATION OF ORGANIC POLLUTANTS IN TERRESTRIAL VEGETATION AT HIGH ALTITUDES

5.1 ABSTRACT

A fugacity-based model was formulated to predict the accumulation of semivolatile organochlorines in plant foliage at high altitudes. The model was simulated at seven elevations using field data collected from sites in the Canadian Rocky Mountains throughout the summers of 1999 and 2000, and predictions were compared with actual accumulation data measured in vegetation at these sites. Contributions from both air and rain to the chemical accumulation of six organochlorine pesticides and four polychlorinated biphenyl congeners in species of pine and spruce were assessed. Model results revealed that lower temperatures at higher elevations favor net deposition of the least volatile compounds to vegetation, while fractionation of lighter compounds upslope is dominated by net volatilization at lower altitudes. Predicted fluxes overestimated fluxes observed from field measurements, with the model predicting the correct direction of chemical transfer for 60% of the compounds assessed. Differences in chemical flux with site elevation were greatest for the most volatile compounds, which corroborated our field measurements. The derived model was sensitive to certain input parameters, such as chemical concentrations in rain and the air-vegetation transfer rate, but relative chemical fluxes predicted at different altitudes were not affected by the modification of these variables.

5.2 INTRODUCTION

Recent studies have examined the influence of temperature on persistent organic pollutant (POP) concentrations in air, vegetation, water, soil, and animal tissue (Burgoyne and Hites 1993, Stern et al. 1997, Donald et al. 1998, Haugen et al. 1998, Wania et al. 1998, Escartín and Porte 1999). From these studies, researchers have developed a theory of global distillation and fractionation, also known as the grasshopper effect (Wania and Mackay 1993a, Ockenden et al. 1998c, Blais et al. 1998). This process involves the evaporation of relatively volatile compounds from environmental compartments in warm, temperate areas followed by their atmospheric transport and deposition onto cold, polar regions, while less volatile compounds accumulate close to their emission source (Wania and Mackay 1993a). Simonich and Hites (1995a) reported a latitudinal increase in concentrations of relatively volatile organochlorine (OC) compounds in tree bark that illustrated the global distillation effect as it pertains to POP accumulation in vegetation.

Persistent OCs tend to concentrate in lipid-rich tissues and can travel great distances via the movement of air masses. Vegetation plays a significant role in the transfer of these pollutants to the soil and provides a means for these chemicals to enter terrestrial food chains (Böhme et al. 1999). Chemicals accumulate in plants primarily via the uptake of vapors from the atmosphere, which are affected by seasonal (Haugen et al. 1998) and daily (Lee et al. 2000) temperature variations that elicit local volatilization and deposition events. Global distribution of air masses and point source emissions also contribute to changes in atmospheric levels of contaminants. As air masses travel over lipid-rich vegetation, chemical will partition from the atmosphere to plant foliage, accumulating in vegetation. The cycle of deposition and revolatilization of pollutants from plant surfaces is influenced by changes in temperature and by rain scavenging events. Thus, vegetation likely contributes to the global fractionation of these chemicals.

Fractionation and distillation events have been modeled on a global scale. In their models describing the global distribution of chemicals, Wania and Mackay (1993b, 1995) considered four environmental compartments, namely air, water, soil, and sediment. Similarly, Strand and Hov (1996) assumed that the atmosphere, the ocean, and soil were primary reservoirs for chlorinated hydrocarbons in the environment. However, from their research, Simonich and Hites (1994a) concluded that vegetation is also a major pathway in POP removal from the atmosphere. This is because vegetation comprises approximately 80% of land surface, and the surface area of vegetation is generally 6 to 14 times greater than that of the land on which it grows (Simonich and Hites 1994a). These observations were based on model estimations that vegetation removes 45% of polycyclic aromatic hydrocarbons (PAH) from the atmosphere in the northeastern U.S. Wagrowski and Hites (1997) later revised this estimate down to 4%, which led the researchers to conclude that the efficiency of POP removal from the atmosphere by vegetation depends on the type and relative distribution of vegetation present in a specific region. Furthermore, Bennett et al. (1998) illustrated the importance of vegetation in the regional transport of chemicals through the atmosphere. In their model, the inclusion of vegetation as an environmental compartment greatly diminished the chemical dispersal distance.

In their multimedia model, Calamari et al. (1987) calculated that 4.4% of γ-hexachlorocyclohexane (γ-HCH) in the environment partitions to vegetation. Wania and McLachlan (2001) made similar observations when they compared the chemical distribution in two models - one without vegetation and one including a forest component. They found that, although the forest canopy is important in reducing a compound's

concentration in air and thus its potential to enter aquatic environments, the majority of chemical taken up by vegetation is transferred to the underlying soil through litterfall. It was estimated that forest vegetation actually retains only 0.3% of semivolatile chemical in the environment (Wania and McLachlan 2001). However, the forest canopy used in their model consisted of both coniferous and deciduous vegetation. When the model was assessed using only coniferous vegetation, which is prevalent in the Canadian Rocky Mountains, the forest played an even more significant role in scavenging chemical from the atmosphere. It is thus essential that the capacity for vegetation to behave both as a chemical source and as a chemical sink be addressed in environmental fate models.

Recent studies have shown that mountain regions are also susceptible to the distillation of POPs upslope (Blais et al. 1998). The present model will attempt to describe the cycling of airborne chemicals, specifically OC pesticides and polychlorinated biphenyls (PCBs), between low-altitude and subalpine vegetation. Variations in temperature and rainfall occur between these ecological regions and may influence the degree to which airborne pollutants accumulate in terrestrial plants.

5.3 MODEL DEVELOPMENT

A simple model based on the fugacity approach outlined by Mackay (1991) was utilized to examine chemical flux between vegetation, air, and rain. Only the outer compartment of solvent-extractable lipid from intact foliage was measured in this study. Although studies have shown that chemical uptake by vegetation may involve two compartments (Tolls and McLachlan 1994, Hauk et al. 1994, Simonich and Hites 1995b, Hung et al. 2001b), the characterization of these compartments is not well understood (Hung et al. 2001b). In addition, the cuticle of coniferous vegetation impedes the transfer of POPs into inner needle compartments (Ockenden et al. 1998b). These studies also revealed that exchange between air and the outer plant compartment is rapid while the uptake kinetics of the inner compartment is slow and negligible (Hauk et al 1994, Tolls and McLachlan 1994, Simonich and Hites 1995b). Furthermore, following extraction of the outer lipid compartment in this study, subsequent extractions performed on minced pine and spruce foliage revealed that the majority of the compounds were retained in the outer compartment. Compounds present in the extraction of the minced residual fraction of the needle comprised only 17.97%±2.70% of the total chemical concentration in the foliage. This is in line with observations made by Kylin et al. (1996), where the pine wax concentration of PCBs was twice that of the interior needle. Likewise, Riederer (1990) noted that the majority

of persistent, hydrophobic chemical in vegetation is found in the cuticle. Thus, for the purpose of this exercise, a one-compartment model is used to characterize vegetation in the air-vegetation partitioning of semivolatile compounds in mountainous regions.

The role of fugacity models is to estimate the chemical distribution in various environmental compartments and not to reproduce true environmental conditions (Calamari et al. 1987). The chemical distribution in air, rain, and vegetation will be investigated as they constitute three bulk phases in this model, and true environmental conditions will be used in the analysis to determine the relative chemical distribution at various altitudes. Precipitation is a possible source of plant contamination because it scavenges airborne particles and deposits them onto plant surfaces. When precipitation is significant, as at higher altitudes, both rain scavenging events and atmospheric deposition cause fluctuations in plant concentrations. Compounds partition from the air and rain to the exterior waxy cuticle surrounding foliage.

Soil as a contaminant reservoir is excluded from this model because studies have shown negligible translocation of lipophilic compounds from soil to foliage (Bacci and Gaggi 1986). Certain semivolatile compounds such as tetra- to octachlorinated PCBs are quite stable in vegetation and do not migrate into the inner plant compartments (Puri et al. 1997). Thus, chemical transformation and transport to other parts of the plant are ignored for the purposes of this model.

Böhme et al. (1999) have shown that particle-bound deposition is important only for those compounds with a log octanol-air partition coefficient (K_{OA}) greater than 11, whereas gaseous deposition dominates for compounds with lower K_{OA} values. The compounds assessed in this model fall within the latter category; thus, the deposition due to aerosols is not incorporated into the model.

Stomatal uptake of airborne chemicals is also neglected since these compounds will likely enter the cuticle layer lining the stomata (Hartley and Graham-Bryce 1980) and contaminate the lipid compartment of the plant. Furthermore, stomatal uptake of gaseous compounds is minimal compared to cuticular uptake due to the small surface area of stomata and the high storage capacity of the cuticle (McLachlan 1999).

Using this model to predict the influence of ambient temperature on chemical accumulation in vegetation at different altitudes, it is hypothesized that higher temperatures at lower elevations will favor volatilization from the plant surface. These chemicals may then be distilled upslope, as cooler temperatures at higher elevations promote deposition. This model examines the exchange between air, rain, and plant material

using meteorological data from seven locations spanning an elevation of 1430 meters in the Canadian Rocky Mountains.

5.3.1 Model Description

Chemical concentration in a certain phase is related to chemical fugacity and the fugacity capacity of the phase,

$$C = f \cdot Z \tag{5.1}$$

where C is the concentration (mol $\cdot m^{-3}$), f is the fugacity (Pa), and Z is the fugacity capacity (mol $\cdot m^{-3} \cdot Pa^{-1}$). Fugacity capacity describes the ability of a medium to internalize a certain chemical, and will depend on the nature of the chemical and the medium, as well as temperature (Mackay 1991). Concentration is also defined as the mass of chemical per unit volume of that medium

$$C = M / V \tag{5.2}$$

where M is the chemical mass (mol) and V is the volume of the medium of interest (m^3).

Using the above relationships, the change in chemical concentration in vegetation over time is given by

$$dM_V / dt = d(C_V \cdot V_V) / dt = d(V_V \cdot f_V \cdot Z_V) / dt \tag{5.3}$$

where the subscript V represents vegetation. This rate of change, or chemical flux, is calculated using D-values, which are parameters that describe transport and transformation processes (Paterson and Mackay 1994). Large D-values represent rapid transport (Mackay 1991). Intermedia D-values (mol $\cdot h^{-1} \cdot Pa^{-1}$) can be used to describe chemical transport between air and vegetation (D_{AV}), and between rain and vegetation (D_{RV}).

$$dM_V / dt = f_V \cdot D_{AV} - (f_A \cdot D_{AV} + f_R \cdot D_{RV}) \tag{5.4}$$

Equation 5.4 describes a net transfer rate and can be viewed as the algebraic sum of the downward adsorption rate from air ($f_A \cdot D_{AV}$) and rain ($f_R \cdot D_{RV}$) and the upward volatilization rate ($f_V \cdot D_{AV}$) (Mackay 1991).

Fugacities can be calculated using Equation 5.1. In air,

$$f_A = C_A / Z_A \tag{5.5}$$

where C_A is the concentration in air (mol $\cdot m^{-3}$) and Z_A is the fugacity capacity of air (mol $\cdot m^{-3} \cdot Pa^{-1}$). The fugacity capacity of air is equivalent to

$$Z_A = 1 / RT \tag{5.6}$$

where R is the universal gas constant (Pa $\cdot m^3 \cdot mol^{-1} \cdot K^{-1}$), and T is temperature (K).

The fugacity in rain is given by

$$f_R = C_R / Z_R \quad (5.7)$$

where C_R is the concentration in rain (mol $\cdot m^{-3}$) and Z_R is the fugacity capacity of rain (mol $\cdot m^{-3} \cdot Pa^{-1}$). The fugacity capacity of rain, or water, is equivalent to the inverse Henry's law constant, H (Pa $\cdot m^3 \cdot mol^{-1}$),

$$Z_R = 1 / H \quad (5.8)$$

The fugacity in vegetation is given by

$$f_V = C_V / Z_V \quad (5.9)$$

where C_V is the concentration in vegetation (mol $\cdot m^{-3}$) and Z_V is the fugacity capacity of vegetation (mol $\cdot m^{-3} \cdot Pa^{-1}$). The fugacity capacity of vegetation can be derived from the fugacity capacity of biotic phases (Mackay 1991), with the biotic phase-water partition coefficient estimated from the lipid fraction of the biota and the octanol-water partition coefficient (Bertelsen et al. 1998):

$$Z_V = K_{OW} \cdot L \cdot H^{-1} \quad (5.10)$$

where K_{OW} is the octanol-water partition coefficient and L is fraction of surface lipids of plant fresh weight (m $\cdot m^{-3}$), assuming a lipid density of 0.91 g $\cdot cm^{-3}$, similar to that of the synthetic lipid triolein. The plant water content is ignored in this calculation since the compounds of interest are hydrophobic and their concentrations in the aqueous phase would be negligible. This equation assumes that the lipid fraction of vegetation retains the entire chemical concentration in the plant and that the lipid storage capacity is similar to that of octanol (Bertelsen et al. 1998).

The intermedia D-value between air and vegetation is given by

$$D_{AV} = U_{AV} \cdot Z_A \cdot A \quad (5.11)$$

where U_{AV} is the air-vegetation diffusion mass transfer coefficient (m $\cdot h^{-1}$) and A is the surface area of vegetation (m^2). The mass transfer coefficient between air and vegetation is obtained from the following equation of Tolls and McLachlan (1994):

$$U_{AV} = B \cdot q^{-1} \quad (5.12)$$

where B is the molecular diffusivity in air ($m^2 \cdot h^{-1}$) and q is the thickness of the laminar boundary layer above the needle (m). A compound's diffusivity in air is the only physical property that affects its gaseous deposition velocity (Horstmann and McLachlan 1998). The molecular diffusivity of a compound in air can be estimated

from its molecular mass, m ($g \cdot mol^{-1}$), and the diffusivity of a known compound, water, which is estimated to be 0.0936 $m^2 \cdot h^{-1}$ (Schwarzenbach et al. 1993):

$$B = [m_{water} / m_{unknown}]^{0.5} \cdot B_{water} \quad (5.13)$$

The intermedia D-value between rain and vegetation is given by

$$D_{RV} = U_{RV} \cdot Z_R \cdot A \quad (5.14)$$

where U_{RV} is the mass transfer coefficient between rain and vegetation ($m \cdot h^{-1}$), equal to the rate of rainfall.

A temperature-adjusted Henry's law constant (H_T) was calculated using the following relationship described by McConnell et al. (1996) for OC pesticides

$$H_T = H \cdot 10\text{^}[m (1 / T - 1 / T_H)] \quad (5.15)$$

where m is the slope of the log-linear relationship between H and inverse temperature (neglecting the apparent intercept) and T_H is the temperature at which the original H was measured.

Bamford et al. (2000) studied the relationship between temperature and H for several PCBs and calculated enthalpies and entropies for the following formula

$$\ln (H / RT) = -\Delta H / RT + \Delta S / R \quad (5.16)$$

where ΔH and ΔS are, respectively, the enthalpy ($J \cdot mol^{-1}$) and entropy ($J \cdot mol^{-1} \cdot K^{-1}$) of phase change from the dissolved phase to the gas phase. In this model, Henry's law constants for PCBs are temperature-adjusted using ΔH and ΔS values from Bamford et al. (2000).

5.3.2 Input of Model Parameters

The model was evaluated using parameters, including surface area, volume, and lipid content, for a 5 gram sample of conifer needles. Samples of Engelmann spruce (*Picea engelmannii*) and lodgepole pine (*Pinus contorta*) were utilized for comparison of modeled behavior between species. Concentrations in vegetation were compiled for six OC pesticides, hexachlorobenzene (HCB), α-HCH, γ-HCH, α-chlordane, *p,p'*-dichlorodiphenyltrichloroethane (*p,p'*-DDT), and *p,p'*-dichlorodiphenyldichloroethylene (*p,p'*-DDD), and four PCB congeners (52, 101, 128, 180). Analyte concentrations in vegetation and meteorological data were compiled as described in Chapter 2.0, and atmospheric levels of these compounds were determined as described in Chapter 3.0.

Specific surface areas and volumes were measured for a subsample of lodgepole pine (*Pinus contorta*) and Engelmann spruce (*Picea engelmannii*). Thirty pine fascicles and 30 spruce needles were weighed, and

the volume was calculated from the amount of water displaced by each pine fascicle or by approximately eight spruce needles when they were submerged in water in a graduated centrifuge tube. Measurements of the pine fascicles and spruce needles were performed using a dissecting microscope and a ruler.

The surface area of each pine fascicle was measured by approximating the fascicle to a cylinder, measuring the diameter of the fascicle at ten points along the length to calculate an average radius, and the surface area calculated from

$$A = (2 \cdot \pi \cdot r^2) + (2 \cdot \pi \cdot r \cdot l) \quad (5.17)$$

where r is the average radius (m) and l is the length of the spruce needle (m).

The surface area of each spruce needle was measured as described in Sellin (2000), where the needle is approximated to an ellipsoid, and can be calculated using the following equation,

$$A = \pi (\Delta_1^2 \cdot \Delta_2^2 \cdot \lambda^2)^{1/3} \quad (5.18)$$

where Δ_1 and Δ_2 are the minor and major diameters (m), respectively, and λ is the length of the needle (m). The minor and major diameters and the length of the needle are treated as principal axes of the ellipsoid. An average volume and surface area were computed for each group of 30 needles.

Average values for temperature and rainfall were calculated for each site from data collected throughout the summer seasons of 1999 and 2000 and inputted into the model. Precipitation contaminant data were estimated from average concentrations in rain at Wapta Lake for the period of May 1994 to August 1994 obtained from Environment Canada. A collector opened upon rainfall triggered by a sensor and precipitation was passed directly through a XAD resin. The rainfall was collected monthly and analyzed for OC compounds by gas chromatography. Rainfall concentrations thus represent contamination from both dissolved chemical and dissolved particles. Atmospheric levels measured at all sites during the summers of 1999 and 2000 were averaged to obtain concentrations in air.

Average concentrations in extracts of 5 grams of vegetation were used for all compounds based on measured levels in conifer needles sampled in the area. The lipid fraction measured by solvent extraction was averaged over all samples of Engelmann spruce (n=74) and lodgepole pine (n=86). Physical properties of pine and spruce foliage calculated for input into the model are listed in Table 5.1. A laminar boundary layer thickness was conservatively estimated to be 0.2 mm (Tolls and McLachlan 1994). Parameters used to

calculate the temperature-adjusted H values and the references from which they were taken are listed in Tables 5.2 and 5.3.

5.4 RESULTS AND DISCUSSION

Based on observations made by Simonich and Hites (1995a) that HCB concentrations increase by a factor of 10 from the equator to the arctic, significant volatilization from vegetation at the low site is expected due to warming effects. Colder temperatures at higher altitudes hinder evaporation of volatile POPs from plant foliage and enhance partitioning to the plant surface from rain and air. For the sites used in this model, temperature generally decreased with elevation, with the exception of Lower Kananaskis Lake and Rock Isle. Average precipitation decreased with elevation, but Lower Kananaskis Lake again showed higher precipitation than predicted by elevation alone (Table 5.4).

As predicted, chemical transfer to vegetation calculated with Equation 5.4 shows either enhanced deposition or lower volatilization at higher elevations and colder temperatures (Figure 5.1). Net deposition is predicted for α-chlordane, *p,p'*-DDT, PCB 128, and PCB 180 at all sites, as well as for *p,p'*-DDE at high altitudes, while the more volatile HCH, HCB, PCB 52, and PCB 101 show net volatilization.

Temperature-induced changes in plant concentrations are only significant for relatively volatile organic compounds, namely those with log octanol-air partition coefficients (K_{OA}) less than 8.1 (Kömp and McLachlan 1997a). Compounds examined with the model that fall into this category include HCH, HCB, and PCB 52 (Tables 5.2, 5.3). These compounds exhibit the greatest flux, which changes markedly with altitude. While PCB 101 has a log K_{OA} greater than 8.1, its Henry's law constant is quite high compared to the other PCB congeners, which may account for its relatively high predicted rate of volatilization from vegetation.

Gaseous deposition velocities tend to increase with chemical volatility (Horstmann and McLachlan 1998). These chemicals will thus reach equilibrium with air more rapidly than their less volatile counterparts, eventually resulting in volatilization if fugacity in vegetation becomes high enough. The model predicts volatilization that is much more significant for the lighter compounds than for the heavier, less volatile chemicals. HCB, with a relatively large Henry's law constant, shows the highest rate of volatilization (Figure 5.1). A high H-value reduces the fugacity capacity of rain for HCB, resulting in an increased tendency for the chemical to transfer from rain to vegetation. Wet deposition of dissolved chemical is unlikely to occur for

organic pollutants due to their hydrophobic nature, but wet deposition of particle-bound chemical could lead to their accumulation in plants (McLachlan and Horstmann 1998).

When comparing chemical flux between two species, it is apparent that chemical volatilizes more readily from spruce than from pine (Figure 5.1). Deposition onto spruce is also favored over adsorption to pine foliage. Spruce has a larger specific surface area than pine foliage (Table 5.1). A larger surface area favors a higher transfer rate (Schreiber and Schoenherr 1992), where the direction will depend on fugacity ratios between the atmosphere and the plant foliage. Furthermore, spruce also has a greater proportion of lipid than pine (Table 5.1), augmenting the capacity for this species to retain lipophilic contaminants.

Precipitation contributed very little to vegetation contamination compared to the contribution from atmospheric deposition in the model predictions. When comparing the relative contribution from rain and air in the chemical deposition onto vegetation, the proportion of contaminant introduced to the plant material from rain increases with elevation, which is expected since precipitation is greater at higher altitudes. Adsorption from rain was highest for α-HCH, γ-HCH, PCB 128, and PCB 180, accounting for up to 55% of chemical deposition at Rock Isle, but input from the atmosphere was responsible for the bulk of the chemical accumulation at all other sites. The HCH isomers had the highest concentrations in rain, from 10 to 100 times the concentrations of other compounds, which are much less hydrophilic. For other compounds, deposition from rain to plant foliage accounted for less that 10% of the total chemical adsorbed. It is believed that contact between precipitation and vegetation is minor and that absorption of dissolved chemical is negligible (Eriksson et al. 1989). Thus, while precipitation at higher altitudes contributes to increased atmospheric deposition onto vegetation, chemical accumulation is primarily a result of gaseous uptake.

5.5 MODEL ASSESSMENT

5.5.1 Distillation with Altitude

Model results were assessed by relating the chemical flux calculated in this model to the change in chemical storage along a 1430-meter elevation gradient. The predicted change in chemical flux with site elevation was determined with linear regression of dM/dt, calculated using Equation 5.4, against altitude for each compound. The slope of this regression line was then plotted against the compound's vapor pressure and octanol-air partition coefficient (K_{OA}), revealing that chemical fluxes of volatile compounds change with site elevation to a greater extent than less volatile chemicals (Figure 5.2, top).

The actual log-transformed chemical concentrations in vegetation samples of each species were plotted versus elevation to assess the degree to which true concentrations change with altitude. The slopes for the lines of best fit were then related to vapor pressure and log K_{OA} (Figure 5.2, bottom). Again, chemical volatility is a significant predictor of the change in chemical concentration in pine foliage with elevation, but was not a very good predictor for accumulation of these compounds in spruce.

5.5.2 Direction and Magnitude of Chemical Flux

Concentrations of several analytes decreased as the summer season progressed, which could be attributed to volatilization from foliage due to warming effects, but growth of vegetation throughout the summer can dilute apparent concentrations (Kömp and McLachlan 1997a). The lipid content in the vegetation increased significantly over the summer for both pine ($R^2 = 0.230$, $p < 0.001$) and spruce ($R^2 = 0.214$, $p < 0.001$), and because analyte concentrations are expressed on a lipid weight basis, seasonal changes in lipid content can result in lower contaminant levels in plant foliage. The rate of increase in lipid content represented by the slope of the regression line for fresh foliage was 8.65×10^{-6} g lipid · g^{-1} needle · day^{-1} for pine and was 5.14×10^{-6} g lipid · g^{-1} needle · day^{-1} for spruce. The observed chemical fluxes, represented by the change in lipid-based concentration over time, are listed in Table 5.5 and were corrected for this growth dilution effect by using the following relationship:

$$dC_L/dt = dC/dt - (C \cdot dL/dt) \qquad (5.19)$$

where dC_L/dt is the corrected flux (ng · g^{-1} lipid · day^{-1}), dC/dt is the observed chemical flux (ng · g^{-1} lipid · day^{-1}), C is the concentration at the beginning of sampling (ng · g^{-1} lipid), and dL/dt is the change in lipid for 5 grams of needle (g lipid · day^{-1}) . The observed chemical flux is the slope of the regression line for the relationship between concentration and Julian day (Table 5.5). The actual average concentration measured on the first day of sampling was taken as C.

The corrected chemical flux was similar to the uncorrected observed flux (Table 5.5), indicating that growth dilution accounts for only a small portion of the change in concentration over the summer season. Dilution due to increased lipid content was insignificant, changing the apparent flux by less than 0.5%. The direction of flux was correctly predicted for six of the ten compounds assessed in the model. The overestimation of the chemical flux may be explained by the fact that, in the real environment, while volatilization from vegetation is occurring, evaporation from other sources, such as soil and water, is taking

place. This adds to the contaminant levels in air and alters the fugacity gradient, promoting deposition onto plant foliage. Thus, while field data reveal a net volatilization from vegetation for most compounds, chemical transfer between air, rain, and plant foliage is dynamic with a constantly changing fugacity gradient. Model predictions are overestimated because the conditions used to construct and run the model represent an average situation at these sites.

Hauk et al. (1994) remark that models based on controlled experiments are laboratory models until they are validated by environmental data, and that most models assessing the accumulation of persistent pollutants in vegetation had not been aptly validated. McLachlan et al. (1995) were successful in validating a mathematical model predicting the partitioning of OCs to Welsh Ray Grass developed by Tolls and McLachlan (1994). Böhme et al. (1999) were also successful in demonstrating the efficacy of a framework developed by McLachlan (1999) describing the uptake of OCs by vegetation. Less than perfect relationships between model estimations and field results likely arise from unstable atmospheric conditions, from inadequate estimations of the vegetation fugacity capacity, or an incomplete or an incorrectly calibrated model. Weak temperature effects and poor altitudinal trends may result either from chemicals introduced to the region via long-range air masses, or from a lack of equilibrium between vegetation and air due to a plant's high storage capacity for these chemicals. Distributions will also be affected by changes in the physical environment throughout the year, such as seasonal weather patterns and growth of vegetation, whereas this model was restricted to distribution throughout the summer months. Moreover, vegetation may not be a homogeneous matrix and it may not be sensible to model it as such (Hauk et al. 1994). However, overall trends in field measurements were consistent with model predictions, supporting the theory that mountain ecosystems are conducive to POP accumulation as a result of cold temperatures.

The discrepancies between predicted and observed chemical fluxes could also be due to incorrect assumptions or parameterization in the model. For instance, literature values for Henry's law constants and K_{OW} are quite variable among research laboratories. Furthermore, the calculation of K_{OA} based on K_{OW} and H may not adequately represent the partitioning process between air and coniferous needles. Thus, model predictions need to be regarded with some degree of doubt and emphasis be placed on findings from true environmental situations.

5.6 MODEL SENSITIVITY TO INPUT PARAMETERS

The variability of certain input parameters may affect results obtained using the developed fugacity model. For instance, values for Henry's law constants determined experimentally have been inconsistent among laboratories. The mass transfer coefficient between air and vegetation employed in the model was obtained from a model using Welsh Ray Grass (*Lolium mulitflorum*), in which an undisturbed boundary layer of 0.2 mm was employed (Tolls and McLachlan 1994). With limited discussion in the literature surrounding the kinetics of air-vegetation exchange of semivolatile chemicals, this derivation for the rate of transfer was one of only a few available and may not reflect the true chemical behavior under the conditions used in the model. Furthermore, chemical concentrations in vegetation, air, and rain may vary throughout the season or with recent emissions. Finally, values for needle surface area and lipid fraction are subject to experimental error, and changes in the rate of precipitation may also affect the chemical input to vegetation from rain.

Both increasing and decreasing the selected values for these parameters by a factor of 2 illustrated the sensitivity of the model to certain variables (Table 5.6). The final results obtained using these adjusted values were then compared to those observed using the default parameters. The relative fluxes in pine between the lowest site, Donald Station, and the highest site, Rock Isle, using the default values were compared with those obtained using the adjusted parameters. The percent change in the flux difference between the high and low site resulting from these adjustments was calculated as

$$\% \text{ Change} = (\text{Adjusted} - \text{Default}) / \text{Default} \cdot 100 \qquad (5.20)$$

Sensitivity analysis was restricted to two compounds with dissimilar properties, the relatively volatile and hydrophilic α-HCH and the less volatile and lipophilic *p,p'*-DDT. The overall trend in chemical flux with altitude did not change when certain input parameters were manipulated. Results obtained using the adjusted values showed either increased volatilization or decreased deposition at the low site compared to the high site. The difference in chemical flux between Rock Isle and Donald Station remained positive throughout the sensitivity analysis, representing enhanced volatilization at the low site. Altering atmospheric concentrations by a factor of 2 had no effect on the relative flux for *p,p'*-DDT between the high and the low site. Dry gaseous deposition is the major pathway by which OC compounds accumulate in vegetation (Tolls and McLachlan 1994), and variable air concentrations would be expected to affect plant concentrations. However, this effect is suppressed because the air concentration remains the same at each site and the transfer rate between air and

vegetation remains relatively constant since the model assumes that vegetation at all sites encounters the same air mass.

Adjusting the Henry's law constant, the mass transfer coefficient between air and vegetation, the plant concentration, or the foliage surface area enhanced volatilization at lower sites when these variables were doubled, and accelerated deposition at higher sites when they were halved. Alterations in plant lipid content had the opposite effect. It is evident that the former variables have a positive impact on chemical fugacity in vegetation while lipophilic tissues magnify the plant storage capacity.

Varying the chemical concentrations in rain and the rate of rainfall had the greatest effect on chemical transfer at higher altitudes that experience elevated precipitation. Increasing these parameters favored deposition, while decreasing them diminished volatilization rates at higher altitudes. Data for rainfall concentrations used in the model were from one site in 1994 and may account for some error in model predictions.

Changes in several parameters appeared to have a large effect on the chemical flux of α-HCH. Transfer of more volatile compounds, such as HCH, is likely controlled by environmental variables to a larger extent than that of less volatile chemicals, like DDT. Furthermore, α-HCH showed relatively large fluxes to pine and spruce, and changes in the values used to calculated these fluxes would have a large influence on the outcome, compared to *p,p'*-DDT that showed small values for chemical flux.

While some values used as input parameters for the fugacity model are uncertain, overall altitudinal trends in chemical flux remain constant throughout the manipulation. The process of chemical transfer, however, is sensitive to several model estimates. Where net volatilization is observed under default settings, net deposition occurs when certain parameters are manipulated. More precise measurements are required if this model is to be used to determine the absolute chemical flux between air, rain, and vegetation.

5.7 CONCLUSIONS

Results from these model simulations and field measurements provide support for the hypothesis that high altitude regions are in some cases more susceptible to enhanced accumulation of semivolatile compounds in terrestrial vegetation than low altitudes due to their cold and rainy environments. However, predicted chemical fluxes greatly overestimated the observed flux, owing to the fact that the model calculations are based on several uncertain factors. It was shown that chemical fluxes under constant atmospheric conditions vary

with elevation, with enhanced volatilization at lower sites and increased deposition at higher sites. The change in chemical flux with altitude was most pronounced for the most volatile compounds. Field data for pine foliage supported the model results, but factors other than temperature and precipitation may influence the distribution of semivolatile compounds in certain areas. Atmospheric sources and vegetation properties, such as surface area and lipid content, also contribute to the accumulation of airborne, lipophilic compounds in plant foliage of mountain regions. Areas such as the Canadian Rocky Mountains that are rich in vegetation and experience low temperatures and high precipitation are potential sinks for persistent organic pollutants emitted around the globe. These ecosystems may be at risk for exposure to various harmful chemicals invading the environment through long-range atmospheric transport and subsequent biomagnification in aquatic and terrestrial food chains. Researchers should make efforts to include vegetation and high-altitude ecosystems in future modeling exercises that describe the global distribution of persistent and hazardous chemicals to account for the ability of these regions to retain semivolatile compounds.

Table 5.1 Physical properties of plant foliage used for model input.

Specific surface area, specific volume, and plant lipid content are presented for pine and spruce foliage. Error estimates represent standard errors of the mean. Sample sizes for surface area estimations: Pine n=30, Spruce n=30; for volume estimations: Pine n=30, Spruce n=4; for lipid fraction: Pine n=86, Spruce n=74.

Species	Specific Surface Area ($m^2 \cdot g^{-1}$)	Specific Volume ($m^3 \cdot g^{-1}$)	Lipid Fraction ($m^3 \cdot m^{-3}$)
Pine	$3.98x10^{-4} \pm 1.07x10^{-5}$	$1.99x10^{-6} \pm 1.95x10^{-8}$	$2.82x10^{-2} \pm 2.82x10^{-8}$
Spruce	$1.51x10^{-3} \pm 1.05x10^{-4}$	$2.04x10^{-6} \pm 1.38x10^{-7}$	$2.75x10^{-2} \pm 2.97x10^{-8}$

Table 5.2 Chemical properties of OCs.

Subcooled liquid vapor pressures (P_L), octanol-air (K_{OA}) and octanol-water (K_{OW}) partition coefficients, Henry's law constants (H) at the temperature (T) indicated, and the slope (m) used to calculate the temperature-dependent H values. a. Mackay et al. 2000, b. $K_{OA}=K_{OW} \cdot R \cdot T \cdot H^{-1}$ (Harner et al. 2000), c. Kucklick et al. 1991, d. ten Hulscher et al. 1992, e. Paasivarta et al. 1999.

Compound	P_L[a] (Pa)	Log K_{OA}[b]	Log K_{OW}[a]	H (Pa $\cdot m^3 \cdot mol^{-1}$)	T (K)	m (K^{-1})
α-HCH	1.00×10^{-1}	7.26	3.81	0.66[c]	296	-2810[c]
γ-HCH	2.74×10^{-2}	7.92	3.70	0.31[c]	296	-2384[c]
HCB	2.45×10^{-1}	6.28	5.50	131[a]	298	-2492[d]
p,p'-DDT	1.35×10^{-4}	9.21	6.19	2.36[a]	298	-3369[e]
p,p'-DDE	3.72×10^{-3}	8.19	5.70	7.95[a]	298	-3291[e]
α-Chlordane	2.65×10^{-3}	9.86	6.00	0.34[a]	298	-3160[e]

Table 5.3 Chemical properties of PCBs.

Subcooled liquid vapor pressures (P_L), octanol-air (K_{OA}) and octanol-water (K_{OW}) partition coefficients, Henry's law constants (H) at 25°C, and enthalpies (ΔH) and entropies (ΔS) of phase change from the dissolved phase to the gas phase used in the calculation of temperature-adjusted Henry's law constants for PCBs. a. Mackay et al. 2000, b. $K_{OA}=K_{OW} \cdot R \cdot T \cdot H^{-1}$ (Harner et al. 2000), c. Paasivarta et al. 1999, d. Burkhard et al. 1985 quoted in Mackay et al. 2000.

Compound	P_L (Pa)	Log K_{OA}[b]	Log K_{OW}[a]	H ($Pa \cdot m^3 \cdot mol^{-1}$)	ΔH[c] ($kJ \cdot mol^{-1}$)	ΔS[c] ($kJ \cdot mol^{-1} \cdot K^{-1}$)
PCB 52	2.00×10^{-3}[a]	7.82	6.10	31.20	30.5	0.066
PCB 101	3.50×10^{-3}[a]	8.24	6.40	43.10	29.7	0.066
PCB 128	3.40×10^{-4}[a]	9.32	7.00	32.64	118.0	0.360
PCB 180	5.06×10^{-4}[d]	9.27	7.36	37.24	143.6	0.447

Table 5.4 Meteorological input parameters.

Elevation in meters above sea level (masl), average temperature (T), and average daily precipitation are presented for the seven sites used in the model. Error estimates represent standard errors of the mean.

Site	Elevation (masl)	T (°C)	Precipitation (mm ·day^{-1})
Donald	770	12.72 ± 0.50	0.81 ± 0.18
Dixon Dam	948	11.54 ± 1.48	1.29 ± 0.51
Vermilion Lakes	1380	9.31 ± 1.04	1.05 ± 0.22
Wapta Lake	1590	8.52 ± 0.64	2.35 ± 0.15
Lower Kananaskis Lake	1667	10.31 ± 0.61	0.66 ± 0.11
Bow Lake	1975	5.20 ± 0.42	3.49 ± 0.92
Rock Isle	2200	6.41 ± 0.78	6.25 ± 1.09

Table 5.5 Predicted and observed chemical fluxes.

'Predicted Flux' is the average flux predicted using Equation 5.4 from the model for all sites and 'Observed Flux' is the slope representing the change in measured log-transformed analyte concentration over time. A positive flux represents net volatilization. 'Corrected Flux' represents the observed flux adjusted for growth dilution. Fluxes in Italics denote observed fluxes with the same direction as predicted fluxes.

	Chemical Flux (ng $\cdot g^{-1}$ lipid $\cdot day^{-1}$)					
	Pine			Spruce		
Compound	**Predicted**	**Observed**	**Corrected**	**Predicted**	**Observed**	**Corrected**
α-HCH	*18.628*	*0.092*	*0.087*	48.382	-0.007	-0.010
γ-HCH	12.401	-0.036	-0.038	*32.318*	*0.056*	*0.055*
α-chlordane	-0.150	0.206	0.204	-0.405	0.051	0.049
HCB	*30.603*	*0.113*	*0.109*	*400.508*	*0.032*	*0.030*
***p,p'*-DDE**	*0.033*	*0.045*	*0.042*	*0.075*	*0.016*	*0.014*
***p,p'*-DDT**	*-0.283*	*-0.009*	*-0.014*	*-0.764*	*-0.015*	*-0.017*
PCB 52	*1.563*	*0.016*	*0.016*	*20.416*	*0.014*	*0.014*
PCB 101	2.965	-0.069	-0.070	7.744	-0.074	-0.075
PCB 128	-0.038	0.003	0.001	-0.102	0.002	0.002
PCB 180	*-0.045*	*-0.032*	*-0.033*	*-0.122*	*-0.043*	*-0.044*

Table 5.6 Model sensitivity to various input parameters.

The percent change in the difference in chemical flux between the highest site, Rock Isle, and the lowest site, Donald Station, using adjusted parameters. Changes greater than 30% are highlighted in bold.

Parameter	Percent Change in Flux Difference (Rock Isle – Donald Station)	
	α-HCH	*p,p'*-DDT
H*2	**87**	**73**
H/2	**-44**	**-37**
U_{AV}*2	**261**	**73**
U_{AV}/2	0	**-37**
U_{RV}*2	**100**	27
U_{RV}/2	**81**	-13
C_V*2	**261**	**73**
C_V/2	0	**-37**
C_A*2	**87**	0
C_A/2	**87**	0
C_R*2	**100**	27
C_R/2	**81**	-13
A*2	**274**	**100**
A/2	-6	**-50**
L*2	**87**	0
L/2	**87**	0

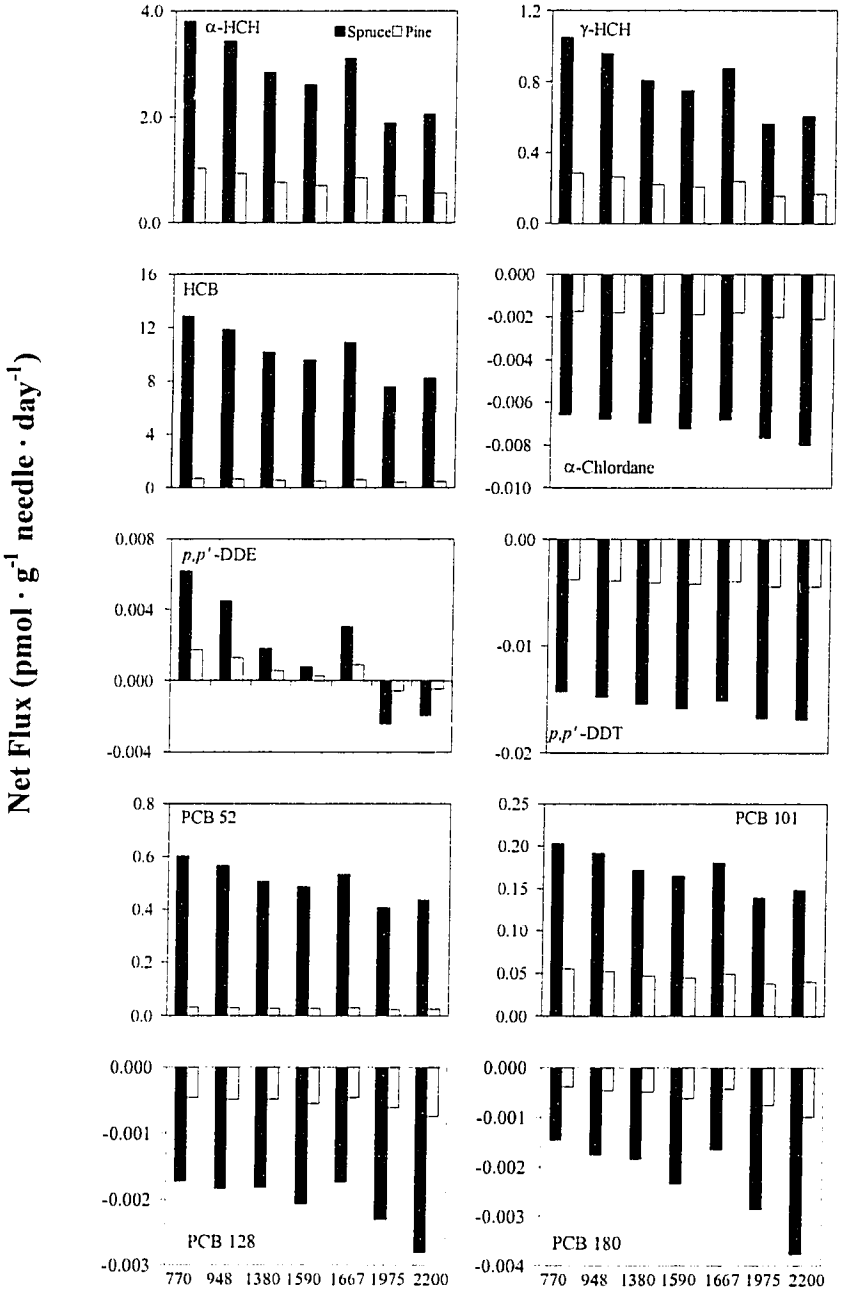


Figure 5.1 Predicted chemical flux in vegetation.

The net flux (pmol $\cdot g^{-1}$ needle $\cdot day^{-1}$) at different altitudes was calculated using Equation 5.4. A positive flux indicates net volatilization.

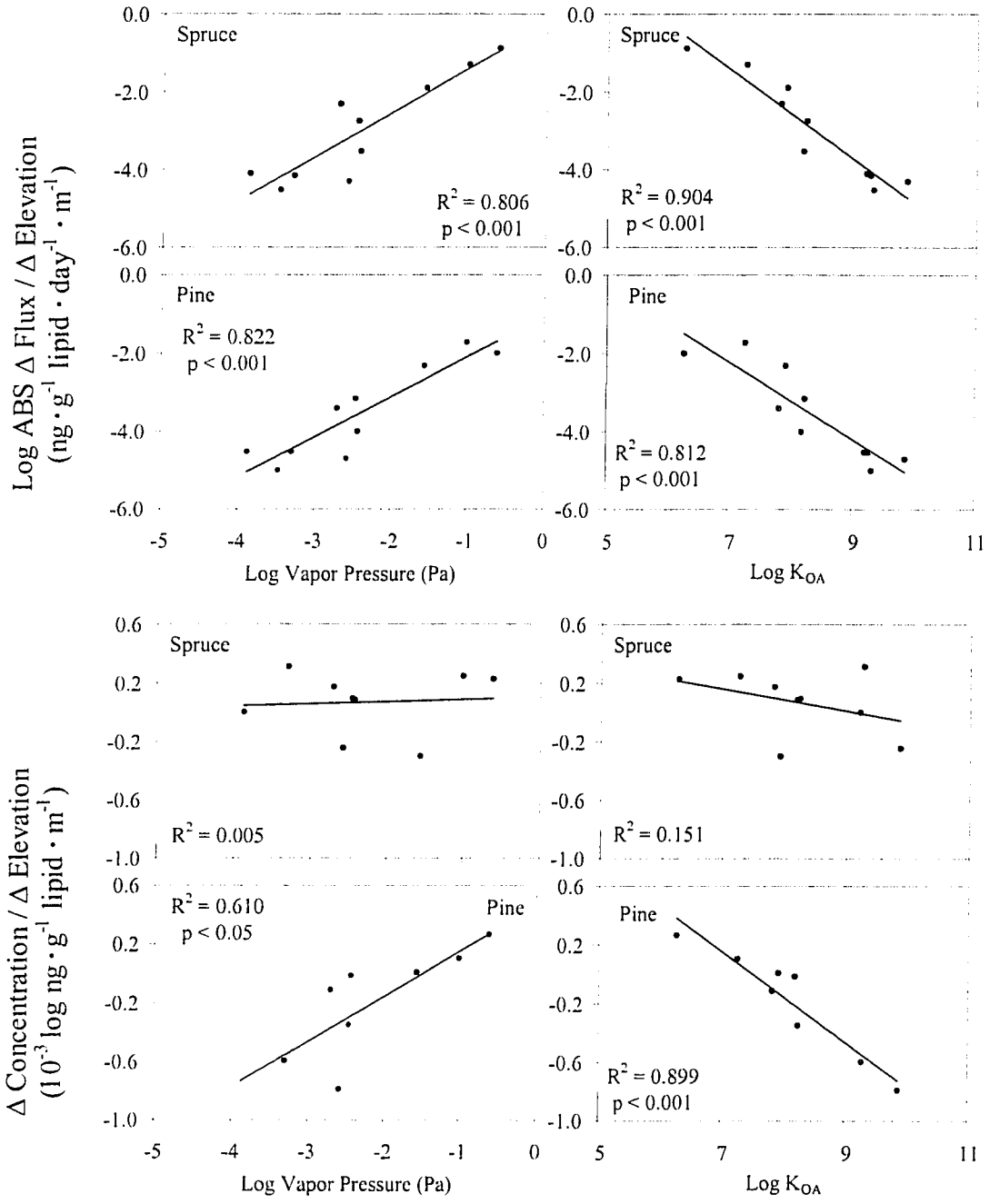


Figure 5.2 Assessment of model predictions.

The absolute value of the log of the slope for the relationship between predicted flux (ng $\cdot g^{-1}$ lipid $\cdot day^{-1}$) and elevation (masl) is plotted for each compound assessed in the model versus its vapor pressure (Pa) and the log of its octanol-air partition coefficient (K_{OA}) in the top diagrams. The bottom plots represent the change in field concentrations (log ng $\cdot g^{-1}$ lipid) with altitude (masl) as a function of chemical vapor pressure (Pa) and log K_{OA}.

6.0 RELATIVE FUGACITY CAPACITIES OF CONIFEROUS VEGETATION AS A FUNCTION OF TEMPERATURE

6.1 ABSTRACT

The capacity for vegetation to internalize organic chemicals is strongly influenced by temperature, yet little work has been done to measure the fugacity capacity of plant tissue, let alone its relationship with temperature. The fugacity capacities of vegetation for six organochlorines were measured at 10°C and 25°C for species of lodgepole pine (*Pinus contorta*) and Engelmann spruce (*Picea engelmannii*) using a vial equilibration technique. Fugacity capacities were calculated based on relative headspace concentrations for reference vials and vials containing tissue. Headspace concentrations were assessed by manual injection on a gas chromatograph. Fugacity capacities were comparable to those predicted based on tissue lipid content, suggesting that the use of lipid-based plant fugacity capacities in modeling exercises is valid. Little differences were observed between fugacity capacities measured at 10°C and 25°C, denoting the need for further analyses at a broader range of temperatures. Species differences in measured fugacity capacities indicate that surface area of plant foliage is just as important as lipid content as an indicator of chemical storage capacity.

6.2 INTRODUCTION

Plant fugacity capacities are strongly influenced by fluctuations in temperature, and little work has been done to characterize this relationship (McLachlan et al. 1995). Fugacity capacity depends on temperature, pressure, the nature of the substance, and the medium in which the chemical is present. It quantifies the capacity of a phase to store chemical, and toxic substances tend to accumulate in phases where this value is large and high concentrations can be reached without creating high fugacities. It reflects the ability of a matrix to solubilize or store chemical (Gobas et al. 1999). For phases with low fugacity capacities, only a small amount of chemical is necessary to exert an escaping tendency (Mackay and Paterson 1981).

The fugacity in vegetation, f_V, is given by

$$f_V = C_V / Z_V \qquad (6.1)$$

where C_V is the concentration in vegetation (mol $\cdot m^{-3}$) and Z_V is the fugacity capacity of vegetation (mol $\cdot m^{-3} \cdot Pa^{-1}$). At equilibrium, the fugacities of the two phases involved in chemical exchange are equal and there is no net rate of exchange (Mackay and Paterson 1981). The fugacity capacity of vegetation can be calculated from the fugacity capacity of biotic phases (Mackay 1991), with the biotic phase-water partition coefficient estimated from the lipid fraction of the biota and the octanol-water partition coefficient (Bertelsen et al. 1998):

$$Z_V = K_{OW} \cdot L \cdot H^{-1} \quad (6.2)$$

where K_{OW} is the octanol-water partition coefficient and L is the surface lipid fraction of plant fresh weight ($m^3 \cdot m^{-3}$). The plant water content is ignored in this calculation since the compounds of interest are hydrophobic and their concentrations in the aqueous phase would be negligible. This equation assumes that the lipid fraction of vegetation retains the entire concentration of chemical in the plant and that the storage capacity of plant lipid can be modeled using octanol (Bertelsen et al. 1998).

The fugacity capacity of vegetation can be determined by measurement of the vegetation-air partition coefficient. The vial equilibration technique has been employed to determine the tissue-air partition coefficient for several media, including avian feces and gastrointestinal contents, and various fish and rat tissues (Gargas et al. 1989, Bertelsen et al. 1998, Drouillard 2000). This procedure involves chemical equilibration in headspace vials containing known volumes of gas and tissue. At equilibrium, the headspace concentration is proportional to the headspace fugacity, which is equivalent to the vegetation fugacity. Reference vials containing only headspace and chemical added in equal quantities to vials containing tissue are used to measure the fugacity capacity of vegetation in a mass-balance approach.

In the reference vial,

$$M_{(REF)} = C_{A(REF)} \cdot V_{A(REF)} \quad (6.3)$$

where $M_{(REF)}$ is the amount of chemical in the reference vial (mol), $C_{A(REF)}$ is the reference headspace concentration (mol $\cdot m^{-3}$), and $V_{A(REF)}$ is the volume of headspace in the reference vial (m^3).

In the sample vials,

$$M_{(SAMPLE)} = C_{A(SAMPLE)} \cdot V_{A(SAMPLE)} + C_V \cdot V_V \quad (6.4)$$

where $M_{(SAMPLE)}$ is the amount of chemical added to the sample vial (mol), $C_{A(SAMPLE)}$ is the headspace concentration in the sample vial (mol $\cdot m^{-3}$), $V_{A(SAMPLE)}$ is the headspace volume in the sample vial (m^3), C_V is the concentration in vegetation (mol $\cdot m^{-3}$), and V_V is the vegetation volume in the sample vial (m^3). Since equivalent amounts of chemical are added to the reference and the sample vials, Equations 6.3 and 6.4 can be combined to give

$$C_{A(REF)} \cdot V_{A(REF)} = C_{A(SAMPLE)} \cdot V_{A(SAMPLE)} + C_V \cdot V_V \quad (6.5)$$

From the definition of fugacity in Equation 6.1, this relationship can be expanded to describe the fugacity capacity of vegetation:

$$Z_A \cdot f_{(REF)} \cdot V_{A(REF)} = Z_A \cdot f_{(SAMPLE)} \cdot V_{A(SAMPLE)} + Z_V \cdot f_{(SAMPLE)} \cdot V_V \quad (6.6)$$

Where Z_A is the fugacity capacity of air (mol $\cdot m^{-3} \cdot Pa^{-1}$), $f_{(REF)}$ and $f_{(SAMPLE)}$ are the chemical fugacities in the reference and sample vials, respectively. Isolating for Z_V,

$$Z_V = (Z_A \cdot V_V^{-1}) \cdot [f_{(REF)} \cdot V_{A(REF)} \cdot f_{(SAMPLE)}^{-1} - V_{A(SAMPLE)}] \quad (6.7)$$

The ratio of the fugacity in the reference vial to that in the sample vial is equivalent to the ratio of the area under the reference peak in the chromatogram to that under the sample peak if the two vials are sampled within an adequate amount of time.

6.3 METHODS

Headspace analysis was performed using 15 ml amber glass vials (Supelco, Bellefonte, PA, USA) sealed with polytetrafluoroethylene mininert valves (VWR Scientific, West Chester, PA, USA). All vials were prepared in a glove box with a volume of 7.7 x 10^{-2} m^3 that had been purged at 12 L $\cdot min^{-1}$ with a volume of ultra high purity nitrogen gas five times that of the box to ensure adequate displacement of air within the box. Pure standards of 1,2-dichlorobenzene (DCB), α-hexachlorocyclohexane (HCH), γ-HCH, heptachlor, and *p,p'*-dichlorodiphenyltrichloroethane (*p,p'*-DDT) dissolved in methanol were purchased from VWR Scientific (West Chester, PA, USA) for spiking tissue samples, reference vials, and calibration vials.

The vial equilibration technique was calibrated with vials containing 1, 2, 3, and 4 µl of triolein (99%, Sigma-Aldrich Canada Ltd., Oakville, ON, Canada) spiked with 10 µg each of 1,2-DCB, α-HCH, γ-HCH, and heptachlor, and with 25 µg of *p,p'*-DDT. A reference vial not containing triolein was also prepared with the same amount of chemical. The vials were allowed to equilibrate for several days at room temperature with daily vortexing. Following equilibration, a 50 µl headspace sample was taken with a locking gas tight syringe (Hamilton Co., Reno, NV, USA). Triplicate headspace samples from each vial were analyzed by manual injection on the same gas chromatograph and using the same temperature program outlined in Chapter 2.0.

Tissue vials containing 100 mg of whole tissue of either lodgepole pine (*Pinus contorta*) or Engelmann spruce (*Picea engelmannii*) needles were prepared in the same manner by adding the five OC pesticides at the amounts used for the method calibration. Vials were equilibrated for several days at approximately 10°C by storing the vials in a refrigerator and at 25°C or laboratory temperature. Three replicate vials containing pine and spruce foliage, as well as three replicate reference vials containing chemical without tissue, were equilibrated at each temperature condition. At each sample point, 50 µl headspace samples were

taken in triplicate with a locking gastight syringe and injected manually on the gas chromatograph. Reference headspace vials were injected for every second tissue vial injected. Three vials, one reference and one each containing pine and spruce tissue, were sampled at multiple times to determine the equilibration period for each temperature condition. Headspace in these vials was sampled seven times at 10°C and five times at 25°C for a maximum loss of 350 µl of headspace, or less than 3% of chemical in the vial. This corresponded to equilibration times of 37 days and 64 days at 10°C and 25°C, respectively. The true equilibration time for 25°C is likely much shorter, but due to an unexpected interruption in equipment operation, headspace samples could not be analyzed between the 27^{th} and 64^{th} day of equilibration.

Chromatographic analysis and identification of pesticides were performed using HP Chemstation software (Rev. A.06.03, Hewlett Packard, Palo Alto, CA, USA). Response was measured as the area integrated under the chromatographic peak in Hertz · second. Statistical analysis was performed using either SYSTAT, version 9.01 (SPSS Inc., Chicago, IL, USA) or SPSS for Windows Student Version, release 9.0.1 (SPSS Inc., Chicago, IL, USA).

Specific surface areas and volumes were measured as described in Chapter 5.0. For quality control, all vials were washed with industrial grade detergent, rinsed in triplicate with tap water followed by deionized water, solvent-rinsed with ACS grade acetone and hexane (BDH Inc., Toronto, ON, Canada), and heated for 12 hours at 200°C. Between each injection, the syringe was rinsed with Omnisolv® acetone and hexane (EM Science-Merck KGaA, Darmstadt, Germany).

6.4 RESULTS AND DISCUSSION

6.4.1 Calibration

Levels of all five pesticides in the headspace calibrated linearly with triolein volume (Figure 6.1). All calibration plots showed slopes significantly different from zero at the 95% confidence level, with triolein volume explaining between 89% and 96% of the variation among the mean headspace concentrations. The vial equilibration technique can be further calibrated by comparing the predicted storage capacity of triolein to the experimental value. The product of the volume and the fugacity capacity, calculated using Equation 6.2, gives the predicted storage capacity (Tolls and McLachlan 1994), while the experimental fugacity capacity is determined from Equation 6.7. Calibration revealed that the vial equilibration technique underestimated the storage capacity of triolein (Figure 6.2), similar to results obtained by Drouillard (2000) using octanol as a lipid

surrogate for avian gastrointestinal tissue. Therefore, all experimentally derived fugacity capacities were subsequently corrected for this underestimation based on the slope of the regression line forced through the origin in Figure 6.2 (Drouillard 2000).

6.4.2 Vegetation Fugacity Capacities

Following correction for the underestimation revealed from the calibration, experimental fugacity capacities were generally similar to predicted values (Table 6.2). Although the relationship on which the correction was based is not flawlessly linear (Figure 6.2), results for the corrected experimental fugacity capacities show that vegetation Z values estimated from plant lipid content as described in Equation 6.2 are close approximations to the corrected experimental fugacity capacity. Lipid-based Z values can thus be used in modeling exercises with confidence. Generally, the predicted Z values underestimated the experimental fugacity capacities, with the exception of α-HCH.

The predicted values for fugacity capacity are based on extractable lipid content, Henry's law constant, and K_{OA}, which all contain some degree of error and uncertainty. Furthermore, the parameterization of the sorptive ability of coniferous foliage as being similar to the partitioning process between octanol and air may not be accurate. Thus, it is possible that the experimentally calculated values for fugacity capacity before the correction are a more suitable estimate of the actual storage ability of plant foliage than that determined from plant lipid.

Fugacity capacities are greater for the less volatile, more lipophilic compounds, namely *p,p'*-DDT and γ-HCH (Table 6.2). Both vapor pressure and the octanol-air partition coefficient (K_{OA}) of the chemicals studied were significant predictors of the vegetation fugacity capacities for both species at 10°C and at 25°C (Figure 6.3), with higher K_{OA} and lower vapor pressures eliciting higher Z values. Plant membrane permeances tend to increase with increasing K_{OW} (Kerler and Schönherr 1988), resulting in higher storage capacities due to increased lipid solubility.

6.4.3 Temperature Effects

Cold temperatures promote chemical deposition onto and accumulation in vegetation. Thus, the fugacity capacity for this compartment should be greater at lower temperatures. Results from this experiment fail to support this hypothesis, as the average calculated fugacity capacity was greater at 10°C only for 1,2-DCB in both pine and spruce foliage, and for α-HCH and heptachlor in spruce needles (Table 6.2).

Furthermore, the error associated with the vial equilibration technique does not allow for, in this experiment, a conclusive argument for greater storage in vegetation at colder temperatures. In order to explain this phenomenon more completely, further experiments are required along a broader range of temperature conditions.

6.4.4 Species Differences

Based on predicted Z values, the fugacity capacity of spruce is greater than that of pine (Table 6.2). However, experimental Z values revealed the opposite trend. The predicted Z value is based solely on plant lipid content, which is higher in spruce than in pine. Experimental Z values are a function of the true environmental and physical variables that govern chemical uptake by plants. Thus, other factors, such as needle surface area and volume, would affect the partitioning process. From Chapter 5.0, it was shown that spruce foliage has a larger specific surface area than pine. Many important physiological processes of plant foliage are strongly influenced by its surface area (Beets 1977), a factor that can be extended to the uptake of airborne chemicals by plants. Add to this the fact that spruce contains a higher proportion of lipid than pine, it would be probable that spruce would show a higher fugacity capacity than pine. However, these experiments fail to support this hypothesis. Hauk et al. (1994) found that the fugacity capacity for DDE of the spruce species with twice the lipid content was only slightly greater than the capacity of the other spruce species, indicating little relationship between fugacity capacity and soluble cuticular lipid content.

6.5 CONCLUSIONS

Although the corrected experimental fugacity capacities of vegetation for OCs determined in this study were comparable to those predicted from plant lipid content, the inclusion of a surface area element in predicting the sorptive capabilities of vegetation would be practical. Plant fugacity capacities seem to be independent of exposure time to air and plant concentrations (Tolls and McLachlan 1994). This study shows that the ability for vegetation to store chemical is influenced strongly by properties of the chemical and physical properties of the plant, such as volatility, lipid solubility, and foliage surface area. However, the range of temperatures used as controlled variables in these experiments was not sufficient to overcome the error inherent in the vial equilibration technique. Thus, further work is needed to properly characterize the temperature-dependence of vegetation fugacity capacities and to develop a mathematical means of predicting a plant's fugacity capacity.

Table 6.1 Properties of compounds used in the vial equilibration technique.

Values were compiled from Mackay et al. (2000). * $K_{OA} = K_{OW} \cdot R \cdot T \cdot H^{-1}$ (Harner et al. 2000).

Compound	P_L (Pa)	Log K_{OW}	Log K_{OA}*	H (Pa $\cdot m^3 \cdot mol^{-1}$)
1,2-DCB	1.70×10^{-2}	3.40	4.41	244
α-HCH	1.00×10^{-1}	3.81	7.26	0.87
γ-HCH	2.74×10^{-2}	3.70	7.92	0.15
Heptachlor	2.67×10^{-1}	5.27	6.12	353
p,p'-DDT	1.35×10^{-4}	6.19	9.21	2.36

Table 6.2 Predicted and experimental fugacity capacities.

Predicted fugacity capacities (Z) for species of spruce and pine were calculated using Equation 6.4. Mean experimental Z values, measured at 10°C and 25°C and calculated using Equation 6.7, were adjusted for the underestimation of the vial equilibration technique using the slopes in Figure 6.2. Error estimates represent standard errors of the mean.

Compound	Z Predicted ($mol \cdot m^{-3} \cdot Pa^{-1}$)	Z @ 10°C ($mol \cdot m^{-3} \cdot Pa^{-1}$)	Z @ 25°C ($mol \cdot m^{-3} \cdot Pa^{-1}$)
SPRUCE			
1,2-DCB	0.283	0.255 ± 0.010	0.086 ± 0.001
α-HCH	203.618	10.035 ± 3.054	8.321 ± 0.812
γ-HCH	925.010	162.046 ± 51.658	233.318 ± 59.783
Heptachlor	14.490	9.062 ± 2.098	6.707 ± 0.858
p,p'-DDT	18047.651	1191.412 ± 11.102	9584.585 ± 440.979
PINE			
1,2-DCB	0.290	0.304 ± 0.012	0.185 ± 0.003
α-HCH	208.801	12.382 ± 4.798	15.563 ± 2.719
γ-HCH	948.556	307.977 ± 183.960	488.056 ± 164.677
Heptachlor	14.859	7.794 ± 1.592	12.969 ± 2.555
p,p'-DDT	18507.046	2205.494 ± 33.608	17960.685 ± 357.571

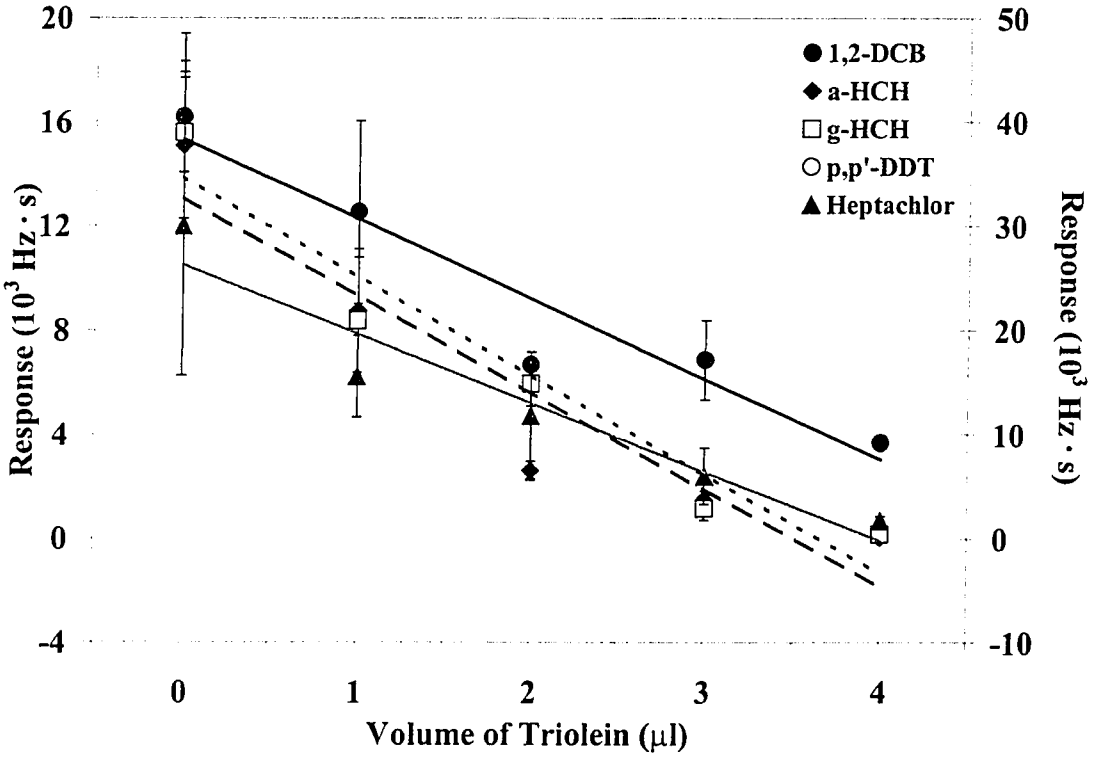


Figure 6.1 Calibration of the vial equilibration technique.

Lines of best fit are drawn for the relationship between instrument response (Hz · s) and triolein volume (μl) for the following compounds: 1,2-DCB, thin line ($r=0.960$, $p<0.05$); α-HCH, dashed line ($r=0.944$, $p<0.05$); γ-HCH, dotted line ($r=0.967$, $p<0.01$); *p,p'*-DDT, thick line ($r=0.980$, $p<0.01$). Heptachlor response, gray line ($r=0.962$, $p<0.01$), corresponds to the right-hand scale.

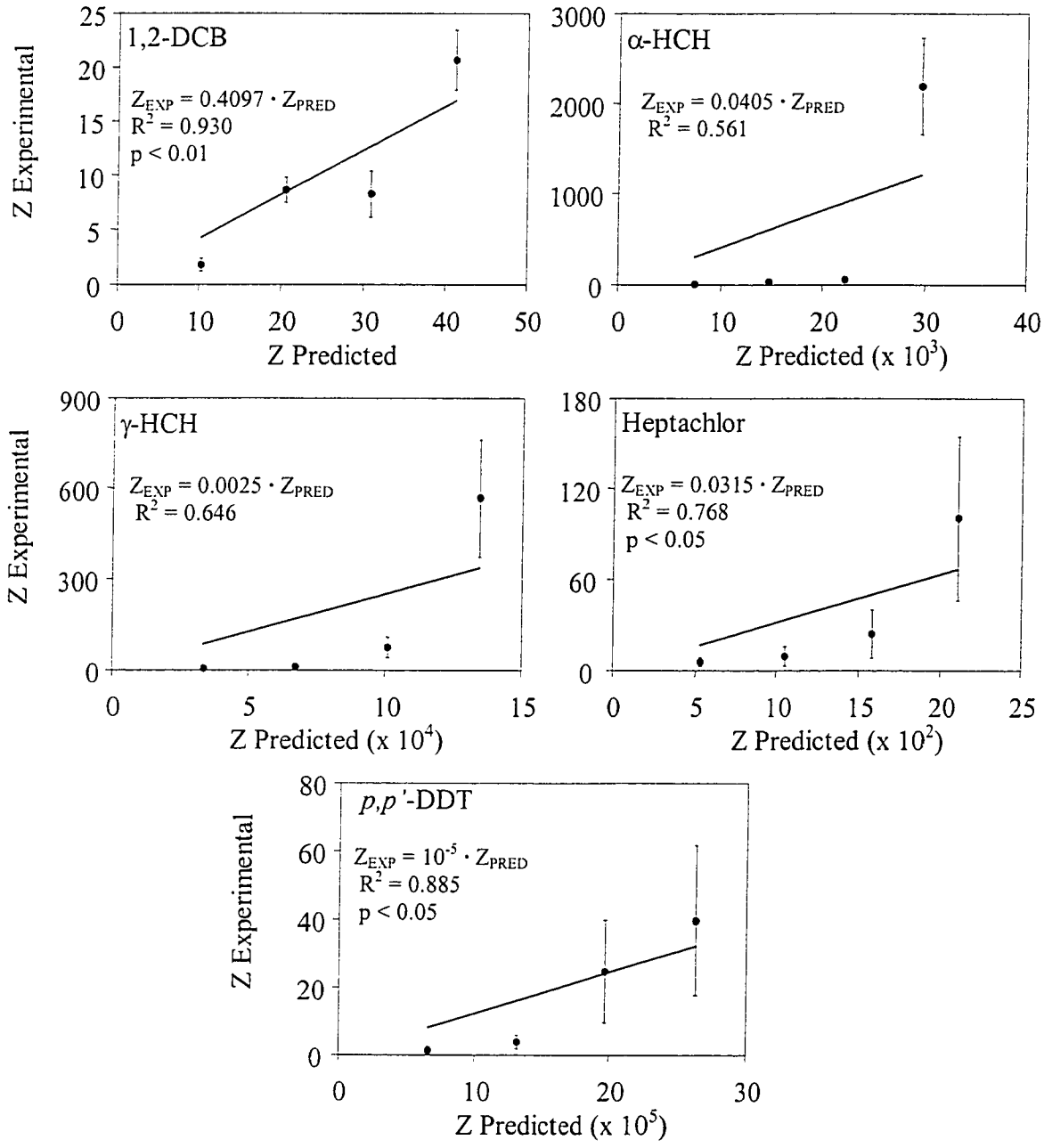


Figure 6.2 Comparison of experimental and predicted triolein fugacity capacities.

The experimental fugacity capacity, Z (mol $\cdot m^{-3} \cdot Pa^{-1}$) was determined using Equation 6.7 and the predicted Z was estimated from the volume of triolein in the headspace vial and Equation 6.2. Regression lines were forced through the origin.

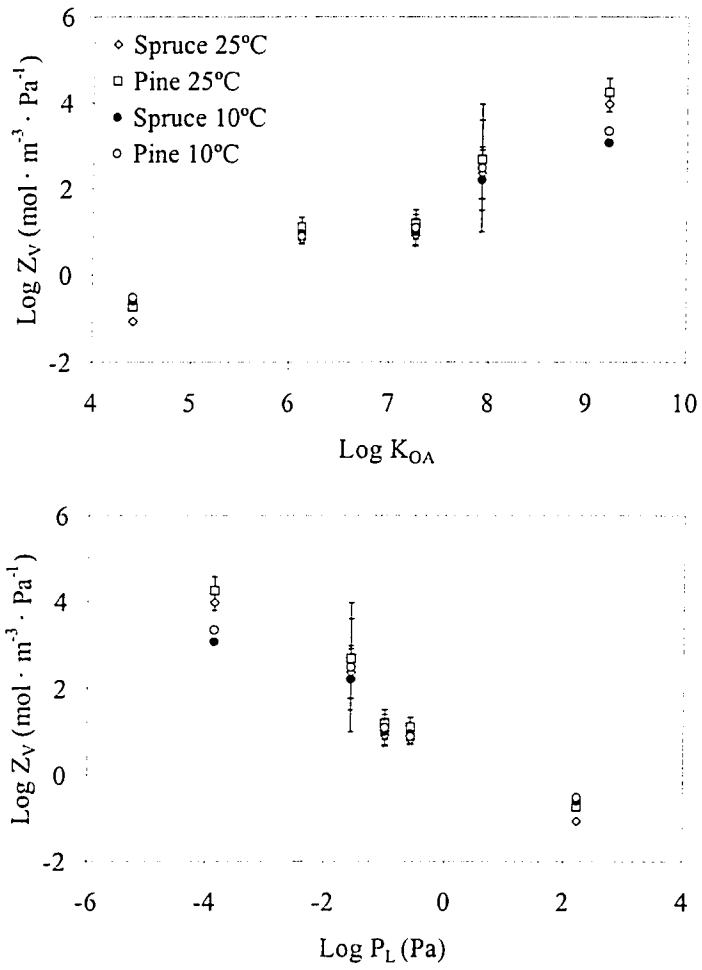


Figure 6.3 Plots of vegetation fugacity capacity versus K_{OA} and vapor pressure.

The vegetation fugacity capacity (Z_V) of each species was measured at 10°C and 25°C using the vial equilibration technique and calculated using Equation 6.7. The octanol-air partition coefficient (K_{OA}) and the subcooled liquid vapor pressure (P_L), listed in Table 6.1, and the experimental fugacity capacities are presented on a logarithmic scale. Error bars represent standard errors of the mean.

7.0 GENERAL DISCUSSION

The research outlined in this thesis was undertaken to characterize the propensity for persistent organic pollutants (POPs) to accumulate in mountain regions and to undergo subsequent fractionation in elevated areas. This phenomenon has been well documented in polar regions (e.g. Cotham and Bidleman 1991, Wania and Mackay 1993a, Simonich and Hites 1995a, Wania and Mackay 1996, Calamari et al. 1991). However, high altitudes have been neglected in this analysis, although both exhibit low temperatures that promote the condensation and deposition of semivolatile chemicals. The temperature and altitudinal dependencies of POP concentrations in vegetation were demonstrated in Chapters 2.0 and 3.0.

The Canadian Rocky Mountains is not the only high-altitude region susceptible to the enrichment of pollutants. Grimalt et al (2001) found that concentrations of low-volatility compounds in fish and sediment in European lakes correlated with elevation, but the relationship did not hold for the more volatile compounds. Higher altitude sites in Austria showed higher concentrations of polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDDFs), and dichlorodiphenyltrichloroethane (DDT) in spruce needles (Weiss 1997b, Weiss et al 1997, Weiss et al 1998). Migaszewski (1999) also found elevated concentrations of many polycyclic aromatic hydrocarbons (PAHs), PCBs, and OC pesticides in soil and vegetation at higher sites in Poland.

7.1 ALTITUDINAL FRACTIONATION IN VEGETATION

Trends in OC concentrations in vegetation with altitude were revealed in Chapter 2.0, where it was shown that more volatile compounds accumulate to a greater degree at higher elevations than less volatile chemicals. Cluster analysis was performed to identify those compounds that behave similarly with respect to altitudinal distillation and temperature-dependent accumulation (Figures 7.1 and 7.2). Cluster analysis attempts to identify relatively homogeneous groups of cases based on selected characteristics, using an algorithm that starts with each case in a separate cluster and combines clusters until only one is left. The tree diagram from the cluster analysis for the change in OC concentration in vegetation with site elevation (Figure 7.1) that was based on vapor pressure reveals that the twelve least volatile compounds are grouped together at the shortest Euclidean distance. The next division occurs with α-hexachlorocyclohexane (α-HCH), in its own group with a vapor pressure of 1.0 Pa, followed by the three compounds with vapor pressures exceeding 0.1 Pa, hexachlorobenzene (HCB) and heptachlor in one group, and β-endosulfan, in its own cluster. These

classifications are in line with the theory of global fractionation, in which semivolatile compounds with vapor pressures between 0.01 Pa and 1.0 Pa are volatile enough to undergo long-range transport, but still tend to condense at colder temperatures. Chemicals that preferentially accumulate in mid-latitudes have relatively low mobility with vapor pressures between 0.001 Pa and 0.01 Pa (Wania and Mackay 1996).

Similar yet less consistent trends were observed in the tree diagram for the cluster analysis of the temperature-dependence of OC concentrations based on vapor pressure (Figure 7.2). The relatively nonvolatile γ-chlordane belongs to its won cluster, joining the eleven least volatile compounds and the volatile α-HCH. Anomalies in expected behavior are likely due to seasonal effects as samples were collected throughout two summer seasons and seasonal warming may compound the effects of decreased temperature with altitude.

7.2 LONG-RANGE TRANSPORT

The lack of a temperature-dependence for atmospheric concentrations of OC pesticides and PCBs, described in Chapter 3.0, indicates that the altitudinal fractionation of these chemicals is not due to local-air surface exchange (Wania et al. 1998). Sources of air masses to the Canadian Rocky Mountains, particularly higher elevations, are predominantly Asian and include the Pacific Ocean, as was demonstrated in Chapter 2.0. The accumulation of more volatile POPs at higher altitudes thus seems to be a result of continuous airborne inputs arriving via long-range transport from ongoing international emissions and volatilization of limited-use compounds from lower latitudes.

Similarly, Weiss (1997a) concluded that much of the PCDD/F inventory in elevated Austrian forest ecosystems likely arose from long-range transport, based on homologue profiles and because levels of PCDD/Fs differed from reported local emissions. In their global study of pollutant concentrations in plants, Calamari et al. (1995) detected high levels of α-HCH in India and Jordan, high levels of γ-HCH and HCB in Europe and Chile, and elevated concentrations of DDT in India, Mexico, Indonesia, and African countries. The fate of POP emissions encompasses a global scale that includes the Canadian Rocky Mountains.

A simple box-model was constructed to determine the relative contribution from volatilization of four compounds from vegetation to atmospheric concentrations. The model consisted of a square-kilometer of spruce forest, with an atmospheric height of 9493 m for a northern temperate location (Wania and Mackay 1995) and a forest canopy density of 0.0017 $m^3 \cdot m^{-2}$ (McLachlan and Horstmann 1998). The specific volume of spruce foliage, 2.04 x 10^{-6} $m^3 \cdot g^{-1}$, and the lipid content of 0.72% as determined in Chapter 5.0 were used.

An average wind speed of 2.25 m $\cdot s^{-1}$ was obtained from meteorological data and used to calculate the advection rate of 1.85 x 10^{12} m^3 $\cdot day^{-1}$. The rate of volatilization from vegetation was taken as the change in lipid-based concentration over time corrected for growth dilution as described in Chapter 5.0. These rates, along with average air concentrations, allowed for the estimation of the input from vegetation to analyte concentrations in air leaving the square-kilometer of forest (Table 7.1). Although these compounds are volatilizing from vegetation, atmospheric concentrations are so high that this evaporation contributes very little to the fractionation occurring in the Canadian Rocky Mountains, accounting for less than 0.01% of the levels in air. This is further support for the notion that the accumulation of POPs at high altitudes in western Canada arises from sources arriving to the region via trans-Pacific long-range transport. This also explains why air concentrations of these chemicals are not sensitive to temperature fluctuations, which would affect partitioning between air and vegetation.

7.3 PERSISTENT POLLUTANTS IN VEGETATION

The contamination of vegetation should be of concern to all individuals as it has great ability to internalize and retain POPs due to its abundance in the environment and high lipid content. More importantly, it is the primary source of nutrients to humans, livestock, and wildlife. Pine needles are efficient at accumulating POPs because they are coated with a waxy surface that can bind airborne particles (Kylin et al. 1994), and the research detailed in this thesis is further testimony to the great ability for vegetation to adsorb airborne contaminants. One of the objectives of this research was to quantify the capacity of coniferous vegetation to retain OC compounds and to relate this storage capacity to temperature. The vial equilibration technique used for this purpose was successful in estimating the fugacity capacities of pine and spruce foliage, but failed to determine the temperature-dependence of such properties. The design of the experiment was such that the desired aims could not be achieved due to other constraints. Continuing this type of research is necessary to define the role of vegetation and forests in the global distribution of POPs, and should be expanded.

Forests play a significant role in the removal of OCs from the atmosphere and their subsequent transfer to the underlying soil through litterfall, where the storage capacity for such chemicals is extremely great (Wania and McLachlan 2001). As a result of this ability for forests to filter organic pollutants from the air, forest soils have been found to contain higher pollutant levels than agricultural soils (Weiss et al. 1993).

Weiss (2000) showed that young needles in a coniferous forest contain higher levels of volatile compounds, such as PAH, HCB, and HCH, and lower levels of heavier PCDDs, PCDDFs and PCBs than the underlying humus layer, indicating loss of the lighter compounds from the humus layer by volatilization. Furthermore, litterfall under a coniferous forest canopy has been shown to contain higher concentrations of PAH than litterfall under a deciduous canopy, confirming the ability of coniferous vegetation to accumulate greater amounts of airborne chemical due to its longer lifetime (Matzner 1984). Forest soils can thus act as either a source or a sink for semivolatile chemicals, complementing the role that forest foliage plays in the removal of airborne chemicals from the atmosphere.

Many factors influence the degree to which forests accumulate airborne POPs. While soil and vegetation can both act as a chemical reservoir in forested areas of the Canadian Rocky Mountains, the rate of gaseous deposition onto vegetation is ten times greater than to bare soil (McLachlan and Horstmann 1998). More volatile compounds have higher gaseous deposition velocities than less volatile chemicals, and dry particle deposition velocities are expected to be higher during the summer than other seasons due to high solar radiation and unstable atmospheric conditions. Higher velocities are also likely for deposition onto trees compared to corn and grass due to the higher roughness of tree foliage surfaces. Furthermore, organic compounds that adsorb to the plant cuticle have higher deposition velocities than inorganic gases that enter the leaf via stomata, which have much smaller adsorption capacities than the cuticle (Horstmann and McLachlan 1998). Air reaching the lower part of the canopy may be depleted of OCs due to adsorption to upper parts of the canopy (McLachlan et al. 1995). Strachan et al. (1994) concluded that sampling of pine needles restricted to a single tree as opposed to many trees at the same site did not impact OC concentrations. Furthermore, tree age was not important, whereas sampling height was, and the direction the tree was facing may only be relevant in cases where local emissions exist. It appears that the air source is the important determining factor in the accumulation of airborne chemicals in forest foliage.

A compound's lipid solubility and volatility, as well as plant lipid content, are also important factors in the partitioning between the air and vegetation (Bacci and Gaggi 1986). This effect was manifested in observations from Chapters 2.0 and 5.0, where increases in plant concentration with elevation were related to vapor pressure and the octanol-air partition coefficient (K_{OA}). Compounds with log K_{OA} between six and eight tend to have a high mobility in the environment, while those with log K_{OA} values between eight and ten are less

mobile (Wania and Mackay 1996). For compounds with K_{OA} greater than seven, air-side resistance dominates the accumulation of airborne compounds in vegetation, whereas plant-side resistance governs adsorption of those compounds with lower K_{OA} values (Kömp and McLachlan 1997a). Thus, in the accumulation of POPs in vegetation, less volatile compounds with high K_{OA} and K_{OW} values are favored over more volatile chemicals (Weiss 2000). Furthermore, the tendency for lipophilic compounds to accumulate in vegetation is weakened if they have a relatively high air-water partition coefficient. Conversely, a low air-water partition coefficient will enhance a water-soluble compound's affinity for the waxy cuticle (Bacci et al. 1990a). Compounds with log K_{OA} between 8.5 and 11 undergo kinetically limited dry gaseous deposition, which is limited by exposure time and advection rate. The ability for plant foliage to store these chemicals is so great that equilibrium is not normally reached within the lifetime of the plant (McLachlan 1995).

7.4 THEORY VERSUS REALITY

Discrepancies between modeled and actual chemical fluxes and between experimentally determined and calculated estimations of vegetation fugacity capacities were revealed in this thesis. The theoretical fugacity capacity and chemical fluxes are both based on various uncertain parameters and include several assumptions that may be incorrect or inadequately estimated. It is possible that the physical processes responsible for temperature-dependent chemical transfer between the air and vegetation are more closely related to those determined experimentally in Chapters 5.0 and 6.0, and that the methods used to model and replicate the true environment are incorrect. More weight should be placed on the results from the field study that represent the actual conditions responsible for the accumulation of POPs in terrestrial vegetation in mountain environments.

This thesis shows that the Canadian Rocky Mountains are susceptible to an enrichment of certain POPs as they exhibit low temperatures and high precipitation and are rich in vegetation. It is conceivable that these patterns of accumulation are manifested in other mountain regions that exhibit cooler temperatures at higher elevations. Recognizing the interplay between chemical properties, accumulation mechanisms, and environmental effects is essential to understanding the processes and subsequent implications of global POP transport. This research advances our comprehension of these interactions.

Table 7.1 Contribution of volatilization from vegetation to air contamination.

The sum of the rate of volatilization from vegetation and the incoming advection rate gives the outgoing rate of migration, as described in the text.

Compound	Incoming ($mol \cdot day^{-1}$)	Volatilized ($mol \cdot day^{-1}$)	Outgoing ($mol \cdot day^{-1}$)	Percent Added From Vegetation
α-HCH	0.1845	8.23×10^{-7}	0.1845	0.0004
HCB	0.0923	1.33×10^{-6}	0.0923	0.0014
p,p'-DDT	0.0092	7.83×10^{-7}	0.0092	0.0085
SUM PCB	0.0369	5.18×10^{-7}	0.0369	0.0014

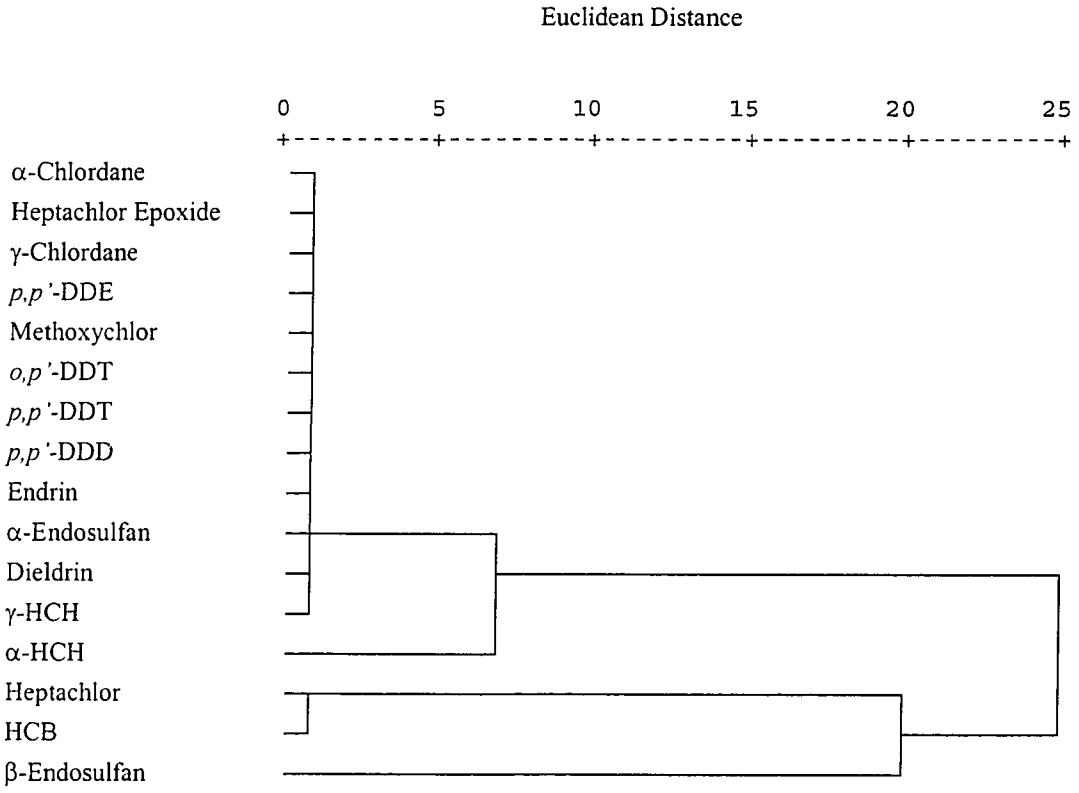


Figure 7.1 Altitudinal behavior of OCs as it relates to volatility.

Tree diagram for the single distance (nearest neighbor) hierarchical cluster analysis performed using the slope of the regression for OC concentration in vegetation versus altitude, listed in Table 2.2 and the compound's vapor pressure (Pa).

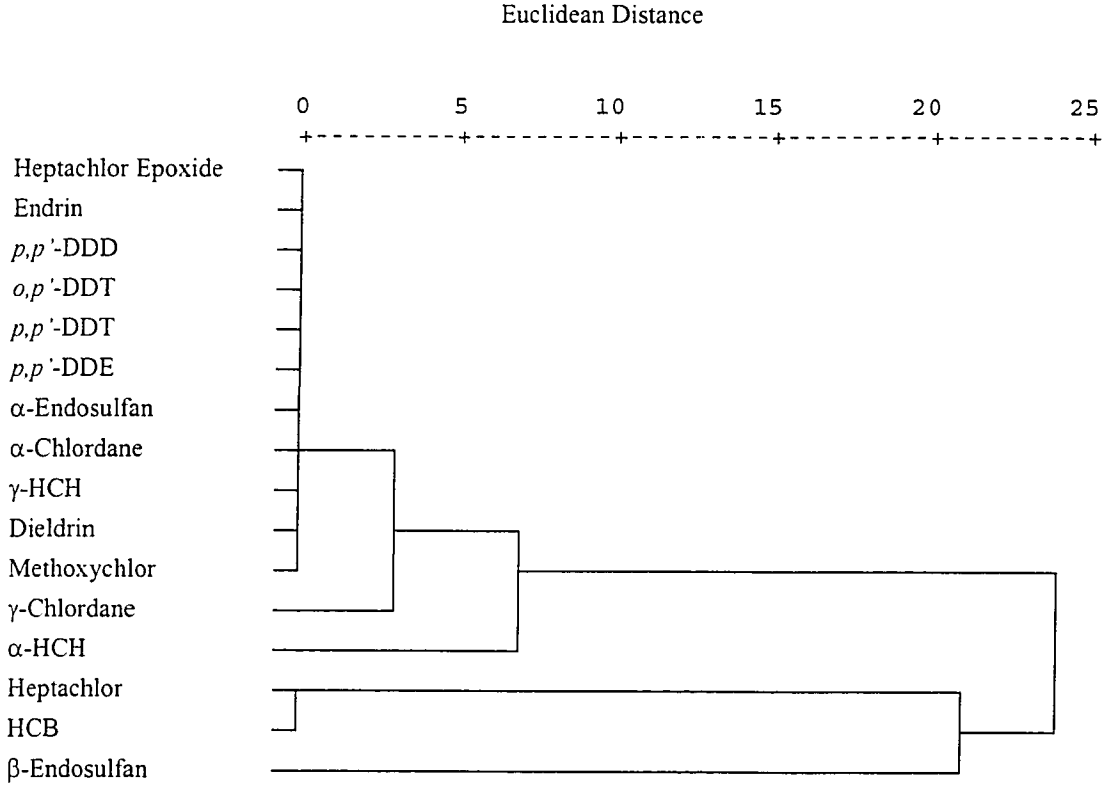


Figure 7.2 Behavior of OCs with temperature as it relates to volatility.

Tree diagram for the single distance (nearest neighbor) hierarchical cluster analysis performed using the slope of the regression of OC concentration in vegetation versus temperature, listed in Table 3.3 and the compound's vapor pressure (Pa).

8.0 SUMMARY AND CONCLUSIONS

This research provides further understanding of the many events involved in the global distribution of persistent organic pollutants (POPs). Observations gleaned from this study can be used to expand the appreciation for the ability of high mountain environments to accumulate persistent organic pollutants (POPs); to quantify and qualify the exchange between coniferous vegetation and air; to add to the knowledge surrounding the atmospheric transport of airborne chemicals; and to develop concepts explaining the interplay between various environmental factors in the fate of POPs.

Results from this study revealed that lower temperatures encountered in high altitude areas are favoring accumulation of certain semivolatile chemicals in terrestrial vegetation. Compounds susceptible to this selective accumulation include those with subcooled liquid vapor pressures between 0.001 Pa and 1.0 Pa. These observations were consistent with the theory of global fractionation. Modeling efforts describing the processes involved in this fractionation upslope further supported these trends, showing either enhanced deposition onto vegetation from air and rain at high altitudes, or increased volatilization of chemicals from vegetation to the atmosphere at lower elevations.

Air concentrations and diurnal vegetation samples suggest that the reason for this enhanced accumulation in elevated areas is increased atmospheric deposition from continuous sources in air masses and not from local revolatilization from vegetation, soil, and water. Examination of longitudinal trends indicates that air masses traveling over the Pacific Ocean are depleted of POPs as a result of deposition onto terrestrial surfaces on the west coast before reaching the Canadian Rocky Mountains. Lower pressures observed at higher elevations result in the arrival of air masses from more distant sources than are encountered at lower altitudes. Volatilization of adsorbed chemical from vegetation occurs in this study area, but contributes very little to levels of these compounds in air and the subsequent fractionation upslope. Although differences were not observed between species of pine and spruce with respect to lipid-based concentrations, differences in direction and rate of flux, and to a lesser extent fugacity capacity, were noted as a result of dissimilar morphologies. Species of spruce showed higher rates of transfer and larger storage capacities due to higher a specific surface area and greater proportion of lipid than species of pine.

In conclusion, cold temperatures, enhanced precipitation, low pressures, large surface areas of lipid-rich vegetation, and proximity to the Pacific Ocean allow for the accumulation of POPs in elevated areas in the

Canadian Rocky Mountains and the fractionation of semivolatile chemicals upslope. Many of these POPs are likely arriving from distant sources, demonstrating the role that high altitude environments play in the destiny of airborne POPs and the need to consider mountain ecosystems in the assessment of the global fate of these chemicals.

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APPENDIX I – SAMPLE AND METEOROLOGICAL DATA

Bow Lake										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
13	6/4/1999	ES	1.13	49.85	0.89	79.85	89.50	0.53		197.00
20	6/4/1999	ES	1.36	50.00	0.89	79.85	89.50	0.53		197.00
14	6/16/1999	ES	1.45	43.86	7.73	81.04	90.60	0.24		208.60
15	6/16/1999	ES	1.37	46.50	7.73	81.04	90.60	0.24		208.60
1	6/30/1999	ES	0.66	45.28	5.18	80.10	90.36	0.52		249.60
2	6/30/1999	ES	0.64	47.12	5.18	80.10	90.36	0.52		249.60
7	6/30/1999	LP	0.96	52.02	5.18	80.10	90.36	0.52		249.60
8	6/30/1999	LP	0.64	51.70	5.18	80.10	90.36	0.52		249.60
16	7/17/1999	ES	0.77	55.71	4.96	80.62	84.62	0.82		208.60
17	7/17/1999	ES	1.47	58.47	4.96	80.62	84.62	0.82		208.60
18	7/17/1999	LP	0.87	53.10	4.96	80.62	84.62	0.82		208.60
19	7/17/1999	LP	0.78	52.93	4.96	80.62	84.62	0.82		208.60
3	7/31/1999	ES	0.92	63.82	10.44	80.46	64.28	0.98		282.60
4	7/31/1999	ES	0.54	63.56	10.44	80.46	64.28	0.98		282.60
9	7/31/1999	LP	0.92	56.04	10.44	80.46	64.28	0.98		282.60
10	7/31/1999	LP	0.79	58.83	10.44	80.46	64.28	0.98		282.60
5	8/11/1999	ES	0.77	65.35	11.54	80.58	92.92	0.54		242.00
6	8/11/1999	ES	1.77	65.43	11.54	80.58	92.92	0.54		242.00
11	8/11/1999	LP	0.88	69.72	11.54	80.58	92.92	0.54		242.00
12	8/11/1999	LP	1.10	69.65	11.54	80.58	92.92	0.54		242.00
121	4/25/2000	LP	0.55	54.89	-1.00	79.95	60.00	6.14		201.00
122	4/25/2000	LP	0.38	55.48	-1.00	79.95	60.00	6.14		201.00
125	4/25/2000	ES	0.32	49.17	-1.00	79.95	60.00	6.14		201.00
126	4/25/2000	ES	0.70	48.38	-1.00	79.95	60.00	6.14		201.00
117	5/9/2000	LP	0.30	56.26	-2.08	79.71	65.00	4.61		174.00
118	5/9/2000	LP	0.21	51.47	-2.08	79.71	65.00	4.61		174.00
137	5/9/2000	LP	0.34	56.90	-2.08	79.71	65.00	4.61		174.00
138	5/9/2000	LP	0.36	52.31	-2.08	79.71	65.00	4.61		174.00
147	5/30/2000	LP	0.32	53.75	1.59	80.02	80.00	4.57		216.86
148	5/30/2000	LP	0.29	52.64	1.59	80.02	80.00	4.57		216.86
149	5/30/2000	ES	0.41	53.67	1.59	80.02	80.00	4.57		216.86
150	5/30/2000	ES	0.39	51.09	1.59	80.02	80.00	4.57		216.86
187	6/28/2000	LP	0.48	51.68	7.41	81.04	69.11	0.88	1.06	154.67
188	6/28/2000	LP	0.55	54.86	7.41	81.04	69.11	0.88	1.06	154.67
189	6/28/2000	ES	0.52	46.78	7.41	81.04	69.11	0.88	1.06	154.67
190	6/28/2000	ES	0.42	45.99	7.41	81.04	69.11	0.88	1.06	154.67
193	7/27/2000	ES	0.25	77.25	9.65	80.58	76.05	0.97	5.92	198.85
194	7/27/2000	ES	0.36	76.36	9.65	80.58	76.05	0.97	5.92	198.85
209	7/27/2000	LP	0.47	54.58	9.65	80.58	76.05	0.97	5.92	198.85
210	7/27/2000	LP	0.54	50.59	9.65	80.58	76.05	0.97	5.92	198.85

ES = Engelmann spruce
WS = white spruce
LP = lodgepole pine
WP = whitebark pine

Prec = precipitation
RH = relative humidity
WS = wind speed
WD = wind direction

Dixon Dam										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
119	4/22/2000	WS	0.37	44.11	9.95					
120	4/22/2000	WS	0.27	45.10	9.95					
133	4/22/2000	LP	0.15	52.38	9.95					
134	4/22/2000	LP	0.17	52.32	9.95					
115	5/10/2000	WS	0.22	42.46	5.79				3.40	
116	5/10/2000	WS	0.29	42.31	5.79				3.40	
151	6/3/2000	WS	0.25	75.27	9.13				0.00	
152	6/3/2000	WS	0.15	75.05	9.13				0.00	
181	6/22/2000	WS	0.35	70.85	12.84				0.16	
182	6/22/2000	WS	0.35	67.81	12.84				0.16	
201	7/12/2000	WS	0.31	55.11	14.45				2.87	
202	7/12/2000	WS	0.38	56.75	14.45				2.87	
225	8/1/2000	WS	0.21	55.84	18.70				0.00	
226	8/1/2000	WS	0.35	59.94	18.70				0.00	

Donald Station										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
21	6/10/1999	WS	0.74	68.75	8.67	92.23	66.05	0.97	0.76	128.16
35	6/10/1999	WS	0.51	77.52	8.67	92.23	66.05	0.97	0.76	128.16
22	6/23/1999	WS	0.92	60.65	13.13	91.94	58.39	0.99	0.04	132.68
23	6/23/1999	WS	0.58	76.81	13.13	91.94	58.39	0.99	0.04	132.68
24	7/7/1999	WS	0.42	65.76	10.17	92.36	74.58	1.89	2.28	192.50
27	7/7/1999	LP	1.08	71.13	10.17	92.36	74.58	1.89	2.28	192.50
28	7/7/1999	LP	0.75	73.82	10.17	92.36	74.58	1.89	2.28	192.50
36	7/7/1999	WS	0.46	67.83	10.17	92.36	74.58	1.89	2.28	192.50
29	7/20/1999	LP	0.56	67.88	13.17	92.63	59.58	1.58	0.08	143.08
30	7/20/1999	LP	0.17	63.07	13.17	92.63	59.58	1.58	0.08	143.08
37	7/20/1999	WS	0.60	55.66	13.17	92.63	59.58	1.58	0.08	143.08
38	7/20/1999	WS	0.73	50.80	13.17	92.63	59.58	1.58	0.08	143.08
31	8/4/1999	LP	1.29	53.45	15.50	93.02	62.89	0.98	0.84	143.32
32	8/4/1999	LP	0.79	64.48	15.50	93.02	62.89	0.98	0.84	143.32
39	8/4/1999	WS	1.02	54.54	15.50	93.02	62.89	0.98	0.84	143.32
40	8/4/1999	WS	0.88	56.00	15.50	93.02	62.89	0.98	0.84	143.32
25	8/19/1999	ES	0.94	59.65	13.87	92.75	71.80	0.44	0.44	70.88
26	8/19/1999	ES	0.94	59.47	13.87	92.75	71.80	0.44	0.44	70.88
33	8/19/1999	LP	0.50	61.54	13.87	92.75	71.80	0.44	0.44	70.88
34	8/19/1999	LP	0.45	60.00	13.87	92.75	71.80	0.44	0.44	70.88

Lower Kananskis Lake										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
101	5/2/2000	ES	0.53	51.02	8.56				0.24	
102	5/2/2000	ES	0.19	51.59	8.56				0.24	
135	5/2/2000	LP	0.32	54.38	8.56				0.24	
136	5/2/2000	LP	0.36	54.66	8.56				0.24	
105	5/18/2000	ES	0.34	45.38	5.62				0.72	
106	5/18/2000	ES	0.25	46.07	5.62				0.72	
109	5/18/2000	LP	0.14	48.17	5.62				0.72	
110	5/18/2000	LP	0.31	50.38	5.62				0.72	
161	6/8/2000	LP	0.27	56.73	10.51				1.12	
162	6/8/2000	LP	0.21	53.40	10.51				1.12	
163	6/8/2000	ES	0.34	42.58	10.51				1.12	
164	6/8/2000	ES	0.48	44.39	10.51				1.12	
183	6/22/2000	LP	0.29	47.57	9.00				1.18	
184	6/22/2000	LP	0.24	50.44	9.00				1.18	
185	6/22/2000	ES	0.43	51.96	9.00				1.18	
186	6/22/2000	ES	0.40	56.62	9.00				1.18	
199	7/14/2000	LP	0.19	51.86	13.76				0.04	
200	7/14/2000	LP	0.25	50.70	13.76				0.04	
207	7/14/2000	ES	0.32	46.82	13.76				0.04	
208	7/14/2000	ES	0.25	43.46	13.76				0.04	
213	8/7/2000	ES	0.45	58.01	14.41					
214	8/7/2000	ES	0.43	59.99	14.41					
223	8/7/2000	LP	0.44	61.46	14.41					
224	8/7/2000	LP	0.52	60.59	14.41					

Rock Isle										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
41	6/25/1999	ES	1.00	57.53	3.40					
42	6/25/1999	ES	0.85	53.05	3.40					
43	7/2/1999	ES	0.76	53.71	2.22					
44	7/2/1999	ES	0.71	52.74	2.22					
61	7/2/1999	WP	1.40	53.37	2.22					
62	7/2/1999	WP	1.20	56.34	2.22					
45	7/8/1999	ES	0.60	53.39	4.21					
46	7/8/1999	ES	0.33	48.86	4.21					
53	7/8/1999	WP	1.09	52.75	4.21					
54	7/8/1999	WP	2.33	53.85	4.21					
47	7/23/1999	ES	0.44	48.31	8.81					
48	7/23/1999	ES	0.98	47.97	8.81					
55	7/23/1999	WP	0.73	48.79	8.81					
56	7/23/1999	WP	0.76	55.29	8.81					
49	8/6/1999	ES	0.82	82.09	12.35					
50	8/6/1999	ES	0.76	81.08	12.35					
57	8/6/1999	WP	1.24	55.05	12.35					
58	8/6/1999	WP	0.77	56.06	12.35					
51	8/18/1999	ES	0.81	72.45	6.07					
52	8/18/1999	ES	0.86	77.88	6.07					
59	8/18/1999	WP	0.82	53.54	6.07					
60	8/18/1999	WP	0.60	51.57	6.07					
165	6/17/2000	WP	0.64	54.08	2.75				8.04	
166	6/17/2000	WP	0.49	54.20	2.75				8.04	
167	6/17/2000	ES	0.40	50.73	2.75				8.04	
168	6/17/2000	ES	0.28	51.04	2.75				8.04	
169	6/29/2000	LP	0.31	48.10	7.20				1.20	
170	6/29/2000	LP	0.52	51.56	7.20				1.20	
171	6/29/2000	ES	0.31	54.85	7.20				1.20	
172	6/29/2000	ES	0.44	51.48	7.20				1.20	
191	7/27/2000	ES	0.33	46.85	8.87				9.50	
192	7/27/2000	ES	0.34	49.58	8.87				9.50	
203	7/27/2000	WP	0.37	50.84	8.87				9.50	
204	7/27/2000	WP	0.31	49.84	8.87				9.50	
221	8/16/2000	WP	0.65	70.94	6.69					
222	8/16/2000	WP	0.46	71.62	6.69					
229	8/16/2000	WS	0.33	73.43	6.69					
230	8/16/2000	WS	0.30	72.44	6.69					

Vermilion Lakes										
Sample	Date	Species	Lipid	Moisture	Temp	Pressure	RH	Prec	WS	WD
			%	%	°C	kPa	%	mm	m/s	°N
63	6/11/1999	WS	1.11	49.00	6.05		65.30	2.01		198.82
74	6/11/1999	WS	1.00	49.29	6.05		65.30	2.01		198.82
64	6/23/1999	WS	0.42	59.51	11.46		64.70	2.91		227.94
65	6/23/1999	WS	0.52	71.13	11.46		64.70	2.91		227.94
66	7/7/1999	LP	0.51	48.90	8.37		77.60	1.78		160.36
67	7/7/1999	LP	0.27	50.01	8.37		77.60	1.78		160.36
75	7/7/1999	WS	0.72	64.96	8.37		77.60	1.78		160.36
76	7/7/1999	WS	0.87	59.30	8.37		77.60	1.78		160.36
68	7/20/1999	LP	0.94	46.80	9.73		70.80	1.69		120.66
69	7/20/1999	LP	0.94	47.38	9.73		70.80	1.69		120.66
77	7/20/1999	WS	0.63	57.47	9.73		70.80	1.69		120.66
78	7/20/1999	WS	0.62	57.30	9.73		70.80	1.69		120.66
70	8/3/1999	LP	0.92	64.10	12.57		66.60	1.81		70.92
71	8/3/1999	LP	1.04	66.81	12.57		66.60	1.81		70.92
79	8/3/1999	WS	0.92	59.74	12.57		66.60	1.81		70.92
80	8/3/1999	WS	1.02	55.33	12.57		66.60	1.81		70.92
72	8/19/1999	LP	0.62	65.57	12.69		64.80	1.96		189.34
73	8/19/1999	LP	0.47	63.58	12.69		64.80	1.96		189.34
81	8/19/1999	WS	0.62	62.35	12.69		64.80	1.96		189.34
82	8/19/1999	WS	1.37	61.99	12.69		64.80	1.96		189.34
129	4/18/2000	ES	0.63	45.87	-0.57	101.49	73.41	1.84	1.44	127.17
130	4/18/2000	ES	0.59	48.58	-0.57	101.49	73.41	1.84	1.44	127.17
131	4/18/2000	LP	0.37	50.32	-0.57	101.49	73.41	1.84	1.44	127.17
132	4/18/2000	LP	0.10	49.19	-0.57	101.49	73.41	1.84	1.44	127.17
107	5/4/2000	WS	0.11	44.48	6.74	101.18	51.39	3.14	1.24	223.75
108	5/4/2000	WS	0.18	46.53	6.74	101.18	51.39	3.14	1.24	223.75
145	5/4/2000	LP	0.50	45.90	6.74	101.18	51.39	3.14	1.24	223.75
146	5/4/2000	LP	0.47	48.27	6.74	101.18	51.39	3.14	1.24	223.75
139	5/14/2000	LP	0.25	49.00	2.45	101.45	79.14	1.38	3.52	156.83
140	5/14/2000	LP	0.41	50.67	2.45	101.45	79.14	1.38	3.52	156.83
141	5/14/2000	WS	0.23	44.24	2.45	101.45	79.14	1.38	3.52	156.83
142	5/14/2000	WS	0.22	46.22	2.45	101.45	79.14	1.38	3.52	156.83
153	6/7/2000	LP	0.39	47.07	11.44	101.73	52.93	1.69	0.32	167.33
154	6/7/2000	LP	0.25	50.56	11.44	101.73	52.93	1.69	0.32	167.33
155	6/7/2000	WS	0.37	67.11	11.44	101.73	52.93	1.69	0.32	167.33
156	6/7/2000	WS	0.36	45.32	11.44	101.73	52.93	1.69	0.32	167.33
173	6/22/2000	WS	0.31	73.41	10.83	101.22	58.92	2.28	0.08	217.08
174	6/22/2000	WS	0.28	80.54	10.83	101.22	58.92	2.28	0.08	217.08
179	6/22/2000	LP	0.72	48.15	10.83	101.22	58.92	2.28	0.08	217.08
180	6/22/2000	LP	0.76	47.37	10.83	101.22	58.92	2.28	0.08	217.08
197	7/14/2000	LP	0.41	46.59	14.64	101.42	49.39	2.20	0.00	200.08
198	7/14/2000	LP	0.27	44.94	14.64	101.42	49.39	2.20	0.00	200.08
205	7/14/2000	WS	0.22	53.71	14.64	101.42	49.39	2.20	0.00	200.08
206	7/14/2000	WS	0.22	62.91	14.64	101.42	49.39	2.20	0.00	200.08
219	8/8/2000	LP	0.30	60.44	14.09	101.40	71.41	1.86	0.72	161.86
220	8/8/2000	LP	0.23	62.64	14.09	101.40	71.41	1.86	0.72	161.86
227	8/8/2000	WS	0.30	62.78	14.09	101.40	71.41	1.86	0.72	161.86
228	8/8/2000	WS	0.41	59.34	14.09	101.40	71.41	1.86	0.72	161.86

Wapta Lake										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
83	6/5/1999	ES	1.80	51.88	13.52			3.62		
96	6/5/1999	ES	1.97	56.17	13.52			3.62		
84	6/16/1999	WS	2.29	47.86	12.44			2.43		
85	6/16/1999	WS	1.87	74.03	12.44			2.43		
97	6/30/1999	WS	2.13	57.00	6.59			4.48		
98	6/30/1999	WS	1.66	74.63	6.59			4.48		
86	7/14/1999	ES	1.38	82.02	12.95			2.87		
87	7/14/1999	ES	2.06	79.86	12.95			2.87		
90	7/14/1999	LP	1.19	63.32	12.95			2.87		
91	7/14/1999	LP	1.10	60.42	12.95			2.87		
92	7/30/1999	LP	1.38	81.31	12.94			5.68		
93	7/30/1999	LP	1.08	73.04	12.94			5.68		
99	7/30/1999	WS	0.65	51.34	12.94			5.68		
100	7/30/1999	WS	0.42	64.37	12.94			5.68		
88	8/11/1999	ES	1.00	68.38	13.48			3.57		
89	8/11/1999	ES	0.57	66.20	13.48			3.57		
94	8/11/1999	LP	1.31	73.03	13.48			3.57		
95	8/11/1999	LP	0.58	72.63	13.48			3.57		
123	4/19/2000	ES	0.34	54.34	0.86					
124	4/19/2000	ES	0.35	53.51	0.86					
127	4/19/2000	LP	0.32	55.64	0.86					
128	4/19/2000	LP	0.32	52.98	0.86					
103	5/3/2000	ES	0.22	52.53	1.90					
104	5/3/2000	ES	0.29	51.21	1.90					
143	5/3/2000	LP	0.21	56.87	1.90					
144	5/3/2000	LP	0.18	54.32	1.90					
111	5/14/2000	LP	0.19	51.31	0.61					
112	5/14/2000	LP	0.38	53.97	0.61					
113	5/14/2000	ES	0.24	50.59	0.61					
114	5/14/2000	ES	0.19	50.42	0.61					
157	6/7/2000	LP	0.27	55.16	9.13					
158	6/7/2000	LP	0.40	53.69	9.13					
159	6/7/2000	ES	0.10	46.28	9.13					
160	6/7/2000	ES	0.44	45.49	9.13					
175	6/22/2000	ES	0.34	88.12	7.39			3.81	2.56	
176	6/22/2000	ES	0.25	49.35	7.39			3.81	2.56	
177	6/22/2000	LP	0.27	56.09	7.39			3.81	2.56	
178	6/22/2000	LP	0.25	56.54	7.39			3.81	2.56	
195	7/13/2000	ES	0.36	79.20	9.97			3.67	1.68	
196	7/13/2000	ES	0.28	80.72	9.97			3.67	1.68	
211	7/13/2000	LP	0.20	57.90	9.97			3.67	1.68	
212	7/13/2000	LP	0.48	55.28	9.97			3.67	1.68	
215	8/8/2000	ES	0.36	54.53	12.58			2.65	2.80	
216	8/8/2000	ES	0.40	64.95	12.58			2.65	2.80	
217	8/8/2000	LP	0.38	66.94	12.58			2.65	2.80	
218	8/8/2000	LP	0.31	69.29	12.58			2.65	2.80	

Bow Lake - Diurnal Samples										
Sample	Date	Species	Time	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	WS m/s	WD °N
D1	6/4/2000	LP	6:15	0.33	55.74	6.22	81.20	98.10	0.23	125.80
D2	6/4/2000	LP	6:15	0.76	57.34	6.22	81.20	98.10	0.23	125.80
D3	6/4/2000	ES	6:15	0.53	53.37	6.22	81.20	98.10	0.23	125.80
D4	6/4/2000	ES	6:15	0.44	54.01	6.22	81.20	98.10	0.23	125.80
D5	6/4/2000	LP	15:00	0.64	56.63	20.19	81.00	32.00	2.85	130.70
D6	6/4/2000	LP	15:00	0.36	52.51	20.19	81.00	32.00	2.85	130.70
D7	6/4/2000	ES	15:00	0.46	52.19	20.19	81.00	32.00	2.85	130.70
D8	6/4/2000	ES	15:00	0.45	51.75	20.19	81.00	32.00	2.85	130.70
D9	6/13/2000	LP	8:30	0.67	56.67	5.81	80.50	87.00	0.24	172.60
D10	6/13/2000	LP	8:30	0.32	48.39	5.81	80.50	87.00	0.24	172.60
D11	6/13/2000	LP	14:30	0.38	55.27	17.14	80.70	56.00	1.53	216.70
D12	6/13/2000	LP	14:30	0.22	53.93	17.14	80.70	56.00	1.53	216.70
D13	6/13/2000	ES	8:30	0.40	46.76	5.81	80.50	87.00	0.24	172.60
D14	6/13/2000	ES	8:30	0.40	45.53	5.81	80.50	87.00	0.24	172.60
D15	6/13/2000	ES	14:30	0.67	46.22	17.14	80.70	56.00	1.53	216.70
D16	6/13/2000	ES	14:30	0.47	47.87	17.14	80.70	56.00	1.53	216.70
D17	8/15/2000	ES	6:40	0.35	54.15	-0.16	80.90	104.00	0.20	169.00
D18	8/15/2000	ES	6:40	0.42	56.60	-0.16	80.90	104.00	0.20	169.00
D19	8/15/2000	ES	15:00	0.40	56.10	12.55	80.80	41.00	2.36	155.90
D20	8/15/2000	ES	15:00	0.46	55.40	12.55	80.80	41.00	2.36	155.90
D21	8/15/2000	LP	6:40	0.33	68.82	-0.16	80.90	104.00	0.20	169.00
D22	8/15/2000	LP	6:40	0.51	66.86	-0.16	80.90	104.00	0.20	169.00
D23	8/15/2000	LP	15:00	0.51	68.01	12.55	80.80	41.00	2.36	155.90
D24	8/15/2000	LP	15:00	0.46	62.48	12.55	80.80	41.00	2.36	155.90

Kamloops										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
T9	7/4/2000	LP	0.14	64.75				5.70		
T10	7/4/2000	LP	0.16	65.04				5.70		
T11	7/4/2000	WS	0.24	59.11				5.70		
T12	7/4/2000	WS	0.31	60.55				5.70		

Kelowna										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
T13	7/4/2000	LP	0.04	63.48	17.15	97.06	53.52	0.80	2.88	162.08
T14	7/4/2000	LP	0.08	64.31	17.15	97.06	53.52	0.80	2.88	162.08
T15	7/4/2000	WS	0.27	59.42	17.15	97.06	53.52	0.80	2.88	162.08
T16	7/4/2000	WS	0.17	59.72	17.15	97.06	53.52	0.80	2.88	162.08

Revelstoke										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
T1	7/4/2000	WP	0.35	71.04	14.86	95.99	72.58	5.70	3.08	182.08
T2	7/4/2000	WP	0.28	72.49	14.86	95.99	72.58	5.70	3.08	182.08
T3	7/4/2000	WP	0.33	68.27	14.86	95.99	72.58	5.70	3.08	182.08
T4	7/4/2000	WP	0.10	69.00	14.86	95.99	72.58	5.70	3.08	182.08
T5	7/4/2000	ES	0.07	63.04	14.86	95.99	72.58	5.70	3.08	182.08
T6	7/4/2000	ES	0.03	68.84	14.86	95.99	72.58	5.70	3.08	182.08
T7	7/4/2000	ES	0.28	59.82	14.86	95.99	72.58	5.70	3.08	182.08
T8	7/4/2000	ES	0.26	56.47	14.86	95.99	72.58	5.70	3.08	182.08

Salmon Arm										
Sample	Date	Species	Lipid %	Moisture %	Temp °C	Pressure kPa	RH %	Prec mm	WS m/s	WD °N
T17	7/9/2000	ES	0.29	56.09	17.05	96.31	66.32	2.00	1.33	113.92
T18	7/9/2000	ES	0.41	53.47	17.05	96.31	66.32	2.00	1.33	113.92
T19	7/9/2000	LP	0.27	64.27	17.05	96.31	66.32	2.00	1.33	113.92
T20	7/9/2000	LP	0.18	64.70	17.05	96.31	66.32	2.00	1.33	113.92

APPENDIX II – OC AND PCB CONCENTRATIONS IN AIR

OC Concentrations in Air (pg/m3) Sampled from Donald Station

Sample	Date	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
1	6/10/1999	30.04	17.13	6.18	0.12	0.74	0.19	0.60	0.09	19.27	0.04	ND	0.72	ND	1.47	2.03	0.73
2	7/7/1999	33.77	16.22	6.33	0.20	1.97	0.12	0.61	0.17	25.48	0.38	ND	0.34	ND	1.20	1.06	0.54
3	7/20/1999	37.22	12.48	6.49	0.05	1.72	ND	0.48	0.11	46.68	1.31	ND	0.65	ND	1.52	1.93	0.37
4	8/4/1999	47.36	11.35	21.41	ND	1.21	0.19	1.38	0.04	46.84	0.15	ND	0.36	0.33	1.30	2.79	0.25
9	6/23/1999	6.28	1.38	15.29	1.44	0.82	ND	2.26	9.52	40.19	5.51	1.52	ND	0.39	0.54	1.42	2.72

OC Concentrations in Air (pg/m3) Sampled from Bow Lake

Sample	Start	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
5	6/4/1999	47.66	12.58	17.74	ND	0.63	0.07	0.78	0.04	10.42	0.04	ND	0.22	0.00	0.07	0.26	0.08
6	6/16/1999	56.63	29.91	12.37	ND	1.14	0.11	1.16	0.06	27.23	0.58	ND	0.96	0.08	0.43	0.77	0.23
7	7/28/1999	53.18	9.82	10.87	ND	0.76	0.10	0.38	0.06	13.59	0.08	ND	ND	0.05	0.53	0.66	0.20
8	8/11/1999	58.11	15.28	11.26	ND	1.84	0.22	0.80	0.16	31.89	0.57	ND	0.51	0.05	0.45	0.70	0.15
10	6/30/1999	4.48	ND	21.51	ND	ND	ND	0.99	1.22	11.71	1.01	ND	ND	ND	0.08	ND	0.71
12	5/9/2000	1.75	0.24	27.88	ND	ND	ND	0.45	0.88	19.59	0.65	0.35	ND	0.45	0.34	0.56	0.83
14	6/1/2000	9.06	1.89	32.46	ND	1.34	0.20	2.02	2.50	14.89	1.20	0.73	0.42	0.58	0.11	ND	1.09
16	6/28/2000	33.00	2.58	23.25	0.29	0.95	0.45	1.26	3.12	13.34	2.32	2.10	ND	0.03	1.17	2.03	2.00
20	8/15/2000	4.28	0.66	21.57	ND	ND	ND	1.47	1.58	20.59	4.06	0.02	ND	0.82	0.48	2.35	2.08
23	7/25/2000	8.76	1.19	12.37	0.28	ND	ND	0.15	ND	6.55	0.02	0.36	2.64	0.72	1.80	0.67	0.46

OC Concentrations in Air (pg/m3) Sampled from Lower Kananaskis Lake

Sample	Start	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
11	5/5/2000	48.72	0.45	99.68	ND	5.12	1.92	6.26	3.65	232.86	1.86	7.24	5.52	1.82	1.44	2.32	3.53
15	6/22/2000	2.64	0.15	14.25	ND	0.15	ND	0.66	1.93	10.51	0.98	ND	ND	ND	ND	ND	0.04
19	8/7/2000	2.89	0.28	10.48	0.03	ND	ND	0.55	0.64	10.21	1.38	ND	ND	0.37	ND	0.97	1.85
21	7/12/2000	23.27	ND	32.18	ND	2.09	0.42	3.34	3.92	97.23	7.18	3.31	5.45	0.67	ND	ND	3.08
22	5/19/2000	7.81	ND	13.17	0.45	5.53	ND	5.20	7.00	233.03	25.23	11.32	4.56	6.51	4.33	ND	6.86

OC Concentrations in Air (pg/m3) Sampled from Sundre

Sample	Start	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
13	5/29/2000	2.64	ND	24.77	0.10	ND	ND	0.15	0.01	3.24	0.01	2.08	0.07	1.28	2.98	3.01	2.15
17	7/10/2000	18.46	77.00	8.20	0.14	2.12	ND	1.84	3.57	22.06	2.68	2.58	1.98	1.31	0.94	3.10	2.70
18	7/31/2000	5.84	0.48	19.94	0.09	1.37	ND	3.93	8.57	31.53	6.16	1.51	2.72	2.48	0.66	8.11	9.04

PCB Concentrations in Air (pg/m3) Sampled from Donald Station

Sample	Mono-CB	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	ΣPCB
1	1.12	7.22	8.87	14.81	1.14	5.47	3.82	0.48	0.01	42.92
2	0.42	6.45	9.06	16.74	2.18	3.75	3.53	0.45	0.00	42.57
3	ND	4.93	7.84	14.51	2.41	4.69	4.08	0.53	0.01	38.99
4	ND	6.30	7.04	25.66	4.30	7.54	6.06	0.55	ND	57.44
9	ND	38.82	72.63	54.11	19.67	13.30	22.53	0.72	0.04	230.09

PCB Concentrations in Air (pg/m3) Sampled from Bow Lake

Sample	Mono-CB	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	ΣPCB
5	1.96	0.80	0.63	3.62	0.31	0.64	0.25	0.01	ND	8.21
6	2.40	1.69	1.74	3.79	0.34	1.13	0.45	0.02	ND	11.56
7	0.95	1.30	1.18	2.64	0.52	0.98	0.53	0.05	ND	8.16
8	2.73	1.88	1.96	3.06	0.10	1.19	0.53	0.02	ND	11.48
10	20.72	19.44	5.64	7.84	3.20	2.11	1.40	0.28	ND	61.38
12	ND	12.45	24.94	69.23	58.25	39.34	3.90	0.48	0.04	214.43
14	11.15	11.98	12.44	18.48	7.28	6.93	3.17	0.10	ND	73.70
16	12.79	3.77	2.25	3.25	0.92	1.81	1.26	0.25	ND	27.64
20	2.78	2.49	13.44	24.93	17.15	12.09	3.74	0.51	ND	80.61
23	6.71	27.71	51.41	82.28	18.01	3.58	0.10	0.22	ND	194.39

PCB Concentrations in Air (pg/m3) Sampled from Lower Kananaskis Lake

Sample	Mono-CB	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	ΣPCB
11	17.74	53.60	89.92	183.71	76.70	25.65	13.84	1.16	ND	474.88
15	0.76	9.91	8.21	15.64	10.01	8.17	15.24	0.88	0.12	70.52
19	20.73	38.75	157.64	49.44	12.08	14.73	32.62	2.67	ND	333.26
21	9.08	78.96	94.78	99.96	49.30	25.95	12.18	0.68	ND	381.50
22	10.76	33.74	59.50	163.26	121.88	67.30	24.58	1.02	ND	497.94

PCB Concentrations in Air (pg/m3) Sampled from Sundre

Sample	Mono-CB	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	ΣPCB
13	39.96	8.94	19.11	34.89	28.65	17.46	21.26	0.41	ND	175.93
17	17.02	1.08	11.72	16.43	13.50	8.87	3.56	0.49	ND	75.39
18	19.78	34.22	25.77	35.68	30.72	27.38	10.75	1.66	ND	192.06

APPENDIX III – OC AND PCB CONCENTRATIONS IN MOUNTAIN SAMPLES

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Bow Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hep Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
13	526.72	104.36	153.96	ND	482.13	ND	698.92	ND	ND	ND	ND	ND	ND	ND	ND	ND
20	290.23	41.62	130.63	ND	552.43	ND	527.54	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	266.21	106.25	133.04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15	47.48	127.66	22.46	ND	ND	ND	97.32	ND	ND	ND	ND	ND	ND	ND	ND	ND
1	145.30	130.65	59.59	ND	199.83	ND	237.46	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	165.67	82.61	71.09	ND	91.06	ND	190.66	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	293.69	331.53	98.03	ND	36.28	ND	38.54	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	211.73	172.62	81.84	ND	56.55	ND	17.20	ND	ND	ND	ND	ND	ND	ND	ND	ND
16	94.31	45.91	24.66	ND	283.67	ND	230.01	ND	ND	ND	ND	ND	ND	ND	ND	ND
17	161.74	52.64	52.52	ND	2075.89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18	77.46	228.58	31.83	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
19	99.04	160.99	49.66	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	104.12	28.02	31.78	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	125.51	38.39	34.33	ND	757.23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	550.47	437.58	202.57	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	176.72	232.71	54.84	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	528.61	313.72	112.68	ND	ND	ND	ND	ND	ND	ND	ND	177.57	ND	ND	ND	ND
6	315.50	189.07	64.54	ND	ND	ND	ND	ND	ND	ND	ND	306.18	ND	ND	ND	ND
11	40.74	44.13	105.79	ND	2334.41	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	65.95	25.46	22.21	ND	2893.55	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
121	38.83	13.34	46.58	ND	236.16	ND	ND	ND	320.96	ND	ND	ND	ND	ND	ND	ND
122	41.43	32.28	50.10	140.16	ND	ND	ND	ND	ND	943.92	ND	ND	ND	ND	ND	ND
125	131.64	38.03	185.33	375.00	ND	ND	ND	ND	ND	ND	ND	ND	26.08	15.21	ND	ND
126	80.94	193.54	53.28	ND	ND	213.60	ND	ND	ND	ND	ND	ND	ND	ND	ND	52.56
117	24.99	ND	86.69	27.14	ND	ND	ND	ND	ND	ND	ND	219.08	ND	28.35	ND	ND
118	76.20	28.78	39.50	96.36	ND	ND	ND	ND	334.23	ND	14.98	ND	ND	0.00	ND	ND
137	26.70	14.08	70.55	77.41	ND	ND	ND	ND	93.69	ND	ND	ND	ND	0.00	ND	ND
138	74.69	28.16	41.59	101.95	ND	ND	ND	ND	ND	ND	139.95	ND	ND	0.00	ND	ND
147	86.85	44.70	86.61	23.01	32.35	ND	ND	ND	69.19	ND	ND	ND	ND	13.75	ND	ND
148	27.52	17.60	33.26	33.53	ND	ND	ND	ND	79.24	ND	ND	ND	ND	12.24	ND	ND
149	47.34	19.43	68.12	53.28	ND	ND	ND	1259.68	ND	ND	ND	ND	ND	35.32	ND	ND
150	71.49	27.98	44.98	61.33	ND	ND	ND	ND	210.29	ND	ND	ND	ND	0.00	ND	ND
187	31.60	40.84	90.71	30.93	ND	94.04	ND	71.60	ND	ND	ND	36.26	ND	0.00	ND	ND
188	69.29	66.97	131.45	107.93	ND	ND	ND	ND	ND	798.23	ND	ND	ND	11.15	ND	ND
189	124.32	ND	106.66	247.47	ND	266.34	ND	ND	ND	701.82	ND	ND	ND	0.00	ND	ND

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Bow Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hep Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
190	80.56	41.69	114.12	488.62	ND	141.33	ND	ND	120.28	234.88	ND	ND	20.12	43.07	ND	ND
193	93.63	14.80	113.40	69.38	ND	68.74	26.95	ND	154.94	223.91	ND	ND	ND	13.77	ND	ND
194	132.05	17.92	209.46	14.46	ND	379.06	39.29	ND	117.78	575.30	ND	ND	ND	23.35	ND	ND
209	44.55	24.13	171.67	407.59	ND	ND	ND	ND	ND	ND	ND	ND	ND	16.42	ND	ND
210	37.99	10.44	166.62	63.84	ND	874.34	ND	ND	ND	ND	ND	ND	ND	13.43	ND	ND

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Bow Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
13	ND	ND	410.76	429.54	ND	63.20	ND	ND	ND	903.51
20	ND	ND	147.53	250.68	ND	71.21	ND	ND	ND	469.42
14	ND	ND	363.62	279.00	ND	84.87	ND	ND	ND	727.49
15	ND	ND	259.59	61.73	ND	447.66	ND	ND	ND	768.98
1	ND	ND	275.57	201.63	ND	ND	247.41	ND	ND	724.61
2	ND	ND	474.37	416.06	ND	ND	145.39	ND	ND	1035.82
7	ND	ND	359.83	178.49	ND	ND	0.00	ND	ND	538.32
8	ND	ND	189.29	221.78	ND	ND	0.00	ND	ND	411.07
16	ND	ND	133.95	33.53	ND	ND	0.00	ND	ND	167.47
17	ND	ND	190.23	93.48	ND	406.96	0.00	ND	ND	690.67
18	ND	ND	284.16	125.06	56.08	ND	75.23	ND	ND	540.53
19	ND	ND	139.09	58.95	45.47	328.44	699.51	167.31	ND	1438.77
3	ND	ND	ND	ND	ND	19.94	ND	ND	ND	19.94
4	ND	ND	14.91	53.67	ND	ND	ND	ND	ND	68.58
9	ND	ND	429.40	361.49	ND	53.71	93.76	ND	ND	938.37
10	ND	ND	210.00	258.00	ND	355.06	509.95	51.58	19.46	1434.41
5	ND	ND	85.46	249.95	ND	ND	ND	ND	ND	335.41
6	ND	ND	259.75	367.41	ND	ND	ND	ND	ND	627.16
11	ND	ND	146.95	159.87	ND	10.41	ND	ND	ND	317.24
12	ND	ND	275.99	304.92	ND	198.76	ND	ND	ND	779.67
121	ND	222.36	851.24	ND	467.55	ND	ND	ND	170.41	1711.55
122	ND	164.26	570.64	52.11	107.11	ND	ND	ND	ND	813.02
125	86.71	540.60	1105.47	96.32	196.29	40.23	44.12	ND	ND	1915.65
126	ND	591.42	4668.84	286.69	400.87	ND	35.85	219.68	ND	6203.36
117	ND	121.54	297.38	35.79	183.98	ND	58.52	ND	ND	697.21
118	ND	ND	624.69	ND	602.69	59.09	49.85	ND	ND	1336.32
137	52.37	128.33	530.75	70.90	325.05	ND	21.65	ND	ND	1129.04
138	ND	82.64	882.80	ND	434.23	39.58	49.89	ND	ND	1450.47
147	ND	ND	266.96	29.47	331.57	ND	ND	ND	ND	628.00
148	ND	ND	490.36	19.94	251.88	ND	ND	ND	ND	762.18
149	ND	ND	539.04	18.24	358.14	30.61	50.22	ND	ND	996.24
150	ND	ND	627.40	ND	448.35	76.32	43.16	ND	ND	1195.23
187	ND	6.53	176.76	10.97	154.24	ND	12.08	ND	ND	360.59
188	ND	175.23	759.17	75.30	191.40	ND	74.86	ND	ND	1242.43
189	ND	197.46	865.21	19.02	414.74	ND	16.51	ND	ND	1331.17

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Bow Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
190	ND	163.91	1130.02	37.37	487.90	24.27	27.61	ND	ND	1777.22
193	ND	77.89	466.38	34.06	322.71	ND	38.29	ND	ND	943.10
194	ND	111.25	347.39	57.42	273.53	ND	ND	ND	ND	789.60
209	ND	370.79	1506.19	50.35	135.16	19.77	24.60	ND	30.56	1918.75
210	ND	85.03	676.18	ND	192.55	ND	39.81	ND	ND	993.57

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Bow Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
13	1050.29	208.10	306.99	ND	961.39	ND	1393.67	ND	ND	ND	ND	ND	ND	ND	ND	ND
20	580.45	83.24	261.25	ND	1104.85	ND	1055.08	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	474.16	189.25	236.97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15	88.75	238.60	41.99	ND	ND	ND	181.89	ND	ND	ND	ND	ND	ND	ND	ND	ND
1	265.54	238.77	108.90	ND	365.20	ND	433.97	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	313.26	156.21	134.44	ND	172.18	ND	360.53	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	612.12	690.99	204.32	ND	75.62	ND	80.32	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	438.32	357.35	169.42	ND	117.07	ND	35.61	ND	ND	ND	ND	ND	ND	ND	ND	ND
16	212.95	103.67	55.68	ND	640.48	ND	519.34	ND	ND	ND	ND	ND	ND	ND	ND	ND
17	389.47	126.77	126.46	ND	4998.92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18	165.17	487.41	67.88	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
19	210.39	341.99	105.50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	287.79	77.45	87.84	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	344.38	105.34	94.20	ND	2077.77	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	1252.09	995.30	460.75	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	429.29	565.29	133.22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	1525.75	905.51	325.22	ND	ND	ND	ND	ND	ND	ND	ND	512.53	ND	ND	ND	ND
6	912.76	546.99	186.73	ND	ND	ND	ND	ND	ND	ND	ND	885.81	ND	ND	ND	ND
11	134.52	145.72	349.35	ND	7708.58	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	217.29	83.89	73.16	ND	9532.80	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
121	86.06	29.56	103.25	ND	523.49	ND	ND	ND	711.47	ND	ND	ND	ND	ND	ND	ND
122	93.06	72.52	112.55	314.85	ND	ND	ND	ND	ND	2120.44	ND	ND	ND	ND	ND	ND
125	258.98	74.81	364.61	737.76	ND	ND	ND	ND	ND	ND	ND	ND	51.31	29.92	ND	ND
126	156.81	374.96	103.22	ND	ND	413.82	ND	ND	ND	ND	ND	ND	ND	ND	ND	101.82
117	57.14	ND	198.18	62.06	ND	ND	ND	ND	ND	ND	ND	500.87	ND	64.82	ND	ND
118	157.01	59.30	81.39	198.56	ND	ND	ND	ND	688.71	ND	30.87	ND	ND	ND	ND	ND
137	61.95	32.68	163.72	179.62	ND	ND	ND	ND	217.41	ND	ND	ND	ND	ND	ND	ND
138	156.63	59.04	87.22	213.80	ND	ND	ND	ND	ND	ND	293.48	ND	ND	ND	ND	ND
147	187.79	96.65	187.27	49.76	69.95	ND	ND	ND	149.61	ND	ND	ND	ND	29.73	ND	ND
148	58.11	37.17	70.23	70.80	ND	ND	ND	ND	167.32	ND	ND	ND	ND	25.84	ND	ND
149	102.19	41.94	147.05	115.01	ND	ND	ND	2719.14	ND	ND	ND	ND	ND	76.24	ND	ND
150	146.17	57.21	91.96	125.39	ND	ND	ND	ND	429.96	ND	ND	ND	ND	ND	ND	ND
187	65.39	84.53	187.73	64.01	ND	194.63	ND	148.19	ND	ND	ND	75.04	ND	ND	ND	ND
188	74.74	72.24	141.79	116.42	ND	ND	ND	ND	ND	861.02	ND	ND	ND	12.03	ND	ND
189	233.57	ND	200.40	464.97	ND	500.42	ND	ND	ND	1318.63	ND	ND	ND	ND	ND	ND
190	149.17	77.20	211.31	904.76	ND	261.70	ND	ND	222.73	434.92	ND	ND	37.26	79.76	ND	ND
193	411.53	65.05	498.42	304.91	ND	302.10	118.43	ND	680.95	984.11	ND	ND	ND	60.52	ND	ND
194	558.54	75.78	885.94	61.15	ND	1603.26	166.20	ND	498.17	2433.29	ND	ND	ND	98.76	ND	ND
209	98.09	53.13	377.97	897.40	ND	ND	ND	ND	ND	ND	ND	ND	ND	36.14	ND	ND
210	76.90	21.12	337.24	129.22	ND	1769.67	ND	ND	ND	ND	ND	ND	ND	27.18	ND	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Bow Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
13	ND	ND	819.07	856.52	ND	126.03	ND	ND	ND	1801.62
20	ND	ND	295.06	501.36	ND	142.42	ND	ND	ND	938.84
14	ND	ND	647.65	496.94	ND	151.16	ND	ND	ND	1295.75
15	ND	ND	485.18	115.38	ND	836.68	ND	ND	ND	1437.24
1	ND	ND	503.62	368.49	ND	ND	452.15	ND	ND	1324.26
2	ND	ND	897.00	786.74	ND	ND	274.93	ND	ND	1958.66
7	ND	ND	749.98	372.02	ND	ND	ND	ND	ND	1122.00
8	ND	ND	391.86	459.12	ND	ND	ND	ND	ND	850.98
16	ND	ND	302.44	75.70	ND	ND	ND	ND	ND	378.13
17	ND	ND	458.09	225.11	ND	979.99	ND	ND	ND	1663.19
18	ND	ND	605.93	266.67	119.59	ND	160.41	ND	ND	1152.60
19	ND	ND	295.48	125.22	96.60	697.71	1485.98	355.43	ND	3056.42
3	ND	ND	ND	ND	ND	55.11	ND	ND	ND	55.11
4	ND	ND	40.91	147.27	ND	ND	ND	ND	ND	188.18
9	ND	ND	976.71	822.25	ND	122.18	213.26	ND	ND	2134.39
10	ND	ND	510.11	626.72	ND	862.49	1238.74	125.30	47.28	3484.39
5	ND	ND	246.67	721.43	ND	ND	ND	ND	ND	968.10
6	ND	ND	751.47	1062.96	ND	ND	ND	ND	ND	1814.43
11	ND	ND	485.25	527.93	ND	34.39	ND	ND	ND	1047.56
12	ND	ND	909.25	1004.55	ND	654.83	ND	ND	ND	2568.62
121	ND	492.89	1886.91	ND	1036.40	ND	ND	ND	377.75	3793.95
122	ND	369.01	1281.88	117.06	240.61	ND	ND	ND	ND	1826.38
125	170.59	1063.57	2174.88	189.51	386.19	79.14	86.80	ND	ND	3768.82
126	ND	1145.80	9045.27	555.43	776.64	ND	69.46	425.60	ND	12018.19
117	ND	277.87	679.87	81.83	420.62	ND	133.80	ND	ND	1593.99
118	ND	ND	1287.25	ND	1241.92	121.76	102.71	ND	ND	2753.64
137	121.52	297.78	1231.57	164.52	754.25	ND	50.24	ND	ND	2619.88
138	ND	173.30	1851.29	ND	910.61	83.01	104.63	ND	ND	3041.74
147	ND	ND	577.21	63.72	716.91	ND	ND	ND	ND	1357.83
148	ND	ND	1035.38	42.10	531.85	ND	ND	ND	ND	1609.33
149	ND	ND	1163.58	39.37	773.07	66.08	108.40	ND	ND	2150.49
150	ND	ND	1282.78	ND	916.69	156.05	88.24	ND	ND	2443.75
187	ND	13.51	365.81	22.71	319.21	ND	25.00	ND	ND	746.25
188	ND	189.01	818.88	81.22	206.46	ND	80.75	ND	ND	1340.16
189	ND	371.01	1625.62	35.74	779.24	ND	31.01	ND	ND	2501.10
190	ND	303.50	2092.39	69.19	903.42	44.93	51.12	ND	ND	3290.80
193	ND	342.35	2049.75	149.69	1418.31	ND	168.29	ND	ND	4144.99
194	ND	470.55	1469.31	242.88	1156.93	ND	ND	ND	ND	3339.68
209	ND	816.39	3316.26	110.87	297.60	43.53	54.17	ND	67.28	4224.63
210	ND	172.11	1368.59	ND	389.71	ND	80.57	ND	ND	2010.99

OC Concentrations in Vegetation (ng/g lipid) Sampled from Bow Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
13	46.63	9.24	13.63	ND	42.68	ND	61.87	ND	ND	ND	ND	ND	ND	ND	ND	ND
20	21.34	3.06	9.60	ND	40.62	ND	38.79	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	18.35	7.32	9.17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15	3.46	9.30	1.64	ND	ND	ND	7.09	ND	ND	ND	ND	ND	ND	ND	ND	ND
1	22.01	19.80	9.03	ND	30.28	ND	35.98	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	25.82	12.88	11.08	ND	14.19	ND	29.72	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	30.52	34.45	10.19	ND	3.77	ND	4.01	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	33.08	26.97	12.79	ND	8.84	ND	2.69	ND	ND	ND	ND	ND	ND	ND	ND	ND
16	12.19	5.94	3.19	ND	36.67	ND	29.73	ND	ND	ND	ND	ND	ND	ND	ND	ND
17	11.00	3.58	3.57	ND	141.16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18	8.95	26.41	3.68	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
19	12.63	20.53	6.33	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	11.34	3.05	3.46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	23.31	7.13	6.38	ND	140.63	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	59.83	47.56	22.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	22.41	29.51	6.96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	68.33	40.55	14.57	ND	ND	ND	ND	ND	ND	ND	ND	22.95	ND	ND	ND	ND
6	17.83	10.69	3.65	ND	ND	ND	ND	ND	ND	ND	ND	17.31	ND	ND	ND	ND
11	4.62	5.00	11.99	ND	264.57	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	6.00	2.31	2.02	ND	263.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
121	7.07	2.43	8.49	ND	43.03	ND	ND	ND	58.48	ND	ND	ND	ND	ND	ND	ND
122	10.96	8.54	13.26	37.09	ND	ND	ND	ND	ND	249.79	ND	ND	ND	ND	ND	ND
125	40.79	11.78	57.43	116.21	ND	ND	ND	ND	ND	ND	ND	ND	8.08	4.71	ND	ND
126	11.51	27.52	7.58	ND	ND	30.37	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.47
117	8.38	ND	29.05	9.10	ND	ND	ND	ND	ND	ND	ND	73.43	ND	9.50	ND	ND
118	36.29	13.71	18.81	45.89	ND	ND	ND	ND	159.18	ND	7.13	ND	ND	ND	ND	ND
137	7.79	4.11	20.59	22.59	ND	ND	ND	ND	27.34	ND	ND	ND	ND	ND	ND	ND
138	20.56	7.75	11.45	28.07	ND	ND	ND	ND	ND	ND	38.53	ND	ND	ND	ND	ND
147	27.23	14.01	27.15	7.22	10.14	ND	ND	ND	21.69	ND	ND	ND	ND	4.31	ND	ND
148	9.38	6.00	11.34	11.43	ND	ND	ND	ND	27.02	ND	ND	ND	ND	4.17	ND	ND
149	11.59	4.76	16.68	13.04	ND	ND	ND	308.38	ND	ND	ND	ND	ND	8.65	ND	ND
150	18.37	7.19	11.56	15.76	ND	ND	ND	ND	54.05	ND	ND	ND	ND	ND	ND	ND
187	6.55	8.46	18.79	6.41	ND	19.48	ND	14.83	ND	ND	ND	7.51	ND	ND	ND	ND
188	12.64	12.22	23.98	19.69	ND	ND	ND	ND	ND	145.61	ND	ND	ND	2.03	ND	ND
189	23.83	ND	20.44	47.43	ND	51.05	ND	ND	ND	134.51	ND	ND	ND	ND	ND	ND
190	19.01	9.84	26.93	115.32	ND	33.36	ND	ND	28.39	55.44	ND	ND	4.75	10.17	ND	ND
193	36.73	5.81	44.48	27.21	ND	26.96	10.57	ND	60.78	87.83	ND	ND	ND	5.40	ND	ND
194	36.26	4.92	57.51	3.97	ND	104.08	10.79	ND	32.34	157.97	ND	ND	ND	6.41	ND	ND
209	9.51	5.15	36.64	86.99	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.50	ND	ND
210	6.98	1.92	30.63	11.74	ND	160.74	ND	ND	ND	ND	ND	ND	ND	2.47	ND	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Bow Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
13	ND	ND	36.36	38.03	ND	5.60	ND	ND	ND	79.98
20	ND	ND	10.85	18.43	ND	5.24	ND	ND	ND	34.52
14	ND	ND	25.06	19.23	ND	5.85	ND	ND	ND	50.14
15	ND	ND	18.91	4.50	ND	32.62	ND	ND	ND	56.03
1	ND	ND	41.75	30.55	ND	ND	37.49	ND	ND	109.79
2	ND	ND	73.95	64.86	ND	ND	22.66	ND	ND	161.47
7	ND	ND	37.39	18.55	ND	ND	ND	ND	ND	55.94
8	ND	ND	29.58	34.65	ND	ND	ND	ND	ND	64.23
16	ND	ND	17.32	4.33	ND	ND	ND	ND	ND	21.65
17	ND	ND	12.94	6.36	ND	27.67	ND	ND	ND	46.97
18	ND	ND	32.84	14.45	6.48	ND	8.69	ND	ND	62.46
19	ND	ND	17.73	7.52	5.80	41.88	89.19	21.33	ND	183.44
3	ND	ND	ND	ND	ND	2.17	ND	ND	ND	2.17
4	ND	ND	2.77	9.97	ND	ND	ND	ND	ND	12.74
9	ND	ND	46.67	39.29	ND	5.84	10.19	ND	ND	102.00
10	ND	ND	26.63	32.72	ND	45.03	64.68	6.54	2.47	181.93
5	ND	ND	11.05	32.31	ND	ND	ND	ND	ND	43.36
6	ND	ND	14.68	20.77	ND	ND	ND	ND	ND	35.45
11	ND	ND	16.65	18.12	ND	1.18	ND	ND	ND	35.95
12	ND	ND	25.09	27.72	ND	18.07	ND	ND	ND	70.88
121	ND	40.51	155.09	ND	85.18	ND	ND	ND	31.05	311.83
122	ND	43.47	151.01	13.79	28.34	ND	ND	ND	ND	215.15
125	26.87	167.53	342.58	29.85	60.83	12.47	13.67	ND	ND	593.65
126	ND	84.10	663.92	40.77	57.01	ND	5.10	31.24	ND	882.13
117	ND	40.74	99.67	12.00	61.66	ND	19.61	ND	ND	233.67
118	ND	ND	297.51	ND	287.04	28.14	23.74	ND	ND	636.43
137	15.28	37.45	154.88	20.69	94.85	ND	6.32	ND	ND	329.46
138	ND	22.75	243.06	ND	119.56	10.90	13.74	ND	ND	399.36
147	ND	ND	83.70	9.24	103.95	ND	ND	ND	ND	196.88
148	ND	ND	167.18	6.80	85.87	ND	ND	ND	ND	259.85
149	ND	ND	131.96	4.46	87.68	7.49	12.29	ND	ND	243.89
150	ND	ND	161.24	ND	115.23	19.61	11.09	ND	ND	307.18
187	ND	1.35	36.61	2.27	31.95	ND	2.50	ND	ND	74.69
188	ND	31.96	138.48	13.74	34.91	ND	13.66	ND	ND	226.64
189	ND	37.85	165.82	3.65	79.49	ND	3.16	ND	ND	255.13
190	ND	38.68	266.70	8.82	115.15	5.73	6.52	ND	ND	419.45
193	ND	30.56	182.94	13.36	126.59	ND	15.02	ND	ND	369.95
194	ND	30.55	95.39	15.77	75.11	ND	ND	ND	ND	216.81
209	ND	79.14	321.46	10.75	28.85	4.22	5.25	ND	6.52	409.51
210	ND	15.63	124.31	ND	35.40	ND	7.32	ND	ND	182.66

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Dixon Dam

Sample	α-HCH	γ-HCH	HCB	Hept	Hep Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
119	10.15	28.92	31.98	16.92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
120	30.05	63.87	99.63	11.23	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.01	ND	ND
133	10.57	39.36	29.29	ND	ND	ND	ND	ND	95.27	ND	209.17	ND	ND	ND	ND	ND
134	25.49	27.21	31.07	ND	43.44	ND	57.86	ND	168.74	ND	ND	ND	ND	ND	ND	ND
115	36.72	171.25	69.06	16.02	ND	ND	ND	ND	21.22	146.89	ND	ND	ND	ND	ND	ND
116	34.05	176.10	70.00	33.39	701.66	ND	ND	ND	ND	378.19	ND	ND	ND	ND	ND	ND
151	27.19	230.04	22.82	12.56	ND	8.94	11.24	ND	ND	ND	ND	ND	ND	ND	ND	ND
152	59.51	282.58	ND	37.44	ND	69.03	28.88	ND	ND	135.83	ND	ND	31.95	2.31	ND	ND
181	27.60	130.60	90.37	ND	ND	30.92	ND	ND	62.03	ND	52.70	ND	ND	ND	ND	ND
182	27.87	84.81	21.44	34.61	ND	ND	ND	ND	103.97	180.07	ND	ND	ND	ND	ND	ND
201	24.54	136.55	116.51	22.39	ND	62.52	ND	ND	189.21	214.70	11.14	ND	ND	13.86	ND	ND
202	33.20	94.10	106.98	49.08	ND	132.79	ND	ND	162.08	ND	95.92	ND	ND	ND	ND	ND
225	31.07	104.22	311.43	34.59	ND	4.32	ND	ND	150.66	111.15	ND	ND	ND	ND	ND	ND
226	39.69	186.12	107.30	22.22	35.88	136.50	72.34	ND	102.67	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Dixon Dam

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
119	ND	33.39	166.46	ND	619.79	63.19	84.97	ND	ND	967.80
120	ND	40.09	258.35	7.44	225.69	325.78	207.84	ND	ND	1065.18
133	ND	25.70	274.85	ND	328.20	ND	24.56	ND	50.10	703.41
134	ND	45.11	181.96	ND	393.71	ND	ND	ND	14.14	634.92
115	ND	71.96	186.00	39.47	543.33	39.96	27.03	ND	ND	907.76
116	ND	ND	99.44	27.98	596.33	90.50	44.83	ND	ND	859.08
151	19.29	97.85	121.18	50.39	100.91	8.05	4.35	ND	13.57	415.59
152	ND	202.15	239.15	89.97	115.33	30.29	55.82	ND	14.30	716.62
181	ND	53.68	148.54	ND	285.59	20.89	34.25	ND	ND	568.78
182	ND	103.24	247.06	19.98	387.84	82.95	ND	ND	ND	831.33
201	ND	ND	373.67	ND	1009.74	67.05	54.81	ND	ND	1505.28
202	ND	ND	235.07	ND	383.95	37.11	ND	ND	ND	656.12
225	107.52	66.08	307.92	40.70	346.45	27.96	ND	ND	ND	896.62
226	ND	91.03	495.97	0.12	622.33	188.46	212.75	ND	57.93	1651.22

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Dixon Dam

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
119	18.17	51.75	57.23	30.28	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
120	54.74	116.33	181.46	20.45	ND	ND	ND	ND	ND	ND	ND	ND	ND	18.23	ND	ND
133	22.19	82.66	61.51	ND	ND	ND	ND	ND	200.08	ND	439.28	ND	ND	ND	ND	ND
134	53.47	57.07	65.17	ND	91.10	ND	121.34	ND	353.90	ND	ND	ND	ND	ND	ND	ND
115	63.82	297.59	120.02	27.84	ND	ND	ND	ND	36.88	255.27	ND	ND	ND	ND	ND	ND
116	59.01	305.23	121.34	57.87	1216.21	ND	ND	ND	ND	655.53	ND	ND	ND	ND	ND	ND
151	109.98	930.30	92.31	50.80	ND	36.17	45.47	ND	ND	ND	ND	ND	ND	ND	ND	ND
152	238.49	1132.38	ND	150.03	ND	276.62	115.75	ND	ND	544.33	ND	ND	128.04	9.26	ND	ND
181	94.68	447.96	309.96	ND	ND	106.05	ND	ND	212.78	ND	180.78	ND	ND	ND	ND	ND
182	86.57	263.44	66.59	107.50	ND	ND	ND	ND	322.93	559.31	ND	ND	ND	ND	ND	ND
201	54.67	304.22	259.58	49.88	ND	139.29	ND	ND	421.54	478.32	24.81	ND	ND	30.88	ND	ND
202	76.77	217.58	247.35	113.48	ND	307.04	ND	ND	374.75	ND	221.79	ND	ND	ND	ND	ND
225	70.36	236.00	705.19	78.33	ND	9.79	ND	ND	341.14	251.69	ND	ND	ND	ND	ND	ND
226	99.09	464.63	267.85	55.48	89.57	340.75	180.58	ND	256.30	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Dixon Dam

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
119	ND	59.74	297.85	ND	1109.03	113.07	152.04	ND	ND	1731.74
120	ND	73.02	470.56	13.54	411.08	593.38	378.56	ND	ND	1940.13
133	ND	53.97	577.22	ND	689.26	ND	51.59	ND	105.22	1477.25
134	ND	94.61	381.64	ND	825.73	ND	ND	ND	29.66	1331.63
115	ND	125.05	323.23	68.60	944.21	69.44	46.97	ND	ND	1577.50
116	ND	ND	172.36	48.49	1033.64	156.87	77.70	ND	ND	1489.07
151	78.01	395.71	490.09	203.78	408.10	32.55	17.60	ND	54.89	1680.72
152	ND	810.09	958.33	360.52	462.17	121.39	223.68	ND	57.32	2871.70
181	ND	184.11	509.49	ND	979.58	71.65	117.47	ND	ND	1950.93
182	ND	320.68	767.42	62.05	1204.68	257.66	ND	ND	ND	2582.23
201	ND	ND	832.50	ND	2249.62	149.39	122.12	ND	ND	3353.63
202	ND	ND	543.51	ND	887.74	85.80	ND	ND	ND	1517.05
225	243.46	149.62	697.24	92.15	784.49	63.31	ND	ND	ND	2030.27
226	ND	227.25	1238.12	0.29	1553.56	470.45	531.10	ND	144.60	4122.03

OC Concentrations in Vegetation (ng/g lipid) Sampled from Dixon Dam

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
119	2.77	7.89	8.73	4.62	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
120	11.16	23.71	36.99	4.17	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.72	ND	ND
133	7.21	26.85	19.98	ND	ND	ND	ND	ND	64.99	ND	142.69	ND	ND	ND	ND	ND
134	14.61	15.60	17.81	ND	24.89	ND	33.16	ND	96.71	ND	ND	ND	ND	ND	ND	ND
115	16.71	77.94	31.43	7.29	ND	ND	ND	ND	9.66	66.86	ND	ND	ND	ND	ND	ND
116	11.66	60.33	23.98	11.44	240.39	ND	ND	ND	ND	129.57	ND	ND	ND	ND	ND	ND
151	10.77	91.11	9.04	4.98	ND	3.54	4.45	ND	ND	ND	ND	ND	ND	ND	ND	ND
152	39.87	189.33	ND	25.09	ND	46.25	19.35	ND	ND	91.01	ND	ND	21.41	1.55	ND	ND
181	7.89	37.33	25.83	ND	ND	8.84	ND	ND	17.73	ND	15.06	ND	ND	ND	ND	ND
182	7.97	24.25	6.13	9.89	ND	ND	ND	ND	29.72	51.48	ND	ND	ND	ND	ND	ND
201	7.90	43.98	37.53	7.21	ND	20.14	ND	ND	60.94	69.15	3.59	ND	ND	4.46	ND	ND
202	8.85	25.07	28.50	13.08	ND	35.38	ND	ND	43.18	ND	25.56	ND	ND	ND	ND	ND
225	14.67	49.20	147.01	16.33	ND	2.04	ND	ND	71.12	52.47	ND	ND	ND	ND	ND	ND
226	11.20	52.54	30.29	6.27	10.13	38.53	20.42	ND	28.98	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Dixon Dam

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
119	ND	9.11	45.43	ND	169.15	17.25	23.19	ND	ND	264.12
120	ND	14.88	95.91	2.76	83.79	120.95	77.16	ND	ND	395.45
133	ND	17.53	187.49	ND	223.89	ND	16.76	ND	34.18	479.85
134	ND	25.85	104.29	ND	225.65	ND	ND	ND	8.10	363.90
115	ND	32.75	84.65	17.97	247.29	18.19	12.30	ND	ND	413.15
116	ND	ND	34.07	9.58	204.30	31.01	15.36	ND	ND	294.32
151	7.64	38.75	48.00	19.96	39.97	3.19	1.72	ND	5.38	164.61
152	ND	135.44	160.23	60.28	77.27	20.30	37.40	ND	9.58	480.13
181	ND	15.34	42.45	ND	81.62	5.97	9.79	ND	ND	162.56
182	ND	29.51	70.63	5.71	110.87	23.71	ND	ND	ND	237.66
201	ND	ND	120.36	ND	325.23	21.60	17.66	ND	ND	484.84
202	ND	ND	62.63	ND	102.30	9.89	ND	ND	ND	174.81
225	50.75	31.19	145.35	19.21	163.54	13.20	ND	ND	ND	423.25
226	ND	25.70	140.00	0.03	175.66	53.19	60.05	ND	16.35	466.08

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Donald Station

Sample	α-HCH	γ-HCH	HCB	Hept	Hep Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
21	113.61	22.32	24.14	ND	ND	ND	ND	ND	47.33	ND	ND	ND	ND	ND	ND	ND
35	131.71	27.25	45.88	ND	ND	ND	ND	ND	79.07	ND	ND	ND	ND	ND	ND	ND
22	55.90	78.26	11.26	ND	420.18	ND	ND	ND	75.93	ND	ND	ND	ND	ND	ND	ND
23	55.76	46.18	4.30	ND	371.81	ND	ND	ND	37.08	ND	ND	ND	ND	ND	ND	ND
24	28.37	19.37	10.60	ND	200.50	ND	117.04	ND	113.29	209.43	39.29	ND	ND	ND	ND	ND
27	41.09	52.68	1.37	ND	1626.85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
28	35.37	57.16	7.09	ND	682.39	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
36	78.45	33.38	28.52	ND	163.50	ND	104.92	ND	96.36	114.62	74.27	ND	ND	ND	ND	ND
29	30.48	93.17	6.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	15.69	26.31	12.73	ND	2298.49	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
37	90.87	36.37	21.07	ND	ND	ND	ND	ND	197.46	ND	ND	ND	ND	ND	ND	ND
38	93.38	75.57	27.68	ND	ND	ND	ND	ND	249.52	ND	ND	ND	ND	ND	ND	ND
31	77.87	124.15	26.55	ND	262.97	ND	634.53	ND	ND	ND	ND	ND	ND	ND	ND	ND
32	115.90	77.20	34.87	ND	ND	ND	ND	ND	308.22	22.85	ND	ND	ND	ND	ND	ND
39	199.36	56.53	178.80	ND	ND	ND	ND	374.02	153.47	ND	ND	ND	ND	ND	ND	ND
40	216.25	18.38	190.70	ND	ND	ND	ND	516.89	443.86	ND	ND	ND	ND	ND	ND	ND
25	44.74	37.97	37.95	ND	229.45	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	58.39	49.70	34.40	ND	527.03	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
33	57.49	25.96	3.32	ND	ND	ND	ND	ND	114.85	ND	ND	ND	ND	ND	ND	ND
34	97.98	69.11	22.56	ND	ND	ND	ND	ND	308.30	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Donald Station

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
21	ND	ND	111.02	98.20	ND	243.78	ND	ND	ND	453.01
35	ND	ND	785.80	295.17	252.55	25.70	ND	ND	ND	1359.21
22	ND	79.50	185.46	198.30	ND	348.53	77.31	ND	ND	889.10
23	ND	60.43	157.32	294.96	107.04	77.20	102.52	ND	ND	799.46
24	ND	148.81	354.65	387.53	119.62	297.76	140.86	ND	ND	1614.47
27	ND	ND	222.23	335.82	ND	101.06	24.18	ND	145.25	828.54
28	ND	ND	183.97	219.71	ND	278.84	26.68	ND	51.31	760.50
36	ND	ND	1709.86	269.66	177.19	39.11	ND	ND	ND	2195.83
29	ND	ND	165.20	286.46	ND	81.39	27.46	ND	ND	593.63
30	ND	176.47	247.95	435.12	102.64	327.84	157.78	ND	ND	1606.77
37	ND	ND	938.77	182.09	113.33	57.16	ND	ND	ND	1291.35
38	ND	ND	2826.51	238.37	261.42	82.88	48.54	ND	ND	3457.72
31	ND	ND	199.75	192.56	ND	ND	ND	ND	ND	392.30
32	ND	ND	2302.96	176.96	75.92	129.49	ND	ND	ND	2685.33
39	ND	ND	1207.17	152.36	104.63	ND	7.07	ND	ND	1492.03
40	ND	ND	700.84	152.46	85.17	57.96	45.78	ND	ND	1042.20
25	ND	ND	412.36	345.54	ND	125.75	70.66	ND	ND	954.31
26	ND	ND	295.12	133.31	ND	152.58	40.93	ND	ND	621.94
33	ND	ND	811.92	152.00	619.31	138.29	ND	ND	ND	1721.52
34	ND	ND	1368.99	170.71	349.27	252.08	48.57	ND	ND	2189.62

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Donald Station

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
21	363.59	71.45	77.26	ND	ND	ND	ND	ND	151.49	ND	ND	ND	ND	ND	ND	ND
35	585.81	121.22	204.07	ND	ND	ND	ND	ND	351.68	ND	ND	ND	ND	ND	ND	ND
22	142.06	198.87	28.60	ND	1067.74	ND	ND	ND	192.96	ND	ND	ND	ND	ND	ND	ND
23	240.49	199.14	18.55	ND	1603.43	ND	ND	ND	159.90	ND	ND	ND	ND	ND	ND	ND
24	82.84	56.56	30.95	ND	585.57	ND	341.82	ND	330.87	611.64	114.73	ND	ND	ND	ND	ND
27	142.33	182.48	4.74	ND	5635.53	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
28	135.11	218.32	27.07	ND	2606.41	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
36	243.87	103.75	88.65	ND	508.22	ND	326.15	ND	299.52	356.28	230.86	ND	ND	ND	ND	ND
29	94.87	290.05	18.74	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	42.49	71.25	34.47	ND	6224.17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
37	204.95	82.03	47.52	ND	ND	ND	ND	ND	445.36	ND	ND	ND	ND	ND	ND	ND
38	189.77	153.59	56.26	ND	ND	ND	ND	ND	507.12	ND	ND	ND	ND	ND	ND	ND
31	167.29	266.70	57.04	ND	564.90	ND	1363.09	ND	ND	ND	ND	ND	ND	ND	ND	ND
32	326.32	217.37	98.18	ND	ND	ND	ND	ND	867.80	64.34	ND	ND	ND	ND	ND	ND
39	438.55	124.35	393.31	ND	ND	ND	ND	822.73	337.60	ND	ND	ND	ND	ND	ND	ND
40	491.45	41.77	433.39	ND	ND	ND	ND	1174.70	1008.74	ND	ND	ND	ND	ND	ND	ND
25	110.86	94.10	94.04	ND	568.59	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	144.07	122.62	84.87	ND	1300.34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
33	149.47	67.50	8.62	ND	ND	ND	ND	ND	298.62	ND	ND	ND	ND	ND	ND	ND
34	244.97	172.78	56.39	ND	ND	ND	ND	ND	770.78	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Donald Station

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
21	ND	ND	355.31	314.28	ND	780.21	ND	ND	ND	1449.80
35	ND	ND	3495.02	1312.84	1123.28	114.30	ND	ND	ND	6045.43
22	ND	202.01	471.29	503.92	ND	885.66	196.45	ND	ND	2259.33
23	ND	260.59	678.44	1272.02	461.62	332.91	442.12	ND	ND	3447.70
24	ND	434.60	1035.76	1131.77	349.36	869.59	411.38	ND	ND	4715.03
27	ND	ND	769.82	1163.30	ND	350.07	83.78	ND	503.14	2870.11
28	ND	ND	702.68	839.17	ND	1065.02	101.89	ND	195.96	2904.73
36	ND	ND	5314.96	838.22	550.77	121.58	ND	ND	ND	6825.53
29	ND	ND	514.25	891.72	ND	253.36	85.48	ND	ND	1847.94
30	ND	477.86	671.44	1178.28	277.94	887.78	427.26	ND	ND	4351.04
37	ND	ND	2117.34	410.69	255.62	128.93	ND	ND	ND	2912.58
38	ND	ND	5744.47	484.46	531.29	168.43	98.65	ND	ND	7027.30
31	ND	ND	429.10	413.65	ND	ND	ND	ND	ND	842.74
32	ND	ND	6484.02	498.24	213.77	364.58	ND	ND	ND	7560.60
39	ND	ND	2655.43	335.16	230.15	ND	15.55	ND	ND	3282.06
40	ND	ND	1592.76	346.48	193.55	131.72	104.03	ND	ND	2368.55
25	ND	ND	1021.87	856.27	ND	311.61	175.10	ND	ND	2364.86
26	ND	ND	728.13	328.92	ND	376.45	101.00	ND	ND	1534.50
33	ND	ND	2110.99	395.20	1610.21	359.55	ND	ND	ND	4475.95
34	ND	ND	3422.59	426.78	873.20	630.23	121.42	ND	ND	5474.21

OC Concentrations in Vegetation (ng/g lipid) Sampled from Donald Station

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
21	15.35	3.02	3.26	ND	ND	ND	ND	ND	6.40	ND	ND	ND	ND	ND	ND	ND
35	25.84	5.35	9.00	ND	ND	ND	ND	ND	15.51	ND	ND	ND	ND	ND	ND	ND
22	6.06	8.48	1.22	ND	45.52	ND	ND	ND	8.23	ND	ND	ND	ND	ND	ND	ND
23	9.67	8.00	0.75	ND	64.45	ND	ND	ND	6.43	ND	ND	ND	ND	ND	ND	ND
24	6.70	4.58	2.50	ND	47.39	ND	27.66	ND	26.78	49.50	9.29	ND	ND	ND	ND	ND
27	3.80	4.88	0.13	ND	150.63	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
28	4.69	7.57	0.94	ND	90.42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
36	16.95	7.21	6.16	ND	35.32	ND	22.66	ND	20.81	24.76	16.04	ND	ND	ND	ND	ND
29	5.46	16.71	1.08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	9.24	15.49	7.50	ND	1353.56	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
37	15.24	6.10	3.53	ND	ND	ND	ND	ND	33.12	ND	ND	ND	ND	ND	ND	ND
38	12.87	10.42	3.82	ND	ND	ND	ND	ND	34.39	ND	ND	ND	ND	ND	ND	ND
31	6.02	9.59	2.05	ND	20.32	ND	49.03	ND	ND	ND	ND	ND	ND	ND	ND	ND
32	14.63	9.74	4.40	ND	ND	ND	ND	ND	38.89	2.88	ND	ND	ND	ND	ND	ND
39	19.56	5.55	17.54	ND	ND	ND	ND	36.70	15.06	ND	ND	ND	ND	ND	ND	ND
40	24.45	2.08	21.56	ND	ND	ND	ND	58.43	50.18	ND	ND	ND	ND	ND	ND	ND
25	4.75	4.03	4.03	ND	24.38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	6.21	5.29	3.66	ND	56.07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
33	11.50	5.19	0.66	ND	ND	ND	ND	ND	22.97	ND	ND	ND	ND	ND	ND	ND
34	21.56	15.20	4.96	ND	ND	ND	ND	ND	67.83	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Donald Station

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
21	ND	ND	15.00	13.27	ND	32.94	ND	ND	ND	61.22
35	ND	ND	154.14	57.90	49.54	5.04	ND	ND	ND	266.61
22	ND	8.61	20.09	21.48	ND	37.76	8.38	ND	ND	96.32
23	ND	10.47	27.27	51.13	18.55	13.38	17.77	ND	ND	138.57
24	ND	35.17	83.83	91.60	28.27	70.38	33.29	ND	ND	381.60
27	ND	ND	20.58	31.09	ND	9.36	2.24	ND	13.45	76.72
28	ND	ND	24.38	29.11	ND	36.95	3.53	ND	6.80	100.77
36	ND	ND	369.33	58.25	38.27	8.45	ND	ND	ND	474.30
29	ND	ND	29.62	51.36	ND	14.59	4.92	ND	ND	106.44
30	ND	103.92	146.02	256.24	60.44	193.06	92.92	ND	ND	946.21
37	ND	ND	157.47	30.54	19.01	9.59	ND	ND	ND	216.61
38	ND	ND	389.60	32.86	36.03	11.42	6.69	ND	ND	476.60
31	ND	ND	15.44	14.88	ND	ND	ND	ND	ND	30.31
32	ND	ND	290.61	22.33	9.58	16.34	ND	ND	ND	338.86
39	ND	ND	118.44	14.95	10.27	ND	0.69	ND	ND	146.39
40	ND	ND	79.23	17.23	9.63	6.55	5.17	ND	ND	117.81
25	ND	ND	43.81	36.71	ND	13.36	7.51	ND	ND	101.40
26	ND	ND	31.40	14.18	ND	16.23	4.35	ND	ND	66.16
33	ND	ND	162.38	30.40	123.86	27.66	ND	ND	ND	344.30
34	ND	ND	301.18	37.56	76.84	55.46	10.68	ND	ND	481.72

Concentrations in Vegetation (pg/g wet weight) Sampled from Lower Kananaskis Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hep Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
101	13.01	16.32	56.70	ND	ND	ND	94.30	ND	ND	770.99	ND	ND	ND	14.65	ND	ND
102	25.39	12.03	26.38	103.71	ND	12.72	ND	ND	ND	245.37	ND	ND	ND	ND	ND	ND
135	46.58	23.08	52.01	12.46	ND	ND	ND	ND	168.55	ND	ND	6.80	ND	19.85	ND	33.19
136	66.46	ND	98.65	38.93	ND	ND	ND	ND	193.10	ND	186.28	ND	ND	42.26	ND	81.51
105	59.82	19.56	140.21	32.44	ND	ND	57.76	11198.92	204.04	ND	ND	ND	ND	24.89	ND	ND
106	34.48	16.74	56.54	56.32	ND	ND	ND	ND	408.36	ND	ND	ND	ND	10.38	ND	ND
109	26.25	16.65	29.46	ND	ND	ND	ND	ND	218.18	ND	165.20	ND	ND	ND	ND	ND
110	32.58	30.23	78.63	13.56	ND	ND	ND	ND	170.82	ND	ND	ND	ND	13.31	ND	ND
161	123.62	51.08	81.14	28.74	ND	ND	7.93	ND	198.36	ND	ND	2971.76	ND	12.71	ND	1961.35
162	19.96	33.44	88.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
163	73.22	34.95	83.71	78.18	ND	ND	ND	ND	63.12	ND	ND	164.20	ND	28.80	ND	ND
164	51.22	44.92	77.19	67.21	ND	ND	ND	ND	19.46	146.66	ND	ND	ND	18.57	ND	ND
183	39.69	25.01	49.97	ND	ND	ND	ND	ND	5.74	ND	ND	ND	ND	ND	ND	ND
184	49.75	29.87	63.77	ND	ND	ND	ND	ND	59.45	ND	ND	ND	ND	ND	ND	ND
185	72.44	22.86	80.55	513.03	ND	ND	155.90	ND	165.68	ND	ND	ND	ND	18.92	ND	ND
186	46.41	14.13	56.83	287.65	ND	13.08	85.65	ND	8.59	ND	ND	ND	ND	15.13	ND	ND
199	48.11	39.32	161.66	21.43	187.91	ND	ND	ND	211.60	ND	ND	ND	ND	15.96	ND	ND
200	55.17	38.98	138.49	19.66	ND	ND	ND	ND	112.75	ND	ND	ND	ND	30.88	ND	ND
207	106.12	85.77	131.29	57.20	ND	ND	ND	ND	175.42	523.50	ND	ND	ND	17.80	ND	ND
208	81.81	77.66	86.61	149.04	ND	299.64	ND	ND	184.59	244.36	ND	ND	ND	12.09	ND	ND
213	38.73	12.28	131.85	52.58	ND	168.05	ND	ND	ND	ND	ND	ND	ND	14.68	ND	ND
214	26.00	ND	118.06	37.39	ND	233.26	ND	ND	177.02	ND	ND	ND	ND	17.47	ND	ND
223	8.17	13.45	82.37	31.61	ND	ND	41.57	ND	70.94	ND	ND	ND	ND	ND	ND	ND
224	7.02	10.31	91.73	81.10	ND	ND	ND	ND	99.81	284.58	ND	ND	ND	ND	ND	ND

Concentrations in Vegetation (pg/g wet weight) Sampled from Lower Kananaskis Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
101	65.81	160.69	626.68	249.71	139.60	141.16	25.67	ND	38.77	1504.10
102	ND	61.58	868.09	84.73	298.17	59.21	38.36	ND	ND	1369.58
135	859.98	393.32	603.07	312.65	370.98	53.78	15.74	ND	ND	2654.70
136	55.23	248.32	347.19	197.75	197.80	125.76	43.92	ND	ND	1235.75
105	ND	25.41	930.12	32.88	390.31	26.24	60.71	ND	22.35	1536.98
106	ND	100.84	1119.63	17.78	540.53	ND	53.23	ND	ND	1757.46
109	ND	ND	140.15	ND	427.68	ND	ND	ND	ND	567.84
110	ND	17.12	109.37	17.26	226.37	ND	24.61	ND	ND	409.40
161	423.74	116.04	1063.56	188.51	305.13	40.20	148.20	ND	7.78	2322.09
162	ND	99.41	336.76	16.97	311.06	26.29	63.78	ND	ND	854.27
163	1442.48	341.13	1377.28	371.01	549.62	212.16	36.21	ND	ND	4371.63
164	ND	ND	409.88	226.68	514.95	31.58	39.52	ND	ND	1252.03
183	ND	18.84	108.00	ND	244.41	29.72	ND	ND	ND	400.96
184	ND	48.82	43.10	ND	457.14	29.46	12.78	ND	22.86	614.16
185	ND	834.10	898.39	79.16	134.14	62.93	24.93	ND	10.50	1560.62
186	ND	432.79	619.75	ND	267.46	184.82	22.78	ND	ND	1320.45
199	ND	96.21	341.81	47.18	212.28	ND	ND	ND	6.46	749.60
200	ND	77.40	458.63	56.46	261.69	ND	64.72	ND	ND	941.84
207	ND	23.70	522.07	137.99	578.75	ND	38.73	ND	ND	1301.24
208	ND	51.45	763.97	30.32	502.38	47.20	157.25	ND	ND	1539.87
213	ND	92.85	439.91	74.72	339.85	ND	ND	ND	ND	967.51
214	ND	72.82	616.21	45.44	552.01	ND	55.53	ND	ND	1387.54
223	ND	98.52	566.90	ND	183.12	ND	ND	ND	ND	870.39
224	ND	80.70	736.06	12.51	160.54	ND	ND	ND	ND	989.81

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Lower Kananaskis Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
101	26.56	33.32	115.77	ND	ND	ND	192.54	ND	ND	1574.11	ND	ND	ND	29.92	ND	ND
102	52.46	24.86	54.49	214.24	ND	26.29	ND	ND	ND	506.89	ND	ND	ND	ND	ND	ND
135	102.12	50.59	114.02	27.31	ND	ND	ND	ND	369.51	ND	ND	14.91	ND	43.52	ND	72.76
136	146.58	ND	217.59	85.86	ND	ND	ND	ND	425.92	ND	410.87	ND	ND	93.21	ND	179.78
105	109.52	35.82	256.69	59.38	ND	ND	105.75	20503.30	373.56	ND	ND	ND	ND	45.58	ND	ND
106	63.94	31.03	104.84	104.44	ND	ND	ND	ND	757.21	ND	ND	ND	ND	19.24	ND	ND
109	50.65	32.13	56.85	ND	ND	ND	ND	ND	420.99	ND	318.75	ND	ND	ND	ND	ND
110	65.65	60.91	158.46	27.33	ND	ND	ND	ND	344.26	ND	ND	ND	ND	26.83	ND	ND
161	285.70	118.05	187.52	66.43	ND	ND	18.33	ND	458.42	ND	ND	6868.00	ND	29.36	ND	4532.86
162	42.83	71.76	188.90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
163	127.52	60.86	145.78	136.15	ND	ND	ND	ND	109.93	ND	ND	285.96	ND	50.15	ND	ND
164	92.10	80.77	138.80	120.85	ND	ND	ND	ND	34.99	263.70	ND	ND	ND	33.39	ND	ND
183	75.70	47.70	95.30	ND	ND	ND	ND	ND	10.96	ND	ND	ND	ND	ND	ND	ND
184	100.38	60.28	128.67	ND	ND	ND	ND	ND	119.94	ND	ND	ND	ND	ND	ND	ND
185	150.79	47.58	167.67	1067.86	ND	ND	324.51	ND	344.86	ND	ND	ND	ND	39.38	ND	ND
186	107.00	32.58	131.02	663.12	ND	30.15	197.45	ND	19.81	ND	ND	ND	ND	34.89	ND	ND
199	99.95	81.68	335.84	44.52	390.37	ND	ND	ND	439.58	ND	ND	ND	ND	33.16	ND	ND
200	111.91	79.08	280.90	39.87	ND	ND	ND	ND	228.70	ND	ND	ND	ND	62.65	ND	ND
207	199.55	161.29	246.89	107.56	ND	ND	ND	ND	329.87	984.44	ND	ND	ND	33.47	ND	ND
208	144.71	137.36	153.19	263.61	ND	530.01	ND	ND	326.50	432.22	ND	ND	ND	21.39	ND	ND
213	92.24	29.23	314.00	125.21	ND	400.21	ND	ND	ND	ND	ND	ND	ND	34.96	ND	ND
214	64.99	ND	295.05	93.44	ND	582.98	ND	ND	442.41	ND	ND	ND	ND	43.66	ND	ND
223	21.21	34.89	213.73	82.03	ND	ND	107.87	ND	184.07	ND	ND	ND	ND	ND	ND	ND
224	17.82	26.16	232.75	205.76	ND	ND	ND	ND	253.24	722.07	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Lower Kananaskis Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
101	134.36	328.07	1279.48	509.82	285.03	288.19	52.40	ND	79.17	3070.90
102	ND	127.21	1793.28	175.04	615.95	122.31	79.24	ND	ND	2829.25
135	1885.30	862.26	1322.09	685.40	813.28	117.89	34.52	ND	ND	5819.78
136	121.82	547.72	765.79	436.17	436.28	277.39	96.86	ND	ND	2725.67
105	ND	46.51	1702.90	60.19	714.58	48.04	111.15	ND	40.92	2813.94
106	ND	186.98	2076.12	32.96	1002.30	ND	98.70	ND	ND	3258.85
109	ND	ND	270.43	ND	825.22	ND	ND	ND	ND	1095.64
110	ND	34.50	220.41	34.79	456.21	ND	49.61	ND	ND	825.06
161	979.30	268.19	2457.99	435.66	705.19	92.92	342.51	ND	17.98	5366.57
162	ND	213.32	722.67	36.43	667.53	56.41	136.87	ND	ND	1833.23
163	2512.13	594.10	2398.57	646.12	957.19	369.48	63.06	ND	ND	7613.32
164	ND	ND	737.02	407.60	925.94	56.78	71.06	ND	ND	2251.29
183	ND	35.94	206.00	ND	466.18	56.68	ND	ND	ND	764.79
184	ND	98.49	86.95	ND	922.33	59.45	25.79	ND	46.12	1239.13
185	ND	1736.16	1869.99	164.77	279.20	130.99	51.89	ND	21.85	3248.42
186	ND	997.73	1428.72	ND	616.58	426.07	52.52	ND	ND	3044.08
199	ND	199.87	710.08	98.01	440.99	ND	ND	ND	13.41	1557.23
200	ND	157.01	930.27	114.53	530.81	ND	131.28	ND	ND	1910.40
207	ND	44.57	981.74	259.49	1088.35	ND	72.84	ND	ND	2446.98
208	ND	91.00	1351.31	53.63	888.62	83.50	278.14	ND	ND	2723.73
213	ND	221.11	1047.62	177.94	809.34	ND	ND	ND	ND	2304.05
214	ND	181.99	1540.05	113.56	1379.60	ND	138.77	ND	ND	3467.77
223	ND	255.63	1470.91	ND	475.13	ND	ND	ND	ND	2258.36
224	ND	204.76	1867.60	31.73	407.33	ND	ND	ND	ND	2511.42

POCConcentrations in Vegetation (ng/g lipid) Sampled from Lower Kananaskis Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
101	2.47	3.10	10.78	ND	ND	ND	17.93	ND	ND	146.61	ND	ND	ND	2.79	ND	ND
102	13.06	6.19	13.57	53.35	ND	6.55	ND	ND	ND	126.22	ND	ND	ND	ND	ND	ND
135	14.51	7.19	16.20	3.88	ND	ND	ND	ND	52.50	ND	ND	2.12	ND	6.18	ND	10.34
136	18.72	ND	27.78	10.96	ND	ND	ND	ND	54.38	ND	52.46	ND	ND	11.90	ND	22.95
105	17.53	5.73	41.08	9.50	ND	ND	16.92	3281.22	59.78	ND	ND	ND	ND	7.29	ND	ND
106	13.66	6.63	22.39	22.31	ND	ND	ND	ND	161.75	ND	ND	ND	ND	4.11	ND	ND
109	18.75	11.89	21.04	ND	ND	ND	ND	ND	155.85	ND	118.00	ND	ND	ND	ND	ND
110	10.57	9.81	25.52	4.40	ND	ND	ND	ND	55.45	ND	ND	ND	ND	4.32	ND	ND
161	46.26	19.12	30.36	10.76	ND	ND	2.97	ND	74.23	ND	ND	1112.10	ND	4.75	ND	733.98
162	9.45	15.83	41.66	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
163	21.44	10.23	24.51	22.89	ND	ND	ND	ND	18.48	ND	ND	48.08	ND	8.43	ND	ND
164	10.56	9.26	15.92	13.86	ND	ND	ND	ND	4.01	30.24	ND	ND	ND	3.83	ND	ND
183	13.82	8.71	17.40	ND	ND	ND	ND	ND	2.00	ND	ND	ND	ND	ND	ND	ND
184	21.12	12.68	27.08	ND	ND	ND	ND	ND	25.24	ND	ND	ND	ND	ND	ND	ND
185	16.95	5.35	18.85	120.02	ND	ND	36.47	ND	38.76	ND	ND	ND	ND	4.43	ND	ND
186	11.58	3.53	14.18	71.77	ND	3.26	21.37	ND	2.14	ND	ND	ND	ND	3.78	ND	ND
199	24.91	20.36	83.70	11.10	97.29	ND	ND	ND	109.55	ND	ND	ND	ND	8.26	ND	ND
200	22.25	15.72	55.84	7.93	ND	ND	ND	ND	45.46	ND	ND	ND	ND	12.45	ND	ND
207	33.22	26.85	41.10	17.91	ND	ND	ND	ND	54.92	163.89	ND	ND	ND	5.57	ND	ND
208	33.09	31.41	35.03	60.28	ND	121.20	ND	ND	74.66	98.84	ND	ND	ND	4.89	ND	ND
213	8.54	2.71	29.08	11.60	ND	37.07	ND	ND	ND	ND	ND	ND	ND	3.24	ND	ND
214	6.06	ND	27.53	8.72	ND	54.40	ND	ND	41.28	ND	ND	ND	ND	4.07	ND	ND
223	1.87	3.08	18.84	7.23	ND	ND	9.51	ND	16.23	ND	ND	ND	ND	ND	ND	ND
224	1.34	1.97	17.50	15.47	ND	ND	ND	ND	19.04	54.29	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Lower Kananaskis Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
101	12.51	30.56	119.17	47.48	26.55	26.84	4.88	ND	7.37	286.02
102	ND	31.68	446.56	43.59	153.38	30.46	19.73	ND	ND	704.54
135	267.86	122.51	187.84	97.38	115.55	16.75	4.90	ND	ND	826.86
136	15.55	69.93	97.78	55.69	55.70	35.42	12.37	ND	ND	348.01
105	ND	7.44	272.52	9.63	114.36	7.69	17.79	ND	6.55	450.33
106	ND	39.94	443.48	7.04	214.10	ND	21.08	ND	ND	696.13
109	ND	ND	100.11	ND	305.49	ND	ND	ND	ND	405.60
110	ND	5.56	35.50	5.60	73.48	ND	7.99	ND	ND	132.90
161	158.57	43.43	398.01	70.54	114.19	15.05	55.46	ND	2.91	868.98
162	ND	47.05	159.39	8.03	147.23	12.44	30.19	ND	ND	404.33
163	422.41	99.90	403.32	108.64	160.95	62.13	10.60	ND	ND	1280.17
164	ND	ND	84.52	46.74	106.19	6.51	8.15	ND	ND	258.17
183	ND	6.56	37.62	ND	85.13	10.35	ND	ND	ND	139.66
184	ND	20.73	18.30	ND	194.08	12.51	5.43	ND	9.70	260.75
185	ND	195.14	210.18	18.52	31.38	14.72	5.83	ND	2.46	365.11
186	ND	107.99	154.64	ND	66.74	46.12	5.68	ND	ND	329.48
199	ND	49.81	176.97	24.43	109.90	ND	ND	ND	3.34	388.10
200	ND	31.21	184.91	22.77	105.51	ND	26.09	ND	ND	379.74
207	ND	7.42	163.44	43.20	181.19	ND	12.13	ND	ND	407.38
208	ND	20.81	309.01	12.26	203.20	19.09	63.60	ND	ND	622.84
213	ND	20.48	97.04	16.48	74.96	ND	ND	ND	ND	213.41
214	ND	16.98	143.70	10.60	128.73	ND	12.95	ND	ND	323.57
223	ND	22.53	129.66	ND	41.88	ND	ND	ND	ND	199.07
224	ND	15.40	140.42	2.39	30.63	ND	ND	ND	ND	188.83

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Rock Isle

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
41	90.71	10.73	46.98	ND	ND	ND	ND	ND	331.21	ND	ND	ND	ND	18.08	10.37	ND
42	271.83	56.34	120.09	ND	ND	ND	ND	ND	245.22	ND	ND	ND	ND	26.37	67.90	ND
43	160.37	30.87	113.97	ND	ND	ND	ND	1636.18	209.21	ND	ND	ND	ND	ND	53.25	ND
44	190.43	20.66	122.67	ND	ND	ND	ND	1095.95	160.96	ND	ND	ND	ND	ND	48.07	ND
61	56.47	59.18	35.34	ND	750.97	ND	ND	ND	26.79	ND	ND	119.99	ND	ND	ND	ND
62	73.01	66.40	36.86	ND	870.28	ND	ND	ND	35.88	ND	ND	86.58	ND	ND	ND	ND
45	172.18	20.79	96.67	ND	ND	ND	ND	270.34	ND	ND	ND	ND	ND	ND	ND	ND
46	109.61	43.15	66.08	ND	ND	ND	ND	208.63	ND	ND	ND	ND	ND	ND	ND	ND
53	92.63	532.93	33.74	ND	ND	ND	ND	375.87	114.58	ND	129.79	ND	ND	ND	ND	ND
54	230.91	135.48	153.37	ND	ND	ND	ND	ND	42.64	ND	255.69	ND	ND	ND	ND	ND
47	101.98	34.79	79.64	ND	ND	29.02	ND	3019.49	48.12	ND	ND	ND	ND	ND	62.11	ND
48	165.69	21.55	102.32	ND	ND	50.76	ND	ND	184.41	ND	ND	ND	ND	ND	48.42	ND
55	66.08	39.86	17.70	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
56	36.24	33.01	21.80	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
49	146.55	28.63	170.62	ND	161.51	82.93	ND	ND	186.58	ND	ND	ND	ND	ND	ND	ND
50	105.39	18.34	225.29	ND	196.99	ND	ND	ND	224.73	ND	ND	ND	ND	ND	ND	ND
57	85.63	252.58	13.19	ND	ND	ND	ND	ND	ND	ND	149.47	ND	ND	ND	ND	ND
58	94.03	316.44	21.92	ND	ND	ND	ND	ND	ND	ND	123.94	ND	ND	ND	ND	ND
51	195.09	10.18	50.27	ND	ND	ND	ND	ND	178.56	ND	ND	ND	ND	24.45	ND	ND
52	205.45	29.79	44.92	ND	ND	ND	ND	ND	253.65	ND	ND	ND	ND	31.06	ND	ND
59	86.78	302.05	13.41	ND	ND	ND	84.92	ND	88.63	ND	42.29	ND	ND	ND	ND	ND
60	82.50	381.26	26.51	ND	ND	ND	131.82	ND	184.71	ND	99.49	ND	ND	ND	ND	ND
165	137.03	77.59	123.00	ND	9.65	ND	ND	ND	235.97	ND	10.89	110.82	ND	21.92	ND	24.79
166	122.13	56.31	98.37	26.22	124.53	ND	47.19	ND	139.90	249.06	8.36	7.95	ND	24.88	ND	32.20
167	81.03	34.26	44.84	ND	ND	ND	ND	ND	314.09	264.71	ND	ND	ND	23.32	ND	71.53
168	86.72	41.00	82.34	92.79	ND	ND	ND	ND	275.92	361.83	8.93	16.98	24.96	25.27	ND	15.95
169	10.69	13.78	98.19	49.78	ND	ND	ND	ND	190.61	ND	ND	ND	ND	ND	ND	ND
170	48.51	33.60	108.40	267.34	ND	ND	ND	ND	264.84	ND	ND	10.91	ND	ND	ND	ND
171	105.22	31.78	165.78	88.60	ND	82.03	ND	ND	41.86	ND	14.38	ND	ND	32.40	ND	ND
172	110.72	31.97	176.26	39.41	ND	86.18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
191	83.46	15.28	117.37	52.82	ND	32.93	ND	ND	135.17	ND	10.11	ND	ND	12.67	ND	ND
192	54.52	16.49	122.37	109.88	ND	100.02	ND	ND	159.61	ND	ND	ND	ND	13.63	ND	ND
203	28.89	14.03	81.21	242.75	ND	ND	ND	ND	158.26	379.73	ND	ND	ND	37.03	ND	ND
204	27.06	18.35	126.45	56.86	ND	303.01	ND	ND	ND	ND	ND	10.93	ND	27.27	ND	ND
221	29.95	15.24	112.47	321.11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
222	ND	ND	54.98	87.31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
229	36.92	13.62	103.21	25.39	ND	27.01	56.86	ND	132.50	466.08	ND	ND	ND	90.44	ND	ND
230	78.39	20.70	156.75	37.22	ND	50.72	ND	ND	ND	277.08	ND	ND	16.41	27.76	ND	ND

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Rock Isle

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
41	ND	ND	212.45	114.93	26.30	49.86	ND	ND	ND	403.54
42	ND	ND	745.85	329.67	142.45	104.73	ND	ND	ND	1359.06
43	ND	ND	801.19	147.91	237.37	ND	ND	ND	ND	1186.48
44	ND	ND	686.35	257.74	234.02	86.62	ND	ND	ND	1264.73
61	ND	ND	645.98	123.71	ND	55.93	ND	ND	ND	849.35
62	ND	ND	886.33	153.57	ND	157.47	23.50	ND	ND	1220.87
45	ND	ND	353.73	38.38	93.72	274.84	234.23	ND	ND	994.89
46	ND	ND	2418.39	2745.58	ND	ND	ND	ND	ND	5163.97
53	ND	ND	1651.03	416.44	76.48	201.81	80.38	ND	ND	2426.14
54	ND	ND	2158.72	586.47	166.81	135.14	ND	ND	ND	3047.14
47	ND	ND	364.41	63.62	260.09	1972.57	1241.39	ND	ND	4046.47
48	ND	ND	497.22	361.34	136.40	107.21	ND	ND	ND	1152.92
55	ND	ND	620.24	68.09	ND	183.63	381.55	315.14	ND	1568.65
56	ND	ND	1052.01	87.05	ND	59.64	86.20	ND	ND	1284.90
49	ND	ND	573.25	311.74	535.89	63.58	ND	ND	ND	1535.68
50	ND	ND	410.30	215.93	242.03	196.18	132.50	ND	ND	1196.94
57	ND	ND	1150.86	274.30	177.87	190.73	ND	ND	ND	1793.76
58	ND	ND	1459.81	269.30	234.15	250.56	ND	ND	ND	2213.82
51	ND	ND	778.25	253.85	ND	104.88	ND	ND	ND	1136.97
52	ND	ND	524.18	308.88	58.62	237.08	ND	ND	ND	1128.75
59	ND	ND	1486.33	410.59	125.63	207.27	ND	ND	ND	2229.82
60	ND	ND	1997.96	406.09	320.05	151.96	34.62	ND	ND	2910.69
165	ND	ND	538.32	121.83	475.17	ND	26.96	ND	ND	1185.23
166	ND	ND	784.10	242.38	443.53	ND	ND	ND	ND	1508.53
167	ND	ND	550.15	191.51	576.41	30.89	29.95	ND	ND	1410.75
168	ND	48.11	179.20	224.40	384.91	39.78	ND	ND	424.50	1321.49
169	ND	53.32	2459.67	ND	405.62	ND	ND	ND	ND	2918.61
170	ND	343.55	3279.03	ND	316.48	35.61	45.03	ND	ND	3843.76
171	ND	49.62	560.79	38.51	136.11	14.09	59.27	ND	ND	834.74
172	ND	ND	245.52	40.95	336.78	ND	51.67	ND	ND	674.92
191	ND	ND	413.51	47.97	384.92	15.82	47.80	ND	ND	954.23
192	ND	64.76	617.19	16.71	287.96	ND	15.93	ND	ND	1002.54
203	ND	612.71	1666.61	34.27	116.36	ND	29.91	ND	ND	2144.95
204	43.98	105.74	2158.82	27.70	193.31	27.78	118.19	12.90	21.21	2691.74
221	ND	1040.31	2676.08	ND	183.30	ND	17.69	ND	23.62	3437.09
222	ND	77.26	1900.57	9.89	292.24	ND	51.97	ND	ND	2276.11
229	ND	41.79	301.77	162.68	ND	50.69	ND	ND	ND	556.93
230	55.49	126.16	414.75	42.53	210.99	13.05	26.74	ND	22.84	897.54

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Rock Isle

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
41	213.60	25.26	110.63	ND	ND	ND	ND	ND	779.94	ND	ND	ND	ND	42.57	24.42	ND
42	578.99	119.99	255.79	ND	ND	ND	ND	ND	522.30	ND	ND	ND	ND	56.17	144.63	ND
43	346.42	66.69	246.19	ND	ND	ND	ND	3534.45	451.93	ND	ND	ND	ND	ND	115.03	ND
44	402.96	43.73	259.57	ND	ND	ND	ND	2319.05	340.59	ND	ND	ND	ND	ND	101.72	ND
61	121.11	126.93	75.79	ND	1610.64	ND	ND	ND	57.45	ND	ND	257.36	ND	ND	ND	ND
62	167.21	152.08	84.41	ND	1993.15	ND	ND	ND	82.17	ND	ND	198.28	ND	ND	ND	ND
45	369.41	44.60	207.40	ND	ND	ND	ND	580.02	ND	ND	ND	ND	ND	ND	ND	ND
46	214.32	84.38	129.21	ND	ND	ND	ND	407.94	ND	ND	ND	ND	ND	ND	ND	ND
53	196.06	1127.93	71.42	ND	ND	ND	ND	795.52	242.51	ND	274.69	ND	ND	ND	ND	ND
54	500.34	293.57	332.32	ND	ND	ND	ND	ND	92.40	ND	554.04	ND	ND	ND	ND	ND
47	197.30	67.30	154.07	ND	ND	56.14	ND	5841.54	93.09	ND	ND	ND	ND	ND	120.15	ND
48	318.47	41.42	196.66	ND	ND	97.57	ND	ND	354.46	ND	ND	ND	ND	ND	93.07	ND
55	129.03	77.83	34.55	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
56	81.05	73.83	48.76	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
49	818.38	159.86	952.82	ND	901.92	463.12	ND	ND	1041.92	ND	ND	ND	ND	ND	ND	ND
50	556.94	96.90	1190.55	ND	1041.02	ND	ND	ND	1187.63	ND	ND	ND	ND	ND	ND	ND
57	190.52	561.95	29.35	ND	ND	ND	ND	ND	ND	ND	332.55	ND	ND	ND	ND	ND
58	214.01	720.21	49.90	ND	ND	ND	ND	ND	ND	ND	282.08	ND	ND	ND	ND	ND
51	708.18	36.94	182.50	ND	ND	ND	ND	ND	648.20	ND	ND	ND	ND	88.74	ND	ND
52	928.62	134.63	203.03	ND	ND	ND	ND	ND	1146.47	ND	ND	ND	ND	140.40	ND	ND
59	186.79	650.14	28.87	ND	ND	ND	182.79	ND	190.77	ND	91.03	ND	ND	ND	ND	ND
60	170.37	787.30	54.75	ND	ND	ND	272.20	ND	381.42	ND	205.44	ND	ND	ND	ND	ND
165	298.44	168.99	267.88	ND	21.01	ND	ND	ND	513.92	ND	23.72	241.35	ND	47.74	ND	54.00
166	266.66	122.94	214.78	57.25	271.91	ND	103.03	ND	305.47	543.79	18.26	17.36	ND	54.32	ND	70.30
167	164.46	69.54	91.02	ND	ND	ND	ND	ND	637.47	537.25	ND	ND	ND	47.32	ND	145.17
168	177.14	83.75	168.20	189.53	ND	ND	ND	ND	563.60	739.08	18.23	34.69	50.98	51.61	ND	32.58
169	20.59	26.56	189.21	95.91	ND	ND	ND	ND	367.29	ND	ND	ND	ND	ND	ND	ND
170	100.15	69.37	223.80	551.95	ND	ND	ND	ND	546.78	ND	ND	22.52	ND	ND	ND	ND
171	233.03	70.38	367.15	196.22	ND	181.68	ND	ND	92.71	ND	31.86	ND	ND	71.76	ND	ND
172	228.20	65.89	363.28	81.23	ND	177.61	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
191	157.03	28.75	220.84	99.39	ND	61.97	ND	ND	254.32	ND	19.02	ND	ND	23.85	ND	ND
192	108.13	32.70	242.70	217.93	ND	198.37	ND	ND	316.54	ND	ND	ND	ND	27.02	ND	ND
203	58.78	28.55	165.19	493.81	ND	ND	ND	ND	321.95	772.46	ND	ND	ND	75.32	ND	ND

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Rock Isle

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
204	53.95	36.59	252.09	113.36	ND	604.09	ND	ND	ND	ND	ND	21.78	ND	54.37	ND	ND
221	103.07	52.44	387.03	1105.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
222	ND	ND	193.75	307.69	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
229	138.96	51.27	388.48	95.55	ND	101.65	214.02	ND	498.74	1754.31	ND	ND	ND	340.42	ND	ND
230	284.49	75.13	568.84	135.06	ND	184.06	ND	ND	ND	1005.54	ND	ND	59.56	100.73	ND	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Rock Isle

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
41	ND	ND	500.28	270.64	61.93	117.42	ND	ND	ND	950.27
42	ND	ND	1588.61	702.18	303.41	223.08	ND	ND	ND	2894.72
43	ND	ND	1730.72	319.52	512.77	ND	ND	ND	ND	2563.01
44	ND	ND	1452.34	545.38	495.19	183.28	ND	ND	ND	2676.19
61	ND	ND	1385.46	265.32	ND	119.96	ND	ND	ND	1821.64
62	ND	ND	2029.89	351.70	ND	360.65	53.81	ND	ND	2796.06
45	ND	ND	758.93	82.34	201.08	589.66	502.54	ND	ND	2134.55
46	ND	ND	4728.80	5368.56	ND	ND	ND	ND	ND	10097.36
53	ND	ND	3494.34	881.37	161.87	427.12	170.12	ND	ND	5134.83
54	ND	ND	4677.56	1270.78	361.45	292.83	ND	ND	ND	6602.62
47	ND	ND	704.99	123.07	503.18	3816.16	2401.62	ND	ND	7828.35
48	ND	ND	955.69	694.52	262.17	206.06	ND	ND	ND	2216.01
55	ND	ND	1211.07	132.95	ND	358.55	745.02	615.35	ND	3062.93
56	ND	ND	2353.14	194.72	ND	133.41	192.80	ND	ND	2874.06
49	ND	ND	3201.26	1740.86	2992.63	355.07	ND	ND	ND	8575.85
50	ND	ND	2168.27	1141.11	1279.01	1036.73	700.22	ND	ND	6325.35
57	ND	ND	2560.53	610.28	395.74	424.36	ND	ND	ND	3990.91
58	ND	ND	3322.50	612.92	532.93	570.27	ND	ND	ND	5038.63
51	ND	ND	2825.11	921.49	ND	380.73	ND	ND	ND	4127.33
52	ND	ND	2369.21	1396.08	264.95	1071.55	ND	ND	ND	5101.79
59	ND	ND	3199.19	883.75	270.41	446.14	ND	ND	ND	4799.49
60	ND	ND	4125.73	838.57	660.90	313.79	71.50	ND	ND	6010.50
165	ND	ND	1172.42	265.33	1034.89	ND	58.72	ND	ND	2581.35
166	ND	ND	1712.02	529.22	968.41	ND	ND	ND	ND	3293.78
167	ND	ND	1116.58	388.68	1169.87	62.69	60.80	ND	ND	2863.25
168	ND	98.27	366.04	458.35	786.21	81.25	ND	ND	867.08	2699.29
169	ND	102.73	4739.45	ND	781.58	ND	ND	ND	ND	5623.76
170	ND	709.29	6769.85	ND	653.41	73.53	92.96	ND	ND	7935.78
171	ND	109.90	1242.02	85.29	301.45	31.20	131.27	ND	ND	1848.75
172	ND	ND	506.02	84.41	694.12	ND	106.49	ND	ND	1391.04
191	ND	ND	778.04	90.26	724.25	29.76	89.94	ND	ND	1795.40
192	ND	128.43	1224.06	33.14	571.10	ND	31.59	ND	ND	1988.31
203	ND	1246.40	3390.28	69.70	236.71	ND	60.84	ND	ND	4363.34

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Rock Isle

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
204	87.67	210.81	4303.86	55.23	385.38	55.39	235.63	25.71	42.28	5366.30
221	ND	3579.93	9208.99	ND	630.77	ND	60.86	ND	81.28	11827.80
222	ND	272.29	6697.97	34.84	1029.89	ND	183.14	ND	ND	8021.47
229	ND	157.29	1135.86	612.31	ND	190.81	ND	ND	ND	2096.26
230	201.38	457.85	1505.18	154.34	765.70	47.35	97.05	ND	82.90	3257.25

OC Concentrations in Vegetation (ng/g lipid) Sampled from Rock Isle

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
41	9.07	1.07	4.70	ND	ND	ND	ND	ND	33.12	ND	ND	ND	ND	1.81	1.04	ND
42	32.13	6.66	14.19	ND	ND	ND	ND	ND	28.98	ND	ND	ND	ND	3.12	8.02	ND
43	21.10	4.06	15.00	ND	ND	ND	ND	215.29	27.53	ND	ND	ND	ND	ND	7.01	ND
44	26.98	2.93	17.38	ND	ND	ND	ND	155.26	22.80	ND	ND	ND	ND	ND	6.81	ND
61	4.03	4.23	2.52	ND	53.64	ND	ND	ND	1.91	ND	ND	8.57	ND	ND	ND	ND
62	6.08	5.53	3.07	ND	72.52	ND	ND	ND	2.99	ND	ND	7.21	ND	ND	ND	ND
45	28.70	3.46	16.11	ND	ND	ND	ND	45.06	ND	ND	ND	ND	ND	ND	ND	ND
46	32.88	12.95	19.82	ND	ND	ND	ND	62.59	ND	ND	ND	ND	ND	ND	ND	ND
53	8.46	48.70	3.08	ND	ND	ND	ND	34.35	10.47	ND	11.86	ND	ND	ND	ND	ND
54	9.92	5.82	6.59	ND	ND	ND	ND	ND	1.83	ND	10.99	ND	ND	ND	ND	ND
47	23.06	7.86	18.01	ND	ND	6.56	ND	682.67	10.88	ND	ND	ND	ND	ND	14.04	ND
48	16.90	2.20	10.44	ND	ND	5.18	ND	ND	18.81	ND	ND	ND	ND	ND	4.94	ND
55	9.11	5.49	2.44	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
56	4.74	4.32	2.85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
49	17.87	3.49	20.81	ND	19.70	10.11	ND	ND	22.75	ND	ND	ND	ND	ND	ND	ND
50	13.87	2.41	29.64	ND	25.92	ND	ND	ND	29.57	ND	ND	ND	ND	ND	ND	ND
57	6.93	20.45	1.07	ND	ND	ND	ND	ND	ND	ND	12.10	ND	ND	ND	ND	ND
58	12.16	40.91	2.83	ND	ND	ND	ND	ND	ND	ND	16.02	ND	ND	ND	ND	ND
51	24.15	1.26	6.22	ND	ND	ND	ND	ND	22.11	ND	ND	ND	ND	3.03	ND	ND
52	23.89	3.46	5.22	ND	ND	ND	ND	ND	29.49	ND	ND	ND	ND	3.61	ND	ND
59	10.58	36.84	1.64	ND	ND	ND	10.36	ND	10.81	ND	5.16	ND	ND	ND	ND	ND
60	13.75	63.54	4.42	ND	ND	ND	21.97	ND	30.79	ND	16.58	ND	ND	ND	ND	ND
165	21.50	12.17	19.30	ND	1.51	ND	ND	ND	37.02	ND	1.71	17.39	ND	3.44	ND	3.89
166	25.09	11.57	20.21	5.39	25.58	ND	9.69	ND	28.74	51.16	1.72	1.63	ND	5.11	ND	6.61
167	20.19	8.54	11.17	ND	ND	ND	ND	ND	78.24	65.94	ND	ND	ND	5.81	ND	17.82
168	30.73	14.53	29.17	32.88	ND	ND	ND	ND	97.76	128.20	3.16	6.02	8.84	8.95	ND	5.65
169	3.45	4.44	31.66	16.05	ND	ND	ND	ND	61.45	ND	ND	ND	ND	ND	ND	ND
170	9.31	6.45	20.81	51.32	ND	ND	ND	ND	50.84	ND	ND	2.09	ND	ND	ND	ND
171	34.03	10.28	53.62	28.65	ND	26.53	ND	ND	13.54	ND	4.65	ND	ND	10.48	ND	ND
172	25.44	7.35	40.50	9.06	ND	19.80	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
191	24.95	4.57	35.09	15.79	ND	9.85	ND	ND	40.41	ND	3.02	ND	ND	3.79	ND	ND
192	15.85	4.79	35.58	31.95	ND	29.08	ND	ND	46.40	ND	ND	ND	ND	3.96	ND	ND
203	7.76	3.77	21.81	65.19	ND	ND	ND	ND	42.50	101.98	ND	ND	ND	9.94	ND	ND
204	8.74	5.93	40.85	18.37	ND	97.88	ND	ND	ND	ND	ND	3.53	ND	8.81	ND	ND
221	4.58	2.33	17.21	49.14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
222	ND	ND	12.07	19.16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
229	11.22	4.14	31.36	7.71	ND	8.20	17.27	ND	40.26	141.60	ND	ND	ND	27.48	ND	ND
230	25.76	6.80	51.51	12.23	ND	16.67	ND	ND	ND	91.06	ND	ND	5.39	9.12	ND	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Rock Isle

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
41	ND	ND	21.24	11.49	2.63	4.99	ND	ND	ND	40.35
42	ND	ND	88.15	38.96	16.84	12.38	ND	ND	ND	160.62
43	ND	ND	105.42	19.46	31.23	ND	ND	ND	ND	156.12
44	ND	ND	97.23	36.51	33.15	12.27	ND	ND	ND	179.17
61	ND	ND	46.14	8.84	ND	4.00	ND	ND	ND	60.67
62	ND	ND	73.86	12.80	ND	13.12	1.96	ND	ND	101.74
45	ND	ND	58.96	6.40	15.62	45.81	39.04	ND	ND	165.82
46	ND	ND	725.52	823.67	ND	ND	ND	ND	ND	1549.19
53	ND	ND	150.87	38.05	6.99	18.44	7.35	ND	ND	221.70
54	ND	ND	92.77	25.20	7.17	5.81	ND	ND	ND	130.95
47	ND	ND	82.39	14.38	58.80	445.97	280.66	ND	ND	914.85
48	ND	ND	50.72	36.86	13.91	10.94	ND	ND	ND	117.60
55	ND	ND	85.49	9.39	ND	25.31	52.59	43.44	ND	216.22
56	ND	ND	137.57	11.38	ND	7.80	11.27	ND	ND	168.02
49	ND	ND	69.91	38.02	65.35	7.75	ND	ND	ND	187.28
50	ND	ND	53.99	28.41	31.85	25.81	17.43	ND	ND	157.49
57	ND	ND	93.17	22.21	14.40	15.44	ND	ND	ND	145.21
58	ND	ND	188.71	34.81	30.27	32.39	ND	ND	ND	286.18
51	ND	ND	96.35	31.43	ND	12.99	ND	ND	ND	140.77
52	ND	ND	60.95	35.92	6.82	27.57	ND	ND	ND	131.25
59	ND	ND	181.26	50.07	15.32	25.28	ND	ND	ND	271.93
60	ND	ND	332.99	67.68	53.34	25.33	5.77	ND	ND	485.12
165	ND	ND	84.45	19.11	74.55	ND	4.23	ND	ND	185.94
166	ND	ND	161.08	49.79	91.11	ND	ND	ND	ND	309.90
167	ND	ND	137.05	47.71	143.59	7.69	7.46	ND	ND	351.44
168	ND	17.05	63.49	79.50	136.37	14.09	ND	ND	150.40	468.21
169	ND	17.19	792.95	ND	130.77	ND	ND	ND	ND	940.91
170	ND	65.95	629.48	ND	60.76	6.84	8.64	ND	ND	737.89
171	ND	16.05	181.37	12.46	44.02	4.56	19.17	ND	ND	269.97
172	ND	ND	56.42	9.41	77.39	ND	11.87	ND	ND	155.08
191	ND	ND	123.64	14.34	115.09	4.73	14.29	ND	ND	285.31
192	ND	18.83	179.45	4.86	83.72	ND	4.63	ND	ND	291.48
203	ND	164.54	447.57	9.20	31.25	ND	8.03	ND	ND	576.03
204	14.21	34.16	697.38	8.95	62.45	8.98	38.18	4.17	6.85	869.54
221	ND	159.18	409.48	ND	28.05	ND	2.71	ND	3.61	525.93
222	ND	16.96	417.10	2.17	64.13	ND	11.40	ND	ND	499.51
229	ND	12.70	91.68	49.42	ND	15.40	ND	ND	ND	169.20
230	18.24	41.46	136.31	13.98	69.34	4.29	8.79	ND	7.51	294.98

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Vermilion Lakes

Sample	α-HCH	γ-HCH	HCB	Hept	Hep Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
63	123.19	286.23	25.85	ND	37447.65	ND	ND	ND	144.10	ND	ND	ND	ND	39.26	151.13	25.95
74	45.03	104.75	6.67	ND	1007.45	ND	ND	ND	25.70	ND	ND	ND	ND	15.32	29.96	14.12
64	59.80	51.68	4.04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	34.23	35.93	ND
65	69.36	55.93	10.79	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	32.20	24.13	ND
66	43.44	123.35	27.71	ND	3395.97	ND	ND	ND	44.61	ND	ND	ND	ND	84.30	134.85	33.77
67	80.63	113.04	39.03	ND	3243.59	ND	ND	ND	32.49	ND	ND	ND	ND	36.85	33.69	23.81
75	66.81	117.69	12.89	ND	ND	ND	ND	ND	47.67	ND	9.20	ND	ND	12.55	19.74	ND
76	78.33	136.65	15.97	ND	572.75	ND	ND	ND	30.22	ND	12.72	ND	ND	12.37	39.88	ND
68	85.35	166.51	39.98	ND	3276.04	ND	ND	ND	121.37	61.46	753.23	ND	ND	54.73	152.36	30.63
69	93.00	161.48	14.58	ND	2269.58	ND	ND	ND	105.21	152.81	554.17	ND	ND	56.61	208.12	41.27
77	69.12	92.13	16.93	ND	30.72	ND	ND	ND	22.09	ND	ND	ND	ND	60.11	99.26	15.95
78	69.79	49.16	23.47	ND	127.87	ND	ND	ND	29.15	ND	ND	ND	ND	60.34	143.88	27.09
70	20.75	124.50	ND	ND	1473.19	ND	ND	ND	7.09	ND	ND	ND	ND	13.00	33.71	ND
71	33.50	102.38	ND	ND	214.83	ND	ND	ND	10.35	ND	ND	ND	ND	20.13	25.94	ND
79	23.08	138.86	11.04	ND	245.46	ND	ND	ND	41.99	144.86	ND	ND	ND	ND	19.91	ND
80	21.84	95.01	18.25	ND	195.18	ND	ND	ND	43.64	135.54	ND	ND	ND	ND	26.35	ND
72	19.43	100.27	15.67	ND	ND	ND	ND	ND	ND	66.62	ND	ND	ND	ND	ND	ND
73	16.47	8.79	0.17	ND	ND	ND	ND	ND	ND	68.48	ND	ND	ND	ND	ND	ND
81	32.75	42.58	7.89	ND	941.46	ND	ND	133.28	24.22	ND	14.89	ND	ND	55.98	59.76	ND
82	28.85	229.64	9.50	ND	2545.48	ND	ND	ND	27.39	ND	28.59	ND	ND	31.46	31.83	ND
129	30.17	13.83	28.89	71.23	ND	ND	ND	ND	150.55	ND	ND	51.65	ND	15.93	ND	ND
130	23.56	8.96	70.17	31.27	ND	ND	24.60	ND	103.19	ND	ND	38.38	ND	15.96	ND	ND
131	18.27	9.91	22.64	47.99	ND	ND	ND	ND	112.89	ND	131.97	ND	ND	24.32	ND	ND
132	34.40	10.00	33.43	ND	ND	ND	ND	ND	48.04	320.08	ND	ND	ND	17.89	ND	ND
107	24.89	17.18	67.51	16.62	ND	ND	ND	ND	137.89	257.25	ND	ND	ND	14.31	ND	ND
108	23.68	14.87	89.90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	16.02	ND	ND
145	32.18	24.40	20.12	ND	ND	471.07	ND	ND	220.64	ND	270.64	ND	ND	16.26	ND	ND
146	51.75	35.25	99.98	18.47	ND	ND	ND	ND	202.73	ND	ND	ND	ND	17.96	ND	ND
139	33.66	21.51	59.67	ND	ND	ND	ND	ND	66.92	ND	ND	ND	ND	30.26	ND	29.26
140	15.24	15.44	60.46	16.73	ND	5053.69	ND	799.27	ND	ND	189.49	ND	ND	17.07	ND	ND
141	39.93	29.58	37.00	37.52	ND	ND	ND	343.05	206.08	423.07	ND	ND	ND	19.80	ND	26.43
142	38.55	15.38	101.81	117.76	ND	ND	ND	ND	ND	ND	ND	ND	ND	59.47	ND	ND
153	22.03	31.16	84.35	25.53	ND	ND	ND	349.26	152.12	ND	ND	492.15	ND	20.35	ND	ND
154	43.32	18.78	33.29	ND	ND	ND	ND	ND	125.40	ND	ND	ND	ND	14.76	ND	ND
155	17.57	14.07	62.98	24.69	ND	132.18	ND	ND	ND	ND	ND	661.03	ND	9.85	ND	ND

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Vermilion Lakes

Sample	α-HCH	γ-HCH	HCB	Hept	Hep Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
156	16.08	29.96	57.85	ND	661.39	ND	112.41	ND	ND	646.79	160.77	ND	ND	27.95	ND	ND
173	88.61	48.80	179.92	37.32	ND	44.26	ND	ND	ND	ND	ND	284.88	ND	15.76	ND	ND
174	45.05	ND	39.50	ND	321.18	ND	ND	ND	49.00	437.05	ND	ND	ND	21.83	ND	ND
179	67.84	67.67	214.63	223.11	ND	ND	ND	ND	37.98	ND	11.90	ND	ND	17.65	ND	ND
180	56.09	51.12	114.06	25.79	ND	333.58	ND	ND	72.20	343.02	63.36	ND	25.18	15.11	ND	ND
197	26.70	19.25	133.94	20.31	ND	ND	ND	ND	82.62	ND	ND	ND	ND	ND	ND	ND
198	22.53	18.51	111.72	16.07	ND	ND	ND	ND	92.71	ND	ND	ND	ND	10.64	ND	ND
205	52.91	32.62	129.67	17.10	ND	185.25	ND	ND	121.02	477.31	ND	ND	ND	17.56	ND	ND
206	47.89	29.58	291.20	43.02	ND	ND	ND	ND	ND	288.93	ND	ND	ND	18.09	ND	ND
219	9.59	16.08	106.13	39.33	ND	ND	ND	ND	24.94	ND	ND	ND	ND	ND	ND	ND
220	4.45	11.81	77.13	27.94	ND	ND	ND	ND	ND	565.21	ND	ND	ND	ND	ND	ND
227	36.05	21.47	86.72	74.76	ND	528.89	ND	ND	ND	ND	ND	ND	39.74	22.63	ND	ND
228	67.33	40.78	376.62	164.00	ND	235.35	ND	ND	122.58	397.13	ND	ND	49.80	32.28	ND	ND

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Vermilion Lakes

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
63	ND	ND	1105.97	530.05	113.57	263.27	ND	ND	ND	2102.55
74	ND	ND	177.52	357.23	53.00	150.28	124.22	ND	64.15	985.07
64	ND	97.54	339.89	268.45	ND	126.45	106.44	ND	ND	999.43
65	ND	84.71	349.94	269.08	ND	137.94	73.87	ND	ND	971.72
66	ND	ND	2752.89	101.27	169.23	37.32	26.54	ND	ND	3087.25
67	ND	ND	2869.93	1943.78	ND	ND	ND	ND	ND	4813.71
75	ND	ND	68.14	190.78	ND	108.76	17.96	ND	26.05	411.69
76	ND	ND	45.72	156.57	ND	56.11	8.37	ND	ND	266.77
68	ND	ND	1724.01	176.89	397.44	145.39	56.57	ND	ND	2500.30
69	ND	ND	162.49	266.38	94.83	117.65	86.72	ND	ND	789.14
77	ND	ND	356.51	661.07	41.10	358.02	ND	ND	45.54	1561.41
78	ND	ND	2606.26	2220.03	ND	1548.62	693.19	ND	ND	7486.62
70	ND	ND	96.12	271.35	ND	32.31	65.08	ND	10.05	474.91
71	ND	ND	ND	138.71	ND	33.76	191.68	ND	ND	364.15
79	ND	ND	259.35	255.67	ND	156.54	ND	ND	ND	671.55
80	ND	ND	467.07	290.70	56.18	42.78	26.51	ND	ND	883.25
72	ND	27.14	21.17	154.60	ND	61.49	25.89	ND	ND	290.30
73	ND	ND	ND	24.26	ND	42.07	31.39	ND	ND	97.72
81	ND	ND	752.32	107.73	204.10	330.79	426.38	ND	ND	1821.31
82	ND	ND	1065.94	164.20	257.43	183.19	64.77	ND	ND	1735.52
129	ND	51.84	835.78	67.82	477.27	ND	63.56	ND	ND	1444.44
130	ND	31.82	677.72	42.15	531.49	49.42	72.43	ND	ND	1373.21
131	ND	ND	855.55	74.73	509.88	ND	ND	ND	ND	1440.17
132	ND	56.18	387.13	ND	406.13	ND	38.41	ND	ND	887.85
107	ND	24.20	139.42	45.70	574.16	19.29	101.32	ND	ND	904.08
108	ND	38.73	155.21	42.60	527.08	16.77	79.56	ND	15.74	875.70
145	ND	ND	617.25	ND	350.82	ND	30.06	ND	ND	998.13
146	ND	ND	191.36	30.57	368.32	ND	61.57	ND	ND	680.07
139	603.63	312.17	984.49	269.39	293.84	ND	ND	ND	ND	2498.68
140	ND	ND	252.17	18.20	323.24	ND	ND	ND	ND	593.61
141	ND	68.77	908.15	34.19	475.94	31.56	52.34	ND	ND	1502.18
142	ND	ND	195.12	37.91	215.15	ND	41.36	ND	ND	489.54
153	ND	ND	289.88	14.43	254.02	13.96	60.91	ND	ND	685.52
154	ND	24.20	404.89	20.40	383.81	ND	358.65	ND	ND	1191.95
155	ND	ND	795.94	42.60	370.24	64.37	51.06	ND	ND	1324.21

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Vermilion Lakes

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
156	ND	42.06	582.48	888.32	880.66	ND	ND	ND	ND	2477.35
173	ND	103.68	338.79	40.62	232.25	11.09	60.19	ND	21.91	786.29
174	ND	69.66	250.50	17.08	322.51	ND	ND	ND	ND	659.75
179	ND	297.57	658.41	99.06	233.46	20.17	25.62	ND	ND	1209.21
180	53.71	76.89	215.55	86.62	162.96	13.63	67.51	ND	8.38	695.69
197	ND	24.20	468.37	39.19	359.35	ND	62.70	ND	ND	984.26
198	ND	16.51	313.69	60.56	221.50	11.26	11.48	ND	ND	649.68
205	ND	ND	171.07	18.65	502.26	16.27	133.86	ND	19.86	861.97
206	ND	91.75	609.53	87.71	355.87	ND	63.14	ND	ND	1208.00
219	ND	39.96	454.47	41.60	116.48	ND	ND	ND	ND	652.51
220	ND	24.45	454.56	14.28	158.40	ND	97.04	ND	ND	748.74
227	ND	182.06	467.72	27.35	237.15	ND	71.56	ND	30.80	911.26
228	ND	220.56	917.04	80.95	532.66	21.22	62.00	ND	ND	1680.86

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Vermilion Lakes

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
63	241.54	561.23	50.68	ND	73426.77	ND	ND	ND	282.56	ND	ND	ND	ND	76.97	296.33	50.88
74	88.79	206.57	13.15	ND	1986.68	ND	ND	ND	50.68	ND	ND	ND	ND	30.21	59.08	27.84
64	147.70	127.63	9.98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	84.53	88.75	ND
65	240.23	193.72	37.38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	111.51	83.57	ND
66	85.01	241.38	54.23	ND	6645.31	ND	ND	ND	87.30	ND	ND	ND	ND	164.96	263.88	66.08
67	161.30	226.13	78.07	ND	6488.47	ND	ND	ND	64.99	ND	ND	ND	ND	73.72	67.39	47.63
75	190.69	335.92	36.80	ND	ND	ND	ND	ND	136.06	ND	26.27	ND	ND	35.83	56.34	ND
76	192.47	335.79	39.24	ND	1407.41	ND	ND	ND	74.27	ND	31.27	ND	ND	30.39	97.99	ND
68	160.42	312.97	75.15	ND	6157.61	ND	ND	ND	228.12	115.52	1415.76	ND	ND	102.87	286.37	57.57
69	176.74	306.87	27.70	ND	4312.97	ND	ND	ND	199.93	290.38	1053.10	ND	ND	107.57	395.49	78.42
77	162.53	216.61	39.80	ND	72.24	ND	ND	ND	51.94	ND	ND	ND	ND	141.33	233.39	37.49
78	163.42	115.11	54.96	ND	299.44	ND	ND	ND	68.26	ND	ND	ND	ND	141.31	336.93	63.44
70	57.80	346.83	ND	ND	4103.99	ND	ND	ND	19.75	ND	ND	ND	ND	36.21	93.90	ND
71	100.93	308.50	ND	ND	647.37	ND	ND	ND	31.19	ND	ND	ND	ND	60.65	78.18	ND
79	57.33	344.91	27.43	ND	609.72	ND	ND	ND	104.31	359.81	ND	ND	ND	ND	49.45	ND
80	48.89	212.70	40.85	ND	436.94	ND	ND	ND	97.69	303.44	ND	ND	ND	ND	59.00	ND
72	56.43	291.20	45.52	ND	ND	ND	ND	ND	ND	193.48	ND	ND	ND	ND	ND	ND
73	45.21	24.14	0.48	ND	ND	ND	ND	ND	ND	188.01	ND	ND	ND	ND	ND	ND
81	86.98	113.10	20.97	ND	2500.53	ND	ND	353.99	64.34	ND	39.54	ND	ND	148.69	158.71	ND
82	75.89	604.10	24.99	ND	6696.18	ND	ND	ND	72.05	ND	75.20	ND	ND	82.75	83.74	ND
129	55.74	25.54	53.37	131.59	ND	ND	ND	ND	278.14	ND	ND	95.42	ND	29.43	ND	ND
130	45.82	17.42	136.47	60.82	ND	ND	47.85	ND	200.70	ND	ND	74.65	ND	31.04	ND	ND
131	36.78	19.95	45.57	96.59	ND	ND	ND	ND	227.22	ND	265.63	ND	ND	48.95	ND	ND
132	67.71	19.67	65.78	ND	ND	ND	ND	ND	94.54	629.96	ND	ND	ND	35.20	ND	ND
107	44.82	30.95	121.58	29.93	ND	ND	ND	ND	248.34	463.31	ND	ND	ND	25.77	ND	ND
108	44.28	27.81	168.11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	29.95	ND	ND
145	59.48	45.11	37.19	ND	ND	870.76	ND	ND	407.84	ND	500.27	ND	ND	30.06	ND	ND
146	100.05	68.14	193.28	35.70	ND	ND	ND	ND	391.91	ND	ND	ND	ND	34.72	ND	ND
139	66.01	42.18	117.00	ND	ND	ND	ND	ND	131.23	ND	ND	ND	ND	59.34	ND	57.37
140	30.90	31.31	122.57	33.92	ND	10244.52	ND	1620.22	ND	ND	384.12	ND	ND	34.60	ND	ND
141	71.61	53.06	66.36	67.28	ND	ND	ND	615.25	369.59	758.75	ND	ND	ND	35.51	ND	47.40
142	71.68	28.59	189.30	218.96	ND	ND	ND	ND	ND	ND	ND	ND	ND	110.57	ND	ND
153	41.62	58.87	159.37	48.23	ND	ND	ND	659.90	287.42	ND	ND	929.89	ND	38.45	ND	ND
154	87.62	37.99	67.33	ND	ND	ND	ND	ND	253.62	ND	ND	ND	ND	29.84	ND	ND
155	53.41	42.77	191.47	75.06	ND	401.84	ND	ND	ND	ND	ND	2009.64	ND	29.94	ND	ND

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Vermilion Lakes

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
156	29.41	54.80	105.79	ND	1209.59	ND	205.59	ND	ND	1182.89	294.03	ND	ND	51.12	ND	ND
173	333.29	183.54	676.71	140.38	ND	166.46	ND	ND	ND	ND	ND	1071.50	ND	59.28	ND	ND
174	231.51	ND	203.01	ND	1650.73	ND	ND	ND	251.81	2246.21	ND	ND	ND	112.19	ND	ND
179	130.84	130.51	413.95	430.30	ND	ND	ND	ND	73.25	ND	22.95	ND	ND	34.03	ND	ND
180	106.58	97.14	216.74	49.00	ND	633.87	ND	ND	137.20	651.82	120.39	ND	47.84	28.71	ND	ND
197	49.98	36.04	250.76	38.02	ND	ND	ND	ND	154.68	ND	ND	ND	ND	ND	ND	ND
198	40.91	33.61	202.91	29.18	ND	ND	ND	ND	168.39	ND	ND	ND	ND	19.32	ND	ND
205	114.28	70.46	280.10	36.94	ND	400.16	ND	ND	261.42	1031.02	ND	ND	ND	37.92	ND	ND
206	129.11	79.75	785.02	115.99	ND	ND	ND	ND	ND	778.89	ND	ND	ND	48.76	ND	ND
219	24.24	40.64	268.26	99.42	ND	ND	ND	ND	63.05	ND	ND	ND	ND	ND	ND	ND
220	11.90	31.62	206.47	74.80	ND	ND	ND	ND	ND	1512.97	ND	ND	ND	ND	ND	ND
227	96.85	57.68	232.98	200.85	ND	1420.96	ND	ND	ND	ND	ND	ND	106.76	60.79	ND	ND
228	165.60	100.29	926.24	403.35	ND	578.82	ND	ND	301.46	976.70	ND	ND	122.48	79.39	ND	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Vermilion Lakes

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
63	ND	ND	2168.58	1039.31	222.68	516.22	ND	ND	ND	4122.65
74	ND	ND	350.07	704.45	104.51	296.34	244.95	ND	126.49	1942.54
64	ND	240.90	839.40	662.98	ND	312.28	262.87	ND	ND	2468.25
65	ND	293.40	1211.98	931.94	ND	477.74	255.83	ND	ND	3365.47
66	ND	ND	5386.92	198.16	331.15	73.02	51.94	ND	ND	6041.19
67	ND	ND	5741.02	3888.34	ND	ND	ND	ND	ND	9629.35
75	ND	ND	194.48	544.53	ND	310.44	51.27	ND	74.34	1175.06
76	ND	ND	112.34	384.73	ND	137.89	20.56	ND	ND	655.52
68	ND	ND	3240.44	332.47	747.02	273.27	106.33	ND	ND	4699.53
69	ND	ND	308.78	506.22	180.21	223.58	164.80	ND	ND	1499.64
77	ND	ND	838.24	1554.35	96.63	841.80	ND	ND	107.08	3671.28
78	ND	ND	6103.10	5198.67	ND	3626.41	1623.25	ND	ND	17531.47
70	ND	ND	267.77	755.92	ND	90.02	181.29	ND	28.01	1323.01
71	ND	ND	ND	417.99	ND	101.73	577.60	ND	ND	1097.32
79	ND	ND	644.21	635.07	ND	388.83	ND	ND	ND	1668.11
80	ND	ND	1045.62	650.78	125.77	95.78	59.35	ND	ND	1977.31
72	ND	78.83	61.48	448.98	ND	178.59	75.20	ND	ND	843.08
73	ND	ND	ND	66.60	ND	115.50	86.20	ND	ND	268.29
81	ND	ND	1998.15	286.13	542.08	878.58	1132.46	ND	ND	4837.40
82	ND	ND	2804.09	431.94	677.20	481.89	170.38	ND	ND	4565.50
129	ND	95.78	1544.14	125.29	881.78	ND	117.44	ND	ND	2668.64
130	ND	61.88	1318.13	81.98	1033.72	96.12	140.88	ND	ND	2670.83
131	ND	ND	1722.04	150.41	1026.28	ND	ND	ND	ND	2898.73
132	ND	110.57	761.91	ND	799.31	ND	75.60	ND	ND	1747.39
107	ND	43.58	251.09	82.31	1034.07	34.73	182.47	ND	ND	1628.27
108	ND	72.43	290.26	79.67	985.68	31.36	148.78	ND	29.44	1637.62
145	ND	ND	1140.97	ND	648.49	ND	55.57	ND	ND	1845.02
146	ND	ND	369.92	59.11	712.03	ND	119.03	ND	ND	1314.69
139	1183.64	612.12	1930.45	528.23	576.18	ND	ND	ND	ND	4899.57
140	ND	ND	511.19	36.89	655.24	ND	ND	ND	ND	1203.32
141	ND	123.34	1628.73	61.32	853.59	56.60	93.87	ND	ND	2694.10
142	ND	ND	362.80	70.49	400.05	ND	76.90	ND	ND	910.24
153	ND	ND	547.71	27.26	479.96	26.37	115.09	ND	ND	1295.26
154	ND	48.95	818.92	41.26	776.28	ND	725.39	ND	ND	2410.80
155	ND	ND	2419.82	129.50	1125.59	195.71	155.23	ND	ND	4025.85

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Vermilion Lakes

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
156	ND	76.92	1065.28	1624.62	1610.61	ND	ND	ND	ND	4530.76
173	ND	389.97	1274.25	152.79	873.53	41.71	226.40	ND	82.40	2957.43
174	ND	358.00	1287.46	87.81	1657.52	ND	ND	ND	ND	3390.79
179	ND	573.91	1269.84	191.04	450.25	38.90	49.41	ND	ND	2332.14
180	102.07	146.11	409.59	164.59	309.67	25.90	128.27	ND	15.93	1321.96
197	ND	45.31	876.85	73.36	672.75	ND	117.38	ND	ND	1842.68
198	ND	29.98	569.74	109.99	402.31	20.45	20.86	ND	ND	1179.98
205	ND	ND	369.52	40.28	1084.93	35.16	289.15	ND	42.89	1861.93
206	ND	247.33	1643.17	236.44	959.36	ND	170.22	ND	ND	3256.51
219	ND	101.00	1148.71	105.14	294.42	ND	ND	ND	ND	1649.28
220	ND	65.45	1216.78	38.24	424.00	ND	259.77	ND	ND	2004.25
227	ND	489.15	1256.60	73.47	637.15	ND	192.26	ND	82.76	2448.25
228	ND	542.43	2255.33	199.08	1310.00	52.18	152.48	ND	ND	4133.85

OC Concentrations in Vegetation (ng/g lipid) Sampled from Vermilion Lakes

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
63	11.09	25.76	2.33	ND	3370.29	ND	ND	ND	12.97	ND	ND	ND	ND	3.53	13.60	2.34
74	4.50	10.48	0.67	ND	100.75	ND	ND	ND	2.57	ND	ND	ND	ND	1.53	3.00	1.41
64	14.14	12.22	0.95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.09	8.49	ND
65	13.36	10.77	2.08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.20	4.65	ND
66	8.53	24.21	5.44	ND	666.62	ND	ND	ND	8.76	ND	ND	ND	ND	16.55	26.47	6.63
67	30.24	42.39	14.64	ND	1216.34	ND	ND	ND	12.18	ND	ND	ND	ND	13.82	12.63	8.93
75	9.32	16.41	1.80	ND	ND	ND	ND	ND	6.65	ND	1.28	ND	ND	1.75	2.75	ND
76	8.95	15.62	1.83	ND	65.46	ND	ND	ND	3.45	ND	1.45	ND	ND	1.41	4.56	ND
68	9.07	17.69	4.25	ND	348.08	ND	ND	ND	12.90	6.53	80.03	ND	ND	5.82	16.19	3.25
69	9.89	17.18	1.55	ND	241.44	ND	ND	ND	11.19	16.26	58.95	ND	ND	6.02	22.14	4.39
77	10.89	14.52	2.67	ND	4.84	ND	ND	ND	3.48	ND	ND	ND	ND	9.47	15.64	2.51
78	11.26	7.93	3.79	ND	20.62	ND	ND	ND	4.70	ND	ND	ND	ND	9.73	23.21	4.37
70	2.26	13.53	ND	ND	160.13	ND	ND	ND	0.77	ND	ND	ND	ND	1.41	3.66	ND
71	3.22	9.85	ND	ND	20.67	ND	ND	ND	1.00	ND	ND	ND	ND	1.94	2.50	ND
79	2.51	15.09	1.20	ND	26.68	ND	ND	ND	4.56	15.75	ND	ND	ND	ND	2.16	ND
80	2.14	9.31	1.79	ND	19.14	ND	ND	ND	4.28	13.29	ND	ND	ND	ND	2.58	ND
72	3.16	16.29	2.55	ND	ND	ND	ND	ND	ND	10.83	ND	ND	ND	ND	ND	ND
73	3.49	1.86	0.04	ND	ND	ND	ND	ND	ND	14.52	ND	ND	ND	ND	ND	ND
81	5.28	6.87	1.27	ND	151.85	ND	ND	21.50	3.91	ND	2.40	ND	ND	9.03	9.64	ND
82	2.11	16.82	0.70	ND	186.43	ND	ND	ND	2.01	ND	2.09	ND	ND	2.30	2.33	ND
129	4.78	2.19	4.57	11.28	ND	ND	ND	ND	23.84	ND	ND	8.18	ND	2.52	ND	ND
130	4.01	1.53	11.96	5.33	ND	ND	4.19	ND	17.59	ND	ND	6.54	ND	2.72	ND	ND
131	4.99	2.71	6.18	13.11	ND	ND	ND	ND	30.84	ND	36.05	ND	ND	6.64	ND	ND
132	32.87	9.55	31.94	ND	ND	ND	ND	ND	45.90	305.84	ND	ND	ND	17.09	ND	ND
107	21.88	15.11	59.35	14.61	ND	ND	ND	ND	121.23	226.18	ND	ND	ND	12.58	ND	ND
108	13.08	8.22	49.67	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.85	ND	ND
145	6.49	4.92	4.06	ND	ND	94.99	ND	ND	44.49	ND	54.58	ND	ND	3.28	ND	ND
146	10.93	7.44	21.12	3.90	ND	ND	ND	ND	42.82	ND	ND	ND	ND	3.79	ND	ND
139	13.55	8.66	24.01	ND	ND	ND	ND	ND	26.93	ND	ND	ND	ND	12.18	ND	11.77
140	3.75	3.80	14.86	4.11	ND	1242.13	ND	196.45	ND	ND	46.57	ND	ND	4.20	ND	ND
141	17.69	13.11	16.40	16.63	ND	ND	ND	152.02	91.32	187.48	ND	ND	ND	8.77	ND	11.71
142	17.17	6.85	45.34	52.45	ND	ND	ND	ND	ND	ND	ND	ND	ND	26.49	ND	ND
153	5.66	8.01	21.67	6.56	ND	ND	ND	89.74	39.09	ND	ND	126.46	ND	5.23	ND	ND
154	17.42	7.55	13.39	ND	ND	ND	ND	ND	50.43	ND	ND	ND	ND	5.93	ND	ND
155	4.78	3.83	17.15	6.72	ND	35.99	ND	ND	ND	ND	ND	179.96	ND	2.68	ND	ND
156	4.51	8.40	16.22	ND	185.44	ND	31.52	ND	ND	181.35	45.08	ND	ND	7.84	ND	ND
173	28.87	15.90	58.63	12.16	ND	14.42	ND	ND	ND	ND	ND	92.83	ND	5.14	ND	ND
174	16.15	ND	14.16	ND	115.14	ND	ND	ND	17.56	156.68	ND	ND	ND	7.83	ND	ND

OC Concentrations in Vegetation (ng/g lipid) Sampled from Vermilion Lakes

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
179	9.39	9.36	29.69	30.87	ND	ND	ND	ND	5.25	ND	1.65	ND	ND	2.44	ND	ND
180	7.35	6.70	14.96	3.38	ND	43.74	ND	ND	9.47	44.98	8.31	ND	3.30	1.98	ND	ND
197	6.47	4.66	32.44	4.92	ND	ND	ND	ND	20.01	ND	ND	ND	ND	ND	ND	ND
198	8.43	6.93	41.82	6.01	ND	ND	ND	ND	34.71	ND	ND	ND	ND	3.98	ND	ND
205	24.04	14.82	58.91	7.77	ND	84.16	ND	ND	54.98	216.84	ND	ND	ND	7.98	ND	ND
206	22.10	13.65	134.38	19.85	ND	ND	ND	ND	ND	133.32	ND	ND	ND	8.35	ND	ND
219	3.19	5.35	35.34	13.10	ND	ND	ND	ND	8.31	ND	ND	ND	ND	ND	ND	ND
220	1.91	5.07	33.12	12.00	ND	ND	ND	ND	ND	242.66	ND	ND	ND	ND	ND	ND
227	12.22	7.28	29.39	25.33	ND	179.23	ND	ND	ND	ND	ND	ND	13.47	7.67	ND	ND
228	16.32	9.88	91.27	39.74	ND	57.03	ND	ND	29.70	96.24	ND	ND	12.07	7.82	ND	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Vermilion Lakes

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
63	ND	ND	99.54	47.70	10.22	23.69	ND	ND	ND	189.23
74	ND	ND	17.75	35.72	5.30	15.03	12.42	ND	6.41	98.51
64	ND	23.06	80.34	63.45	ND	29.89	25.16	ND	ND	236.23
65	ND	16.32	67.40	51.82	ND	26.57	14.23	ND	ND	187.15
66	ND	ND	540.38	19.88	33.22	7.33	5.21	ND	ND	606.01
67	ND	ND	1076.23	728.92	ND	ND	ND	ND	ND	1805.14
75	ND	ND	9.50	26.61	ND	15.17	2.51	ND	3.63	57.42
76	ND	ND	5.23	17.89	ND	6.41	0.96	ND	ND	30.49
68	ND	ND	183.18	18.79	42.23	15.45	6.01	ND	ND	265.66
69	ND	ND	17.29	28.34	10.09	12.52	9.23	ND	ND	83.95
77	ND	ND	56.18	104.17	6.48	56.42	ND	ND	7.18	246.04
78	ND	ND	420.36	358.07	ND	249.78	111.80	ND	ND	1207.52
70	ND	ND	10.45	29.49	ND	3.51	7.07	ND	1.09	51.62
71	ND	ND	ND	13.35	ND	3.25	18.44	ND	ND	35.04
79	ND	ND	28.19	27.79	ND	17.01	ND	ND	ND	72.99
80	ND	ND	45.79	28.50	5.51	4.19	2.60	ND	ND	86.59
72	ND	4.41	3.44	25.12	ND	9.99	4.21	ND	ND	47.17
73	ND	ND	ND	5.14	ND	8.92	6.66	ND	ND	20.72
81	ND	ND	121.34	17.38	32.92	53.35	68.77	ND	ND	293.76
82	ND	ND	78.07	12.03	18.85	13.42	4.74	ND	ND	127.11
129	ND	8.21	132.35	10.74	75.58	ND	10.07	ND	ND	228.74
130	ND	5.42	115.49	7.18	90.57	8.42	12.34	ND	ND	234.02
131	ND	ND	233.69	20.41	139.27	ND	ND	ND	ND	393.38
132	ND	53.68	369.90	ND	388.05	ND	36.71	ND	ND	848.34
107	ND	21.28	122.58	40.18	504.82	16.96	89.08	ND	ND	794.89
108	ND	21.40	85.76	23.54	291.22	9.26	43.96	ND	8.70	483.83
145	ND	ND	124.47	ND	70.75	ND	6.06	ND	ND	201.28
146	ND	ND	40.41	6.46	77.79	ND	13.00	ND	ND	143.63
139	242.89	125.61	396.14	108.40	118.24	ND	ND	ND	ND	1005.43
140	ND	ND	61.98	4.47	79.45	ND	ND	ND	ND	145.90
141	ND	30.48	402.44	15.15	210.91	13.98	23.19	ND	ND	665.68
142	ND	ND	86.90	16.88	95.83	ND	18.42	ND	ND	218.04
153	ND	ND	74.48	3.71	65.27	3.59	15.65	ND	ND	176.14
154	ND	9.73	162.84	8.20	154.36	ND	144.24	ND	ND	479.37
155	ND	ND	216.70	11.60	100.80	17.53	13.90	ND	ND	360.52
156	ND	11.79	163.31	249.07	246.92	ND	ND	ND	ND	694.60
173	ND	33.79	110.39	13.24	75.68	3.61	19.61	ND	7.14	256.21
174	ND	24.97	89.80	6.12	115.62	ND	ND	ND	ND	236.52

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Vermilion Lakes

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
179	ND	41.17	91.09	13.70	32.30	2.79	3.54	ND	ND	167.29
180	7.04	10.08	28.26	11.36	21.37	1.79	8.85	ND	1.10	91.22
197	ND	5.86	113.42	9.49	87.02	ND	15.18	ND	ND	238.36
198	ND	6.18	117.42	22.67	82.92	4.22	4.30	ND	ND	243.19
205	ND	ND	77.72	8.47	228.18	7.39	60.82	ND	9.02	391.60
206	ND	42.34	281.27	40.47	164.22	ND	29.14	ND	ND	557.43
219	ND	13.31	151.34	13.85	38.79	ND	ND	ND	ND	217.28
220	ND	10.50	195.16	6.13	68.00	ND	41.66	ND	ND	321.46
227	ND	61.70	158.50	9.27	80.37	ND	24.25	ND	10.44	308.81
228	ND	53.45	222.23	19.62	129.08	5.14	15.02	ND	ND	407.32

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Wapta Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
83	135.24	138.07	82.93	ND	277.93	149.06	ND	431.37	61.19	ND	61.36	ND	ND	ND	ND	ND
96	108.73	113.38	34.04	ND	83.91	403.48	ND	250.95	74.79	ND	ND	ND	ND	ND	ND	ND
84	119.22	144.72	100.22	ND	1422.11	268.84	ND	719.48	423.16	ND	576.08	ND	ND	ND	ND	ND
85	109.40	66.68	106.06	ND	1062.56	254.73	ND	582.10	523.22	ND	482.99	ND	ND	ND	ND	ND
97	47.08	53.25	8.75	ND	ND	ND	ND	ND	6.71	ND	ND	ND	ND	ND	ND	ND
98	90.02	57.20	16.93	ND	ND	ND	ND	ND	9.43	ND	ND	ND	ND	ND	ND	ND
86	129.29	93.67	43.68	ND	102.10	ND	ND	ND	147.40	ND	28.26	ND	ND	ND	ND	ND
87	78.64	82.41	14.25	ND	ND	ND	ND	ND	29.79	ND	19.68	ND	ND	ND	ND	ND
90	32.18	73.01	4.03	ND	ND	ND	ND	ND	10.73	70.41	57.76	ND	ND	ND	ND	ND
91	101.08	189.36	54.64	ND	515.58	ND	ND	ND	78.08	56.44	ND	ND	ND	ND	ND	ND
92	32.46	36.95	ND	ND	996.90	ND	ND	ND	23.98	ND	ND	ND	ND	ND	ND	ND
93	26.76	40.20	ND	ND	905.11	ND	ND	ND	11.23	ND	ND	ND	ND	ND	ND	ND
99	71.93	21.32	7.26	ND	236.34	ND	45.58	ND	ND	92.98	ND	ND	ND	ND	ND	ND
100	73.64	71.26	7.60	ND	126.21	ND	25.53	ND	ND	67.78	ND	ND	ND	ND	ND	ND
88	62.62	23.00	8.72	ND	ND	ND	ND	ND	113.13	ND	ND	ND	ND	12.98	18.59	16.30
89	54.73	277.47	11.90	ND	108.50	ND	ND	ND	51.54	ND	ND	ND	ND	16.44	26.31	20.02
94	48.03	54.55	2.72	ND	1066.83	ND	ND	ND	8.41	ND	ND	ND	ND	ND	ND	ND
95	24.83	74.38	ND	ND	59.60	ND	ND	ND	46.20	ND	ND	ND	ND	ND	ND	ND
123	54.48	10.73	65.06	14.50	ND	5.01	ND	ND	256.56	436.89	65.23	ND	24.97	36.91	ND	ND
124	54.33	11.38	72.52	17.17	ND	ND	ND	ND	142.04	419.59	9.22	ND	ND	26.25	ND	ND
127	36.92	24.59	84.97	15.28	ND	ND	ND	ND	142.27	190.25	185.65	ND	ND	13.77	ND	ND
128	50.64	51.78	136.09	39.71	ND	105.92	ND	ND	156.94	559.10	104.39	ND	29.71	16.28	ND	44.29
103	65.56	ND	163.32	51.86	ND	15.87	ND	ND	ND	223.05	ND	ND	ND	21.05	ND	ND
104	71.52	21.74	159.99	20.28	ND	90.90	37.81	ND	ND	ND	158.77	ND	ND	16.93	ND	ND
143	120.70	54.91	100.29	55.45	ND	ND	ND	331.34	220.07	ND	ND	ND	31.67	17.88	ND	ND
144	42.57	11.74	91.33	ND	ND	21.18	ND	ND	100.88	ND	ND	ND	ND	25.23	ND	37.62
111	44.83	36.49	59.63	ND	ND	ND	ND	503.15	117.39	ND	ND	ND	ND	20.99	ND	ND
112	69.66	30.07	103.44	57.29	ND	ND	ND	735.21	ND	ND	ND	ND	ND	6.75	ND	ND
113	39.23	13.84	118.58	50.31	ND	ND	ND	ND	ND	ND	25.02	ND	ND	13.47	ND	ND
114	38.52	17.46	107.03	88.96	ND	63.40	ND	ND	ND	ND	107.20	ND	ND	15.46	ND	ND
157	34.12	22.64	104.81	20.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
158	65.00	28.75	116.08	ND	1082.38	ND	53.27	ND	234.79	ND	ND	ND	ND	26.00	ND	ND
159	21.38	13.43	55.66	ND	ND	ND	ND	ND	53.45	37.76	ND	ND	ND	ND	ND	18.84
160	47.31	16.16	92.04	24.02	ND	ND	ND	ND	ND	ND	8.49	ND	ND	17.13	ND	ND
175	83.37	30.95	86.78	27.13	ND	ND	19.73	ND	106.63	109.19	90.67	ND	ND	14.94	ND	ND

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Wapta Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
176	101.01	23.08	116.00	ND	ND	ND	39.92	ND	ND	ND	ND	ND	ND	18.67	ND	ND
177	38.12	25.71	78.57	ND	124.04	ND	ND	859.26	ND	ND	ND	ND	ND	13.68	ND	ND
178	47.88	27.93	113.89	ND	ND	ND	15.22	ND	158.51	ND	51.21	ND	ND	15.32	ND	ND
195	48.79	14.84	90.61	69.47	ND	95.85	59.22	ND	112.28	222.58	ND	ND	ND	18.67	ND	ND
196	86.73	21.33	149.71	24.57	ND	105.76	ND	2131.70	11.73	380.86	206.66	ND	ND	16.56	ND	ND
211	9.06	11.26	101.42	13.41	ND	ND	ND	ND	61.86	ND	ND	ND	ND	ND	ND	ND
212	99.35	31.95	173.04	476.69	ND	ND	ND	ND	72.04	ND	ND	ND	ND	ND	ND	ND
215	45.70	8.59	170.54	316.82	ND	ND	ND	ND	ND	ND	ND	ND	ND	15.21	ND	ND
216	44.17	14.40	164.55	100.78	1299.84	ND	88.01	ND	ND	ND	ND	ND	ND	28.46	ND	ND
217	27.00	15.60	172.30	268.25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
218	24.45	12.04	173.43	127.78	ND	350.66	ND	690.68	ND	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Wapta Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
83	ND	ND	1512.01	128.34	44.36	167.04	ND	ND	ND	1851.75
96	ND	ND	150.32	232.14	ND	503.97	303.98	162.42	ND	1352.83
84	ND	ND	5833.77	225.52	84.73	195.69	39.98	ND	ND	6379.70
85	ND	ND	258.91	137.17	ND	21.29	ND	ND	ND	437.14
97	ND	ND	553.84	374.60	39.51	578.17	843.51	202.06	ND	2674.73
98	ND	ND	969.95	736.63	ND	476.47	46.45	ND	ND	2229.50
86	ND	ND	539.40	99.32	36.29	780.21	906.10	109.76	ND	2535.26
87	ND	ND	112.32	142.35	ND	80.71	30.50	ND	16.29	406.89
90	ND	ND	60.51	18.45	99.16	1005.17	861.76	237.27	ND	2370.60
91	ND	ND	954.20	541.15	ND	39.31	13.90	ND	ND	1548.55
92	ND	ND	458.35	222.93	ND	925.87	583.72	178.55	ND	2369.42
93	ND	ND	1373.22	169.59	149.70	422.42	146.46	ND	ND	2261.39
99	ND	ND	20.71	57.66	ND	ND	22.68	ND	ND	101.04
100	ND	ND	9.80	41.67	ND	7.44	48.45	ND	ND	107.36
88	ND	ND	23.16	62.68	ND	ND	ND	ND	ND	110.82
89	ND	ND	117.02	116.08	ND	153.29	178.55	38.82	ND	603.76
94	ND	ND	1272.00	219.82	92.31	294.79	256.00	ND	ND	2134.93
95	ND	ND	372.17	198.13	ND	65.22	71.68	ND	ND	707.21
123	ND	ND	152.75	364.97	579.52	164.81	1064.71	ND	ND	2387.68
124	ND	85.37	282.14	279.01	789.88	68.17	163.90	ND	ND	1710.71
127	ND	274.63	219.30	33.89	328.30	38.10	15.26	ND	ND	929.70
128	ND	ND	230.42	65.44	243.16	114.21	33.27	ND	ND	708.63
103	ND	277.19	251.21	179.57	142.47	81.63	38.69	ND	ND	985.43
104	ND	19.63	402.84	61.67	462.30	54.28	195.80	ND	ND	1239.98
143	ND	ND	532.39	ND	468.39	153.96	119.36	ND	ND	1274.09
144	1421.65	556.47	1058.60	429.36	339.13	27.99	ND	ND	31.87	3909.28
111	ND	45.44	391.49	59.76	241.88	54.06	23.79	ND	ND	816.43
112	51.98	59.56	724.79	93.88	133.69	76.56	ND	ND	ND	1156.12
113	ND	19.81	407.32	69.09	440.58	21.86	100.32	ND	ND	1075.55
114	135.43	150.86	936.89	36.31	485.81	ND	130.70	ND	ND	1909.53
157	ND	ND	262.62	ND	301.87	54.96	54.68	ND	ND	674.12
158	ND	ND	573.73	86.74	ND	42.44	89.91	ND	ND	792.83
159	ND	37.44	3.42	26.75	316.71	16.27	37.67	ND	34.66	472.92
160	ND	ND	459.24	18.23	539.96	26.13	115.16	ND	ND	1158.72
175	ND	21.38	313.70	14.40	510.71	41.26	122.80	ND	ND	1044.42

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Wapta Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
176	ND	69.63	ND	ND	ND	ND	ND	ND	ND	69.63
177	ND	ND	150.58	15.48	180.52	10.91	53.69	ND	ND	411.18
178	ND	ND	154.71	ND	286.05	ND	58.88	ND	ND	499.64
195	ND	ND	251.94	ND	311.97	25.30	61.39	ND	ND	650.61
196	ND	23.58	423.95	15.00	224.66	ND	32.04	ND	ND	747.89
211	ND	ND	257.32	8.05	188.94	20.65	53.28	ND	ND	542.54
212	ND	673.42	1893.28	4.21	223.44	63.83	92.85	ND	ND	2645.43
215	ND	1245.61	1328.23	35.94	334.70	30.63	64.53	ND	21.95	2187.38
216	63.15	200.07	612.01	78.65	296.89	23.37	22.34	ND	ND	1243.41
217	ND	48.66	502.58	29.69	67.06	ND	ND	ND	ND	647.99
218	ND	56.71	449.72	19.26	43.94	ND	ND	ND	ND	569.63

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Wapta Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
83	281.06	286.93	172.35	ND	577.59	309.79	ND	896.47	127.16	ND	127.52	ND	ND	ND	ND	ND
96	248.08	258.69	77.66	ND	191.46	920.59	ND	572.58	170.64	ND	ND	ND	ND	ND	ND	ND
84	228.64	277.54	192.20	ND	2727.35	515.58	ND	1379.83	811.55	ND	1104.82	ND	ND	ND	ND	ND
85	421.17	256.72	408.32	ND	4090.77	980.71	ND	2241.03	2014.34	ND	1859.49	ND	ND	ND	ND	ND
97	109.50	123.85	20.36	ND	ND	ND	ND	ND	15.60	ND	ND	ND	ND	ND	ND	ND
98	354.87	225.49	66.74	ND	ND	ND	ND	ND	37.19	ND	ND	ND	ND	ND	ND	ND
86	719.14	521.03	242.99	ND	567.90	ND	ND	ND	819.87	ND	157.19	ND	ND	ND	ND	ND
87	390.39	409.11	70.75	ND	ND	ND	ND	ND	147.87	ND	97.71	ND	ND	ND	ND	ND
90	87.72	199.05	10.98	ND	ND	ND	ND	ND	29.26	191.96	157.46	ND	ND	ND	ND	ND
91	255.36	478.39	138.05	ND	1302.53	ND	ND	ND	197.26	142.59	ND	ND	ND	ND	ND	ND
92	173.67	197.68	ND	ND	5333.96	ND	ND	ND	128.31	ND	ND	ND	ND	ND	ND	ND
93	99.25	149.13	ND	ND	3357.25	ND	ND	ND	41.64	ND	ND	ND	ND	ND	ND	ND
99	147.83	43.81	14.91	ND	485.69	ND	93.68	ND	ND	191.07	ND	ND	ND	ND	ND	ND
100	206.69	200.03	21.34	ND	354.25	ND	71.66	ND	ND	190.26	ND	ND	ND	ND	ND	ND
88	198.04	72.73	27.57	ND	ND	ND	ND	ND	357.77	ND	ND	ND	ND	41.04	58.78	51.54
89	161.90	820.84	35.20	ND	320.98	ND	ND	ND	152.47	ND	ND	ND	ND	48.65	77.85	59.22
94	178.11	202.29	10.08	ND	3956.30	ND	ND	ND	31.19	ND	ND	ND	ND	ND	ND	ND
95	90.74	271.81	ND	ND	217.81	ND	ND	ND	168.83	ND	ND	ND	ND	ND	ND	ND
123	119.32	23.49	142.50	31.75	ND	10.96	ND	ND	561.94	956.93	142.87	ND	54.68	80.84	ND	ND
124	116.85	24.48	155.98	36.94	ND	ND	ND	ND	305.50	902.44	19.84	ND	ND	56.46	ND	ND
127	83.23	55.44	191.56	34.44	ND	ND	ND	ND	320.73	428.88	418.51	ND	ND	31.04	ND	ND
128	107.70	110.12	289.45	84.45	ND	225.27	ND	ND	333.80	1189.13	222.02	ND	63.18	34.63	ND	94.19
103	138.10	ND	344.03	109.23	ND	33.43	ND	ND	ND	469.86	ND	ND	ND	44.34	ND	ND
104	146.61	44.56	327.94	41.57	ND	186.33	77.51	ND	ND	ND	325.44	ND	ND	34.70	ND	ND
143	279.86	127.31	232.54	128.57	ND	ND	ND	768.25	510.25	ND	ND	ND	73.43	41.45	ND	ND
144	93.19	25.70	199.93	ND	ND	46.36	ND	ND	220.85	ND	ND	ND	ND	55.23	ND	82.36
111	92.09	74.95	122.48	ND	ND	ND	ND	1033.48	241.11	ND	ND	ND	ND	43.11	ND	ND
112	151.36	65.33	224.75	124.48	ND	ND	ND	1597.40	ND	ND	ND	ND	ND	14.67	ND	ND
113	79.39	28.01	239.97	101.81	ND	ND	ND	ND	ND	ND	50.64	ND	ND	27.27	ND	ND
114	77.69	35.20	215.87	179.43	ND	127.87	ND	ND	ND	ND	216.20	ND	ND	31.18	ND	ND
157	76.08	50.49	233.73	44.62	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
158	140.36	62.08	250.64	ND	2337.19	ND	115.02	ND	506.99	ND	ND	ND	ND	56.14	ND	ND
159	39.79	24.99	103.60	ND	ND	ND	ND	ND	99.49	70.29	ND	ND	ND	ND	ND	35.06
160	86.80	29.65	168.85	44.06	ND	ND	ND	ND	ND	ND	15.57	ND	ND	31.42	ND	ND
175	162.08	60.16	168.70	52.75	ND	ND	38.36	ND	207.29	212.28	176.27	ND	ND	29.04	ND	ND
176	199.45	45.56	229.05	ND	ND	ND	78.81	ND	ND	ND	ND	ND	ND	36.87	ND	ND
177	86.81	58.56	178.92	ND	282.49	ND	ND	1956.86	ND	ND	ND	ND	ND	31.16	ND	ND
178	47.75	27.86	113.57	ND	ND	ND	15.17	ND	158.07	ND	51.07	ND	ND	15.27	ND	ND

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Wapta Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
195	234.52	71.32	435.54	333.90	ND	460.73	284.64	ND	539.66	1069.84	ND	ND	ND	89.73	ND	ND
196	449.85	110.62	776.50	127.41	ND	548.53	ND	11056.62	60.86	1975.43	1071.88	ND	ND	85.91	ND	ND
211	21.51	26.76	240.94	31.85	ND	ND	ND	ND	146.96	ND	ND	ND	ND	ND	ND	ND
212	222.13	71.44	386.92	1065.86	ND	ND	ND	ND	161.07	ND	ND	ND	ND	ND	ND	ND
215	100.50	18.89	375.06	696.77	ND	ND	ND	ND	ND	ND	ND	ND	ND	33.45	ND	ND
216	126.03	41.07	469.46	287.54	3708.41	ND	251.10	ND	ND	ND	ND	ND	ND	81.18	ND	ND
217	81.68	47.19	521.17	811.42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
218	79.62	39.22	564.78	416.12	ND	1141.92	ND	2249.20	ND	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Wapta Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
83	ND	ND	3142.25	266.71	92.19	347.13	ND	ND	ND	3848.28
96	ND	ND	342.97	529.66	ND	1149.88	693.56	370.58	ND	3086.65
84	ND	ND	11188.09	432.51	162.50	375.31	76.68	ND	ND	12235.09
85	ND	ND	996.80	528.08	ND	81.98	ND	ND	ND	1682.96
97	ND	ND	1288.15	871.27	91.90	1344.73	1961.89	469.96	ND	6221.02
98	ND	ND	3823.73	2903.94	ND	1878.33	183.11	ND	ND	8789.11
86	ND	ND	3000.32	552.44	201.84	4339.82	5040.08	610.52	ND	14102.07
87	ND	ND	557.59	706.67	ND	400.70	151.43	ND	80.86	2019.97
90	ND	ND	164.97	50.30	270.34	2740.41	2349.42	646.87	ND	6462.99
91	ND	ND	2410.66	1367.13	ND	99.31	35.11	ND	ND	3912.20
92	ND	ND	2452.43	1192.82	ND	4953.93	3123.20	955.32	ND	12677.70
93	ND	ND	5093.57	629.05	555.27	1566.86	543.23	ND	ND	8387.99
99	ND	ND	42.55	118.49	ND	ND	46.60	ND	ND	207.65
100	ND	ND	27.50	116.98	ND	20.89	135.99	ND	ND	301.36
88	ND	ND	73.25	198.21	ND	ND	ND	ND	ND	350.43
89	ND	ND	346.17	343.41	ND	453.49	528.21	114.83	ND	1786.11
94	ND	ND	4717.18	815.21	342.34	1093.22	949.37	ND	ND	7917.32
95	ND	ND	1360.02	724.04	ND	238.33	261.96	ND	ND	2584.35
123	ND	ND	334.57	799.41	1269.34	360.98	2332.06	ND	ND	5229.78
124	ND	183.61	606.82	600.10	1698.86	146.63	352.51	ND	ND	3679.36
127	ND	619.11	494.38	76.39	740.09	85.90	34.39	ND	ND	2095.83
128	ND	ND	490.07	139.18	517.16	242.92	70.75	ND	ND	1507.16
103	ND	583.90	529.16	378.26	300.10	171.96	81.50	ND	ND	2075.78
104	ND	40.25	825.73	126.42	947.62	111.27	401.34	ND	ND	2541.70
143	ND	ND	1234.39	ND	1086.02	356.96	276.75	ND	ND	2954.13
144	3112.24	1218.21	2317.45	939.94	742.40	61.28	ND	ND	69.76	8558.07
111	ND	93.34	804.14	122.74	496.83	111.05	48.86	ND	ND	1676.95
112	112.94	129.41	1574.76	203.97	290.47	166.35	ND	ND	ND	2511.91
113	ND	40.10	824.33	139.83	891.63	44.24	203.03	ND	ND	2176.67
114	273.14	304.27	1889.59	73.24	979.81	ND	263.61	ND	ND	3851.28
157	ND	ND	585.62	ND	673.14	122.56	121.92	ND	ND	1503.24
158	ND	ND	1238.86	187.31	ND	91.65	194.15	ND	ND	1711.97
159	ND	69.69	6.36	49.80	589.51	30.28	70.12	ND	64.51	880.27
160	ND	ND	842.46	33.45	990.54	47.93	211.26	ND	ND	2125.64
175	ND	41.57	609.86	27.99	992.86	80.21	238.73	ND	ND	2030.41
176	ND	137.49	ND	ND	ND	ND	ND	ND	ND	137.49
177	ND	ND	342.93	35.25	411.11	24.84	122.28	ND	ND	936.42
178	ND	ND	154.28	ND	285.25	ND	58.72	ND	ND	498.25

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Wapta Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
195	ND	ND	1210.98	ND	1499.50	121.59	295.09	ND	ND	3127.17
196	ND	122.29	2198.90	77.79	1165.25	ND	166.16	ND	ND	3879.12
211	ND	ND	611.28	19.13	448.84	49.06	126.58	ND	ND	1288.84
212	ND	1505.72	4233.25	9.41	499.60	142.72	207.62	ND	ND	5914.99
215	ND	2739.41	2921.10	79.04	736.08	67.37	141.92	ND	48.27	4810.59
216	180.17	570.78	1746.05	224.39	847.02	66.66	63.74	ND	ND	3547.42
217	ND	147.19	1520.23	89.80	202.85	ND	ND	ND	ND	1960.07
218	ND	184.67	1464.51	62.72	143.10	ND	ND	ND	ND	1855.00

OC Concentrations in Vegetation (ng/g lipid) Sampled from Wapta Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
83	7.51	7.67	4.61	ND	15.44	8.28	ND	23.96	3.40	ND	3.41	ND	ND	ND	ND	ND
96	5.52	5.76	1.73	ND	4.26	20.48	ND	12.74	3.80	ND	ND	ND	ND	ND	ND	ND
84	5.20	6.31	4.37	ND	61.99	11.72	ND	31.36	18.45	ND	25.11	ND	ND	ND	ND	ND
85	5.86	3.57	5.69	ND	56.96	13.66	ND	31.21	28.05	ND	25.89	ND	ND	ND	ND	ND
97	2.21	2.49	0.41	ND	ND	ND	ND	ND	0.31	ND	ND	ND	ND	ND	ND	ND
98	5.42	3.44	1.02	ND	ND	ND	ND	ND	0.57	ND	ND	ND	ND	ND	ND	ND
86	9.37	6.79	3.17	ND	7.40	ND	ND	ND	10.68	ND	2.05	ND	ND	ND	ND	ND
87	3.82	4.01	0.69	ND	ND	ND	ND	ND	1.45	ND	0.96	ND	ND	ND	ND	ND
90	2.71	6.14	0.34	ND	ND	ND	ND	ND	0.90	5.92	4.86	ND	ND	ND	ND	ND
91	9.19	17.21	4.97	ND	46.87	ND	ND	ND	7.10	5.13	ND	ND	ND	ND	ND	ND
92	2.35	2.68	ND	ND	72.24	ND	ND	ND	1.74	ND	ND	ND	ND	ND	ND	ND
93	2.48	3.73	ND	ND	83.93	ND	ND	ND	1.04	ND	ND	ND	ND	ND	ND	ND
99	11.12	3.29	1.12	ND	36.53	ND	7.04	ND	ND	14.37	ND	ND	ND	ND	ND	ND
100	17.53	16.97	1.81	ND	30.05	ND	6.08	ND	ND	16.14	ND	ND	ND	ND	ND	ND
88	6.26	2.30	0.87	ND	ND	ND	ND	ND	11.31	ND	ND	ND	ND	1.30	1.86	1.63
89	9.62	48.80	2.09	ND	19.08	ND	ND	ND	9.06	ND	ND	ND	ND	2.89	4.63	3.52
94	3.66	4.15	0.21	ND	81.21	ND	ND	ND	0.64	ND	ND	ND	ND	ND	ND	ND
95	4.28	12.82	ND	ND	10.28	ND	ND	ND	7.97	ND	ND	ND	ND	ND	ND	ND
123	16.06	3.16	19.18	4.27	ND	1.48	ND	ND	75.63	128.78	19.23	ND	7.36	10.88	ND	ND
124	15.35	3.22	20.49	4.85	ND	ND	ND	ND	40.13	118.53	2.61	ND	ND	7.42	ND	ND
127	11.65	7.76	26.82	4.82	ND	ND	ND	ND	44.90	60.05	58.59	ND	ND	4.35	ND	ND
128	15.63	15.98	42.02	12.26	ND	32.70	ND	ND	48.45	172.61	32.23	ND	9.17	5.03	ND	13.67
103	30.47	ND	75.91	24.10	ND	7.38	ND	ND	ND	103.67	ND	ND	ND	9.78	ND	ND
104	24.83	7.55	55.55	7.04	ND	31.56	13.13	ND	ND	ND	55.13	ND	ND	5.88	ND	ND
143	58.80	26.75	48.86	27.01	ND	ND	ND	161.41	107.20	ND	ND	ND	15.43	8.71	ND	ND
144	23.34	6.44	50.07	ND	ND	11.61	ND	ND	55.31	ND	ND	ND	ND	13.83	ND	20.63
111	23.31	18.97	31.01	ND	ND	ND	ND	261.64	61.04	ND	ND	ND	ND	10.91	ND	ND
112	18.28	7.89	27.14	15.03	ND	ND	ND	192.92	ND	ND	ND	ND	ND	1.77	ND	ND
113	16.18	5.71	48.89	20.74	ND	ND	ND	ND	ND	ND	10.32	ND	ND	5.56	ND	ND
114	20.48	9.28	56.91	47.30	ND	33.71	ND	ND	ND	ND	56.99	ND	ND	8.22	ND	ND
157	12.55	8.33	38.56	7.36	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
158	16.25	7.19	29.02	ND	270.59	ND	13.32	ND	58.70	ND	ND	ND	ND	6.50	ND	ND
159	21.38	13.43	55.66	ND	ND	ND	ND	ND	53.45	37.76	ND	ND	ND	ND	ND	18.84
160	10.75	3.67	20.91	5.46	ND	ND	ND	ND	ND	ND	1.93	ND	ND	3.89	ND	ND
175	24.65	9.15	25.65	8.02	ND	ND	5.83	ND	31.52	32.28	26.80	ND	ND	4.42	ND	ND
176	40.78	9.32	46.83	ND	ND	ND	16.12	ND	ND	ND	ND	ND	ND	7.54	ND	ND
177	13.91	9.38	28.66	ND	45.26	ND	ND	313.50	ND	ND	ND	ND	ND	4.99	ND	ND
178	19.35	11.29	46.02	ND	ND	ND	6.15	ND	64.06	ND	20.69	ND	ND	6.19	ND	ND

OC Concentrations in Vegetation (ng/g lipid) Sampled from Wapta Lake

Sample	α-HCH	γ-HCH	HCB	Hept	Hept Epox	Endrin	Dieldrin	Methox	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
195	13.40	4.08	24.89	19.08	ND	26.33	16.27	ND	30.84	61.14	ND	ND	ND	5.13	ND	ND
196	31.37	7.71	54.15	8.89	ND	38.25	ND	771.02	4.24	137.75	74.75	ND	ND	5.99	ND	ND
211	4.44	5.52	49.72	6.57	ND	ND	ND	ND	30.33	ND	ND	ND	ND	ND	ND	ND
212	20.80	6.69	36.22	99.79	ND	ND	ND	ND	15.08	ND	ND	ND	ND	ND	ND	ND
215	12.53	2.36	46.76	86.87	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.17	ND	ND
216	11.07	3.61	41.25	25.26	325.84	ND	22.06	ND	ND	ND	ND	ND	ND	7.13	ND	ND
217	7.19	4.15	45.86	71.39	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
218	7.94	3.91	56.31	41.49	ND	113.85	ND	224.26	ND	ND	ND	ND	ND	ND	ND	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Wapta Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
83	ND	ND	84.00	7.13	2.46	9.28	ND	ND	ND	102.87
96	ND	ND	7.63	11.79	ND	25.59	15.43	8.25	ND	68.68
84	ND	ND	254.29	9.83	3.69	8.53	1.74	ND	ND	278.09
85	ND	ND	13.88	7.35	ND	1.14	ND	ND	ND	23.43
97	ND	ND	25.95	17.55	1.85	27.09	39.52	9.47	ND	125.30
98	ND	ND	58.42	44.37	ND	28.70	2.80	ND	ND	134.28
86	ND	ND	39.09	7.20	2.63	56.54	65.66	7.95	ND	183.71
87	ND	ND	5.46	6.92	ND	3.92	1.48	ND	0.79	19.78
90	ND	ND	5.09	1.55	8.34	84.56	72.50	19.96	ND	199.43
91	ND	ND	86.75	49.20	ND	3.57	1.26	ND	ND	140.78
92	ND	ND	33.21	16.15	ND	67.09	42.30	12.94	ND	171.70
93	ND	ND	127.34	15.73	13.88	39.17	13.58	ND	ND	209.69
99	ND	ND	3.20	8.91	ND	ND	3.50	ND	ND	15.62
100	ND	ND	2.33	9.92	ND	1.77	11.54	ND	ND	25.56
88	ND	ND	2.32	6.27	ND	ND	ND	ND	ND	11.08
89	ND	ND	20.58	20.41	ND	26.96	31.40	6.83	ND	106.18
94	ND	ND	96.82	16.73	7.03	22.44	19.49	ND	ND	162.51
95	ND	ND	64.17	34.16	ND	11.24	12.36	ND	ND	121.93
123	ND	ND	45.03	107.59	170.83	48.58	313.85	ND	ND	703.83
124	ND	24.12	79.70	78.82	223.14	19.26	46.30	ND	ND	483.27
127	ND	86.68	69.22	10.70	103.62	12.03	4.82	ND	ND	293.43
128	ND	ND	71.14	20.20	75.07	35.26	10.27	ND	ND	218.77
103	ND	128.83	116.75	83.46	66.21	37.94	17.98	ND	ND	458.00
104	ND	6.82	139.87	21.41	160.51	18.85	67.98	ND	ND	430.53
143	ND	ND	259.35	ND	228.17	75.00	58.15	ND	ND	620.66
144	779.45	305.10	580.39	235.40	185.93	15.35	ND	ND	17.47	2143.33
111	ND	23.63	203.58	31.07	125.78	28.11	12.37	ND	ND	424.55
112	13.64	15.63	190.19	24.63	35.08	20.09	ND	ND	ND	303.36
113	ND	8.17	167.96	28.49	181.67	9.01	41.37	ND	ND	443.49
114	72.00	80.21	498.12	19.31	258.29	ND	69.49	ND	ND	1015.26
157	ND	ND	96.62	ND	111.06	20.22	20.12	ND	ND	248.01
158	ND	ND	143.43	21.69	ND	10.61	22.48	ND	ND	198.21
159	ND	37.44	3.42	26.75	316.71	16.27	37.67	ND	34.66	472.92
160	ND	ND	104.35	4.14	122.69	5.94	26.17	ND	ND	263.29
175	ND	6.32	92.74	4.26	150.98	12.20	36.30	ND	ND	308.75
176	ND	28.11	ND	ND	ND	ND	ND	ND	ND	28.11
177	ND	ND	54.94	5.65	65.86	3.98	19.59	ND	ND	150.02
178	ND	ND	62.52	ND	115.59	ND	23.79	ND	ND	201.91

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Wapta Lake

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
195	ND	ND	69.20	ND	85.69	6.95	16.86	ND	ND	178.71
196	ND	8.53	153.34	5.42	81.26	ND	11.59	ND	ND	270.51
211	ND	ND	126.15	3.95	92.62	10.13	26.12	ND	ND	265.97
212	ND	140.97	396.32	0.88	46.77	13.36	19.44	ND	ND	553.77
215	ND	341.55	364.21	9.86	91.78	8.40	17.70	ND	6.02	599.79
216	15.83	50.15	153.42	19.72	74.42	5.86	5.60	ND	ND	311.70
217	ND	12.95	133.76	7.90	17.85	ND	ND	ND	ND	172.46
218	ND	18.41	146.02	6.25	14.27	ND	ND	ND	ND	184.95

APPENDIX IV – OC AND PCB CONCENTRATIONS IN TRANSECT SAMPLES

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Revelstoke

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T1	15.21	8.76	13.59	149.85	112.05	ND	ND	ND	ND	ND	ND	ND	221.31	ND
T2	14.49	ND	1.05	248.64	ND	ND	ND	ND	ND	ND	ND	ND	90.61	ND
T3	25.03	15.94	6.69	ND	ND	ND	ND	ND	ND	ND	ND	11.53	ND	ND
T4	20.87	2.89	18.77	ND	ND	ND	310.03	430.03	ND	ND	ND	ND	ND	ND
T5	29.91	6.50	17.60	ND	ND	206.56	159.26	90.81	ND	ND	ND	ND	ND	ND
T6	19.72	7.62	11.06	ND	ND	ND	204.00	69.08	ND	ND	ND	ND	ND	ND
T7	103.90	22.40	152.64	2974.08	ND	72.62	ND	656.15	ND	ND	ND	22.12	57.93	ND
T8	97.93	8.93	82.25	5837.17	ND	ND	ND	1050.69	ND	ND	ND	19.35	102.15	ND

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Salmon Arm

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T9	33.67	6.80	24.06	736.81	ND	ND	132.50	704.89	ND	ND	ND	38.89	ND	ND
T10	36.97	59.05	75.67	234.13	ND	ND	139.01	483.15	78.22	ND	ND	26.79	ND	ND
T11	19.92	7.56	38.11	3535.55	49.10	ND	241.45	383.38	ND	ND	ND	171.86	171.16	ND
T12	8.93	ND	25.78	801.71	ND	ND	ND	299.90	ND	ND	ND	226.13	205.03	ND

OC Concentrations in Vegetation (pg/g wet weight) Sampled from Kamloops

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T13	17.23	13.93	53.81	104.71	ND	ND	142.38	273.74	74.96	ND	ND	16.82	98.79	ND
T14	13.99	23.47	49.79	ND	ND	ND	ND	ND	333.35	ND	ND	ND	ND	ND
T15	63.02	ND	16.70	661.34	24.20	ND	ND	154.23	ND	ND	ND	145.11	211.43	ND
T16	28.75	ND	27.40	1495.73	37.85	ND	128.82	307.08	ND	ND	28.25	175.84	279.98	ND

OC Concentrations in Vegetation (pg/g wet weight) Sampled at Kelowna

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T17	13.00	6.48	41.98	604.17	ND	ND	247.93	653.98	239.69	287.33	74.98	769.92	216.78	248.45
T18	22.29	ND	51.39	1129.30	ND	ND	624.79	1257.56	124.58	218.84	58.99	439.42	361.41	112.89
T19	ND	ND	ND	128.01	ND	ND	375.36	641.47	ND	ND	ND	102.55	122.71	ND
T20	9.91	ND	3.05	81.21	ND	ND	581.51	468.26	ND	ND	ND	104.24	102.16	ND

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Revelstoke

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T1	94.78	108.82	1220.57	66.15	241.07	21.96	ND	ND	16.22	2086.12
T2	ND	30.41	804.73	ND	315.10	211.47	ND	ND	183.25	1544.95
T3	34.26	98.84	291.32	249.37	308.67	37.08	74.84	ND	ND	1110.71
T4	24.87	72.10	986.89	211.01	342.38	245.50	74.39	ND	ND	2148.05
T5	ND	ND	635.91	35.25	332.96	44.19	ND	ND	ND	1048.31
T6	ND	18.41	2.88	ND	234.91	ND	ND	ND	ND	256.20
T7	ND	114.87	1355.58	325.84	365.04	ND	ND	ND	ND	2197.58
T8	ND	340.31	1009.02	32.45	403.58	59.83	156.34	ND	ND	2072.60

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Salmon Arm

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T9	56.14	48.27	466.72	53.57	192.22	ND	ND	ND	ND	816.92
T10	130.70	31.68	528.54	45.03	193.74	ND	ND	ND	ND	929.69
T11	ND	40.28	104.74	260.26	530.62	80.86	ND	ND	ND	1016.75
T12	122.94	121.06	379.13	441.59	651.51	102.21	116.10	ND	5.23	1961.70

PCB Concentrations in Vegetation (pg/g wet weight) Sampled from Kamloops

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T13	21.79	58.38	482.33	110.71	231.25	21.69	5.92	ND	ND	949.88
T14	263.72	45.56	367.49	91.07	260.43	24.26	ND	ND	ND	1066.90
T15	ND	151.28	3353.59	2390.13	1850.56	122.31	33.43	ND	ND	8127.41
T16	49.07	342.72	2706.61	3797.89	4337.92	1284.28	139.82	ND	ND	13297.53

PCB Concentrations in Vegetation (ng/g lipid) Sampled at Kelowna

Sample	2-CB	3-CB	4-CB	5-CB	6-CB	7-CB	8-CB	9-CB	10-CB	ΣPCB
T17	35.88	294.78	437.90	1208.77	315.06	118.81	ND	ND	ND	2447.33
T18	ND	57.58	409.46	614.61	329.84	32.63	ND	ND	ND	1444.12
T19	ND	ND	435.34	145.60	261.10	45.90	ND	ND	ND	887.94
T20	ND	93.57	577.23	147.41	353.15	79.14	60.67	ND	44.05	1563.55

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Revelstoke

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T1	52.50	30.24	46.92	517.39	386.88	ND	ND	ND	ND	ND	ND	ND	764.13	ND
T2	52.68	ND	3.82	903.91	ND	ND	ND	ND	ND	ND	ND	ND	329.43	ND
T3	78.89	50.23	21.08	ND	ND	ND	ND	ND	ND	ND	ND	36.33	ND	ND
T4	67.32	9.33	60.55	ND	ND	ND	1000.01	1387.08	ND	ND	ND	ND	ND	ND
T5	80.90	17.59	47.62	ND	ND	558.79	430.84	245.66	ND	ND	ND	ND	ND	ND
T6	63.28	24.47	35.50	ND	ND	ND	654.66	221.67	ND	ND	ND	ND	ND	ND
T7	258.59	55.74	379.87	7401.63	ND	180.74	ND	1632.97	ND	ND	ND	55.04	144.18	ND
T8	224.98	20.52	188.95	13410.06	ND	ND	ND	2413.81	ND	ND	ND	44.45	234.68	ND

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Salmon Arm

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T9	95.52	19.28	68.24	2090.02	ND	ND	375.85	1999.47	ND	ND	ND	110.32	ND	ND
T10	105.74	168.90	216.45	669.68	ND	ND	397.62	1381.98	223.74	ND	ND	76.62	ND	ND
T11	48.72	18.48	93.18	8645.49	120.07	ND	590.41	937.47	ND	ND	ND	420.25	418.55	ND
T12	22.63	ND	65.35	2032.25	ND	ND	ND	760.22	ND	ND	ND	573.21	519.74	ND

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Kamloops

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T13	47.19	38.15	147.35	286.74	ND	ND	389.91	749.64	205.29	ND	ND	46.07	270.52	ND
T14	39.18	65.76	139.49	ND	ND	ND	ND	ND	933.89	ND	ND	ND	ND	ND
T15	155.29	ND	41.15	1629.59	59.64	ND	ND	380.02	ND	ND	ND	357.55	520.97	ND
T16	71.37	ND	68.02	3713.48	93.97	ND	319.83	762.40	ND	ND	70.12	436.57	695.12	ND

OC Concentrations in Vegetation (pg/g dry weight) Sampled from Kelowna

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T17	29.60	14.75	95.61	1376.05	ND	ND	564.69	1489.51	545.91	654.41	170.77	1753.57	493.75	565.87
T18	47.90	ND	110.45	2427.09	ND	ND	1342.80	2702.75	267.75	470.33	126.78	944.41	776.75	242.63
T19	ND	ND	ND	358.30	ND	ND	1050.62	1795.46	ND	ND	ND	287.03	343.46	ND
T20	28.06	ND	8.64	230.07	ND	ND	1647.43	1326.59	ND	ND	ND	295.31	289.41	ND

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Revelstoke

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T1	327.25	375.72	4214.40	228.39	832.36	75.83	ND	ND	56.01	7202.95
T2	ND	110.56	2925.58	ND	1145.53	768.79	ND	ND	666.21	5616.68
T3	107.98	311.50	918.11	785.89	972.81	116.86	235.87	ND	ND	3500.49
T4	80.23	232.55	3183.29	680.62	1104.38	791.89	239.94	ND	ND	6928.69
T5	ND	ND	1720.33	95.36	900.76	119.54	ND	ND	ND	2835.98
T6	ND	59.08	9.25	ND	753.87	ND	ND	ND	ND	822.19
T7	ND	285.88	3373.65	810.93	908.47	ND	ND	ND	ND	5169.13
T8	ND	781.81	2318.09	74.55	927.17	137.45	359.17	ND	ND	4761.50

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Salmon Arm

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T9	159.24	136.92	1323.87	151.96	545.24	ND	ND	ND	ND	2317.25
T10	373.84	90.62	1511.82	128.79	554.17	ND	ND	ND	ND	2659.23
T11	ND	98.49	256.11	636.42	1297.52	197.72	ND	ND	ND	2486.26
T12	311.64	306.87	961.05	1119.38	1651.51	259.09	294.29	ND	13.25	4972.70

PCB Concentrations in Vegetation (pg/g dry weight) Sampled from Kamloops

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T13	59.68	159.86	1320.85	303.18	633.28	59.39	16.22	ND	ND	2601.26
T14	738.83	127.63	1029.53	255.14	729.61	67.97	ND	ND	ND	2988.93
T15	ND	372.76	8263.44	5889.41	4559.90	301.38	82.38	ND	ND	20026.40
T16	121.82	850.89	6719.76	9429.12	10769.87	3188.50	347.14	ND	ND	33014.10

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Kelowna

Sample	2-CB	3-CB	4-CB	5-CB	6-CB	7-CB	8-CB	9-CB	10-CB	ΣPCB
T17	81.72	671.38	997.36	2753.10	717.57	270.59	ND	ND	ND	5574.02
T18	ND	123.74	880.01	1320.93	708.89	70.14	ND	ND	ND	3103.71
T19	ND	ND	1218.51	407.55	730.81	128.47	ND	ND	ND	2485.33
T20	ND	265.08	1635.31	417.61	1000.47	224.21	171.88	ND	124.80	4429.55

OC Concentrations in Vegetation (ng/g lipid) Sampled from Revelstoke

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T1	4.31	2.48	3.85	42.44	31.74	ND	ND	ND	ND	ND	ND	ND	62.69	ND
T2	5.23	ND	0.38	89.81	ND	ND	ND	ND	ND	ND	ND	ND	32.73	ND
T3	7.55	4.81	2.02	ND	ND	ND	ND	ND	ND	ND	ND	3.48	ND	ND
T4	20.66	2.86	18.58	ND	ND	ND	306.88	425.66	ND	ND	ND	ND	ND	ND
T5	41.10	8.94	24.19	ND	ND	283.89	218.88	124.81	ND	ND	ND	ND	ND	ND
T6	57.53	22.25	32.28	ND	ND	ND	595.24	201.56	ND	ND	ND	ND	ND	ND
T7	37.62	8.11	55.27	1076.94	ND	26.30	ND	237.60	ND	ND	ND	8.01	20.98	ND
T8	37.04	3.38	31.10	2207.57	ND	ND	ND	397.36	ND	ND	ND	7.32	38.63	ND

OC Concentrations in Vegetation (ng/g lipid) Sampled from Salmon Arm

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T9	23.84	4.81	17.03	521.60	ND	ND	93.80	499.00	ND	ND	ND	27.53	ND	ND
T10	22.74	36.32	46.55	144.03	ND	ND	85.52	297.22	48.12	ND	ND	16.48	ND	ND
T11	8.41	3.19	16.09	1492.90	20.73	ND	101.95	161.88	ND	ND	ND	72.57	72.27	ND
T12	2.87	ND	8.29	257.74	ND	ND	ND	96.42	ND	ND	ND	72.70	65.92	ND

OC Concentrations in Vegetation (ng/g lipid) Sampled from Kamloops

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T13	46.16	37.31	144.12	280.45	ND	ND	381.36	733.19	200.78	ND	ND	45.06	264.59	ND
T14	18.37	30.83	65.41	ND	ND	ND	ND	ND	437.89	ND	ND	ND	ND	ND
T15	23.26	ND	6.16	244.09	8.93	ND	ND	56.92	ND	ND	ND	53.56	78.03	ND
T16	17.42	ND	16.60	906.49	22.94	ND	78.07	186.11	ND	ND	17.12	106.57	169.68	ND

OC Concentrations in Vegetation (ng/g lipid) Sampled from Kelowna

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	γ-chlor	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
T17	4.46	2.22	14.41	207.35	ND	ND	85.09	224.45	82.26	98.61	25.73	264.24	74.40	85.27
T18	5.44	ND	12.54	275.54	ND	ND	152.44	306.83	30.40	53.40	14.39	107.21	88.18	27.55
T19	ND	ND	ND	46.88	ND	ND	137.47	234.93	ND	ND	ND	37.56	44.94	ND
T20	5.52	ND	1.70	45.23	ND	ND	323.89	260.81	ND	ND	ND	58.06	56.90	ND

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Revelstoke

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T1	26.85	30.82	345.73	18.74	68.28	6.22	ND	ND	4.60	590.89
T2	ND	10.99	290.68	ND	113.82	76.39	ND	ND	66.19	558.06
T3	10.33	29.80	87.85	75.20	93.08	11.18	22.57	ND	ND	334.93
T4	24.62	71.36	976.86	208.86	338.90	243.01	73.63	ND	ND	2126.23
T5	ND	ND	874.00	48.45	457.62	60.73	ND	ND	ND	1440.80
T6	ND	53.71	8.41	ND	685.44	ND	ND	ND	ND	747.57
T7	ND	41.60	490.87	117.99	132.18	ND	ND	ND	ND	795.76
T8	ND	128.70	381.60	12.27	152.63	22.63	59.13	ND	ND	783.84

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Salmon Arm

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T9	39.74	34.17	330.40	37.92	136.08	ND	ND	ND	ND	578.31
T10	80.40	19.49	325.15	27.70	119.19	ND	ND	ND	ND	571.92
T11	ND	17.01	44.23	109.90	224.06	34.14	ND	ND	ND	429.33
T12	39.52	38.92	121.89	141.97	209.46	32.86	37.32	ND	1.68	630.67

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Kamloops

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T13	58.37	156.36	1291.86	296.53	619.39	58.09	15.86	ND	ND	2544.17
T14	346.43	59.85	482.73	119.63	342.10	31.87	ND	ND	ND	1401.48
T15	ND	55.84	1237.76	882.16	683.01	45.14	12.34	ND	ND	2999.70
T16	29.74	207.71	1640.34	2301.71	2629.00	778.34	84.74	ND	ND	8058.97

PCB Concentrations in Vegetation (ng/g lipid) Sampled from Kelowna

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
T17	12.31	101.17	150.29	414.85	108.13	40.77	ND	ND	ND	839.92
T18	ND	14.05	99.90	149.96	80.48	7.96	ND	ND	ND	352.35
T19	ND	ND	159.44	53.33	95.62	16.81	ND	ND	ND	325.20
T20	ND	52.11	321.50	82.10	196.70	44.08	33.79	ND	24.54	870.86

APPENDIX V – OC AND PCB CONCENTRATIONS IN DIURNAL SAMPLES

OC Concentrations in Diurnal Vegetation Samples (ng/g lipid)

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
D1	25.81	97.45	14.13	ND	ND	ND	ND	ND	ND	ND	ND	133.67
D2	4.18	3.22	5.97	ND	ND	ND	ND	ND	ND	ND	ND	ND
D3	15.64	7.75	6.23	ND	ND	ND	ND	ND	ND	ND	ND	ND
D4	8.14	6.26	11.27	38.97	ND	ND	3.11	ND	8.58	ND	32.98	ND
D5	11.47	126.84	5.66	ND	ND	ND	ND	ND	470.30	ND	ND	ND
D6	27.07	53.28	22.34	514.53	ND	ND	ND	ND	ND	ND	3.14	ND
D7	19.16	9.34	10.45	ND	ND	ND	ND	ND	ND	ND	ND	ND
D8	18.68	8.76	15.32	ND	ND	ND	ND	ND	15.48	ND	ND	ND
D9	1.76	49.73	1.37	56.70	36.61	ND	4.16	ND	ND	ND	ND	ND
D10	14.62	23.67	11.40	ND	ND	ND	12.75	ND	737.44	ND	2.78	ND
D11	15.63	7.83	15.41	28.31	ND	ND	12.72	ND	180.61	ND	11.73	ND
D12	26.43	13.99	30.11	2.78	ND	ND	22.28	83.03	31.73	ND	ND	ND
D13	29.01	16.91	20.57	78.24	ND	ND	6.38	ND	2.52	2.75	18.60	ND
D14	41.84	25.91	17.36	165.05	ND	ND	17.33	ND	ND	1.67	5.68	ND
D15	25.22	10.18	14.92	ND	ND	ND	3.54	ND	ND	ND	ND	ND
D16	24.72	11.09	17.95	648.36	ND	ND	ND	ND	ND	ND	7.01	ND
D17	25.48	5.19	20.53	560.40	82.61	ND	4.78	277.90	235.47	5.45	ND	ND
D18	17.80	6.06	9.47	45.04	ND	ND	36.84	ND	ND	ND	4.01	ND
D19	14.14	2.47	13.92	113.70	ND	ND	ND	ND	143.71	ND	9.24	ND
D20	9.96	2.51	5.53	3.96	ND	55.65	12.94	ND	ND	ND	3.85	ND
D21	6.79	2.87	13.45	ND	ND	ND	ND	ND	ND	ND	ND	ND
D22	2.13	1.50	7.34	ND	ND	ND	7.16	ND	ND	ND	11.47	ND
D23	2.73	5.54	5.68	ND	ND	ND	ND	ND	199.15	ND	ND	ND
D24	6.71	2.10	8.39	39.35	ND	ND	28.96	ND	45.71	ND	ND	ND

OC Concentrations in Diurnal Vegetation Samples (pg/g wet weight)

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
D1	86.29	325.77	47.22	ND	ND	ND	ND	ND	ND	ND	ND	446.85
D2	31.82	24.49	45.38	ND	ND	ND	ND	ND	ND	ND	ND	ND
D3	82.72	40.99	32.94	ND	ND	ND	ND	ND	ND	ND	ND	ND
D4	35.84	27.56	49.63	171.56	ND	ND	13.70	ND	37.77	ND	145.18	ND
D5	73.70	815.01	36.36	ND	ND	ND	ND	ND	3021.89	ND	ND	ND
D6	97.44	191.75	80.40	1851.84	ND	ND	ND	ND	ND	ND	11.31	ND
D7	88.61	43.22	48.32	ND	ND	ND	ND	ND	ND	ND	ND	ND
D8	84.84	39.79	69.58	ND	ND	ND	ND	ND	70.29	ND	ND	ND
D9	11.83	334.27	9.20	381.12	246.08	ND	27.97	ND	ND	ND	ND	ND
D10	46.20	74.80	36.02	ND	ND	ND	40.30	ND	2330.55	ND	8.78	ND
D11	58.74	29.44	57.90	106.37	ND	ND	47.79	ND	678.73	ND	44.07	ND
D12	58.11	30.76	66.20	6.10	ND	ND	48.99	182.53	69.75	ND	ND	ND
D13	114.95	67.01	81.51	310.02	ND	ND	25.27	ND	9.99	10.91	73.69	ND
D14	165.81	102.65	68.80	654.02	ND	ND	68.68	ND	ND	6.61	22.51	ND
D15	168.47	68.02	99.72	ND	ND	ND	23.64	ND	ND	ND	ND	ND
D16	116.85	52.43	84.83	3064.95	ND	ND	ND	ND	ND	ND	33.14	ND
D17	89.49	18.24	72.12	1968.45	290.18	ND	16.78	976.16	827.12	19.14	ND	ND
D18	74.81	25.47	39.79	189.28	ND	ND	154.81	ND	ND	ND	16.84	ND
D19	56.09	9.81	55.21	451.05	ND	ND	ND	ND	570.10	ND	36.65	ND
D20	45.97	11.60	25.50	18.25	ND	256.74	59.69	ND	ND	ND	17.75	ND
D21	22.29	9.41	44.19	ND	ND	ND	ND	ND	ND	ND	ND	ND
D22	10.86	7.65	37.44	ND	ND	ND	36.48	ND	ND	ND	58.48	ND
D23	13.80	28.01	28.70	ND	ND	ND	ND	ND	1006.92	ND	ND	ND
D24	31.13	9.75	38.93	182.66	ND	ND	134.45	ND	212.18	ND	ND	ND

OC Concentrations in Diurnal Vegetation Samples (pg/g dry weight)

Sample	α-HCH	γ-HCH	HCB	Hept Epox	Dieldrin	Endrin	α-endo	β-endo	α-chlor	*p,p'*-DDE	*p,p'*-DDT	*o,p'*-DDT
D1	194.94	735.98	106.69	ND	ND	ND	ND	ND	ND	ND	ND	1009.53
D2	74.58	57.41	106.38	ND	ND	ND	ND	ND	ND	ND	ND	ND
D3	177.37	87.89	70.65	ND	ND	ND	ND	ND	ND	ND	ND	ND
D4	77.93	59.93	107.91	373.03	ND	ND	29.78	ND	82.12	ND	315.69	ND
D5	169.92	1879.02	83.82	ND	ND	ND	ND	ND	6967.03	ND	ND	ND
D6	205.17	403.74	169.28	3899.11	ND	ND	ND	ND	ND	ND	23.81	ND
D7	185.34	90.40	101.06	ND	ND	ND	ND	ND	ND	ND	ND	ND
D8	175.83	82.46	144.21	ND	ND	ND	ND	ND	145.69	ND	ND	ND
D9	27.30	771.46	21.24	879.59	567.93	ND	64.55	ND	ND	ND	ND	ND
D10	89.52	144.93	69.80	ND	ND	ND	78.08	ND	4515.78	ND	17.01	ND
D11	131.34	65.83	129.46	237.83	ND	ND	106.86	ND	1517.50	ND	98.52	ND
D12	126.13	66.76	143.69	13.24	ND	ND	106.33	396.18	151.40	ND	ND	ND
D13	215.91	125.86	153.09	582.31	ND	ND	47.46	ND	18.77	20.49	138.42	ND
D14	304.42	188.46	126.31	1200.73	ND	ND	126.10	ND	ND	12.13	41.32	ND
D15	313.29	126.49	185.43	ND	ND	ND	43.96	ND	ND	ND	ND	ND
D16	224.14	100.57	162.72	5879.20	ND	ND	ND	ND	ND	ND	63.57	ND
D17	195.17	39.77	157.30	4293.17	632.88	ND	36.59	2129.00	1803.93	41.75	ND	ND
D18	172.38	58.69	91.69	436.15	ND	ND	356.73	ND	ND	ND	38.79	ND
D19	127.77	22.35	125.78	1027.52	ND	ND	ND	ND	1298.73	ND	83.49	ND
D20	103.08	26.00	57.17	40.91	ND	575.62	133.82	ND	ND	ND	39.79	ND
D21	71.50	30.18	141.73	ND	ND	ND	ND	ND	ND	ND	ND	ND
D22	32.76	23.07	112.97	ND	ND	ND	110.07	ND	ND	ND	176.46	ND
D23	43.14	87.53	89.69	ND	ND	ND	ND	ND	3147.21	ND	ND	ND
D24	82.97	25.98	103.74	486.81	ND	ND	358.31	ND	565.49	ND	ND	ND

PCB Concentrations in Diurnal Vegetation Samples (ng/g lipid)

Sample	Di-CB	Tri-CB	Tetra-CB	Penta-CB	Hexa-CB	Hepta-CB	Octa-CB	Nona-CB	Deca-CB	ΣPCB
D1	ND	ND	49.57	16.67	ND	24.88	ND	ND	ND	91.12
D2	ND	16.77	45.28	4.15	ND	ND	ND	ND	ND	80.74
D3	ND	ND	39.98	25.79	5.84	66.06	14.82	ND	ND	152.50
D4	ND	ND	22.97	ND	7.80	ND	ND	ND	ND	30.77
D5	ND	ND	33.59	31.21	3.89	16.71	6.97	ND	4.91	97.28
D6	ND	ND	131.82	48.09	9.58	27.50	41.01	11.38	ND	269.38
D7	ND	ND	30.80	28.71	ND	47.91	4.79	ND	ND	112.21
D8	ND	16.46	107.76	4.00	ND	11.93	4.62	ND	18.28	229.61
D9	ND	ND	10.21	4.79	1.01	5.14	1.86	ND	ND	23.02
D10	ND	ND	37.73	29.73	4.34	24.43	ND	ND	ND	96.23
D11	ND	6.00	61.94	ND	6.08	ND	ND	ND	ND	89.22
D12	ND	36.62	152.43	ND	ND	ND	12.81	ND	ND	249.46
D13	ND	11.35	78.37	3.92	10.90	ND	ND	ND	ND	104.55
D14	ND	ND	47.12	78.57	32.11	24.30	6.99	ND	2.30	191.40
D15	ND	5.20	60.66	6.91	5.63	ND	9.82	ND	8.74	136.92
D16	ND	ND	115.05	8.39	29.28	9.56	11.04	ND	4.65	179.83
D17	ND	8.02	167.98	1.57	ND	ND	ND	ND	ND	225.74
D18	ND	ND	33.86	11.37	0.83	8.78	ND	ND	2.65	57.49
D19	ND	7.28	129.13	2.47	ND	ND	ND	ND	8.79	244.79
D20	ND	ND	8.61	8.22	ND	8.73	ND	ND	2.33	27.90
D21	ND	ND	111.17	ND	ND	ND	ND	ND	ND	140.75
D22	ND	ND	26.62	0.40	7.61	ND	2.58	ND	ND	44.80
D23	ND	5.38	147.42	29.40	3.09	ND	ND	ND	5.57	237.75
D24	ND	9.27	64.73	ND	ND	ND	ND	ND	10.53	121.25

PCB Concentrations in Diurnal Vegetation Samples (pg/g wet weight)

Sample	2-CB	3-CB	4-CB	5-CB	6-CB	7-CB	8-CB	9-CB	10-CB	ΣPCB
D1	ND	ND	165.71	55.73	ND	83.18	ND	ND	ND	304.62
D2	ND	127.56	344.43	31.57	ND	ND	ND	ND	ND	614.22
D3	ND	ND	211.41	136.38	30.87	349.28	78.35	ND	ND	806.30
D4	ND	ND	101.13	ND	34.33	ND	ND	ND	ND	135.46
D5	ND	ND	215.86	200.56	24.99	107.37	44.77	ND	31.53	625.07
D6	ND	ND	474.43	173.08	34.47	98.99	147.61	40.95	ND	969.53
D7	ND	ND	142.44	132.81	ND	221.60	22.17	ND	ND	519.02
D8	ND	74.76	489.34	18.15	ND	54.18	20.96	ND	83.02	1042.67
D9	ND	ND	68.62	32.23	6.82	34.54	12.52	ND	ND	154.72
D10	ND	ND	119.25	93.97	13.70	77.20	ND	ND	ND	304.13
D11	ND	22.54	232.77	ND	22.86	ND	ND	ND	ND	335.30
D12	ND	80.51	335.10	ND	ND	ND	28.17	ND	ND	548.42
D13	ND	44.98	310.56	15.53	43.20	ND	ND	ND	ND	414.28
D14	ND	ND	186.72	311.35	127.23	96.30	27.71	ND	9.13	758.44
D15	ND	34.73	405.28	46.17	37.63	ND	65.59	ND	58.38	914.78
D16	ND	ND	543.87	39.64	138.43	45.19	52.21	ND	22.00	850.10
D17	ND	28.18	590.03	5.51	ND	ND	ND	ND	ND	792.92
D18	ND	ND	142.29	47.79	3.49	36.89	ND	ND	11.15	241.60
D19	ND	28.87	512.29	9.79	ND	ND	ND	ND	34.88	971.09
D20	ND	ND	39.74	37.94	ND	40.28	ND	ND	10.76	128.72
D21	ND	ND	365.07	ND	ND	ND	ND	ND	ND	462.21
D22	ND	ND	135.71	2.06	38.80	ND	13.16	ND	ND	228.39
D23	ND	27.21	745.36	148.62	15.63	ND	ND	ND	28.17	1202.04
D24	ND	43.03	300.48	ND	ND	ND	ND	ND	48.86	562.87

PCB Concentrations in Diurnal Vegetation Samples (pg/g dry weight)

Sample	2-CB	3-CB	4-CB	5-CB	6-CB	7-CB	8-CB	9-CB	10-CB	ΣPCB
D1	ND	ND	374.37	125.90	ND	187.93	ND	ND	ND	688.19
D2	ND	299.02	807.39	74.00	ND	ND	ND	ND	ND	1439.81
D3	ND	ND	453.35	292.45	66.20	749.00	168.01	ND	ND	1729.02
D4	ND	ND	219.89	ND	74.65	ND	ND	ND	ND	294.53
D5	ND	ND	497.67	462.38	57.62	247.55	103.21	ND	72.69	1441.12
D6	ND	ND	998.93	364.43	72.58	208.42	310.80	86.22	ND	2041.38
D7	ND	ND	297.92	277.77	ND	463.49	46.37	ND	ND	1085.55
D8	ND	154.94	1014.17	37.61	ND	112.30	43.45	ND	172.06	2160.99
D9	ND	ND	158.37	74.38	15.73	79.71	28.89	ND	ND	357.07
D10	ND	ND	231.07	182.08	26.55	149.58	ND	ND	ND	589.29
D11	ND	50.39	520.42	ND	51.11	ND	ND	ND	ND	749.65
D12	ND	174.75	727.32	ND	ND	ND	61.14	ND	ND	1190.32
D13	ND	84.49	583.33	29.18	81.15	ND	ND	ND	ND	778.14
D14	ND	ND	342.81	571.61	233.59	176.79	50.88	ND	16.76	1392.44
D15	ND	64.58	753.64	85.85	69.97	ND	121.96	ND	108.57	1701.09
D16	ND	ND	1043.25	76.04	265.54	86.68	100.14	ND	42.20	1630.66
D17	ND	61.46	1286.86	12.02	ND	ND	ND	ND	ND	1729.35
D18	ND	ND	327.87	110.11	8.03	85.00	ND	ND	25.70	556.70
D19	ND	65.77	1167.05	22.31	ND	ND	ND	ND	79.47	2212.23
D20	ND	ND	89.10	85.06	ND	90.31	ND	ND	24.12	288.58
D21	ND	ND	1170.97	ND	ND	ND	ND	ND	ND	1482.55
D22	ND	ND	409.51	6.20	117.07	ND	39.70	ND	ND	689.14
D23	ND	85.04	2329.69	464.53	48.85	ND	ND	ND	88.04	3757.08
D24	ND	114.69	800.79	ND	ND	ND	ND	ND	130.22	1500.10