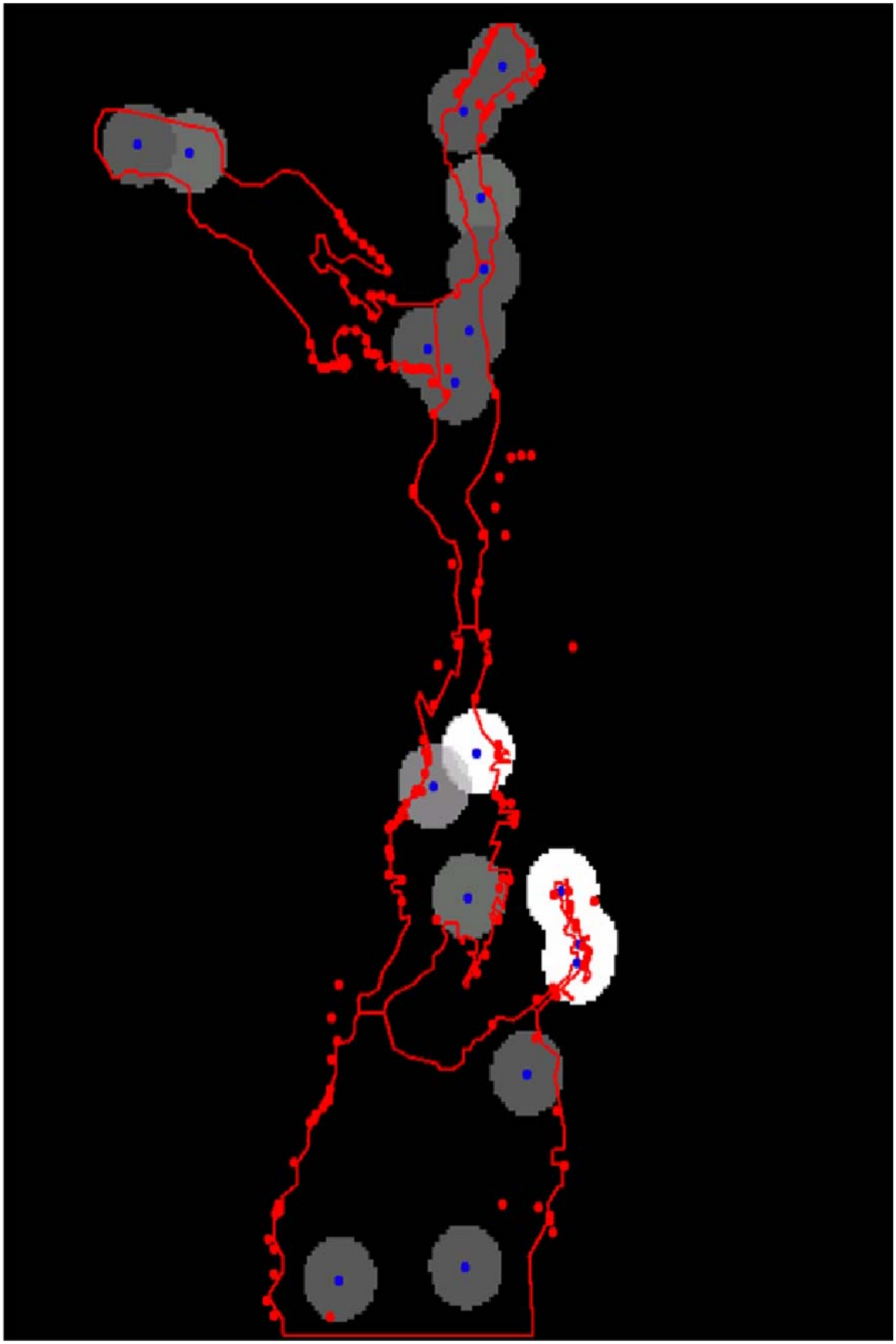

IDW Interpolation

Development of a Food Web Model to Develop Sediment Target Levels for Selected Persistent Organic Pollutants in Burrard Inlet

by

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ABSTRACT

This study reports the development and testing of a computer simulation model of the fate of Persistent Organic Pollutants (POPs) in Burrard Inlet. POPs are introduced into Burrard Inlet by a number of sources including both, *point sources* (e.g., industrial and municipal effluent discharges) and *non-point sources* such as storm water runoff. Once introduced to the inlet, contaminants are subject to physical, chemical and biological processes that lead to dispersion and accumulation in different matrices of the marine environment.

The main purpose of the model is to provide a comprehensive ecosystem-level assessment of the fate of contaminants in Burrard Inlet to characterize the relationship between concentrations of POPs in sediments and organisms of the Burrard Inlet food-web. The results provided significant evidence of bioaccumulation of a PCB mixture in some key biological receptors in the food web and also include recommendations for the development of sediment target levels and loading for PCBs in support management decisions regarding POPs in Burrard Inlet.

Keywords: Food web model, Biomagnification, PCBs, Burrard Inlet.

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1. INTRODUCTION

1.1. Purpose

The purpose of this project is to develop, test and apply a computer simulation model that can predict the dynamics and distribution of PCBs in the aquatic food web of Burrard Inlet.

Contaminants are introduced into Burrard Inlet by a number of sources including point sources (e.g., industrial and municipal effluent discharges) and non-point sources such as storm water runoff. Once introduced to the inlet, contaminants are subject to physical, chemical and biological processes that lead to dispersion and accumulation in different matrices of the marine environment.

The main purpose of the model is to provide a comprehensive ecosystem-level assessment of the fate of PCBs in Burrard Inlet aquatic ecosystems with a focus on the relationship between chemical emissions and resulting concentrations in biota as a function of observed elevated concentrations of Persistent Organic Pollutants (POPs) in sediments.

In addition, the multi-media compartment modeling approach, summarized the dynamics and mechanisms of uptake and elimination of chemicals under conditions of spatial and temporal variability, and predicts a range of possible environmental trends, to meet the objective of better evaluating the partitioning and fate of some Persistent Organic Pollutants (POPs) into the ecosystem.

Finally, this research produces recommendations for the development of sediment target levels to facilitate management decisions in regulating chemical discharges in Burrard Inlet.

1.1.1. Background

Burrard Inlet is one of the most recognizable features in Greater Vancouver. The Inlet is an 11,300 hectare marine-tidal water body, contained by 190 kilometers of shoreline. The surrounding natural drainage basin is home to several municipalities and comprises an additional 98,000 hectares of land (BIEAP, 1997). As part of the larger Georgia Basin region, Burrard Inlet is a significant component of one of Canada's most productive marine and terrestrial ecosystems.

Several monitoring studies in the past, have observed elevated concentrations of Persistent Organic Pollutants in sediments and biota of Vancouver Harbour and other areas of Burrard Inlet (i.e Gobas et al. 1997, Maldonado 2003, Mackintosh et al. 2004).

Understanding the relationships between contaminant emissions and ambient concentrations is crucial for achieving environmental quality objectives.

The characterization of local and regional relationships between chemical loadings and resulting concentrations in biota is an important component of environmental quality management because toxicological impacts are ultimately determined by the control of chemical emissions.

For some substances, e.g. PCBs, observed sediment concentrations in Burrard Inlet are close to, or in excess of, the sediment quality guidelines (Maldonado 2003). The ecological significance of these current contaminant-concentrations remains difficult to assess because laboratory toxicity- tests and benthic studies only provide information about the effects of contaminants on small benthic organisms. However, the impact of current contaminants on organisms at higher trophic levels, such as harbor seals, herons and other waterfowl, are not addressed by these tests. The latter is particularly important for persistent and bioaccumulative contaminants, which biomagnify in the food-web and cause organisms in higher trophic levels to be exposed to contaminant concentrations that are much greater than those experienced by organisms at lower trophic levels. For these bioaccumulative substances, toxicological effects appear in higher trophic level organisms such as birds, mammals and upper-trophic level fish before they are manifested in species from lower trophic levels. Since it is not possible to conduct toxicity tests that directly relate pollution level effects to particular contaminants in ecosystems, it is important to develop other means of interpreting contaminant levels in terms of effects in higher trophic level organisms.

1.1.2. Objective

In this study, a model is developed that describes the trophodynamics of contaminants in the Vancouver harbor food-web. It is a time–dependent, ecosystem-level simulation model of the environmental distribution and bioaccumulation of organic contaminants in aquatic ecosystems. The main purpose of the model is to provide a comprehensive ecosystem-level assessment of the fate of contaminants in aquatic ecosystems. The model is focused on the relationships between chemical emissions and resulting concentrations in biota as a function of observed elevated concentrations of Persistent Organic Pollutants in sediments.

2. THEORY

2.1. Modeling background:

Since the 1950's, large quantities of organic pesticides such as DDT, hexachlorocyclohexanes (HCHs), hexachlorobenzene (HCB), dieldrin and industrial based chemicals such a PCBs have been discharged into the environment. As a result, observed reproductive disruptions in the 1970's were attributed to exposure to organochlorines contaminants (1-3). It is also well documented that persistent hydrophobic organic chemicals such as polychlorinated biphenyls (PCB's) and DDT can biomagnify, causing chemical concentrations to increase with every step in ecological food chains (4-6). Various studies have demonstrated that organochlorine chemicals with high octanol-water partition coefficients (Kow), usually expressed as Log Kow>6, can biomagnify, which means that the fugacity of the chemical in the organism reaches a level that exceeds that in the diet of the organism. In other words, a chemical biomagnifies when the concentration of that chemical (on a lipid normalized basis) in an organism (C_B) exceeds the concentration in the consumed prey (C_D) . Many of these compounds are also resistant to chemical degradation, showing long resident times in the environment. Organic compounds with long resident times and the ability to biomagnify in the food chain have been classified as persistent organic pollutants (POPs) and they are likely to trigger toxic effects on higher trophic organisms.

Different regulatory agencies in Canada, the United States and Europe have attempted to control the use of first generation POPs (e.g. PCBs, DDT, dioxins) by banning or reducing their emission into the environment. For example, Canada adopted a Toxic Substances Management Policy (TSMP) under the Canadian Environmental Protection Act (CEPA) and the United Nations Environmental Program (UNEP). Also, long range transboundary air pollution protocol (LRTAP) on POPs, have adopted a policy that considers the virtual elimination of those chemical substances that meet a criteria based on chemical persistence (P), Bioaccumulation (B), and toxicity (T). The above mentioned regulatory agencies identified chemicals as bioaccumulative if they have bioaccumulation or bioconcentration factors (BAF or BCF) greater than 5000 in aquatic ecosystems. In the absence of BAFs or BCFs data, bioaccumulative substances are defined as those compounds with octanol-water partition coefficients (Kow) greater than 10^5. This criterion is based on the concept that chemicals with Kow $<10^5$ may biocconcentrate in aquatic organisms, but not necessarily biomagnify in the food chain (7-10). Some nations involved in the UNEP's LRTAP treaty, proposed an even more sensitive Kow threshold value of 10^4 to be used for bioaccumulation assessments rather than 10^5. Relatively recent developments in the area of environmental toxicology (11-14), have demonstrated that chemicals with a Kow less than 10^4 or 10^5 could still shows the same ability to biomagnify in terrestrial food chains. Therefore, the substances categorization and screening level of risk criteria used by the Canadian Environmental Protection Act (CEPA) are known to inadequately represent bioaccumulation in real food-webs in Canada.

2.1.1. Basic Definitions

We follow the definitions set out by Gobas and Morrison (2000) and also used later on by Mackay and Fraser (2000) in an effort to standardize nomenclature in the existing literature (15-16).

Bioconcentration:

Bioconcentration in fish involves the uptake of chemical by absorption from the water only (usually under laboratory conditions), can occur via the respiratory surface and/or the skin, and results in the chemical concentration in an aquatic organism being greater than that in water. The bioconcentration factor (BCF) is defined as the ratio of the chemical concentration in an organism CB, to the total chemical concentration in the water C_{WT}, or to C_{WD}, the freely dissolved chemical concentration in water and is expressed as follows:

$$BCF = C_B/C_{WD} \qquad (2.1.1)$$

The use of C_{WD} is preferred because it only takes into account the fraction of the chemical in the water that is biologically available for uptake.

Bioaccumulation:

Bioaccumulation is the process which causes an increased chemical concentration in an aquatic organism compared to that in water, due to uptake by all exposure routes including dietary absorption, transport across respiratory surfaces and dermal absorption. Bioaccumulation can thus be viewed as a combination of bioconcentration and food uptake. The bioaccumulation factor (BAF) in fish is the ratio of the concentration of the chemical in the organism C_B to that in the water, similarly to that of BCF.

$$BAF = C_B / C_{WD} \qquad (2.1.2)$$

Biomagnification:

Biomagnification occurs if dietary uptake causes the chemical concentration in the organism exceeds that in the organism's diet due to dietary absorption. A biomagnification factor (BMF) can be defined as the ratio of the concentration of chemical in the organism C_B to that in the organism's diet C_D and can be expressed as:

$$BMF = C_B / C_D \qquad (2.1.3)$$

2.2. Model Development

2.2.1. Steady-State assumptions

The development of the Burrard Inlet Food web bioaccumulation model follow a steady-state approach to calculate and predict the PCB concentration in the Inlet. Such Steady State approach is based on the rational that the PCB transfer between media, has time enough to reach a dynamic equilibrium where the PCB concentrations in each separate media or compartments remain constant over time. Under steady-state condition, the relationship between the emission of contaminants discharges (e.g. PCBs) and changes in concentration over time in water, sediment and fish remain constant. Under steady-state approach, seasonal changes in the model, can be represented by adjusting parameters to reflect specific seasonal conditions. However, the steady-state assumption does imply that throughout that seasonal period, PCB concentrations in water, sediment and biota achieve a dynamic equilibrium where PCB concentrations no longer change over time. The assumption of steady-state is most appropiate for modeling small aquatic organisms, like phytoplankton, plankton, benthic species and small fish, which reach the dynamic equilibrium between uptake and elimination of chemicals faster than larger organisms. In larger organisms like seals, large fish and birds, the exchange of chemicals (ie large PCBs congeners) with the environment can be very slow too reflect the changing environmental conditions. Therefore, larger species typically take long periods of time to reach steady-state (28) and the PCB concentrations may deviate to some degree from the dynamic equilibrium that the model predicts. In an attempt to keep the simulation modeling simple and practical, we avoided using time dependent equations that can reflect seasonal changes in the environment and adopted the steady-state approach. Time dependent equations are more complicated, computing intensive and require extra input data that is in most cases not available. However, we did capture the effects of seasonal variations in PCB concentrations by using a Monte Carlo Simulation (MCS) during the sensitivity analysis. When using MCS to incorporate cyclic fluctuations such us seasonal changes in parameter values, the PCB concentrations in biota are usually expressed as a range of concentrations that can be expected as a result of a variation in seasonal conditions. The range of concentrations expressed in the calculations are a function of a range of possible values in the model parameters and state variables. This range of concentrations in the model outputs, can be considered as a reasonable estimate of the concentration of PCBs observed in the Inlet for those organisms that reach steady-state fairly quickly. For those large organisms and PCB congeners that reach steady-state slowly, the range of calculated concentrations in the model output are expected to be an overestimate of the real values, since the upper and lower levels observed in the plots, are not likely to be reached in the period of time the model calculations apply. To capture the differences in uptake and elimination of PCBs in different age groups, the model includes four different age stages for key biological receptors in higher throphic levels (i.e. mammals and birds) and two age stages for some fish species (i.e. juveniles and adults).

We believed that the adoption of steady-state approach used in the model is justified for two reasons: Firstly, as a computer modeler, it is of paramount importance to keep models as simple as possible. Secondly, the time-response effect in sediments to the changes in loading and chemical discharges into the ecosystem, is relatively slow compare with the time-response effect observed in biota. Davis et al. 2004(29), estimated that the half-life time of PCBs in similar ecosystems is approximately 20 years, while a comparable half- life time of PCBs in adult White croaker is approximately 100 days. Therefore it is justified to assume that the changes observed in PCB concentrations in biota will reflect the changes in sediments concentrations as a result of elevated chemical discharges in the Inlet. In this case, the sediments are acting as the slowest compartment and controlling PCBs changes in biota over time. As a result, the main output of the model are Biota Sediment Accumulation Factors (BSAFs) used to calculate the concentration in biota (C_B) from the observed consentration in sediments (C_S) in a simple multiplication (C_B =BSAF. C_S).

The food-web bioaccumulation model consists of a number of mathematical expressions describing the uptake and elimination dynamics of PCBs in biota for an specific site, in our case, the pre-parameterized site is Burrard Inlet. The expressions for air-breathing (seals, cormorants, terns) and water-breathing organisms (fish, benthic invertebrates, plankton) are fundamentally different. For this reason we have described the architecture of the model in three sections. The first section is for water breathing organisms and includes phytoplankton, zooplankton, aquatic invertebrates and fish. The second section describes the model for marine mammals that is used to derive the BSAF for Harbor seals. The third section lays out the model for birds, which is used to assess the BSAF in cormorants and terns.

2.2.2. Abiotic Model development and Parameterization

The development of the abiotic model it is not within the scope of work of this research project, for that reason, a simple abiotic model has been included as an optional feature within the food web model. Results for the abiotic model will not be discussed on this paper, but model's equations will be briefly described and documented in Appendix B. The abiotic model simply predict changes in sediment and water concentration over time based on point and non point sources discharges into the Inlet and can use those outputs to feed the food web model making it also time dependent.

2.3. Food-Web Model development and Parameterization

2.3.1. Model Description: Phytoplankton, Zooplankton, Aquatic Invertebrates, Fish

Figure 2.3.1: Conceptual diagram of the major uptake and elimination processes of PCBs in fish

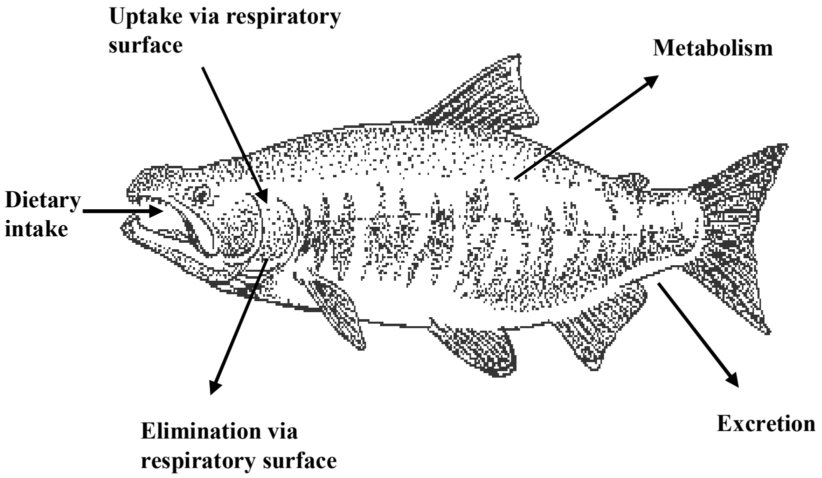


Figure 2.3.1 shows an overview of major routes of chemical uptake and elimination in aquatic organisms. In this case, uptake and elimination processes of PCBs in fish rely on dietary intake and gas exchange with the water for respiration.

Our model has been based on the equations and assumptions already presented and tested by Arnot and Gobas for the San Francisco Bay ecosystem (30). The major presumption for the model is that the exchange of PCB congeners between the organism and its ambient environment can be described by a single equation for a large number of aquatic organisms:

$$dM_B/dt=\{W_B.(k_1.[m_O.\phi.C_{WT,O} + m_P.C_{WD,S}] + k_D.\Sigma(P_i.C_{D,i}))\} - (k_2 + k_E + k_M).M_B \quad (2.4.1.1)$$

where M_B is the mass (g) of the PCB congener in the organism, dM_B/dt is the net flux of PCB congener being absorbed or depurated by the organism at any point in time t (d), W_B is the weight of the organism (kg) at time t, k_1 is the clearance rate constant (L/kg . d) for uptake via the respiratory area (i.e. gills and skin), m_O is the fraction of the respiratory ventilation that involves overlying water, m_P is the fraction of the respiratory ventilation that involves sediment associated pore water, ϕ (unitless) is the fraction of the total chemical concentration in the overlying water that is freely dissolved and can be absorbed via membrane diffusion, $C_{WT,O}$ is the total concentration of the PCB congener in the water column above the sediments (g/L), $C_{WD,S}$ is the freely dissolved PCB congener concentration in the sediment associated pore (or interstitial) water (g/L), k_D is the clearance rate constant (kg/kg . d) for chemical uptake via ingestion of food and water, P_i is the fraction of the diet consisting of prey item i, $C_{D,i}$ is the concentration of PCB congener (g/kg) in prey item i, k_2 is the rate constant (d^{-1}) for elimination of PCBs via the respiratory area (i.e. gills and skin), k_E is the rate constant (d^{-1}) for the elimination of the PCB congener via excretion into egested feces and k_M is the rate constant (d^{-1}) for metabolic transformation of the PCB congener. For phytoplankton, algae and macrophytes, $k_{D,i}$ is zero and k_E is considered to be insignificant.

The model is based on several key assumptions. First, it is assumed that the pollutant or PCB congener is homogeneously distributed within the organism as long as differences in tissue composition and phase partitioning are taken into account. There is enough evidence that supports this assumption (31). Afterward, concentrations in specific fish tissues can therefore be estimated based on the partition coefficients between the fish tissues of interest. This first assumption is of paramount importance in characterizing the risk experienced by fishermen who eat fish caught from the Inlet. Secondly, it is assumed that the organism can be described as a single compartment in its exchange with its surrounding environment. Many studies can be quoted to support this (32). The one-compartment model for an organism is best applied in situations where variations in PCB concentrations in water and sediment are relatively slow over time. To better understand the uptake and elimination dynamics of PCBs in fish, the abiotic part of the model, also includes the equations for a two compartment pharmacokinetics model in fish (see abiotic model development and parametrization). A third assumption of the model concerns the PCB congener elimination via sperm ejection or egg deposition.

Many studies have shown that the lipid normalized concentration of many POPs in adult female fish, and PCBs in particular, are approximately equal to the observed concentration in eggs (33). Consequently, even though the adult female fish can transfer a significant fraction of the body burden through the eggs deposition process, the lipid normalized concentration in tissue of that female fish remains the same.

In the model, we assumed that the key mechanisms by which an organism lowers its internal PCBs concentration is through growth dilution. Growth dilution it is a process associated with the formation of extra tissue where the PCBs congeners could reside, therefore reducing the organism PCBs concentration. In the case of an adult female fish, eggs formation produce that extra tissue where PCBs can move and potentially be eliminated from the organism through eggs deposition. Nevertheless, the main model (equation 2.4.1) illustrates that growth dilution effect is always counteracted by uptake of PCB congener from water and the diet. Therefore, the ultimate internal concentration in the organism is controlled by the balance of those multiple uptake and elimination processes.

As it was explained above, equation 2.4.1 can be simplified by applying a steady- state assumption ($dM_B/dt = 0$), resulting in:

$$C_B = \{k_1 \, . \, (m_O \, . \, \phi \, . \, C_{WT,O} + m_P \, . \, C_{WD,S}) + k_D \, . \, \sum P_i \, . \, C_{D,i}\} / (k_2 + k_E + k_G + k_M) \quad (2.3.1.2)$$

where C_B is the PCB congener concentration in the organism (g/kg wet weight) (i.e. M_B/W_B). The steady-state assumption applies very well for organisms in the Inlet which have been exposed to the PCB congener over a long period of time or throughout their entire life. One of the implications of applying a steady-state assumption is that the growth of the organism needs to be expressed as a growth rate constant k_G, which is $dW_B/(W_B \, . \, dt)$.

The growth rate constant assumes that over the period of time the model applies, the growth of the organism can be represented by a constant fraction of the organism's body weight.

The model's bioaccumulation factor (BAF) is $C_B/C_{WT,O}$ and the wet weight based biota-sediment accumulation factor (BSAF) is C_B/C_S, where C_S is the concentration (g/kg dry sediment) in the bottom sediment:

$$BSAF = C_B/C_S \qquad (2.3.1.3)$$

The BSAF is the key outcome of the Burrard inlet food web bioaccumulation model. BSAFs provides the means to predict the concentrations of PCBs in biota from the PCB concentration in the sediments of the inlet. The different sub-models and complementary equations for k_1, k_2, k_E, k_M, k_G and ϕ, used to estimate the BSAF are described below.

ϕ: Is simply the ratio of the freely dissolved water concentration C_{WD} (g/L) to the total water concentration C_{WT} (g/L). PCBs have shown high affinity for organic matter, such as particulate organic carbon (POC) and dissolved organic carbon (DOC) in the water column (34-35). If associated with particulate or dissolved organic matter, the PCB congener is believed to be unavailable for uptake via diffusion into organisms. Therefore ϕ was estimated for non-ionizing PCBs as:

$$\phi = C_{WD} / C_{WT} = 1 / (1 + \chi_{POC} \cdot D_{POC} \cdot \alpha_{POC} \cdot K_{OW} + \chi_{DOC} \cdot D_{DOC} \cdot \alpha_{DOC} \cdot K_{OW}) \quad (2.3.1.4)$$

where χ_{POC} and χ_{DOC} are the concentrations of POC and DOC in the water (kg/L), respectively. D_{POC} and D_{DOC} are the disequilibrium factors for POC and DOC partitioning. They represent the degree to which POC-water and DOC-water distribution coefficients vary from POC-water and DOC-water equilibrium partition coefficients. D_{POC} or D_{DOC} values greater than 1.0 indicate distribution coefficients in excess of equilibrium partition coefficients, while values less than 1.0 represent conditions where equilibrium has not been reached. D_{POC} and D_{DOC} values equal to 1.0 represent equilibrium partitioning. Disequilibria between OC and water have been observed for a range of organic chemicals, including PCBs, in several ecosystems (36) but their values remain difficult to predict at this point. In this study, we have used empirical water and sediment concentration data from the Inlet to characterize D_{POC} and D_{DOC} in the model. In equation 2.8, α_{POC} and α_{DOC} are proportionality constants describing the similarity in phase partitioning of POC and DOC in relation to that of octanol. These proportionality constants can vary substantially among different types of organic carbon. Based on a study by Seth et al. [1999] (37), we have assumed that α_{POC} can be estimated as 0.35 with error bars equivalent to a factor of 2.5. Following Burkhard et al. [2000](38) we have estimated α_{DOC} to be 0.08 with error bars equivalent to a factor of 2.5.

k_1 and k_2: The rate at which chemicals are absorbed from the water via the respiratory surface (e.g. gills and skin) is expressed by the aqueous uptake clearance rate constant k_1 (L/kg . d). In fish, invertebrates and zooplankton, it is viewed as a function of the ventilation rate G_V (L/d) and the diffusion rate of the chemical across the respiratory surface area (39, 22):

$$k_1 = E_W \cdot G_V / W_B \qquad (2.3.1.5)$$

where E_W is the gill chemical uptake efficiency and W_B is the wet weight of the organism (kg). E_W is a function of the K_{OW} of the PCB congener and is approximated based on observations in fish by (40):

$$E_W = (1.85 + (155 / K_{OW}))^{-1} \qquad (2.3.1.6)$$

G_V was calculated based on an allometric relationship between wet weight and oxygen consumption for 200 different fish species (41) ranging in weight between $2.0 \cdot 10^{-5}$ and 60 kg under routine metabolic test conditions as well as G_V data for zooplankton and aquatic invertebrate species:

$$G_V = 1400 \cdot W_B^{\,0.65} / C_{OX} \qquad (2.3.1.7)$$

where C_{OX} is the dissolved oxygen concentration in the water (mg O_2/L) and were available from empirical measurements of dissolved oxygen concentration made at RMP stations.

For algae, phytoplankton and aquatic macrophytes, we used a biphasic relationship for k_1 and k_2 based on a water-organic carbon two-phase resistance model:

$$k_1 = (A + (B / K_{OW}))^{-1} \qquad (2.3.1.8)$$

where A and B are constants (with units of time) describing the resistance to PCB uptake through respectively the aqueous and organic phases of the algae, phytoplankton or macrophytes. To obtain reasonable values for A and B for phytoplankton, we evaluated several data sets. Constant B (default value = 5.5) is derived by calibration to empirical k_2 values from various phytoplankton, algae and cyanobacteria species over a range of K_{OW} using data described in Koelmans et al. [1993, 1995, 1999](42-44) and Wang et al. [1996].(45) Constant A (default value = $6.0 \cdot 10^{-5}$) is derived from calibration to phytoplankton field BCF data from the Great Lakes [Swackhamer and Skoglund 1993 and Oliver and Niimi 1988](46,47). A mean annual k_G value of 0.125 d^{-1} was selected from based on the studies by Alpine and Cloern [1988 and 1992] (48,49).

The elimination rate constant k_2 (d^{-1}) is closely related to k_1 as both k_1 and k_2 involve the same processes of water ventilation and membrane permeation:

$$k_2 = k_1/K_{BW} \quad (2.3.1.9)$$

where K_{BW} (L/kg wet weight) is the biota-water partition coefficient. The partitioning of PCBs between biota in the inlet and water is believed to occur into the lipids, non-lipid organic matter (e.g. proteins and carbohydrates) and water. Each of these media has their own capacity to sorb and "store" PCB congeners. Hence, for every PCB congener in each organism of the Bay we define an organism-water partition coefficient KBW on a wet weight basis (ww) as:

$$K_{BW} = k1 / k2 = v_{LB} . KOW + v_{NB} . ß. K_{OW} + v_{WB} \quad (2.3.1.10)$$

where v_{LB} is the lipid fraction (kg lipid/kg organism ww), v_{NB} is the non- lipid organic matter (NLOM) fraction (kg NLOM/kg organism ww) and v_{WB} is the water content (kg water/kg organism ww) of the organism. ß is a proportionality constant expressing the sorption capacity of NLOM to that of octanol. Based on a previous work of Gobas et al. [1999] (28), a value of approximately 0.035 ±0.010 was chosen. This implies that the sorption affinity of NLOM for PCBs is approximately 3.5% that of octanol. While the sorption affinity of NLOM is low compared to that of lipid, it can play an important role in controlling the partitioning of organic chemicals in organisms that have low lipid contents (e.g. phytoplankton, algae, certain invertebrates). Good databases exist (50) to parameterize the three phase partitioning model, especially for fish, crustaceans and shellfish consumed by humans. For the calculation of the phytoplankton-water partition coefficient (K_{PW}) NLOM in equation 2.3.10 is replaced by non-lipid organic carbon (kg NLOC/kg organism ww) with a proportionality constant of 0.35 i.e.:

$$K_{PW} = v_{LP} \,.\, K_{OW} + v_{NP} \,.\, 0.35 \,.\, K_{OW} + v_{WP} \quad (2.3.1.11)$$

Since the BAF is a function of the ratio of k1 and k2, errors in the exact determination of G_V and E_W typically have a minor effect on the BAF as errors in k1 will cancel out similar errors in k2. This makes the model relatively insensitive to parameterization error in G_V and E_W and allows a single equation to represent ventilation rates and uptake efficiencies in a range of species. The partitioning properties of the chemical, represented by K_{BW} play a more important role. This is reasonable as the main roles of k1 and k2 are to describe how quickly or slowly equilibrium partitioning in the organism will be achieved. The model is most sensitive to k1 and k2 for substances that (i) are absorbed from water and food in comparable amounts and/or (ii) eliminated by gill ventilation at rates that are comparable to the combined elimination rate of feces egestion, metabolic transformation and growth dilution.

m_O, m_P: Organisms that are in close contact with the bottom sediments, such as benthic fish and invertebrates, can exchange PCB with sediment pore water. Freely dissolved chemical concentrations in pore water can exceed the overlying water concentrations as a result of sediment-water disequilibria, which can be very large under certain conditions (51). In many cases, benthic fish and invertebrates do not ventilate a large amount of pore water because of poor oxygen concentrations and low food content. Although pore water ventilation is likely small, it can have a significant effect on the BAF for PCBs that are at large sediment-water column disequilibria. For organisms that have no direct contact with the pore water, m_P is 0. In all cases m_O equals 1 - m_P.

C_{WDP}: Freely dissolved concentrations of PCBs in pore water are estimated from the chemical concentration in the bottom-sediment as (Mackintosh et al. 2004) (77). Bottom sediment-water distribution coefficients (K_{WS}) are expressed based on a theoretically relationship between the organic carbon normalized bottom sediment-water distribution partition coefficient (K_{WSOC}) and K_{OW}:

$$Log K_{SWOC} = 0.826(\pm 0.099).\log K_{OW} + 2.04(\pm 0.69) \qquad (2.3.1.12)$$

(n=13, R^2=0.86, p=4.2x10^{-6})

Then $K_{SWOC} = 10^{(\log Kswoc)} = \dfrac{C_{SOC}}{C_{WD}}$ (2.3.1.13)

And finally $C_{WD} = \dfrac{C_{SOC}}{K_{SWOC}}$ (2.3.1.14)

$$C_{WDP} = C_{SOC} \,.\, \delta_{OCS} / K_{OC} \qquad (2.3.1.15)$$

where C_{WDP} is the freely concentration of the PCBs in the pore water (g/L), C_{SOC} is the PCB concentration in the sediment normalized for organic carbon content (g/kg OC),

δ_{OCS} is the density of the organic carbon in sediment (kg/L) and K_{OC} is the organic carbon-water partition coefficient. Apparently, when suspended matter is incorporated into the bottom sediments of False Creek (77) the concent5rations of very hydrophobic PCBs (e.g. 73/52, 110, 149, 132/153, 187/182, 180 and 194) in organic particulate matter increase. Also hight sorption coefficients imply that freely dissolved chemical concentrations in the water phase can reach very low levels , hence reducing exposure of aquatic organisms via the respiratory route.

*k_D and k_E***:** The rate at which PCBs are absorbed from the diet via the GIT is expressed by the dietary uptake clearance rate constant k_D (kg-food/kg-organism . d) and is a function of the dietary chemical transfer efficiency E_D, the feeding rate G_D (kg/d) and the weight of the organism W_B (kg) (22):

$$k_D = E_D \,.\, G_D / W_B \qquad (2.3.1.16)$$

Empirical E_D observations are highly variable in aquatic invertebrates, ranging between 0 and 100% in amphipods, molluscs, oligochaetes, snails, clams and bivalves (52-57,45,58) and between 0 and 90% in fish (24,59,18,22,60). Explanations have been proposed for the variations in E_D, including differences among the sorption coefficient of chemicals in dietary matrices, the composition of dietary matrices (e.g. organic carbon and soot carbon content), the digestibility of the dietary matrix, metabolic transformation, hindrance in gut membrane permeation, experimental artifacts, differences in gut morphology and variability in food digestion between different species. Because of the large variability in the empirical data it is difficult to develop accurate models for the dietary uptake rate. However, there are some notable trends in the E_D data that can provide guidance in model development. First, several authors have observed a reduction in dietary uptake efficiency with increasing K_{OW} for high K_{OW} chemicals in invertebrates (59,56) and fish (59,18). Secondly, the average dietary chemical transfer efficiency (E_D) for chemicals with a log K_{OW} 4 - 6 is approximately 50% in aquatic invertebrates and fish that were fed continuously. These trends are consistent with a two-phase resistance model for gut-organism exchange which is further documented in Gobas et al. 1988 (18). The following equation based on the lipid-water two- phase resistance model was selected to calculate the dietary absorption efficiencies of the PCB congeners:

$$E_D = (8.5 \,.\, 10^{-8} .\, K_{OW} + 2.0)^{-1} \qquad (2.3.1.17)$$

We applied a general bioenergetic relationship, based on studies in trout byWeininger 1978 (61), for estimating feeding rates in Burrard Inlet fish species and aquatic invertebrate species:

$$G_D = 0.022 \,.\, W_B^{0.85} .\, e^{(0.06 \,.\, T)} \quad (2.3.1.18)$$

Filter feeding species have a distinct mechanism of dietary uptake that was represented as:

$$G_D = G_V \,.\, C_{SS} \,.\, \sigma \qquad (2.3.1.19)$$

where the feeding rate is a product of gill ventilation rate G_V (L/d), the concentration of suspended solids C_{SS} (kg/L) and the scavenging efficiency y of particles σ (%) absorbed from the water.

The rate at which PCBs are eliminated by the egestion of fecal matter is expressed by the fecal elimination rate constant k_E (d^{-1}) (22) and was estimates as:

$$k_E = G_F \,.\, E_D \,.\, K_{GB} / W_B \qquad (2.3.1.20)$$

where G_F (kg-feces/kg-organism . d) is the fecal egestion rate and K_{GB} is the partition coefficient of the chemical between the GIT and the organism. G_F is a function of the feeding rate and the digestibility of the diet, which in turn is a function of the composition of the diet according to:

$$G_F = \{(1-\varepsilon_L) \,.\, v_{LD}) + (1-\varepsilon_N) \,.\, v_{ND} + (1-\varepsilon_W) \,.\, v_{WD}\} \,.\, G_D \qquad (2.3.1.21)$$

where ε_L, ε_N and ε_W are the dietary absorption efficiencies of lipid, NLOM and water, respectively. v_{LD}, v_{ND}, and v_{WD} are the overall lipid, NLOM and water contents of the diet, respectively. In fish, the absorption efficiencies of lipid and NLOM are approximately 90% and 55%, respectively (28,62). Absorption and assimilation efficiencies for invertebrates range from 15 to 96% (55,63,64,65). In general, these efficiencies are a reflection of the dietary preferences (e.g. organic matter quantity and quality) and the digestive physiology of the organism (e.g. feeding rates and gut retention time). Species with low absorption efficiencies (e.g. worms) typically feed on poor quality substrate (e.g. sediment or detritus) but maintain high feeding rates to obtain required nutrients for energy budgets and survival. A value of 75% is used for lipid and non- lipid organic matter absorption efficiencies in aquatic invertebrates.

In zooplankton, assimilation efficiencies for organic matter range from 55 to 85% (66), while carbon and phosphorus assimilation are measured at approximately 85% (67). A value of 72% is assumed for lipid and non-lipid organic matter absorption efficiencies in zooplankton. Water absorption varies between freshwater and marine organisms as a result of their distinct requirements for osmoregulatory balance. Since water is not a significant contributor to the storage capacity of PCBs its value has a negligible impact on the mechanism of bio magnification for these chemicals. The water absorption efficiency for all zooplankton, invertebrate and fish species was assumed to be 55%.

K_{GB}: The partition coefficient of the PCBs between the contents of the GIT and the organism, expresses the change in phase partitioning properties that occur as a result of the digestion of the diet after ingestion. It is estimated as:

$$K_{GB} = (v_{LG} . K_{OW} + v_{NG} . \beta . K_{OW} + v_{WG}) / (v_{LB} . K_{OW} + v_{NB} . \beta . K_{OW} + v_{WB}) \quad (2.3.1.22)$$

where v_{LG}, v_{NG},, and v_{WG} are the lipid (kg lipid/kg digesta ww), NLOM (kg NLOM/kg digesta ww) and water (kg water/kg digesta ww) contents in the gut, respectively. The sum of these fractions (i.e. total digesta) approach 1 and are dependent on the absorption efficiency for each component of the diet as:

$$v_{LG} = (1-\varepsilon_L) . v_{LD} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\} \quad (2.3.1.23)$$

$$v_{NG} = (1-\varepsilon_N) . v_{ND} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\} \quad (2.3.1.24)$$

$$v_{WG} = (1-\varepsilon_W) . v_{WD} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\} \quad (2.3.1.25)$$

Because the bioaccumulation model (equation 2.3.1) is based on the ratio of k_D and k_E, which is $G_D/(G_F . K_{GB})$, the model parameterization errors for the feeding rate G_D (and hence G_F, eq. (2.3.18) and the dietary uptake efficiency E_D tend to cancel out to a significant extent. Hence, the model can be expected to provide reasonable estimates of the BAF and BSAF of PCBs in organisms even if G_D and E_D are poorly characterized. This is an attractive feature of the model since the variability and error in G_D and E_D are often large.

k_G: In many cases, reliable data for the growth rate of organisms are available. Growth rates vary considerably among species and even within species as a function of size, temperature, prey availability and quality and other factors. For the majority of species included in the Burrard Inlet model, reliable growth rate data are not available. We therefore used the following generalized growth equations, based on (68), to provide a reasonable approximation for the growth rate constant k_G (d-1) of the aquatic species in the Inlet. For invertebrates, we used: representative for temperatures around 10ºC, while for fish species we used

$k_G = 0.00035 \;.\; W_B^{-0.2}$ (2.3.1.26)

$k_G = 0.0007 \;.\; W_B^{-0.2}$ (2.3.1.27)

based on an average water temperatures of approximately 15oC.

k_M: The rate at which a parent compound can be eliminated via metabolic transformation is represented by the metabolic transformation rate constant k_M (d^{-1}). This process is dependent on the PCB congener and the species in question. The majority of PCB congeners are very poorly metabolized by aquatic micro- and macrophytes, invertebrates and fish. In this study, we have therefore assumed that for the PCB congeners considered in this model, k_M is negligible in these species. Table 2.1 provides a summary of other model variables.

Table 2.4.1: A summary of recently mentioned model variables, units and their definitions

Definition	Parameter	Units
Chemical concentration in biota	C_B	g/kg
Chemical concentration in diet	C_D	g/kg
Chemical concentration in pore water	C_{PW}	g/L
Bioavailable solute fraction	ϕ	Unitless
Gill uptake rate constant	k_1	d
Dietary uptake rate constant	Kd	d
Gill elimination, fecal egestion, growth dilution, and metabolic transformation rate constants, respectively	k_2, k_E, k_G, k_M	d-1
Biota-water partition coefficient	K_{BW}	Unitless
Phytoplankton-water partition coefficient	K_{PW}	Unitless
Gut-biota partition coefficient	K_{GB}	Unitless
Gill ventilation rate	G_V	L/d
Feeding and fecal egestion rates, respectively	G_D, G_F	kg/d
Chemical transfer efficiency for gill and diet, respectively	E_W, E_D	%
Non-lipid organic matter – octanol proportionality constant	β	Unitless
Lipid fraction in diet (D) and gut (G)	v_{LD}, v_{LG}	kg/kg
Non-lipid organic matter fraction in diet (D) and gut (G)	v_{ND}, v_{NG}	kg/kg
Water fraction in biota (B), diet (D), gut (G) and phytoplankton (P)	v_{WB}, v_{WD}, v_{WG}, v_{WP}	kg/kg
Dietary absorption efficiency of lipid	ε_L	%
Dietary absorption efficiency of non-lipid organic matter	ε_N	%
Dietary absorption efficiency of water	ε_W	%
Particle scavenging efficiency (default = 100)	σ	%
Density of organic carbon in sediment (0.9)	δ_{OCS}	kg/L
Organic carbon-water partition coefficient	K_{OC}	Unitless
Dissolved oxygen concentration	C_{OX}	O2/L

2.3.2. Detailed Bioaccumulation Model Description for Harbor Seals

Figure 2.3.2: Conceptual diagram of the major uptake and elimination processes of PCBs in Harbor seals

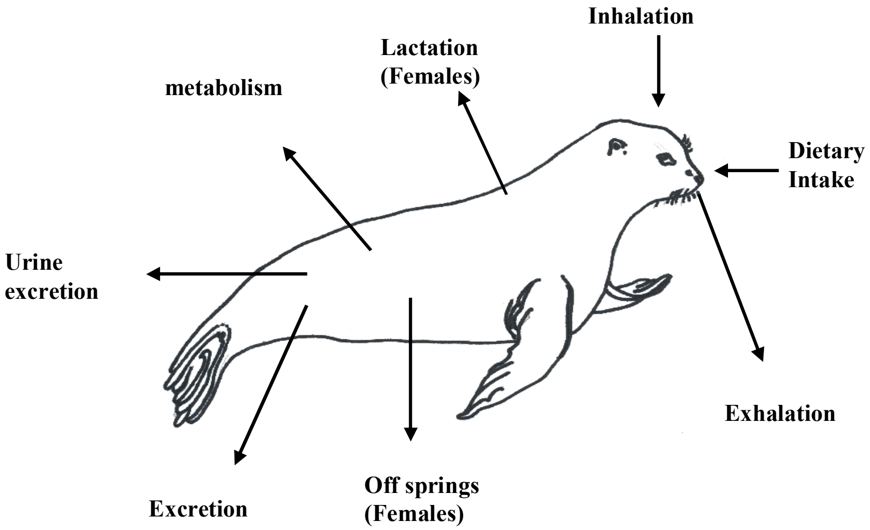


Figure 2.3 provides a conceptual overview of major routes of PCB uptake and elimination in harbor seals. PCB uptake is due to dietary uptake and inhalation of air. Dietary uptake is expected to be the most important source of PCBs in the Harbor seal. Elimination of PCBs from the seals is due to several processes. They include elimination of PCBs in exhaled air, PCB excreted in fecal matter, and elimination in urine. In addition, there is evidence that certain PCB congeners can be metabolized in harbor seals (69,70). In addition, female seals can transfer PCBs into their off spring by giving birth to pups and by lactation. Molting and growth periods can also affect PCB concentrations. Several of these uptake and elimination processes occur at particular times of the year and are non-continuous. Harbor seals are known to go through fasting periods and molt at particular times of the year and female animals give birth and nurse their pups for a

period of approximately 4 weeks. To represent these processes in a relatively simple model, it is important to consider some key characteristics of PCBs. First, PCBs are lipophilic chemicals that build up high concentrations in the lipids of organisms. In seals, which contain large amounts of fat in their blubber (i.e. the lipid content of healthy harbor seals in the Inlet varies between 36 to 50%). This means that the great majority of PCBs are found in the lipid tissues. Secondly, PCBs show a natural tendency to establish a chemical equilibrium. Within an organism like a seal this means that PCBs distribute themselves between various parts of the organism in a way that the concentrations in lipids of any part of the organism is approximately equal. In other words, the lipid normalized concentration is approximately the same. This behavior of PCBs is of particular relevance to transfer PCBs from female seals into their pups. If it can be assumed that PCBs in mother and pup achieve an internal equilibrium, then the lipid normalized concentration in female seals will not change upon parturition. In essence, the reduction in the mass of PCBs in the mother upon parturition (due to transfer to the pup) is associated with a proportional drop in lipid mass, causing the lipid normalized concentration to remain approximately the same. The same principle is at work during lactation. Assuming that PCB is equally distributed among fats in the nursing female, transfer of PCB in milk does not cause a change in concentration as proportional declines in PCB mass and lipid mass occur during lactation.

The same philosophy applies to molting. While production of off-spring, lactation and molting are not expected to have an immediate effect on the lipid normalized concentration in the seal, they do have a long-term concentration effect in seals because of the growth dilution effect that takes place during fetus development, milk production and skin formation. Seals have to grow body mass to accommodate these processes in addition to any net (year-to-year) increases in body weight. This process of growth takes place more gradually over the seal's life cycle and can be represented as a continuous process. Of course, the growth induced decline of the PCB concentration in seals is compensated by intake of PCB with the diet that makes growth possible. The balance between uptake and elimination is represented by the following mass balance equation:

$$dC_{HS,l}/dt = k_A C_{AG} + k_D.\Sigma(P_i . C_{D,i}) - (k_O + k_E + k_U + k_G + k_P + k_L + k_M) . C_{HS,l} \quad (2.3.2.1)$$

where $C_{HS,l}$ is the lipid normalized concentration of the PCB congener in the seal and $dC_{HS,l}/dt$ is the net change in lipid normalized concentration over time t (d). C_{AG} is the gaseous aerial concentration ($g \cdot L^{-1}$). k_A is the inhalation rate constant (L/kg lipid $\cdot d^{-1}$). k_D is the clearance rate constant (kg/kg lipid.d^{-1}) for PCB uptake via ingestion of food and water. Pi is the fraction of the diet consisting of prey item i and $C_{D,i}$ is the concentration of the PCB congener (g/kg) in prey item i. k_O is the rate constant (d^{-1}) for exhalation of PCB via the lungs. k_E is the rate constant (d^{-1}) for the elimination of the PCB congener via excretion into egested feces. k_U is the rate constant for urinary excretion of PCBs. k_G is the rate constant for growth dilution. This term accounts for year-to-year increases in the net growth of the animals. k_P is the rate constant for transfer of PCBs into the pups. It represents the increase in lipid mass (equivalent to the post-parturition lipid mass of the pup) over the duration of the gestation period. k_L is the rate constant for transfer of PCBs to the pups as a result of lactation. It portrays the growth of lipid mass of the female seals over the year that is transferred to the pup during lactation. k_G, k_P and k_L are expressed as fixed annual proportional increases in body lipid weight, i.e. $dW_{S,l}/(W_{S,l}.dt)$ where $W_{S,l}$ is the weight of the lipids in the seal, and has units of d^{-1}. k_M is the rate constant for metabolic transformation of the PCB congener. At steady-state, equation 2.29 can be simplified to:

$$C_{HS,l} = (k_A C_{AG} + k_D . \Sigma(Pi . C_D,i)) / (k_O + k_E + k_U + k_G + k_P + k_L + k_M) \qquad (2.3.2.2)$$

A whole organisms wet weight based concentration in the seal C_{HS} can be calculated from the lipid normalized concentration as:

$$C_{HS} = L_{HS} . C_{S,l} \qquad (2.3.2.3)$$

Because the whole organism lipid content undergoes significant changes throughout the year, the wet weight concentration in the seal can be expected to undergo changes of similar magnitude. These can be represented in the model by varying L_{HS}. Because the lipid content in seals is high, the contribution of non-lipid organic matter as a storage compartment for PCBs is relatively insignificant.

The ratio of the PCB concentrations in the seal C_{HS} and the concentration in the sediment C_S is the biota-sediment accumulation factor (BSAF in units of kg dry sediment/kg wet weight):

$$BSAF = C_{HS}/C_S \qquad (2.3.2.4)$$

The BSAF provides a simple means to anticipate the concentrations of PCBs in seals from the PCB concentration in the sediments of the Inlet.

The various submodels for calculating k_D, k_A, k_O, k_E, k_U, k_G, k_P and k_L in the seal model are described below.

***k_D and k_E*:** The dietary uptake clearance rate constant k_D (kg-food/kg- lipid . d) for PCBs was estimated as a function of the dietary chemical transfer efficiency E_D, and reported measurements of the feeding rate G_D (kg/d) and the lipid mass of the organism $W_{S,l}$ (kg):

$$k_D = E_D . G_D / W_{S,l} \qquad (2.3.2.5)$$

The following equation based on the lipid-water two-phase resistance model was used to calculate the dietary absorption efficiencies of the PCB congeners in male and female seals:

$$E_D = (1.0 . 10^{-9} . K_{OW} + 1.025)^{-1} \qquad (2.3.2.6)$$

The rate constant for fecal excretion of PCBs in seals k_E (d^{-1}) was estimated as:

$$k_E = G_F . E_D . K_{GS,l} / W_{S,l} \qquad (2.3.2.7)$$

where G_F (kg-feces/kg-organism . d) is the fecal egestion rate and $K_{GS,l}$ is the partition coefficient of the chemical between the GIT and seal lipids. G_F is a function of the feeding rate and the digestibility of the diet, which in turn is a function of the composition of the diet according to:

$$G_F = \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\} . G_D \qquad (2.3.2.8)$$

where ε_L, ε_N and ε_W are the dietary absorption efficiencies of lipid, NLOM and water, respectively. v_{LD}, v_{ND}, and v_{WD} are the overall lipid, NLOM and water contents of the diet, respectively. In seals, the absorption efficiencies of lipid and NLOM are assumed to be approximately 98% and 75%, respectively (71.72).

The partition coefficient $K_{GS,l}$ of the PCBs between the contents of the GIT and the seal's body lipids is estimated as:

$$K_{GB} = (v_{LG} . K_{OW} + v_{NG} . \beta . K_{OW} + v_{WG}) / K_{OW} \qquad (2.3.2.9)$$

where v_{LG}, v_{NG},, and v_{WG} are the lipid (kg lipid/kg digesta ww), NLOM (kg NLOM/kg digesta ww) and water (kg water/kg digesta ww) contents in the gut of the seal respectively. The sum of these fractions (i.e. total digesta) approach 1 and are dependent on the absorption efficiency for each component of the diet as:

$$v_{LG} = (1-\varepsilon_L) . v_{LD} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\} \qquad (2.3.2.10)$$

$v_{NG} = (1-\varepsilon_N) . v_{ND} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\}$ (2.3.2.11)

$v_{WG} = (1-\varepsilon_W) . v_{WD} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\}$ (2.3.2.12)

k_A and k_O: The absorption rate of PCBs from inhalation of air is expressed by the inhalation clearance rate constant k_A (L/kg lipid . d):

$k_A = E_A . G_A / W_{S,l}$ (2.3.2.13)

The rate constant for PCB elimination via exhalation k_O (d^{-1}) is related to k_A as inhalation and exhalation involve the same processes of lung ventilation and pulmonary membrane permeation:

$k_O = k_A / K_{S,lA}$ (2.3.2.14)

where $K_{S,lA}$ (L/kg lipid) is the partition coefficient of the PCB congener between the lipid biomass of the seal and the air, which was estimated from the octanol-air partition coefficient K_{OA} and the density of lipids δ_L (kg/L) as:

$K_{S,lA} = k_A / k_O = K_{OA} . \delta_L^{-1}$ (2.3.2.15)

The urinary excretion rate constant k_U (d^{-1}) is calculated as:

$k_U = G_U / (W_{S,l} . K_{OW} . \delta_L^{-1})$ (2.3.2.16) where G_U is the urinary excretion rate (L/d) and K_{OW} is the octanol-water partition coefficient.

k_G, k_P, k_L: In this model, the "quasi" elimination rate constants for growth dilution of the PCB concentration in male and female Harbor seals and elimination of PCB in off- spring and milk in female Harbor seals, represent the reduction in the PCB concentration in the lipid biomass of the seals that is achieved due to the increase in lipid biomass as a result of growth, off spring production and lactation. Each of these rate constants is represented by the proportional increase in the lipid biomass per unit of time according to:

$$dW_{HS,l} / (W_{HS,l} \cdot dt) \qquad (2.3.2.17)$$

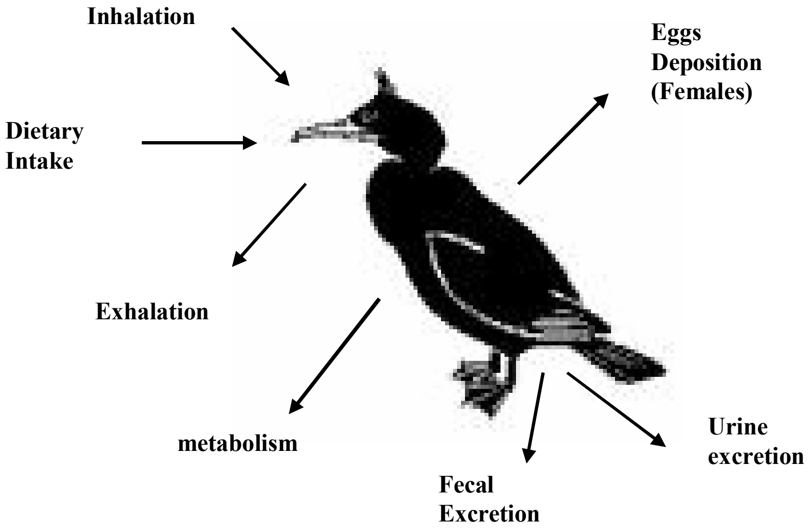
When calculating k_G, $dW_{HS,l}$ represents the increase in lipid mass achieved over a year. When assessing k_P, $dW_{HS,l}$ describes the mass of lipid of the pup at the time of birth. This lipid biomass is generated over the duration of the gestation period. To estimate k_L, $dW_{HS,l}$ describes the mass of lipid transferred to the pup in the milk over the length of the lactation period. To make a relatively simple steady-state solution of the model possible, we calculated the increase in the lipid biomass of the female seals as the sum of the lipid masses generated for growth, off-spring production and lactation and expressed it as a fraction of the animal's lipid biomass generated per unit of time.

k_M: Metabolic transformation rates of individual PCB congeners were derived from the studies of Boon and colleges (69,70,73). This general method estimates congener specific metabolic transformation rates relative to the non- metabolizable PCB congener 153 by assuming that the relative difference between individual congeners and PCB 153 is the result of metabolic transformation. This was done utilizing the empirical San Francisco Bay Harbor Seal data such that k_M was calibrated in the model to agree with the observed relative ratios of individual congeners to PCB 153 used by Arnot 2004 (30). The estimated metabolic transformation rate for each PCB congener as well as the congener specific-PCB 153 ratios derived in the model in comparison to the congener specific-PCB 153 ratios derived from the empirical data for both male and female harbor seals. The general strategy was to provide slightly conservative estimates of model ratios in comparison to the observed ratios to account for the fact that the model slightly underestimates PCB congener 153 while acknowledging that empirical PCB 153 measurements also include the co-elution of PCB congener 132.

2.3.3. Detailed Bioaccumulation Model Description: Cormorants and Terns

A conceptual overview of the major routes of PCB uptake and elimination in cormorants and terms is presented in Figure 2.3.3. PCB uptake is due to dietary uptake and inhalation of air. Dietary uptake is believed to be the most important process for uptake of PCBs in these bird species. The mechanisms by which these bird species eliminate PCBs include the elimination of PCBs in exhaled air, PCB excreted in fecal matter, elimination in urine and metabolic transformation. During periods of growth, PCB concentrations can be affected by growth dilution, which is not a real elimination process but has the potential effect of reducing the PCB body burden in the animals. Female birds can also transfer PCBs into eggs.

Figure 2.3.3: Conceptual diagram of the major uptake and elimination processes of PCBs in birds



In the model, the effect of transferring PCBs to eggs on the maternal PCB body burden is assumed to be similar to that described above in the section on the bioaccumulation model for harbor seals. Again, we make the assumption that PCBs are well distributed among the lipid tissues in the bird. This assumption implies that the reduction in the mass of PCBs in the mother as a result of transfer of PCBs in the eggs is associated with a proportional drop in lipid mass, causing the lipid normalized concentration to remain approximately the same. The wet weight based concentration in the female bird may undergo a change as a result of laying eggs, due to the change in body composition (i.e. predominantly due to changes in lipid content). The main impact of producing eggs on the maternal PCB body burden is the result of the increase in body mass required to produce the eggs. Any growth induced decline of the PCB concentration in the female birds is compensated by intake of PCB with the diet that makes growth possible. The balance between uptake and elimination rates is represented by the following mass balance equation:

$$dC_{C,l}/dt = k_A C_{AG} + k_D.\Sigma(Pi\ .\ C_D,i) - (k_O + k_E + k_G + k_C + k_M)\ .\ C_{C,l} \qquad (2.3.3.1)$$

where $C_{C,l}$ is the lipid normalized concentration of the PCB congener in either the cormorant or the tern; and $dC_{C,l}/dt$ is the net change in lipid normalized concentration over time t (d). C_{AG} is the gaseous aerial concentration ($g \cdot L^{-1}$). k_A is the inhalation rate constant (L/kg lipid·d-1). k_D is the clearance rate constant (kg/kg lipid.d-1) for PCB uptake via ingestion of food and water. P_i is the fraction of the diet consisting of prey item i and C_D,i is the concentration of the PCB congener (g/kg) in prey item i. k_O is the rate constant (d^{-1}) for exhalation of PCB via the lungs of the birds. k_E is the rate constant (d^{-1}) for the elimination of the PCB congener via excretion into egested feces. k_G is the rate constant for growth dilution due to year-to-year increases in the net body mass of the birds. k_C is the rate constant for transfer of PCBs into eggs in female birds. It represents the increase in lipid mass due to egg production. k_M is the rate constant for metabolic transformation of the PCB congener in the bird.

At steady-state, equation 2.3.3.1 can be simplified to:

$$C_{C,l} = (k_A C_{AG} + k_D\ .\ \Sigma(Pi\ .\ C_D,i))\ /\ (k_O + k_E + k_G + k_C + k_M) \qquad (2.3.3.2)$$

The whole organisms wet weight based concentration can be calculated from the lipid normalized concentration as;

$$C_C = L_C \,.\, C_{C,l} \qquad (2.3.3.3)$$

Where L_C is the lipid content of the cormorants or the terns. Since L_C can undergo significant changes throughout the year, the wet weight concentration in the seal can be expected to vary as well. This can be represented in the model by varying L_C. The ratio of the PCB concentrations in the cormorants or the terms and the concentration in the sediment C_S is the biota-sediment accumulation factor ($BSAF_C$):

$$BSAFC = C_C/C_S \qquad (2.3.3.4)$$

The BSAF provides a simple means to anticipate the concentrations of PCBs in the cormorants or the terns from the PCB concentration in the sediments of the Bay.
The various submodels for calculating k_D, k_A, k_O, k_E, k_C and k_G in the models for the bird species are described below.

***k_D and k_E*:** The dietary uptake clearance rate constant k_D (kg-food/kg- lipid . d) for PCBs was estimated as a function of the dietary chemical transfer efficiency E_D, and reported measurements of the feeding rate G_D (kg/d) and the lipid mass of the organism $W_{C,l}$ (kg):

$$k_D = E_D \,.\, G_D \,/\, W_{C,l} \qquad (2.3.3.5)$$

The following equation based on the lipid-water two-phase resistance model was used to calculate the dietary absorption efficiencies of the PCB congeners in male and female birds:

$$E_D = (3.0 \cdot 10^{-9} \cdot K_{OW} + 1.04)^{-1} \qquad (2.3.3.6)$$

The rate constant for fecal excretion of PCBs in cormorants and terns k_E (d^{-1}) was estimated as:

$$k_E = G_F \cdot E_D \cdot K_{GC,l} / W_{C,l} \qquad (2.3.3.7)$$

where G_F (kg-feces/kg-organism . d) is the fecal egestion rate and $K_{GC,l}$ is the partition coefficient of the chemical between the GIT and the lipids of the birds. G_F is a function of the feeding rate and the digestibility of the diet, which in turn is a function of the composition of the diet according to:

$$G_F = \{(1-\varepsilon_L) \cdot v_{LD} + (1-\varepsilon_N) \cdot v_{ND} + (1-\varepsilon_W) \cdot v_{WD}\} \cdot G_D \qquad (2.3.3.8)$$

where ε_L, ε_N and ε_W are the dietary absorption efficiencies of lipid, NLOM and water, respectively. v_{LD}, v_{ND}, and v_{WD} are the overall lipid, NLOM and water contents of the diet, respectively.

The partition coefficient $K_{GC,l}$ of the PCBs between the contents of the GIT and the body lipids of the birds is estimated as:

$K_{GB} = (v_{LG} . K_{OW} + v_{NG} . \beta . K_{OW} + v_{WG}) / K_{OW}$ (2.3.3.9)

where v_{LG}, v_{NG},, and v_{WG} are the lipid (kg lipid/kg digesta ww), NLOM (kg NLOM/kg digesta ww) and water (kg water/kg digesta ww) contents in the gut of the birds respectively. The sum of these fractions (i.e. total digesta) approach 1 and are dependent on the absorption efficiency for each component of the diet as:

$v_{LG} = (1-\varepsilon_L) . v_{LD} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\}$ (2.3.3.10)

$v_{NG} = (1-\varepsilon_N) . v_{ND} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\}$ (2.3.3.11)

$v_{WG} = (1-\varepsilon_W) . v_{WD} / \{(1-\varepsilon_L) . v_{LD} + (1-\varepsilon_N) . v_{ND} + (1-\varepsilon_W) . v_{WD}\}$ (2.3.3.12)

k_A and k_O: The absorption rate of PCBs from inhalation of air is expressed by the inhalation clearance rate constant k_A (L/kg lipid . d):

$k_A = E_A . G_A / W_{C,l}$ (2.3.3.13)

The rate constant for PCB elimination via exhalation k_O (d^{-1}) is related to k_A as inhalation and exhalation involve the same processes of lung ventilation and membrane permeation:

$k_O = k_A / K_{C,lA}$ (2.3.3.14)

where $K_{C,lA}$ (L/kg lipid) is the partition coefficient of the PCB congener between the lipid biomass of the birds and the air, which was estimated from the octanol-air partition coefficient, i.e.:

$K_{C,lA} = k_A / k_O = K_{OA} . \delta_L^{-1}$ (2.3.3.15)

KU: The urinary excretion rate constant k_U (d^{-1}) is calculated as:

$k_U = G_U / (W_{C,l} . K_{OW} . \delta_L^{-1})$ (2.3.3.16)

where G_U is the urinary excretion rate (L/d) and K_{OW} is the octanol-water partition coefficient.

kG, *kC*: The rate constants for growth dilution of the PCB concentration in male and female birds and deposition of PCB in eggs by female birds, are calculated from the reduction in the PCB concentration in the lipid biomass of the bird that can be expected to occur as the lipid biomass increases due to growth and egg production in the female bird. Each of these rate constants is represented by the proportional increase in the lipid biomass per unit of time according to:

$dW_{HS,l} /(W_{C,l} . dt)$ (2.3.3.17)

In equation (2.3.3.17), $dW_{C,l}$ represents the increase in lipid mass achieved over a year due to growth in the bird when calculating k_G. It represents the mass of lipid transferred into the egg when calculating k_C. This lipid biomass is generated over the duration of the gestation period. To keep the model simple, we calculated the increase in the lipid biomass of the female birds as the sum of the lipid masses generated for growth and egg production and expressed it as a fraction of the animal's lipid biomass generated per unit of time.

k_M: Metabolic transformation rates of individual PCB congeners in double–crested cormorants were derived from empirical cormorant egg data using a similar method as described previously for seals (30). These estimated metabolic rates were generally comparable to metabolic transformation rates derived from controlled laboratory studies in American kestrels (*Falco sparverius*) (74). The data estimated metabolic transformation rates for each PCB congener as well as the congener specific-PCB 153 ratios derived in the model predictions for cormorant eggs in comparison to the congener specific-PCB 153 ratios derived from the empirical data for cormorant eggs..

2.4. Model Parameterization

2.4.1. General

The model parameterization is the phase in the model development where values for the model's state variables are selected to ensure that the model is representative of conditions in the Inlet. This section lists the values for the various state variables that were chosen. These values are also documented in the Excel model that accompanies this research project. In the parameterization we have attempted to make use of information reported in the scientific literature. For the great majority of the model input variables sufficient information is available to select appropriate values. However, we also encountered instances where required model input variables needed to be estimated because of a lack of appropriate data in the literature. In these cases we have documented the rationale of our selection.

2.4.2. Physical Chemical Properties of PCBs

The octanol-water (K_{OW}) and octanol-air partition (K_{OA}) coefficients of the PCB congeners that were used in the model calculations are summarized in Table A-6 and also tabulated in the worksheet entitled “PCBs” in the Burrard Inlet Food Web Model. This Table lists the freshwater-based octanol-water partition coefficient at the mean ambient water temperature of the Inlet of 14.9 ºC. These were used to derive the saltwater- based octanol-water partition coefficient following Xie et al. 1997 (75). The saltwater-based K_{OW} values were used in the calculations of the distribution of the PCBs between fish and water of the Inlet. The model also uses the freshwater-based octanol-water partition coefficient at 37.5 ºC to represent partitioning between lipids and aqueous media (e.g. urine) in warm-blooded mammals and birds. Table A-6 also includes the data used to represent the octanol-air partition coefficients at 14.9 ºC and 37.5 ºC. The latter values are used to represent the exchange of PCBs between the animal and the air via the lungs.

2.4.3. Biological Variables

The species that are represented in the Burrard Inlet Food Web Model are listed in **Table A-**7a and Table A-7b**.** They include a total of 23 species, several age classes, male and female animals as well as their off-spring. The feeding interactions of selected resident pelagic and benthic species has been based in the current knowledge of the southwestern British Columbia marine environment. The food web, summarized in Figure 2.4.3.1, integrates research that has mainly been reported on individual species, thus, reproducing a broader, ecosystem-wide picture of the trophic interactions. Additional information on the distribution, habitat, life history and size of the fishery has been collected from Appendix B of Mackintosh thesis (78) and fishbase.org. The trophodynamic interactions and life history information of selected marine species for the Burrard inlet food web have been carefully considered during the model development and food web parameterization stages. Nevertheless, with the purpose of simplifying the model, it has been assumed that all species of the food web are 100% resident species. Even though several species (Spiny Dogfish, English Sole, Pacific Staghorn Sculpin and Pacific Hearring) have parts of their stocks that are very mobile and susceptible to seasonal changes and water temperature, this assumption makes the model very versatile and easily applicable to similar ecosystems. During the modeling development, each species, trophic position and trophodynamic interaction have been carefully represented by groups of previously tested equations describing the complex mechanics of uptake and elimination of chemicals in aquatic organisms (see section 2.2.1 - Model Development). Therefore, from a model's engineering point of view, it is valid to represent each species by a "black box" of equations that suit the purpose of fatefully representing a living organism and its interactions in the local food web.

A detailed account of the values chosen for each of the model variables is presented in **Table A-5.** It also includes the metabolic transformation rate constants used in the model. **Table A-8** list the feeding preferences of the various species represented in the model.

Figure 2.4.3.1: Summary of Trophic Interactions Between Selected Marine Species in the Burrard Inlet Food Web Model

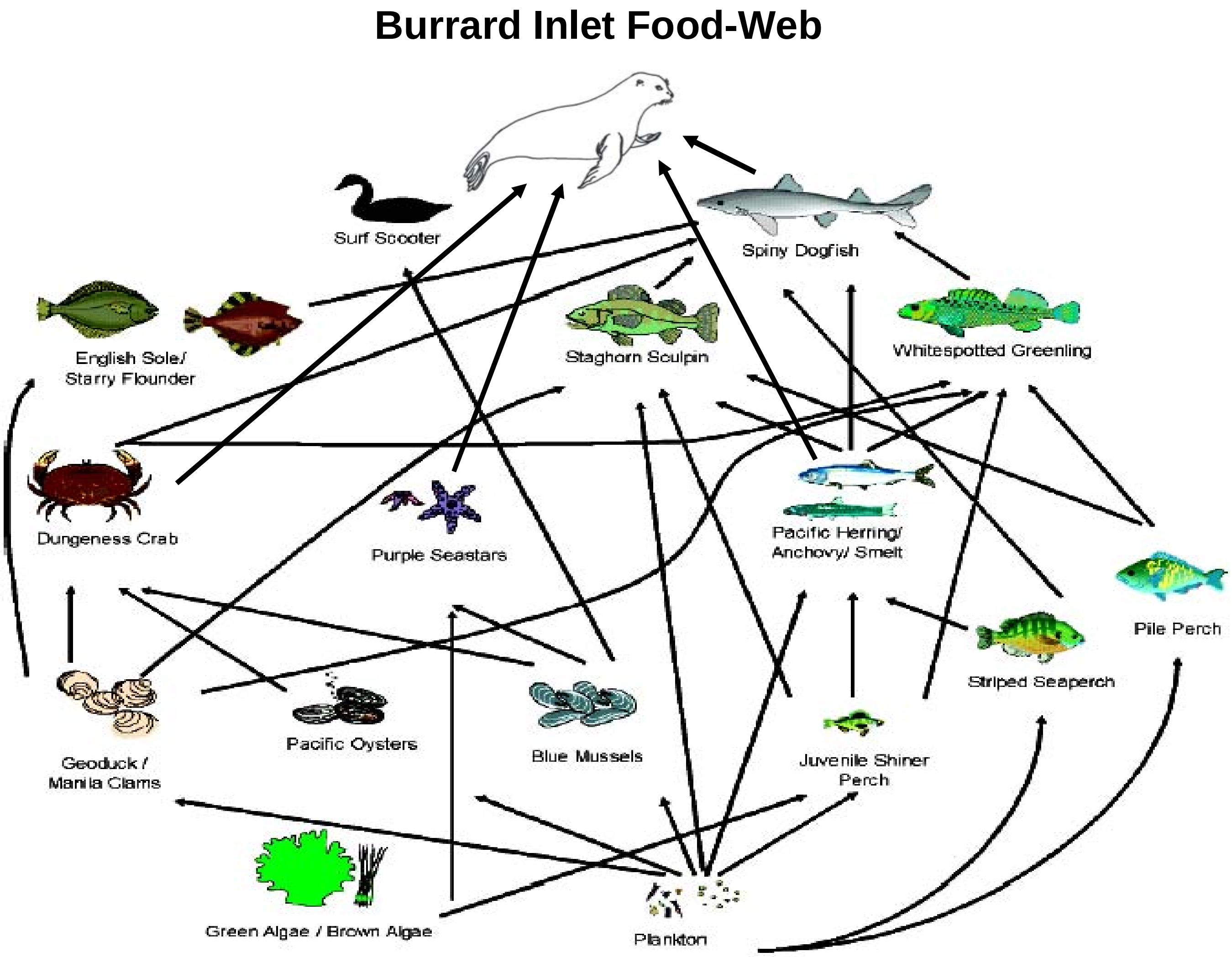


Figure 2.4.3.2: Correlation between dietary model-based trophic position and $\delta^{15}N$ isotope ratios (‰) for species in the marine food web. The line represents a linear regression of data for green macroalgae, plankton, manila clams, pacific oyster, blue mussels, geoduck clams, purple seastar, Dungeness crab, striped seaperch, pacific herring, pacific staghorn sculpin, English sole. White spotted greenling, spiny dogfish, surf scoters.

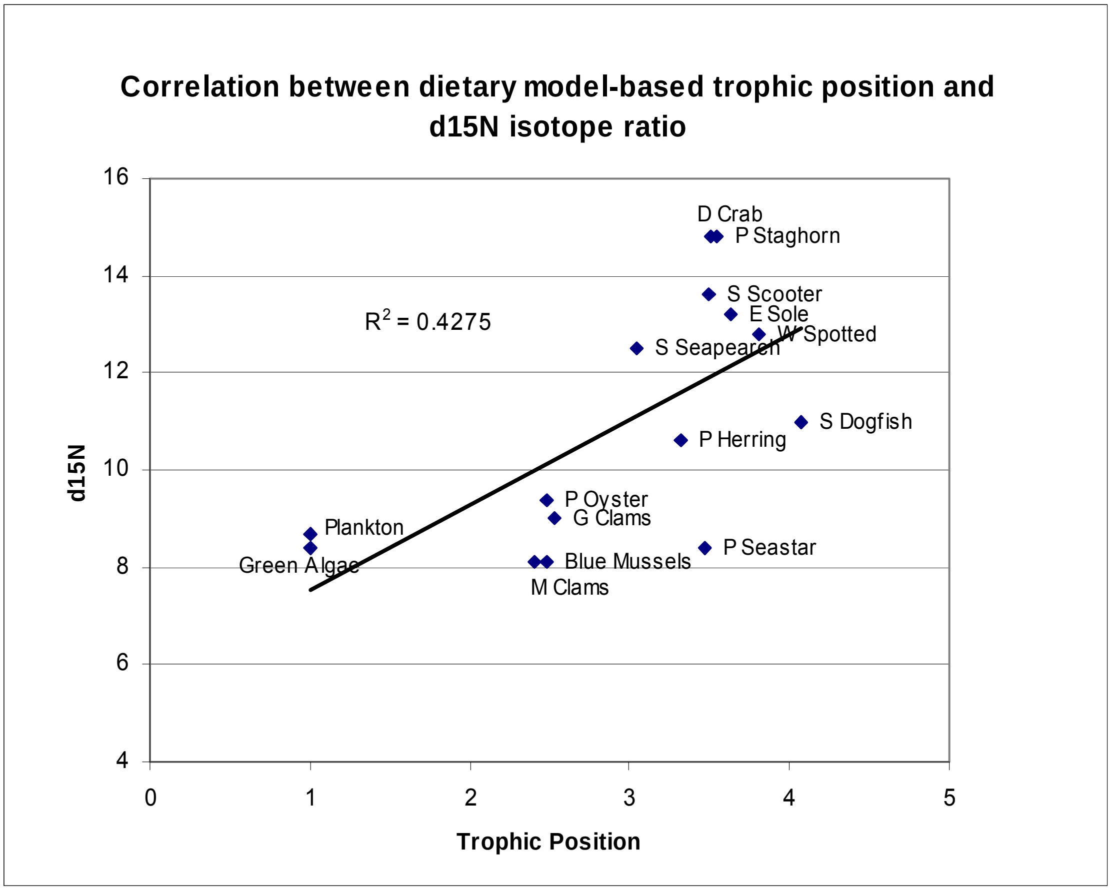


Figure 2.4.3.2 illustrate a strong proportional relationship between trophic position and **δ15N** isotopic ratios. The isotropic enrichment of **$\delta^{15}N$** and **$\delta^{13}N$** ratios is usually consistent with the 3-4 ‰ per trophic level observed in some other food webs (77). Figure 2.4.3.2 also show that the local food web representation of the Burrard Inlet ecosystem used by the model closely reproduce the trophodynamic interactions of a real food web.

3. METHODS

3.1. General Modeling Strategy

The simulation model provides a simple relationship between the sediment concentrations of certain contaminants (e.g. PCBs) and the internal concentrations of contaminants in the tissues of a range of organisms including harbor seals, great blue herons, herring gulls and other key biological receptors in the area. Internal contaminant concentrations are interpreted in terms of their toxic effects using the internal body burden and related approaches. For example, in PCBs, dioxins, furans and other contaminants with dioxin-like toxicity, tissue concentrations can be interpreted using the Toxic Effects-Quantity (TEQ) approach in terms of a dioxin equivalent concentration (79). This concentration can be compared to various threshold values to assess whether the tissue concentration can be expected to trigger the effect. Currently, a number of these threshold concentration levels have been proposed for harbor seals (e.g. Ross et al. 1996, Ross et al 2001, Mos et al. 2006)(79, 80,81,82)), bird and fish species (e.g. Cooke et al. 2003, Giesy et al. 2002)(83, 84). Determining sediment target levels that protect organisms from high trophic levels, involves the application of the sediment-tissue concentration relationship to the threshold effects levels. Essentially, from the internal concentration of contaminant found in fish, back-calculating the sediment concentration that can be expected not to cause tissue concentration in excess of the threshold concentrations. These target concentrations provide ecologically relevant target levels to guide pollution control and/or remediation efforts. It is also possible to take this approach one step further and identify source loadings of contaminants that are consistent with the sediment target concentration. The latter may be important for pharmaceuticals, and newly emerging POPs, which are not easily removed after primary (and sometimes conventional secondary) treatments.

The PCB food web bioaccumulation model for Burrard Inlet consists of two parts or modules: The abiotic module and the biotic module. The abiotic module (also refered as "the fate model" includes all the information (i.e. the model's internal and external variables, functional relationships and model performance evaluation data) to calculate the "fate" of a chemical into the ecosystem, or in other words, how a chemical discharge partition into the different media or compartments in the environment (water, sediment, air and a virtual fish based on a two-compartment pharmacokinetic model).

The biotic module, usually called "food-web model", includes all the necessary data to calculate the Biota Sediment Accumulation Factor (BSAF) for individual PCB congeners and also for ΣPCBs. The BSAF is the main output of the model and represents the relationship between the PCB concentrations in biota (C_B) and that in the sediment (C_S) that is predicted by the model:

$$\mathrm{BSAF} = C_B/C_S \qquad (3.1.1)$$

Where CB has units of g PCB/kg wet weight organism, C_S has units of g PCB/kg dry sediment and the BSAF has units of kg dry sediment/kg wet weight organism. A BSAF is calculated for each PCB congener in every species included in the model, including the seal and bird species. The BSAF is a quick and simple way to relate sediment and biota concentrations. The BSAF is further represented as a statistical distribution of values rather than a single point estimate to capture seasonal variations in the conditions of the Inlet. Once the model is run, the BSAF is used for two purposes. In a “forwards” calculation, the BSAF is used to assess the PCB concentration in fish and wildlife in the Inlet (C_B) based on measured or anticipated PCB concentrations in the sediment (C_S):

$$C_B = BSAF \,.\, C_S \qquad (3.1.2)$$

In a “backwards” calculation, the PCB concentration in the sediment (C_S) is calculated based on a PCB concentration in a fish or wildlife species (C_B). This calculation is designed to determine target PCB concentrations in sediments that meet ecological and/or human health criteria that are expressed in terms of a PCB concentration CB. This calculation is:

$$C_S = C_B / BSAF \qquad (3.1.3)$$

To derive the BSAF, the model uses a number of chemical, biological and environmental variables (e.g. the octanol- water partition coefficient, lipid content, weight, temperature), which are referred to as the model’s state variables. The food web model is a useful management tool to help to predict the fate of contaminant discharges into the inlet by using PCB concentration data in sediments (forward calculation) or in Biota (Backwards calculation). For example, in the forward calculation, actual PCB concentrations can be used to make predictions of the PCB concentration in fish and wildlife in the Inlet that are expected to occur as a result of the PCB concentrations in the sediments. In this model application, the PCB concentration in the sediment is referred to as an “external variable” (an external variable is also sometimes referred to as a forcing function). In the backward calculation, the PCB concentration in fish or wildlife species is the external variable.

3.2. Sediment Sample Collection:

The sediment samples were collected in the summer of 2004. Surface sediment samples were collected in 250 ml pre-cleaned glass jars from 18 different locations across Burrard Inlet using a petit ponar grab sampler. With the purpose of attaining a more thorough analysis, we divided the entire site into six different compartments as shown in the **figures 3.2.1**. We assigned three sample collection points to each compartment in the Inlet and sediment samples were sent to the lab (AXYS) for full PCB congener analysis composition.

Figure 3.2.1: Sediment sample collection areas (from left to right: Outer Harbour, Inner Harbor, Central Harbor, Port Moody, Indian Arn and Flase Creek).

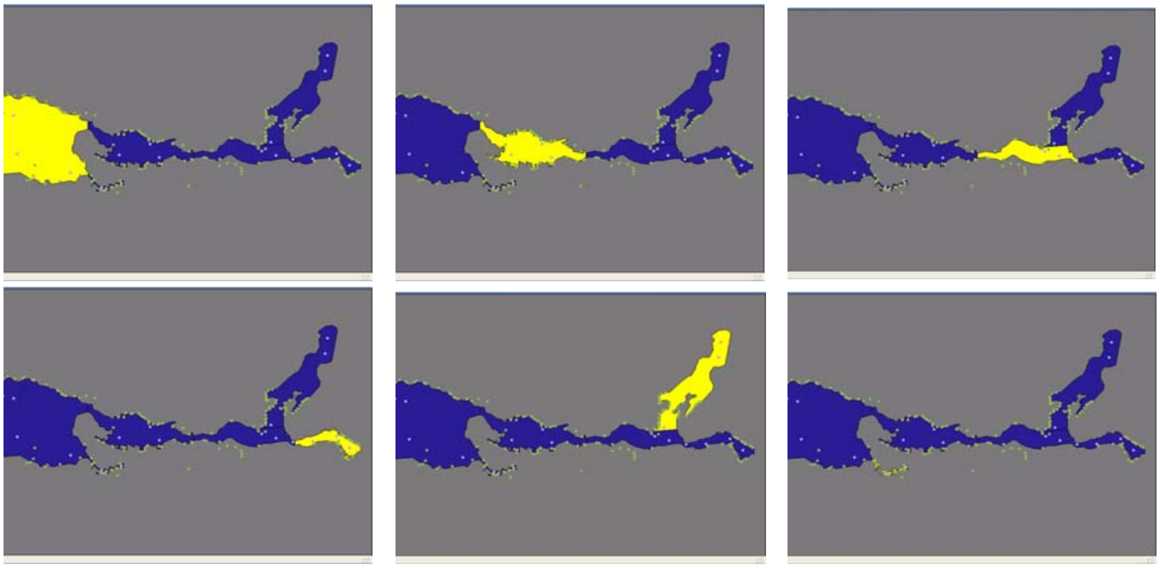
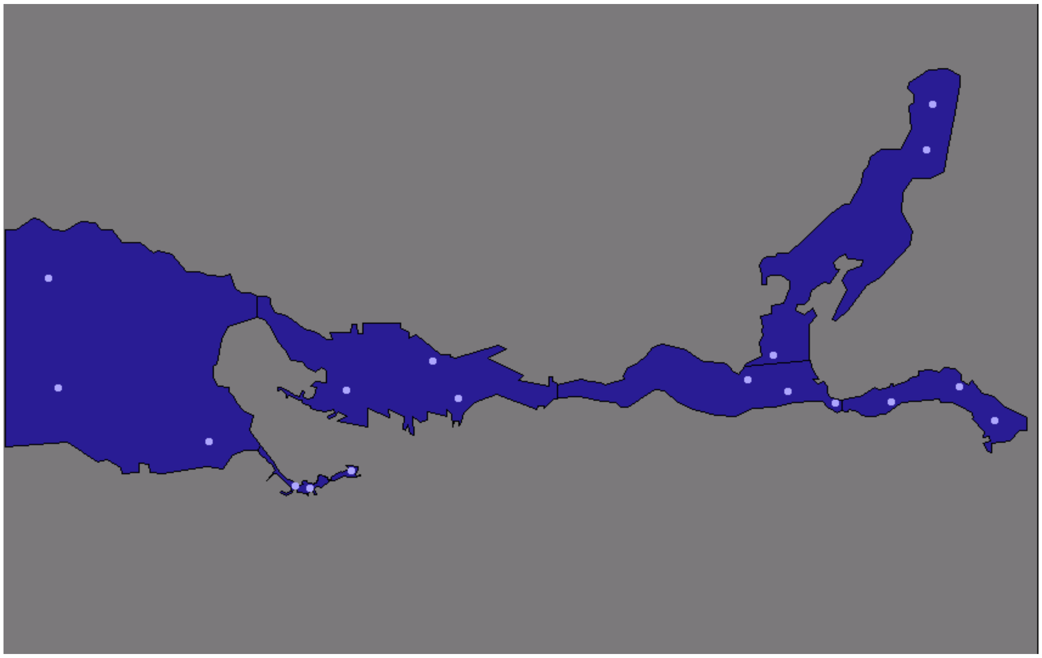


Table 3.2.1: Sediment Sample Locations.

Sample-ID	X-lon-W	Y-lat-N	Depth	Water-Temp	Water-DO	Salinity	Notes
1	508680.84	5468668.01	12	15.2	8.8		North of Croker Island
2	508503.65	5467351.78	32.3	15.8	8.9		IA - close to W point
3	504200.62	5461302.22	29	15.3	8.35		IA - close to BR point
15	492276.14	5457903.1	9.1	18.5	7.4	17	East Basin - False Creek
14	491130.35	5457406.98	3.5	18.6	7.45	17.4	Marina South - False Creek
13	490716.92	5457481.79	4.2	18.7	7.77	17.3	North Central- False Creek
12	488279.38	5458771.02	9	19	9	16	Outer Harbour
11	484026.96	5460340.36	50.2	19.95	9.1	15.03	Outer Harbour
10	483748.53	5463554.98	58.8	18.94	8.8	17.06	Outer Harbour
8	494582.06	5461150.35	30.9	15.49	7.13	23.7	Inner Harbour
9	492152.11	5460264.43	28.5	26.3	7.96	22.77	Inner Harbour
7	495316.11	5460036.62	23.6	15.65	7.27	23.33	Inner Harbour
6	505947.14	5459884.75	16.7	16.14	8.38	23.16	Central Harbour
5	504605.61	5460239.11	22.5	16.46	8.44	22.2	Central Harbour
4	503466.57	5460593.48	27.1	17.04	8.23	24.01	Central Harbour
16	507516.49	5459935.37	22.2	17.33	8.35	23.89	Port Moody
17	509414.88	5460390.99	7.3	17.57	8.36	23.33	Port Moody
18	510427.36	5459378.51	10.1	17.33	8.25	25.01	Port Moody

Figure 3.2.2: Sediment sample point location



3.3. Model Performance Evaluation

The model was programmed in Excel spreadsheets using Visual Basic for Applications (VBA) and then parameterized to make predictions of the BSAFs of a range of organochlorines in Burrard Inlet. The model performance has been evaluated by comparing predicted BSAFs to independently observed BSAFs in False Creek ecosystem. The food-web model is calibrated using observed biota and sediment PCBs concentrations from Maldonado, 2003 (76) (Table A-1) and as a secondary dataset we used biota and sediment concentrations from Mackintosh et al. 2005 (77) (Table A-4). Table A-5, shows the list of all parameters and state variables considered in the model calibration stage.

To quantitatively express the general model's performance, we used the equation 3.3.1 (Gobas et al. 1998)(87), which combines the results for all "n" congeners in the PCB mixture by a single species, "j". Therefore, the model bias (MBi) by species "j" is described by equation 3.4.1 as follow:

BSAF predicted ⟺ BSAF observed

$$MB_j = 10^{\left(\sum_{i=1}^{n} \frac{\left[\log\left(BAF_{P,i} / BAF_{O,i} \right) \right]}{n} \right)} \qquad (3.3.1)$$

where BAF_P is the model predicted BAF, BAF_O is the observed BAF and the subscript "i" refer respectively to the number of PCB congeners and the subscript "j" refer to species included in the model performance evaluation. In essence, MB is the geometric mean (assuming a log-normal distribution of the ratio $BAF_{P,\, i,}$ / $BAF_{O,\, i}$) of the ratio of predicted and observed BAFs for all chemicals in a particular species for which empirical data were available. MB is a measure of the systematic over ($MB>1$) or under prediction ($MB<1$) of the model. For example, $MB = 2$ indicates that the model in general over predicts the empirical data by a factor of 2. Conversely, a model bias of 0.5 indicates that the model under predicts the observed data by a factor of 2. The 95% confidence intervals of the geometric mean represent the accuracy of the model. Due to the lognormal distribution of the ratio of predicted and observed BSAFs, variability can be expressed as a factor (rather than a term) of the geometric mean. One of the main characteristics of the MB and its confidence interval (± SD) is that it represents possible sources of error in model parameterization, errors in model structure and philosophy, but also analytical errors in the empirical data (e.g. chemical concentrations in water, sediment and biota) and natural, spatial and temporal variability in the empirical data used for the model performance. The rationale behind the model performance analysis is that it is most relevant when the model is used to make practical estimations of the BSAF for exposure assessment or water-sediment quality guidelines development. In those cases, the confidence intervals represent the range of BSAFs that includes 95% of the observed BSAFs. With caution, the confidence limits can be extrapolated from one system for which empirical BSAFs exist to another system where empirical BSAFs do not exist.

The standard deviations in Figure 3.3.1 for the predicted BSAFs, are based on the observed variability in BSAFs. The extrapolation of observed variability in sediments and biota into the predicted BSAFs by the model, incorporates more realistic and accurate predictions into the model outcome.

The SD for observed BSAF was calculated as follow:

Log BSAFo = Log CB observed - Log Cs observed

Therefore

$$SD_{BSAFO} = \sqrt{\log SD_{CB}^{2} + \log SD_{CS}^{2}} \qquad (3.3.2)$$

3.4. Sensitivity Analysis

The objective of this approach is to find out what model parameters are the most significant to reduce the overall uncertainty in the projections. In other words, we want to measure the relative changes in predicted PCB concentrations in targeted species for small changes in individual state variables.

Sensitivity analysis also look for changes in the rank order of policy options (which parameters are more sensitive and how management decisions take into consideration this sensitivity in the parameters). The rank order of policy options are directly associated with the ranges of predictions from the model outcome. The implementation of the sensitivity analysis in the model can help us to determine how sensitive the model outcome is to relative changes in the state variables. To perform a sensitivity analysis we used a well documented technique known as Univariate Sensitivity Analysis (UVSA)

(Johnston et al.,1999)(88). This analysis measures the contribution to variance for a selected variable at a time while the rest of the model's state variables remain constant. In order to perform the sensitivity analysis, we run the model individually for each of the state variables, with the purpose of recording the variability in the CB (or BSAF) for each targeted PCB in all species as a result of variability in a previously selected model's state variable.

The simulations are perform with a fixed variability, equivalent to 5 % of the mean, for those state variables that were assumed to be normally distributed. The model's state variables that were included in the simulations are air temperature, water temperature, body temperature of the targeted species in birds and seals, Salinity (which affects Kow), dissolved oxygen, dissolved organic carbon in the water column. particulate organic carbon in the water column, organic carbon content of bottom sediment sediments, lipid contents of all species, phytoplankton growth rate, concentration of suspended solids, non-lipid organic matter contents, the sediment-water distribution coefficient and the non-lipid organic matter to octanol proportionality constant. We did not include feeding preferences in the sensitivity analysis.

The sensitivity analysis conducted, was included in the model within the Excel spread sheets using Visual Basic for Applications (VBA). The contribution to variance in the BSAF for all state variables as a measure of the model sensitivity was calculated and reported in the model's output spreadsheet.

The model state variable that contribute the greatest to the resulting change in the value of the output variable it is consider as the most sensitive state variable from a theoretical point of view (in our case lipid content by species). In other words, the sensitivity analysis in this case is measuring the relative change in the value of the output parameter over relative change in the value of the input parameter. However, it should be stressed, that if the actual variability in a sensitive state variable is small, then, that particular state variable has an small contribution to the variability of the model outcome despite being a "sensitive" variable. Conversely, it is possible to have a high actual variability in a relatively "insensitive" model state variable, therefore this variable has the potential to significantly contribute to the variability in the model outcome.

In the model, sensitivity is calculated as:

$$S = \left(\frac{(\Delta O / O)}{(\Delta I / I)} \right) \qquad (3.4.1)$$

Where :

ΔI is the selected change in the value of the input variable.***I*** is the value of the input variable***ΔI/I*** is the relative change in the value of the input parameter (e.g. 0.1 is a 10% change in I).***ΔO*** is the resulting change in the value of the output variable.***O*** is the value of the output variable***ΔO/O*** is the relative change in the value of the output parameter ***S*** is the relative change in the value of the output parameter as a result of the relative change in the input parameter.

3.5. Uncertainty Analysis

An important consideration in any model prediction is the uncertainty or error that can be expected in the model output (i.e. BSAF). One of the most popular method to assess error is through the application of a very well documented technique, known as Monte Carlo Simulation (MCS) (Decisioneering 2000)(89). The MCS methodology represents each model state variable by a statistical probability distribution of values. Based on the conditions surrounding that variable, a probability distribution that better represent such a variable is chosen. The more commonly used probability distribution types include normal, triangular, uniform or lognormal. These distributions are then repeatedly sampled, as an input value to run the model, to generate a distribution of model outcomes. Such distribution of model outcomes represents the variability that can be expected in the model outcome due to variability and error in the model's external and state variables. This method assesses the impact of variations in all model parameter values in terms of variations in the model output.

A number of authors have applied conventional MCS techniques for all the variables in food web bioaccumulation models (e.g. Arnot et al. 2004)(30). The latter is particularly useful in determining the sensitivity of the model output to variability and error in the model input parameters. However, care should be taken not to over interpret these numbers in terms of error or uncertainty in model predictions. The MCS does not consider the error in the model structure by comparing model's predictions and observed data sets . Therefore, we used a model performance analysis as an alternative method to measure error, based on the comparison of predicted model outcomes and observed data (as discussed in section 3.4 – model performance). If there is a sufficiently large population of observed C_B, the degree of similarity between observed and predicted BSAFs (C_B/ C_S) can be used to characterize the overall error of the model. This error includes model and model parameterization errors, as well as errors and natural variability associated with the empirical measurements. If these errors can be established for a number of different food webs, chemical substances and databases, the error can be used as a measure of the model uncertainty in applications where no empirical data are available (e.g. when the model is applied to food webs for which no empirical data exist).

3.6. Application: Forward Calculation (BSAF: C sediment → C biota)

Forwards Calculation: Estimation of Total PCB Concentrations in Fish and Wildlife

In the "forwards" calculation, the PCB concentration in fish and wildlife in the inlet (C_B) is calculated based on a measured or observed PCB concentrations in the sediment (C_S). This means that the PCB concentrations in sediments, in this case, are an input of the model which calculates the corresponding PCB concentrations in organisms of the Burrard Inlet ecosystem. All the factors from the equation above ($C_B = BSAF \cdot C_S$) are presented in the logarithmic format, with the purpose of representing such lognormal distribution concentration as a normal distribution of log C_S. The model outcome, the BSAF, is also presented in a logarithmic format as log BSAF, which provides the advantage that the lognormal distribution of the BSAF can be presented as a normal distribution of log BSAF. The model calculation that is conducted is:

$$\log C_B = \log C_S + \log BSAF \quad (3.6.1)$$

And C_B then follows as:

$$C_B = 10^{\log(CB)} \qquad (3.6.2)$$

Equation 3.6.1 is mathematically equivalent to:

$$C_B = BSAF \,.\, C_S \qquad (3.6.3)$$

Variability and error in log C_S and log BSAF are propagated to produce variability and error in log C_B. The variability and error in the biota concentrations is expressed by the standard deviation of the geometric mean concentration. It is expressed as the standard deviation of log C_B (SD_{CB}). It is calculated from the standard deviations of log BSAF (SD_{BSAF}) estimates and the standard deviation of the sediment concentrations (SD_{CS}) are according to

$$SD_{CB} = \sqrt{SD_{CS}^{\;2} + SD_{BSAF}^{\;2}} \qquad (3.6.4)$$

In the forward calculation C_B is calculated for each congener and total-PCBs. Variability and error in the BSAF of total PCB concentration is based on the variability and error calculated by the Monte Carlo simulations.

BSAFs are calculated for all species in the model, but we only use some key higher throphic level to make predictions and test the model. Therefore, the more significant model predictions of C_B, in terms of bioaccumulation, are carried out for Surf Scoters and Spiny Dogfish as the key biological receptors. It is possible to include any of the species in the model as a “validation control parameter”. However, to keep the prediction and model testing relatively simple, we used 18 different species for which we have observed biota PCB concentrations from (Maldonado, 2003)(76), representing those species that are most relevant for management purposes.

3.7. Forwards Calculation: Estimation of Upper-Bound Excess Cancer Risks in Burrard Inlet Residents Consuming Local Fish

The forward calculations further include several methods to estimate the human health and ecological risks associated with the entered PCB concentrations for the Bay sediments. Two types of human health risk assessments are presented. The first risk assessment determines the upper-bound lifetime excess cancer risk, R, due to consumption of those fish species for which the model calculations are conducted. It follows the methodology used by the USEPA and is documented in USEPA [1996] (90). The

assessment is based on the assumption that only the fish species for which the concentration C_B is derived by the model is consumed by residents. The calculation for R (unitless) is:

$$R = F \times E \times DE \times CL \times Q \times C_B / (BW \times LT) \qquad (3.7.1)$$

The rate of local Bay fish consumption F by a person (in kg fish per day) is set at 0.021 kg/d [SFEI 2003]. The dietary absorption efficiency of PCBs in human is set at 100% or

1. C_B is the concentration (in units of mg PCB/kg wet weight fish) of the PCB congener or total PCB in the fish that is consumed by members of the target population for which the risk assessment is conducted. C_B is calculated by the model. DE is the exposure duration to PCB contaminated fish from the Bay and set at 30 years. CL represents the loss of PCBs due to cooking of fish. It is set at a value of 0.75, which is a loss equivalent to 25% of the original PCB concentration. Q is the slope factor for PCBs and following the US-EPA IRIS database, is set at 2 $(mg/kg/d)^{-1}$. The body weight BW (in kg) is set at 70 kg, representing an adult human being. The lifetime LT of an adult person is set at 70 years. Alternative calculations of the excess cancer risk can be added in the spreadsheet.

3.8. Forwards Calculation: Estimation of Hazard to Human Health due to Consumption of Burrard Inlet Fish

The second type of human health risk assessment that is included in the model assumes that PCBs are not carcinogens. It is based on the derivation of a reference dose or an acceptable daily intake for PCBs. In the model, the hazard H is derived by first estimating the dose D (mg/kg/d) of PCBs for Bay residents consuming local fish:

$$D = F \times E \times CB \times CL / BW \qquad (3.8.1)$$

And then dividing the dose D by the acceptable daily intake ADI (or reference dose) in mg/kg/d according to:

$$H = D/ADI \qquad (3.8.2)$$

Where F is the rate of local Bay fish consumption F by a person (in kg fish per day) and set at 0.021 kg/d [SFEI 2003]. E is the dietary absorption efficiency of PCBs in human and set at 100% or 1. C_B is the concentration (in units of mg PCB/kg wet weight fish) of the PCB congener or total PCB in the fish that is consumed by members of the target population for which the risk assessment is conducted. C_B is calculated by the model and the hazard estimation is only based on the assumption that only the fish species for which the model calculations are conducted are being consumed. CL represents the loss of PCBs due to cooking of fish. It is set at 0.75 which is equivalent to 25% of the original PCB concentration. BW is the body weight BW (in kg) of an adult human being and is set at 70 kg. The ADI is set at 2.10^{-5} mg/kg/d following the USEPA IRIS database for Aroclor 1254. A value for H equal or greater than 1 indicates there is a potential that, under the scenario described above, PCBs in fish are hazardous to people consuming Bay fish. A value of H less than 1 indicates that there is no hazard.

3.9. Backwards Calculation: Estimation of Total PCB Concentrations in Sediments from PCB Concentration in Fish and Wildlife

In the "backwards" calculation, the PCB concentration in the sediment (C_S) is calculated based on a PCB concentration in a fish or wildlife species (C_B). This calculation is designed to determine target PCB concentrations in sediments that meet ecological and/or human health criteria that are expressed in terms of a PCB concentration C_B. The calculation that is conducted is:

$$\log C_S = \log C_B - \log \mathrm{BSAF} \qquad (3.9.1)$$

Which is equivalent to:

$$C_S = C_B / BSAF \qquad (3.9.2)$$

Where C_B is now the external variable that needs to be entered and the BSAF is derived by the model. The backwards calculations are presented for total PCBs. The calculations can also be conducted for Toxic Equivalent Concentrations (TEQs). However, considering the lack of knowledge of the composition of PCBs that is needed to make meaningful TEQ calculations, the backwards TEQ calculations are not included in the current version of the model. Uncertainty in the model error is included in the backwards calculation in terms of the uncertainty in the BSAF, which is calculated by the model as described above. In addition, it is possible, when entering the PCB concentrations in the biota, to include an accepted variability in the target biota concentration C_B in the Inlet. The uncertainty in the BSAF and C_B is combined in the model to determine a distribution of PCB concentrations in the sediments that are expected to produce the entered distribution of PCB concentrations in fish or wildlife species.

4. RESULTS AND DISCUSSION

4.1. Model Performance Analysis

Figures 4.1.1 to figure 4.1.9 illustrate the comparison between observed and predicted BSAFs for approximately 30 PCBs congeners. All plots represent the outcome of the performance analysis for different throphic level organisms. The food web model in excel, includes a plot for each of the thirty species considered in the Burrard Inlet food web model. To simplify the results of the performance analysis, we show only nine of the most representative species of the food web, for which data was available. It includes results for five filter feeders (Manila Clams, Geoduck Clams, Blue Mussels, Pacific Oster and Dungeness Crab Adult) and three fish species (Pacific Staghorn Sculpin, English Sole and Spiny Dogfish). Unfortunately , the analysis for PCB concentrations in tissue for the seal's samples (taken at the end of the summer of 2006), were not available for the completion of this study.

Figures 4.1.1 to figure 4.1.9 reported low observed BSAFs values of False Creek (the most contaminated compartment in Burrard Inlet ecosystem). The means of the BSAF for various PCBs congeners contain standard deviations ranging from 0.23 to 0.7. which is equivalent to a standard deviation of the BSAF's arithmetic mean of a factor ranging between approximately 2 and 5. This variability includes a spatial variation as the observed sediment samples were taken from various locations in False Creek. The standard deviations in Figures 4.1.1 to Figure 4.1.9 are based on the variability in observed BSAFs. As it was discussed in previous sections, the extrapolation of observed variability in sediments and biota directly into predicted BSAFs, incorporates more realistic and accurate model's predictions.

Figures 4.1.1 to 4.1.9 show that model's predicted BSAFs are within a close range to the geometric mean of the observations. In particular, congener patterns of PCBs in all organism, are reasonable well reproduced by the model, indicating that exist an apparent agreement between observed and predicted BSAFs along a selected mixture of PCBs congeners.

Calculated concentration for highly hydrophobic PCB congeners (Kow>8) for certain benthic organisms (e.i. Pacific Oyster, Blue Mussels and Geoduck Clams) over predicted the empirical data in the mixture. Therefore, the Model Bias (MB) in Benthos-2 (Pacific Oysters) indicates an overestimation of observed concentrations by a factor of 1.20 (20 % overestimation), for Benthos-3 (Blue Mussels) by a factor of 1.50 and for Benthos-4 (Geoduck Clams) by a factor of 1.97 (see figures 4.1.2 to 4.1.4). Such over estimation in BSAFs for high Kow congeners in the PCB mixture may be attributable to the consumption of some inorganic matter by these particular benthic organisms (partialy detritus feeders). We believe the inorganic matter in the diet of small benthic organism physically retains highly chlorinated PCBs, making difficult the subsequent chemical uptake by a simple gastro intestinal extraction (refer to theory of intestinal absorption mechanisms in Appendix E).

The model performance analysis shows a high level of agreement between predicted PCB concentrations and empirical data with the exception of one bird species (Surf Scoters).

The MB in Table 4.1.1 shows an over prediction by a factor of 39.5 and a transformed SD of approximately 1.4, which is equivalent to a standard deviation of the BSAF's arithmetic mean of a factor of 24. This over prediction is attributable to the migratory nature of this bird species. We assumed that surf Scoters are feeding exclusively in False Creek, instead, diet intake for these birds species is expected to be extended over the boundaries of False Creek towards less contaminated areas, showing as a consequence, less signs of contamination by PCBs. As a result, model predictions are reflecting concentrations of PCB in tissue of a Surf Scoter feeding exclusively from the modeled site (in this case False Greek).

The MB on tables 4.1.1 and 4.1.2, further illustrates the model's ability to estimate concentrations of PCBs in biota of False Creek.

Tables 4.1.1 and Figure 4.1.9 shows that among different species (excluding Surf Scoters), the mean model bias (MB) among the 30 PCBs congeners mixture, ranges between approximately 0.52 and 3.57. The best level of agreement is represented by Manila Clams in Figures 4.1.1 and 4.1.10 with a perfect model bias (MB) of 1.00 and a transformed SD of 0.286, what is equivalent to an arithmetic SD of 1.9. Figure 4.1.10 shows the high level of agreement of the model for different species, in particular phytoplankton, English sole and Spiny Dogfish, among others species, show an excellent MB with a transformed SD of 0.37, 0.29 and 0.58 respectively of a factor of the geometric mean. (equivalent to an arithmetic mean of 2.37, 1.96 and 3.77 respectively). It is evident, analyzing Figure 4.1.10, that over predictions of BSAF for certain congeners are cancelled out by under predictions for other congeners, producing a MB for BSAF throughout all species considered in the food web, that is fairly close to the unity or what is equivalent to the log predicted BSAF over the log of observed BSAF equal to zero. The later indicates that apparent systematic error in the model is relatively small. It further implies that while the model may produce over or under estimates of BSAFs for some congeners in the mixture, it is expected to predict estimates for the total PCBs congeners in the mixture that are in very good agreement with the empirical data. This successful agreement between PCB concentration in sediment and biota in Burrard Inlet is an encouraging sign, suggesting that the model's simulation may be able to make realistic predictions of BSAFs in the Inlet.

Table 4.1.1: **Model Bias by species. MB is the geometric mean (assuming a log-normal distribution of the ratio $BSAF_P$, i, / $BSAF_O$, i) of the ratio of predicted and observed BSAFs for all chemicals in a particular species for which empirical data were available.**

Log(BSAFp/ BSAFo)	16	18	28	32	47	48	52	73	75	90	99	101	110	118	132	138	149	153	160	163	164	180	182	187	194	196	203	206	209	Output	SD
HYTOPLANKTO	0.67	N/A	N/A	0.29	-0.50	-0.45	-0.39	-0.51	-0.61	0.25	-0.30	0.24	0.37	-0.06	-0.17	0.10	0.17	-0.11	0.12	0.14	0.15	0.64	0.29	0.28	0.74	0.43	0.43	0.37	-0.03	1.23	0.37
PLANKTON	0.11	N/A	N/A	-0.28	0.07	0.12	0.20	0.09	-0.04	0.83	-0.58	0.83	1.00	0.83	0.49	0.93	0.90	0.55	0.96	0.97	0.98	1.75	0.86	0.85	1.06	0.70	0.70	1.14	N/A	3.57	0.52
BENTHOS - 1	0.12	-0.13	N/A	0.23	-0.60	-0.63	0.01	0.07	-0.53	0.13	-0.21	0.14	0.38	0.08	-0.38	0.00	0.28	-0.36	0.00	-0.01	-0.02	0.43	0.08	0.09	0.38	0.27	0.27	0.07	-0.07	1.00	0.29
BENTHOS - 2	0.38	0.22	N/A	0.49	-0.70	-0.73	-0.37	-0.30	-0.64	-0.72	-0.94	-0.72	-0.46	-0.80	-1.25	-0.65	-0.73	-1.24	-0.66	-0.67	-0.67	1.08	-0.60	-0.59	3.00	3.06	3.06	2.65	1.78	1.20	1.36
BENTHOS - 3	1.04	N/A	N/A	1.16	-0.61	-0.65	-0.09	0.01	-0.51	-0.26	-0.54	-0.25	0.47	-0.48	-0.83	-0.34	-0.13	-0.75	-0.33	-0.32	-0.32	0.91	0.03	0.03	1.75	1.75	1.75	2.61	N/A	1.50	0.93
BENTHOS - 4	0.05	-0.43	N/A	0.16	-0.35	-0.38	-0.09	-0.02	-0.28	0.02	-0.08	0.02	0.22	-0.04	-0.14	0.24	0.23	-0.09	0.25	0.25	0.25	1.08	0.47	0.48	1.93	1.23	1.23	1.63	0.75	1.97	0.61
BENTHOS - 5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BENTHOS - 6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BENTHOS - 7	1.32	1.30	N/A	1.37	-0.76	-0.77	0.22	0.25	-0.74	0.08	-0.67	0.08	0.46	-0.94	0.76	0.14	0.74	0.63	0.08	0.04	0.02	1.22	0.00	0.03	1.04	2.99	2.99	2.72	N/A	3.19	1.08
BENTHOS - 8	0.23	0.25	N/A	0.37	-0.92	-0.99	-0.64	-0.43	-0.71	-0.46	-0.65	-0.44	0.07	-0.53	-0.67	-0.36	-0.06	-0.73	-0.41	-0.45	-0.47	0.07	-0.29	-0.25	-0.19	0.17	0.17	-0.24	0.24	0.52	0.38
FISH - 1	1.28	1.28	N/A	1.45	0.47	0.41	0.12	0.29	0.64	-0.04	-0.43	-0.03	0.50	-0.39	-0.71	-0.24	0.68	-0.64	-0.24	-0.24	-0.24	0.47	0.21	0.22	0.84	0.73	0.73	1.42	1.59	2.24	0.65
FISH - 2	N/A	N/A	N/A	N/A	1.32	1.23	0.36	0.59	1.54	0.37	-0.10	0.39	1.45	0.04	-0.20	0.25	1.76	-0.17	0.24	0.23	0.22	0.75	0.62	0.64	0.86	0.76	0.76	0.79	0.82	3.43	0.53
FISH - 3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 5	1.45	0.95	N/A	1.45	0.04	0.04	0.12	0.12	0.04	-0.15	-0.40	-0.15	0.20	-0.32	-0.68	-0.25	0.13	-0.68	-0.26	-0.27	-0.27	0.29	0.02	0.03	0.21	-0.01	-0.01	0.19	0.45	1.20	0.50
FISH - 6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 7	0.13	0.11	N/A	0.35	-0.36	-0.47	-0.36	-0.04	-0.05	0.01	0.00	0.04	0.26	0.37	-0.10	0.37	0.78	-0.04	0.36	0.34	0.33	0.57	0.45	0.48	0.26	0.21	0.21	0.33	0.50	1.49	0.29
FISH - 8	0.36	0.24	N/A	0.42	-0.80	-0.83	-0.48	-0.40	-0.72	-0.39	-0.86	-0.38	0.06	-0.67	-0.81	-0.42	0.24	-0.77	-0.42	-0.42	-0.43	0.20	-0.03	-0.02	0.39	0.52	0.52	0.56	0.69	0.69	0.50
FISH - 9	0.51	0.50	N/A	1.11	0.15	0.00	0.71	1.09	0.53	0.67	0.02	0.69	1.47	0.14	-0.40	0.02	1.00	-0.41	-0.02	-0.06	-0.08	0.10	-0.01	0.03	-0.46	-0.39	-0.39	-0.85	-0.64	1.49	0.58
FISH - 10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BIRD1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BIRD2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BIRD3	N/A	N/A	N/A	N/A	1.88	2.14	4.62	4.43	2.12	3.45	0.72	3.49	4.67	0.89	0.14	0.55	2.76	0.23	0.56	0.56	0.57	1.57	0.66	0.67	2.00	1.85	1.85	2.17	1.76	39.50	1.38
BIRD4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 4.1.2: Model Bias by congener. MB is the geometric mean (assuming a log-normal distribution of the ratio $BSAF_{P}$, i, / $BSAF_{O}$, i) of the ratio of predicted and observed BSAFs for all species in a particular PCB congener for which empirical data were available.

Log(BSAFp/ BSAFo)	16	18	28	32	47	48	52	73	75	90	99	101	110	118	132	138	149	153	160	163	164	180	182	187	194	196	203	206	209
HYTOPLANKTO	0.67	N/A	N/A	0.29	-0.50	-0.45	-0.39	-0.51	-0.61	0.25	-0.30	0.24	0.37	-0.06	-0.17	0.10	0.17	-0.11	0.12	0.14	0.15	0.64	0.29	0.28	0.74	0.43	0.43	0.37	-0.03
PLANKTON	0.11	N/A	N/A	-0.28	0.07	0.12	0.20	0.09	-0.04	0.83	-0.58	0.83	1.00	0.83	0.49	0.93	0.90	0.55	0.96	0.97	0.98	1.75	0.86	0.85	1.06	0.70	0.70	1.14	N/A
BENTHOS - 1	0.12	-0.13	N/A	0.23	-0.60	-0.63	0.01	0.07	-0.53	0.13	-0.21	0.14	0.38	0.08	-0.38	0.00	0.28	-0.36	0.00	-0.01	-0.02	0.43	0.08	0.09	0.38	0.27	0.27	0.07	-0.07
BENTHOS - 2	0.38	0.22	N/A	0.49	-0.70	-0.73	-0.37	-0.30	-0.64	-0.72	-0.94	-0.72	-0.46	-0.80	-1.25	-0.65	-0.73	-1.24	-0.66	-0.67	-0.67	1.08	-0.60	-0.59	3.00	3.06	3.06	2.65	1.78
BENTHOS - 3	1.04	N/A	N/A	1.16	-0.61	-0.65	-0.09	0.01	-0.51	-0.26	-0.54	-0.25	0.47	-0.48	-0.83	-0.34	-0.13	-0.75	-0.33	-0.32	-0.32	0.91	0.03	0.03	1.75	1.75	1.75	2.61	N/A
BENTHOS - 4	0.05	-0.43	N/A	0.16	-0.35	-0.38	-0.09	-0.02	-0.28	0.02	-0.08	0.02	0.22	-0.04	-0.14	0.24	0.23	-0.09	0.25	0.25	0.25	1.08	0.47	0.48	1.93	1.23	1.23	1.63	0.75
BENTHOS - 5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BENTHOS - 6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BENTHOS - 7	1.32	1.30	N/A	1.37	-0.76	-0.77	0.22	0.25	-0.74	0.08	-0.67	0.08	0.46	-0.94	0.76	0.14	0.74	0.63	0.08	0.04	0.02	1.22	0.00	0.03	1.04	2.99	2.99	2.72	N/A
BENTHOS - 8	0.23	0.25	N/A	0.37	-0.92	-0.99	-0.64	-0.43	-0.71	-0.46	-0.65	-0.44	0.07	-0.53	-0.67	-0.36	-0.06	-0.73	-0.41	-0.45	-0.47	0.07	-0.29	-0.25	-0.19	0.17	0.17	-0.24	0.24
FISH - 1	1.28	1.28	N/A	1.45	0.47	0.41	0.12	0.29	0.64	-0.04	-0.43	-0.03	0.50	-0.39	-0.71	-0.24	0.68	-0.64	-0.24	-0.24	-0.24	0.47	0.21	0.22	0.84	0.73	0.73	1.42	1.59
FISH - 2	N/A	N/A	N/A	N/A	1.32	1.23	0.36	0.59	1.54	0.37	-0.10	0.39	1.45	0.04	-0.20	0.25	1.76	-0.17	0.24	0.23	0.22	0.75	0.62	0.64	0.86	0.76	0.76	0.79	0.82
FISH - 3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 5	1.45	0.95	N/A	1.45	0.04	0.04	0.12	0.12	0.04	-0.15	-0.40	-0.15	0.20	-0.32	-0.68	-0.25	0.13	-0.68	-0.26	-0.27	-0.27	0.29	0.02	0.03	0.21	-0.01	-0.01	0.19	0.45
FISH - 6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 7	0.13	0.11	N/A	0.35	-0.36	-0.47	-0.36	-0.04	-0.05	0.01	0.00	0.04	0.26	0.37	-0.10	0.37	0.78	-0.04	0.36	0.34	0.33	0.57	0.45	0.48	0.26	0.21	0.21	0.33	0.50
FISH - 8	0.36	0.24	N/A	0.42	-0.80	-0.83	-0.48	-0.40	-0.72	-0.39	-0.86	-0.38	0.06	-0.67	-0.81	-0.42	0.24	-0.77	-0.42	-0.42	-0.43	0.20	-0.03	-0.02	0.39	0.52	0.52	0.56	0.69
FISH - 9	0.51	0.50	N/A	1.11	0.15	0.00	0.71	1.09	0.53	0.67	0.02	0.69	1.47	0.14	-0.40	0.02	1.00	-0.41	-0.02	-0.06	-0.08	0.10	-0.01	0.03	-0.46	-0.39	-0.39	-0.85	-0.64
FISH - 10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FISH - 12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SEAL4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BIRD1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BIRD2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BIRD3	N/A	N/A	N/A	N/A	1.88	2.14	4.62	4.43	2.12	3.45	0.72	3.49	4.67	0.89	0.14	0.55	2.76	0.23	0.56	0.56	0.57	1.57	0.66	0.67	2.00	1.85	1.85	2.17	1.76
BIRD4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MBs	**1.09**	**1.12**	**N/A**	**1.22**	**1.33**	**1.39**	**2.03**	**1.97**	**1.39**	**1.70**	**1.12**	**1.71**	**2.05**	**1.15**	**1.02**	**1.09**	**1.53**	**1.04**	**1.09**	**1.09**	**1.09**	**1.27**	**1.11**	**1.11**	**1.36**	**1.33**	**1.33**	**1.40**	**1.40**
Stdev	**0.51**	**0.58**	**N/A**	**0.57**	**0.81**	**0.85**	**1.26**	**1.20**	**0.87**	**0.97**	**0.42**	**0.98**	**1.20**	**0.54**	**0.53**	**0.42**	**0.84**	**0.52**	**0.42**	**0.43**	**0.43**	**0.52**	**0.38**	**0.38**	**0.92**	**1.04**	**1.04**	**1.13**	**0.76**

Figure 4.1.1: Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Burrard Inlet.

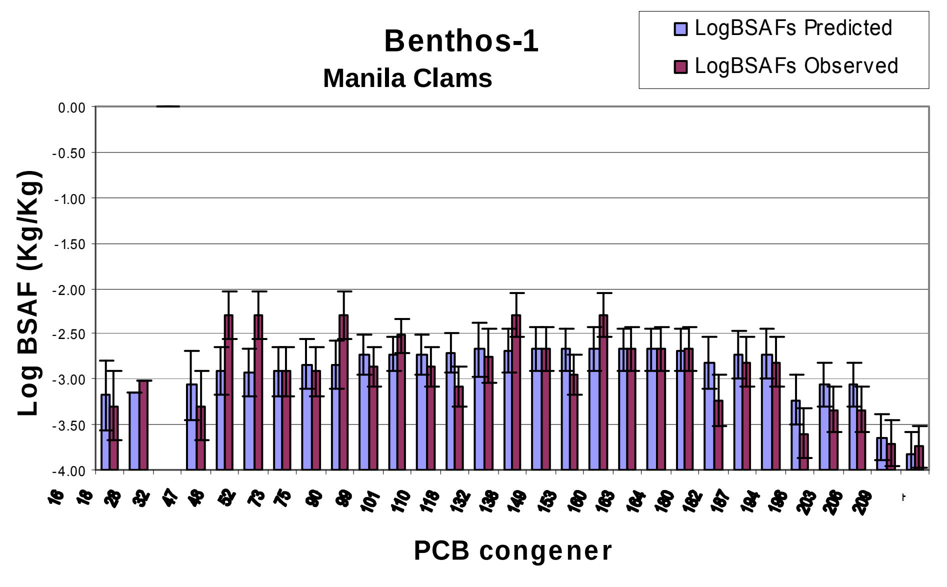


Figure 4.1.2: Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Benthos-2 (Pacific Oster) in Burrard Inlet.

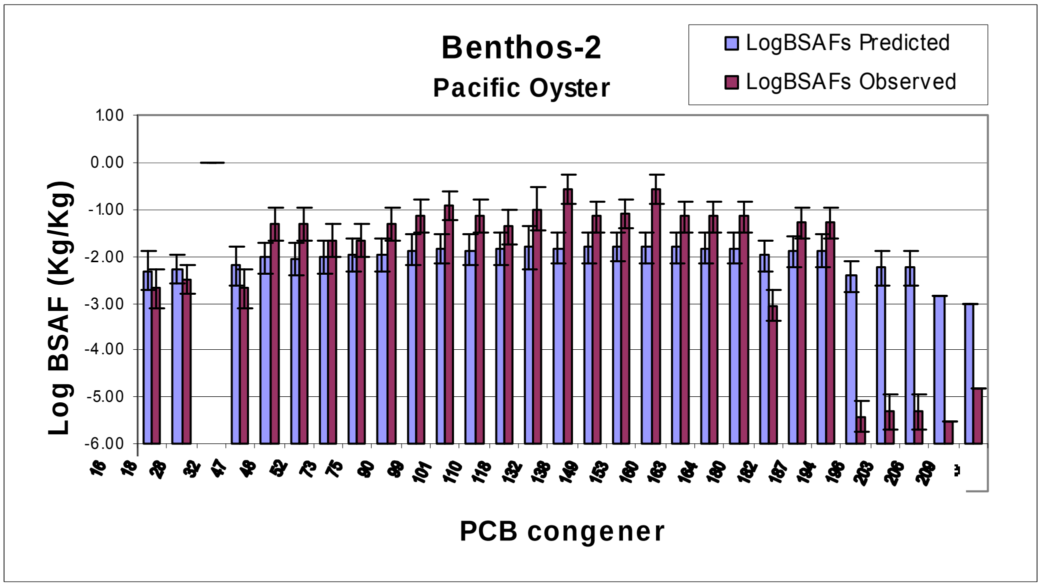


Figure 4.1.3: **Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Benthos-3 (Blue Mussels) in Burrard Inlet.**

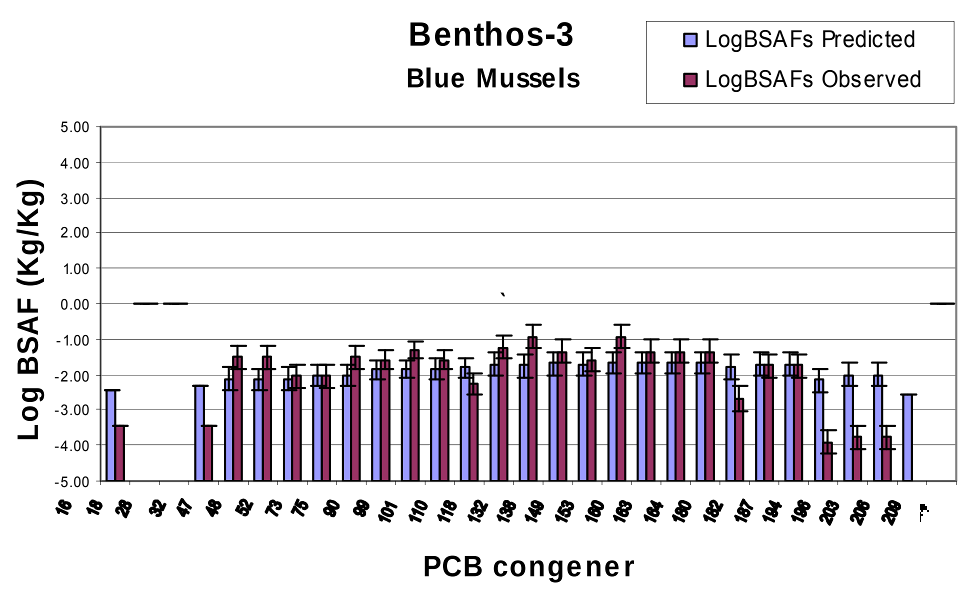


Figure 4.1.4: **Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Benthos-4 (Geoduck Clams) in Burrard Inlet.**

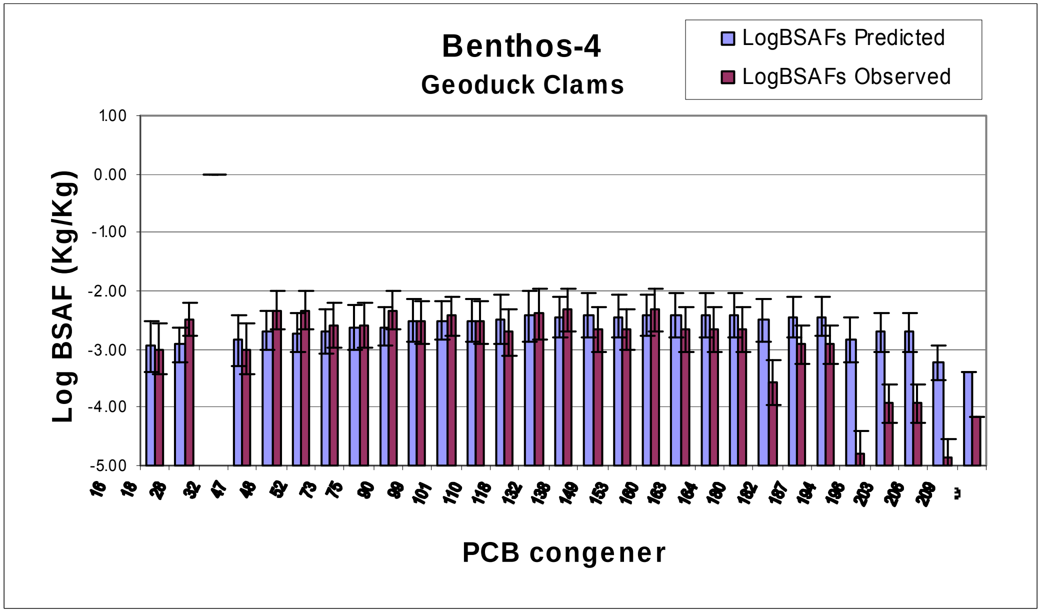


Figure 4.1.5: **Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Benthos-8 (Dungeness Grab Adults) in Burrard Inlet.**

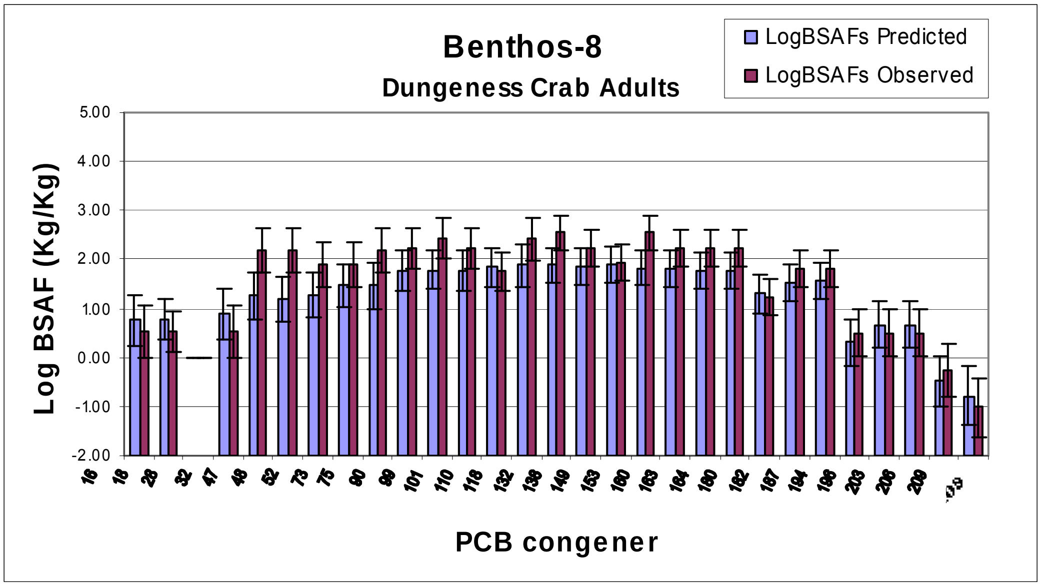


Figure 4.1.6: **Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Fish (Pacific Staghorn Sculpin) in Burrard Inlet.**

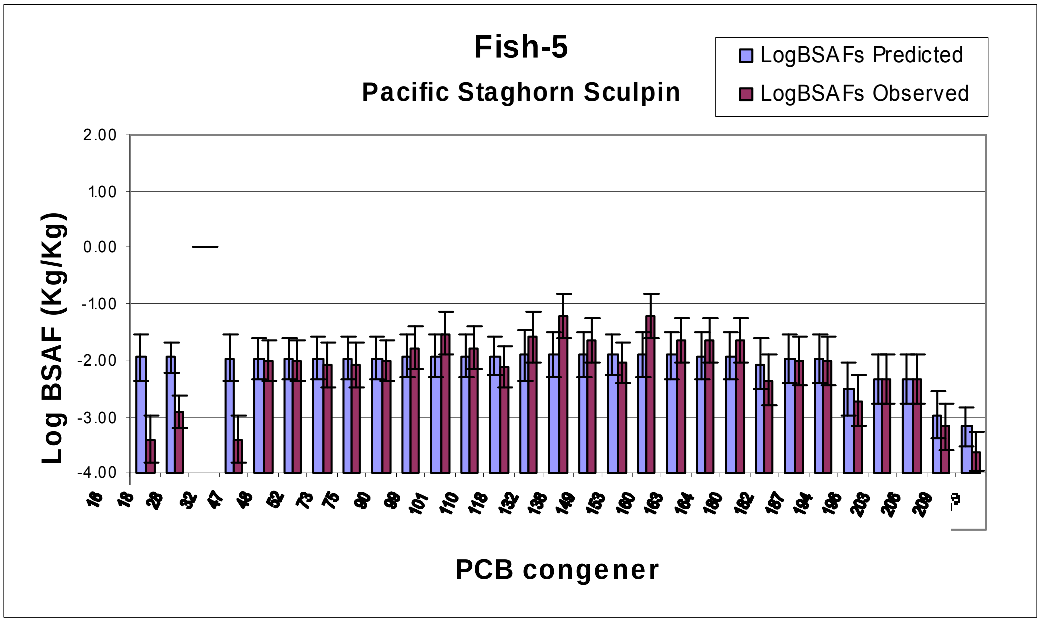


Figure 4.1.7: Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Fish (English Sole) in Burrard Inlet.

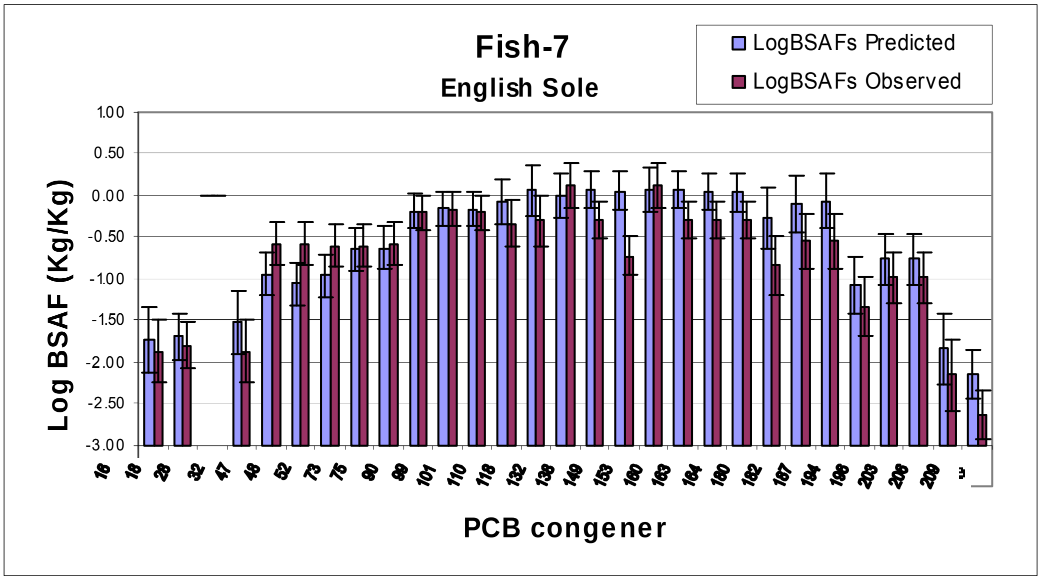


Figure 4.1.8: Model predicted and observed BSAFs (kg dry sediment/kg wet weight) of approximately 30 PCBs in Fish (Spiny Dogfish) in Burrard Inlet.

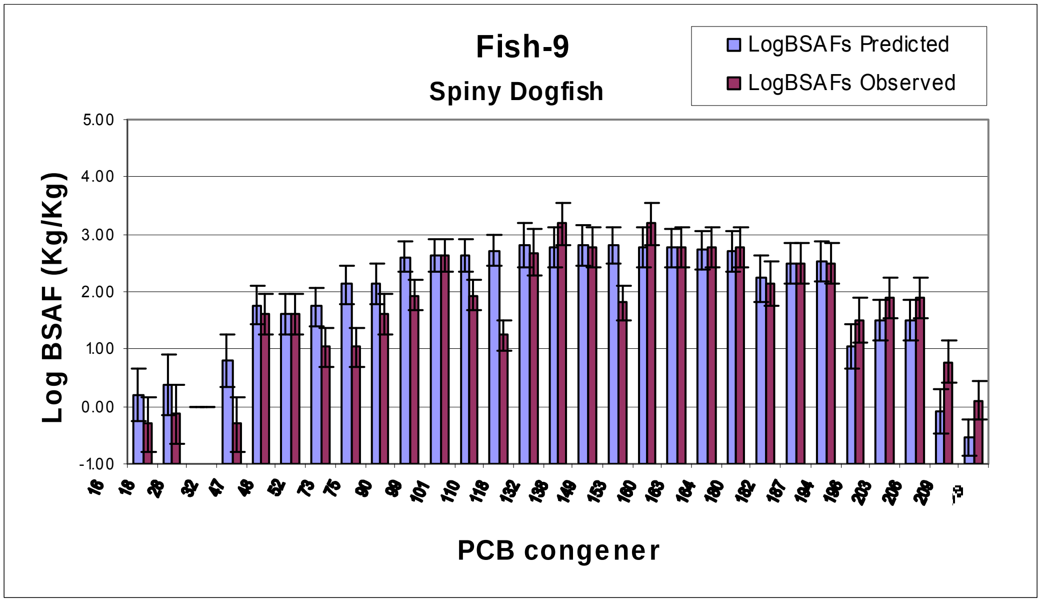


Figure 4.1.9: Model Bias (MB) by species. MB is the geometric mean (assuming a log-normal distribution of the ratio $BSAF_P$, i, / $BSAF_O$, i) of the ratio of predicted and observed BSAFs for all chemicals in a particular species for which empirical data were available

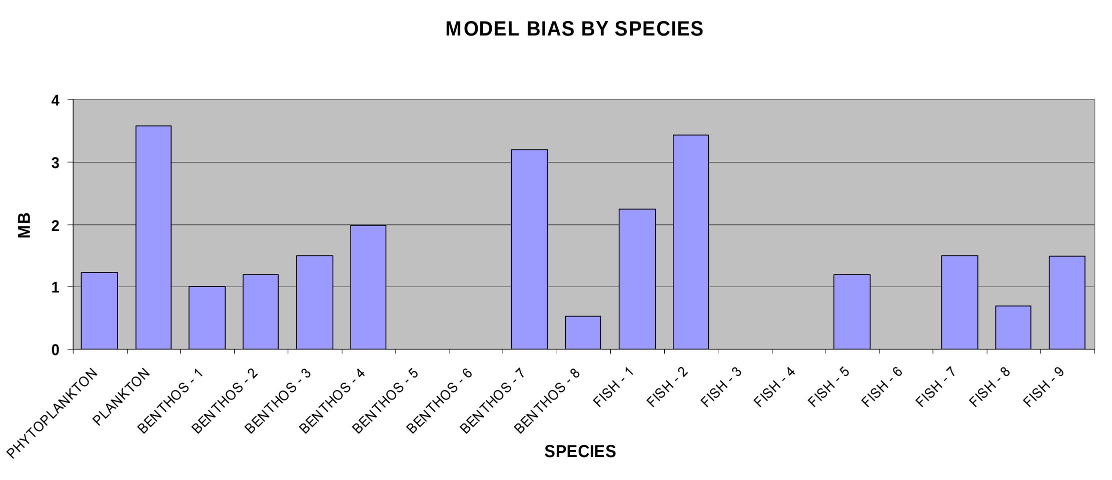
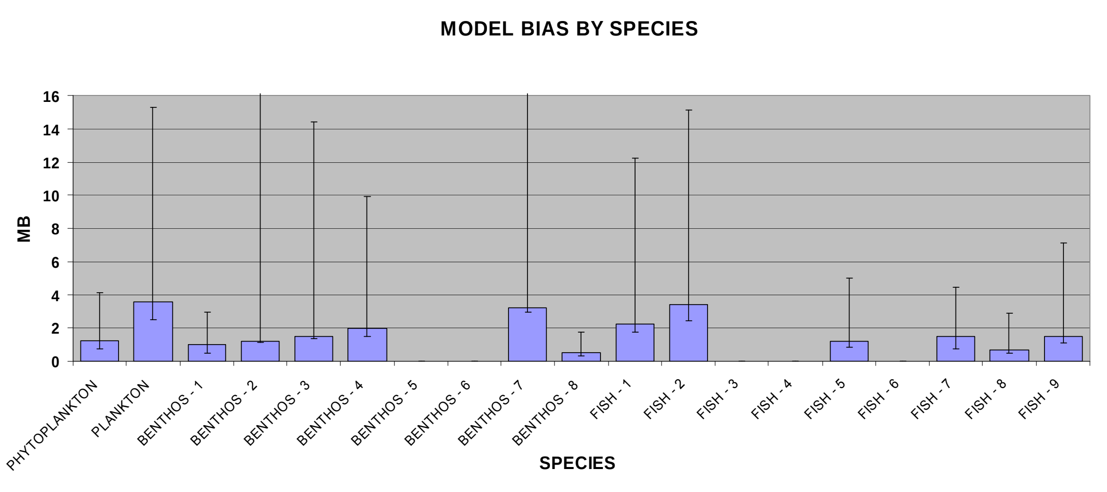


Figure 4.1.10: Model Bias (MB) by species with the standard deviations expressed as upper and lower limits.



The Toxic Substances Management Policy under the Canadian Environmental Protection Act, considers the virtual elimination of chemicals that meet criteria for persistence (P), Bioaccumulation (B) and inherent toxicity (T). Based on CEPA's current mandated evaluation of the environmental and human health hazards of commercial chemicals, we have identified several sections in the Act which are not consistent with the current state of science and could potentially lead to serious errors in the categorization and risk assessment of DSL chemicals. One of those errors, is the current criteria for bioaccumulation used in the act. Regulations under the section 73 of CEPA Act, define the BAF or BCF as the chemical concentration in a live organism relative to those in the water. The act uses a criteria values of 5000 for BAF or BCF and 100,000 for kow which are consistent with empirical data on bioaccumulation of POPs in aquatic food-webs. However, advances in science of toxicology during the last decades have proven that CEPA criteria in bioaccumulation is inadequate to represent the real bioaccumulation phenomenon occurring in higher throphic level organisms and in particular, in terrestrial food-chains. As a result, the main objective of this study is to predict the fate of contaminant discharges into the inlet and develop a more accurate sediment quality criteria that can be used to better protect sensitive species and higher throphic level organisms in Burrard Inlet. One of the most important stages in the model development is to analyze the overall model performance by running different types of test analysis.

4.2. Model Sensitivity

The objective of this approach is to find out what model's state variables/parameters are the most important to reduce the overall uncertainty in the model outputs. All figures in this section are trying to measure the variability in the CB (or BSAFs) of each PCB congener in targeted species as a result of individual changes in each of the selected model's state variables. To measure sensitivity in the model , we introduced a fixed variability of 1% of the mean in each state variable and some selected parameters. Figures G1 to G6 in Appendix G, report the contribution to the variability of the CB using PCB 18. To simplify the presentation of results, we have recorded only the contribution to variance for Phytoplankton, Minnows, English Sole, Spiny Dogfish, Harbor Seal and Surf Scoter, however, the model output for the sensitivity analysis display results for each of the thirty species included in the food web.

Figures G1 to G6 show that the lipid fraction in biota (V_{LB}) is usually the state variable which contributes the most to the variance in C_B for PCB 18. Lipid content is therefore the most sensitive variable. This is due to the fact, that lipid tissue is the main driver for PCB bioaccumulation in biota. Consequently, a larger lipid content in organisms should be associated with a higher concentration of lipophilic chemicals. Some other important parameters like Kow, Koc, d_{OCS}, OC and β (non-lipid organic matter – octanol proportionality constant) have also been incorporated into the analysis. The reason for including a fairly known parameter like Kow in the analysis is mainly because is indirectly affected by temperature and also due to its significance in introducing uncertainty in the model. Although, Kow values for all PCBs congeners are quite popular in the literature, Kow is a sensitive parameter in the model and is also sensitive to temperature changes. Water temperature also is a sensitive variable as it affects several key processes such as the gill ventilation rate in fish and the partitioning properties of the chemical between water, air and lipids. The fraction of pore water, Koc, OC, and particulate organic carbon in the water phase are also sensitive variables. In essence, the sensitivity analysis indicates that the properties controlling the partitioning of the PCBs between the different media play a key role in the food web bioaccumulation model.

The results of the sensitivity analysis conducted to determine the relative contribution to variability and error in the model outcome due to the introduction of variability and error in the model's state variables can be found in the worksheet entitled "FW-sense" of the Burrard Inlet Food web model. There are two main reasons to explain why the results show that the lipid content in biota is such a key variable in the model. First, lipids constitute the organism's internal compartment in which the majority of the lipophilic compounds reside. Secondly, lipid content is the main driver in controlling the uptake and elimination mechanisms for PCBs in aquatic organisms. As discussed in the section 3.5, conventional MCS that randomly variate all variables at the same time, end up being a not realistic representations of the modeled ecosystem, usually overestimating variance and error in the model's predictions (30). Table 4.2.1 shows mean, standard deviation and a summary of statistics for the univariate MCS run for the lipid fraction on all species.

Table 4.2.1: Sensitivity Analysis output for five key species .

PCB # 18 Sensitivity % Summary Table

Sorted Code Name	Base Value	New Value	Delta in input	# of variables analized	PHYTOPLANKTON	FISH - 1	FISH - 7	FISH - 9	SEAL-1	BIRD-3
KOW	394266.983	398209.6525	0.01	1	77.9	100.5	117.6	157.0	111.4	123.5
VLB	0.07	0.0707	0.01	2	51.3	73.5	70.7	175.1	204.3	168.3
VNB	0.2	0.202	0.01	3	44.5	38.8	67.9	39.0	32.4	78.1
VWB	0.73	0.7373	0.01	4	0.0	0.0	0.0	0.0	0.0	0.0
B	0.035	0.03535	0.01	5	44.5	33.9	58.8	11.6	-7.2	58.3
CWD	1.1269E-12	1.1382E-12	0.01	6	0.0	0.0	0.0	0.0	0.0	0.0
CWT	1.4202E-12	1.43438E-12	0.01	7	0.0	0.0	0.0	0.0	0.0	0.0
XPOC	5.6571E-07	5.71371E-07	0.01	8	-6.2	-1.7	-2.2	-2.4	-1.3	-6.2
XDOC	0.00000132	1.3332E-06	0.01	9	-14.4	-4.0	-5.2	-5.5	-3.0	-14.4
DPOC	1	1.01	0.01	10	-6.2	-1.7	-2.2	-2.4	-1.3	-6.2
DDOC	1	1.01	0.01	11	-14.4	-4.0	-5.2	-5.5	-3.0	-14.4
APOC	0.35	0.3535	0.01	12	-6.2	-1.7	-2.2	-2.4	-1.3	-6.2
ADOC	0.35	0.3535	0.01	13	-14.4	-4.0	-5.2	-5.5	-3.0	-14.4
EW	0.52899049	0.5342804	0.01	14	0.0	-30.8	-33.1	-91.9	-75.6	-45.1
WB	0.175	0.17675	0.01	15	0.0	26.4	28.5	79.3	58.8	38.8
COX	5.88	5.9388	0.01	16	0.0	0.0	0.0	0.0	0.0	0.0
Temp	9.5	9.595	0.01	17	0.0	18.4	19.9	57.3	45.9	26.7
TB	37.5	37.875	0.01	18	0.0	0.0	0.0	0.0	0.0	0.0
S	0.5	0.505	0.01	19	0.0	0.0	0.0	0.0	0.0	0.0
AA	8.5E-08	8.585E-08	0.01	20	0.0	0.0	0.0	0.0	0.0	0.0
BE	2	2.02	0.01	21	0.0	0.0	0.0	0.0	0.0	0.0
mp	0	0	0	22	0.0	46.3	54.2	34.2	19.4	0.0
CWDP	3.376E-11	3.40979E-11	0.01	23	0.0	0.0	0.0	0.0	0.0	0.0
CSOC	5.1763E-06	5.22809E-06	0.01	24	0.0	0.0	0.0	0.0	0.0	0.0
dOCS	0.9	0.909	0.01	25	0.0	47.9	56.1	35.4	20.1	0.0
KOC	137993.444	139373.3784	0.01	26	0.0	-47.4	-55.6	-35.0	-19.9	0.0
GD	0.0385	0.038885	0.01	27	0.0	0.0	0.0	0.0	69.5	77.4
GV	320.536627	323.7419934	0.01	28	0.0	-30.8	-33.1	-91.9	-138.3	-121.8
CSS	2.4577E-05	2.48223E-05	0.01	29	0.0	0.0	0.0	0.0	0.0	0.0
Sigma	1	1.01	0.01	30	0.0	0.0	0.0	0.0	0.0	0.0
GF	0.00646355	0.006528189	0.01	31	0.0	0.0	0.0	0.0	0.0	0.0
KGB	0	0	0	32	0.0	0.0	0.0	0.0	0.0	0.0
VLD	0.02115503	0.021366585	0.01	33	0.0	-0.9	-3.8	-19.5	-7.6	-0.7
VND	0.2	0.202	0.01	34	0.0	-4.8	-9.0	-27.2	-17.0	-1.2
VWD	0.77884497	0.786633415	0.01	35	0.0	0.0	0.0	0.0	0.0	0.0
EL	0.95	0.9595	0.01	36	0.0	8.0	31.1	160.4	457.4	77.8
EN	0.75	0.7575	0.01	37	0.0	4.9	9.8	30.4	86.3	59.2
EWW	0.85	0.8585	0.01	38	0.0	0.0	0.0	0.0	0.0	0.0
VLG	0.00630047	0.006363478	0.01	39	0.0	0.0	0.0	0.0	0.0	0.0
VNG	0.29782381	0.300802046	0.01	40	0.0	0.0	0.0	0.0	0.0	0.0
VWG	0.69587572	0.702834477	0.01	41	0.0	0.0	0.0	0.0	0.0	0.0
KG	0	0	0	42	-4.2	-0.5	-0.3	-0.2	-6.3	-2.0
KMM	0	0	0	43	0.0	0.0	0.0	0.0	0.0	0.0
KL	0	0	0	44	0.0	0.0	0.0	0.0	0.0	0.0
KP	0	0	0	45	0.0	0.0	0.0	0.0	0.0	0.0
ED	0.96044614	0.970050599	0.01	46	0.0	0.0	0.0	0.0	0.0	0.0
EA	0.7	0.707	0.01	47	0.0	0.0	0.0	0.0	0.0	0.0
GA	320.536627	323.7419934	0.01	48	0.0	0.0	0.0	0.0	0.0	0.0
KOA	6560130.72	6625732.023	0.01	49	0.0	0.0	0.0	0.0	0.0	0.0
ELL	0.7	0.707	0.01	50	0.0	0.0	0.0	0.0	-63.2	-77.0
GAC	1E-10	1.01E-10	0.01	51	0.0	0.0	0.0	0.0	0.0	0.0
GU	0.00129271	0.001305638	0.01	52	0.0	0.0	0.0	0.0	0.0	0.0
MCS	0.5	0.505	0.01	53	0.0	0.0	0.0	0.0	0.0	0.0
OC	0.02775455	0.028032091	0.01	54	-99.0	-99.0	-99.0	-99.0	-99.0	-99.0
dSED	1.5	1.515	0.01	55	0.0	0.0	0.0	0.0	0.0	0.0

4.3. Model Uncertainty

Table 4.3.1 shows the model calculated BSAF and their variability (expressed as std dev., upper and lower limits) of PCB 180 for all species considered in the model.

The lipid content in organisms, is difficult to determine within species, hence carrying substantial measurement errors into the model. The variability and error in the lipid content therefore will produce a range of BSAFs. In the model's uncertainty analysis worksheet, named "FW-uncertainty", we recorded the mean and standard deviation for the key and most sensitive variables

Table 4.3.1: **The model calculated BSAF (kg dw/kg ww) and their variability (expressed as std dev., upper and lower limits) of PCB 180 for all species considered in the model.**

BSAFs Summary **PCB # 180** **[g/Kg ww] / [g/Kg Sed dw]**

Descriptive Statistics	PHYTO	ZOOPLANK	BENTH - 1	BENTH- 2	BENTH- 3	BENTH- 4	BENTH- 5	BENTHOS - 6	BENTH- 7	BENTH- 8
Mean	**0.104**	**0.074**	**0.111**	**0.177**	**0.691**	**0.086**	**3.014**	**8.329**	**0.676**	**4.701**
Std dev.	**0.002**	**0.000**	**0.003**	**0.008**	**0.027**	**0.003**	**0.116**	**0.370**	**0.026**	**0.149**
Log Mean	**-0.981**	**-1.129**	**-0.956**	**-0.752**	**-0.161**	**-1.067**	**0.479**	**0.921**	**-0.170**	**0.672**
Log Sdev	**-2.703**	**-3.473**	**-2.502**	**-2.089**	**-1.568**	**-2.465**	**-0.936**	**-0.432**	**-1.593**	**-0.826**
upper stdev	0.106	0.075	0.114	0.185	0.718	0.089	3.130	8.699	0.702	4.850
lower stdev	0.102	0.074	0.108	0.169	0.664	0.082	2.898	7.958	0.651	4.551
upper 95%	0.108	0.075	0.117	0.193	0.744	0.092	3.242	9.054	0.726	4.994
lower 95%	0.101	0.074	0.105	0.161	0.638	0.079	2.787	7.603	0.626	4.408
maximun	0.108	0.075	0.119	0.192	0.753	0.092	3.285	9.130	0.741	5.074
minimun	0.099	0.073	0.101	0.157	0.596	0.076	2.739	7.452	0.614	4.326
Sum	10.45	7.43	11.08	17.70	69.08	8.56	301.43	832.86	67.62	470.08
iterations	500	500	500	500	500	500	500	500	500	500
log SUM BSAFs	1.01903	0.87125	1.04449	1.24795	1.83933	0.93270	2.47919	2.92057	1.83005	2.67217

Table 4.3.1: (continued) The model calculated BSAF (kg dw/kg ww) and their variability (expressed as std dev., upper and lower limits) of PCB 180 for all species considered in the model.

BSAFs Summary **PCB # 180** **[g/Kg ww] / [g/Kg Sed dw]**

Descriptive Statistics	FISH - 1	FISH - 2	FISH - 3	FISH - 4	FISH - 5	FISH - 6	FISH - 7	FISH - 8	FISH - 9	FISH - 10
Mean	**1.254**	**0.553**	**5.415**	**3.990**	**0.269**	**5.367**	**1.036**	**0.421**	**11.656**	**13.299**
Std dev.	**0.053**	**0.015**	**0.331**	**0.249**	**0.011**	**0.353**	**0.035**	**0.016**	**0.744**	**0.777**
Log Mean	**0.098**	**-0.257**	**0.734**	**0.601**	**-0.570**	**0.730**	**0.015**	**-0.375**	**1.067**	**1.124**
Log Sdev	**-1.274**	**-1.811**	**-0.480**	**-0.604**	**-1.959**	**-0.452**	**-1.450**	**-1.794**	**-0.129**	**-0.110**
upper stdev	1.307	0.569	5.747	4.238	0.280	5.720	1.071	0.438	12.399	14.076
lower stdev	1.201	0.538	5.084	3.741	0.258	5.014	1.000	0.405	10.912	12.522
upper 95%	1.358	0.583	6.065	4.477	0.290	6.060	1.105	0.453	13.113	14.822
lower 95%	1.150	0.523	4.766	3.502	0.247	4.674	0.966	0.390	10.198	11.776
maximun	1.405	0.589	6.328	4.602	0.296	6.092	1.113	0.459	13.408	15.581
minimun	1.114	0.508	4.659	3.353	0.244	4.585	0.951	0.390	9.824	11.702
Sum	125.40	55.31	541.54	398.96	26.89	536.70	103.58	42.15	1165.56	1329.91
iterations	500	500	500	500	500	500	500	500	500	500
log SUM BSAFs	2.09830	1.74279	2.73363	2.60093	1.42963	2.72973	2.01529	1.62475	3.06653	3.12382

Table 4.3.1: (continued) The model calculated BSAF (kg dw/kg ww) and their variability (expressed as std dev., upper and lower limits) of PCB 180 for all species considered in the model.

BSAFs Summary **PCB # 180** **[g/Kg ww] / [g/Kg Sed dw]**

Descriptive Statistics	FISH - 11	FISH - 12	SEAL-1	SEAL-2	SEAL-3	SEAL-4	BIRD-1	BIRD-2	BIRD-3	BIRD-4
Mean	**1.131**	**1.133**	**757.640**	**71.183**	**571.111**	**79.263**	**173.729**	**172.430**	**7.965**	**97.764**
Std dev.	**0.034**	**0.033**	**62.851**	**7.159**	**48.098**	**7.972**	**18.204**	**14.832**	**0.701**	**9.444**
Log Mean	**0.054**	**0.054**	**2.879**	**1.852**	**2.757**	**1.899**	**2.240**	**2.237**	**0.901**	**1.990**
Log Sdev	**-1.463**	**-1.488**	**1.798**	**0.855**	**1.682**	**0.902**	**1.260**	**1.171**	**-0.154**	**0.975**
upper stdev	1.166	1.166	820.491	78.341	619.209	87.235	191.933	187.262	8.667	107.207
lower stdev	1.097	1.101	694.789	64.024	523.013	71.291	155.526	157.598	7.264	88.320
upper 95%	1.199	1.197	880.828	85.213	665.384	94.888	209.409	201.501	9.340	116.273
lower 95%	1.064	1.070	634.452	57.152	476.838	63.638	138.050	143.359	6.591	79.255
maximun	1.222	1.203	911.295	86.571	673.390	96.406	235.987	203.401	9.897	126.339
minimun	1.042	1.035	622.077	50.631	452.673	56.386	139.751	119.385	6.080	74.148
Sum	113.13	113.33	75764.03	7118.25	57111.10	7926.34	17372.95	17242.99	796.53	9776.38
iterations	500	500	500	500	500	500	500	500	500	500
log SUM BSAFs	2.05357	2.05434	4.87946	3.85237	4.75672	3.89907	4.23987	4.23661	2.90120	3.99018

4.4. Forwards Calculation: Estimation of Total PCB Concentrations in Fish and Wildlife

Figure 4.4 shows the sum of PCB concentration for three of the major compartments in the Inlet, based on a total of nine samples collected on the summer of 2004 (three samples per compartment). The sum of PCB concentrations range by approximately 2 orders of magnitude for each compartment. The probability distributions in Figure 4.5 show that Inner Harbor is the most contaminated of the three compartment sampled in this study. Therefore, we will make predictions on PCB concentrations in biota, based on the observed sediment concentration in Inner Harbor, that already exceed the British Columbia sediment quality guidelines.

Figure 4.4: **Distributions of sum PCBs in sediments observed in Inner Harbor (green line), Central Harbor (blue line) and Port Moody (pink line) based on three samples per site, collected in summer of 2004 as well as the geometric mean and probability distribution for the British Columbia Sediment Quality Guidelines.**

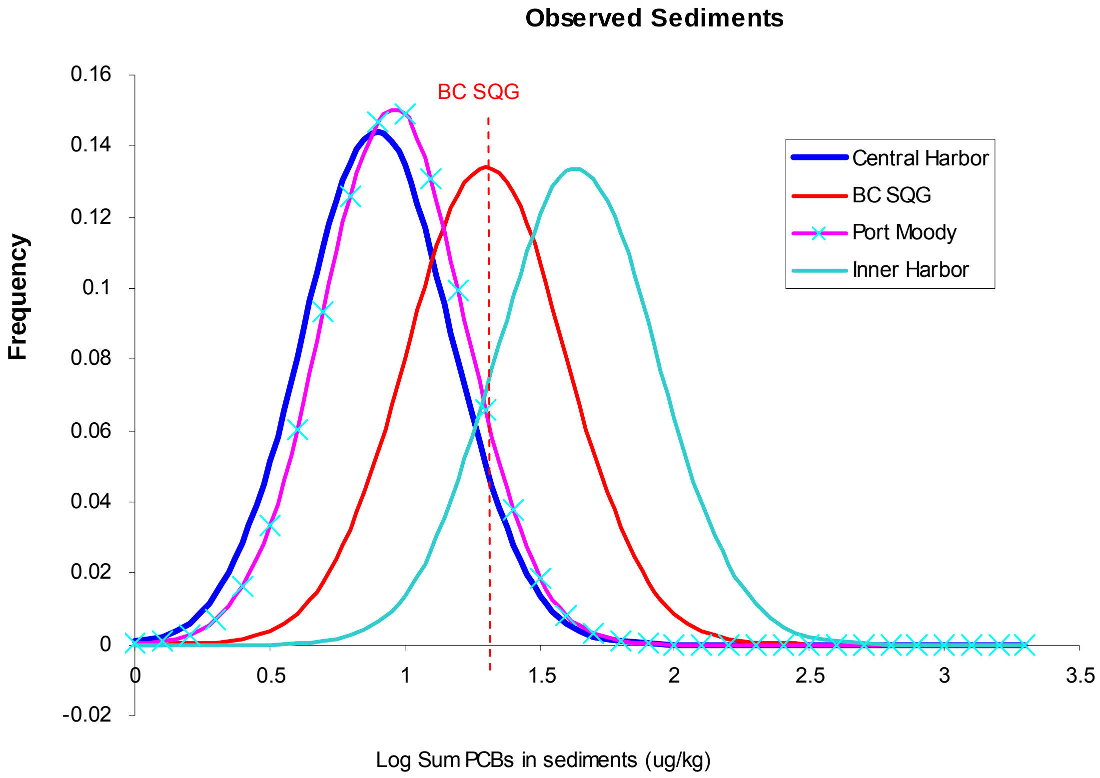


Figure 4.4.1 summarizes the observed log normal distribution of total PCB mixture in Inner Harbor based on three samples collected in summer of 2004 (blue line) in relation to the current BC SQG. The figure shows that the Inner Harbor log normal distribution is not in agreement with the current B.C. threshold concentration to protect wild life in Burrard Inlet. The current BC SQG is 20 ug/kg dw, while the geometric mean of the actual distribution in sediment concentrations is 43 ug/kg dw (which is equivalent, expressed in logarithmic format, to 1.3 and 1.64 ug/kg dw respectively). This indicates that fish and wildlife in Inner Harbor are exposed to PCB concentrations that exceed provincial quality guidelines and could potentially trigger toxic effects in biota. The SD

for the geometric mean are equivalent to a factor of 2 (0.297 in log format), which indicates, based only in three samples, that the PCB concentrations do not substantially diverge from the mean in this particular compartment.

Figures 4.4.1 to 4.4.19 illustrate the results of the model calculations of the total PCB concentrations in some key species of the Burrard Inlet food web. In these figures, threshold concentrations are usually represented not only by the geometric mean, but also by the probability distribution associated with it (mean and SD). The model calculations include the observed variability in the total PCB concentrations in Inner Harbor, but do not include the contribution to the variance in the PCB concentrations in biota calculated through MCS by the model's sensitivity analysis.

Figure 4.4.3 shows the Normal Probability Distributions (NPD) for the total PCBs in observed sediments in Inner Harbor (blue line) based on three samples collected in summer of 2004, as well as the geometric mean and associated probability distribution calculated by the model for the British Columbia Sediment Quality Guidelines (in log format). The black line represents a sediment concentration distribution where only 5% of the PCB concentrations in sediments would surpass the geometric mean of the current BC SQG.

The red lines in Figures 4.4.4 to 4.4.19 represent the current quality criteria to protect wildlife species, expressed as the geometric mean and associated log NPD of total PCB concentrations, that should not be exceeded. The pink lines, when data was available, represent the observed total PCB concentrations in each of the species based on Maldonado 2003 (76).

The blue lines in Figures 4.4.4 to 4.4.19 represent the distributions of predicted total PCB concentrations in the various species based on the spatial variability in the total PCB concentration in the sediment of Inner Harbor. We believed, that the contribution to variance incorporated through the direct extrapolation of the observed variability in sediments into the model's outcome, helped to obtain more realistic predictions which should be used for management purposes.

Finally, the black lines shown in most figures from Figures 4.4.3 to Figure 4.4.19, represent the 5% exceedance NPD. The purpose of these curves is to suggest a more conservative quality control criteria in which only 5% of the observed NPD would surpass or exceed the geometric mean of the current BC threshold / quality criteria. The purpose of the 5% exceedance model application is because using the geometric mean, is expected that half of the population of the compartment analyzed exceeds the criterion value while the PCB concentration in the other half of the population will be less than the criterion value.

Figure 4.4.3 shows that the 5% exceedance curve overlap the observed probability distribution for PCB concentrations in Inner Harbor almost at the geometric mean of the current BC SQG (1.3 ug/kg dw). In Figures 4.4.1 and 4.4.3, the geometric mean of the observed PCBs concentration in sediment are exceeding the BC SQG for approximately a factor of 0.5. The overlap of both curves (see specifically Figure 4.4.1) indicates the probability that the observed PCB sediment concentrations are greater than the geometric mean of the BC SQG. Therefore, the accumulative probability distribution plotted in Figure 4.4.2, shows that approximately 80 % of the observed sediment concentrations in Inner Harbor exceed the BC SQG. In figure 4.4.3 shows the level of disagreement between the observed sediment concentrations and the ideally 5% exceedance as the optimal control criteria. We observed that the grade of disagreement between curves is approximately of one order of magnitude or what is equivalent to an arithmetic mean of 0.8 ug/kg dw and 1.64 ug/kg dw for the 5% exceedance and observed distributions respectively.

Figure 4.4.4, incorporates the observed distribution for total PCB concentrations in False Creek into Figure 4.4. Figure 4.4.4, shows the log NPD for the three compartment sampled in this study (Inner Harbor, Central Harbor and Port Moody) plus the log NPD for False Greek based on Mackintosh et al. 2003. The red lines represent the geometric mean and probability distribution for the British Columbia Sediment Quality Guidelines and the new black doted line represent the average mean and probability distribution for the PCB concentrations in the previously mentioned four compartments . The average curve is simply the average for all NPD considered in the plot. Figure 4.4.4 shows that the level of agreement between the means of BC SQG and the average curve are almost identical (1.30 and 1.34 respectively). The later explain why we did not observed for most species a substantial exceedance in the sediment and biota quality criteria, given that most species selected for the analysis dwell in the whole Burrard Inlet area and therefore presenting a level of contamination that is close to the average curve in Figure 4.4.4. As a result, the PCB concentrations in some of the aquatic organism and wildlife species in the inlet may not represent the full spatial variation in PCB concentrations that is expected by the model in a particular compartment.

Figure 4.4.1: Normal Probability Distributions for the total PCBs in sediments observed in Inner Harbor (blue line) based on three samples collected in summer of 2004 as well as the geometric mean and associated probability distribution calculated by the model for the British Columbia Sediment Quality Guidelines.

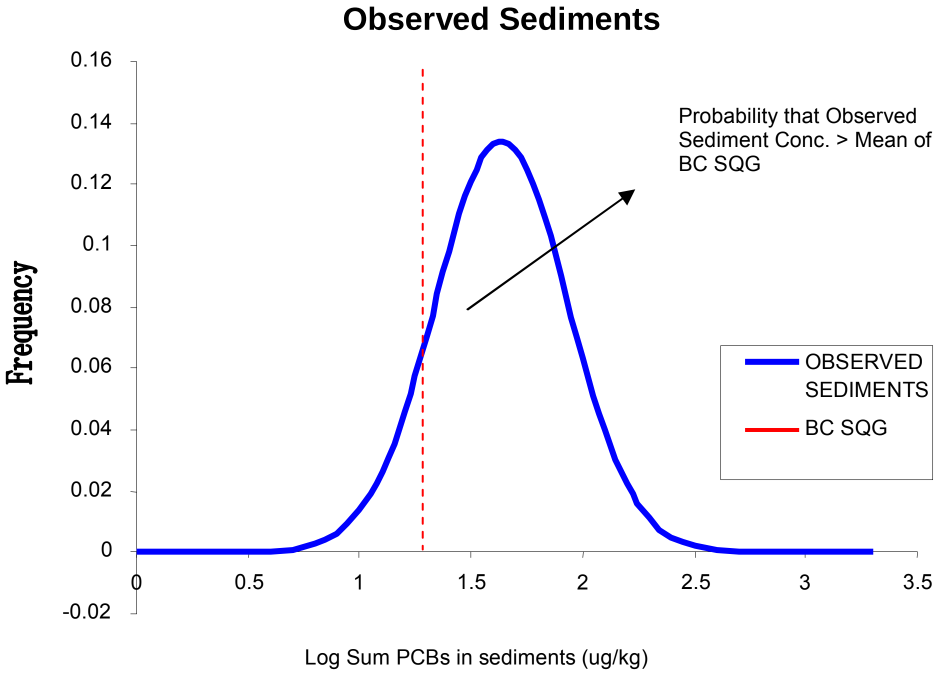


Figure 4.4.2: Cumulative Probability Distribution for the total PCB concentration in observed sediment samples in Inner Harbor for the summer of 2004 in relation to the BC SQG.

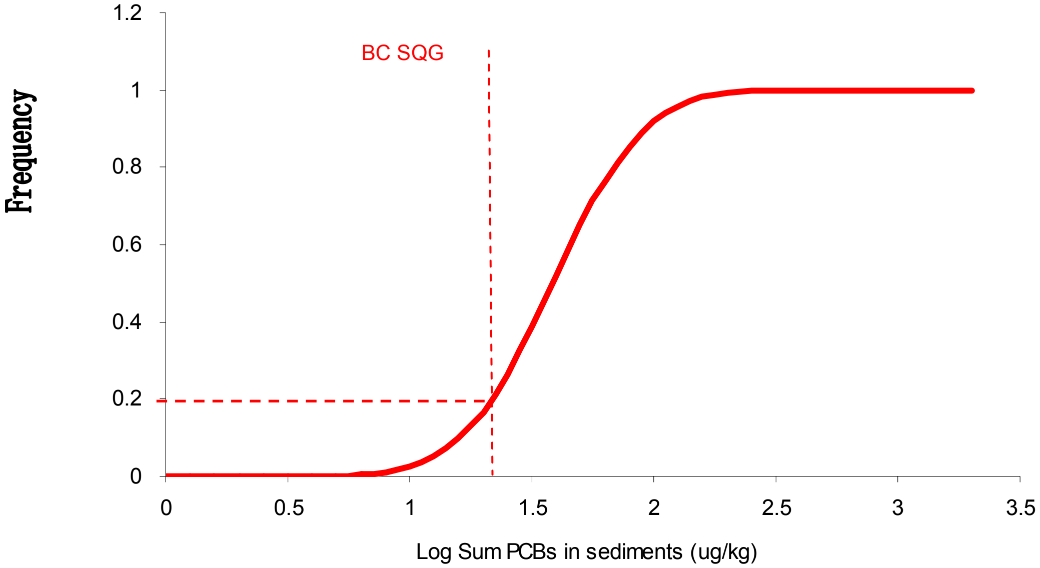


Figure 4.4.3: Normal Probability Distributions of total PCBs in sediments observed in Inner Harbor (blue line) based on three samples collected in summer of 2004 as well as the geometric mean and probability distribution for the British Columbia Sediment Quality Guidelines (in log format). The black line represent the recommended SQG in which only 5% of the PCB concentrations in sediments would surpass the geometric mean of the current BC SQG.

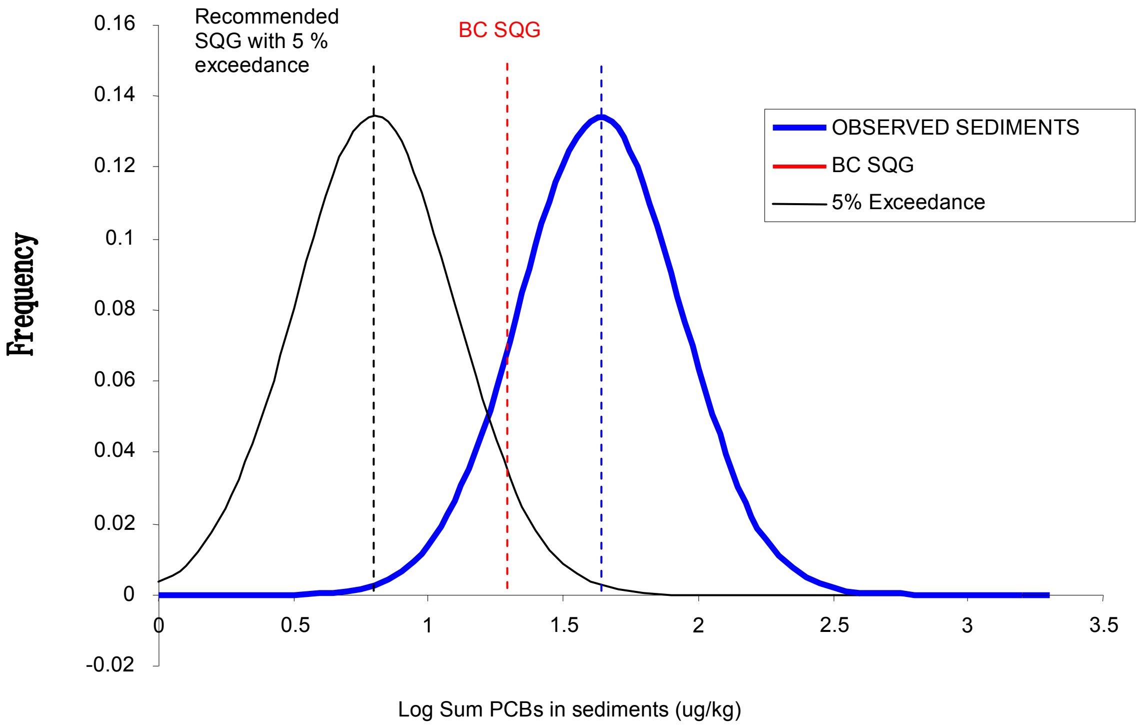
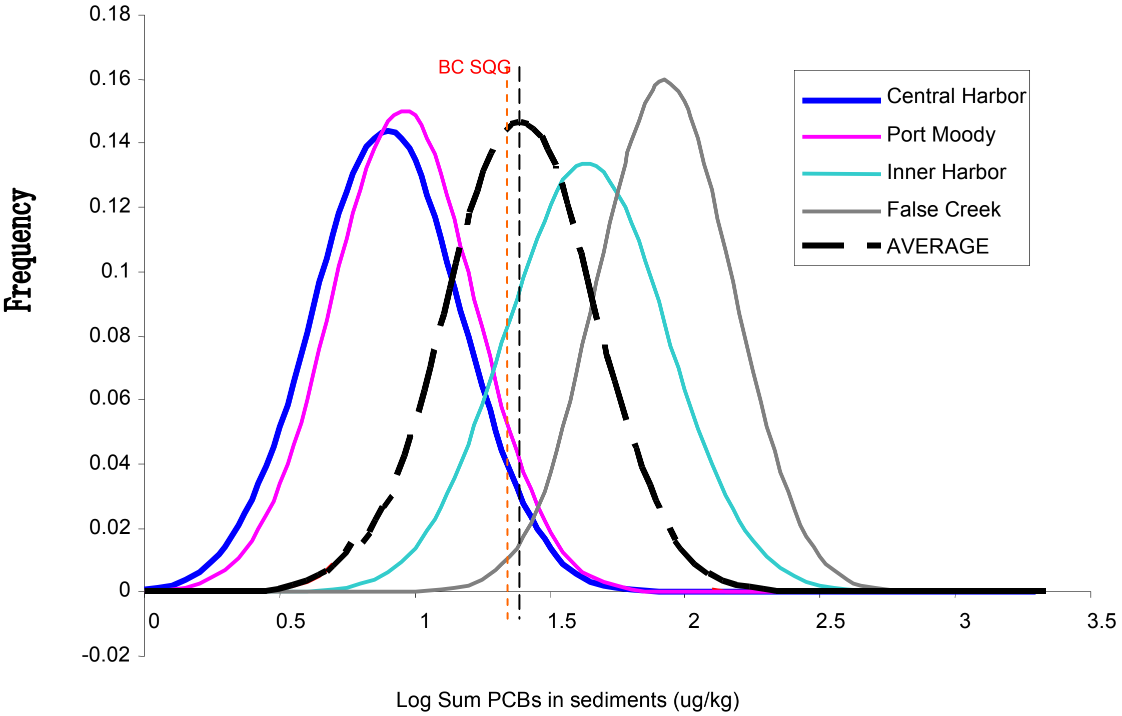


Figure 4.4.4: Distributions of sum PCBs in sediments observed in Inner Harbor (green line), Central Harbor (blue line), Port Moody (pink line) and False Creek (black solid line) based on three samples per site, collected in summer of 2004 and data for False Creek from Mackintosh et al. 2004. The black doted line represent the mean and probability distribution for the average curve.



It is also possible that the low number of sediment samples per compartment and the derived NPD does not provide an accurate description of the actual distribution of the PCB concentrations in the sediments or the PCB concentration distribution experienced by the biota of the inlet. Possibly, areas that are very contaminated with PCBs and areas that are devoid of PCB contamination are not perfectly identify by the sediment concentration database. To ascertain this possibility it is important to further explore in detail the spatial distribution of PCB concentrations in Burrard Inlet.

Figure 4.4.5 shows the Normal Probability Distribution for total predicted PCB concentrations in female adult harbor seals in Burrard Inlet calculated from sediment samples taken on summer of 2004. Predictions for all species are based on the variability in sediment concentrations and variability in the observed BSAF if empirical data is available. In more detail, Figure 4.4.6 shows that the geometric mean for the predicted PCB concentration distribution in harbor seals fell below the threshold concentration protecting this species. However the NPD exceeds the threshold by approximately 4%, which implies that total predicted PCB concentrations are almost in agreement with the ideally 5% exceedance curve and any further increase in sediment concentrations could be threatening harbor seals in the ecosystem. The latter is extremely important, in view of the fact that female seals usually present lower PCB concentrations in tissue than male seals. Female seals transfer a considerable amount of PCBs into the offspring while giving birth and later on, through the lactation process. As a consequence, it is expected to observed PCB concentrations in male seals that exceed protective threshold concentrations. Figure 4.4.11 illustrate the Normal Probability Distribution for total predicted PCB concentrations in adult male harbor seals in Burrard Inlet calculated from sediment samples taken in the summer of 2004. Figure 4.4.11 shows that approximately 95 % of the NPD exceeded the threshold concentrations. In other words, considering that we sample one hundred male seals and measure the PCB concentrations in tissue there will be an exceedance of the threshold concentration in 95 male seals (95 % of the cases) shown in figure 4.4.12. Finally, Figure 4.4.13, which includes the 5% exceedance curve, shows that the predicted PCB concentrations in male seals are a perfect “mirror image” of the 5% exceedance curve, reassuring that there is a 95% probability that male seals concentrations will exceed the geometric mean of the protective threshold criteria. Predicted PCB concentrations in cormorant male in Figures 4.4.8 to 4.4.10, show a similar exceedance of approximately 85 % from the threshold criteria.

Figure 4.4.5: Normal Probability Distribution for total predicted PCB concentrations in female adult harbor seals in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available.

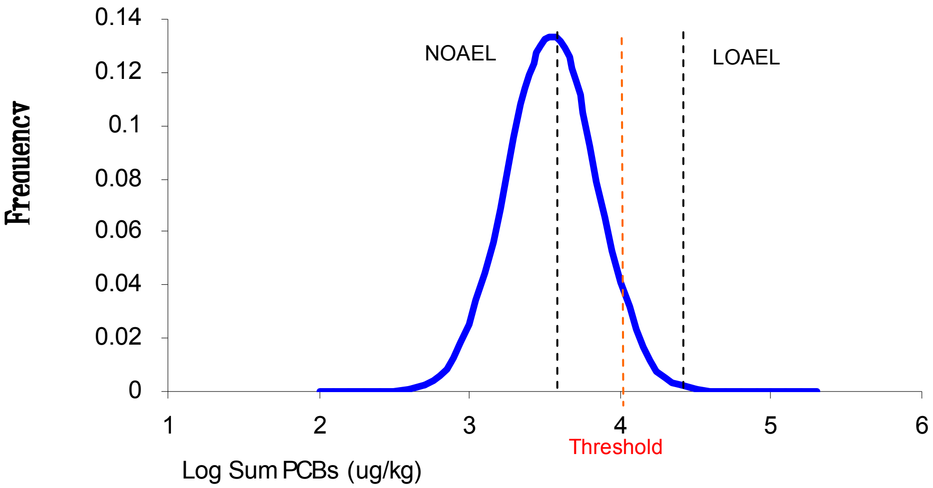


Figure 4.4.6: **Cumulative Probability Distribution for total predicted PCB concentrations in female adult harbor seals in Inner Harbor calculated from sediment samples taken in the summer of 2004**

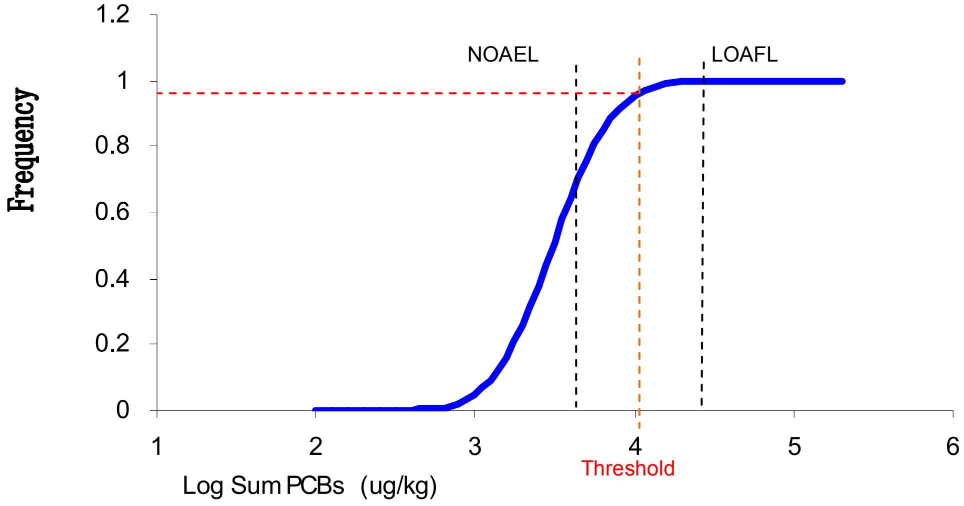


Figure 4.4.7: **Normal Probability Distributions for total predicted and 5% exceedance PCB concentrations in female adult harbor seals in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available**

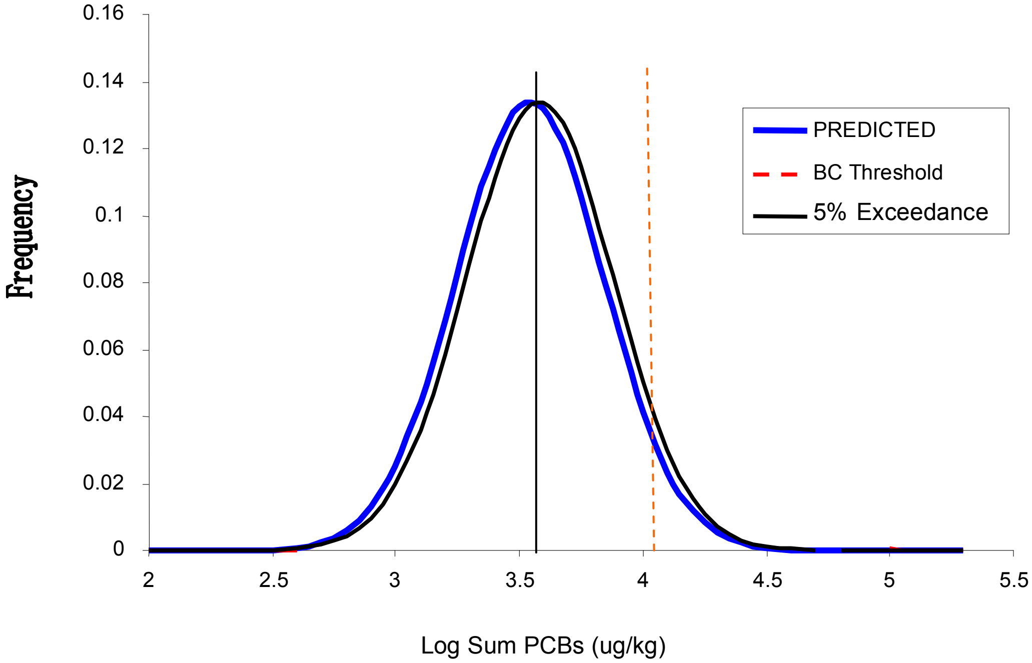


Figure 4.4.8: Normal Probability Distribution for total predicted PCB concentrations in male cormorant in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available.

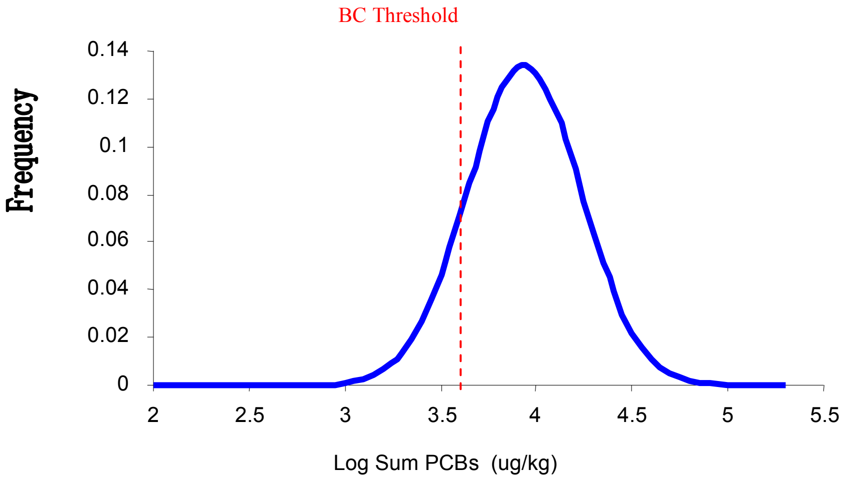


Figure 4.4.9: Cumulative Probability Distribution for total predicted PCB concentrations in male cormorant in Inner Harbor calculated from sediment samples taken in the summer of 2004.

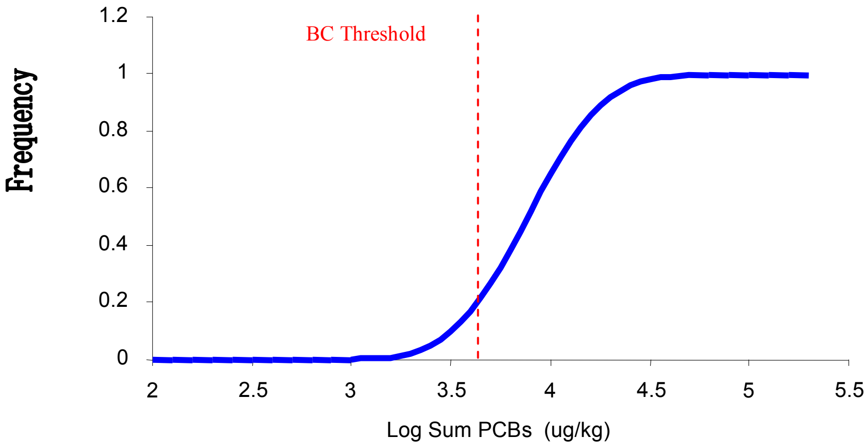


Figure 4.4.10: Normal Probability Distributions for total predicted and 5% exceedance PCB concentrations in male cormorant in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available)

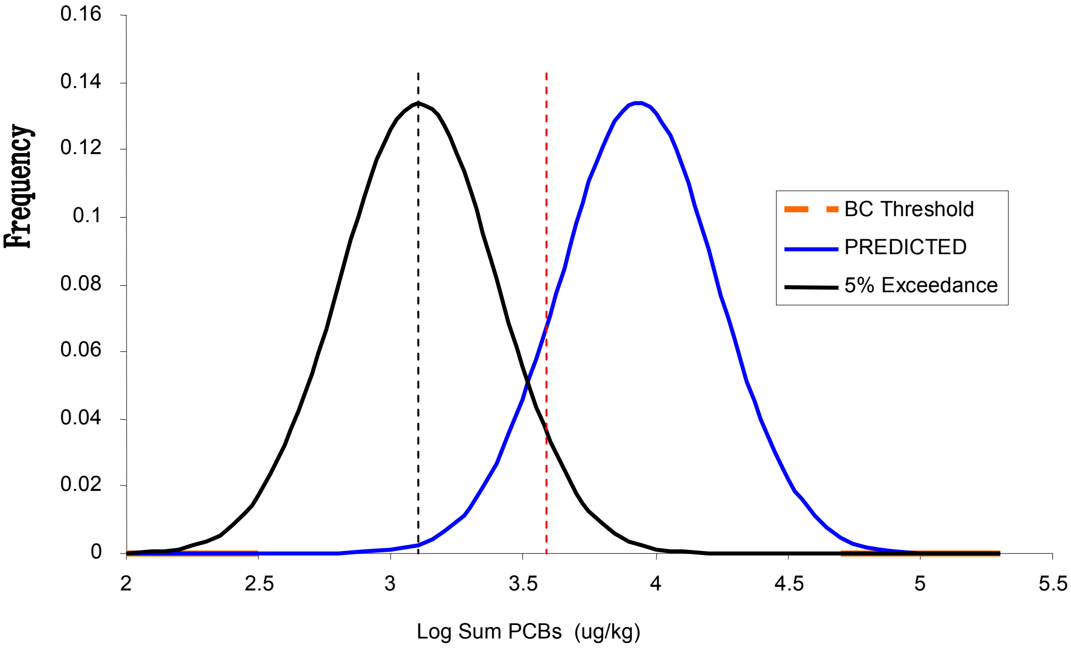


Figure 4.4.11: Normal Probability Distribution for total predicted PCB concentrations in adult male harbor seals in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on spacial variability in sediment concentrations and variability in the observed BSAF when empirical data is available

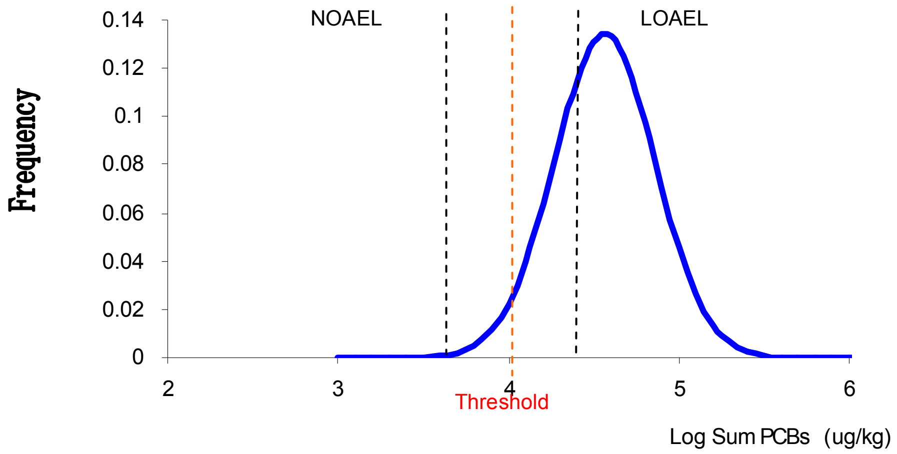


Figure 4.4.12: Cumulative Probability Distribution for total predicted PCB concentrations in female adult harbor seals in Inner Harbor calculated from sediment samples taken in the summer of 2004

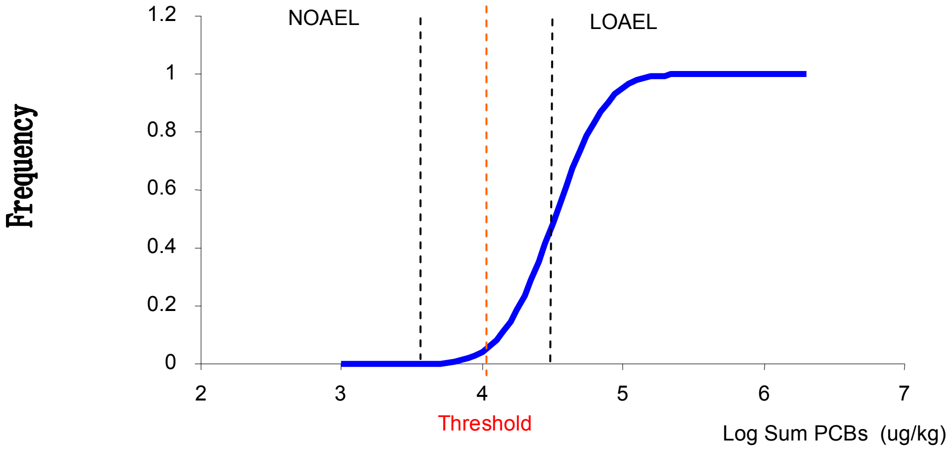


Figure 4.4.13: Normal Probability Distributions for total predicted, BC threshold and 5% exceedance PCB concentrations in male adult seals in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available.

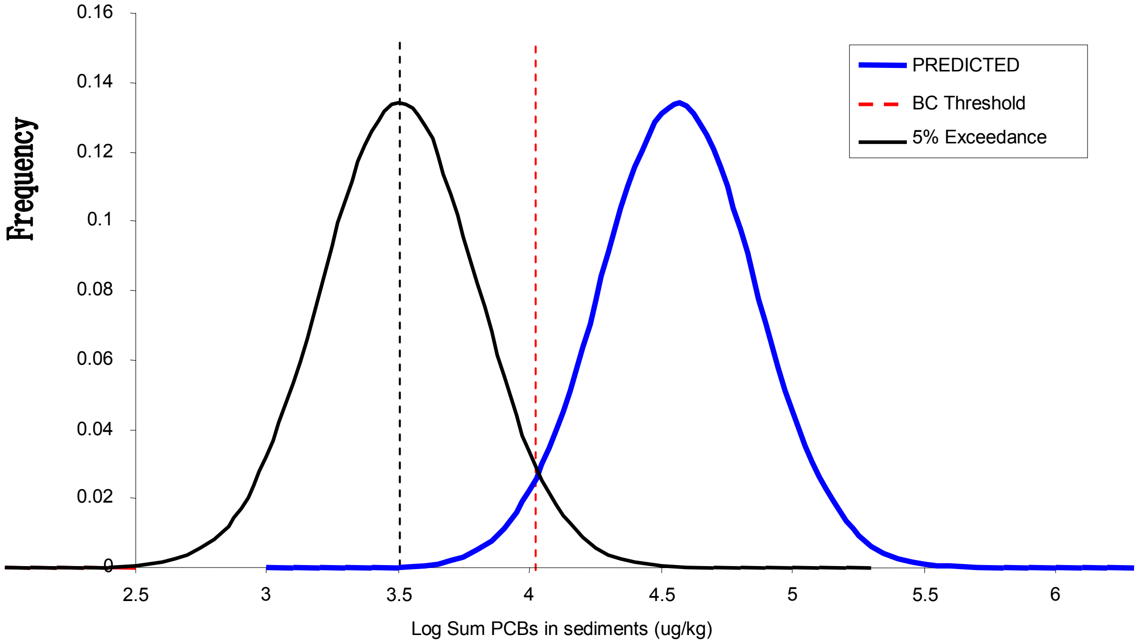


Figure 4.4.14: Normal Probability Distributions for total predicted, observed and 5% exceedance PCB concentrations in pacific staghorn sculpin in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available.

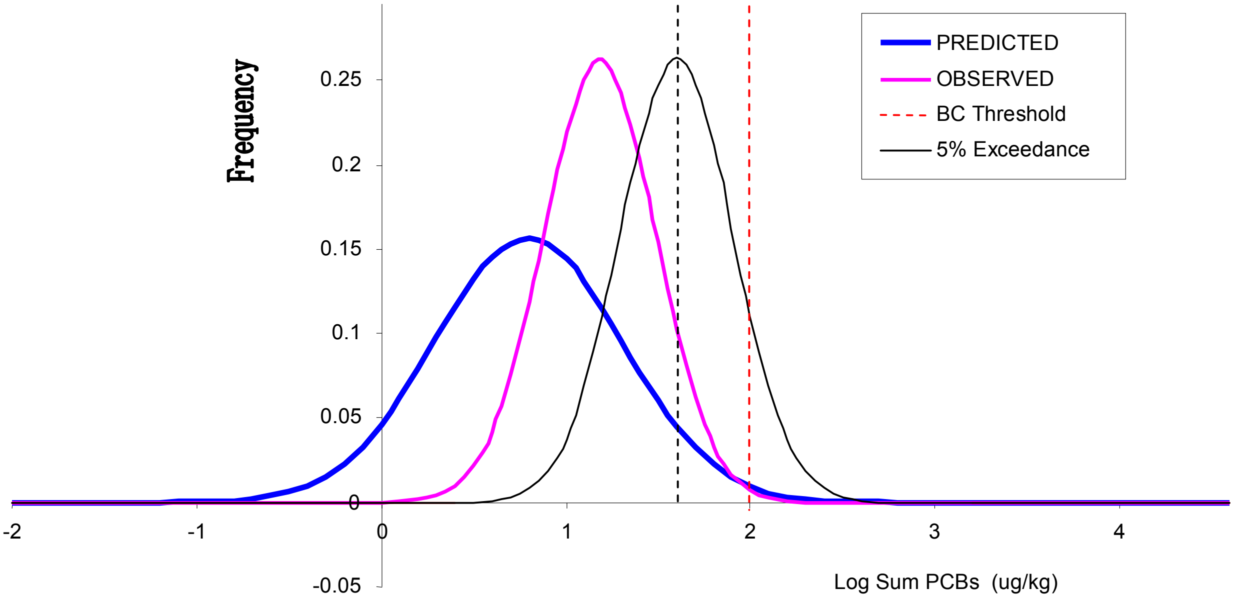


Figure 4.4.15: Cumulative Probability Distribution for total observed and predicted PCB concentrations in pacific staghom sculpin in Inner Harbor calculated from sediment samples taken in the summer of 2004

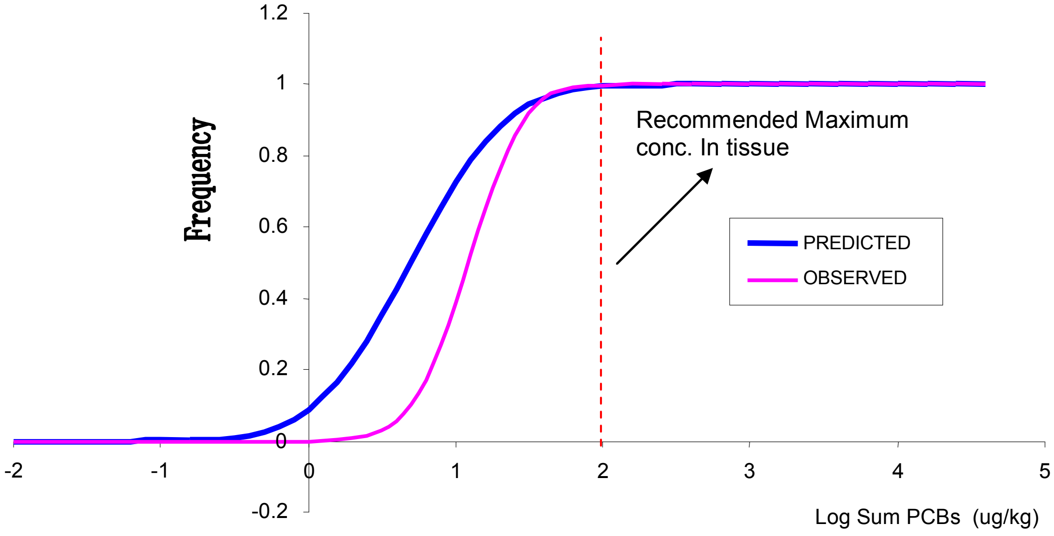


Figure 4.4.16: Normal Probability Distributions for total predicted and observed PCB concentrations in English Sole in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available.

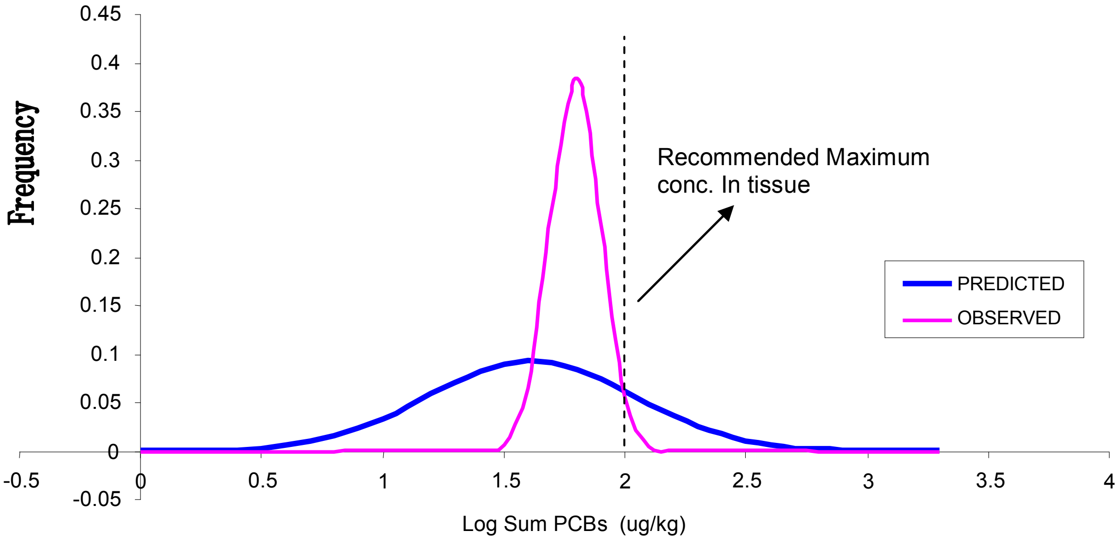


Figure 4.4.17: Cumulative Probability Distribution for total predicted PCB concentrations in English Sole in Inner Harbor calculated from sediment samples taken in the summer of 2004

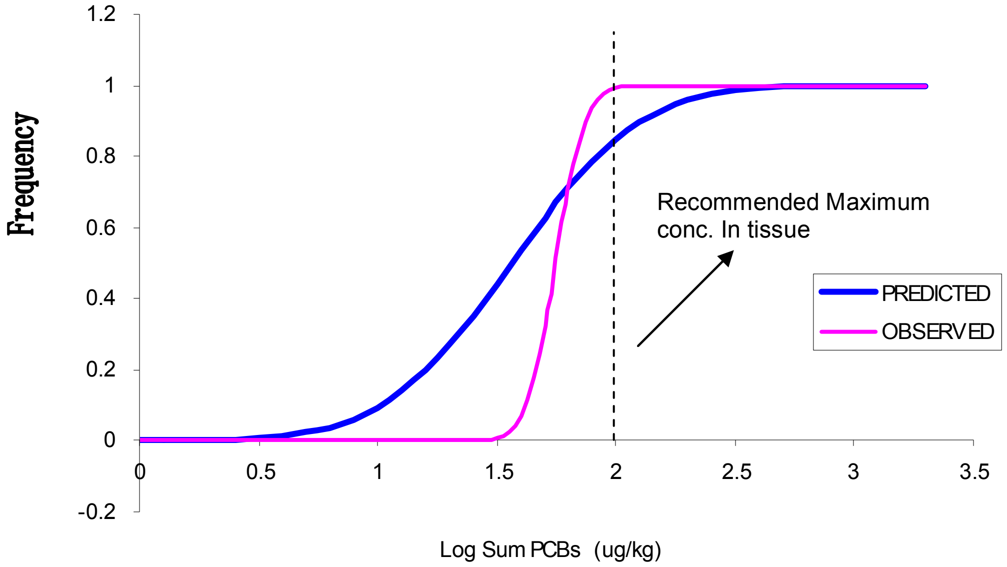


Figure 4.4.18: Normal Probability Distributions for total predicted, observed, BC threshold and 5% exceedance PCB concentrations in English Sole in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available.

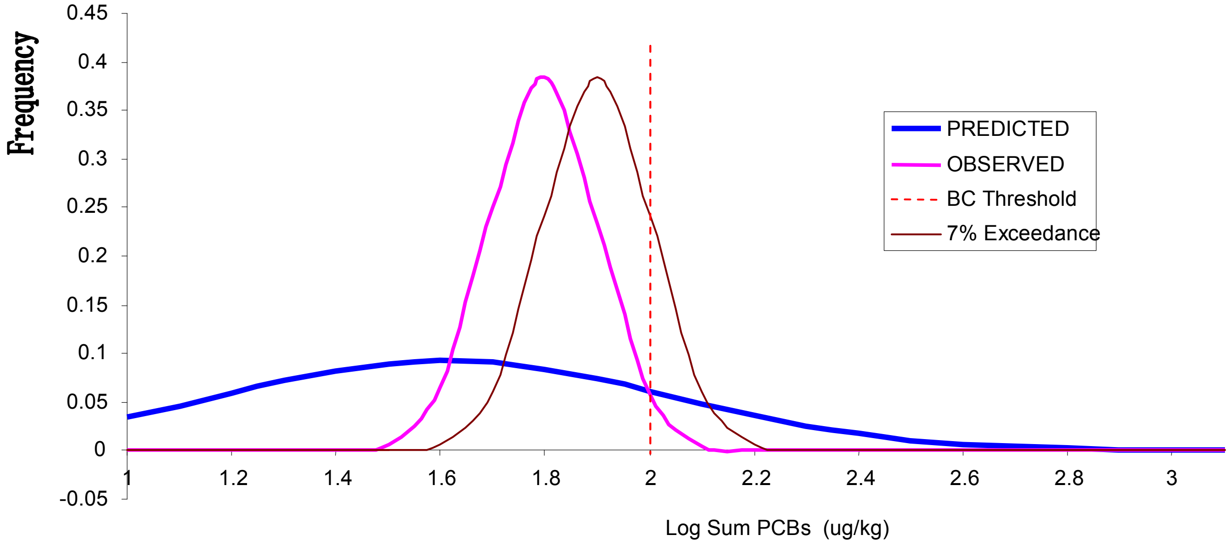


Figure 4.4.19: Cumulative Probability Distribution for total predicted PCB concentrations in Spiny Dogfish in Inner Harbor calculated from sediment samples taken in the summer of 2004.

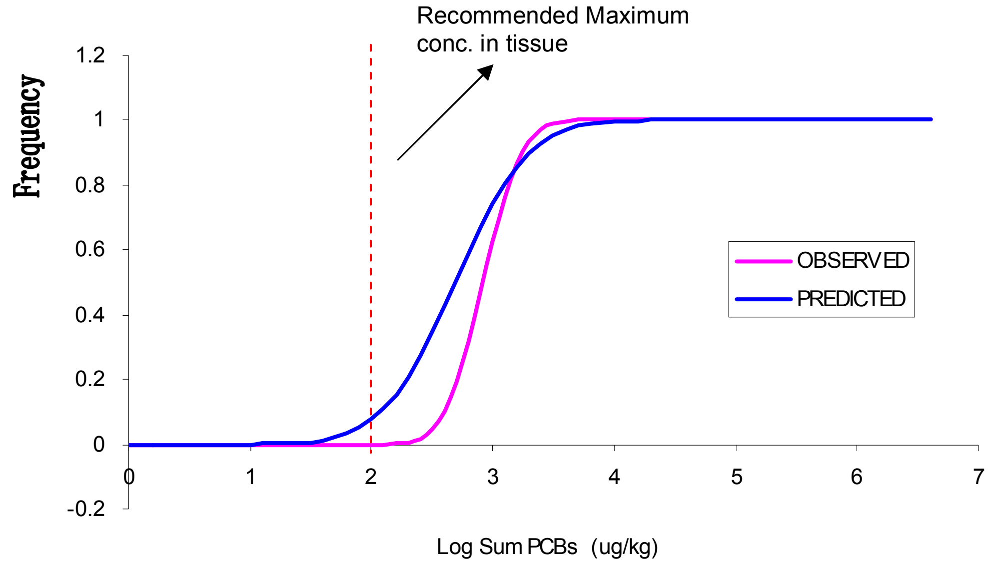
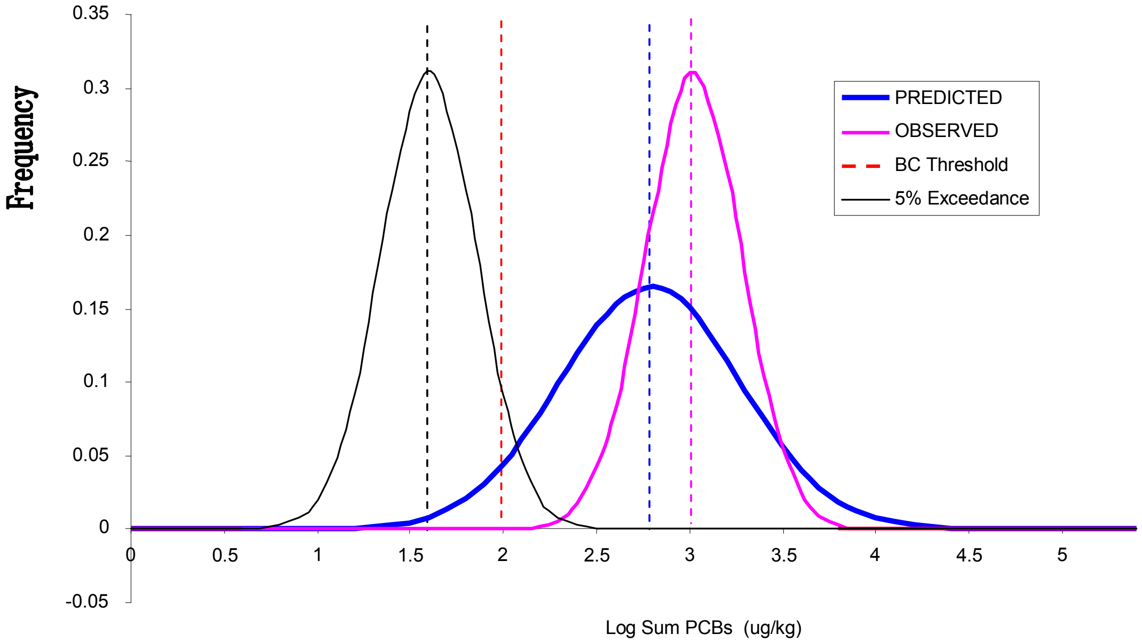


Figure 4.4.20: Normal Probability Distributions for total predicted, observed and 5% exceedance PCB concentrations in Spiny Dogfish in Inner Harbor calculated from sediment samples taken in the summer of 2004. Predictions are based on the observed spatial variability in sediment concentrations and variability in the observed BSAF when empirical data is available.



Finally, Figures 4.4.19 and 4.4.20 shows the accumulative and log Normal Probability Distribution respectively for total predicted PCB concentrations in Spiny Dogfish in Burrard Inlet. Figure 4.4.20 shows that the level of difference between current PCB threshold concentrations and empirical data (observed) is of one order of magnitude. Such exceedance of the current quality criteria in one order of magnitude (from 2 to 3 ug/kg) could be also of 1.5 order of magnitude if we decide to use the 5% exceedance curve (black line), as a more conservative threshold concentration criteria.

Even if the predicted NPD in Spiny Dogfish is approximately one order of magnitude wider than the observed NPD, the geometric means from both probability distributions do not substantially diverge from each other, which indicates a good level of agreement between model predictions and empirical data, considering that in this particular case, we are comparing model predictions for Inner Harbor with biota samples taken from False Creek. Figure 4.4.20 is a perfect example of how higher throphic level organisms, at the top of the food chain, usually exceed the threshold concentration criteria (internal concentration in tissue - see Table 4.5.2). Observed PCB concentrations in dog fish exceed the threshold quality criteria by one order of magnitude, while the observed PCB concentrations in sediment only exceed the sediment quality criteria by 0.5 order of magnitude. Also we should consider that larger fish usually dwell and feed in bigger areas, therefore, larger fish are most likely to be subject to a lower overall PCB concentration. Consequently, model's predictions for PCB concentrations in Spiny Dogfish represented in Figure 4.4.19, represented a situation where Spiny Dogfish are exclusively feeding in Inner Harbor.

There are a few general conclusions emerging from the comparison of the observed and model predicted distributions of PCB concentrations. First, as demonstrated later in section 4.1 (Model Performance), model predictions of concentrations of PCB congeners are in good agreement with the distributions of observed PCB concentrations. The geometric means of observed and predicted total PCB concentrations were comparable (i.e. within 20% of the model predicted geometric mean) for all species investigated in the model, with the exception of Pacific Staghom Sculpin. The geometric mean of the total PCBs concentration distribution for Staghom Sculpin was underestimated by 33 %. The later may be due to the fact that biota samples were collected in 1999 (Mackintosh et al.) where PCB exposure concentrations may have been higher than in 2004 when sediment samples were collected and used for the model's forward calculation. Also, all biota samples were collected in False Greek, where PCB exposure concentrations in sediment are the highest in the Inlet and the models predictions represented in Figures 4.4.1 to 4.4.20, were calculated from sediment samples in Inner Harbor. Thus, subsequent small model under-predictions in English Sole and Spiny Dogfish could be attributable to similar reasons. Secondly, the range of model predicted concentrations based on the spatial variability in the PCB concentration in the sediments and the predicted BSAF was in most cases greater than the range of observed concentrations. Thirdly, among all compartments sampled in the inlet, total predicted and observed PCB concentration in sediments are not in excess of the B.C. sediment quality criteria, with the exception of sediment samples taken from Inner Harbor and False Creek. In the case of Inner Harbor, most species show PCB concentrations below the threshold quality criteria, with the exclusion of some higher throphic level organism, like Spiny dogfish, male Seals and male Cormorant. The later could be explained due to the fact that some birds and large fish species could be very mobile, feeding from many different and less contaminated compartments, therefore reflecting levels of exposure to PCB contamination that do not surpass the current quality criteria. The model's predicted BSAFs incorporate such spatial variability through the model performance analysis and parameterization stages based on False Creek empirical data provided by Maldonado 2004 and Mackintosh et al. 2003 (76,77).

4.5. Backward Calculation: Estimation of Total PCB Concentrations in sediments from endpoints in Fish and Wildlife.

The main purpose of the backwards calculation is to recommend a PCB concentration in sediment that meets an appropriate ecological risk criteria and/or human health endpoints. The selection of human health and ecological risk criteria is usually subject to debate. As a result, different criteria may emerge and also how such a criterion is applied to empirical data varies depending on the goals of the remedial initiatives. Therefore, the model's structure allows to easily adjust or change to a different new criteria.

Aquatic life is the most sensitive factor with respect to polychlorinated biphenyls contamination in humans. It was noted that consumable water was a minor source of PCB body burden for humans and animals and there was more likelihood of adverse effects from PCBs in the environment due to consumption of contaminated foods (most likely sea food resulting from contaminated aquatic life). Therefore, it is of paramount importance to recommend sediment quality guidelines that well protect wildlife and high throphic level organisms in the inlet. The aquatic life (freshwater and marine) criterion recommended by the Ministry of the Environment in B.C. is one to two orders of magnitude lower than the Canadian Water Quality Guidelines (CCREM, 1987; CCME, 1991)(91,92). Canadian Environmental Quality Guidelines for PCBs, provide nationally consistent benchmarks for environmental quality across Canada and are intended as decision support tools in protecting and sustaining aquatic and terrestrial ecosystems in Canada and the beneficial uses they support. Accordingly, to protect wildlife from harmful effects of PCBs in the diet, it is recommended by the provincial government, that the concentration of total PCBs in fish and shellfish should not exceed 0.1 μg/g wet weight in whole fish for wildlife consumption and 2.0 µg/g wet weight for human consumption (see table 4.6.2).

Table 4.5.1 shows a summary of several human health and ecological risk criteria for Polychlorinated Biphenyls (PCBs), including Non cancer risk hazard indices for the consumption of three species of primary interest, Human excess lifetime cancer risk and other acceptable threshold effects concentrations also summarized in Table 4.5.3

Table 4.5.1: Human health end points and ecological risk criteria used to "backwards calculate" the PCB target concentration in sediment that should not be exceeded to preserve human health and ecological integrity.

End Points	Value	Units
Human Health		
Acceptable Upperbound Estimate of Excess LifeTime Cancer Risk	0.00001	no units
Acceptable Human Health Hazard Index	1	no units
Ecological Risk		
Acceptable Threshold Effects Concentration-Shiner Surfperch	20	ug Aroclors/kg ww
Acceptable Threshold Effects Concentration-Jacksmelt	20	ug Aroclors/kg ww
Acceptable Threshold Effects Concentration-White Croaker	20	ug Aroclors/kg ww
LOAEL - Cormorant Egg	5000	ug/kg
NOAEL - Cormorant Egg		ug/kg
LOAEL - Tern Egg	4000	ug/kg
NOAEL - Tern Egg		ug/kg
Threshold Effects Concentration - Harbor Seals	11000	ug/kg lipid
LOAEL - Harbor Seals	25000	ug/kg lipid
NOAEL - Harbor Seals	5000	ug/kg lipid

Table 4.5.2: Summary of the provincial criteria for Polychlorinated Biphenyls (PCBs)

Water Use	PCBs	Recommended MaximumConcentration
Drinking Water Supply	—	None proposed
Wildlife	—	None proposed
Livestock Water Supply	—	None proposed
Irrigation Water	Total	0.5 µg/L
Primary Contact Recreation	—	None proposed
Freshwater and Marine Aquatic Life	TotalPCB #105PCB #169 PCB #77PCB #126	0.1 ng/L0.09 ng/L0.06 ng/L0.04 ng/L0.00025 ng/L
Freshwater and Marine Aquatic Life- Fish and/or Shellfish(for wildlife consumption: whole animal)	Total	0.1 µg/g wet weight
Freshwater and Marine Aquatic Life- Fish and/or Shellfish(for human consumption: edible tissue only)	Total	2.0 µg/g wet weight
Freshwater and Marine Aquatic Life- Sediment(*containing 1% organic carbon)	Total	0.02 µg/g dry weight

*Note: If sediment organic carbon is not 1%, the criteria is = (0.02 µg/g) x (1% organic carbon content).

Table 4.5.2 shows a summary of the environmental quality criteria for Polychlorinated Biphenyls (PCBs) for sediment, freshwater and marine aquatic life. Prepared pursuant to Section 2(e) of the Environment Management Act, 1981.(Assistant Deputy Minister Ministry of Environment, Lands and Parks, signed in January 24, 1992)

Table 4.5.3 presents the geometric mean concentrations of total PCB in sediments, calculated by the model, from the geometric means concentration in biota that meet human health and ecological criteria in Burrard Inlet. Figure 4.5.1 is a graphic representation of Table 4.5.3 and shows that the current sediment concentration of False Creek (84 ± 1.77 ug/kg dw) surpasses several calculated sediment target concentrations from selected critical endpoints in humans and aquatic organisms. Surf sooter and Pacific

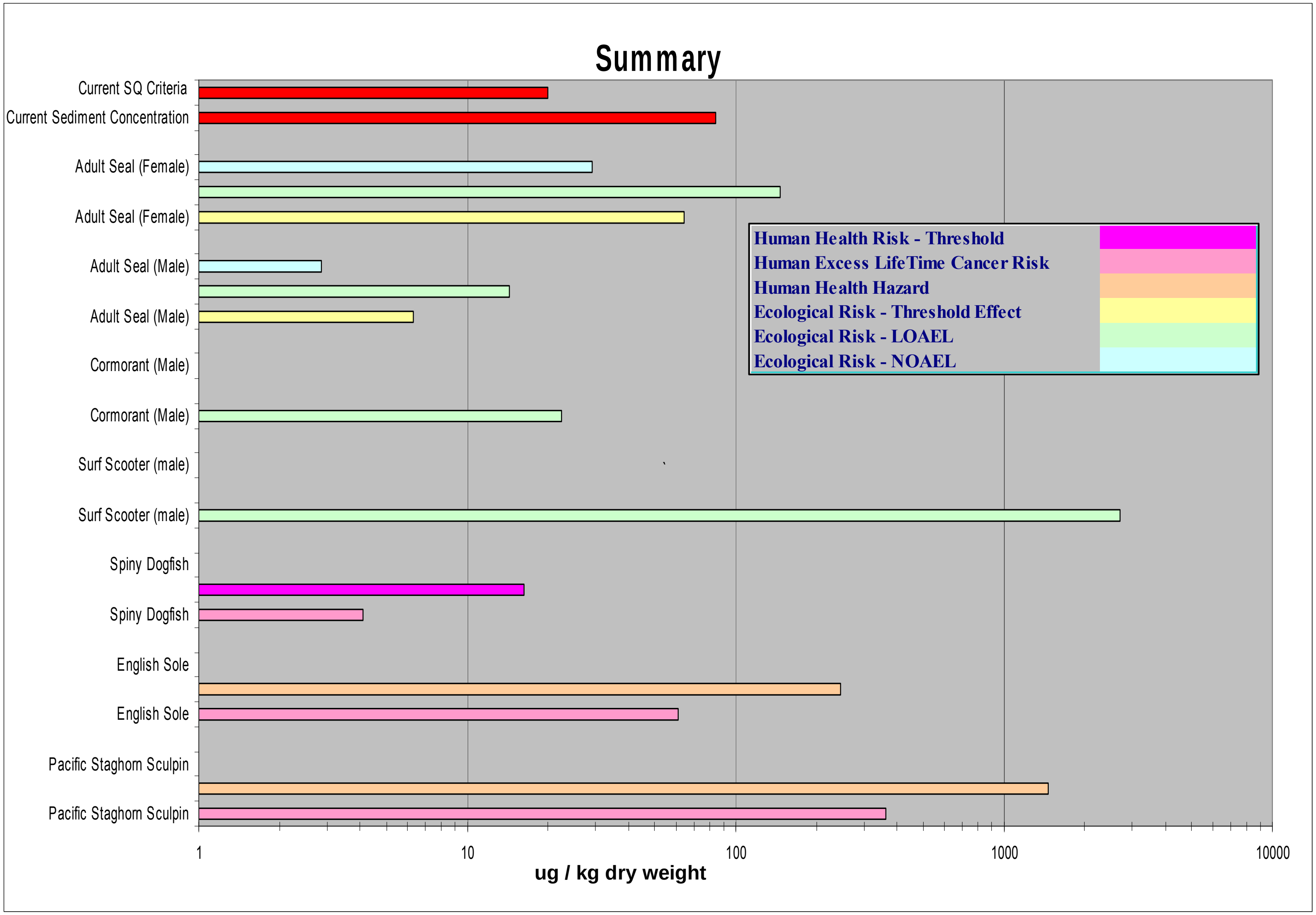
Staghorn Sculpin are the only two aquatic species in the plot that are expected not to be at risk at the current level of PCB contamination.

Figure 4.5.1 also compares the current BC sediment quality criteria of 20 ug/kg dw with the new calculated sediment quality criteria expected to meet the toxicological endpoints for six key species. Although the current sediment quality criteria is four times smaller than the observed sediment concentration, it still surpasses all model's recommended sediment target concentrations for male seals and Spiny dogfish. Figure 4.5.1 suggests that the current sediment quality criteria is not protective of key biological receptors at the top of the food chain, since do not meet several human health endpoints and ecological risk criteria (see Table 4.5.1) used to "backwards calculate" target PCB concentrations in sediment that should not be exceeded. The ecological risk threshold level of 6 ug/kg dw in sediments for male seals is below the current BC SQC and also the ecological risk criteria of 14 ug/kg dw for the LOAEL in the same species. Estimated PCB concentrations in sediment based on no-cancer risk hazard indices for the consumption of spiny dogfish are less than 16 ug/kg dw while current BC SQG geometric mean is 20 ug/kg dw. Current total PCB concentrations in sediment of different compartments of Burrard Inlet can be expected to produce geometric means for total PCB concentrations in fish and wildlife that do not meet the criteria investigated in this research project, thus Table 4.5.3 illustrates the levels of PCB concentration in sediment that need to be achieved to meet the various and previously mentioned human health and ecological risk criteria. Table 4.5.3 shows that human excess lifetime cancer risk criterion of 1.10^{-5} for fish consumption in the inlet can be expected to be the new recommended criteria, if the geometric mean of total PCB concentration in sediment is reduced to 3 ug/kg dw. The later value still implies that approximately half the population of male seals can be expected to exceed the threshold effect concentration. The geometric mean of total PCB concentrations in sediment that is required to produce only 5% exceedance of the threshold effect concentration in male seals is 1.13 ug/kg dw. The model is very versatile and also has been develop with the purpose of easily exploring different future scenarios.

Table 4.5.3: Geometric mean concentrations of PCB in the sediment calculated from the geometric means concentration in biota that meet human health and ecological criteria in Burrard Inlet.

Output		TARGET	TARGET
Organism	Endpoint	SUM PCBs (SFEI) Tissue Concentration (ug/kg wet weight)	SUM PCBs (SFEI) Sediment Concentration (ug/kg dry weight)
Pacific Staghorn Sculpin	Human Excess LifeTime Cancer Risk	52	364
Pacific Staghorn Sculpin	Human Health Hazard	207	1456
Pacific Staghorn Sculpin	Ecological Risk - TEQ		
Pacific Staghorn Sculpin	Ecological Risk - SUM Aroclor	20	
English Sole	Human Excess LifeTime Cancer Risk	52	61
English Sole	Human Health Hazard	207	245
English Sole	Ecological Risk - TEQ		
English Sole	Ecological Risk - SUM Aroclor	20	
Spiny Dogfish	Human Health Risk - Cancer	52	4
Spiny Dogfish	Human Health Risk - Threshold	207	16
Spiny Dogfish	Ecological Risk - TEQ		
Spiny Dogfish	Ecological Risk - SUM Aroclor	20	
Surf Scooter (male)	Ecological Risk - LOAEL	5000	2717
Surf Scooter (male)	Ecological Risk - NOAEL		
Surf Scooter (male)	Ecological Risk - TEQ		
Surf Scooter (male)			
Cormorant (Male)	Ecological Risk - LOAEL	4000	22
Cormorant (Male)	Ecological Risk - NOAEL		
Cormorant (Male)	Ecological Risk - TEQ		
Cormorant (Male)			
Adult Seal (Male)	Ecological Risk - Threshold Effect	4730	6
Adult Seal (Male)	Ecological Risk - LOAEL	10750	14
Adult Seal (Male)	Ecological Risk - NOAEL	2150	3
Adult Seal (Male)	Ecological Risk - TEQ		
Adult Seal (Female)	Ecological Risk - Threshold Effect	4730	65
Adult Seal (Female)	Ecological Risk - LOAEL	10750	147
Adult Seal (Female)	Ecological Risk - NOAEL	2150	29
Adult Seal (Female)	Ecological Risk - TEQ		

Figure 4.5.1: **Target PCB concentrations in sediments expected to meet various human health and ecological risk objectives calculated from the geometric means concentration in biota that meet human health and ecological criteria in Burrard Inlet.**



5. CONCLUSIONS

In this study I developed a computer model to describe the fate of contaminant discharges in different compartments in Burrard Inlet. The model was intended to be a tool that can be used to assess the magnitude of PCBs contamination in the Inlet and recommend better sediment quality guidelines. In essence, the model developed, uses mathematical equations describing uptake and elimination of contaminants to explain the dynamics of a number of PCB congeners in water, sediments and its distribution in various aquatic and terrestrial organisms (Section 3).

Potential uses and benefits of this model include the consideration of point and non-point sources of chemical discharges, PCBs loadings management, development and application of a more protective environmental quality criteria, not only for PCBs, but also applicable to other emerging POPs. Also, through the application of emerging geographic information technology, it is possible to analyze the geographic distribution and dynamics of PCBs in detail, improve the collection of empirical data and properly maintain current databases.

The model assesses the exposure of non-ionizing hydrophobic organic chemicals with a log Kow from 1 to approximately 9. It is also a useful tool to predict the PCBs dynamics in a specific environment. The model gives description of how PCBs can partition into different compartments and into the food web, improves the understanding of the fate and distribution of PCBs and with its results, we can recommend management actions to protect higher trophic level organisms. Also, the model focus on humans as the main biological receptor in the food chain and recommend the optimal sediment target levels that do not trigger adverse effects in humans.

The model performance analysis shows reasonable agreement between predicted and observed BSAFs for approximately 30 species considered in the food web. The model's predicted BSAFs are within a close range of the geometric mean of the observations (average $MB_{\text{by species}} = 1.77$ and average $MB_{\text{by congener}} = 1.34$). Congener patterns of PCBs in all organisms are reasonably well reproduced by the model, indicating that an apparent agreement exists between observed and predicted BSAFs along a selected mixture of PCBs congeners. Small over predictions of BSAFs for heavy chlorinated PCBs in some species was observed and may be attributable to seasonal changes in the diet and/or a barrier to the transfer/uptake of high Kow PCBs. Another factor to consider is that the food web adopted by the model is assumed to include only resident species. However, it is known that several species like Spiny Dogfish, English Sole, Pacific Staghorn Sculpin and Pacific Hearring are mobile stocks in response to seasonal changes and water temperatures. The model's over prediction for surf Scoters is attributable to the migratory nature of this bird species. The model's assumption is that surf Scoters are feeding exclusively in False Creek; instead, diet intake for most bird species is expected to be extended over the boundaries of False Creek towards less contaminated areas, showing as a consequence, less signs of contamination by PCBs.

In accordance with the results and considering the previously mentioned limitations, the model also demonstrates that the current BC sediment quality criteria is not sufficiently protective of high throphic level and terrestrial organisms.

Figure 4.5.1 shows that the most sensitive species are adult male harbor seals with a resulting concentration in sediment that trigger adverse effects of 3 ug/kg dw. Considering that a concentration of 3 ug/kg dw is associated with a probability distribution where approximately half of the male seal population can be expected to contain PCB concentrations that exceed the threshold effects concentration of PCBs uin harbor seals. It is important to take a more conservative approach and recommend a new value that will be protective of 95 % of the population of male seals. The geometric mean of total PCB concentrations in sediment that is required to produce only 5% exceedance of the threshold effect concentration in male seals is 1.13 ug/kg dw.

According to the results, current sediment quality guidelines should be revised and reduced approximately 18 times or by a factor of 0.055 to better protect higher trophic level organism (New SQG = Current SQG / 18).

Results provided significant evidence of bioaccumulation of a PCB mixture in some key biological receptors in the food web and also contributed to knowledge to the science of toxicology, in recommending a new sediment quality criterion in the Burrard Inlet ecosystem.

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APPENDICES

Appendix A: PCB Concentrations in Biota, Seawater, and Sediment

Table A-1: Geometric Means and Upper and Lower Limits (1 Std. Dev.) of Lipid-Normalized Biota Concentrations (pg/kg LW) for 18 Marine Organisms from False Creek Harbour. Lipid Content (LC) are also reported.

PCB CONGENER	Brown Algae (N = 2)				Plankton (N = 7)				Green Algae (N = 8)			
	LC = 2.28% ± 1.87% (1 SD)				LC = 0.30% ± 0.08% (1 SD)				LC = 2.38% ± 0.60% (1 SD)			
	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)
18	0	ND	n/a	n/a	0	ND	n/a	n/a	0	ND	n/a	n/a
16/32	0	ND	n/a	n/a	1	8.27E+00	n/a	n/a	1	1.34E+00	n/a	n/a
73/52	1	2.15E+00	n/a	n/a	2	8.26E+00	2.23E+01	3.06E+00	4	4.28E+00	1.25E+01	1.47E+00
47/75/48	0	ND	n/a	n/a	2	2.98E+00	4.85E+00	1.83E+00	3	1.50E+00	2.12E+00	1.06E+00
101/90	2	5.04E-01	2.84E+00	8.96E-02	6	5.21E+00	1.65E+01	1.64E+00	8	2.66E+00	1.87E+01	3.77E-01
99	1	5.50E-01	n/a	n/a	2	9.42E+00	1.68E+01	5.29E+00	6	2.02E+00	1.43E+01	2.86E-01
110	2	4.59E-01	1.19E+00	1.76E-01	7	5.13E+00	1.53E+01	1.72E+00	8	2.75E+00	2.33E+01	3.24E-01
118	2	1.81E-01	4.47E-01	7.36E-02	7	4.01E+00	1.25E+01	1.29E+00	8	2.76E+00	2.13E+01	3.57E-01
149	2	4.68E-01	1.46E+00	1.50E-01	7	4.41E+00	1.17E+01	1.66E+00	8	2.61E+00	1.71E+01	3.96E-01
132/153	2	4.07E-01	7.43E-01	2.23E-01	7	7.64E+00	1.89E+01	3.09E+00	8	4.20E+00	2.89E+01	6.10E-01
160/163/164/138	2	4.19E-01	7.12E-01	2.46E-01	7	6.86E+00	1.81E+01	2.60E+00	8	4.50E+00	3.44E+01	5.89E-01
187/182	1	4.65E-02	n/a	n/a	7	2.93E+00	7.45E+00	1.16E+00	7	1.48E+00	8.69E+00	2.51E-01
177	0	ND	n/a	n/a	3	9.45E-01	2.26E+00	3.95E-01	8	3.54E-01	3.00E+00	4.18E-02
180	1	8.83E-02	n/a	n/a	7	2.52E+00	6.33E+00	9.99E-01	7	2.17E+00	1.26E+01	3.71E-01
200	0	ND	n/a	n/a	1	9.73E-01	n/a	n/a	3	6.55E-01	8.99E-01	4.78E-01
194	0	ND	n/a	n/a	2	1.29E+00	2.82E+00	5.89E-01	7	5.05E-01	2.61E+00	9.77E-02
203/196	0	ND	n/a	n/a	2	1.59E+00	2.57E+00	9.89E-01	7	5.93E-01	2.41E+00	1.46E-01
206	0	ND	n/a	n/a	1	6.96E-01	n/a	n/a	5	4.30E-01	1.66E+00	1.11E-01
208	0	ND	n/a	n/a	0	ND	n/a	n/a	3	3.31E-01	3.70E-01	2.97E-01
209	0	ND	n/a	n/a	0	ND	n/a	n/a	5	3.17E-01	9.59E-01	1.05E-01

Notes: PCB congeners listed as BZ numbers. Abbreviations: N = Number of biota samples; n = number of values above MRLs (which make up the geometric means and upper and lower limits); UL = Upper Level (1 standard deviation above the geometric mean); LL = Lower Level (1 standard deviation below the geometric mean).

Table A-1 (continued). Geometric Means and Upper and Lower Limits (1 Std. Dev.) of Lipid-Normalized Biota Concentrations (pg/kg LW) for 18 Marine Organisms from False Creek Harbour. Lipid Content (LC) are also reported.

PCB CONGENER	Manila Clams (N = 3)				Blue Mussels (N = 7)				Pacific Oysters (N = 8)			
	LC = 1.17% ± 0.17% (1 SD)				LC = 1.25% ± 0.10% (1 SD)				LC = 2.06% ± 0.64% (1 SD)			
	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)
18	1	4.12E+00	n/a	n/a	0	ND	n/a	n/a	4	3.94E+00	5.20E+00	2.98E+00
16/32	3	4.43E+00	5.03E+00	3.89E+00	1	3.44E+00	n/a	n/a	5	4.64E+00	6.75E+00	3.19E+00
73/52	3	1.58E+01	1.96E+01	1.28E+01	5	3.55E+01	5.56E+01	2.27E+01	8	3.11E+01	5.39E+01	1.80E+01
47/75/48	3	9.24E+00	1.09E+01	7.81E+00	5	1.92E+01	2.93E+01	1.25E+01	8	1.39E+01	2.36E+01	8.16E+00
101/90	3	2.38E+01	2.86E+01	1.98E+01	7	7.96E+01	1.20E+02	5.27E+01	8	7.55E+01	1.40E+02	4.07E+01
99	3	1.49E+01	1.73E+01	1.29E+01	7	4.70E+01	6.90E+01	3.21E+01	8	4.18E+01	7.48E+01	2.34E+01
110	3	2.24E+01	2.76E+01	1.81E+01	7	4.72E+01	7.38E+01	3.01E+01	8	7.00E+01	1.40E+02	3.51E+01
118	3	2.01E+01	2.36E+01	1.72E+01	7	8.54E+01	1.27E+02	5.76E+01	8	6.52E+01	1.50E+02	2.85E+01
149	3	1.95E+01	2.30E+01	1.66E+01	7	7.06E+01	1.25E+02	4.00E+01	8	7.16E+01	1.19E+02	4.33E+01
132/153	3	4.34E+01	5.25E+01	3.59E+01	7	1.61E+02	2.65E+02	9.84E+01	8	1.39E+02	2.35E+02	8.24E+01
160/163/164/138	3	4.07E+01	4.73E+01	3.50E+01	7	1.42E+02	2.36E+02	8.53E+01	8	1.04E+02	1.77E+02	6.15E+01
187/182	3	1.25E+01	1.43E+01	1.10E+01	7	3.44E+01	5.31E+01	2.23E+01	8	3.24E+01	5.19E+01	2.02E+01
177	3	4.76E+00	5.60E+00	4.04E+00	7	1.19E+01	1.83E+01	7.75E+00	8	1.21E+01	2.06E+01	7.09E+00
180	3	1.61E+01	1.94E+01	1.33E+01	7	2.64E+01	4.23E+01	1.65E+01	8	1.09E+01	1.64E+01	7.28E+00
200	3	8.06E-01	1.25E+00	5.20E-01	7	2.59E+00	4.42E+00	1.51E+00	8	1.74E+00	2.55E+00	1.18E+00
194	3	2.44E+00	2.94E+00	2.02E+00	7	1.66E+00	2.63E+00	1.05E+00	6	2.24E-01	3.64E-01	1.38E-01
203/196	3	2.90E+00	3.69E+00	2.28E+00	7	1.78E+00	3.09E+00	1.03E+00	6	2.27E-01	4.61E-01	1.12E-01
206	3	1.13E+00	1.32E+00	9.64E-01	1	2.40E-01	n/a	n/a	1	1.06E-01	n/a	n/a
208	3	3.70E-01	3.97E-01	3.45E-01	0	ND	n/a	n/a	0	ND	n/a	n/a
209	3	5.18E-01	5.87E-01	4.57E-01	0	ND	n/a	n/a	1	1.01E-01	n/a	n/a

Notes: PCB congeners listed as BZ numbers. Abbreviations: N = Number of biota samples; n = number of values above MRLs (which make up the geometric means and upper and lower limits); UL = Upper Level (1 standard deviation above the geometric mean); LL = Lower Level (1 standard deviation below the geometric mean).

Table A-1 (continued). Geometric Means and Upper and Lower Limits (1 Std. Dev.) of Lipid-Normalized Biota Concentrations (pg/kg LW) for 18 Marine Organisms from False Creek Harbour. Lipid Content (LC) are also reported.

PCB CONGENER	Geoduck Clams (N = 8)				Minnows (N = 16)				Striped Seaperch (N = 8)			
	LC = 0.68% ± 0.25% (1 SD)				LC = 2.10% ± 1.02% (1 SD)				LC = 0.18% ± 0.09% (1 SD)			
	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)
18	2	1.20E+01	1.35E+01	1.07E+01	9	4.67E+00	8.59E+00	2.53E+00	0	ND	n/a	n/a
16/32	4	1.02E+01	1.61E+01	6.51E+00	10	6.37E+00	1.12E+01	3.62E+00	0	ND	n/a	n/a
73/52	8	3.70E+01	7.08E+01	1.94E+01	16	8.14E+01	2.20E+02	3.01E+01	8	2.39E+02	5.87E+02	9.77E+01
47/75/48	8	1.53E+01	2.54E+01	9.23E+00	16	1.84E+01	4.64E+01	7.32E+00	8	2.96E+01	6.32E+01	1.38E+01
101/90	8	5.72E+01	1.15E+02	2.84E+01	16	2.09E+02	6.25E+02	7.00E+01	8	5.66E+02	1.23E+03	2.61E+02
99	8	2.79E+01	5.32E+01	1.46E+01	16	1.38E+02	3.64E+02	5.19E+01	8	4.09E+02	8.75E+02	1.91E+02
110	8	5.62E+01	1.28E+02	2.46E+01	16	1.52E+02	4.56E+02	5.06E+01	8	2.40E+02	5.39E+02	1.07E+02
118	8	4.94E+01	1.05E+02	2.32E+01	16	2.62E+02	7.05E+02	9.76E+01	8	6.88E+02	1.45E+03	3.27E+02
149	8	4.46E+01	8.53E+01	2.33E+01	16	1.05E+02	2.36E+02	4.71E+01	8	1.44E+02	3.00E+02	6.87E+01
132/153	8	7.33E+01	1.39E+02	3.87E+01	16	4.75E+02	1.26E+03	1.80E+02	8	1.17E+03	2.18E+03	6.28E+02
160/163/164/138	8	7.00E+01	1.41E+02	3.48E+01	16	4.28E+02	1.15E+03	1.60E+02	8	1.04E+03	2.00E+03	5.41E+02
187/182	8	1.93E+01	3.21E+01	1.17E+01	16	9.35E+01	2.33E+02	3.76E+01	8	2.27E+02	3.98E+02	1.29E+02
177	8	9.27E+00	1.64E+01	5.25E+00	16	2.96E+01	7.12E+01	1.23E+01	8	5.23E+01	1.04E+02	2.64E+01
180	8	1.97E+01	3.60E+01	1.08E+01	16	1.33E+02	3.55E+02	4.98E+01	8	3.50E+02	6.75E+02	1.82E+02
200	8	1.60E+00	2.58E+00	9.98E-01	16	4.89E+00	1.30E+01	1.84E+00	8	1.10E+01	2.06E+01	5.85E+00
194	8	1.29E+00	2.46E+00	6.74E-01	16	1.35E+01	3.69E+01	4.93E+00	8	3.81E+01	8.24E+01	1.77E+01
203/196	8	2.74E+00	4.88E+00	1.54E+00	16	1.61E+01	4.17E+01	6.22E+00	8	4.83E+01	9.89E+01	2.35E+01
206	5	6.19E-01	9.19E-01	4.17E-01	16	2.56E+00	6.68E+00	9.84E-01	8	1.14E+01	2.86E+01	4.57E+00
208	1	2.89E-01	n/a	n/a	14	9.13E-01	1.72E+00	4.85E-01	6	2.21E+00	4.48E+00	1.09E+00
209	1	5.96E-01	n/a	n/a	14	8.44E-01	1.58E+00	4.51E-01	8	3.98E+00	8.68E+00	1.83E+00

Notes: PCB congeners listed as BZ numbers. Abbreviations: N = Number of biota samples; n = number of values above MRLs (which make up the geometric means and upper and lower limits); UL = Upper Level (1 standard deviation above the geometric mean); LL = Lower Level (1 standard deviation below the geometric mean).

Table A-1 (continued). Geometric Means and Upper and Lower Limits (1 Std. Dev.) of Lipid-Normalized Biota Concentrations (pg/kg LW) for 18 Marine Organisms from False Creek Harbour. Lipid Content (LC) are also reported.

PCB CONGENER	Pile Perch (N = 3)				Forage Fish (N = 4)				Purple Seastar (N = 2)			
	LC = 0.71% ± 0.87% (1 SD)				LC = 3.24% ± 1.29% (1 SD)				LC = 10.3% ± 11.1% (1 SD)			
	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)
18	0	ND	n/a	n/a	2	3.88E+00	9.66E+00	1.56E+00	1	2.17E+00	n/a	n/a
16/32	0	ND	n/a	n/a	2	5.90E+00	1.30E+01	2.69E+00	2	2.97E+00	4.44E+00	1.99E+00
73/52	3	1.30E+02	4.45E+02	3.77E+01	3	2.77E+01	5.23E+01	1.46E+01	2	2.43E+01	3.75E+01	1.57E+01
47/75/48	3	2.38E+01	7.49E+01	7.57E+00	3	1.01E+01	2.30E+01	4.48E+00	2	2.07E+01	3.95E+01	1.09E+01
101/90	3	2.27E+02	7.51E+02	6.84E+01	4	3.50E+01	6.82E+01	1.80E+01	2	4.22E+01	9.10E+01	1.96E+01
99	3	1.39E+02	4.56E+02	4.26E+01	4	2.11E+01	4.93E+01	9.01E+00	2	3.92E+01	9.01E+01	1.71E+01
110	3	9.96E+01	3.41E+02	2.90E+01	4	3.70E+01	5.76E+01	2.37E+01	2	3.33E+01	7.65E+01	1.45E+01
118	3	2.47E+02	7.64E+02	7.99E+01	4	3.24E+01	8.45E+01	1.24E+01	2	8.14E+01	8.53E+01	7.77E+01
149	3	8.14E+01	2.21E+02	2.99E+01	4	1.93E+01	3.42E+01	1.08E+01	2	1.83E+01	3.62E+01	9.23E+00
132/153	3	3.69E+02	1.12E+03	1.21E+02	4	5.23E+01	1.17E+02	2.34E+01	2	2.14E+01	8.79E+01	5.19E+00
160/163/164/138	3	3.33E+02	1.03E+03	1.08E+02	4	4.79E+01	1.07E+02	2.13E+01	2	4.92E+01	1.37E+02	1.76E+01
187/182	3	6.65E+01	2.08E+02	2.12E+01	4	1.19E+01	2.53E+01	5.60E+00	2	1.48E+01	3.69E+01	5.91E+00
177	3	1.85E+01	5.64E+01	6.08E+00	4	3.18E+00	5.18E+00	1.96E+00	2	4.31E+00	1.00E+01	1.85E+00
180	3	8.08E+01	2.53E+02	2.58E+01	4	1.64E+01	3.95E+01	6.80E+00	2	7.18E+00	2.93E+01	1.76E+00
200	3	5.50E+00	1.72E+01	1.76E+00	4	6.49E-01	1.35E+00	3.12E-01	1	2.10E-02	n/a	n/a
194	3	9.44E+00	3.18E+01	2.80E+00	4	2.15E+00	4.51E+00	1.03E+00	2	9.18E-01	4.09E+00	2.06E-01
203/196	3	1.37E+01	4.91E+01	3.82E+00	4	2.27E+00	4.74E+00	1.09E+00	2	1.53E-01	1.18E+00	1.98E-02
206	3	2.50E+00	1.19E+01	5.23E-01	4	7.49E-01	1.26E+00	4.46E-01	2	4.97E-02	3.45E-01	7.18E-03
208	2	6.18E-01	4.61E+00	8.29E-02	4	2.32E-01	3.69E-01	1.46E-01	2	3.81E-02	2.11E-01	6.87E-03
209	3	8.83E-01	3.59E+00	2.17E-01	4	2.80E-01	3.89E-01	2.01E-01	0	ND	n/a	n/a

Notes: PCB congeners listed as BZ numbers. Abbreviations: N = Number of biota samples; n = number of values above MRLs (which make up the geometric means and upper and lower limits); UL = Upper Level (1 standard deviation above the geometric mean); LL = Lower Level (1 standard deviation below the geometric mean).

Table A-1 (continued). Geometric Means and Upper and Lower Limits (1 Std. Dev.) of Lipid-Normalized Biota Concentrations (pg/kg LW) for 18 Marine Organisms from False Creek Harbour. Lipid Content (LC) are also reported.

PCB CONGENER	Surf Scoter (N = 7)				Pacific Staghorn Sculpin (N = 7)				Dungeness Crab (N = 3)			
	LC = 2.27% ± 0.68% (1 SD)				LC = 0.37% ± 0.09% (1 SD)				LC = 8.70% ± 7.87% (1 SD)			
	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)
18	0	ND	n/a	n/a	2	1.46E+01	1.66E+01	1.28E+01	3	1.93E+01	3.88E+01	9.61E+00
16/32	0	ND	n/a	n/a	5	1.26E+01	1.94E+01	8.13E+00	3	2.72E+01	6.14E+01	1.20E+01
73/52	2	1.42E+00	1.66E+00	1.22E+00	7	1.15E+02	2.20E+02	6.01E+01	3	2.60E+02	6.16E+02	1.10E+02
47/75/48	7	6.04E+00	9.30E+00	3.93E+00	7	3.97E+01	7.34E+01	2.15E+01	3	1.10E+02	2.72E+02	4.47E+01
101/90	7	1.20E+01	1.84E+01	7.88E+00	7	2.24E+02	4.68E+02	1.07E+02	3	5.19E+02	1.15E+03	2.35E+02
99	7	8.53E+01	1.46E+02	4.98E+01	7	1.27E+02	2.77E+02	5.82E+01	3	2.83E+02	6.47E+02	1.24E+02
110	7	4.45E+00	8.17E+00	2.42E+00	7	1.87E+02	3.59E+02	9.70E+01	3	3.84E+02	8.45E+02	1.74E+02
118	7	1.45E+02	2.69E+02	7.87E+01	7	2.05E+02	4.58E+02	9.15E+01	3	4.73E+02	9.80E+02	2.28E+02
149	7	2.59E+01	3.91E+01	1.71E+01	7	1.54E+02	3.09E+02	7.67E+01	3	3.50E+02	6.86E+02	1.79E+02
132/153	7	4.03E+02	8.17E+02	1.99E+02	7	4.04E+02	8.64E+02	1.89E+02	3	7.47E+02	1.40E+03	3.99E+02
160/163/164/138	7	3.90E+02	6.08E+02	2.50E+02	7	3.55E+02	7.77E+02	1.63E+02	3	7.24E+02	1.44E+03	3.63E+02
187/182	7	1.22E+02	1.94E+02	7.74E+01	7	8.86E+01	1.96E+02	4.00E+01	3	1.73E+02	3.25E+02	9.17E+01
177	7	4.45E+01	6.75E+01	2.94E+01	7	2.92E+01	6.51E+01	1.31E+01	3	5.72E+01	1.02E+02	3.22E+01
180	7	9.14E+01	1.80E+02	4.65E+01	7	1.24E+02	2.75E+02	5.57E+01	3	1.88E+02	3.38E+02	1.05E+02
200	7	7.55E+00	1.12E+01	5.10E+00	7	7.77E+00	1.78E+01	3.39E+00	3	7.29E+00	1.63E+01	3.25E+00
194	7	8.65E+00	1.72E+01	4.36E+00	7	1.87E+01	4.47E+01	7.82E+00	3	1.99E+01	5.01E+01	7.93E+00
203/196	7	1.07E+01	2.33E+01	4.94E+00	7	2.53E+01	6.01E+01	1.07E+01	3	1.80E+01	4.88E+01	6.67E+00
206	7	2.48E+00	6.23E+00	9.85E-01	7	6.20E+00	1.34E+01	2.86E+00	3	4.87E+00	1.45E+01	1.63E+00
208	6	1.13E+00	3.14E+00	4.09E-01	7	1.98E+00	3.91E+00	1.00E+00	3	1.20E+00	4.52E+00	3.20E-01
209	7	1.50E+00	2.87E+00	7.79E-01	7	1.86E+00	3.41E+00	1.01E+00	3	1.06E+00	3.79E+00	2.98E-01

Notes: PCB congeners listed as BZ numbers. Abbreviations: N = Number of biota samples; n = number of values above MRLs (which make up the geometric means and upper and lower limits); UL = Upper Level (1 standard deviation above the geometric mean); LL = Lower Level (1 standard deviation below the geometric mean).

Table A-1 (continued). Geometric Means and Upper and Lower Limits (1 Std. Dev.) of Lipid-Normalized Biota Concentrations (pg/kg LW) for 18 Marine Organisms from False Creek Harbour. Lipid Content (LC) are also reported.

PCB CONGENER	Sole (N = 2)				Whitespotted Greenling (N = 8)				Spiny Dogfish – Muscle (N = 10)			
	LC = 0.49% ± 0.00% (1 SD)				LC = 0.44% ± 0.18% (1 SD)				LC = 8.23% ± 3.61% (1 SD)			
	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)	n	Geomean (ug/kg LW)	UL (ug/kg LW)	LL (ug/kg LW)
18	2	3.30E+01	3.31E+01	3.29E+01	8	2.31E+01	3.10E+01	1.73E+01	6	1.05E+01	2.86E+01	3.86E+00
16/32	2	4.37E+01	5.00E+01	3.82E+01	8	2.89E+01	4.11E+01	2.03E+01	6	1.25E+01	2.36E+01	6.61E+00
73/52	2	3.79E+02	3.99E+02	3.60E+02	8	1.99E+02	2.83E+02	1.40E+02	10	1.17E+02	1.90E+02	7.26E+01
47/75/48	2	1.23E+02	1.34E+02	1.13E+02	8	8.74E+01	1.25E+02	6.08E+01	10	6.64E+01	1.15E+02	3.83E+01
101/90	2	8.16E+02	8.27E+02	8.05E+02	8	3.27E+02	4.35E+02	2.46E+02	10	4.16E+02	6.39E+02	2.72E+02
99	2	3.76E+02	4.77E+02	2.96E+02	8	2.34E+02	3.19E+02	1.72E+02	10	3.62E+02	5.98E+02	2.20E+02
110	2	8.38E+02	1.29E+03	5.44E+02	8	2.53E+02	3.34E+02	1.91E+02	10	2.43E+02	3.63E+02	1.62E+02
118	2	5.54E+02	6.95E+02	4.41E+02	8	3.59E+02	4.87E+02	2.64E+02	10	6.51E+02	1.22E+03	3.46E+02
149	2	4.27E+02	5.25E+02	3.48E+02	8	1.71E+02	2.34E+02	1.25E+02	10	3.23E+02	5.33E+02	1.95E+02
132/153	2	1.16E+03	1.62E+03	8.37E+02	8	5.57E+02	7.92E+02	3.92E+02	10	1.49E+03	2.79E+03	7.99E+02
160/163/164/138	2	1.04E+03	1.05E+03	1.03E+03	8	5.26E+02	7.29E+02	3.80E+02	10	1.35E+03	2.49E+03	7.33E+02
187/182	2	2.86E+02	4.61E+02	1.77E+02	8	1.19E+02	1.65E+02	8.57E+01	10	3.59E+02	6.36E+02	2.02E+02
177	2	7.32E+01	1.79E+02	2.99E+01	8	4.19E+01	5.75E+01	3.05E+01	10	9.58E+01	1.71E+02	5.38E+01
180	2	4.22E+02	7.24E+02	2.46E+02	8	1.71E+02	2.52E+02	1.16E+02	10	4.93E+02	9.43E+02	2.58E+02
200	2	1.82E+01	3.33E+01	9.93E+00	8	6.17E+00	8.64E+00	4.41E+00	10	1.86E+01	3.77E+01	9.19E+00
194	2	5.61E+01	9.61E+01	3.27E+01	8	1.83E+01	2.79E+01	1.20E+01	10	5.76E+01	1.16E+02	2.85E+01
203/196	2	7.27E+01	1.17E+02	4.50E+01	8	1.81E+01	2.74E+01	1.20E+01	10	7.68E+01	1.49E+02	3.95E+01
206	2	1.27E+01	2.86E+01	5.68E+00	8	4.54E+00	7.88E+00	2.61E+00	10	1.42E+01	2.72E+01	7.43E+00
208	2	5.06E+00	7.11E+00	3.60E+00	8	1.47E+00	2.38E+00	9.03E-01	10	3.63E+00	6.33E+00	2.09E+00
209	2	3.70E+00	5.74E+00	2.39E+00	8	1.48E+00	2.13E+00	1.02E+00	10	3.45E+00	6.16E+00	1.93E+00

Notes: PCB congeners listed as BZ numbers. Abbreviations: N = Number of biota samples; n = number of values above MRLs (which make up the geometric means and upper and lower limits); UL = Upper Level (1 standard deviation above the geometric mean); LL = Lower Level (1 standard deviation below the geometric mean).

Table A-1 (continued). Geometric Means and Upper and Lower Limits (1 Std. Dev.) of Lipid-Normalized Biota Concentrations (pg/kg LW) for 18 Marine Organisms from False Creek Harbour. Lipid Content (LC) are also reported.

PCB CONGENER	**Spiny Dogfish – Embryo (N = 4)**				**Spiny Dogfish – Liver (N = 10)**			
	LC = 22.4% ± 10.9% (1 SD)				**LC = 65.9% ± 7.29% (1 SD)**			
	n	**Geomean (ug/kg LW)**	**UL (ug/kg LW)**	**LL (ug/kg LW)**	**n**	**Geomean (ug/kg LW)**	**UL (ug/kg LW)**	**LL (ug/kg LW)**
18	0	ND	n/a	n/a	10	1.81E+01	6.80E+01	4.84E+00
16/32	2	3.66E+00	1.13E+01	1.19E+00	10	1.95E+01	6.65E+01	5.74E+00
73/52	4	7.63E+01	9.22E+01	6.31E+01	10	2.30E+02	5.81E+02	9.09E+01
47/75/48	4	3.16E+01	4.51E+01	2.22E+01	10	1.24E+02	3.32E+02	4.64E+01
101/90	4	2.27E+02	2.38E+02	2.15E+02	10	7.07E+02	1.69E+03	2.96E+02
99	4	1.61E+02	1.77E+02	1.46E+02	10	5.98E+02	1.42E+03	2.52E+02
110	4	1.38E+02	1.54E+02	1.23E+02	10	4.17E+02	9.86E+02	1.76E+02
118	4	2.44E+02	2.69E+02	2.21E+02	10	5.72E+02	1.25E+03	2.60E+02
149	4	1.56E+02	1.66E+02	1.46E+02	10	5.32E+02	1.17E+03	2.41E+02
132/153	4	6.59E+02	6.99E+02	6.21E+02	10	2.66E+03	6.46E+03	1.10E+03
160/163/164/138	4	5.97E+02	6.24E+02	5.72E+02	10	2.27E+03	5.55E+03	9.27E+02
187/182	4	1.76E+02	1.86E+02	1.67E+02	10	5.63E+02	1.31E+03	2.42E+02
177	4	4.98E+01	5.78E+01	4.30E+01	10	1.54E+02	3.65E+02	6.54E+01
180	4	2.32E+02	2.60E+02	2.07E+02	10	8.29E+02	2.10E+03	3.26E+02
200	4	9.02E+00	9.44E+00	8.62E+00	10	2.59E+01	5.95E+01	1.13E+01
194	4	3.15E+01	3.98E+01	2.49E+01	10	1.03E+02	2.64E+02	4.01E+01
203/196	4	3.78E+01	4.69E+01	3.05E+01	10	9.71E+01	2.22E+02	4.26E+01
206	4	8.70E+00	1.16E+01	6.55E+00	10	2.90E+01	7.26E+01	1.16E+01
208	4	2.12E+00	2.54E+00	1.77E+00	10	6.62E+00	1.56E+01	2.80E+00
209	4	2.51E+00	3.25E+00	1.94E+00	10	6.46E+00	1.48E+01	2.83E+00

Notes: PCB congeners listed as BZ numbers. Abbreviations: N = Number of biota samples; n = number of values above MRLs (which make up the geometric means and upper and lower limits); UL = Upper Level (1 standard deviation above the geometric mean); LL = Lower Level (1 standard deviation below the geometric mean).

Table A-2. Summary of Mean Log PCB Concentrations (and Standard Deviations, SD) in False Creek Seawater [C$_{18}$, Glass Fibre (GF), and Total fractions] (log pg/L), as well as, C18+GF and Freely-Dissolved (FD) PCB concentrations (pg/L).

WATER FRACTION:		C18 (N = 11)			GF (N = 11)			TOTAL (N = 12)			C18+GF	FD
PCB CONGENER	# of Cl	n	MEAN LOG (pg/L)	SD LOG (pg/L)	n	MEAN LOG (pg/L)	SD LOG (pg/L)	n	MEAN LOG (pg/L)	SD LOG (pg/L)	(pg/L)	(pg/L)
4/10	2	3	1.88	0.26	3	2.17	0.46	4	2.21	0.55	2.23E+02	2.19E+01
7/9	2	0	ND	n/a	0	ND	n/a	0	ND	n/a	ND	ND
6	2	2	1.84	0.32	0	ND	n/a	1	2.07	n/a	6.88E+01	2.87E+00
8/5	2	3	2.20	0.43	2	2.54	0.07	3	2.68	0.04	5.03E+02	2.06E+01
23	3	0	ND	n/a	0	ND	n/a	0	ND	n/a	ND	ND
34	3	0	ND	n/a	0	ND	n/a	0	ND	n/a	ND	ND
29	3	0	ND	n/a	0	ND	n/a	0	ND	n/a	ND	ND
26	3	3	1.42	0.51	2	1.74	0.03	3	1.92	0.09	8.11E+01	8.41E-01
25	3	2	1.50	0.16	0	ND	n/a	3	1.79	0.02	3.13E+01	3.17E-01
31	3	4	1.75	0.63	3	2.19	0.21	3	2.48	0.10	2.12E+02	2.15E+00
28	3	3	2.15	0.33	4	2.03	0.50	3	2.56	0.05	2.50E+02	2.53E+00
19	3	3	1.32	0.23	1	1.91	n/a	3	1.87	0.13	1.02E+02	4.44E+00
30	3	0	ND	n/a	0	ND	n/a	0	ND	n/a	ND	ND
18	3	3	2.38	0.17	5	2.26	0.36	5	2.44	0.45	4.19E+02	1.12E+01
17	3	4	1.79	0.41	5	1.95	0.37	3	2.42	0.15	1.50E+02	3.94E+00
27/24	3	4	1.37	0.50	2	1.79	0.22	2	2.05	0.05	8.48E+01	1.52E+00
16/32	3	4	2.11	0.54	5	2.24	0.36	5	2.44	0.43	3.04E+02	7.69E+00
54	4	0	ND	n/a	0	ND	n/a	0	ND	n/a	ND	ND
50	4	0	ND	n/a	0	ND	n/a	0	ND	n/a	ND	ND
53	4	3	1.50	0.14	2	1.43	0.22	3	1.75	0.09	5.86E+01	6.37E-01
51	4	2	0.91	0.31	0	ND	n/a	1	1.35	n/a	8.18E+00	8.69E-02
45	4	4	1.41	0.24	7	1.04	0.53	4	1.69	0.30	3.68E+01	4.92E-01
46	4	1	0.74	n/a	1	1.61	n/a	4	1.10	0.36	4.64E+01	6.20E-01

Table A-3: **Instrumental minimum detectable amounts (MDA, pg), method detection limits (MDL, ng/L or ng/g), defined as mean procedural blank concentration + 3 standard deviations of phthalate esters and polychlorinated biphenyls in seawater and sediment samples.**

Chemical	MDA	Seawater MDL1		Samples >MDL	Sediment MDL	Samples > MDL
	(pg)	Minimum (ng/L)	Maximum (ng/L)	%	Mean (ng/g)	%
Individual Phthalate Esters (GC-LRMS analysis)						
DMP	0.5	3.3	4.3	100	0.7	100
DEP	0.5	39	52	92	7.7	88
DiBP	0.03	6.4	7.9	67	1.1	100
DnBP	0.03	180	220	58	22	100
BBP	0.6	6.6	44	92	6.1	100
DEHP	0.03	400	540	33	24	100
DnOP	0.06	6.0	15	42	3.0	100
DnNP	0.06	4.3	35	33	1.6	100
Phthalate Ester Isomers (LC-ESI/MS analysis)						
C6	8.3	4.7	26	42	0.6	85
C7	39	8.3	61	42	2.7	92
C8	35	330	1,060	17	41	92
C9	40	200	530	25	4.4	92
C10	50	50	99	83	4.6	92

Chemical	**MDA**	**Seawater MDL1**		**Samples >MDL**	**Sediment MDL**	**Samples > MDL**
	(pg)	**Minimum (ng/L)**	**Maximum (ng/L)**	**%**	**Mean (ng/g)**	**%**
Polychlorinated Biphenyls		Seawater MDL (Mean, ng/L)		Samples >MDL (%)	Sediment MDL (Mean, ng/g)	Samples >MDL (%)
18	1.8	0.62		42	0.26	82
16/32	1.8	0.51		42	0.28	91
53	1.8	0.05		25	0.03	91
73/52	1.8	0.22		42	0.10	100
110	1.8	0.05		17	0.01	100
149	1.8	0.05		50	0.01	100
132/153	1.8	0.06		25	0.04	100
187/182	1.8	0.02		42	0.03	100
180	1.8	0.02		25	0.04	100
194	1.8	0.02		8	0.003	100

[1] Minimum and maximum MDLs are reported for phthalate esters in water because MDLs were determined on a per batch basis.

Table A-4: Measured concentrations of polychlorinated biphenyls in bottom sediment.

Measured concentrations of polychlorinated biphenyls in bottom sediment (CSS, ng/g dw) and large diameter suspended sediment (CBS ng/g dw); measured total concentrations in seawater CW (based on concentrations measured on GFF and C18 extraction disks) and the operationally defined freely dissolved concentration in seawater COD,W (based on concentrations measured on C18 extraction disks) in False Creek Harbor; organic carbon normalized bottom-sediment-water (KBS,OC) and suspended sediment-water distribution (KSS,OC) coefficients based on operationally defined freely dissolved (OD) and estimated truly freely dissolved (FD) water concentrations. Concentration ranges or values in brackets represent one standard deviation of the geometric mean.

DPE/ PCB	**CBS ng/g dw**	**n**	**CSS ng/g dw**	**n**	**CW ng/L for DPEs, ρg/L for PCBs**	**n**	**COD ng/L for DPEs, ρg/L for PCBs**	**n**	**Log KBS,OC L/kg OC**		**Log KSS,OC L/kg OC**	
									OD	**FD**	**OD**	**FD**
PCBs												
18	0.822 (0.429 – 1.58)	9	201 (64 - 630)	5	275 (98 – 775)	5	128 (46 – 360)	5	5.04 (0.27)	6.09 (0.27)	6.63 (0.36)	7.31 (0.29)
16/32	1.07 (0.443 – 2.56)	10	201 (65 - 624)	5	277 (104 – 743)	5	126 (47 – 337)	5	5.15 (0.34)	6.22 (0.34)	6.63 (0.36)	7.33 (0.29)
53	0.288 (0.144 – 0.577)	10	33.3 (23.0 - 48.4)	3	56 (45 – 69)	3	29 (23 – 36)	3	5.08 (0.27)	6.50 (0.27)	6.49 (0.28)	7.60 (0.15)
73/52	2.76 (1.53 – 4.99)	11	35.9 (7.65 - 168)	5	88 (34 – 226)	5	46 (18 – 119)	5	7.27 (0.22)	8.90 (0.22)	6.28 (0.38)	7.65 (0.28)
110	4.90 (3.07 – 7.83)	11	16.9 (9.39 - 30.3)	2	12	2	6	2	6.85 (0.18)	9.14 (0.18)	6.96 (0.27)	8.82 (0.25)
149	3.66 (2.23 – 6.01)	11	13.1 (6.22 - 27.8)	6	27 (15 – 48)	6	14 (8 – 25)	6	6.36 (0.20)	8.85 (0.20)	6.41 (0.31)	8.58 (0.33)
132/153	4.23 (2.51 – 7.14)	11	22.1 (9.94 - 49.3)	3	54 (47 – 62)	3	26 (23 – 30)	3	6.64 (0.21)	9.25 (0.21)	6.33 (0.31)	8.62 (0.30)
187/182	1.94 (1.07 – 3.54)	11	13.3 (7.91 - 22.3)	5	25 (17 – 38)	5	12 (8 – 18)	5	6.51 (0.25)	9.53 (0.25)	6.45 (0.28)	9.13 (0.17)
180	3.76 (1.99 – 7.09)	11	13.6 (8.74 - 21.1)	3	21 (18 – 25)	3	11 (9 – 13)	3	6.78 (0.26)	9.99 (0.26)	6.57 (0.32)	9.40 (0.13)
194	0.839 (0.465 – 1.51)	11	5.63	1	18	1	9	1	6.28 (0.24)	9.94 (0.24)	6.19	9.55
Total	24.3 (13.9 – 42.8) (n=10) 85.8 (49.2 – 151) (n=209)		N/A		0.85 (0.39 – 2.00) (n=10) 3.54 (2.47 – 6.01) (n=209)		N/A					

1 Concentration of chemical on the glass fibre filter (ng/g); 2 Concentration of chemical on the C18 extraction disk (ng/L or ρg/L).

Table A-5.: Parameters and Stated Variables by species. Detailed account of the values chosen for each of the model variables. It also includes the metabolic transformation rate constants used in the model.

For full details see CD appendix forming a parto f this thesis. See Appendix H.

				PHYTOPLANKTON	**'LANKTON**	**NTHOS - 1**	**NTHOS - 2**	**NTHOS - 3**	**NTHOS - 4**	**NTHOS - 5**	**NTHOS - 6**	**NTHOS - 7**
Model Parameters	**Name**	**Code**	**Units**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
Kow		**KOW**		5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08
Lipid fraction (kg lipid/kg organism ww)	V_{LB}	**VLB**	kg lipid/kg	0.024	0.002	0.005	0.025	0.016	0.010	0.080	0.087	0.103
Non-lipid organic matter (NLOM) fraction (kg NLOM/kg organism ww)	V_{NB}	**VNB**	kg NLOM/kg org ww	0.059	0.050	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Water content (kg water/kg organism ww) of the organism.	V_{WB}	**VWB**	kg w/kg org ww	0.917	0.948	0.795	0.775	0.784	0.790	0.720	0.713	0.697
Proportionality constant expressing the sorption capacity of NLOM to that of octanol	ß	**B**	Unitless	0.35	0.35	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Freely dissolved water concentration C_{WD} (g/L)	CWD	**CWD**	g/L	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15
Total water concentration C_{WT} (g/L)	CWT	**CWT**	g/L	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12
Concentrations of POC in the water (kg/L)	χ_{POC}	**XPOC**	kg/L	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07
Concentrations of DOC in the water (kg/L)	χ_{DOC}	**XDOC**	kg/L	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06
Disequilibrium factors for POC partitioning	D_{POC}	**DPOC**	Unitless	1	1	1	1	1	1	1	1	1
Disequilibrium factors for DOC partitioning	D_{DOC}	**DDOC**	Unitless	1	1	1	1	1	1	1	1	1
Proportionality constant describing the similarity in phase partitioning of POC in relation to that of octanol	α_{POC}	**APOC**	Unitless	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Proportionality constant describing the similarity in phase partitioning of DOC in relation to that of octanol	α_{DOC}	**ADOC**	Unitless	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Gill chemical uptake efficiency	E_W	**EW**	%	0.00	0	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291
Wet weight of the organism (kg).	W_B	**WB**	kg	1.00E-06	1.00E-06	1.50E-03	3.13E-06	1.00E-02	1.50E-05	1.50E-03	9.79E-04	1.00E-07
Dissolved oxygen concentration (mg O2/L)	COX	**COX**	mg O2/L	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88
T is water temperature (°C)	T	**Temp**	°C	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Mean homeothermic biota temperature (°C)	T_B	**TB**	°C	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
S is saturation of the water column (%)	S	**S**	%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
For algae, phytoplankton and aquatic macrophytes	A	**AA**	Unitless	6.00E-06	6.00E-06	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
For algae, phytoplankton and aquatic macrophytes	B	**BE**	Unitless	5.50E+00	5.50E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00
Pore water	mp	**mp**	%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%
Freely dissolved chemical concentration in the pore water (g/L),	$C_{WD,P}$	**CWDP**	g/L	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14
Chemical concentration in the sediment normalized for organic carbon content (g/kg OC)	$C_{S,OC}$	**CSOC**	g/kg	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06
Density of the organic carbon in sediment (kg/L)	δ_{OCS}	**dOCS**	kg/L	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Organic carbon-water partition coefficient	K_{OC}	**KOC**	Unitless	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08
Feeding rate GD (kg/d)	G_D	***GD***	kg/d	0.00E+00	0.00E+00	1.55E-04	8.15E-07	7.76E-04	3.09E-06	1.55E-04	1.08E-04	4.36E-08
Gill ventilation rate GV (L/d)	G_V	***GV***	L/d	0.00E+00	0.00E+00	3.48E+00	6.29E-02	1.19E+01	1.74E-01	3.48E+00	2.64E+00	6.71E-03
Concentration of suspended solids Css (kg/L)	Css	**CSS**	kg/L	1.55E-05	1.55E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05
Scavenging efficiency of particles sigma (%) absorbed from the water	Sigma	**Sigma**	Unitless	0.1	0.1	1	1	1	1	1	1	1
Fecal egestion rate	G_F	**GF**	Kg fec/kg org*d	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Partition coefficient of the chemical between the GIT and the organism	K_{GB}	**KGB**	Unitless	0	0	0	0	0	0	0	0	0
Overall lipid, NLOM and water contents of the diet, respectively	V_{LD}	**VLD**	kg Lipid/kg diet ww	0	0	0.0012	0.0012	0.0012	0.0012	0.006858	0.019319	0.007185
	V_{ND}	**VND**	kg NLOM/kg diet ww	0	0	0.06	0.06	0.06	0.06	0.185502	0.184404	0.193
	V_{WD}	**VWD**	kg Water/kg diet ww	0	0	0.9388	0.9388	0.9388	0.9388	0.80764	0.786278	0.799815
Dietary absorption efficiencies of lipid, NLOM and water, respectively	ε_L	**EL**	%	0.0%	0.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
	ε_N	**EN**	%	0.0%	0.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
	ε_W	**EWW**	%	0.0%	0.0%	55.0%	55.0%	55.0%	55.0%	55.0%	55.0%	55.0%
vLG, vNG,, vWG are the lipid (kg lipid/kg digesta ww), NLOM (kg NLOM/kg digesta ww) and water (kg water/kg digesta ww) contents in the gut, respectively	V_{LG}	**VLG**	kg Lipid/kg digesta ww	0.0%	0.0%	0.0%	0.2%	0.1%	0.2%	0.1%	0.1%	0.0%
	V_{NG}	**VNG**	kg NLOM/kg digesta ww	0.0%	0.0%	1.2%	5.5%	4.6%	6.9%	3.3%	3.3%	1.2%
	V_{WG}	**VWG**	kg Water/kg digesta ww	0.0%	0.0%	98.7%	94.4%	95.2%	92.8%	96.6%	96.6%	98.7%
Growth Rate Constant - (1/day)	KG	**KG**	1/day	**1.25E-01**	**1.25E-01**	**1.28E-03**	**4.42E-03**	**8.79E-04**	**3.23E-03**	**1.28E-03**	**1.40E-03**	**8.79E-03**
Metabolic Transformation Rate Constant - (1/day)	KMM	**KMM**	1/day	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Transfer of PCBa to pups through Lactation	KL	**KL**	1/day	0	0	0	0	0	0	0	0	0
Transfer of PCBa to pups	KP	**KP**	1/day	0	0	0	0	0	0	0	0	0
Dietary chemical tranfer efficiency	*ED*	***ED***	%	0	0	0.002327	0.002327	0.022336	0.000234	0.022336	0.022336	0.002327
Absortion efficiency from air	EA	**EA**	%	0	0	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Pulmonarl ventilation rate GA (L/d)	GA	**GA**	L/day	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Octanol-Air partition coefficient	KOA	**KOA**	Unitless	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12
Lung uptake efficiency	ELL	**ELL**	%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Gaseous Aereal Concentration	GAC	**GAC**	g/L	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10
Urinary Excretion rate	GU	**GU**	L/day	3.45E-01	3.45E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Molar concentration of seawater @ 35 ppt	MCS	**MCS**	mol/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fraction of OC in sediments	OC	**OC**	kg OC/kg Sed	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02
Sediment Density (kg/L)	δ_{SED}	**dSED**	kg/L	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
aquous exchange constant AA - Phyto	A	**AA**	Unitless	6.00E-06	6.00E-06	8.50E-07	8.50E-07	8.50E-08	8.50E-06	8.50E-08	8.50E-08	8.50E-07
aquous exchange constant BE - Phyto	B	**BE**	Unitless	5.5	5.5	2	2	2	2	2	2	2
Activity Factor	AF	**AF**	Unitless	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Growth rate factor	GRF	**GRF**	Unitless	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Fugavity Capacity for lipids	ZLH	**ZLH**	(mol/Pa.m^3)	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08
Fugavity Capacity for lipids	ZLL	**ZLL**	(mol/Pa.m^3)	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08
Fugavity Capacity for Air	ZAIRH	**ZAIRH**	(mol/Pa.m^3)	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137
Fugavity Capacity for Air	ZAIRL	**ZAIRL**	(mol/Pa.m^3)	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439
Fugavity Capacity for water	ZWH	**ZWH**	(mol/Pa.m^3)	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713
Fugavity Capacity for water	ZWL	**ZWL**	(mol/Pa.m^3)	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523

Table A-5. (continued). Parameters and Stated Variables by species. Detailed account of the values chosen for each of the model variables. It also includes the metabolic transformation rate constants used in the model.

For full details see CD appendix forming a part f this thesis. See Appendix H.

				BENTHOS - 8	FISH - 1	FISH - 2	FISH - 3	FISH - 4	FISH - 5	FISH - 7	FISH - 8	FISH - 8	FISH - 9
Model Parameters	**Name**	**Code**	**Units**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
Kow		**KOW**		5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08
Lipid fraction (kg lipid/kg organism ww)	V_{LB}	**VLB**	kg lipid/kg	0.150	0.015	0.001	0.027	0.025	0.005	0.005	0.004	0.004	0.030
Non-lipid organic matter (NLOM) fraction (kg NLOM/kg organism ww)	V_{NB}	**VNB**	kg NLOM/kg org ww	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Water content (kg water/kg organism ww) of the organism.	V_{WB}	**VWB**	kg w/kg org ww	0.650	0.785	0.799	0.773	0.775	0.795	0.795	0.797	0.797	0.770
Proportionality constant expressing the sorption capacity of NLOM to that of octanol	ß	**B**	Unitless	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Freely dissolved water concentration C_{WD} (g/L)	CWD	**CWD**	g/L	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15
Total water concentration C_{WT} (g/L)	CWT	**CWT**	g/L	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12
Concentrations of POC in the water (kg/L)	χ_{POC}	**XPOC**	kg/L	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07
Concentrations of DOC in the water (kg/L)	χ_{DOC}	**XDOC**	kg/L	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06
Disequilibrium factors for POC partitioning	D_{POC}	**DPOC**	Unitless	1	1	1	1	1	1	1	1	1	1
Disequilibrium factors for DOC partitioning	D_{DOC}	**DDOC**	Unitless	1	1	1	1	1	1	1	1	1	1
Proportionality constant describing the similarity in phase partitioning of POC in relation to that of octanol	α_{POC}	**APOC**	Unitless	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Proportionality constant describing the similarity in phase partitioning of DOC in relation to that of octanol	α_{DOC}	**ADOC**	Unitless	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Gill chemical uptake efficiency	E_W	**EW**	%	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291
Wet weight of the organism (kg).	W_B	**WB**	kg	3.72E-04	1.50E-02	7.50E-01	1.50E+00	1.00E+00	1.00E+00	5.00E-02	3.00E+00	3.00E+00	1.50E+01
Dissolved oxygen concentration (mg O2/L)	COX	**COX**	mg O2/L	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88
T is water temperature (^oC)	T	**Temp**	°C	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Mean homeothermic biota temperature (^oC)	T_B	**TB**	°C	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
S is saturation of the water column (%)	S	**S**	%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
For algae, phytoplankton and aquatic macrophytes	A	**AA**	Unitless	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
For algae, phytoplankton and aquatic macrophytes	B	**BE**	Unitless	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00
Pore water	mp	**mp**	%	10.0%	10.0%	0.0%	0.0%	0.0%	10.0%	10.0%	10.0%	10.0%	5.0%
Freely dissolved chemical concentration in the pore water (g/L),	$C_{WD,P}$	**CWDP**	g/L	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14
Chemical concentration in the sediment normalized for organic carbon content (g/kg OC)	$C_{S,OC}$	**CSOC**	g/kg	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06
Density of the organic carbon in sediment (kg/L)	δ_{OCS}	**dOCS**	kg/L	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Organic carbon-water partition coefficient	K_{OC}	**KOC**	Unitless	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08
Feeding rate GD (kg/d)	G_D	***GD***	kg/d	4.73E-05	1.10E-03	3.05E-02	5.49E-02	3.89E-02	3.89E-02	3.05E-03	9.90E-02	9.90E-02	3.89E-01
Gill ventilation rate GV (L/d)	G_V	***GV***	L/d	1.40E+00	1.55E+01	1.97E+02	3.10E+02	2.38E+02	2.38E+02	3.40E+01	4.86E+02	4.86E+02	1.38E+03
Concentration of suspended solids Css (kg/L)	Css	**CSS**	kg/L	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05
Scavenging efficiency of particles sigma (%) absorbed from the water	Sigma	**Sigma**	Unitless	1	1	1	1	1	1	1	1	1	1
Fecal egestion rate	G_F	**GF**	Kg fec/kg org*d	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Partition coefficient of the chemical between the GIT and the organism	K_{GB}	**KGB**	Unitless	0	0	0	0	0	0	0	0	0	0
Overall lipid, NLOM and water contents of the diet, respectively	V_{LD}	**VLD**	kg Lipid/kg diet ww	0.014532	0.003683	0.008625	0.022609	0.021607	0.00611	0.011334	0.00762	0.00762	0.023095
	V_{ND}	**VND**	kg NLOM/kg diet ww	0.199051	0.115051	0.2	0.2	0.193	0.158	0.172	0.186	0.186	0.2
	V_{WD}	**VWD**	kg Water/kg diet ww	0.786417	0.881267	0.791375	0.777391	0.785393	0.83589	0.816666	0.80638	0.80638	0.776905
Dietary absorption efficiencies of lipid, NLOM and water, respectively	ε_L	**EL**	%	75.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%
	ε_N	**EN**	%	75.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
	ε_W	**EWW**	%	55.0%	55.0%	55.0%	55.0%	55.0%	55.0%	55.0%	55.0%	55.0%	55.0%
vLG, vNG,, vWG are the lipid (kg lipid/kg digesta ww), NLOM (kg NLOM/kg digesta ww) and water (kg water/kg digesta ww) contents in the gut, respectively	V_{LG}	**VLG**	kg Lipid/kg digesta ww	0.4%	0.2%	0.1%	0.1%	0.2%	0.2%	0.1%	0.2%	0.2%	0.2%
	V_{NG}	**VNG**	kg NLOM/kg digesta ww	9.5%	20.1%	9.7%	18.8%	20.1%	18.9%	12.0%	21.9%	21.9%	20.9%
	V_{WG}	**VWG**	kg Water/kg digesta ww	90.1%	79.8%	90.2%	81.0%	79.7%	81.0%	87.9%	77.9%	77.9%	78.9%
Growth Rate Constant - (1/day)	KG	**KG**	1/day	**1.70E-03**	**1.62E-03**	**7.41E-04**	**6.45E-04**	**7.00E-04**	**7.00E-04**	**1.27E-03**	**5.62E-04**	**5.62E-04**	**4.07E-04**
Metabolic Transformation Rate Constant - (1/day)	KMM	**KMM**	1/day	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Transfer of PCBa to pups through Lactation	KL	**KL**	1/day	0	0	0	0	0	0	0	0	0	0
Transfer of PCBa to pups	KP	**KP**	1/day	0	0	0	0	0	0	0	0	0	0
Dietary chemical tranfer efficiency	*ED*	***ED***	%	0.022336	0.022336	0.022336	0.022336	0.022336	0.022336	0.022336	0.022336	0.022336	0.022336
Absorption efficiency from air	EA	**EA**	%	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Pulmonarl ventilation rate GA (L/d)	GA	**GA**	L/day	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Octanol-Air partition coefficient	KOA	**KOA**	Unitless	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12
Lung uptake efficiency	ELL	**ELL**	%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Gaseous Aereal Concentration	GAC	**GAC**	g/L	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10
Urinary Excretion rate	GU	**GU**	L/day	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Molar concentration of seawater @ 35 ppt	MCS	**MCS**	mol/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fraction of OC in sediments	OC	**OC**	kg OC/kg Sed	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02
Sediment Density (kg/L)	δ_{SED}	**dSED**	kg/L	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
aquous exchange constant AA - Phyto	A	**AA**	Unitless	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
aquous exchange constant BE - Phyto	B	**BE**	Unitless	2	2	2	2	2	2	2	2	2	2
Activity Factor	AF	**AF**	Unitless	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Growth rate factor	GRF	**GRF**	Unitless	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Fugavity Capacity for lipids	ZLH	**ZLH**	(mol/Pa.m^3)	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08
Fugavity Capacity for lipids	ZLL	**ZLL**	(mol/Pa.m^3)	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08
Fugavity Capacity for Air	ZAIRH	**ZAIRH**	(mol/Pa.m^3)	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137
Fugavity Capacity for Air	ZAIRL	**ZAIRL**	(mol/Pa.m^3)	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439
Fugavity Capacity for water	ZWH	**ZWH**	(mol/Pa.m^3)	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713
Fugavity Capacity for water	ZWL	**ZWL**	(mol/Pa.m^3)	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523

Table A-5. (continued). Parameters and Stated Variables by species. Detailed account of the values chosen for each of the model variables. It also includes the metabolic transformation rate constants used in the model.

For full details see CD appendix forming a part of this thesis. See Appendix H.

				FISH - 10	**SEAL-1**	**SEAL-2**	**SEAL-3**	**SEAL-4**	**BIRD-1**	**BIRD-2**	**BIRD-3**	**BIRD-4**
Model Parameters	**Name**	**Code**	**Units**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
Kow		**KOW**		5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08	5.03E+08
Lipid fraction (kg lipid/kg organism ww)	V_{LB}	**VLB**	kg lipid/kg	0.030	0.430	0.430	0.400	0.250	0.075	0.075	0.020	0.070
Non-lipid organic matter (NLOM) fraction (kg NLOM/kg organism ww)	V_{NB}	**VNB**	kg NLOM/kg org ww	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Water content (kg water/kg organism ww) of the organism.	V_{WB}	**VWB**	kg w/kg org ww	0.770	0.370	0.370	0.400	0.550	0.725	0.725	0.780	0.730
Proportionality constant expressing the sorption capacity of NLOM to that of octanol	ß	**B**	Unitless	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Freely dissolved water concentration C_{WD} (g/L)	CWD	**CWD**	g/L	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15	5.47E-15
Total water concentration C_{WT} (g/L)	CWT	**CWT**	g/L	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12	1.82E-12
Concentrations of POC in the water (kg/L)	χ_{POC}	**XPOC**	kg/L	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07	5.66E-07
Concentrations of DOC in the water (kg/L)	χ_{DOC}	**XDOC**	kg/L	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06	1.32E-06
Disequilibrium factors for POC partitioning	D_{POC}	**DPOC**	Unitless	1	1	1	1	1	1	1	1	1
Disequilibrium factors for DOC partitioning	D_{DOC}	**DDOC**	Unitless	1	1	1	1	1	1	1	1	1
Proportionality constant describing the similarity in phase partitioning of POC in relation to that of octanol	α_{POC}	**APOC**	Unitless	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Proportionality constant describing the similarity in phase partitioning of DOC in relation to that of octanol	α_{DOC}	**ADOC**	Unitless	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Gill chemical uptake efficiency	E_W	**EW**	%	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291	0.5291
Wet weight of the organism (kg).	W_B	**WB**	kg	3.71E-01	9.00E+01	8.00E+01	4.16E+01	1.60E+01	2.50E+00	2.40E+00	1.90E-01	1.75E-01
Dissolved oxygen concentration (mg O2/L)	COX	**COX**	mg O2/L	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88
T is water temperature (°C)	T	**Temp**	°C	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Mean homeothermic biota temperature (°C)	T_B	**TB**	°C	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
S is saturation of the water column (%)	S	**S**	%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
For algae, phytoplankton and aquatic macrophytes	A	**AA**	Unitless	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08	8.50E-08
For algae, phytoplankton and aquatic macrophytes	B	**BE**	Unitless	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00
Pore water	mp	**mp**	%	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Freely dissolved chemical concentration in the pore water (g/L),	$C_{WD,P}$	**CWDP**	g/L	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14	4.72E-14
Chemical concentration in the sediment normalized for organic carbon content (g/kg OC)	$C_{S,OC}$	**CSOC**	g/kg	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06	9.25E-06
Density of the organic carbon in sediment (kg/L)	δ_{OCS}	**dOCS**	kg/L	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Organic carbon-water partition coefficient	K_{OC}	**KOC**	Unitless	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08	1.76E+08
Feeding rate GD (kg/d)	G_D	***GD***	kg/d	1.67E-02	6.30E+00	8.80E+00	3.33E+00	9.60E-01	7.50E-01	7.20E-01	4.18E-02	3.85E-02
Gill ventilation rate GV (L/d)	G_V	***GV***	L/d	1.25E+02	3.51E+04	3.21E+04	1.97E+04	5.76E+03	2.48E+03	2.41E+03	3.41E+02	3.21E+02
Concentration of suspended solids Css (kg/L)	Css	**CSS**	kg/L	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05
Scavenging efficiency of particles sigma (%) absorbed from the water	Sigma	**Sigma**	Unitless	1	1	1	1	1	1	1	1	1
Fecal egestion rate	G_F	**GF**	Kg fec/kg org*d	0.00E+00	1.05E+00	-6.70E+01	5.55E-01	8.74E-01	1.25E-01	1.20E-01	7.07E-03	6.46E-03
Partition coefficient of the chemical between the GIT and the organism	K_{GB}	**KGB**	Unitless	0	0	0	0	0	0	0	0	0
Overall lipid, NLOM and water contents of the diet, respectively	V_{LD}	**VLD**	kg Lipid/kg diet ww	0.0085	0.029844	0.029844	0.026688	0.45	0.029244	0.029244	0.0075	0.021155
	V_{ND}	**VND**	kg NLOM/kg diet ww	0.190509	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2
	V_{WD}	**VWD**	kg Water/kg diet ww	0.800991	0.770156	0.770156	0.773312	0.45	0.770756	0.770756	0.7925	0.778845
Dietary absorption efficiencies of lipid, NLOM and water, respectively	ε_L	**EL**	%	90.0%	98.0%	20.0%	98.0%	10.0%	95.0%	95.0%	95.0%	95.0%
	ε_N	**EN**	%	50.0%	75.0%	69.0%	75.0%	45.0%	75.0%	75.0%	75.0%	75.0%
	ε_W	**EWW**	%	55.0%	85.0%	1100.0%	85.0%	0.0%	85.0%	85.0%	85.0%	85.0%
vLG, vNG,, vWG are the lipid (kg lipid/kg digesta ww), NLOM (kg NLOM/kg digesta ww) and water (kg water/kg digesta ww) contents in the gut, respectively	V_{LG}	**VLG**	kg Lipid/kg digesta ww	0.2%	0.4%	0.0%	0.3%	0.0%	0.9%	0.9%	0.6%	0.6%
	V_{NG}	**VNG**	kg NLOM/kg digesta ww	20.9%	30.1%	98.0%	30.0%	98.0%	29.9%	29.9%	29.8%	29.8%
	V_{WG}	**VWG**	kg Water/kg digesta ww	78.9%	69.5%	75.0%	69.7%	75.0%	69.2%	69.2%	69.6%	69.6%
Growth Rate Constant - (1/day)	KG	**KG**	1/day	**8.54E-04**	**7.50E-05**	**7.50E-05**	**7.50E-05**	**7.50E-05**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
Metabolic Transformation Rate Constant - (1/day)	KMM	**KMM**	1/day	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Transfer of PCBa to pups through Lactation	KL	**KL**	1/day	0	0	0	0	0	0	0	0	0
Transfer of PCBa to pups	KP	**KP**	1/day	0	0	0	0	0	0	0	0	0
Dietary chemical tranfer efficiency	*ED*	***ED***	%	0.022336	0.654375	0.654375	0.654375	0.654375	0.39223	0.39223	0.39223	0.39223
Absortion efficiency from air	EA	**EA**	%	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Pulmonarl ventilation rate GA (L/d)	GA	**GA**	L/day	0.00E+00	3.84E+04	3.50E+04	2.12E+04	6.09E+03	2.48E+03	2.41E+03	3.41E+02	3.21E+02
Octanol-Air partition coefficient	KOA	**KOA**	Unitless	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12	1.44E+12
Lung uptake efficiency	ELL	**ELL**	%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Gaseous Aereal Concentration	GAC	**GAC**	g/L	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10	1E-10
Urinary Excretion rate	GU	**GU**	L/day	0.00E+00	3.45E-01	-2.21E+01	1.83E-01	2.88E-01	2.51E-02	2.41E-02	1.41E-03	1.29E-03
Molar concentration of seawater @ 35 ppt	MCS	**MCS**	mol/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fraction of OC in sediments	OC	**OC**	kg OC/kg Sed	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02	2.78E-02
Sediment Density (kg/L)	δ_{SED}	**dSED**	kg/L	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
aquous exchange constant AA - Phyto	A	**AA**	Unitless	8.50E-08	1.00E-09	1.00E-09	1.00E-09	1.00E-09	3.00E-09	3.00E-09	3.00E-09	3.00E-09
aquous exchange constant BE - Phyto	B	**BE**	Unitless	2	1.025	1.025	1.025	1.025	1.04	1.04	1.04	1.04
Activity Factor	AF	**AF**	Unitless	1.0	2.5	2.5	2.5	1.5	3.0	3.0	3.0	3.0
Growth rate factor	GRF	**GRF**	Unitless	0.0007	0.0007	0.0007	0.0007	0.0007	0	0	0	0
Fugavity Capacity for lipids	ZLH	**ZLH**	(mol/Pa.m^3)	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08	5.56E+08
Fugavity Capacity for lipids	ZLL	**ZLL**	(mol/Pa.m^3)	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08	6.11E+08
Fugavity Capacity for Air	ZAIRH	**ZAIRH**	(mol/Pa.m^3)	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137	0.003137
Fugavity Capacity for Air	ZAIRL	**ZAIRL**	(mol/Pa.m^3)	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439	0.003439
Fugavity Capacity for water	ZWH	**ZWH**	(mol/Pa.m^3)	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713	1.486713
Fugavity Capacity for water	ZWL	**ZWL**	(mol/Pa.m^3)	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523	1.21523

Table A-6: Freshwater and Seawater-Temperature corrected Octanol-Water Partition Coefficients (log Kow) and Koa

For full details see CD appendix forming a part of this thesis. See Appendix H.

H&K, 1988	H&K, 1988)												
PCB CONGENER	SUBSTITUTION PATTERN	# of Cl	MW (g/mol)	LeBas Molar Volume [cm3/mol	Log Kow (FW -9.5º)	Kow (FW -9.5º)	Log Kow* (SW 9.5)	Kow* (SW 9.5)	KOA (37.5 °C)	Log Kow (FW 37.5º)	Kow (FW 37.5º)	Log Kow* (SW 37.5)	Kow* (SW 37.5)
1	2	1	188.65	205.4	4.58	3.83E+04	4.77	5.87E+04	4.29E+05	4.49	3.08E+04	4.67	4.71E+04
2	3	1	188.65	205.4	4.81	6.51E+04	5.00	9.96E+04	1.72E+06	4.72	5.23E+04	4.90	8.00E+04
3	4	1	188.65	205.4	4.81	6.51E+04	5.00	9.96E+04	2.92E+06	4.72	5.23E+04	4.90	8.00E+04
4	2,2'	2	223.10	226.4	4.78	6.00E+04	4.98	9.60E+04	7.92E+05	4.68	4.78E+04	4.88	7.64E+04
5	2,3	2	223.10	226.4	5.10	1.25E+05	5.30	2.00E+05	3.91E+06	5.00	9.99E+04	5.20	1.60E+05
6	2,3'	2	223.10	226.4	5.19	1.54E+05	5.39	2.47E+05	2.76E+06	5.09	1.23E+05	5.29	1.96E+05
7	2,4	2	223.10	226.4	5.20	1.58E+05	5.40	2.52E+05	3.18E+06	5.10	1.26E+05	5.30	2.01E+05
8	2,4'	2	223.10	226.4	5.20	1.58E+05	5.40	2.52E+05	3.88E+06	5.10	1.26E+05	5.30	2.01E+05
9	2,5	2	223.10	226.4	5.19	1.54E+05	5.39	2.47E+05	3.86E+06	5.09	1.23E+05	5.29	1.96E+05
10	2,6	2	223.10	226.4	4.97	9.30E+04	5.17	1.49E+05	6.52E+05	4.87	7.40E+04	5.07	1.18E+05
11	3,3'	2	223.10	226.4	5.41	2.56E+05	5.61	4.09E+05	2.29E+07	5.31	2.04E+05	5.51	3.26E+05
12	3,4	2	223.10	226.4	5.35	2.23E+05	5.55	3.57E+05	2.06E+07	5.25	1.78E+05	5.45	2.84E+05
13	3,4'	2	223.10	226.4	5.42	2.62E+05	5.62	4.19E+05	1.77E+07	5.32	2.09E+05	5.52	3.34E+05
14	3,5	2	223.10	226.4	5.41	2.56E+05	5.61	4.09E+05	9.13E+06	5.31	2.04E+05	5.51	3.26E+05
15	4,4'	2	223.10	226.4	5.43	2.68E+05	5.63	4.29E+05	2.48E+07	5.33	2.13E+05	5.53	3.41E+05
16	2,2',3	3	257.54	247.4	5.29	1.96E+05	5.52	3.28E+05	5.51E+06	5.19	1.55E+05	5.41	2.59E+05
17	2,2',4	3	257.54	247.4	5.38	2.42E+05	5.61	4.03E+05	4.05E+06	5.28	1.91E+05	5.50	3.19E+05
18	2,2',5	3	257.54	247.4	5.37	2.36E+05	5.60	3.94E+05	6.56E+06	5.27	1.86E+05	5.49	3.11E+05
19	2,2',6	3	257.54	247.4	5.15	1.42E+05	5.38	2.38E+05	1.74E+06	5.05	1.12E+05	5.27	1.88E+05
20	2,3,3'	3	257.54	247.4	5.70	5.05E+05	5.93	8.43E+05	2.31E+07	5.60	3.99E+05	5.82	6.65E+05
21	2,3,4	3	257.54	247.4	5.64	4.40E+05	5.87	7.34E+05	3.81E+07	5.54	3.47E+05	5.76	5.80E+05
22	2,3,4'	3	257.54	247.4	5.71	5.17E+05	5.94	8.63E+05	3.12E+07	5.61	4.08E+05	5.83	6.81E+05
23	2,3,5	3	257.54	247.4	5.70	5.05E+05	5.93	8.43E+05	5.32E+07	5.60	3.99E+05	5.82	6.65E+05
24	2,3,6	3	257.54	247.4	5.48	3.04E+05	5.71	5.08E+05	1.47E+07	5.38	2.40E+05	5.60	4.01E+05
25	2,3',4	3	257.54	247.4	5.80	6.36E+05	6.03	1.06E+06	2.41E+07	5.70	5.02E+05	5.92	8.38E+05
26	2,3',5	3	257.54	247.4	5.79	6.21E+05	6.02	1.04E+06	6.16E+07	5.69	4.90E+05	5.91	8.19E+05
27	2,3',6	3	257.54	247.4	5.57	3.74E+05	5.80	6.25E+05	4.78E+06	5.47	2.95E+05	5.69	4.93E+05
28	2,4,4'	3	257.54	247.4	5.80	6.36E+05	6.03	1.06E+06	2.76E+07	5.70	5.02E+05	5.92	8.38E+05
29	2,4,5	3	257.54	247.4	5.73	5.41E+05	5.96	9.03E+05	3.65E+07	5.63	4.27E+05	5.85	7.13E+05
30	2,4,6	3	257.54	247.4	5.57	3.74E+05	5.80	6.25E+05	6.57E+06	5.47	2.95E+05	5.69	4.93E+05
31	2,4',5	3	257.54	247.4	5.80	6.36E+05	6.03	1.06E+06	3.05E+07	5.70	5.02E+05	5.92	8.38E+05
32	2,4',6	3	257.54	247.4	5.57	3.74E+05	5.80	6.25E+05	9.78E+06	5.47	2.95E+05	5.69	4.93E+05
33	2,3',4'	3	257.54	247.4	5.73	5.41E+05	5.96	9.03E+05	2.53E+07	5.63	4.27E+05	5.85	7.13E+05
34	2,3',5'	3	257.54	247.4	5.79	6.21E+05	6.02	1.04E+06	1.50E+07	5.69	4.90E+05	5.91	8.19E+05
35	3,3',4	3	257.54	247.4	5.95	8.98E+05	6.18	1.50E+06	1.33E+08	5.85	7.09E+05	6.07	1.18E+06
36	3,3',5	3	257.54	247.4	6.01	1.03E+06	6.24	1.72E+06	8.28E+07	5.91	8.14E+05	6.13	1.36E+06
37	3,4,4'	3	257.54	247.4	5.96	9.19E+05	6.19	1.53E+06	1.67E+08	5.86	7.25E+05	6.08	1.21E+06
38	3,4,5	3	257.54	247.4	5.89	7.82E+05	6.12	1.31E+06	1.62E+08	5.79	6.17E+05	6.01	1.03E+06
39	3,4',5	3	257.54	247.4	6.02	1.05E+06	6.25	1.76E+06	1.05E+08	5.92	8.33E+05	6.14	1.39E+06
40	2,2',3,3'	4	291.99	268.4	5.80	6.28E+05	6.04	1.10E+06	2.72E+07	5.69	4.92E+05	5.93	8.57E+05
41	2,2',3,4	4	291.99	268.4	5.83	6.73E+05	6.07	1.17E+06	6.20E+07	5.72	5.27E+05	5.96	9.19E+05
42	2,2',3,4'	4	291.99	268.4	5.90	7.91E+05	6.14	1.38E+06	2.92E+07	5.79	6.19E+05	6.03	1.08E+06
43	2,2',3,5	4	291.99	268.4	5.89	7.73E+05	6.13	1.35E+06	3.85E+07	5.78	6.05E+05	6.02	1.05E+06
44	2,2',3,5'	4	291.99	268.4	5.89	7.73E+05	6.13	1.35E+06	9.10E+07	5.78	6.05E+05	6.02	1.05E+06
45	2,2',3,6	4	291.99	268.4	5.67	4.66E+05	5.91	8.12E+05	3.90E+07	5.56	3.64E+05	5.80	6.35E+05
46	2,2',3,6'	4	291.99	268.4	5.67	4.66E+05	5.91	8.12E+05	1.72E+07	5.56	3.64E+05	5.80	6.35E+05

Table A-6. (Continued) Freshwater and Seawater-Temperature corrected Octanol-Water Partition Coefficients (log Kow) and Koa

For full details see CD appendix forming a part of this thesis. See Appendix H.

PCB CONGENER	SUBSTITUTION PATTERN	# of Cl	MW (g/mol)	LeBas Molar Volume (cm3/mol	Log Kow (FW -9.5º)	Kow (FW -9.5º)	Log Kow* (SW 9.5)	Kow* (SW 9.5)	KOA (37.5 °C)	Log Kow (FW 37.5º)	Kow (FW 37.5º)	Log Kow* (SW 37.5)	Kow* (SW 37.5)
47	2,2',4,4'	4	291.99	268.4	5.99	9.73E+05	6.23	1.70E+06	2.86E+07	5.88	7.61E+05	6.12	1.33E+06
48	2,2',4,5	4	291.99	268.4	5.92	8.28E+05	6.16	1.44E+06	6.55E+07	5.81	6.48E+05	6.05	1.13E+06
49	2,2',4,5'	4	291.99	268.4	5.99	9.73E+05	6.23	1.70E+06	4.11E+07	5.88	7.61E+05	6.12	1.33E+06
50	2,2',4,6	4	291.99	268.4	5.77	5.86E+05	6.01	1.02E+06	1.98E+07	5.66	4.59E+05	5.90	8.00E+05
51	2,2',4,6'	4	291.99	268.4	5.77	5.86E+05	6.01	1.02E+06	1.09E+07	5.66	4.59E+05	5.90	8.00E+05
52	2,2',5,5'	4	291.99	268.4	5.98	9.50E+05	6.22	1.66E+06	4.13E+07	5.87	7.44E+05	6.11	1.30E+06
53	2,2',5,6'	4	291.99	268.4	5.76	5.73E+05	6.00	9.99E+05	1.83E+07	5.65	4.48E+05	5.89	7.82E+05
54	2,2',6,6'	4	291.99	268.4	5.35	2.23E+05	5.59	3.89E+05	5.18E+06	5.24	1.74E+05	5.48	3.04E+05
55	2,3,3',4	4	291.99	268.4	6.25	1.77E+06	6.49	3.09E+06	2.21E+08	6.14	1.39E+06	6.38	2.42E+06
56	2,3,3',4'	4	291.99	268.4	6.25	1.77E+06	6.49	3.09E+06	1.44E+08	6.14	1.39E+06	6.38	2.42E+06
57	2,3,3',5	4	291.99	268.4	6.31	2.03E+06	6.55	3.54E+06	1.40E+08	6.20	1.59E+06	6.44	2.77E+06
58	2,3,3',5'	4	291.99	268.4	6.31	2.03E+06	6.55	3.54E+06	1.32E+08	6.20	1.59E+06	6.44	2.77E+06
59	2,3,3',6	4	291.99	268.4	6.09	1.22E+06	6.33	2.14E+06	1.04E+08	5.98	9.58E+05	6.22	1.67E+06
60	2,3,4,4'	4	291.99	268.4	6.25	1.77E+06	6.49	3.09E+06	3.59E+08	6.14	1.39E+06	6.38	2.42E+06
61	2,3,4,5	4	291.99	268.4	6.18	1.51E+06	6.42	2.63E+06	1.72E+08	6.07	1.18E+06	6.31	2.06E+06
62	2,3,4,6	4	291.99	268.4	6.03	1.07E+06	6.27	1.86E+06	1.17E+08	5.92	8.35E+05	6.16	1.46E+06
63	2,3,4',5	4	291.99	268.4	6.31	2.03E+06	6.55	3.54E+06	1.70E+08	6.20	1.59E+06	6.44	2.77E+06
64	2,3,4',6	4	291.99	268.4	6.09	1.22E+06	6.33	2.14E+06	7.95E+07	5.98	9.58E+05	6.22	1.67E+06
65	2,3,5,6	4	291.99	268.4	6.00	9.95E+05	6.24	1.74E+06	7.07E+07	5.89	7.79E+05	6.13	1.36E+06
66	2,3',4,4'	4	291.99	268.4	6.34	2.18E+06	6.58	3.80E+06	3.82E+08	6.23	1.70E+06	6.47	2.97E+06
67	2,3',4,5	4	291.99	268.4	6.34	2.18E+06	6.58	3.80E+06	2.26E+08	6.23	1.70E+06	6.47	2.97E+06
68	2,3',4,5'	4	291.99	268.4	6.40	2.50E+06	6.64	4.36E+06	1.27E+08	6.29	1.96E+06	6.53	3.41E+06
69	2,3',4,6	4	291.99	268.4	6.18	1.51E+06	6.42	2.63E+06	7.02E+07	6.07	1.18E+06	6.31	2.06E+06
70	2,3',4',5	4	291.99	268.4	6.34	2.18E+06	6.58	3.80E+06	1.77E+08	6.23	1.70E+06	6.47	2.97E+06
71	2,3',4',6	4	291.99	268.4	6.12	1.31E+06	6.36	2.29E+06	2.91E+07	6.01	1.03E+06	6.25	1.79E+06
72	2,3',5,5'	4	291.99	268.4	6.40	2.50E+06	6.64	4.36E+06	1.59E+08	6.29	1.96E+06	6.53	3.41E+06
73	2,3',5',6	4	291.99	268.4	6.18	1.51E+06	6.42	2.63E+06	2.16E+07	6.07	1.18E+06	6.31	2.06E+06
74	2,4,4',5	4	291.99	268.4	6.34	2.18E+06	6.58	3.80E+06	2.59E+08	6.23	1.70E+06	6.47	2.97E+06
75	2,4,4',6	4	291.99	268.4	6.19	1.54E+06	6.43	2.69E+06	4.12E+07	6.08	1.21E+06	6.32	2.10E+06
76	2,3',4',5'	4	291.99	268.4	6.27	1.85E+06	6.51	3.23E+06	2.01E+08	6.16	1.45E+06	6.40	2.53E+06
77	3,3',4,4'	4	291.99	268.4	6.50	3.15E+06	6.74	5.49E+06	8.16E+08	6.39	2.46E+06	6.63	4.30E+06
78	3,3',4,5	4	291.99	268.4	6.49	3.08E+06	6.73	5.36E+06	9.95E+08	6.38	2.41E+06	6.62	4.20E+06
79	3,3',4,5'	4	291.99	268.4	6.56	3.61E+06	6.80	6.30E+06	7.85E+08	6.45	2.83E+06	6.69	4.93E+06
80	3,3',5,5'	4	291.99	268.4	6.62	4.15E+06	6.86	7.24E+06	4.10E+08	6.51	3.25E+06	6.75	5.66E+06
81	3,4,4',5	4	291.99	268.4	6.50	3.15E+06	6.74	5.49E+06	1.28E+09	6.39	2.46E+06	6.63	4.30E+06
82	2,2',3,3',4	5	326.43	289.4	6.34	2.20E+06	6.60	4.01E+06	2.77E+08	6.23	1.71E+06	6.49	3.11E+06
83	2,2',3,3',5	5	326.43	289.4	6.40	2.53E+06	6.66	4.60E+06	2.14E+08	6.29	1.96E+06	6.55	3.57E+06
84	2,2',3,3',6	5	326.43	289.4	6.18	1.52E+06	6.44	2.77E+06	1.64E+08	6.07	1.18E+06	6.33	2.15E+06
85	2,2',3,4,4'	5	326.43	289.4	6.44	2.77E+06	6.70	5.05E+06	3.24E+08	6.33	2.15E+06	6.59	3.92E+06
86	2,2',3,4,5	5	326.43	289.4	6.37	2.36E+06	6.63	4.30E+06	3.00E+08	6.26	1.83E+06	6.52	3.34E+06
87	2,2',3,4,5'	5	326.43	289.4	6.43	2.71E+06	6.69	4.93E+06	3.25E+08	6.32	2.10E+06	6.58	3.83E+06
88	2,2',3,4,6	5	326.43	289.4	6.21	1.63E+06	6.47	2.97E+06	3.33E+08	6.10	1.27E+06	6.36	2.31E+06
89	2,2',3,4,6'	5	326.43	289.4	6.21	1.63E+06	6.47	2.97E+06	1.72E+08	6.10	1.27E+06	6.36	2.31E+06
90	2,2',3,4',5	5	326.43	289.4	6.50	3.18E+06	6.76	5.80E+06	2.21E+08	6.39	2.47E+06	6.65	4.50E+06
91	2,2',3,4',6	5	326.43	289.4	6.27	1.87E+06	6.53	3.41E+06	1.86E+08	6.16	1.45E+06	6.42	2.65E+06
92	2,2',3,5,5'	5	326.43	289.4	6.49	3.11E+06	6.75	5.66E+06	2.17E+08	6.38	2.41E+06	6.64	4.40E+06

Table A-6. (Continued) Freshwater and Seawater-Temperature corrected Octanol-Water Partition Coefficients (log Kow) and Koa

For full details see CD appendix forming a part of this thesis. See Appendix H.

PCB CONGENER	SUBSTITUTION PATTERN	# of Cl	MW (g/mol)	LeBas Molar Volume (cm3/mol	Log Kow (FW -9.5º)	Kow (FW -9.5º)	Log Kow* (SW 9.5)	Kow* (SW 9.5)	KOA (37.5 ºC)	Log Kow (FW 37.5º)	Kow (FW 37.5º)	Log Kow* (SW 37.5)	Kow* (SW 37.5)
93	2,2',3,5,6	5	326.43	289.4	6.18	1.52E+06	6.44	2.77E+06	1.89E+08	6.07	1.18E+06	6.33	2.15E+06
94	2,2',3,5,6'	5	326.43	289.4	6.27	1.87E+06	6.53	3.41E+06	1.05E+08	6.16	1.45E+06	6.42	2.65E+06
95	2,2',3,5',6	5	326.43	289.4	6.27	1.87E+06	6.53	3.41E+06	1.93E+08	6.16	1.45E+06	6.42	2.65E+06
96	2,2',3,6,6'	5	326.43	289.4	5.85	7.12E+05	6.11	1.30E+06	1.04E+08	5.74	5.53E+05	6.00	1.01E+06
97	2,2',3,4',5'	5	326.43	289.4	6.43	2.71E+06	6.69	4.93E+06	2.84E+08	6.32	2.10E+06	6.58	3.83E+06
98	2,2',3,4',6'	5	326.43	289.4	6.27	1.87E+06	6.53	3.41E+06	1.68E+08	6.16	1.45E+06	6.42	2.65E+06
99	2,2',4,4',5	5	326.43	289.4	6.53	3.41E+06	6.79	6.21E+06	3.82E+08	6.42	2.65E+06	6.68	4.82E+06
100	2,2',4,4',6	5	326.43	289.4	6.37	2.36E+06	6.63	4.30E+06	1.10E+08	6.26	1.83E+06	6.52	3.34E+06
101	2,2',4,5,5'	5	326.43	289.4	6.52	3.33E+06	6.78	6.07E+06	3.67E+08	6.41	2.59E+06	6.67	4.71E+06
102	2,2',4,5,6'	5	326.43	289.4	6.30	2.01E+06	6.56	3.66E+06	1.85E+08	6.19	1.56E+06	6.45	2.84E+06
103	2,2',4,5',6	5	326.43	289.4	6.36	2.31E+06	6.62	4.20E+06	1.66E+08	6.25	1.79E+06	6.51	3.26E+06
104	2,2',4,6,6'	5	326.43	289.4	5.95	8.97E+05	6.21	1.63E+06	5.83E+07	5.84	6.96E+05	6.10	1.27E+06
105	2,3,3',4,4'	5	326.43	289.4	6.79	6.20E+06	7.05	1.13E+07	2.28E+09	6.68	4.82E+06	6.94	8.77E+06
106	2,3,3',4,5	5	326.43	289.4	6.78	6.06E+06	7.04	1.10E+07	8.69E+08	6.67	4.71E+06	6.93	8.57E+06
107	2,3,3',4',5	5	326.43	289.4	6.85	7.12E+06	7.11	1.30E+07	8.58E+08	6.74	5.53E+06	7.00	1.01E+07
108	2,3,3',4,5'	5	326.43	289.4	6.85	7.12E+06	7.11	1.30E+07	1.35E+09	6.74	5.53E+06	7.00	1.01E+07
109	2,3,3',4,6	5	326.43	289.4	6.62	4.20E+06	6.88	7.64E+06	6.32E+08	6.51	3.26E+06	6.77	5.93E+06
110	2,3,3',4',6	5	326.43	289.4	6.62	4.20E+06	6.88	7.64E+06	3.04E+08	6.51	3.26E+06	6.77	5.93E+06
111	2,3,3',5,5'	5	326.43	289.4	6.90	7.99E+06	7.16	1.46E+07	2.30E+09	6.79	6.20E+06	7.05	1.13E+07
112	2,3,3',5,6	5	326.43	289.4	6.59	3.92E+06	6.85	7.13E+06	3.67E+08	6.48	3.04E+06	6.74	5.53E+06
113	2,3,3',5',6	5	326.43	289.4	6.68	4.82E+06	6.94	8.77E+06	3.38E+08	6.57	3.74E+06	6.83	6.81E+06
114	2,3,4,4',5	5	326.43	289.4	6.79	6.20E+06	7.05	1.13E+07	1.16E+09	6.68	4.82E+06	6.94	8.77E+06
115	2,3,4,4',6	5	326.43	289.4	6.63	4.29E+06	6.89	7.82E+06	6.61E+08	6.52	3.33E+06	6.78	6.07E+06
116	2,3,4,5,6	5	326.43	289.4	6.47	2.97E+06	6.73	5.41E+06	4.38E+08	6.36	2.30E+06	6.62	4.20E+06
117	2,3,4',5,6	5	326.43	289.4	6.60	4.01E+06	6.86	7.30E+06	3.89E+08	6.49	3.11E+06	6.75	5.66E+06
118	2,3',4,4',5	5	326.43	289.4	6.88	7.63E+06	7.14	1.39E+07	1.24E+09	6.77	5.92E+06	7.03	1.08E+07
119	2,3',4,4',6	5	326.43	289.4	6.72	5.28E+06	6.98	9.62E+06	2.95E+08	6.61	4.10E+06	6.87	7.47E+06
120	2,3',4,5,5'	5	326.43	289.4	6.93	8.57E+06	7.19	1.56E+07	1.36E+09	6.82	6.65E+06	7.08	1.21E+07
121	2,3',4,5',6	5	326.43	289.4	6.78	6.06E+06	7.04	1.10E+07	1.96E+08	6.67	4.71E+06	6.93	8.57E+06
122	2,3,3',4',5'	5	326.43	289.4	6.78	6.06E+06	7.04	1.10E+07	9.41E+08	6.67	4.71E+06	6.93	8.57E+06
123	2,3,4,4',5'	5	326.43	289.4	6.88	7.63E+06	7.14	1.39E+07	1.42E+09	6.77	5.92E+06	7.03	1.08E+07
124	2,3',4',5,5'	5	326.43	289.4	6.87	7.46E+06	7.13	1.36E+07	1.27E+09	6.76	5.79E+06	7.02	1.05E+07
125	2,3',4',5',6	5	326.43	289.4	6.65	4.50E+06	6.91	8.19E+06	2.26E+08	6.54	3.49E+06	6.80	6.35E+06
126	3,3',4,4',5	5	326.43	289.4	7.03	1.08E+07	7.29	1.96E+07	6.06E+09	6.92	8.37E+06	7.18	1.52E+07
127	3,3',4,5,5'	5	326.43	289.4	7.09	1.24E+07	7.35	2.26E+07	5.83E+09	6.98	9.61E+06	7.24	1.75E+07
128	2,2',3,3',4,4	6	360.88	310.4	6.89	7.72E+06	7.17	1.47E+07	1.45E+09	6.77	5.94E+06	7.05	1.13E+07
129	2,2',3,3',4,5	6	360.88	310.4	6.88	7.54E+06	7.16	1.44E+07	1.48E+09	6.76	5.80E+06	7.04	1.10E+07
130	2,2',3,3',4,5	6	360.88	310.4	6.95	8.86E+06	7.23	1.69E+07	1.43E+09	6.83	6.82E+06	7.11	1.30E+07
131	2,2',3,3',4,6	6	360.88	310.4	6.73	5.34E+06	7.01	1.02E+07	1.44E+09	6.61	4.11E+06	6.89	7.82E+06
132	2,2',3,3',4,6	6	360.88	310.4	6.73	5.34E+06	7.01	1.02E+07	8.70E+08	6.61	4.11E+06	6.89	7.82E+06
133	2,2',3,3',5,5	6	360.88	310.4	7.01	1.02E+07	7.29	1.94E+07	9.15E+08	6.89	7.83E+06	7.17	1.49E+07
134	2,2',3,3',5,6	6	360.88	310.4	6.70	4.98E+06	6.98	9.48E+06	9.30E+08	6.58	3.83E+06	6.86	7.30E+06
135	2,2',3,3',5,6	6	360.88	310.4	6.79	6.13E+06	7.07	1.17E+07	7.67E+08	6.67	4.72E+06	6.95	8.98E+06
136	2,2',3,3',6,6	6	360.88	310.4	6.37	2.33E+06	6.65	4.44E+06	4.60E+08	6.25	1.79E+06	6.53	3.41E+06
137	2,2',3,4,4',5	6	360.88	310.4	6.98	9.50E+06	7.26	1.81E+07	1.67E+09	6.86	7.31E+06	7.14	1.39E+07
138	2,2',3,4,4',5	6	360.88	310.4	6.98	9.50E+06	7.26	1.81E+07	1.81E+09	6.86	7.31E+06	7.14	1.39E+07

Table A-6. (Continued) Freshwater and Seawater-Temperature corrected Octanol-Water Partition Coefficients (log Kow) and Koa

For full details see CD appendix forming a part of this thesis. See Appendix H.

PCB CONGENER	SUBSTITUTION PATTERN	# of Cl	MW (g/mol)	LeBas Molar Volume (cm3/mol	Log Kow (FW -9.5º)	Kow (FW -9.5º)	Log Kow* (SW 9.5)	Kow* (SW 9.5)	KOA (37.5 ºC)	Log Kow (FW 37.5º)	Kow (FW 37.5º)	Log Kow* (SW 37.5)	Kow* (SW 37.5)
139	2,2',3,4,4',6	6	360.88	310.4	6.82	6.57E+06	7.10	1.25E+07	1.85E+09	6.70	5.06E+06	6.98	9.62E+06
140	2,2',3,4,4',6	6	360.88	310.4	6.82	6.57E+06	7.10	1.25E+07	1.04E+09	6.70	5.06E+06	6.98	9.62E+06
141	2,2',3,4,5,5	6	360.88	310.4	6.97	9.28E+06	7.25	1.77E+07	1.67E+09	6.85	7.14E+06	7.13	1.36E+07
142	2,2',3,4,5,6	6	360.88	310.4	6.66	4.55E+06	6.94	8.65E+06	1.45E+09	6.54	3.50E+06	6.82	6.65E+06
143	2,2',3,4,5,6	6	360.88	310.4	6.75	5.59E+06	7.03	1.06E+07	8.80E+08	6.63	4.30E+06	6.91	8.19E+06
144	2,2',3,4,5',6	6	360.88	310.4	6.82	6.57E+06	7.10	1.25E+07	1.81E+09	6.70	5.06E+06	6.98	9.62E+06
145	2,2',3,4,6,6	6	360.88	310.4	6.40	2.50E+06	6.68	4.75E+06	9.47E+08	6.28	1.92E+06	6.56	3.66E+06
146	2,2',3,4',5,5	6	360.88	310.4	7.04	1.09E+07	7.32	2.07E+07	1.65E+09	6.92	8.39E+06	7.20	1.60E+07
147	2,2',3,4',5,6	6	360.88	310.4	6.79	6.13E+06	7.07	1.17E+07	1.02E+09	6.67	4.72E+06	6.95	8.98E+06
148	2,2',3,4',5,6	6	360.88	310.4	6.88	7.54E+06	7.16	1.44E+07	6.99E+08	6.76	5.80E+06	7.04	1.10E+07
149	2,2',3,4',5',6	6	360.88	310.4	6.82	6.57E+06	7.10	1.25E+07	8.77E+08	6.70	5.06E+06	6.98	9.62E+06
150	2,2',3,4',6,6	6	360.88	310.4	6.47	2.93E+06	6.75	5.58E+06	5.73E+08	6.35	2.26E+06	6.63	4.30E+06
151	2,2',3,5,5',6	6	360.88	310.4	6.79	6.13E+06	7.07	1.17E+07	9.87E+08	6.67	4.72E+06	6.95	8.98E+06
152	2,2',3,5,6,6	6	360.88	310.4	6.37	2.33E+06	6.65	4.44E+06	4.93E+08	6.25	1.79E+06	6.53	3.41E+06
153	2,2',4,4',5,5	6	360.88	310.4	7.07	1.17E+07	7.35	2.22E+07	1.59E+09	6.95	8.99E+06	7.23	1.71E+07
154	2,2',4,4',5,6	6	360.88	310.4	6.91	8.08E+06	7.19	1.54E+07	1.01E+09	6.79	6.22E+06	7.07	1.18E+07
155	2,2',4,4',6,6	6	360.88	310.4	6.56	3.61E+06	6.84	6.87E+06	3.20E+08	6.44	2.78E+06	6.72	5.29E+06
156	2,3,3',4,4',5	6	360.88	310.4	7.33	2.13E+07	7.61	4.04E+07	5.48E+09	7.21	1.64E+07	7.49	3.11E+07
157	2,3,3',4,4',5	6	360.88	310.4	7.33	2.13E+07	7.61	4.04E+07	6.26E+09	7.21	1.64E+07	7.49	3.11E+07
158	2,3,3',4,4',6	6	360.88	310.4	7.17	1.47E+07	7.45	2.80E+07	2.70E+09	7.05	1.13E+07	7.33	2.15E+07
159	2,3,3',4,5,5	6	360.88	310.4	7.39	2.44E+07	7.67	4.64E+07	5.75E+09	7.27	1.88E+07	7.55	3.57E+07
160	2,3,3',4,5,6	6	360.88	310.4	7.08	1.20E+07	7.36	2.27E+07	2.58E+09	6.96	9.20E+06	7.24	1.75E+07
161	2,3,3',4,5',6	6	360.88	310.4	7.23	1.69E+07	7.51	3.21E+07	3.24E+09	7.11	1.30E+07	7.39	2.47E+07
162	2,3,3',4',5,5	6	360.88	310.4	7.39	2.44E+07	7.67	4.64E+07	5.85E+09	7.27	1.88E+07	7.55	3.57E+07
163	2,3,3',4',5,6	6	360.88	310.4	7.14	1.37E+07	7.42	2.61E+07	1.64E+09	7.02	1.06E+07	7.30	2.01E+07
164	2,3,3',4',5',6	6	360.88	310.4	7.17	1.47E+07	7.45	2.80E+07	5.42E+09	7.05	1.13E+07	7.33	2.15E+07
165	2,3,3',5,5',6	6	360.88	310.4	7.20	1.58E+07	7.48	3.00E+07	1.81E+09	7.08	1.21E+07	7.36	2.31E+07
166	2,3,4,4',5,6	6	360.88	310.4	7.08	1.20E+07	7.36	2.27E+07	2.22E+09	6.96	9.20E+06	7.24	1.75E+07
167	2,3',4,4',5,5	6	360.88	310.4	7.42	2.62E+07	7.70	4.98E+07	7.27E+09	7.30	2.01E+07	7.58	3.83E+07
168	2,3',4,4',5',6	6	360.88	310.4	7.26	1.81E+07	7.54	3.44E+07	4.95E+09	7.14	1.39E+07	7.42	2.65E+07
169	3,3',4,4',5,5	6	360.88	310.4	7.57	3.69E+07	7.85	7.03E+07	2.91E+10	7.45	2.84E+07	7.73	5.41E+07
170	,2',3,3',4,4',	7	395.32	331.4	7.42	2.64E+07	7.72	5.26E+07	7.70E+09	7.30	2.02E+07	7.60	4.01E+07
171	,2',3,3',4,4',	7	395.32	331.4	7.26	1.83E+07	7.56	3.64E+07	6.41E+09	7.14	1.40E+07	7.44	2.77E+07
172	,2',3,3',4,5,	7	395.32	331.4	7.48	3.04E+07	7.78	6.03E+07	6.37E+09	7.36	2.32E+07	7.66	4.60E+07
173	,2',3,3',4,5,	7	395.32	331.4	7.17	1.49E+07	7.47	2.96E+07	6.02E+09	7.05	1.13E+07	7.35	2.25E+07
174	,2',3,3',4,5,	7	395.32	331.4	7.26	1.83E+07	7.56	3.64E+07	4.19E+09	7.14	1.40E+07	7.44	2.77E+07
175	,2',3,3',4,5',	7	395.32	331.4	7.32	2.10E+07	7.62	4.17E+07	7.74E+09	7.20	1.60E+07	7.50	3.19E+07
176	,2',3,3',4,6,	7	395.32	331.4	6.91	8.17E+06	7.21	1.62E+07	4.20E+09	6.79	6.24E+06	7.09	1.24E+07
177	,2',3,3',4,5',	7	395.32	331.4	7.23	1.71E+07	7.53	3.39E+07	5.33E+09	7.11	1.30E+07	7.41	2.59E+07
178	,2',3,3',5,5',	7	395.32	331.4	7.29	1.96E+07	7.59	3.90E+07	4.10E+09	7.17	1.50E+07	7.47	2.97E+07
179	,2',3,3',5,6,	7	395.32	331.4	6.88	7.63E+06	7.18	1.52E+07	2.80E+09	6.76	5.82E+06	7.06	1.16E+07
180	,2',3,4,4',5,	7	395.32	331.4	7.51	3.25E+07	7.81	6.47E+07	1.38E+10	7.39	2.48E+07	7.69	4.93E+07
181	,2',3,4,4',5,	7	395.32	331.4	7.26	1.83E+07	7.56	3.64E+07	6.49E+09	7.14	1.40E+07	7.44	2.77E+07
182	,2',3,4,4',5,	7	395.32	331.4	7.35	2.25E+07	7.65	4.47E+07	4.51E+09	7.23	1.72E+07	7.53	3.41E+07
183	,2',3,4,4',5',	7	395.32	331.4	7.35	2.25E+07	7.65	4.47E+07	7.67E+09	7.23	1.72E+07	7.53	3.41E+07
184	,2',3,4,4',6,	7	395.32	331.4	7.00	1.01E+07	7.30	2.00E+07	5.31E+09	6.88	7.67E+06	7.18	1.52E+07

Table A-6. (Continued) Freshwater and Seawater-Temperature corrected Octanol-Water Partition Coefficients (log Kow) and Koa

For full details see CD appendix forming a part of this thesis. See Appendix H.

PCB CONGENER	SUBSTITUTION PATTERN	# of Cl	MW (g/mol)	LeBas Molar Volume (cm3/mol	Log Kow (FW -9.5º)	Kow (FW -9.5º)	Log Kow* (SW 9.5)	Kow* (SW 9.5)	KOA (37.5 ºC)	Log Kow (FW 37.5º)	Kow (FW 37.5º)	Log Kow* (SW 37.5)	Kow* (SW 37.5)
185	,2',3,4,5,5',	7	395.32	331.4	7.26	1.83E+07	7.56	3.64E+07	6.80E+09	7.14	1.40E+07	7.44	2.77E+07
186	,2',3,4,5,6,	7	395.32	331.4	6.84	6.96E+06	7.14	1.38E+07	3.83E+09	6.72	5.31E+06	7.02	1.05E+07
187	,2',3,4',5,5',	7	395.32	331.4	7.32	2.10E+07	7.62	4.17E+07	5.17E+09	7.20	1.60E+07	7.50	3.19E+07
188	,2',3,4',5,6,	7	395.32	331.4	6.97	9.38E+06	7.27	1.86E+07	2.67E+09	6.85	7.16E+06	7.15	1.42E+07
189	,3,3',4,4',5,	7	395.32	331.4	7.86	7.28E+07	8.16	1.45E+08	2.80E+10	7.74	5.56E+07	8.04	1.10E+08
190	,3,3',4,4',5,	7	395.32	331.4	7.61	4.10E+07	7.91	8.14E+07	1.66E+10	7.49	3.13E+07	7.79	6.21E+07
191	,3,3',4,4',5',	7	395.32	331.4	7.70	5.04E+07	8.00	1.00E+08	1.68E+10	7.58	3.84E+07	7.88	7.64E+07
192	,3,3',4,5,5',	7	395.32	331.4	7.67	4.70E+07	7.97	9.35E+07	1.27E+10	7.55	3.59E+07	7.85	7.13E+07
193	,3,3',4',5,5',	7	395.32	331.4	7.67	4.70E+07	7.97	9.35E+07	7.47E+09	7.55	3.59E+07	7.85	7.13E+07
194	2',3,3',4,4',5	8	429.77	352.4	7.96	9.06E+07	8.27	1.88E+08	2.80E+10	7.84	6.85E+07	8.15	1.42E+08
195	2',3,3',4,4',5	8	429.77	352.4	7.72	5.21E+07	8.03	1.08E+08	2.79E+10	7.60	3.94E+07	7.91	8.19E+07
196	2',3,3',4,4',5	8	429.77	352.4	7.81	6.41E+07	8.12	1.33E+08	2.64E+10	7.69	4.85E+07	8.00	1.01E+08
197	2',3,3',4,4',6	8	429.77	352.4	7.46	2.87E+07	7.77	5.95E+07	1.82E+10	7.34	2.17E+07	7.65	4.50E+07
198	2',3,3',4,5,5	8	429.77	352.4	7.78	5.99E+07	8.09	1.24E+08	2.66E+10	7.66	4.53E+07	7.97	9.40E+07
199	2',3,3',4,5,6	8	429.77	352.4	7.36	2.28E+07	7.67	4.72E+07	1.67E+10	7.24	1.72E+07	7.55	3.57E+07
200	2',3,3',4,5',6	8	429.77	352.4	7.43	2.67E+07	7.74	5.55E+07	1.70E+10	7.31	2.02E+07	7.62	4.20E+07
201	2',3,3',4,5,5	8	429.77	352.4	7.78	5.99E+07	8.09	1.24E+08	1.83E+10	7.66	4.53E+07	7.97	9.40E+07
202	2',3,3',5,5',6	8	429.77	352.4	7.40	2.50E+07	7.71	5.18E+07	9.05E+09	7.28	1.89E+07	7.59	3.92E+07
203	2',3,4,4',5,5	8	429.77	352.4	7.81	6.41E+07	8.12	1.33E+08	2.66E+10	7.69	4.85E+07	8.00	1.01E+08
204	2',3,4,4',5,6	8	429.77	352.4	7.46	2.87E+07	7.77	5.95E+07	1.82E+10	7.34	2.17E+07	7.65	4.50E+07
205	3,3',4,4',5,5	8	429.77	352.4	8.16	1.44E+08	8.47	2.98E+08	4.05E+10	8.04	1.09E+08	8.35	2.25E+08
206	,3,3',4,4', 5,	9	464.21	373.4	8.25	1.79E+08	8.59	3.87E+08	9.47E+10	8.13	1.34E+08	8.46	2.90E+08
207	,3,3',4,4',5,	9	464.21	373.4	7.90	7.98E+07	8.24	1.73E+08	8.06E+10	7.78	5.98E+07	8.11	1.30E+08
208	,3,3',4,5,5',	9	464.21	373.4	7.87	7.45E+07	8.21	1.61E+08	6.34E+10	7.75	5.59E+07	8.08	1.21E+08
209	3,3',4,4',5,5	10	498.66	394.4	8.35	2.22E+08	8.70	5.03E+08	1.44E+12	8.22	1.65E+08	8.57	3.74E+08

Table A-7a: Trophic Positions for False Creek Biota, as reported in Mackintosh (2002). Species / organisms in BOLD type are reported on in the current study.

Species/Organism	Trophic Position
Phytoplankton	1.00
Algae (Brown & Green)	1.00
Zooplankton / Pelagic Invertebrates	2.00
Small Forage Fish	2.33
Manila Clams	2.40
Blue Mussels	2.48
Pacific Oysters	2.48
Cockle Clams	2.48
Detritus/ Sediment	2.50
Geoduck Clams	2.53
Benthic Invertebrates	2.53
Striped Seaperch	3.05
Pile Perch	3.05
Shrimp	3.16
Surf Smelt	3.18
“Forage Fish”(Herring + Smelt + Anchovy)	3.25
Pacific Herring	3.32
Small Crabs	3.37
Purple Seastar	3.47
Surf Scoter	3.49
Pacific Staghorn Sculpin	3.51
Starry Flounder	3.54
Dungeness Crab	3.55
“Sole” (Flounder + Sole)	3.64
English Sole	3.74
Whitespotted Greenling	3.81
Spiny Dogfish	4.07

Table A-7b: Trophic Positions for False Creek Biota, as reported in Mackintosh (2002). Species / organisms in BOLD type are reported on in the current study.

MODEL ID	NAME	TROPHIC POSITION
PHYTOPLANKTON	Green algae	1
PLANKTON	Plankton	1
BENTHOS - 1	Manila Clams	2.4
BENTHOS - 2	Pacific Oyster	2.48
BENTHOS - 3	Blue Mussels	2.48
BENTHOS - 4	Geoduck Clams	2.53
BENTHOS - 5	Pink Shrimp	3.16
BENTHOS - 6	Dangeness Crabs Juvenile	3.37
BENTHOS - 7	Purple Seastar	3.47
BENTHOS - 8	Dungeness Crab Adults	3.55
FISH - 1	Minnows	2.33
FISH - 2	Striped Seaperch	3.05
FISH - 3	Surf Smelt	3.18
FISH - 4	Pacific Herring	3.32
FISH - 5	Pacific Staghorn Sculpin	3.51
FISH - 6	Starry Flounder	3.54
FISH - 7	English Sole	3.64
FISH - 8	White Spotted Greenling	3.81
FISH - 9	Spiny Dogfish	4.07
FISH - 10	White croaker (>juvenile)	3.684
SEAL-1	Adult Seal (Male)	4.05
SEAL-2	Adult Seal (Female)	4.05
SEAL-3	Juvenile Seal	4.36
SEAL-4	Seal Pup	2
BIRD-1	Cormorant (Male)	4.1
BIRD-2	Cormorant (Female)	4.06
BIRD-3	Surf Scoter	3.49
BIRD-4	Tern (Female)	4.06

Table A-8: **Feeding preferences of various species represented in the model. Generalized trophic interactions between most of the species described in Table A-7b.**

PREY SPECIES	BENTHOS - 1				BENTHOS - 2				BENTHOS - 3			
	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%
PHYTOPLANKTON	1.00	0.1%	6.0%	93.9%	1.00	0.1%	6.0%	93.9%	1.00	0.1%	6.0%	93.9%
0.00E+00	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 1	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 2	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 3	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 4	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				1.00			

PREY SPECIES	BENTHOS - 4				BENTHOS - 5				BENTHOS - 6			
	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.01	0.0%	1.0%	99.0%	0.02	0.0%	1.0%	99.0%
PHYTOPLANKTON	1.00	0.1%	6.0%	93.9%	0.09	0.1%	6.0%	93.9%	0.07	0.1%	6.0%	93.9%
0.00E+00	0.00	0.8%	20.0%	79.3%	0.90	0.8%	20.0%	79.3%	0.40	0.8%	20.0%	79.3%
BENTHOS - 1	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.15	0.8%	20.0%	79.3%
BENTHOS - 2	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 3	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.15	0.8%	20.0%	79.3%
BENTHOS - 4	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%	0.20	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				0.99			

Table A-8: (Continued) Feeding preferences of various species represented in the model. Generalized trophic interactions between most of the species described in Table A-7b.

	BENTHOS - 7				BENTHOS - 8				FISH - 1			
PREY SPECIES	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.01	0.0%	1.0%	99.0%	0.01	0.0%	1.0%	99.0%
PHYTOPLANKTON	0.05	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%	0.60	0.1%	6.0%	93.9%
0.00E+00	0.05	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.30	0.8%	20.0%	79.3%
BENTHOS - 1	0.40	0.8%	20.0%	79.3%	0.65	0.8%	20.0%	79.3%	0.10	0.8%	20.0%	79.3%
BENTHOS - 2	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 3	0.50	0.8%	20.0%	79.3%	0.15	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 4	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.10	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.05	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.05	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				1.00			

	FISH - 2				FISH - 3				FISH - 4			
PREY SPECIES	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%
PHYTOPLANKTON	0.00	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%	0.05	0.1%	6.0%	93.9%
0.00E+00	0.00	0.8%	20.0%	79.3%	0.20	0.8%	20.0%	79.3%	0.05	0.8%	20.0%	79.3%
BENTHOS - 1	0.40	0.8%	20.0%	79.3%	0.20	0.8%	20.0%	79.3%	0.30	0.8%	20.0%	79.3%
BENTHOS - 2	0.00	0.8%	20.0%	79.3%	0.10	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 3	0.25	0.8%	20.0%	79.3%	0.10	0.8%	20.0%	79.3%	0.10	0.8%	20.0%	79.3%
BENTHOS - 4	0.20	1.0%	20.0%	79.0%	0.10	1.0%	20.0%	79.0%	0.30	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.10	7.0%	20.0%	73.0%	0.15	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.10	9.4%	20.0%	70.6%	0.05	9.4%	20.0%	70.6%
BENTHOS - 7	0.10	0.8%	20.0%	79.3%	0.10	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%
FISH - 1	0.05	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				0.00			

Table A-8: (Continued) Feeding preferences of various species represented in the model. Generalized trophic interactions between most of the species described in Table A-7b.

	FISH - 5				FISH - 6				FISH - 7			
PREY SPECIES	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%
PHYTOPLANKTON	0.30	0.1%	6.0%	93.9%	0.05	0.1%	6.0%	93.9%	0.20	0.1%	6.0%	93.9%
0.00E+00	0.20	0.8%	20.0%	79.3%	0.20	0.8%	20.0%	79.3%	0.25	0.8%	20.0%	79.3%
BENTHOS - 1	0.30	0.8%	20.0%	79.3%	0.15	0.8%	20.0%	79.3%	0.20	0.8%	20.0%	79.3%
BENTHOS - 2	0.00	0.8%	20.0%	79.3%	0.15	0.8%	20.0%	79.3%	0.05	0.8%	20.0%	79.3%
BENTHOS - 3	0.00	0.8%	20.0%	79.3%	0.10	0.8%	20.0%	79.3%	0.05	0.8%	20.0%	79.3%
BENTHOS - 4	0.20	1.0%	20.0%	79.0%	0.10	1.0%	20.0%	79.0%	0.10	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.10	7.0%	20.0%	73.0%	0.05	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.10	9.4%	20.0%	70.6%	0.02	9.4%	20.0%	70.6%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.05	0.8%	20.0%	79.3%	0.08	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				1.00			

	FISH - 8				FISH - 9				FISH - 10			
PREY SPECIES	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)	% Diet Composition	Lipid Content (Diet)	NLOM Content (Diet)	Water Content (Diet)
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%	0.05	0.0%	1.0%	99.0%
PHYTOPLANKTON	0.10	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%
0.00E+00	0.10	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 1	0.20	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.20	0.8%	20.0%	79.3%
BENTHOS - 2	0.15	0.8%	20.0%	79.3%	0.05	0.8%	20.0%	79.3%	0.15	0.8%	20.0%	79.3%
BENTHOS - 3	0.15	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.15	0.8%	20.0%	79.3%
BENTHOS - 4	0.30	1.0%	20.0%	79.0%	0.10	1.0%	20.0%	79.0%	0.15	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.05	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.05	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.05	0.8%	20.0%	79.3%	0.20	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.10	1.5%	20.0%	78.5%	0.05	1.5%	20.0%	78.5%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.05	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.05	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.05	2.0%	20.0%	78.0%	0.05	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.25	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%	0.00	2.5%	20.0%	77.5%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%	0.00	2.6%	20.0%	77.4%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.10	1.6%	20.0%	78.4%	0.00	1.6%	20.0%	78.4%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.10	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%	0.00	3.0%	20.0%	77.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%	0.00	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				1.00			

Table A-8: (Continued) Feeding preferences of various species represented in the model. Generalized trophic interactions between most of the species described in Table A-7b.

PREY SPECIES	SEAL-1				SEAL-2				SEAL-3			
	% Diet Compos	Lipid Content	NLOM Content	Water Content	% Diet Compos	Lipid Content	NLOM Content	Water Content	% Diet Compos	Lipid Content	NLOM Content	Water Content
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%
PHYTOPLANKTON	0.00	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%
0.00E+00	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 1	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 2	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 3	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 4	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.10	1.5%	20.0%	78.5%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%	0.00	1.8%	20.0%	78.2%
FISH - 5	0.05	2.5%	20.0%	77.5%	0.05	2.5%	20.0%	77.5%	0.10	2.5%	20.0%	77.5%
FISH - 6	0.05	2.6%	20.0%	77.4%	0.05	2.6%	20.0%	77.4%	0.10	2.6%	20.0%	77.4%
FISH - 7	0.05	1.6%	20.0%	78.4%	0.05	1.6%	20.0%	78.4%	0.10	1.6%	20.0%	78.4%
FISH - 8	0.50	3.0%	20.0%	77.0%	0.50	3.0%	20.0%	77.0%	0.40	3.0%	20.0%	77.0%
FISH - 9	0.15	3.0%	20.0%	77.0%	0.15	3.0%	20.0%	77.0%	0.10	3.0%	20.0%	77.0%
FISH - 10	0.20	3.5%	20.0%	76.5%	0.20	3.5%	20.0%	76.5%	0.10	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				1.00			

PREY SPECIES	SEAL-4				BIRD-1				BIRD-2			
	% Diet Compos	Lipid Content	NLOM Content	Water Content	% Diet Compos	Lipid Content	NLOM Content	Water Content	% Diet Compos	Lipid Content	NLOM Content	Water Content
SEDIMENT	1.00	45.0%	10.0%	45.0%	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%
PHYTOPLANKTON	0.00	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%
0.00E+00	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 1	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 2	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 3	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 4	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%	0.00	1.2%	20.0%	78.8%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%	0.00	2.0%	20.0%	78.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.05	1.8%	20.0%	78.2%	0.05	1.8%	20.0%	78.2%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.05	2.5%	20.0%	77.5%	0.05	2.5%	20.0%	77.5%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.05	2.6%	20.0%	77.4%	0.05	2.6%	20.0%	77.4%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.05	1.6%	20.0%	78.4%	0.05	1.6%	20.0%	78.4%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.30	3.0%	20.0%	77.0%	0.30	3.0%	20.0%	77.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.30	3.0%	20.0%	77.0%	0.30	3.0%	20.0%	77.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.20	3.5%	20.0%	76.5%	0.20	3.5%	20.0%	76.5%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%
Sum (Confirmation)	1.00				1.00				1.00			

Table A-8: (Continued) Feeding preferences of various species represented in the model. Generalized trophic interactions between most of the species described in Table A-7b.

	BIRD-3				BIRD-4				N/A			
PREY SPECIES	% Diet Compos	Lipid Content	NLOM Content	Water Content	% Diet Compos	Lipid Content	NLOM Content	Water Content	% Diet Compos	Lipid Content	NLOM Content	Water Content
SEDIMENT	0.00	0.0%	1.0%	99.0%	0.00	0.0%	1.0%	99.0%	0.00	0.0%	0.0%	0.0%
PHYTOPLANKTON	0.00	0.1%	6.0%	93.9%	0.00	0.1%	6.0%	93.9%	0.00	0.0%	0.0%	0.0%
0.00E+00	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.0%	0.0%	0.0%
BENTHOS - 1	0.05	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.0%	0.0%	0.0%
BENTHOS - 2	0.05	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.0%	0.0%	0.0%
BENTHOS - 3	0.90	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.0%	0.0%	0.0%
BENTHOS - 4	0.00	1.0%	20.0%	79.0%	0.00	1.0%	20.0%	79.0%	0.00	0.0%	0.0%	0.0%
BENTHOS - 5	0.00	7.0%	20.0%	73.0%	0.00	7.0%	20.0%	73.0%	0.00	0.0%	0.0%	0.0%
BENTHOS - 6	0.00	9.4%	20.0%	70.6%	0.00	9.4%	20.0%	70.6%	0.00	0.0%	0.0%	0.0%
BENTHOS - 7	0.00	0.8%	20.0%	79.3%	0.00	0.8%	20.0%	79.3%	0.00	0.0%	0.0%	0.0%
BENTHOS - 8	0.00	1.5%	20.0%	78.5%	0.00	1.5%	20.0%	78.5%	0.00	0.0%	0.0%	0.0%
FISH - 1	0.00	2.0%	20.0%	78.0%	0.15	2.0%	20.0%	78.0%	0.00	0.0%	0.0%	0.0%
FISH - 2	0.00	1.2%	20.0%	78.8%	0.15	1.2%	20.0%	78.8%	0.00	0.0%	0.0%	0.0%
FISH - 3	0.00	2.0%	20.0%	78.0%	0.15	2.0%	20.0%	78.0%	0.00	0.0%	0.0%	0.0%
FISH - 4	0.00	1.8%	20.0%	78.2%	0.15	1.8%	20.0%	78.2%	0.00	0.0%	0.0%	0.0%
FISH - 5	0.00	2.5%	20.0%	77.5%	0.10	2.5%	20.0%	77.5%	0.00	0.0%	0.0%	0.0%
FISH - 6	0.00	2.6%	20.0%	77.4%	0.10	2.6%	20.0%	77.4%	0.00	0.0%	0.0%	0.0%
FISH - 7	0.00	1.6%	20.0%	78.4%	0.05	1.6%	20.0%	78.4%	0.00	0.0%	0.0%	0.0%
FISH - 8	0.00	3.0%	20.0%	77.0%	0.05	3.0%	20.0%	77.0%	0.00	0.0%	0.0%	0.0%
FISH - 9	0.00	3.0%	20.0%	77.0%	0.05	3.0%	20.0%	77.0%	0.00	0.0%	0.0%	0.0%
FISH - 10	0.00	3.5%	20.0%	76.5%	0.05	3.5%	20.0%	76.5%	0.00	0.0%	0.0%	0.0%
FISH - 11	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	0.0%	0.0%	0.0%
FISH - 12	0.00	5.0%	20.0%	75.0%	0.00	5.0%	20.0%	75.0%	0.00	0.0%	0.0%	0.0%
Sum (Confirmation)	1.00				1.00				0.00			

Table A-9: **Observed Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek**

PCB#	PHYTOPLANKTON		ZOOPLANKTON		BENTHOS - 1		BENTHOS - 2		BENTHOS - 3		BENTHOS - 4		BENTHOS - 5	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	-1.64	0.00	-1.75	0.00	-1.43	0.38	-1.16	0.41	-1.51	0.00	-1.30	0.43	N/A	0.00
18	N/A	0.00	N/A	0.00	-1.31	0.00	-1.08	0.31	N/A	0.00	-1.08	0.29	N/A	0.00
28	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00
32	N/A	0.00	N/A	0.00	N/A	0.38	N/A	0.41	N/A	0.00	N/A	0.43	N/A	0.00
47	-1.64	0.30	-1.75	0.33	-1.43	0.26	-1.16	0.34	-1.51	0.31	-1.30	0.34	N/A	0.00
48	-1.48	0.30	-2.08	0.33	-1.00	0.26	-0.58	0.34	-0.65	0.31	-1.02	0.34	N/A	0.00
52	-1.48	0.53	-2.08	0.50	-1.00	0.27	-0.58	0.35	-0.65	0.32	-1.02	0.38	N/A	0.00
73	-1.52	0.53	-2.14	0.50	-1.27	0.27	-0.73	0.35	-0.88	0.32	-1.13	0.38	N/A	0.00
75	-1.52	0.30	-2.14	0.33	-1.27	0.26	-0.73	0.34	-0.88	0.31	-1.13	0.34	N/A	0.00
90	-1.48	0.87	-2.08	0.54	-1.00	0.22	-0.58	0.34	-0.65	0.27	-1.02	0.37	N/A	0.00
99	-1.89	0.87	-2.50	0.31	-1.25	0.19	-0.50	0.31	-0.69	0.24	-1.10	0.33	N/A	0.00
101	-1.65	0.87	-1.88	0.54	-1.09	0.22	-0.40	0.34	-0.57	0.27	-1.06	0.37	N/A	0.00
110	-1.89	0.95	-2.50	0.52	-1.25	0.22	-0.50	0.36	-0.69	0.28	-1.10	0.41	N/A	0.00
118	-1.94	0.93	-2.57	0.57	-1.34	0.30	-0.60	0.46	-0.99	0.34	-1.18	0.44	N/A	0.00
132	-1.75	0.87	-2.48	0.45	-1.19	0.24	-0.44	0.32	-0.54	0.31	-1.04	0.36	N/A	0.00
138	-1.71	0.91	-2.35	0.48	-1.00	0.23	-0.25	0.32	-0.40	0.31	-1.01	0.38	N/A	0.00
149	-1.81	0.84	-2.52	0.48	-1.16	0.23	-0.50	0.31	-0.59	0.33	-1.16	0.35	N/A	0.00
153	-1.85	0.87	-2.52	0.45	-1.28	0.24	-0.47	0.32	-0.69	0.31	-1.16	0.36	N/A	0.00
160	-1.71	0.91	-2.35	0.48	-1.00	0.23	-0.25	0.32	-0.40	0.31	-1.01	0.38	N/A	0.00
163	-1.81	0.91	-2.52	0.48	-1.16	0.23	-0.50	0.32	-0.59	0.31	-1.16	0.38	N/A	0.00
164	-1.81	0.91	-2.52	0.48	-1.16	0.23	-0.50	0.32	-0.59	0.31	-1.16	0.38	N/A	0.00
180	-1.81	0.81	-2.52	0.49	-1.16	0.29	-0.50	0.33	-0.59	0.34	-1.16	0.38	N/A	0.00
182	-1.97	0.81	-2.80	0.48	-1.41	0.27	-1.33	0.33	-1.16	0.32	-1.56	0.34	N/A	0.00
187	-1.84	0.81	-2.44	0.48	-1.22	0.27	-0.56	0.33	-0.75	0.32	-1.27	0.34	N/A	0.00
194	-1.84	0.76	-2.44	0.42	-1.22	0.27	-0.56	0.33	-0.75	0.32	-1.27	0.38	N/A	0.00
196	-1.94	0.65	-2.43	0.31	-1.56	0.25	-2.36	0.38	-1.70	0.33	-2.08	0.34	N/A	0.00
203	-1.83	0.65	-2.30	0.31	-1.45	0.25	-2.31	0.38	-1.63	0.33	-1.71	0.34	N/A	0.00
206	-1.83	0.63	-2.30	0.00	-1.45	0.25	-2.31	0.00	-1.63	0.00	-1.71	0.30	N/A	0.00
209	-1.72	0.53	-2.41	0.00	-1.61	0.22	-2.40	0.00	-2.26	0.00	-2.11	0.00	N/A	0.00
AVERAGE	**-1.74**	**0.73**	**-2.32**	**0.45**	**-1.25**	**0.26**	**-0.88**	**0.35**	**-0.92**	**0.31**	**-1.26**	**0.36**	**0.00**	**0**

Table A-9: (Continued) Observed Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek

PCB#	BENTHOS - 6		BENTHOS - 7		BENTHOS - 8		FISH - 1		FISH - 2		FISH - 3		FISH - 4	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	N/A	0.00	-0.66	0.42	0.23	0.52	-1.02	0.45	N/A	0.00	N/A	0.00	N/A	0.00
18	N/A	0.00	-0.64	0.00	0.23	0.41	-1.00	0.39	N/A	0.00	N/A	0.00	N/A	0.00
28	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00
32	N/A	0.00	N/A	0.42	N/A	0.52	N/A	0.45	N/A	0.00	N/A	0.00	N/A	0.00
47	N/A	0.00	-0.66	0.38	0.23	0.47	-1.02	0.48	N/A	0.42	N/A	0.00	N/A	0.00
48	N/A	0.00	0.30	0.38	0.95	0.47	-0.45	0.48	-1.31	0.42	N/A	0.00	N/A	0.00
52	N/A	0.00	0.30	0.32	0.95	0.45	-0.45	0.50	-1.31	0.47	N/A	0.00	N/A	0.00
73	N/A	0.00	-0.13	0.32	0.82	0.45	-0.30	0.50	-0.90	0.47	N/A	0.00	N/A	0.00
75	N/A	0.00	-0.13	0.38	0.82	0.47	-0.30	0.48	-0.90	0.42	N/A	0.00	N/A	0.00
90	N/A	0.00	0.30	0.39	0.95	0.40	-0.45	0.52	-1.31	0.40	N/A	0.00	N/A	0.00
99	N/A	0.00	-0.05	0.40	0.96	0.40	-0.05	0.46	-0.68	0.37	N/A	0.00	N/A	0.00
101	N/A	0.00	0.27	0.39	1.06	0.40	0.13	0.52	-0.47	0.40	N/A	0.00	N/A	0.00
110	N/A	0.00	-0.05	0.41	0.96	0.40	-0.05	0.52	-0.68	0.41	N/A	0.00	N/A	0.00
118	N/A	0.00	-0.22	0.29	0.77	0.43	-0.25	0.52	-1.12	0.43	N/A	0.00	N/A	0.00
132	N/A	0.00	0.36	0.65	1.05	0.35	0.18	0.48	-0.47	0.35	N/A	0.00	N/A	0.00
138	N/A	0.00	-0.36	0.50	1.11	0.37	0.29	0.48	-0.38	0.36	N/A	0.00	N/A	0.00
149	N/A	0.00	-0.13	0.37	0.96	0.36	0.12	0.41	-0.56	0.38	N/A	0.00	N/A	0.00
153	N/A	0.00	-0.36	0.65	0.84	0.35	-0.30	0.48	-1.23	0.35	N/A	0.00	N/A	0.00
160	N/A	0.00	-0.36	0.50	1.11	0.37	0.29	0.48	-0.38	0.36	N/A	0.00	N/A	0.00
163	N/A	0.00	-0.13	0.50	0.96	0.37	0.12	0.48	-0.56	0.36	N/A	0.00	N/A	0.00
164	N/A	0.00	-0.13	0.50	0.96	0.37	0.12	0.48	-0.56	0.36	N/A	0.00	N/A	0.00
180	N/A	0.00	-0.13	0.67	0.96	0.38	0.12	0.51	-0.56	0.40	N/A	0.00	N/A	0.00
182	N/A	0.00	-0.81	0.47	0.53	0.38	-0.24	0.47	-0.88	0.36	N/A	0.00	N/A	0.00
187	N/A	0.00	-0.20	0.47	0.79	0.38	-0.09	0.47	-0.77	0.36	N/A	0.00	N/A	0.00
194	N/A	0.00	-0.20	0.70	0.79	0.48	-0.09	0.51	-0.77	0.42	N/A	0.00	N/A	0.00
196	N/A	0.00	-1.04	0.92	0.22	0.49	-0.57	0.47	-1.18	0.38	N/A	0.00	N/A	0.00
203	N/A	0.00	-1.78	0.92	0.22	0.49	-0.45	0.47	-1.04	0.38	N/A	0.00	N/A	0.00
206	N/A	0.00	-1.78	0.88	0.22	0.53	-0.45	0.48	-1.04	0.47	N/A	0.00	N/A	0.00
209	N/A	0.00	-2.03	0.00	-0.11	0.59	-1.00	0.35	-1.42	0.40	N/A	0.00	N/A	0.00
AVERAGE	**0**	**0**	**-0.39**	**0.51**	**0.72**	**0.43**	**-0.26**	**0.47**	**-0.85**	**0.40**	**0.00**	**0**	**0**	**0**

Table A-9: (Continued) Observed Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek

PCB#	FISH - 5		FISH - 6		FISH - 7		FISH - 8		FISH - 9		FISH - 10		FISH - 11	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	-1.48	0.42	N/A	0.00	-0.81	0.39	-1.04	0.41	-0.13	0.47	N/A	0.00	N/A	0.00
18	-1.26	0.29	N/A	0.00	-0.78	0.28	-0.98	0.31	-0.06	0.52	N/A	0.00	N/A	0.00
28	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00
32	N/A	0.42	N/A	0.00	N/A	0.39	N/A	0.41	N/A	0.47	N/A	0.00	N/A	0.00
47	-1.48	0.37	N/A	0.00	-0.81	0.26	-1.04	0.30	-0.13	0.35	N/A	0.00	N/A	0.00
48	-0.87	0.37	N/A	0.00	-0.25	0.26	-0.45	0.30	0.70	0.35	N/A	0.00	N/A	0.00
52	-0.87	0.38	N/A	0.00	-0.25	0.26	-0.45	0.30	0.70	0.33	N/A	0.00	N/A	0.00
73	-0.90	0.38	N/A	0.00	-0.26	0.26	-0.59	0.30	0.45	0.33	N/A	0.00	N/A	0.00
75	-0.90	0.37	N/A	0.00	-0.26	0.26	-0.59	0.30	0.45	0.35	N/A	0.00	N/A	0.00
90	-0.87	0.38	N/A	0.00	-0.25	0.21	-0.45	0.24	0.70	0.28	N/A	0.00	N/A	0.00
99	-0.77	0.38	N/A	0.00	-0.09	0.20	-0.53	0.22	0.84	0.28	N/A	0.00	N/A	0.00
101	-0.66	0.38	N/A	0.00	-0.07	0.21	-0.32	0.24	1.14	0.28	N/A	0.00	N/A	0.00
110	-0.77	0.35	N/A	0.00	-0.09	0.28	-0.53	0.24	0.84	0.27	N/A	0.00	N/A	0.00
118	-0.92	0.45	N/A	0.00	-0.14	0.31	-0.71	0.32	0.54	0.40	N/A	0.00	N/A	0.00
132	-0.69	0.40	N/A	0.00	-0.13	0.27	-0.37	0.27	1.16	0.35	N/A	0.00	N/A	0.00
138	-0.53	0.41	N/A	0.00	0.05	0.22	-0.32	0.26	1.38	0.35	N/A	0.00	N/A	0.00
149	-0.72	0.37	N/A	0.00	-0.13	0.23	-0.47	0.25	1.21	0.31	N/A	0.00	N/A	0.00
153	-0.88	0.40	N/A	0.00	-0.32	0.27	-0.76	0.27	0.78	0.35	N/A	0.00	N/A	0.00
160	-0.53	0.41	N/A	0.00	0.05	0.22	-0.32	0.26	1.38	0.35	N/A	0.00	N/A	0.00
163	-0.72	0.41	N/A	0.00	-0.13	0.22	-0.47	0.26	1.21	0.35	N/A	0.00	N/A	0.00
164	-0.72	0.41	N/A	0.00	-0.13	0.22	-0.47	0.26	1.21	0.35	N/A	0.00	N/A	0.00
180	-0.72	0.44	N/A	0.00	-0.13	0.36	-0.47	0.32	1.21	0.39	N/A	0.00	N/A	0.00
182	-1.02	0.43	N/A	0.00	-0.37	0.33	-0.81	0.30	0.93	0.36	N/A	0.00	N/A	0.00
187	-0.87	0.43	N/A	0.00	-0.24	0.33	-0.67	0.30	1.08	0.36	N/A	0.00	N/A	0.00
194	-0.87	0.46	N/A	0.00	-0.24	0.35	-0.67	0.31	1.08	0.40	N/A	0.00	N/A	0.00
196	-1.18	0.44	N/A	0.00	-0.58	0.31	-1.11	0.29	0.66	0.37	N/A	0.00	N/A	0.00
203	-1.01	0.44	N/A	0.00	-0.43	0.31	-1.08	0.29	0.82	0.37	N/A	0.00	N/A	0.00
206	-1.01	0.41	N/A	0.00	-0.43	0.43	-1.08	0.34	0.82	0.37	N/A	0.00	N/A	0.00
209	-1.37	0.34	N/A	0.00	-0.94	0.29	-1.43	0.27	0.33	0.33	N/A	0.00	N/A	0.00
AVERAGE	**-0.91**	**0.40**	**0.00**	**0**	**-0.30**	**0.28**	**-0.67**	**0.29**	**0.79**	**0.36**	**0.00**	**0**	**0**	**0**

Table A-9: (Continued) Observed Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek

PCB#	SEAL-2		SEAL-3		SEAL-4		BIRD-1		BIRD-2		BIRD-3		BIRD-4	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00
18	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00
28	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00
32	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00
47	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.32	N/A	0.00
48	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.90	0.32	N/A	0.00
52	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.90	0.27	N/A	0.00
73	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-2.02	0.27	N/A	0.00
75	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-2.02	0.32	N/A	0.00
90	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.90	0.28	N/A	0.00
99	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-1.26	0.29	N/A	0.00
101	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.05	0.28	N/A	0.00
110	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-1.26	0.33	N/A	0.00
118	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-1.75	0.39	N/A	0.00
132	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.05	0.38	N/A	0.00
138	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.26	0.29	N/A	0.00
149	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.11	0.28	N/A	0.00
153	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.87	0.38	N/A	0.00
160	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.26	0.29	N/A	0.00
163	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.11	0.29	N/A	0.00
164	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.11	0.29	N/A	0.00
180	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.11	0.40	N/A	0.00
182	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.37	0.33	N/A	0.00
187	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.06	0.33	N/A	0.00
194	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	0.06	0.39	N/A	0.00
196	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.73	0.41	N/A	0.00
203	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.59	0.41	N/A	0.00
206	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.59	0.47	N/A	0.00
209	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	N/A	0.00	-0.98	0.36	N/A	0.00
AVERAGE	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-0.59**	**0.33**	**0.00**	**0**

Table A-10: **Predicted Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek**

PCB#	PHYTOPLANKTON		ZOOPLANKTON		BENTHOS - 1		BENTHOS - 2		BENTHOS - 3		BENTHOS - 4		BENTHOS - 5	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	-1.35	0.30	-1.70	0.33	-1.38	0.38	-1.00	0.41	-1.06	0.31	-1.28	0.43	-0.18	0.13
18	-1.40	0.38	-1.75	0.33	-1.36	0.41	-0.99	0.31	-1.05	0.34	-1.27	0.29	-0.13	0.15
28	-1.63	0.38	-1.98	0.38	-1.29	0.34	-0.91	0.35	-0.96	0.41	-1.20	0.30	0.14	0.22
32	-1.63	0.38	-1.98	0.38	-1.29	0.34	-0.91	0.35	-0.96	0.41	-1.20	0.30	0.14	0.22
47	-1.52	0.33	-1.87	0.26	-1.33	0.38	-0.95	0.41	-1.01	0.34	-1.24	0.43	-0.01	0.23
48	-1.70	0.30	-2.05	0.33	-1.26	0.26	-0.88	0.34	-0.92	0.31	-1.17	0.34	0.26	0.25
52	-1.68	0.30	-2.03	0.33	-1.27	0.26	-0.89	0.34	-0.93	0.31	-1.18	0.34	0.22	0.27
73	-1.70	0.53	-2.05	0.50	-1.26	0.27	-0.88	0.35	-0.92	0.32	-1.17	0.38	0.25	0.35
75	-1.74	0.53	-2.10	0.50	-1.23	0.27	-0.85	0.35	-0.88	0.32	-1.14	0.38	0.36	0.60
90	-1.75	0.30	-2.10	0.33	-1.23	0.26	-0.85	0.34	-0.88	0.31	-1.14	0.34	0.36	0.65
99	-1.78	0.87	-2.14	0.54	-1.19	0.22	-0.81	0.34	-0.81	0.27	-1.09	0.37	0.49	0.40
101	-1.78	0.87	-2.14	0.31	-1.19	0.19	-0.81	0.31	-0.80	0.24	-1.09	0.33	0.50	0.33
110	-1.78	0.87	-2.14	0.54	-1.19	0.22	-0.81	0.34	-0.80	0.27	-1.09	0.37	0.49	0.41
118	-1.78	0.95	-2.14	0.52	-1.18	0.22	-0.80	0.36	-0.78	0.28	-1.08	0.41	0.52	0.44
132	-1.77	0.93	-2.13	0.57	-1.16	0.30	-0.79	0.46	-0.74	0.34	-1.06	0.44	0.55	0.36
138	-1.78	0.87	-2.13	0.45	-1.17	0.24	-0.79	0.32	-0.76	0.31	-1.07	0.36	0.54	0.38
149	-1.76	0.91	-2.12	0.48	-1.16	0.23	-0.79	0.32	-0.73	0.31	-1.05	0.38	0.54	0.35
153	-1.78	0.84	-2.13	0.48	-1.16	0.23	-0.79	0.31	-0.75	0.33	-1.06	0.35	0.54	0.50
160	-1.75	0.87	-2.11	0.45	-1.16	0.24	-0.79	0.32	-0.73	0.31	-1.05	0.36	0.54	0.52
163	-1.75	0.91	-2.11	0.48	-1.16	0.23	-0.79	0.32	-0.73	0.31	-1.05	0.38	0.54	0.55
164	-1.74	0.91	-2.10	0.48	-1.16	0.23	-0.79	0.32	-0.73	0.31	-1.05	0.38	0.53	0.31
180	-1.74	0.91	-2.09	0.48	-1.16	0.23	-0.80	0.32	-0.73	0.31	-1.05	0.38	0.52	0.31
182	-1.69	0.81	-2.04	0.49	-1.22	0.29	-0.86	0.33	-0.77	0.34	-1.09	0.38	0.41	0.34
187	-1.71	0.81	-2.07	0.48	-1.19	0.27	-0.82	0.33	-0.74	0.32	-1.06	0.34	0.47	0.32
194	-1.72	0.81	-2.07	0.48	-1.18	0.27	-0.82	0.33	-0.74	0.32	-1.06	0.34	0.48	0.32
196	-1.62	0.76	-1.97	0.42	-1.40	0.27	-1.05	0.33	-0.94	0.32	-1.24	0.38	0.14	0.32
203	-1.64	0.65	-2.00	0.31	-1.33	0.25	-0.98	0.38	-0.87	0.33	-1.18	0.34	0.24	0.33
206	-1.64	0.65	-2.00	0.31	-1.33	0.25	-0.98	0.38	-0.87	0.33	-1.18	0.34	0.24	0.33
209	-1.56	0.63	-1.92	0.53	-1.58	0.25	-1.24	0.35	-1.12	0.32	-1.40	0.30	-0.10	0.32
AVERAGE	**-1.69**	**0.67**	**-2.04**	**0.43**	**-1.25**	**0.27**	**-0.88**	**0.35**	**-0.85**	**0.32**	**-1.14**	**0.36**	**0.33**	**0.352591**

Table A-10: (Continued) Predicted Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek

PCB#	BENTHOS - 6		BENTHOS - 7		BENTHOS - 8		FISH - 1		FISH - 2		FISH - 3		FISH - 4	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	0.07	0.27	-0.08	0.42	0.33	0.52	-0.46	0.45	-1.18	0.42	-0.31	0.33	-0.50	0.38
18	0.14	0.25	-0.08	0.38	0.34	0.41	-0.44	0.39	-1.13	0.39	-0.23	0.33	-0.42	0.41
28	0.48	0.31	-0.05	0.30	0.46	0.46	-0.32	0.42	-0.85	0.40	0.22	0.38	0.04	0.34
32	0.48	0.31	-0.05	0.30	0.46	0.46	-0.32	0.42	-0.85	0.40	0.22	0.38	0.04	0.34
47	0.30	0.33	-0.07	0.42	0.39	0.52	-0.39	0.45	-1.00	0.40	-0.02	0.26	-0.21	0.38
48	0.64	0.29	-0.04	0.38	0.55	0.47	-0.24	0.48	-0.74	0.42	0.41	0.33	0.24	0.26
52	0.59	0.34	-0.04	0.38	0.52	0.47	-0.27	0.48	-0.77	0.42	0.35	0.33	0.17	0.26
73	0.63	0.35	-0.04	0.32	0.54	0.45	-0.25	0.50	-0.74	0.47	0.40	0.50	0.23	0.27
75	0.77	0.40	-0.03	0.32	0.63	0.45	-0.17	0.50	-0.64	0.47	0.57	0.50	0.40	0.27
90	0.78	0.41	-0.03	0.38	0.64	0.47	-0.17	0.48	-0.64	0.42	0.57	0.33	0.41	0.26
99	0.94	0.40	-0.02	0.39	0.77	0.40	-0.07	0.52	-0.52	0.40	0.77	0.54	0.61	0.22
101	0.95	0.35	-0.02	0.40	0.77	0.40	-0.06	0.46	-0.51	0.37	0.78	0.31	0.62	0.19
110	0.95	0.40	-0.02	0.39	0.77	0.40	-0.06	0.52	-0.51	0.40	0.78	0.54	0.62	0.22
118	0.98	0.42	-0.02	0.41	0.80	0.40	-0.04	0.52	-0.49	0.41	0.81	0.52	0.65	0.22
132	1.02	0.32	-0.05	0.29	0.82	0.43	0.00	0.52	-0.46	0.43	0.86	0.57	0.70	0.30
138	1.01	0.45	-0.03	0.65	0.81	0.35	-0.01	0.48	-0.47	0.35	0.84	0.45	0.68	0.24
149	1.02	0.42	-0.07	0.50	0.81	0.37	0.01	0.48	-0.45	0.36	0.85	0.48	0.70	0.23
153	1.02	0.13	-0.04	0.37	0.82	0.36	0.00	0.41	-0.46	0.38	0.85	0.48	0.70	0.23
160	1.01	0.56	-0.09	0.65	0.79	0.35	0.02	0.48	-0.46	0.35	0.84	0.45	0.69	0.24
163	1.01	0.52	-0.09	0.50	0.79	0.37	0.02	0.48	-0.46	0.36	0.84	0.48	0.69	0.23
164	1.00	0.38	-0.11	0.50	0.77	0.37	0.02	0.48	-0.46	0.36	0.83	0.48	0.68	0.23
180	1.00	0.38	-0.12	0.50	0.76	0.37	0.02	0.48	-0.47	0.36	0.82	0.48	0.67	0.23
182	0.85	0.38	-0.28	0.67	0.56	0.38	-0.03	0.51	-0.56	0.40	0.64	0.49	0.51	0.29
187	0.93	0.34	-0.20	0.47	0.67	0.38	0.00	0.47	-0.51	0.36	0.74	0.48	0.60	0.27
194	0.94	0.34	-0.19	0.47	0.68	0.38	0.00	0.47	-0.50	0.36	0.75	0.48	0.61	0.27
196	0.52	0.38	-0.59	0.70	0.14	0.48	-0.20	0.51	-0.81	0.42	0.20	0.42	0.09	0.27
203	0.65	0.34	-0.48	0.92	0.29	0.49	-0.13	0.47	-0.71	0.38	0.37	0.31	0.25	0.25
206	0.65	0.34	-0.48	0.92	0.29	0.49	-0.13	0.47	-0.71	0.38	0.37	0.31	0.25	0.25
209	0.24	0.30	-0.84	0.88	-0.21	0.53	-0.39	0.48	-1.08	0.47	-0.22	0.53	-0.32	0.25
AVERAGE	**0.744925**	**0.358348**	**-0.15**	**0.49**	**0.58**	**0.43**	**-0.14**	**0.48**	**-0.66**	**0.40**	**0.51**	**0.429702**	**0.357826**	**0.269754**

Table A-10: (Continued) Predicted Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek

PCB#	FISH - 5		FISH - 6		FISH - 7		FISH - 8		FISH - 9		FISH - 10		FISH - 11	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	-0.85	0.42	-0.36	0.29	-0.76	0.39	-0.89	0.41	0.09	0.47	0.47	0.31	-0.57	0.42
18	-0.85	0.29	-0.28	0.28	-0.74	0.28	-0.88	0.31	0.16	0.52	0.53	0.34	-0.56	0.39
28	-0.85	0.30	0.18	0.29	-0.54	0.31	-0.83	0.33	0.58	0.40	0.83	0.41	-0.51	0.40
32	-0.85	0.30	0.18	0.29	-0.54	0.31	-0.83	0.33	0.58	0.40	0.83	0.41	-0.51	0.40
47	-0.85	0.42	-0.06	0.40	-0.66	0.39	-0.86	0.41	0.35	0.47	0.68	0.34	-0.53	0.40
48	-0.85	0.37	0.38	0.30	-0.41	0.26	-0.80	0.30	0.77	0.35	0.95	0.31	-0.49	0.42
52	-0.85	0.37	0.32	0.31	-0.46	0.26	-0.81	0.30	0.70	0.35	0.91	0.31	-0.49	0.42
73	-0.85	0.38	0.37	0.32	-0.42	0.26	-0.80	0.30	0.76	0.33	0.94	0.32	-0.49	0.47
75	-0.85	0.38	0.54	0.32	-0.28	0.26	-0.76	0.30	0.93	0.33	1.04	0.32	-0.47	0.47
90	-0.85	0.37	0.55	0.31	-0.27	0.26	-0.76	0.30	0.93	0.35	1.05	0.31	-0.47	0.42
99	-0.84	0.38	0.75	0.29	-0.08	0.21	-0.70	0.24	1.14	0.28	1.16	0.27	-0.46	0.40
101	-0.84	0.38	0.77	0.28	-0.07	0.20	-0.70	0.22	1.15	0.28	1.17	0.24	-0.46	0.37
110	-0.84	0.38	0.76	0.28	-0.07	0.21	-0.70	0.24	1.14	0.28	1.17	0.27	-0.46	0.40
118	-0.83	0.35	0.80	0.30	-0.03	0.28	-0.68	0.24	1.18	0.27	1.19	0.28	-0.46	0.41
132	-0.83	0.45	0.84	0.33	0.03	0.31	-0.66	0.32	1.22	0.40	1.22	0.34	-0.47	0.43
138	-0.83	0.40	0.83	0.35	0.00	0.27	-0.67	0.27	1.21	0.35	1.21	0.31	-0.46	0.35
149	-0.83	0.41	0.84	0.30	0.03	0.22	-0.65	0.26	1.22	0.35	1.21	0.31	-0.48	0.36
153	-0.83	0.37	0.84	0.32	0.02	0.23	-0.66	0.25	1.22	0.31	1.21	0.33	-0.46	0.38
160	-0.83	0.40	0.83	0.35	0.03	0.27	-0.65	0.27	1.20	0.35	1.21	0.31	-0.49	0.35
163	-0.83	0.41	0.83	0.31	0.03	0.22	-0.65	0.26	1.20	0.35	1.20	0.31	-0.49	0.36
164	-0.83	0.41	0.82	0.30	0.02	0.22	-0.65	0.26	1.19	0.35	1.20	0.31	-0.50	0.36
180	-0.83	0.41	0.81	0.31	0.02	0.22	-0.66	0.26	1.18	0.35	1.19	0.31	-0.51	0.36
182	-0.90	0.44	0.64	0.38	-0.12	0.36	-0.72	0.32	0.97	0.39	1.08	0.34	-0.61	0.40
187	-0.86	0.43	0.73	0.38	-0.04	0.33	-0.68	0.30	1.08	0.36	1.14	0.32	-0.56	0.36
194	-0.86	0.43	0.75	0.39	-0.03	0.33	-0.68	0.30	1.10	0.36	1.15	0.32	-0.55	0.36
196	-1.09	0.46	0.20	0.41	-0.47	0.35	-0.94	0.31	0.46	0.40	0.84	0.32	-0.84	0.42
203	-1.01	0.44	0.36	0.37	-0.33	0.31	-0.85	0.29	0.65	0.37	0.93	0.33	-0.76	0.38
206	-1.01	0.44	0.36	0.80	-0.33	0.31	-0.85	0.29	0.65	0.37	0.93	0.33	-0.76	0.38
209	-1.29	0.41	-0.22	0.42	-0.80	0.43	-1.19	0.34	-0.04	0.37	0.63	0.32	-1.05	0.47
AVERAGE	**-0.88**	**0.39**	**0.50**	**0.344138**	**-0.25**	**0.28**	**-0.76**	**0.29**	**0.86**	**0.36**	**1.01**	**0.320607**	**-0.54843**	**0.396469**

Table A-10: (Continued) Predicted Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek

PCB#	SEAL-2		SEAL-3		SEAL-4		BIRD-1		BIRD-2		BIRD-3		BIRD-4	
	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD	Log BSAF	SD
16	1.05	0.42	1.54	0.29	1.09	0.39	1.10	0.41	1.10	0.47	-0.67	0.32	0.48	0.41
18	1.12	0.29	1.64	0.28	1.16	0.28	1.21	0.31	1.20	0.52	-0.60	0.32	0.60	0.38
28	1.47	0.30	2.22	0.29	1.52	0.31	1.75	0.33	1.74	0.40	-0.13	0.27	1.31	0.28
32	1.47	0.30	2.22	0.29	1.52	0.31	1.75	0.33	1.74	0.40	-0.13	0.27	1.31	0.28
47	1.28	0.42	1.87	0.40	1.33	0.39	1.44	0.41	1.44	0.47	-0.43	0.28	0.89	0.28
48	1.61	0.37	2.36	0.30	1.66	0.26	1.91	0.30	1.90	0.35	-0.08	0.32	1.48	0.30
52	1.57	0.37	2.40	0.31	1.62	0.26	1.90	0.30	1.89	0.35	0.03	0.32	1.53	0.31
73	1.61	0.38	2.40	0.32	1.65	0.26	1.92	0.30	1.92	0.33	-0.02	0.27	1.53	0.33
75	1.72	0.38	2.44	0.32	1.77	0.26	2.01	0.30	2.00	0.33	-0.10	0.27	1.57	0.33
90	1.74	0.37	2.53	0.31	1.78	0.26	2.06	0.30	2.06	0.35	0.03	0.32	1.68	0.35
99	1.89	0.38	2.78	0.29	1.94	0.21	2.28	0.24	2.27	0.28	0.24	0.28	1.97	0.28
101	1.90	0.38	2.80	0.28	1.95	0.20	2.29	0.22	2.29	0.28	0.27	0.29	2.00	0.28
110	1.90	0.38	2.79	0.28	1.95	0.21	2.29	0.24	2.28	0.28	0.26	0.28	1.99	0.28
118	1.93	0.35	2.82	0.30	1.97	0.28	2.32	0.24	2.31	0.27	0.28	0.33	2.02	0.27
132	1.96	0.45	2.87	0.33	2.01	0.31	2.36	0.32	2.35	0.40	0.34	0.39	2.08	0.40
138	1.95	0.40	2.85	0.35	2.00	0.27	2.35	0.27	2.34	0.35	0.32	0.38	2.07	0.35
149	1.96	0.41	2.86	0.30	2.01	0.22	2.36	0.26	2.35	0.35	0.35	0.29	2.08	0.35
153	1.96	0.37	2.86	0.32	2.01	0.23	2.36	0.25	2.35	0.31	0.33	0.28	2.08	0.31
160	1.95	0.40	2.85	0.35	1.99	0.27	2.35	0.27	2.34	0.35	0.35	0.38	2.07	0.35
163	1.95	0.41	2.85	0.31	1.99	0.22	2.34	0.26	2.34	0.35	0.36	0.29	2.07	0.35
164	1.93	0.41	2.84	0.30	1.98	0.22	2.33	0.26	2.33	0.35	0.35	0.29	2.06	0.35
180	1.93	0.41	2.83	0.31	1.97	0.22	2.32	0.26	2.32	0.35	0.36	0.29	2.05	0.35
182	1.78	0.44	2.67	0.38	1.83	0.36	2.16	0.32	2.16	0.39	0.31	0.40	1.90	0.39
187	1.86	0.43	2.76	0.38	1.91	0.33	2.25	0.30	2.24	0.36	0.34	0.33	1.98	0.36
194	1.87	0.43	2.77	0.39	1.92	0.33	2.26	0.30	2.26	0.36	0.35	0.33	2.00	0.36
196	1.46	0.46	2.31	0.41	1.50	0.35	1.80	0.31	1.79	0.40	0.14	0.39	1.52	0.40
203	1.58	0.44	2.45	0.37	1.62	0.31	1.93	0.29	1.92	0.37	0.21	0.41	1.66	0.37
206	1.58	0.44	2.45	0.40	1.62	0.31	1.93	0.29	1.92	0.37	0.21	0.41	1.66	0.37
209	1.18	0.41	2.01	0.42	1.23	0.43	1.49	0.34	1.48	0.37	-0.04	0.47	1.20	0.37
AVERAGE	**1.695319**	**0.393141**	**2.518034**	**0.330345**	**1.741167**	**0.283903**	**2.02816**	**0.294646**	**2.022267**	**0.361608**	**0.11**	**0.33**	**1.68**	**0.336894**

Appendix B: Abiotic Model Development and Parametrization

Abiotic Model development and Parameterization

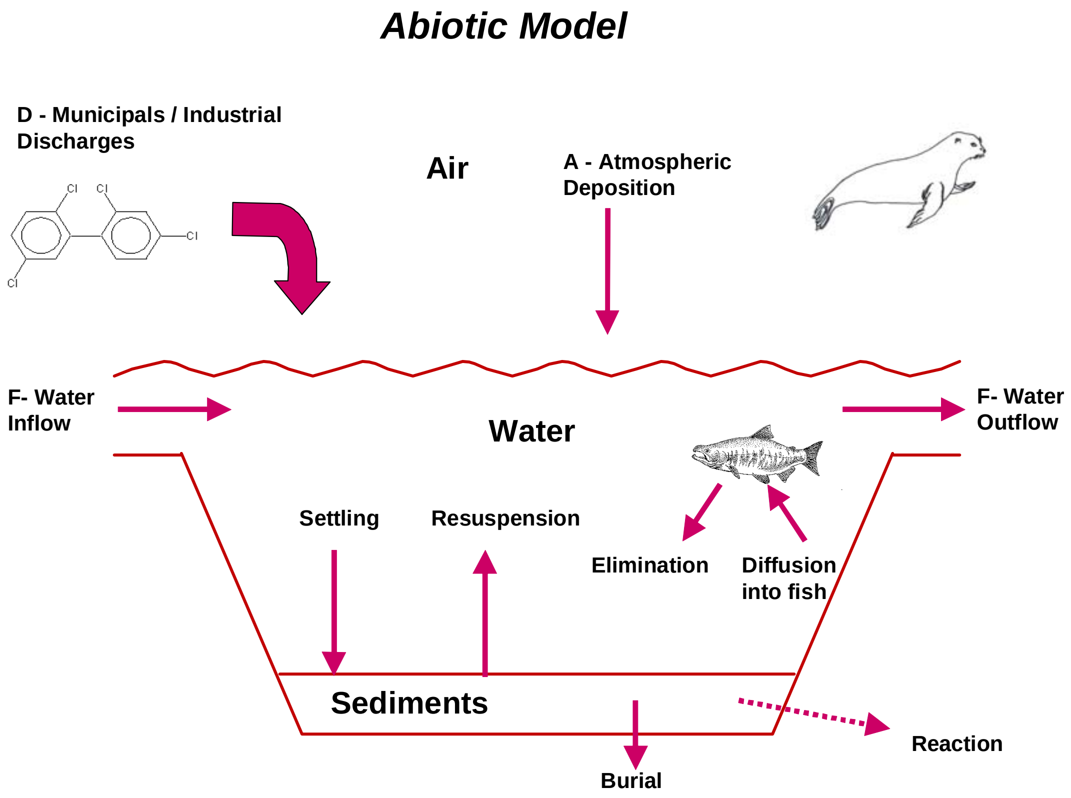
The purpose of the model is to develop a simple relationship between the emission of certain contaminants (e.g. PCBs) and changes in concentration over time in water, sediment and fish. In the Biotic model (Part IB), this model will focus on the relationship between chemical emissions and resulting concentrations in biota as a function of observed elevated concentrations of Persistent Organic Pollutants in sediments.

This model is intended as a tool that can be used to assess the source and magnitude of contaminant issues in Burrard Inlet.

Potential uses and benefits of this model include: consideration of point and non-point sources, loadings management, receiving environment monitoring, development and application of environmental criteria and risk assessment. In essence, this approach uses mathematical equation to describe uptake and elimination of contaminants to explain the dynamics of a number of contaminants in water, sediments and an optional virtual fish.

This simulation describes a situation in which a chemical is continuously discharged at a constant rate. Using the Mass balance equations for three environmental media (or compartments), this model will calculate the changes in sediment concentration, water concentration and fish concentration of a pollutant over time. To achieve this goal, we first use the Mass Balance Equations for a steady-state condition at which the input and output rates are equal. Second, we solve the differential equations using a numerical integration method or an Euler approximation. Degrading reactions, advective processes and diffusion are the loss or output processes treated. Intermedia transport processes like wet deposition or sedimentation are also quantified. The medium receiving the emission is the water face of Burrard Inlet.

Figure B1: **Mass balance diagram for the Abiotic Model**



Abiotic Model Parameters

Variable Type	Description	Units	
Vw	Total lake volume	L	Parameter
Vs	Total sediment volume	L	Parameter
Vf	Mean fish volume	L	Parameter
D	Muni/indus discharge	g/yr	Parameter
A	Atmospheric deposition	1/yr	Parameter
F	Streamflow in and out	L/yr	External driver
Cin	Concentration in streamflow	g/L	Control
Cf	Concentration in fish	g/L	State Variable / indicator
Cw	Concentration in water	g/L	State Variable / indicator
Cs	Concentration in sediments	g/L	State Variable / indicator
Kws	Exchange rate water-sediment	1/yr	Parameter
Ksw	Exchange rate sediment-water	1/yr	Parameter
Kwa	Exchange rate water-air	1/yr	Parameter
Kwf	Exchange rate water-fish	1/yr	Parameter
Kfw	Exchange rate fish-water	1/yr	Parameter
Kb	Permanent burial rate in sediment	1/yr	Parameter
Km	Microbial degradation in sediment	1/yr	Parameter

Functional relationships and equations

a) Differential equations:

To meet the objective of recommending sediment target levels for POPs, especially for polychlorinated Biphenyls (PCBs), we will develop and run a simulation model, that will give us a clear understanding of the distribution and trophodynamics of toxic organic compounds in the Burrard Inlet.

In this case, the simulation will describe a situation in which a chemical is continuously discharged at a constant rate. Using the Mass balance equations for three environmental media (or compartments), the model will calculate changes in the contaminant concentration of sediments, water, and fish over time. .

$$\frac{dX}{dt} = INPUTS - OUTPUTS$$

$$\frac{dX_W}{dt} = D + A + F.C_{IN} + K_{SW}.X_S - F.C_W - K_{WA}X_W - K_{WS}X_W \quad (1)$$

$$\frac{dX_S}{dt} = K_{WS}X_W - K_{SW}X_S - K_BX_S - K_MX_S \quad (2)$$

$$\frac{dX_F}{dt} = K_{WF}V_WC_W - K_{FW}V_FC_F \quad (3)$$

Where dx/dt it is the flux of chemical in units of gr/year, D is the municipal/industrial discharges into the inlet in units of gr/year, A is the atmospheric deposition or the input of chemicals from air into the inlet in units of gr/year. K_{WS}, K_{SW}, K_{WA}, K_{WF}, K_{FW}, K_B, K_M are respectively the rate constants in units of 1/year for water-sediment, sediment-water, water-air, water-fish, fish-water, permanent burial rate constant in sediment and microbial degradation in sediments.

V_F, V_S and V_W are respectively the volumes in liters of Fish, sediment and water.

X_F, X_S and X_W are respectively the mass of chemical contained in fish, sediments and water.

Dividing both sides of the equation (3) by V_F

$$\frac{dC_F}{dt} = \frac{K_{WF}V_WC_W}{V_F} - K_{FW}.C_F$$

If we define $K_{01} = \frac{K_{WF}V_W}{V_F}$ and $K_{10} = K_{FW}$ then

$$\frac{dC_F}{dt} = K_{01}.C_W - K_{10}.C_F \quad \text{(3b)}$$

Equation (3b) is considering the fish as a single compartment model

b) Including differential equations for two-compartment model in fish

During exposure, the uptake and elimination of a Persistent Organic Pollutant (POP) in aquatic organisms can be best described by a two-compartment pharmacokinetic model:

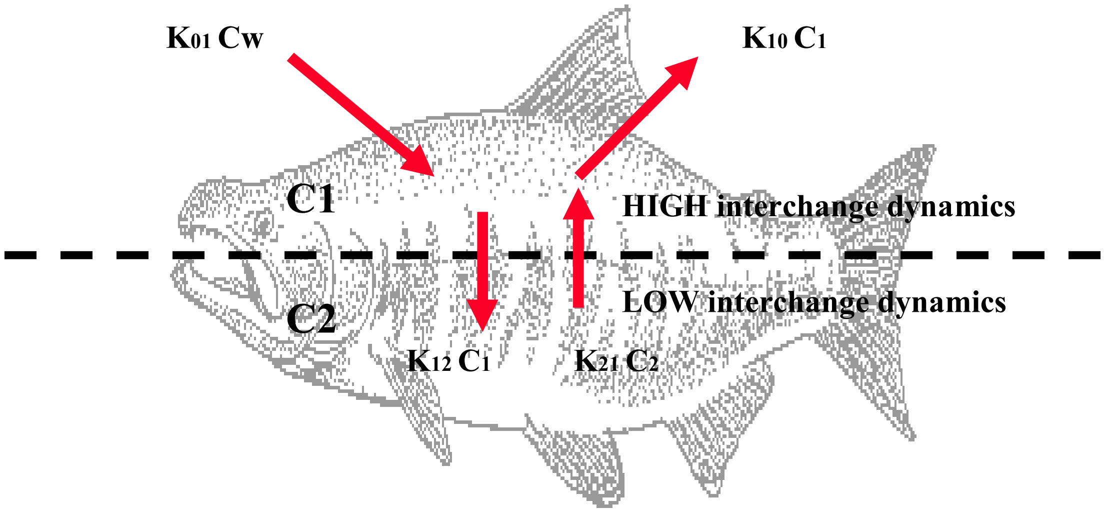


Figure B2: Two compartment pharmacokinetic model for fish

$$\frac{dC_1}{dt} = K_{01}C_W + K_{21}C_2 - K_{10}C_1 - K_{12}C_1 \qquad (4)$$

$$\frac{dC_2}{dt} = K_{12}C_1 - K_{21}C_2 \qquad (5)$$

Where Cw is the concentration in water, C_1 is the concentration of the chemical in compartment 1 (the only one in contact with water), C_2 is the concentration of the chemical in compartment 2 (internal compartment only in contact with C_1 and insulated from the water) and K values are rate constants which give us the magnitude of the interchange dynamics of the chemical between compartments. K_{12} and K_{21} are respectively the rate constants in units of **1/time** from C_1-to C_2 and from C_2 to C_1. In the same way, K_{10} and K_{01} are respectively the rate constants in units of **1/time** from C_1-to water and from water to C_1 (K_{12} and K_{21} are very small compared with K_{10} and K_{01}).

Figure B3: **Bioaccumulation in fish over time considering a two compartment pharmacokinetic model in fish**

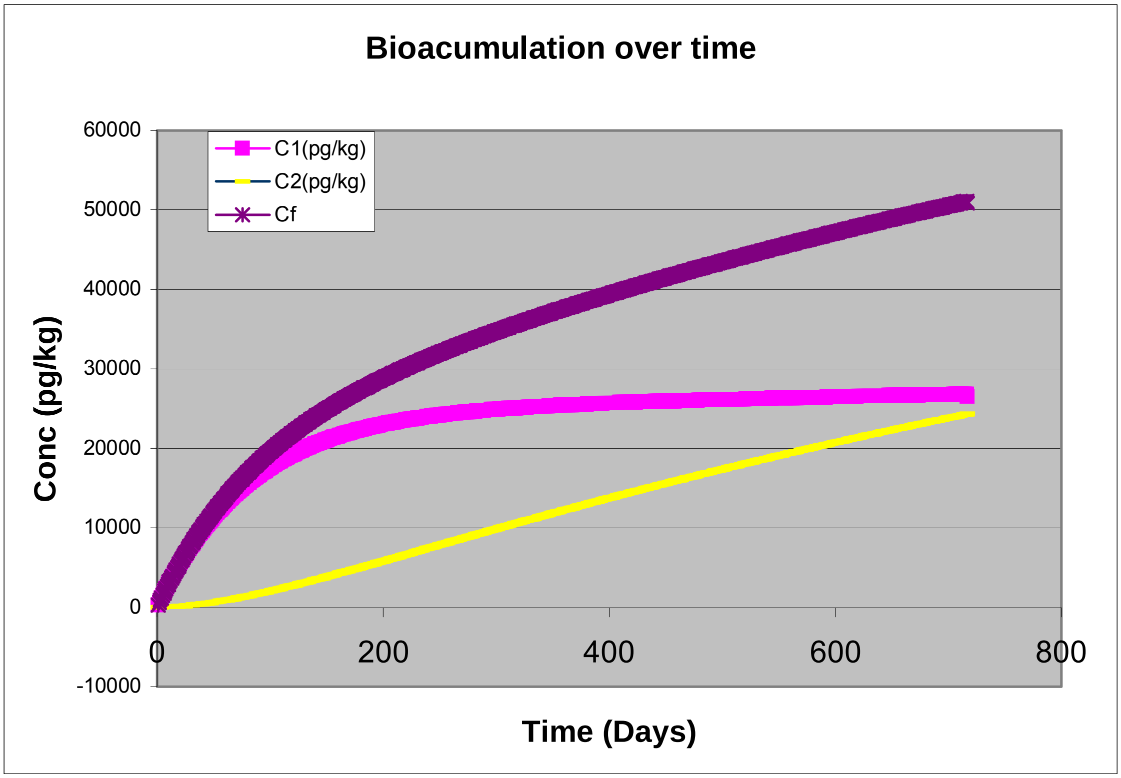


Figure B.3 shows that the uptake of chemicals by fish is very slow and it does not reach a steady state in a two-year period. Thus, the same deadly internal concentration in fish calculated from LC50s can be reached by aquatic organisms that are exposed to much lower concentrations during long periods of time (i.e. 2-3 years exposure).

c) Solving equations for initial conditions based on Steady State (Mass Balance Equations)

We have five differential equations with five unknown variables We can easily solve these equations assuming a Steady State, where the net flux of mass is zero or dX/dt=0. Thus for Steady State dx/dt=0, from equation (1), (2) and (3) we obtain

$$X_w = \frac{D + F.C_{IN} + A}{\frac{F}{V_W} + K_{WA} + K_{WS} - \left(\frac{K_{SW}.K_{WS}}{K_{SW} + K_B + K_M} \right)} \qquad (6)$$

$$X_S = \frac{X_W.K_{WS}}{K_{SW} + K_B + K_M} \qquad (7)$$

From the equations for the two-compartment model for fish

$$C_1 = \frac{K_{WF}.\frac{V_w}{V_{F.}}C_W}{K_{FW}} \qquad (8) \qquad \text{and} \qquad C_2 = \frac{K_{12}.C_{1.}}{K_{21}} \qquad (9)$$

$$C_F = \frac{C_{1.} + C_2}{2} \qquad (10)$$

$$X_F = C_F.V_F \qquad (11)$$

d) Solving equations using a numerical integration method

Equations (1), (2), (3) and (5) could be solved using an Euler approximation. We have to be very careful in selecting an appropriate integration time step.

The ordinary differential equations (ODEs) are integrated with the forward-Euler method, which uses a fixed time step to numerically solve ODEs. The forward Euler method is simple and fast, but its accuracy and stability depend critically on the size of the integration time step, which is specified by the user. As a general rule, the Euler approximation is numerically unstable unless the time step is at least two times (2 x) smaller than the smallest time constant within a model. Moreover, the integration will be numerically inaccurate unless the time step is at least ten times (10 x) smaller than the smallest time constant. We can illustrate how the size of the integration time step can affect accuracy and stability of a simulation by changing the time step dt in the model. After running the model many times, we found that a time step of 0.1 described the dynamics of a three environmental compartment model well enough.

$$\frac{dX}{dt} = INPUTS - OUTPUTS$$

$$\frac{\Delta X}{\Delta t} = INPUTS - OUTPUTS$$

$$\frac{X_{NEW} - X_{OLD}}{\Delta t} = INPUTS - OUTPUTS$$

$$X_{NEW} = X_{OLD} + (INPUTS - OUTPUTS)\Delta t + \varepsilon rror \quad \text{If} \quad \downarrow \Delta t \Rightarrow \downarrow \varepsilon rror$$

Univariate Sensitivity Analysis

The objective of this approach is to find out what model parameters are the most important to reduce the overall uncertainty in the projections. In other words, we want to measure the relative changes in projected PCBs masses in water, sediment and fish for small changes in individual parameters.

Sensitivity analysis also look for changes in the rank order of policy options -which of my parameters is more sensitive and how management decisions can take into consideration this sensitivity in the parameters. With this sensitivity analysis we are looking for ranges of predictions.

General Approach:

A- run the model using a baseline / default parameter to get a baseline prediction to each state variable / indicator in each projection year and save those base projections to use as a reference (baseline prediction).

B- Generate a loop over all parameters varying one parameter at the time in 10%, run the model and measure the percentage of change in the projections.

Results show that the most sensitive parameter in all projection years is Kwf (PCBs uptake rate by fish). Therefore we are going to chose this parameter for the uncertainty analysis in the following step.

Uncertainty Analysis

The objective of this approach is to measure the relative changes in a projected PCBs masses in water, sediment and fish, for random changes in the most sensitive individual parameters selected from the previous Univariate Sensitivity Analysis.

In this stage we select one of the most sensitive parameters, randomly variate that parameter from a random uniform distribution and run the model. We repeat this process a five hundred times and measure the percentage of change in the projections. We use a histogram and descriptive statistics to analyze the results.

The uniform distribution leads to the most conservative estimate of uncertainty i.e., it gives the largest standard deviation. The calculation of the standard deviation is based on the assumption that the end-points, ± a, of the distribution are known. It also embodies the assumption that all effects on the reported value, between -a and +a, are equally likely for the particular source of uncertainty.

Fate model conclusions

The simulation objective is to find out what reduction in Persistence Organic Pollutants (POPs) in water, sediment and fish are expected to occur over some fixed period of time (e.g. 2006-2050) as a result of reducing inputs (Emissions) by a certain percentage (Y%).

Limitations of the fate model:

- The Model considers that all rate constants are invariable over time. Many of the rate constants are quite variable (especially for diffusion and advective mass transports) depending on the Inflow / outflow and in the gradient of concentration between different compartments. Ignores Biomagnification: Assumes that fish absorb chemicals via simple partitioning (i.e. uptake from the water via the gills)
- Metabolism, growing or other loss processes are not considered
- The accuracy of the model is based on measurement of the rate constants
- Rate constants are in many cases very difficult to measured or estimate

Merits of the fate model:

- It is a powerful tool to predict the dynamics in an specific environment
- Gives an excellent idea about how PCBs can partition into different compartments over time
- Helps management to make and support decisions.

Appendix C: Model Equations

Equations

Phytoplankton, Zooplankton, aquatic invertebrates, fish

Mass balance equations:

$dM_B/dt = \{W_B \bullet (k_1 \bullet [m_O \bullet \phi \bullet C_{WT,O} + m_P \bullet C_{WD,S}] + k_D \bullet \Sigma(P_i \bullet C_{D,i}))\} - (k_2 + k_E + k_M) \bullet M_B$

at steady state ($dM_B/dt = 0$):

$C_B = \{k_1 \bullet (m_O \bullet \phi \bullet C_{WT,O} + m_P \bullet C_{WD,S}) + k_D \bullet \sum P_i \bullet C_{D,i}\} / (k_2 + k_E + k_G + k_M)$

Functional equations

$\phi = C_{WD} / C_{WT} = 1 / (1 + \chi_{POC} \bullet D_{POC} \bullet \alpha_{POC} \bullet K_{OW} + \chi_{DOC} \bullet D_{DOC} \bullet \alpha_{DOC} \bullet K_{OW})$

Phytoplankton

$A = 6x10^{-5}$ ^ $B = 5.5$

$k_1 = (A + (B / K_{OW}))^{-1}$

$k_2 = k_1/K_{PW}$

$K_{PW} = k_1 / k_2 = v_{LB} \bullet K_{OW} + v_{NB} \bullet 0.35 \bullet K_{OW} + v_{WB}$

$k_G = 1.25x10^{-1}$

Zooplankton

$k_1 = E_W \bullet G_V / W_B$

$E_W = (1.89 + (155 / K_{OW}))^{-1}$

$k_2 = k_1/K_{BW}$

$G_V = 1400 \bullet W_B^{0.65} / C_{OX}$

$C_{OX} = (-0.24 \bullet T + 14.04) \bullet S$

$G_D = G_V \bullet C_{ss} \bullet \sigma$

$k_G = 0.00035 \bullet W_B^{-0.2}$

$E_D = (A \bullet K_{OW} + B)^{-1}$

$k_D = E_D \bullet G_D / W_B$

$k_E = G_F \bullet E_D \bullet K_{GB} / W_B$

$G_F = \{(1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\} \bullet G_D$

$K_{BW} = k_1 / k_2 = v_{LB} \bullet K_{OW} + v_{NB} \bullet \beta \bullet K_{OW} + v_{WB}$

$Z_{GUT} = (v_{LG} \bullet Z_L + v_{NG} \bullet \beta \bullet Z_L + v_{WG} \bullet Z_W)$

$Z_{ORG} = (v_{LD} \bullet Z_L + v_{ND} \bullet \beta \bullet Z_L + v_{WD} \bullet Z_W)$

$K_{GB} = Z_{GUT} / Z_{ORG}$

$v_{LG} = (1-\varepsilon_L) \bullet v_{LD} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

$v_{NG} = (1-\varepsilon_N) \bullet v_{ND} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

$v_{WG} = (1-\varepsilon_W) \bullet v_{WD} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

Fish

$k_1 = E_W \bullet G_V / W_B$

$E_W = (1.89 + (155 / K_{OW}))^{-1}$

$k_2 = k_1 / K_{BW}$

$G_V = 1400 \bullet W_B^{0.65} / C_{OX}$

$C_{OX} = (-0.24 \bullet T + 14.04) \bullet S$

$G_D = 0.022 \bullet W_B^{0.85} \bullet e^{(0.06 \bullet T)}$

$k_G = GRF \bullet W_B^{-0.2}$ (GRF=0.0007)

$E_D = (A \bullet K_{OW} + B)^{-1}$

$k_D = E_D \bullet G_D / W_B$

$k_E = G_F \bullet E_D \bullet K_{GB} / W_B$

$G_F = \{(1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\} \bullet G_D$

$K_{BW} = k_1 / k_2 = v_{LB} \bullet K_{OW} + v_{NB} \bullet \beta \bullet K_{OW} + v_{WB}$

$Z_{GUT} = (v_{LG} \bullet Z_L + v_{NG} \bullet \beta \bullet Z_L + v_{WG} \bullet Z_W)$

$Z_{ORG} = (v_{LD} \bullet Z_L + v_{ND} \bullet \beta \bullet Z_L + v_{WD} \bullet Z_W)$

$K_{GB} = Z_{GUT} / Z_{ORG}$

$v_{LG} = (1-\varepsilon_L) \bullet v_{LD} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

$v_{NG} = (1-\varepsilon_N) \bullet v_{ND} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

$v_{WG} = (1-\varepsilon_W) \bullet v_{WD} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

Harbor Seals

Mass balance equation

$dC_{HS,l}/dt = \quad k_A C_{AG} + k_D.\Sigma(P_i \bullet C_{D,i}) - (k_O + k_E + k_U + k_G + k_P + k_L + k_M) \bullet C_{HS,l}$

at steady state ($dC_{HS,l}/dt = 0$):

$C_B = \quad (k_A C_{AG} + k_D.\ \Sigma(P_i \bullet C_{D,i})) / (k_O + k_E + k_U + k_L + k_M)$

Functional equations

$E_L = 0.7$ = Lung Uptake

$A = 1x10^{-9} \quad \wedge \quad B = 1.03$

$k_1 = E_L \bullet G_V / W_B$

$G_V = ((.408 \bullet W_B^{0.75}) \bullet 1000) \bullet AF$

$G_D = 0.07 \bullet W_B$

$G_U = 0.33 \bullet GF$

$k_2 = (E_L \bullet G_V / W_B) \bullet Z_{AIR} / Z_{ORG} = k_1 \bullet Z_{AIR} / Z_{ORG}$

$E_D = (A \bullet K_{OW} + B)^{-1}$

$k_D = E_D \bullet G_D / W_B$

$G_F = \{(1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\} \bullet G_D$

$K_{BW} = k_1 / k_2 = v_{LB} \bullet K_{OW} + v_{NB} \bullet \beta \bullet K_{OW} + v_{WB}$

$Z_{GUT} = (v_{LG} \bullet Z_L + v_{NG} \bullet \beta \bullet Z_L + v_{WG} \bullet Z_W)$

$Z_{ORG} = (v_{LD} \bullet Z_L + v_{ND} \bullet \beta \bullet Z_L + v_{WD} \bullet Z_W)$

$K_{GB} = \ Z_{GUT} / Z_{ORG}$

$v_{LG} = (1-\varepsilon_L) \bullet v_{LD} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

$v_{NG} = (1-\varepsilon_N) \bullet v_{ND} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

$v_{WG} = (1-\varepsilon_W) \bullet v_{WD} / \{((1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\}$

$k_E = (K_{GB} / W_B) \bullet E_D \bullet G_F = K_{GB} \bullet E_D \bullet G_F / W_B$

$k_G = 0.000075$

Pop Seals

$k_A = E_A \bullet G_A / W_{S,l}$

$k_O = k_A / K_{S,lA}$

$K_{S,lA} = k_A / k_O = K_{OA}$

$k_U = G_U / K_{OW}$

Cormorants and Terns

Mass balance equation

$dC_{C,l}/dt = \; k_A C_{AG} + k_D.\Sigma(P_i \bullet C_{D,i}) - (k_O + k_E + k_G + k_C + k_M) \bullet C_{C,l}$

at steady state ($dC_{C,l}/dt = 0$):

$C_{C,l} = \; (k_A C_{AG} + k_D.\ \Sigma(P_i \bullet C_{D,i})) / (k_O + k_E + k_G + k_C + k_M)$

Functional equations

Avian

$E_L = 0.7$ = Lung Uptake

$A = 3x10^{-0.9} \quad \wedge \quad B = 1.04$

$k_1 = E_L \bullet G_V / W_B$

$E_W = (1.89 + (155 / K_{OW}))^{-1}$

$G_V = ((.4089 \bullet W_B^{0.77}) \bullet 1000) \bullet AF$

$G_D = 0.3 \bullet W_B$

$G_U = 0.2 \bullet GF$

$k_2 = (E_L \bullet G_V / W_B) \bullet Z_{AIR} / Z_{ORG} = k_1 \bullet Z_{AIR} / Z_{ORG}$

$E_D = (A \bullet K_{OW} + B)^{-1}$

$k_D = E_D \bullet G_D / W_B$

$G_F = \{(1-\varepsilon_L) \bullet v_{LD}) + (1-\varepsilon_N) \bullet v_{ND} + (1-\varepsilon_W) \bullet v_{WD}\} \bullet G_D$

$K_{BW} = k_1 / k_2 = v_{LB} \bullet K_{OW} + v_{NB} \bullet \beta \bullet K_{OW} + v_{WB}$

$Z_{GUT} = (v_{LG} \bullet Z_L + v_{NG} \bullet \beta \bullet Z_L + v_{WG} \bullet Z_W)$

$Z_{ORG} = (v_{LD} \bullet Z_L + v_{ND} \bullet \beta \bullet Z_L + v_{WD} \bullet Z_W)$

$K_{GB} = \; Z_{GUT} / Z_{ORG}$

$$v_{LG} = (1-\varepsilon_L)\bullet v_{LD} / \{((1-\varepsilon_L)\bullet v_{LD}) + (1-\varepsilon_N)\bullet v_{ND} + (1-\varepsilon_W)\bullet v_{WD}\}$$

$$v_{NG} = (1-\varepsilon_N)\bullet v_{ND} / \{((1-\varepsilon_L)\bullet v_{LD}) + (1-\varepsilon_N)\bullet v_{ND} + (1-\varepsilon_W)\bullet v_{WD}\}$$

$$v_{WG} = (1-\varepsilon_W)\bullet v_{WD} / \{((1-\varepsilon_L)\bullet v_{LD}) + (1-\varepsilon_N)\bullet v_{ND} + (1-\varepsilon_W)\bullet v_{WD}\}$$

$$k_E = (K_{GB} / W_B) \bullet E_D \bullet G_F = K_{GB} \bullet E_D \bullet G_F / W_B$$

$$k_U = (G_U / W_B) \bullet E_D \bullet Z_W / Z_{ORG}$$

Table C-1: Summary of Equations Formalizing the Mechanism of Organic Chemical Magnification in Gastrointestinal Tract and Biomagnification in Fish

Mass balance equation in gastrointestinal tract:

(1) $N_G = V_G\, dC_G/dt = (V_G Z_G\, df_G)/dt = D_D f_D + D_G f_B - (D_F + D_G) f_G$

mass balance equation in fish:

(2) $N_B = d(V_B C_B)/dt = d(V_B Z_B f_B)/dt = D_W f_W + D_G f_G - (D_G + D_W + D_M) f_B$

Assume steady state in GIT (NG=0):

(3) $f_G = (D_D f_D + D_G f_B) / (D_G + D_F)$

substitution of eq 3 into eq 2:

(4) $N_B = D_W f_W + D_D D_G f_D/(D_F, D_G) - D_F D_G f_B/(D_F + D_G) - (D_W + D_M) f_B$

Where:

(5) chemical intake from water (mol/day): $N_W = D_W f_W = k_1 V_B C_W$

(6) chemical intake from diet (mol/day) $N_D = D_D D_G f_D/(D_F + D_G) = G_D E C_D$

(7) dietary uptake efficiency: $E = D_G(D_F + D_G)$

(8) chemical elimination to the water (mol/day): $D_W f_B = k_2 V_B C_B$

(9) chemical elimination in feces (mol/day): $N_F = D_F D_G f_B/(D_F + D_G) = G_F E K_{GB} C_B$

(10) chemical elimination through metabolic transformation (mol/day): $N_M = D_M f_B = k_M V_B C_B$

steady-state fugacity ratios:

(11) fugacity-based GIT magnification factor (fw = 0): $f_G / f_D = D_D/(D_F + D_G(1 - D_G/(D_G + D_W + D_M)))$

(12) fugacity-based biomagnification factor qw = 0): $f_B / f_D = (f_G/f_D) D_G/(D_G + D_W + D_M)$

(13) fugacity-based bioconcentration factor (***f D*** = 0) $f_B/f_W = D_W/(D_W + D_G + D_M)$

supporting equations:

concentration = fugacity x fugacity capacity

Glossary

C_B , C_D ,C_G , C_W	chemical concentration (mourn3) in, respectively, organism, diet, GIT, and water
f_B , f_D ,f_G , f_W	chemical fugacity (Pa) in, respectively, organism, diet, GIT, and water
N_B ,N_G	chemical net flux (mol/day) into, respectively, the organism and the GIT
N_D , N_W ,N_M	chemical flux (mol/day) from, respectively, diet-to-organism and water-to-organism and the metabolic transformation flux
V_V , V_G	volume (m3) of organism and GIT
D_D , D_F ,D_G ,D_M , D_W	transport parameter (mol/Pa.day) of, respectively, chemical intake through food consumption; chemical egestion by fecal excretion; chemical transfer across the gut between the GIT and the organism; metabolic transformation; and water-organism exchange through the gills
Z_B , Z_D , Z_G	fugacity capacity (mol/ms.Pa) of, respectively, organism, diet, and GIT contents
G_D , G_F , G_A	rates (mS/day) of, respectively, food intake, fecal egestion, and food absorption from the GIT
E	dietary absorption efficiency (no units)
k_1 , k_2 , k_M	rate constants (day*) of, respectively, gill uptake, gill elimination, and metabolic transformation
K_{GB}	chemical partition coefficient between GIT contents and organism (no units)
Φ_D	rate of food intake by fish (in units of kg of food/day)
ρ_D	density of food (kg/L)

Note: This table is couresy of Gobas et al., 1993

Appendix D: Model Parameters

Table D-1: Summary of model's parameters, units and definitions

PARAMETER	UNITS	DEFINITION
M_B	g	Mass of PCB congener in the organism
C_{WT}	g/kg	Chemical concentration in water (total)
C_{WD}	g/kg	Chemical concentration in water (dissolved)
C_{AG}	g/L	Chemical concentration in the gas phase of the air
W_B	kg	Weight of biota
m_O, m_P	%	Percentage of overlying and pore water respired by benthic organisms
C_B	g/kg	Chemical concentration in biota
C_D	g/kg	Chemical concentration in diet
ϕ	Unitless	Bioavailable fraction of chemical in overlying water
k_1	L/kg•d	Respiratory uptake rate constant (gills and skin)
k_D	$kg/kg_{lipid}/d$	Dietary uptake rate constant
k_A	$L/kg_{lipid}/d$	Inhalation rate constant
k_O	d^{-1}	Exhalation rate constant
k_P	d^{-1}	Placental transfer to pups rate constant
k_L	d^{-1}	Lactation transfer to pups rate constant
k_C	d^{-1}	Bird transfer to eggs rate constant
k_U	d^{-1}	Urinary excretion rate constant
k_2, k_E, k_G, k_M	d^{-1}	Gill elimination, fecal egestion, growth dilution, and metabolic transformation rate constants, respectively
Pi	Unitless	The fraction of the diet consisting of prey item i

Table D-1: (Continued) Summary of model's parameters, units and definitions

PARAMETER	UNITS	DEFINITION
C_S	g/kg	Chemical concentration in sediment
C_{SS}	g/kg	Chemical concentration in suspended solids
K_{OW}	Unitless	Octanol-water partition coefficient
v_{LB}, v_{LP}	kg/kg	Lipid fraction in biota ($_B$) and phytoplankton ($_P$)
v_{NB}	kg/kg	Non-lipid organic matter fraction in biota ($_B$)
v_{NP}	kg/kg	Non-lipid organic carbon fraction in phytoplankton ($_P$)
T	°C	Mean annual water temperature
S	%	Dissolved oxygen saturation
χ_{POC}	kg/L	Concentration of particulate organic carbon
χ_{DOC}	kg/L	Concentration of dissolved organic carbon
D_{POC}	Unitless	Disequilibrium factor POC
D_{DOC}	Unitless	Disequilibrium factor DOC
α_{POC}	Unitless	POC – octanol proportionality constant
α_{DOC}	Unitless	DOC – octanol proportionality constant
C_{PW}	g/L	Chemical concentration in pore water
K_{BW}	Unitless	Biota-water partition coefficient
K_{PW}	Unitless	Phytoplankton-water partition coefficient
K_{GB}	Unitless	Gut-biota partition coefficient
G_V	L/d	Gill ventilation rate
G_D, G_F	kg/d	Feeding and fecal egestion rates, respectively
E_W, E_D	%	Chemical transfer efficiency for gill and diet, respectively

Table D-1: (Continued) Summary of model's parameters, units and definit

β	Unitless	Non-lipid organic matter – octanol proportionality constant
v_{LD}, v_{LG}	kg/kg	Lipid fraction in diet ($_D$) and gut ($_G$)
v_{ND}, v_{NG}	kg/kg	Non-lipid organic matter fraction in diet ($_D$) and gut ($_G$)
v_{WB}, v_{WD}, v_{WG}, v_{WP}	kg/kg	Water fraction in biota ($_B$), diet ($_D$), gut ($_G$) and phytoplankton ($_P$)
ε_L	%	Dietary absorption efficiency of lipid
ε_N	%	Dietary absorption efficiency of non-lipid organic matter
ε_W	%	Dietary absorption efficiency of water
σ	%	Particle scavenging efficiency (default = 100)
δ_{OCS}	kg/L	Density of organic carbon in sediment (0.9)
K_{OC}	Unitless	Organic carbon-water partition coefficient
C_{OX}	mg O_2/L	Dissolved oxygen concentration
$C_{WD,P}$	g/L	Freely dissolved concentration of chemical in the pore water
$C_{S,OC}$	g/kg $_{OC}$	Chemical concentration in the sediment normalized for organic carbon content
$W_{S,l}$	Kg	Lipid mass of the organism
$K_{S,lA}$	L/kg lipid	Partition coefficient of the chemical between the lipid biomass of the organism and the air
K_{OA}	Unitless?	Octanol-air partition coefficient
G_U	L/d	Urinary excretion rate
$K_{GC,l}$		Partition coefficient between the GIT and the lipids of birds
$K_{C,lA}$	L/kg lipid	Partition coefficient of the chemical between the lipid biomass of the birds and the air.

Appendix E: Theory of Bioacculation Mechanisms

1.1 Two originals models

Two original models were proposed in the 1990's by Gobas and Mackay, to explain the biomagnification phenomenon of hydrophobic organic substances. The first model assumes that intestinal absorption of hydrophobic organic substances from the gastrointestinal tract (GIT) into the organism's tissues is predominantly through *passive diffusion (PD).* Thus, to achieve a fugacity in the organism (f_B) that exceeds that in its diet (f_D), a fugacity gradient has to be establish in which the fugacity in the gut (f_G) exceeds that in the organism. A fugacity gradient between GIT and the organism would produce a net uptake of chemicals across the GIT. There are two major assumptions in this process, first, the reduction of the volume of food in the GIT as the food is absorbed and digested, and second, the reduction in the fugacity capacity of the food (Z_G) due to absorption during digestion (17-18).

The second model assumes that biomagnification occurs in the organism's tissues and not in the GIT. The increase in the fugacity is due to a simple transformation of lipids into energy, causing the previously digested and non-metabolized chemicals to remain in the organism's tissue, but at higher concentrations and therefore, at a higher fugacity. Passive diffusion was thought not to be the main dietary absorption route since the fugacity in the organism (f_B) is higher than the fugacity in the diet (f_D) and the fugacity in the gut (f_G), causing a net diffusion of the chemicals from the organism to the GIT. As a result, chemical uptake across the GIT was believed to be due to *lipid coassimilation (LC),* which is a process in which the chemical moves across the GIT in association with dietary lipids. Several studies support the lipid co-transport in dietary uptake of hydrophobic organic molecules in fish and mammals (19).

It is evident that the absorption, assimilation and biomagnification processes are the combined action of different, but additive mechanisms. To better understand the processes and mechanisms which lead to the biomagnification of hydrophobic compounds, it is important to review and categorized the main assimilation mechanisms. A basic review of biomagnification processes would positively contribute to develop a food web model and also more proactive policies and standards to protect organisms from an ecosystem-management prospective. Therefore, I will briefly present a few of the most relevant models and mechanisms of intestinal absorption to better support the final analysis and implications of this research project in developing sediment target levels for selected Persistent Organic Pollutants in Burrard Inlet.

1.2 Theory of Intestinal Absorption Mechanisms:

The first mechanistic explanation of the food-chain bioaccumulation process was given by Woodwell (4), who proposed that biomagnification was due to biomass-to-energy conversion (BMC). Later on, Hamelink (20) proposed that bioaccumulation in aquatic food chains is due to a physical-chemical partitioning (or bioconcentration) of the chemical between the water and the organism. Connolly and Pedersen (21) showed that in food chains, chemical distribution could not be explained by the equilibrium partitioning theory and that chemicals in food chains are transported against the thermodynamic gradient, i.e., from a low fugacity in the prey to a high fugacity in the predator. Gobas et al. (22) reported laboratory observations in guppies and goldfish which showed that chemical fugacities can be elevated in the gastrointestinal tract (GIT).

This process was referred to as gastrointestinal magnification and can explain why fugacities of certain hydrophobic compounds in predators exceed those in their prey.

The reason for expressing some models in terms of fugacities is that net passive (i.e. diffusive) transport of a chemical between different and temporally changing media, (i.e. food, digested food in the GIT and organism) occurs in response to fugacity, not concentration, differences between the media. Fugacity is a thermodynamic quantity that can be viewed as the "escaping tendency" of the chemical from its medium (23). It can be measured as the partial pressure that the chemical substance exerts and is hence expressed in units of pressure, i.e. Pascal (23). The chemical's concentration C in mol/m3 and the fugacity *f* in the food in units of Pa are related as *C* equals *f.Z*, where the fugacity capacity *Z* (in mol/m3,Pa) reflects the ability of the matrix to "solubilize" or "store" the chemical.

1.2.1 Biomass conversion (BMC):

The first mechanistic explanation of the food-chain bioaccumulation process was given by Woodwell (4). In this case, the increase in the fugacity is due to a simple transformation of biomass into energy, causing that the previously digested and non-metabolized chemicals to be depurated at a rate slower than the consumption of biomass. Thus, causing certain chemicals to remain in the organism's tissue, but at a higher concentration than that found in the diet and therefore at a higher fugacity.

$$N_B = V_B Z_B \frac{df_B}{dt} = D_D f_D - D_E f_B \qquad (2.2.1)$$

N_B is the net absorption of a chemical by the organism (i.e. $V_B \cdot Z_B \cdot df_B/dt$); $D_D \cdot f_D$ the rate of chemical absorption (in units of $mol \cdot d^{-1}$) via dietary ingestion and $D_E \cdot f_B$ the rate of chemical depuration (in units of $mol \cdot d^{-1}$) *via* all possible routes. D_D the transport parameter of chemical absorption *via* dietary ingestion ($mol \cdot d^{-1} \cdot Pa^{-1}$), f_D is the chemical fugacity in the diet, D_E is the transport parameter for chemical depuration ($mol \cdot d^{-1} \cdot Pa^{-1}$) and, f_B is the chemical fugacity in the organism. At steady state ($N_B = 0$), equation (2.2.1) becomes $f_B/f_D = D_D/D_E$, which illustrates that biomagnification can occur for chemicals for which $D_E < D_D$.

One of the characteristics of this mechanism is that a chemical is moved from a low fugacity in the prey to a high fugacity in the predator. This constitutes a mass transport against the thermodynamic gradient, which indicates that an ingested chemical is predominantly absorbed via a non-diffusive active transport process. A second feature of this mechanism is that the magnification of the chemical concentration occurs as a result of energy consumption in the tissues of the organism.

1.2.2 Lipid Coassimilation (LC)

In this case, Gobas et al. (24) show that the chemical uptake from food can be explained as the combined result of chemical transport through the GIT and between the GIT and the organism .

Two remarkable aspects of the digestion and biomagnification of chemicals were supported by Gobas et al. (24), the first being that passive diffusion is the predominant driving force for gastrointestinal uptake of hydrophobic organic substances and secondly, that magnification occurs in the GIT as a result of food digestion. According to these findings, chemical biomagnification factors in organisms can be determined from:

a) The feeding and fecal egestion rates of the organism

b) The chemical's partition coefficient KGB between the GIT and the organism

c) The rate of chemical elimination through routes other than fecal egestion (i.e. via gills and metabolic transformation) relative to the rate of chemical elimination in feces.

1.2.3 Digestion or Gastro-intestinal magnification (GI Magnification):

The phenomenon of biomagnification and food chain accumulation of persistent hydrophobic organic chemicals has been explained through the hypothesis that food digestion and absorption in the gastrointestinal tract (GIT) can raise the fugacity of persistent hydrophobic organic substances in the GIT above that of the consumed food (18,25). Food digestion is believed to alter the composition of the food in the GIT, causing the fugacity capacity of the food to fall below the fugacity capacity of the consumed food. Therefore, the chemical fugacity in the GIT increase above that of the food (18,22). In other words, food absorption is expected to "magnify" the chemical concentration in the food, consequently raising the chemical fugacity in the GIT over that in the food (18,22). Food digestion and absorption combined thus raise the chemical fugacity in the GIT above that of the food, and at that point, simple passive diffusion of the chemical from the GIT into the organism can then explain why hydrophobic organic chemicals can achieve fugacities in the organism that exceed those fugacities in the organism's diet. This hypothesis has been tested by Gobas et al. (24), and the test performed indicate that passive diffusion is the main transport mechanism for gastrointestinal absorption in fish. The results provide indirect evidence for the proposed bio-magnification mechanism; however, they do not demonstrate the increase in chemical fugacity in the GIT, which is the essence of the proposed mechanism.

Biomagnification or dietary accumulation can be viewed as a two-step process (9). First, the chemical enters the GIT in association with food. Second, the chemical is absorbed by the organism from the GIT. If, as previous work suggests, passive diffusion from high to low fugacity is indeed the only significant mode of gastro-intestinal transport, then the chemical entering the GIT, for example, at a fugacity in the food of 1 Pa and remaining in the GIT at a fugacity of 1 Pa would result in a chemical fugacity in the organism of no more than 1 Pa. Biomagnification and food chain accumulation thus could not occur unless there was an active uptake mechanism. However, if the chemical fugacity in the food is elevated from 1 Pa to 5 Pa in the GIT, then passive diffusion could result in a chemical fugacity in the organism of up to 5 Pa and biomagnification could occur (refer to Table C-1 for equations).

The experimental findings discussed by Gobas and colleagues in different studies (18,21,22), provide conclusive evidence in support of the hypothesis that the biomagnification of hydrophobic organic chemicals in food chains is the result of food digestion and food absorption in the GIT. Food digestion and absorption can act as a fugacity pump by increasing the fugacity or activity of the chemical in the GIT above that of the food that is consumed and altering the fugacity capacity of the food, thus increasing the chemical concentration in the GIT. This fugacity pump is applied each time one organism is consumed by another causing the fugacity and slow elimination of chemical substances to increase with each step in the food chain, as a result providing the driving force for food chain accumulation.

1.2.4 Micelle mediated diffusion (MMD):

To explain the higher BMFs in homeotherms (birds and mammals) compared to aquatic poikilotherms (invertebrates, fish), Drouillard and Norstrom (26) proposed that micelle mediated diffusion can produce a magnification effect in addition to or in place of food digestion. This process involves micelle facilitated chemical transport from the bulk lumen to the organism (i.e.GIT-to-organism) through unidirectional advection of mixed micelles across the aqueous resistance of the unstirred water layer (UWL), while the reverse flux (i.e. organism-to-GIT) is somewhat reduced because micelles become dissociated within an acidic pH microclimate present at the vicinity of the intestinal wall. In essence, the MMD model assumes intestinal absorption of a chemical (enhanced by mixed micelle facilitation) occurs in the upper GIT in association with dietary lipid absorption, while chemical elimination (in time and space along the GIT) occurs at a much slower rate in the lower digestive tract. Thus, the mixed micelle transport in the upper intestine causes the rate of chemical uptake across the UWL into gut tissue to be substantially faster than the rate of reverse diffusion back to the intestine. In fugacity terms, the transport parameter D_{GB} (from the gut into the organism) is greater than D_{BG} (from the organism into the food in the GIT). This results in a sustained fugacity increase in the organism's tissues over that in the intestines and the original diet consumed. The authors propose that the higher energy demands of homoeothermic animals (birds and mammals) compared to fish results in higher feeding rates in homoeothermic animals. The higher feeding rates produce greater mixed micelle concentrations in the GIT and hence greater chemical uptake rates through direct transfer of the chemical containing micelles to intestinal tissue. This ultimately causes a high fugacity build up in the animal's tissues due to a very slow diffusive elimination rate back to the GIT.

1.2.5 Fat flush diffusion (FFD):

Fat flush diffusion (FFD) is a model presented by Schlummer et al. (27), where it is hypothesized that during dietary lipid absorption, the lipid absorbed into the gut tissue increases the lipid content of the tissue; therefore, increasing the fugacity capacity of the gut tissue, resulting in a temporary reduction of the fugacity (or lipid based concentrations) of persistent lipophilic organic pollutants (PLOPs) in the gut's wall. The decrease in effective lipid-based concentration of the PLOPs in the gut tissue serves to increase the gradient or driving force for PLOP absorption. This occurs at the same time as the removal of the lipids from the gut contents increasing the effective lipid-based concentration of PLOPs in this compartment. These two processes combine together to amplify the diffusion gradient and greatly facilitate PLOP absorption.

Appendix F: Spatial Data Analysis

1 Spatial Data Analysis:

1.1 General

Contaminants are introduced into Burrard Inlet by a number of sources including both, *point sources* (e.g., industrial and municipal effluent discharges) and *non-point sources* such as storm water runoff. Once introduced to the inlet, contaminants are subject to physical, chemical and biological processes that lead to dispersion and accumulation in different matrices of the marine environment.

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Being one of the most recognizable features in Greater Vancouver, Burrard Inlet is a significant component of one of Canada's most productive marine and terrestrial ecosystems. With an extension of 11,300 hectare of marine-tidal water body and 190 kilometers of shoreline, Burrard Inlet is a very fragile ecosystem stressed by many different sources of pollution. The surrounding natural drainage basin is home to several municipalities and comprises an additional 98,000 hectares of land, which is also a considerable extended watershed for non-point sources of contamination.(BIEAP, 1997)(85).

Several monitoring studies in the past have observed elevated concentrations of PCBs in the sediments and biota of Vancouver Harbour, False Creek and other areas of Burrard Inlet. knowing the geographical distribution of sediment concentrations in Burrard Inlet is also a key component in understanding the fate of contaminants in aquatic and terrestrial ecosystems with a focus on the relationship between chemical emissions and resulting concentrations in biota as a function of observed elevated concentrations of PCBs in sediments

The purpose of mapping the spatial distribution of the existing sediment concentrations of PCBs in the Inlet using a GIS software **(Figure 3.2.2 and Figure 3.3.2.1),** is to further analyze and understand the possible loading sources into the Inlet using available monitoring data sets.

The spatial data analysis using a GIS software (Arcview 3.3) is a very powerful tool which will lead to recommendations for the development of sediment target levels and loading, GIS software analysis could facilitate more defensible management decisions regarding future policies regulating PCBs concentrations in Burrard Inlet.

1.2 Point source discharges

1.2.1 Combined Sewer Overflows (CSOs): Combined Sewer Overflows are sewers where both sanitary sewage and storm water are conveyed in the same pipe (GVRD 1993). Under flow conditions below the capacity of the sewer, the combined flow is carried to municipal wastewater treatment plants (WWTP). When the pipe capacity is exceeded due to high flow conditions, the combined sanitary sewage and storm water is discharged through the CSO.

The CSO inventory for Burrard Inlet was obtained from the Burrard Inlet Point Source Inventory (85) . The Satelite picture used to digitalize a map of Burrard Inlet is a Lansat picture of June 28-2000 of the Greater Vancouver Regional District (GVRD) that perfectly suited the purposes of mapping the PCB's sediment concentration on Burrard inlet. (courtesy of Dr. Kris Rothley). Figure 3.3.2.3 shows the most relevant CSO discharges into the inlet.

1.2.2 Emergency Overflows (LFT): The seven municipalities in the study area (District of West Vancouver, District of North Vancouver, City of North Vancouver, City of Burnaby, City of Port Moody and Village of Belcarra) operate their own sewerage system and discharge to the GVRD trunk lines, with the exception of the Village of Belcarra, which operates entirely on septic systems (Scott, 1995) (86). Each municipality is responsible for controlling the overflows from their sewerage systems and the GVRD is responsible for the main trunk line emergency overflow points. Emergency overflows are highly unlikely, but it may occur in the event of a prolonged power outage or pumping failure.

Storm water (SW): The municipalities are responsible for administering storm sewers within their own jurisdiction. Sites of storm water discharge were obtained from the Burrard Inlet Point Source Inventory (BIEAP, 1997)(85). These plants include outfalls which discharge directly to the marine environment or watercourses. Figure 3.3.2.2 shows the emergency overflow (FLT) and storm water sources (SW).

Table F-1: **Main Combined Sewer Overflows (CSO) point discharges.**

name	Record id	x	y	owner	annual overflow (m3)	annual overflow frequency	polygon	Type
Crowe St East	14	491990	5457680	vancouver	92300	35	fc	CSO
Granville St	18	490156	5458130	vancouver	0	0	fc	CSO
Heather St	20	491481	5457536	vancouver	485000	41	fc	CSO
Hemlock St	22	490022	5458032	vancouver	46200	75	fc	CSO
Jervis St	23	489906.11	5458504.66	vancouver	0	0	fc	CSO
Laurel St	24	491069	5457333	vancouver	5380	12	fc	CSO
Terminal Ave	27	492051	5457055	vancouver	1420	3	fc	CSO
Alma discovery	1	485321	5458491	vancouver	0	0	oh	CSO
Arbutus St	2	489056	5458552	vancouver	3115	10	oh	CSO
Balaclava St	3	487440	5458003	vancouver	547000	49	oh	CSO
English Bay	16	485427	5459390	vancouver	694000	47	oh	CSO
Park Lane	25	489361	5459665	vancouver	0	0	oh	CSO
Brockton Point	4	491675	5461083	vancouver	0	0	ih	CSO
Burrard St	5	491646	5459504	vancouver	1380000	80	ih	CSO
Cassiar St East	7	497953	5459816	vancouver	0	0	ih	CSO
Cassiar St North	8	497877	5459891	vancouver	2760000	112	ih	CSO
Clark Drive1	9	494407	5459589	vancouver	20800000	143	ih	CSO
Clark Drive2	10	494360	5459523	vancouver	0	0	ih	CSO
Columbia St 1	11	492365	5459457	vancouver	197000	74	ih	CSO
Columbia St 2	12	492545	5459211	vancouver	0	0	ih	CSO
Columbia St 3	13	492582	5459409	vancouver	0	0	ih	CSO
Denman St	15	490493	5460052	vancouver	0	0	ih	CSO
Harbour West	19	493963	5459069	vancouver	0	0	ih	CSO
Heatley Ave	21	493764	5459088	vancouver	0	0	ih	CSO
Slocan	26	496535	5460090	vancouver	566	2	ih	CSO
Vernon Relief	28	494228	5459409	vancouver	0	0	ih	CSO
Victoria Drive	29	495287	5459523	vancouver	1020000	110	ih	CSO
Cartlon	6	499070	5459998	Burnaby	0	0	ch	CSO
Gilmore	17	498873	5460060	Burnaby	170000	108	ch	CSO
Westridge	30	503222	5459563	Burnaby	610000	94	ch	CSO
Willingdong1	31	500085	5459894	Burnaby	596000	110	ch	CSO
Willingdong2	32	500147	5459884	Burnaby	0	0	ch	CSO

Figure F1: **Sediment sample points**

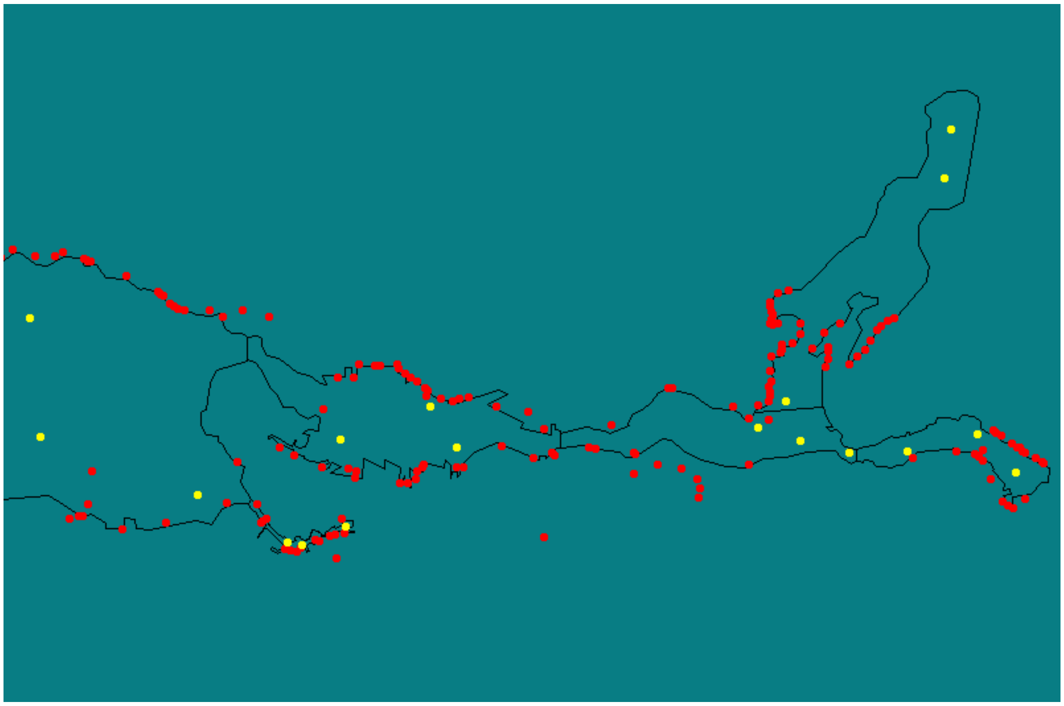


Figure F2: **Emergency Overflows (LFT) and storm water (SW) sources (yellow points)**

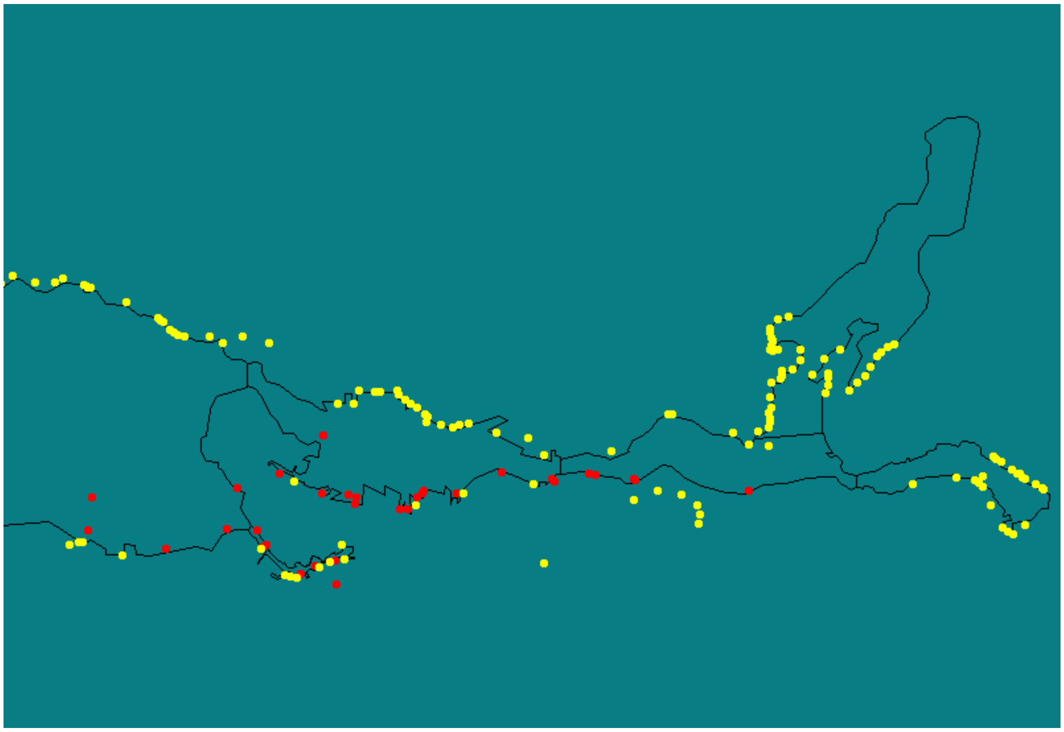
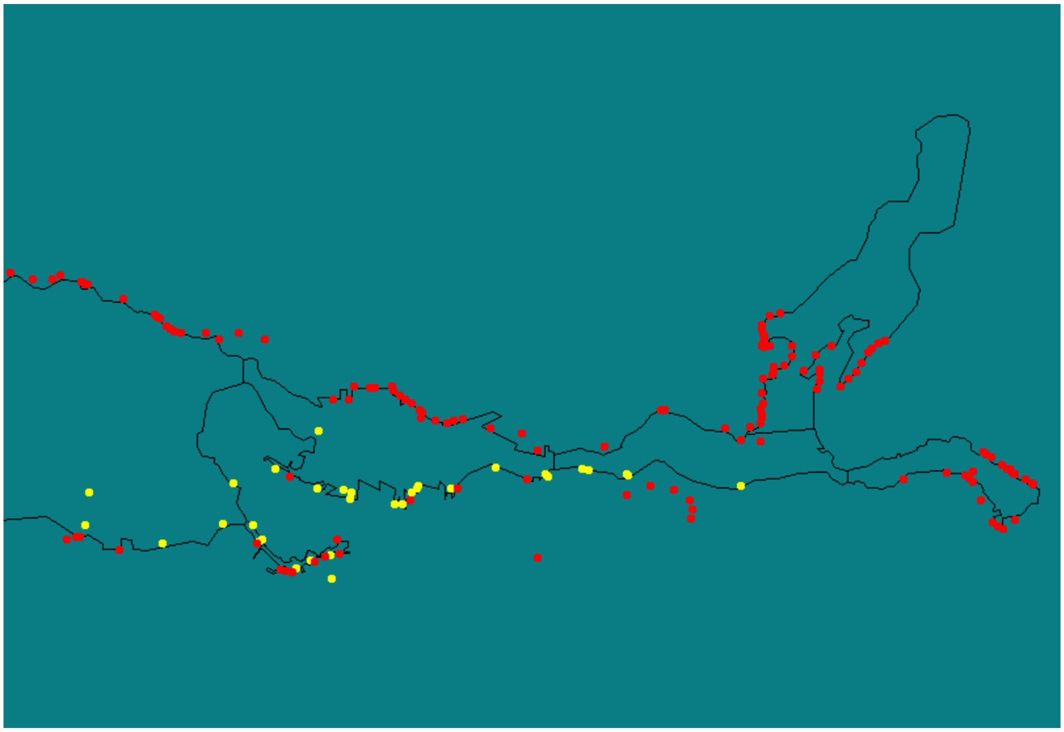


Figure F3.: **Main Combined Sewer Overflows (CSO) point discharges (yellow points)**



1.3 Analysis of contamination sources (Point Sources):

Table 3.3.2.1 shown a splines and IDW interpolation to all CSO point sources discharges of chemicals into the Inlet, for which we had the data for, including volumetric flow discharges into the Inlet and frequency of overflow discharges per year.

It is evident, after performing interpolation, that the main CSO (combined sewer overflow) discharge, Clark Drive #1 with 20,800,000 m3/year, has the major impact in the observed PCB sediment concentration distribution in the Inner Harbor. In particular, this major CSOs discharge, is responsible for the high PCB concentration observed in Clark Drive #1 (See Table 3.3.2.1, Figures 3.3.3.1 and Figure 3.3.3.2)

Figure F4: Splines interpolation for the main Combined Sewer Overflows (CSO)

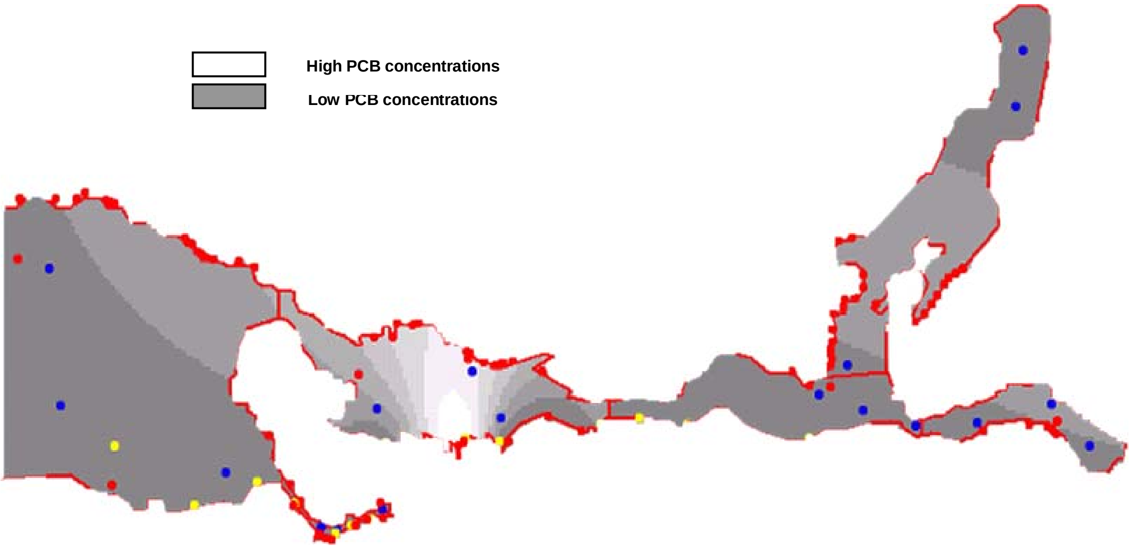
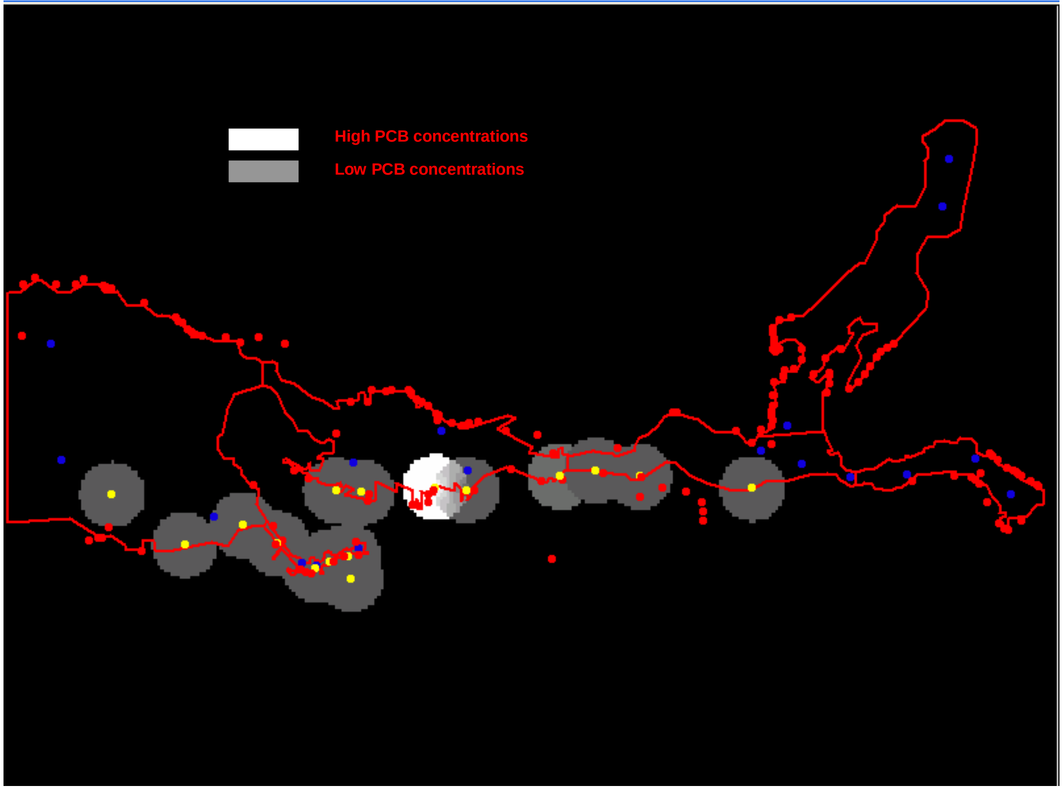
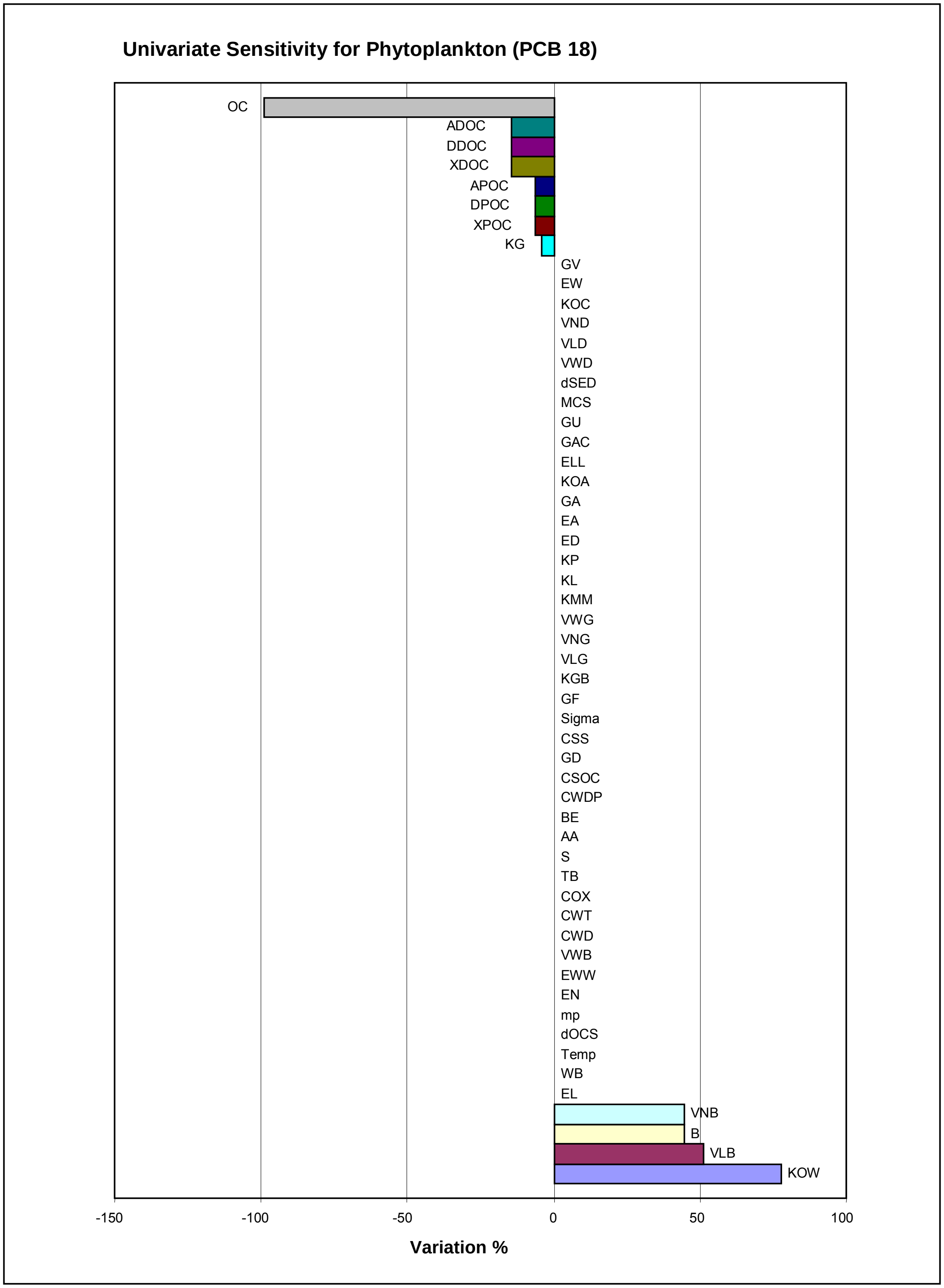


Figure F5: IDW interpolation for the main Combined Sewer Overflows (CSO) point discharges.



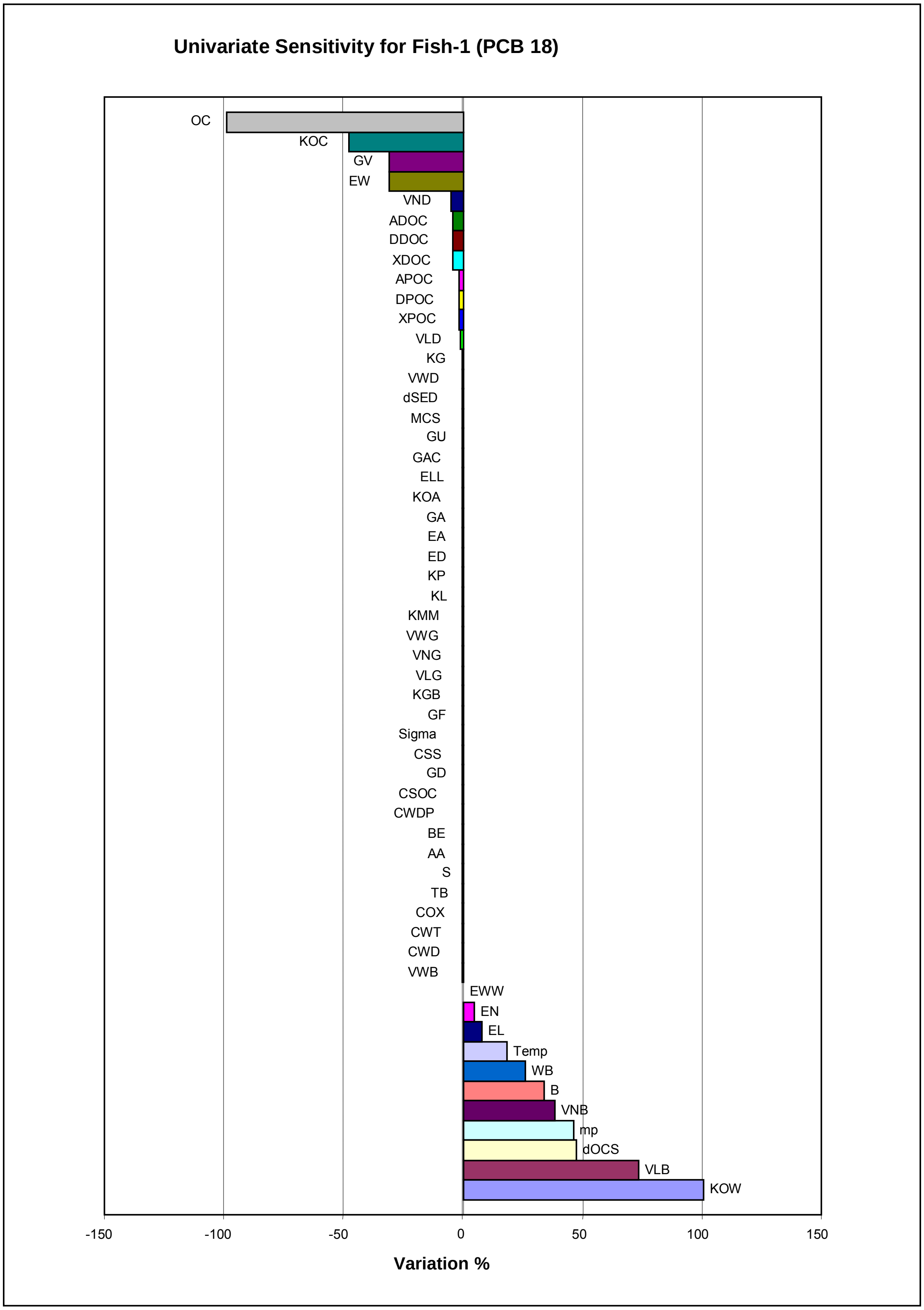
Appendix G: Sensitivity Analysis

Figure G1: **Sensitivity Analysis for Phytoplankton . Contribution of a 5% variation in various model state variables to the variance in the BSAF in Phytoplankton.**



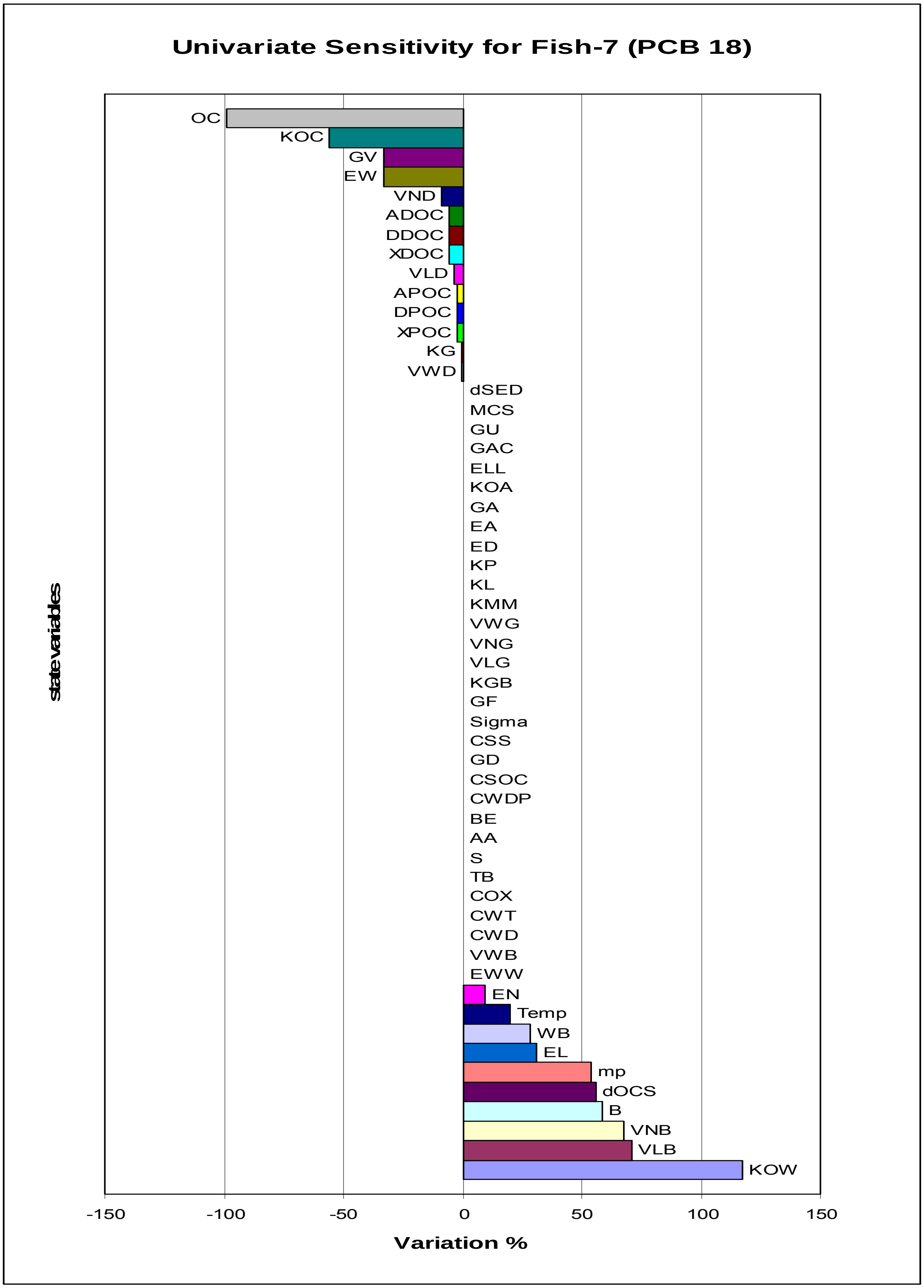
Note: Refer to Apendix D for model Parameter's units and definitions

Figure G2: Sensitivity Analysis for Minnows. Contribution of a 5% variation in various model state variables to the variance in the BSAF in Minnows.



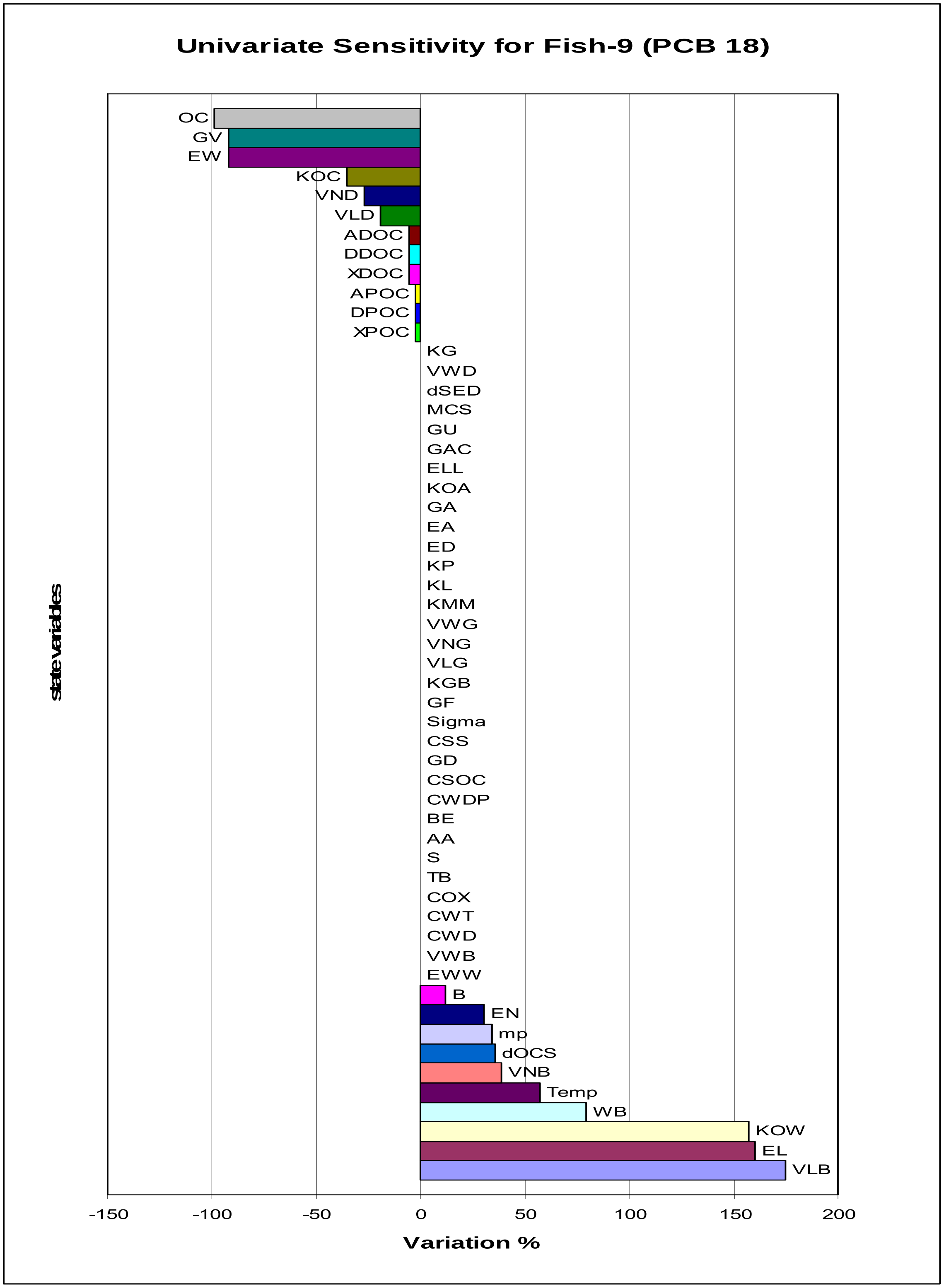
Note: Refer to Apendix D for model Parameter's units and definitions

Figure G3: **Sensitivity Analysis for English Sole. Contribution of a 5% variation in various model state variables to the variance in the BSAF in English Sole.**



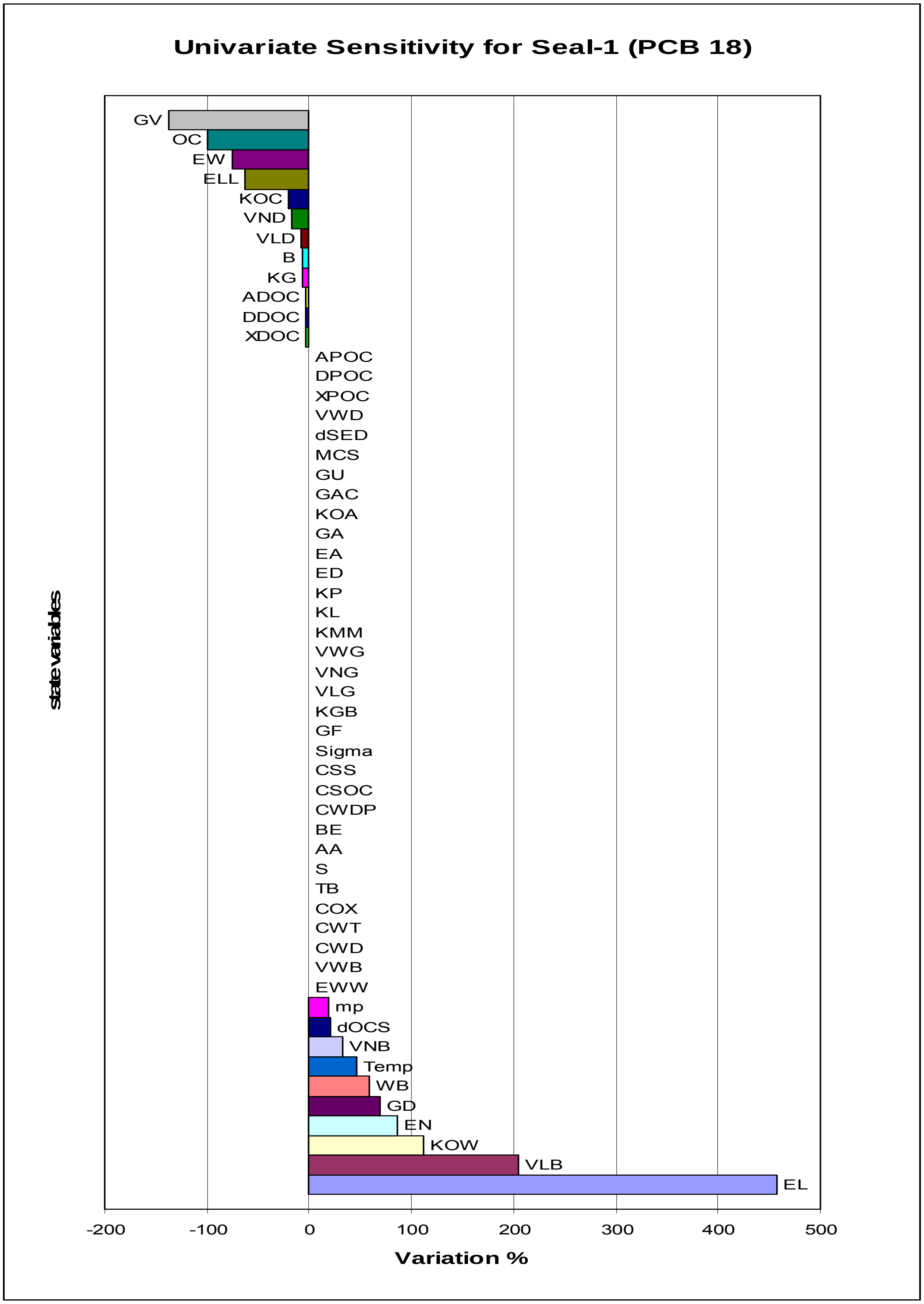
Note: Refer to Apendix D for model Parameter’s units and definitions

Figure G4: Sensitivity Analysis for Spiny Dogfish. Contribution of a 5% variation in various model state variables to the variance in the BSAF in Spiny Dog Fish.



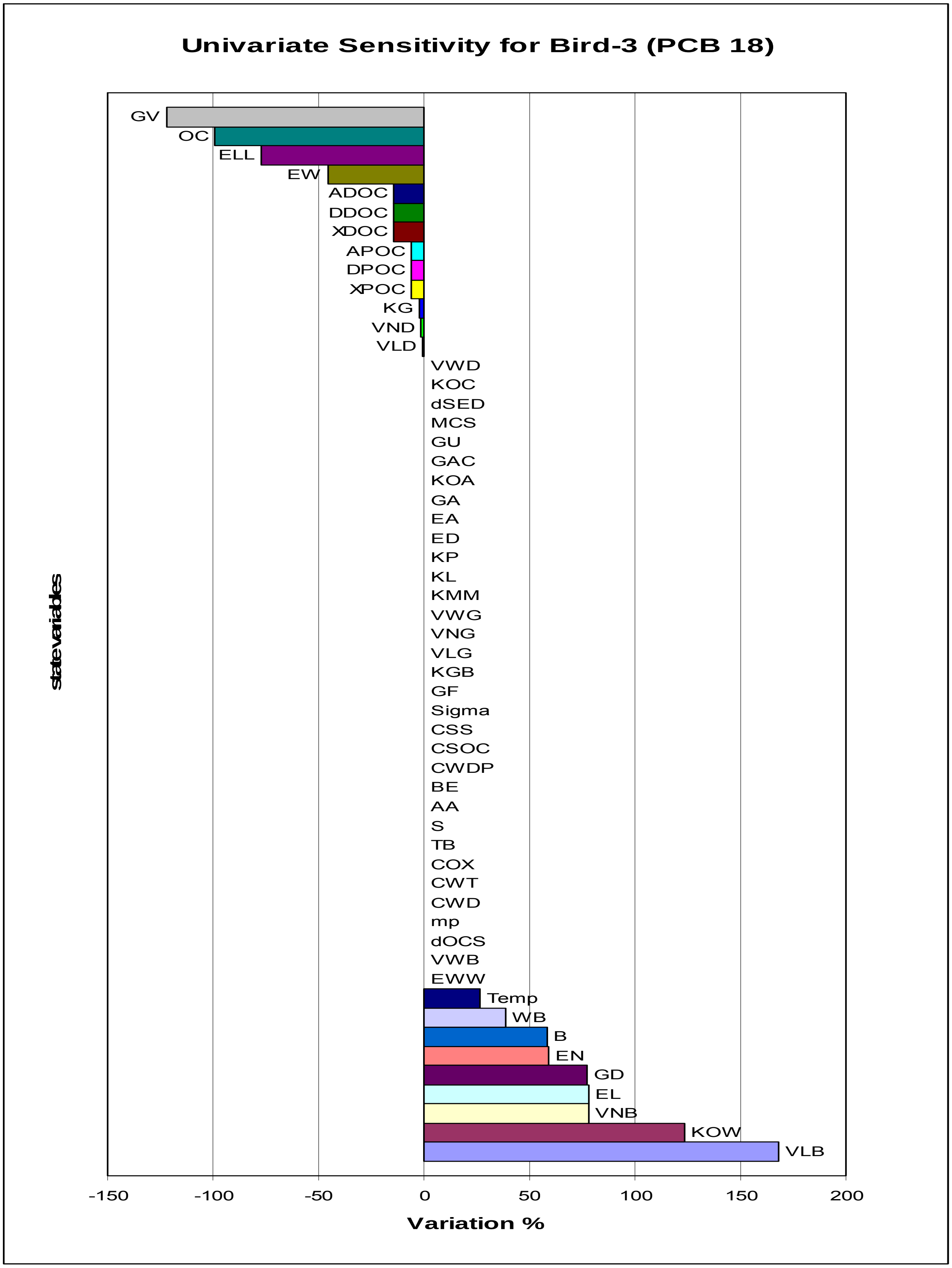
Note: Refer to Apendix D for model Parameter's units and definitions

Figure G5: Sensitivity Analysis for Seal-1. . Contribution of a 5% variation in various model state variables to the variance in the BSAF in Adult Male Seal.



Note: Refer to Apendix D for model Parameter's units and definitions

Figure G6: **Sensitivity Analysis for Surf Scoter. Contribution of a 5% variation in various model state variables to the variance in the BSAF in Surf Scoter.**



Note: Refer to Apendix D for model Parameter's units and definitions

Appendix H: CD-ROM Contents

An attached CD-ROM forms a part of this thesis. Fullly detailed tables from preceding Appendices are available in this CD. All files may be opened in Excel.

Contents:	
Table A-5	Parameters and Stated Variables by species. Detailed account of the values chosen for each of the model variables. It also includes the metabolic transformation rate constants used in the model.
Table A-6	Freshwater and Seawater-Temperature corrected Octanol-Water Partition Coefficients (log Kow) and Koa
Table A-7	Feeding preferences of various species represented in the model. Generalized trophic interactions between most of the species described in Table A-7b
Table A-9	Observed Biota Sediment Accumulation Factors (BSAFs) and standard deviations (SD) in False Creek
Figure G1	Sensitivity Analysis for Phytoplankton . Contribution of a 5% variation in various model state variables to the variance in the BSAF in Phytoplankton
Biotic model	Burrard Inlet Food web Model
Abiotic model	Steady State Fate Model