Overview of Results from a Workshop Addressing PCBs in Puget Sound and Georgia Basin Ecosystems

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Abstract
From September 16 -19, 2002, the Pacific Northwest Chapter of the Society of Environmental Toxicology and Chemistry (PNW-SETAC) sponsored a workshop at the University of Washington, Friday Harbor Marine Laboratory, on San Juan Island, WA. The workshop was co-sponsored with the Puget Sound Action Team, Axys Environmental labs (BC), NOAA-Montlake Lab, and EPA-Region 10. More than 50 scientists (including managers) gathered to discuss how PCBs enter and move through marine food webs in Puget Sound and the Georgia Basin. One of the main goals accomplished was to provide a forum to encourage collaborations between disciplines as well as between U.S. and Canadian counterparts. Early sessions (management issues, modeling, sources and inputs, trophic linkages to and from invertebrates, fish, and marine mammals, human health issues, and analytical methodology) laid the foundations for workgroup discussions.

Welcoming Address and Management Issues
Although the workshop did not address toxicity from PCBs, the welcoming address acknowledged that PCBs are well known to cause early life-stage mortality in birds, fish, and mammals due to dioxin-like effects. Early in the workshop, managers (chaired by Pat Cirone, EPA-Region 10, and including decision-makers in Superfund, dredging, and monitoring programs) presented a broad range of management needs relative to PCBs in our marine ecosystems. These included:

- What is safe?
- How much sediment to clean up?
- Do trophic models perpetuate and magnify uncertainty?
- What would successful control of regional sources and sinks mean in terms of future risk from PCBs?

Keynote Session
Keynote presentations by Frank Gobas (Simon Fraser University, BC) and Phil Cook (EPA Office of Research and Development, Duluth, MN) focused on lessons learned from modeling PCBs in other aquatic systems. Models are valuable when used to evaluate whether potential actions are likely to have potential benefit. Some of the key factors emphasized were data availability, the need to start simple and balance simplicity with realism, and recognition that the Puget Sound/Georgia Basin ecosystems are not closed. Furthermore, it is important to know the sediment-water partitioning of PCBs so that uptake into organisms via the food web and respiration can be modeled. Ongoing research is evaluating the role of organic carbon mineralization in sediments in the fate of PCBs.

The need for a clear concept of management goals was emphasized, i.e., what is to be protected, to what degree and how? Likewise cost was discussed and the recommendation made to use a model scale and construct which are sufficient to provide the predictive power needed, given the resources available. Part of this involves using previous models wisely. Retrospective analysis can be used to test model accuracy. Other lessons include: Always get the fundamentals right before focusing on details; You cannot violate the Laws of Thermodynamics; Make sure you are modeling the right chemicals with the right data for the right media (biota, sediment, water, air); and model complex mixtures of chemicals with a common mechanism of action individually to the receptors at risk. Figure 1 illustrates the types of data needed for a PCB model that will predict concentrations in organisms.

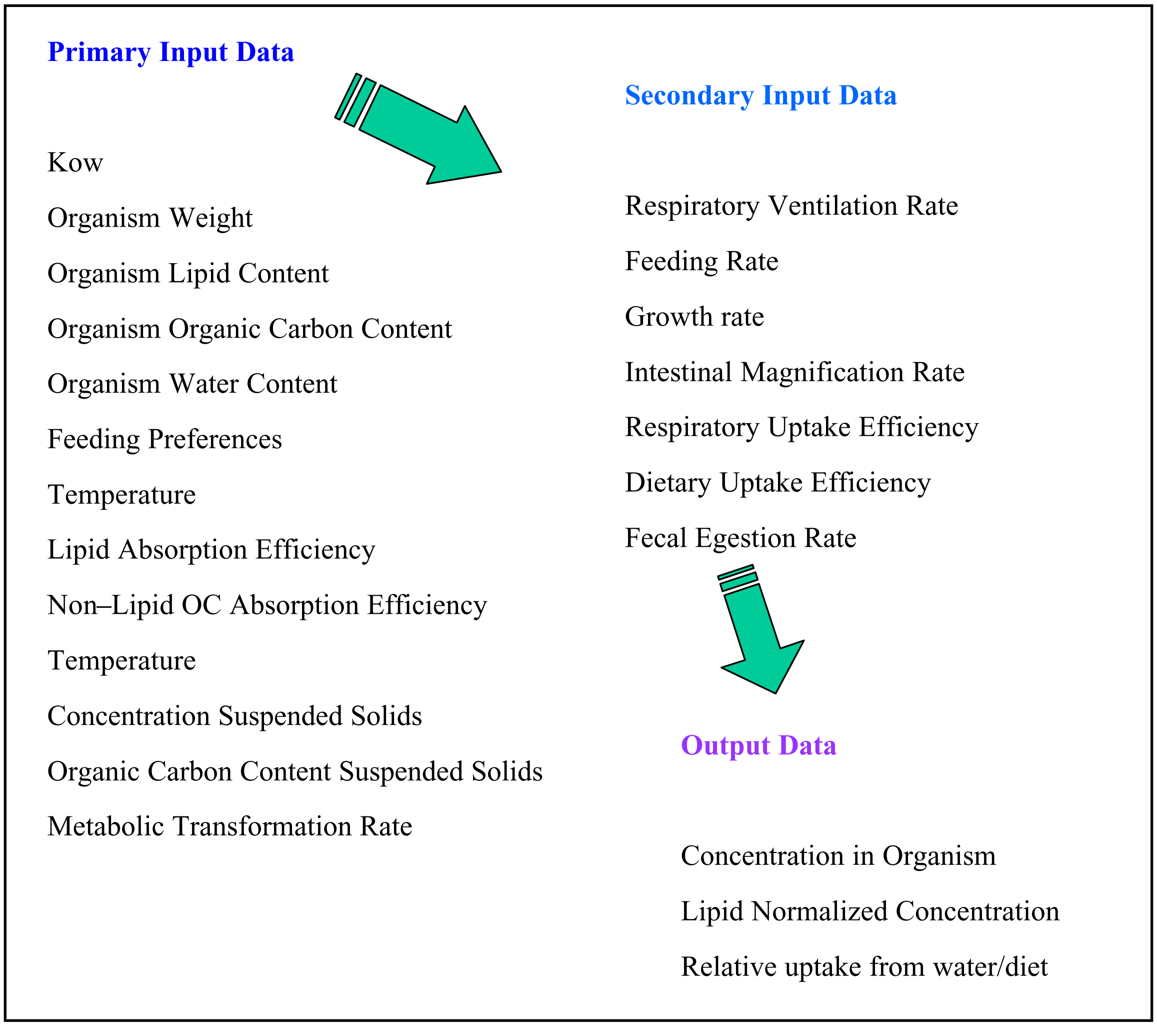

Figure 1. Input data for and output data from a trophic food web model.

Discussion Sessions

Following the keynotes, discussion sessions ensued. Their goal was to share available information on PCBs that encompassed four main themes:

- Sources/inputs
- Organisms (fish/invertebrates/mammals)
- Human health
- Analytical methodology

Sources/Inputs

Alan Mearns (NOAA) chaired this session and opened with an outline of possible sources and types of inputs: Solid and electrical waste products, paint, marinas, cooling water, wastewater, global and local atmospheric inputs, surface water runoff, sediments, and biota. Gayle Garman (NOAA) gave a brief demonstration of NOAA's Query Manager database-mapping tool that contains data on many potential contributors of contaminants to the Puget Sound Basin. Users can query the data for each location where data are available. The data on PCBs, for example, indicate that only a few areas (Bremerton, Seattle, off the north end of Maury Island, Commencement Bay, Everett, Bellingham Bay, and potentially off the northwest end of San Juan Island have concentrations that exceed 150 ppb. The take-home story from the MARPLOT output is that looking at all the sites in Puget Sound, the problem isn't "all of Puget Sound," but rather a few locations, specifically in a few estuaries.

Randy Shuman, King County Department of Natural Resources (DNR) presented PCB effluent data for West Point Wastewater Treatment Plant on the eastern shore of central Puget Sound and from the Duwamish River. In Puget Sound over 200 of the wastewater effluent samples taken had non detects of PCBs at the 0.05 ppb level. Moreover, PCBs were also undetectable in 57 samples of intertidal water. Wastewater treatment plants therefore may not be significant sources of PCBs to Puget Sound. The treatment efficiency of each plant is well documented and it should be easy to calculate, as well as predict the loading from these sources into Puget Sound. For example, King County estimates the effluent PCB concentration to be about 0.00285 µg/L/day for a total PCB effluent load of 750 g/year for two large wastewater treatment plants. Interestingly, for comparison, the average body burden of PCBs in salmon are 50 µg/kg, which when multiplied by the number of fish coming into the Puget Sound basin each year, equals about 250 g/year of PCB loading

Staci Simonich (Oregon State University) discussed "Atmospheric Deposition of PCBs to Puget Sound." She cited estimates of total atmospheric loading of PCBs to the Great Lakes and indicated the primary source to the Great Lakes was from the city of Chicago, Illinois. If Puget Sound is similar to the Great Lakes in atmospheric loading, we might be experiencing particle dry deposition on the order of 1100 kg/yr (with air/water exchange (880 kg/yr) and wet deposition of 50 to 250 kg/yr) [Note that wet deposition is comparable to King County DNR's estimate of annual PCB loadings from wastewater treatment plants to Puget Sound]. When industrial PCB wastewater effluent sources are cleaned up, the atmosphere may become more important as a primary source of PCBs. In the Puget Sound and Georgia Basin regions, atmospheric deposition occurs at high elevations with snow. Shared transboundary airsheds between Canada and the US, as well as the trans-Pacific air currents provide sources of dry and wet deposition to the Puget Sound region. PCB inputs to low elevation areas including aquatic ecosystems, estuaries, and embayments in Puget Sound and Georgia Basin are during annual snow and glacial melt. Currently air monitoring is conducted at stations on Cheeka Peak observatory (Makah Reservation) located on the Olympic peninsula and at Whistler, B.C., whereas snow samples are collected and analyzed from Olympic National Park and 5 sites in Canada. Currently, 12 PCB congeners are analyzed, with semi-volatile PCBs targeted as tracers of sources. No data are yet available for Puget Sound/Georgia Basin.

Maggie Dutch (WA Dept. Ecology) gave highlights from the 1997-1999 PSAMP/NOAA Sediment Survey. The PCB data summarized and displayed were collected from 300 randomly selected sites throughout Puget Sound, where surficial sediments were collected from the top 2-3cm. In summary, this study accomplished a number of goals: (1) Identifying the distribution of 8 PCB Aroclors and 19 PCB congeners at 300 stations around Puget Sound; (2) Documenting total PCB concentrations, as well as their spatial patterns and gradients in Puget Sound and comparing the concentrations to both WA State Sediment Quality Standards and nationally derived sediment guidelines; and (3) Using the compiled information to calculate the spatial extent of contamination (km^2) regionally and Sound wide, setting the stage for future statistically-based comparison of these values.

Eric Crecelius (Battelle Marine Science Laboratory) evaluated historical changes in PCB concentrations in Puget Sound by using lead as a surrogate, since most PCB levels are below analytical detection limits and bind to particles like lead. A mass balance model for particulate lead in metric tons/yr for Puget Sound was presented. Inputs and exports to the Pacific Ocean and to south Puget Sound, including sinks and sources from outfalls, air deposition, stormwater runoff, and erosion provided a fairly good mass balance. About 75% of particulate-bound lead ends up in sediments, so particles should remove PCBs to sediments as well. PCBs have been identified in Puget Sound's Central Basin since the 1920s. Concentrations of PCBs in sediments peaked in the early 1970s and have been decreasing ever since. Concentrations of PCBs at the surface of sediments are staying at about 5 ppb. The same pattern has been seen in sediment cores taken from Georgia Basin and European Basins. We should be able to apply knowledge about the history and the budget for lead to develop a budget for PCBs in Puget Sound. Using the formula of sedimentation rate multiplied by concentration will provide a PCB mass balance budget. For example, the mass balance computes out to about 9.2 kg/yr of PCBs deposited in the Central Basin of Puget Sound during the 1990s. This is approximately equivalent to 2 quarts of oil. This estimate seems to be reasonably close to the estimate for the San Francisco Bay Basin.

Alan Mearns (NOAA Hazmat) presented Mussel Watch data collected along the Pacific coast from Canada to Mexico during 1997 and 1998. There are four major PCB sources along the coast and PCBs are also prevalent in the deeper Pacific Ocean basins. Of the four coastal states Oregon has the lowest PCB concentrations.

Trends indicate a decrease in PCB concentrations from 1986 to 1993, with a sharp increase in concentrations in 1998 and then a decrease until the present. The same pattern has been seen in samples collected from the Great Lakes and from other areas around the country. PCB congener patterns in 1998 for Columbia River to Cape Flattery, into the Strait of Juan de Fuca and down into Puget Sound were shown. The headwaters of the Duwamish were dominated by a light-weight congener PCBs not present elsewhere. Mussels placed in the Columbia River accumulated 91 µg/kg dry weight, whereas some mussels placed in Puget Sound accumulated as much as 200 µg /kg dry weight.

Organisms (fish/invertebrates/mammals)
Sandie O'Neill (WA Dept Fisheries/PSAMP) presented information on fish and invertebrate tissue levels. Puget Sound/ Georgia Basin hydrography is important. In Puget Sound water flow is predominantly from Whidbey and Admiralty Inlet Basins into the Central Basin where it is retained for long periods of time due to the basin's morphometry. The Whidbey Basin receives a lot of contaminant input from the city of Everett, which is routed into the Central Basin where it accumulates. Inputs from the Admiralty Inlet Basin are relatively low due to its underwater sills and greater water circulation that keeps it flushed of contaminants. Organism retention in each basin is also a function of hydrology and basin morphometry with organisms in the Central Basin being retained for long periods of time. Consequently, organisms in the Central Basin are exposed to higher concentrations of contaminants over longer periods of time compared to organisms in the other Puget Sound basins. TOC normalized PCB tissue data provide evidence of varying concentrations of PCBs in each basin.

In the Strait of Georgia Basin there are no underwater sills to hinder flow, allowing the huge inputs of freshwater from the Fraser River to flush the entire Basin. The Georgia Basin and Puget Sound basins are separated by the San Juan Islands, which serve as a physical barrier

Factors affecting PCB exposure and accumulation in biota include: proximity to contaminant sources, gender and age of fish, lipid content of tissues, and trophic level. PCBs move from sediments through the benthic food web via bioaccumulation by benthic infauna, biomagnification to benthic consumers, and bioaccumulation in older organisms and males. Sediment concentrations correlate well with tissue concentrations in lower trophic and bottom dwelling organisms e.g., English sole muscle tissue. Moreover, longer lived organisms e.g., quillback rockfish that are at a higher trophic level, accumulate more PCBs than shorter-lived, lower trophic level organisms. The growing evidence indicates that PCBs flow from benthic food web to pelagic food web via maternal transfer. PCBs are transferred from adult benthic/ demersal species to their planktonic eggs, larvae which then biomagnify up through the pelagic food web as higher trophic level pelagic predators consume benthic prey. PCB concentrations in herring, coho and Chinook salmon were discussed. Mechanisms of transfer of PCBs to the terrestrial food web were also discussed.

Main conclusions were:

- End of the pipe sources contribute much less PCBs than they used to.
- In Puget Sound: Sediments are the major source of PCBs, especially in Central Puget Sound near urban centers.
- In Georgia Basin: Sediments are less of a source of PCBs.
- Basin-specific models are more appropriate given the hydrographic and morphometric differences between Georgia Basin and Puget Sound.
- PCBs are transferred among biotic components via the food web
- We need to account for the life history of biota to predict PCB body burdens.
- The area of contaminated sediments is much smaller than the biological impact zone.
- If a contaminated area is capped, it may only be cleaned up to background levels for Central Puget Sound.

Peter Ross (Institute of Ocean Sciences, Sidney B.C.) presented information on the characteristics that make marine mammals useful sentinels of marine ecosystem contamination. We need to understand where the prey are coming from to know where the sources of contaminants are located. Unfortunately little is known of where migratory species go once they leave the Puget Sound and Georgia Basin areas. Estimates suggest PCB inputs to the Strait of Georgia come from the atmosphere (77 kg/a), municipal effluent (4 kg/a), the Fraser River (56 kg/a), and other rivers (16 kg/a). It is not surprising that high levels of legacy persistent contaminants have been found in killer whales inhabiting the NE Pacific Ocean.

There are three Orca communities in the Puget Sound/Georgia basin regions: a northern, southern, and transient population. Their differences in PCB tissue concentrations, predatory preferences, and diet were discussed. Age and sex of marine mammals also influence the levels of contaminants in their tissues. A trend of concern is that concentrations of PCBs in harbor seals have decreased from 1972-1988, but have decreased little since then. Seals from Puget Sound are characterized by having higher molecular weight PCBs in their tissues, while those in Strait of Georgia are characterized by lower molecular weight PCBs. When food items in Puget Sound were analyzed for PCBs, they found 7.1 times more PCBs in Puget Sound food items than in Strait of Georgia food. Marine mammal tissue burdens of PCBs in Puget Sound and Georgia Basin are not a dietary issue, i.e., a result of the types of food items consumed, but rather a level of contamination issue, i.e., the amount of contaminants in a region.

Jim West (WDFW) addressed two main questions, "Are biota a significant sink/source of PCBs in Puget Sound and Georgia Basin? And "Can we populate a mass-balance model with existing information?"

A mass-balance model needs: PCB body-burden data, species biomass data, predator-prey linkages, and basin specific modules that are linked, e.g. Whidbey basin with Central Basin. Gut content studies are few and current salmon diet knowledge in Puget Sound is lacking (only have MESA studies done in the early 1970s). EcoSym and EcoPath are two models that can be helpful. The EcoPath model is an analysis of ecosystem dynamics, trophic shifts, and salmonid population changes in south Puget Sound from 1970-1999. The models allowed some investigation of how PCBs might be distributed in biota, as well as the influence of primary productivity on that distribution.

The main conclusions were:

- Model is very sensitive to PCB in plants.
- Plants may play important role in PCB recycling

The main questions included:

- How do other basins compare?
- What happens to benthic plants in the winter?
- Do plants sequester PCBs in sediments or pump them into higher trophic levels?
- How do PCBs behave under high productivity/turnover of plants?
- What happens to plants when they die?
- What happens to killer whales when they die?
- What are sediments anyways? Do PCBs get stuck in biota?
- Pros and cons of mass-balance type models were discussed.

PCB Fate and Effects—Human health

Lon Kissinger (EPA Region 10) and Nancy Judd (University of Washington) discussed human health assessment concerns such as fish advisories, seafood consumption surveys, human health effects of PCB exposure, and general human health risk assessment approaches (exposure routes, fish consumption studies, for example).

It is very important to consider factors such as consumption rate, source, species and portion of fish/shellfish consumed. One also has to consider if it is realistic to collect this information as part of environmental monitoring.

In particular, the issue of congeners was discussed. Using Aroclors vs. congeners data to estimate risk is an important question. The congener composition of Aroclors released into the environment changes due to differential partitioning, environmental degradation, bioaccumulation, and metabolism. It is important to know what is eaten and where it is from, as well as PCBs concentrations in the tissues consumed.

Analytical method, its sensitivity, and cost are also important considerations For example, PCB congener 126 was the dominant cancer risk contributor found in a number of studies. Detection sensitivity to 10 parts per trillion or better is likely to be needed to assess cancer risk from this specific congener. Aroclor data are useful for comparison with historical measurements since PCBs have generally been measured in this way. It is preferred that both Aroclor and congener PCB data be collected.

Joan Hardy (Washington Department of Health) described a project that assessed PSAMP data for English sole from 39 locations. Weight-of-evidence for permissible human intake concentration of PCBs will probably be 0.2 µg/kg/day (same as EPA reference dose for Aroclor 1254). Only one location exceeded the permissible level. Health benefits of fish should also be considered. We do not want to scare people away from eating fish and lose the great health benefits.

Methods

Gina Ylitalo (NOAA/NWFSC) and Erika Hoffman (USEPA Region 10) discussed the pros and cons of different methods for analyzing PCBs by type (Homolog, Aroclor, Congener, and Cell line bioassays) and by instrument (GC/MS, GC/ECD/HRMS, and HPLC/PDA). They noted that each method will provide different results that may not be comparable. They also noted that different agencies use various summing techniques to calculate total PCBs. Methods can be used to screen for individual PCBs and/or in a tiered approach for greater accuracy and precision. The greatest consideration is that as analytical detection limits get lower, costs get much higher.

There are no simple answers on how many and which type of PCBs to monitor; they will be different in different environmental compartments (water, air, sediments) and organisms (invertebrates, fish, seals, and whales). Some progress is being made to estimate congeners from Aroclors.

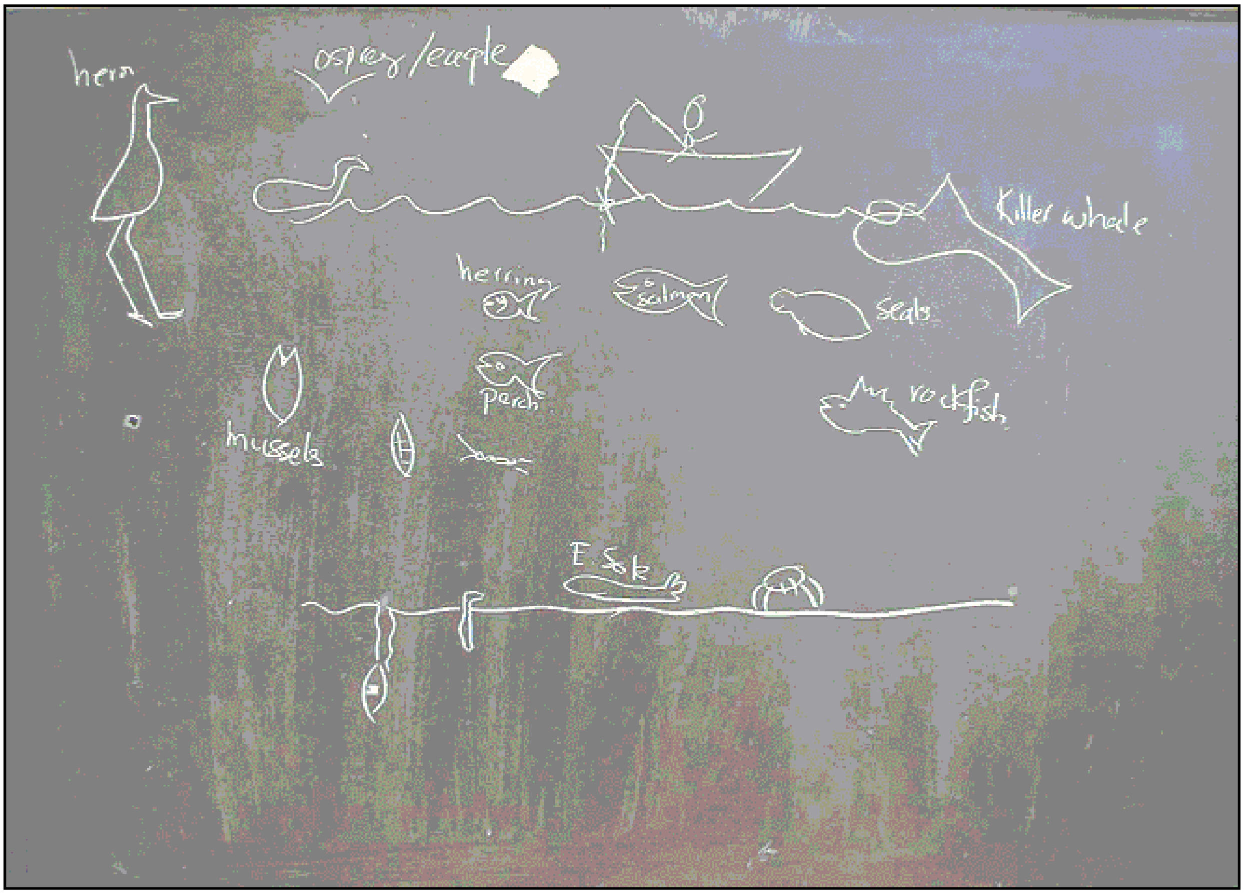

Figure 2. Developing a conceptual model of trophic components in Puget Sound/Georgia Basin food webs.

They also discussed differences in methods for analyzing lipid content, including extraction solvents (e.g., hexane, ether, chloroform), extraction techniques (e.g., Soxhlet, ASE, SFE), and lipid determination methods (gravimetric, TLC/FID). As for the PCBs, each method will provide different results that may not be comparable. Their main points were that there is no standardized lipid analytical method, non-polar lipids correlate more with PCBs than polar lipids; and lipid concentrations do not always vary with PCB levels. They concluded that it doesn't really matter how PCBs are created or where they are from because once they are in the environment they will behave according to their specific chemical properties

Modeling 101

The information presented at the discussion sessions indicated to Frank Gobas that we are incredibly data rich, but we still don't know how to answer the most basic questions about linkages. Rather than focus on collecting more data, he recommended that we work on linkages by developing a model, which will help us to define these causal relationships. Phil Cook echoed that we need better basic characterization of the existing data and develop more effective models that require minimal resources. Both Frank and Phil saw the need to answer whether and how existing PCB hotspots are affecting the rest of Puget Sound/Georgia Basin.

The first steps in developing a model are to bring the existing knowledge together and describe the linkages, as well as the groupings. This is shown in Figure 2 where workshop participants helped define the food web components and linkages. The participants also helped define the external variables (stressors that bring PCBs into the environment), describe the internal variables and attributes of interest (what we are interested in: PCB concentrations in various compartments and attributes about them; health, population declines, for e.g.), and the processes that link the variables (e.g., volatilization, predation, pore water flux, toxicokinetics, etc.) together.

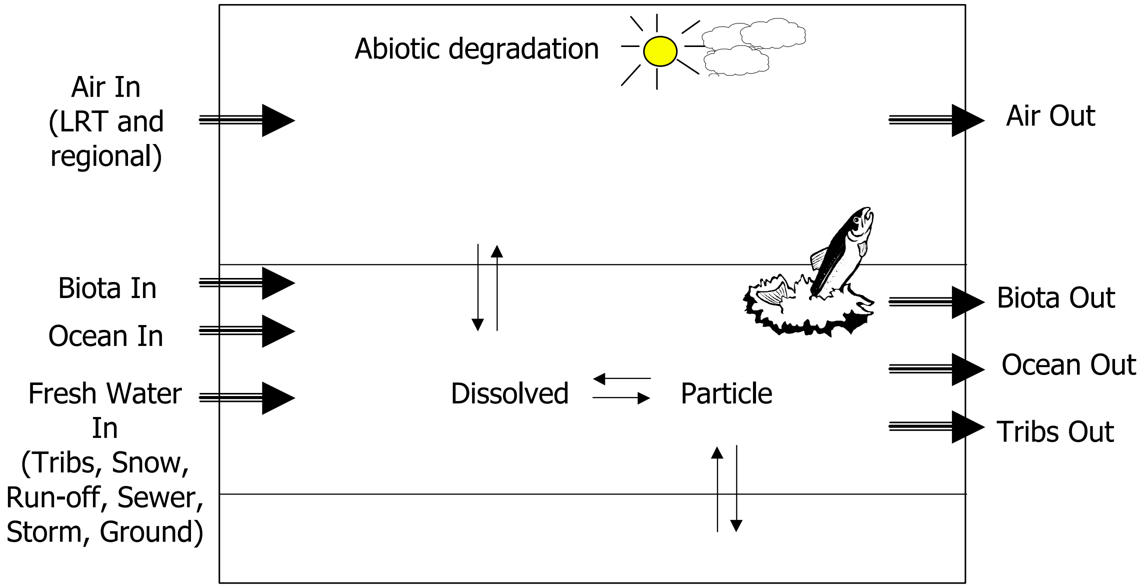

Figure 3. Example from abiotic fate processes work group. Multi-media Model.

Workgroup Findings

Participants split into three workgroups:

- Abiotic factors
- Lower trophic structure
- Upper trophic structure.

Abiotic Factors

Staci Simonich chaired this group and their major findings included the following: Three interconnected mass balance models are needed, i.e., one for each of the major basin ecosystems: the Strait of Georgia, Puget Sound, and Strait of Juan de Fuca. An example was presented (Figure 3). The models will try to predict freely dissolved PCB concentrations in the water column to determine if they are low enough to protect marine life. A list of data needs was presented to achieve this, including congener-specific data and information on fluxes (including biota flux) and the influence of seasonality. The models would provide dissolved water concentrations and surface sediment concentrations to the other two workgroups.

Lower Trophic

Sandie O'Neill and Jim West co-chaired this workgroup. The participants developed and presented a model that grouped lower trophic organisms by feeding type from infauna to fish and included the role of seagrasses and algae. The next steps will be to measure PCB bioaccumulation and biomagnification suggested by the initial model showing the trophic connections. Average sediment concentrations and non-migratory benthic organism tissue concentrations will be useful in apportioning PCB uptake into the various exposure routes (ingestion, respiration/gill, dermal, etc.).

Upper Trophic

Peter Ross chaired this workgroup. This workgroup reviewed what is known about upper trophic organisms (longevity, abundance, links with humans, use as sentinels, linkages with prey) and data needs. The confounding factor in modeling upper trophic organisms is establishing the connections based on PCB concentration data for both predator and prey. Data needs include life history, predator/prey linkages, and metabolic differences (e.g., in PCB elimination). The workgroup then identified a top ten species list of upper trophic organisms for use as biological indicators in the Puget Sound/Georgia Basin regions, which ranged from humans and killer whales to mallard ducks. Linkage issues were also identified (e.g., within and across Basins for PCB sources and exposure pathways, organism life history, integrated with human health/ecological risk assessment). The importance of migration by upper trophic organisms in moving PCBs in and out of the system was also discussed.

Next Steps

The workshop ended with considerable interest by participants to keep up the momentum in developing an integrated model, identifying data gaps/research needs, and continuing to develop partnerships across international borders and scientific disciplines. More detailed information on the workshop can be found at the Pacific Northwest SETAC web site, hosted at the SETAC web site, by contacting the authors of this overview, and from other authors who presented in this session (4E): **PCBs in Georgia Basin/Puget Sound Ecosystems.**