The long-term fate and bioaccumulation of polychlorinated biphenyls in Puget Sound

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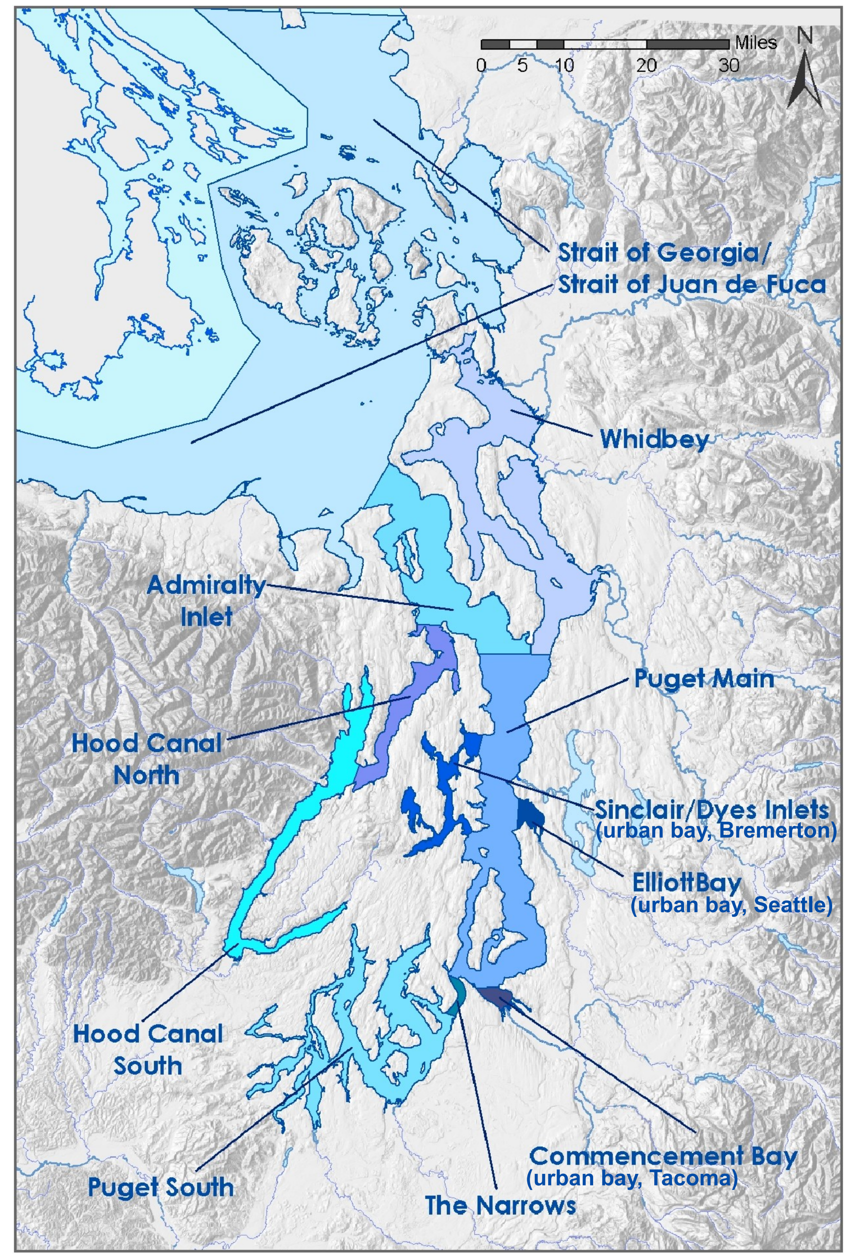

Fig. 1. Map of Puget Sound box model regions.

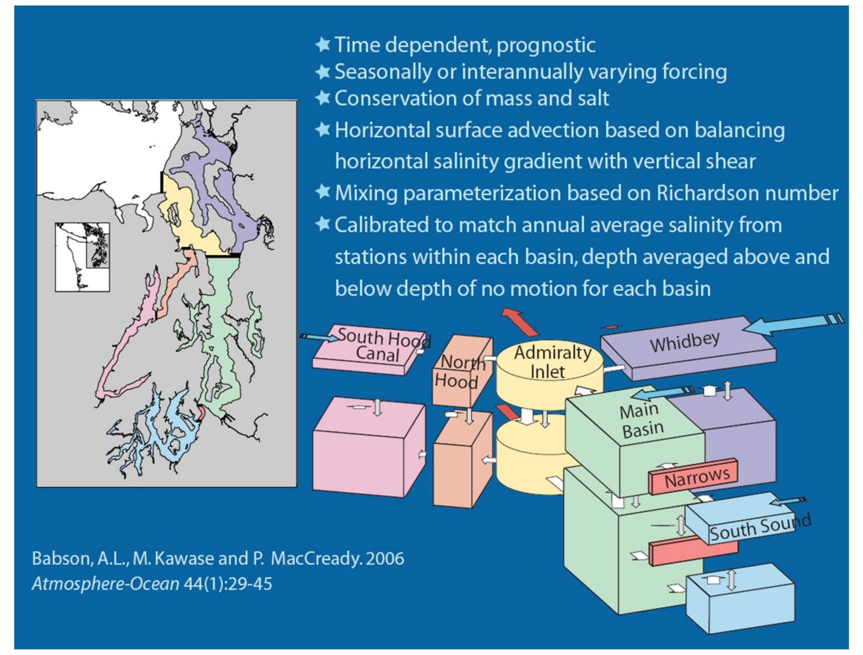

Fig. 2. Box model overview.

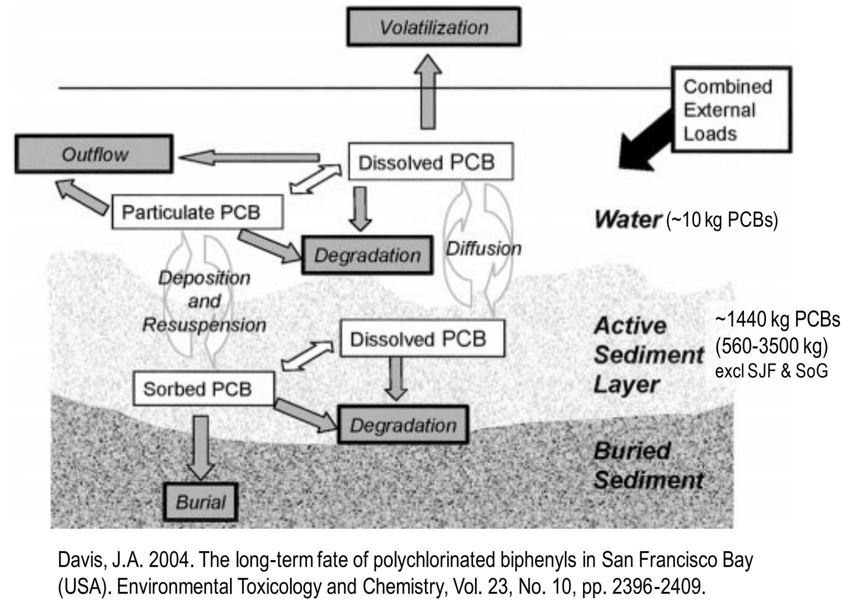

Fig. 3. Contaminant model kinetics.

Abstract

In this study, we developed computer models to predict the concentration of polychlorinated biphenyls (PCBs) in water, sediment, and biota of Puget Sound (Fig. 1 to 4). The models include the following:

- **a box model to predict transport and fate of PCBs** in surface and deep water column layers and a sediment layer for 10 interconnected basins in Puget Sound.
- **a food web bioaccumulation model** to predict concentrations of PCBs in the aquatic food web in each basin of Puget Sound.

Predicted future PCBs in water, sediment, and biota are very sensitive to external loading (Fig. 5 to 15). The mass of PCBs in the aquatic ecosystem of Puget Sound may either increase or decrease over time considering the wide range of uncertainty in loading estimates (Fig. 10). The median response suggests recent increases in loading, possibly from nonpoint sources. Limited available biota data also suggest an increasing trend in loading (Fig. 13 to 15). PCBs appear to be increasing in the large basins and decreasing in the urban bays (Fig. 6, 7, and 14).

Reduction of external loading is predicted to decrease future concentrations of PCBs in the water, sediment, and biota of Puget Sound. Comprehensive source control measures and best management practices are recommended to reduce PCB loading from residential, commercial/industrial, forest, and agricultural watershed areas.

The modeling framework for quantifying transport, fate, and bioaccumulation of PCBs is adaptable for the evaluation of other toxic contaminants.

Models

The numerical modeling approach for this project is composed of three parts:

1. **Circulation and transport of water**. A model to predict transport of water between basins of Puget Sound (Fig. 1 and 2) and between surface and deep layers of the water column.

2. **Contaminant transport and fate**. A model to predict water and sediment concentrations of PCBs in response to external loading and internal processes (Fig. 3).

3. **Food web bioaccumulation**. A model to predict PCBs in Puget Sound biota in response to water and sediment concentrations (Fig. 4).

The data for model calibration are from various sources.

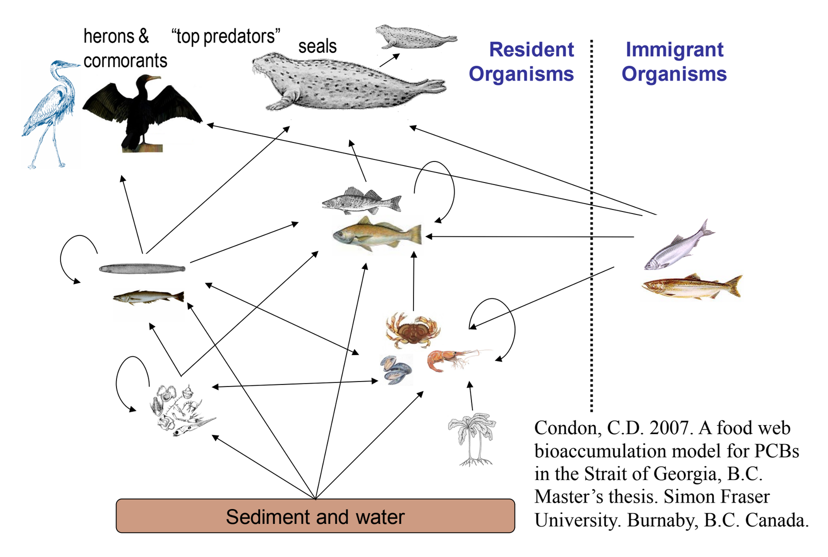

Fig. 4. Feeding relationships in the food web model.

Major findings

- External loads of PCBs in runoff from watershed areas are the main driver of PCB concentrations in water, sediment, and biota in Puget Sound (Fig. 5 to 15).
- External loads from the watershed account for most of the PCBs entering Puget Sound (Fig. 8). The plausible range of about 20 to 200 Kg/year of external loading to explain 1990s sediment PCBs (Fig. 12) is not significantly different from loading estimates in two previous studies. Uncertainty in the external loading sources dominates uncertainty of predicted future concentrations in sediment and biota.
- External loading of PCBs in runoff from commercial/industrial and residential lands accounts for about 50% to more than 75% of the total load of PCBs. PCBs in runoff from forest areas are considerably less concentrated than other land covers, but the area of forest land cover is large enough to result in a major source of loading of PCBs from forests.
- Assumed initial concentrations of PCBs in sediments in the 1990s were found to have little influence on future conditions in the years 2020 to 2050 (Fig. 11) due to continual burial of sediment and replacement with newly deposited material that is derived from external sources.
- Burial of deep sediment accounts for the largest loss of PCBs, with loss also due to outflow through the marine boundary, degradation, and volatilization (Fig. 9).
- Approximately 97% of the total mass of PCBs in the aquatic ecosystem of Puget Sound is in the active sediment layer (top 10 cm), about <1% is in the water column, and about <3% is in the biota.
- Increases in PCBs in sediment and biota are possible by the year 2020 in the larger basins (South Puget Sound, main basin, Whidbey basin, Hood Canal, and Admiralty Inlet) (Fig. 6, 7, and 14).
- Decreases in PCBs in sediment and biota are possible by the year 2020 in the urban bays (Sinclair and Dyes Inlets, Elliott Bay, and Commencement Bay) due to burial and transport of sediment (Fig. 6, 7, and 14).
- Considering the wide range of uncertainty in external contaminant loading, the mass of PCBs in the aquatic ecosystem of Puget Sound may either increase or decrease over time (Fig. 10).

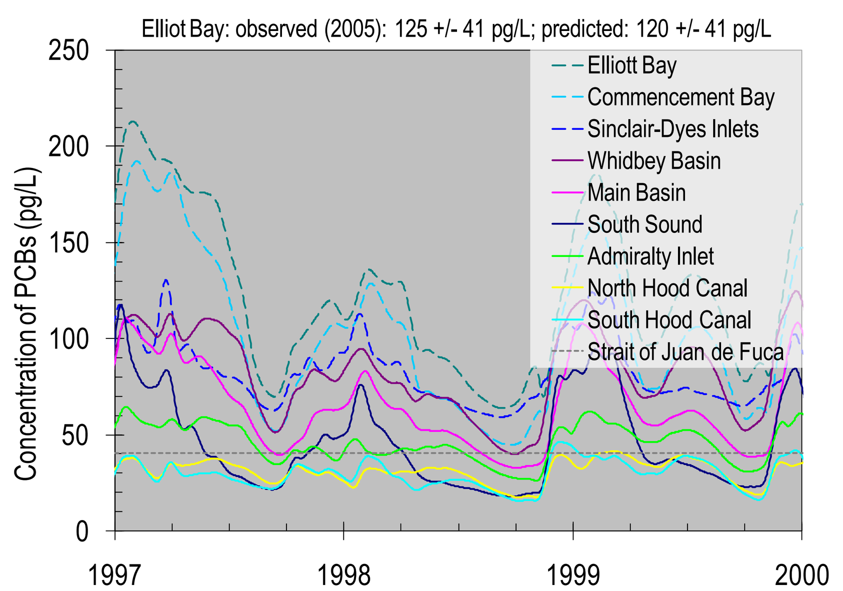

Fig. 5. Predicted PCBs in the water column.

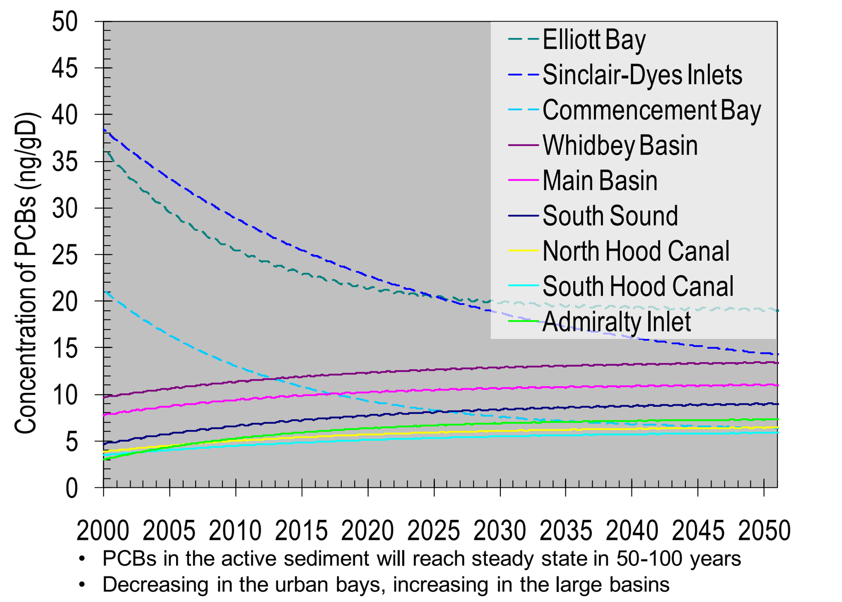

Fig. 6. Predicted PCBs in the sediment (top 10 cm).

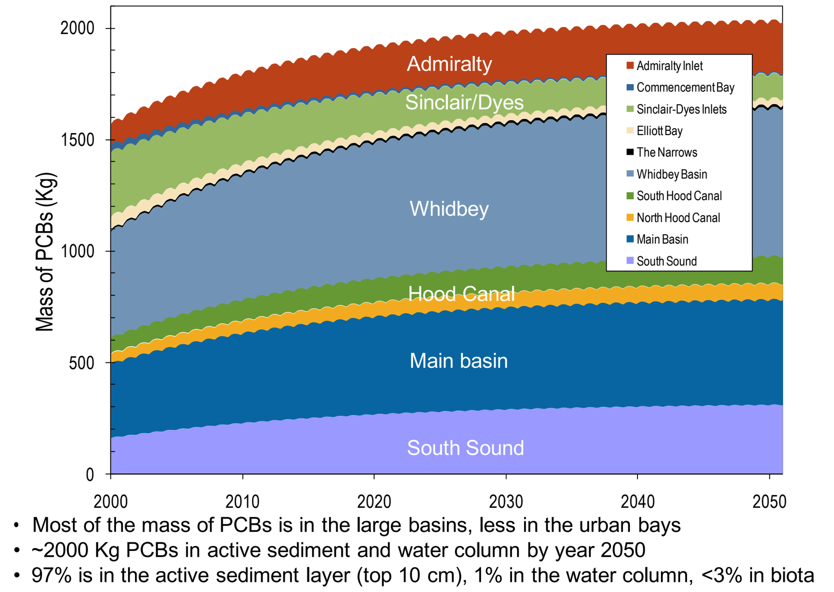

Fig. 7. PCBs in Puget Sound water and sediment.

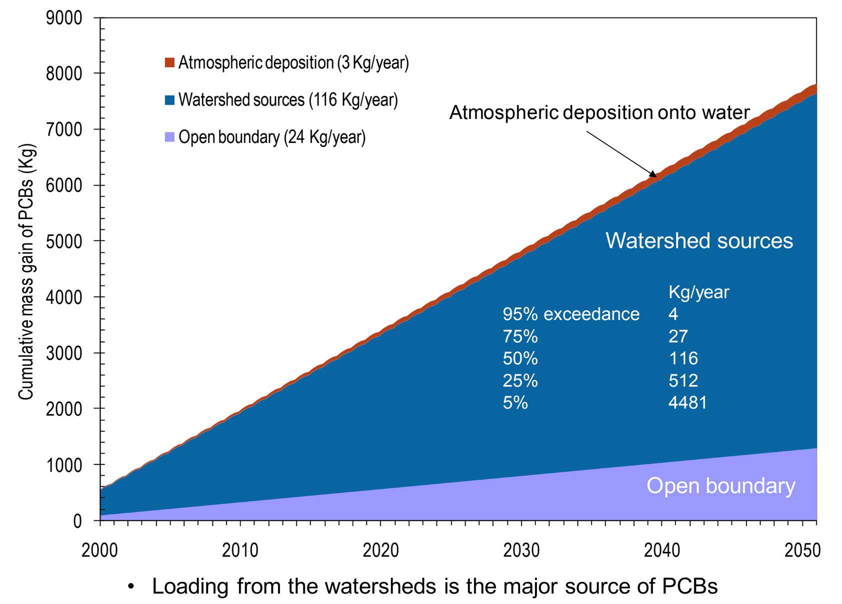

Fig. 8. Cumulative mass sources of PCBs.

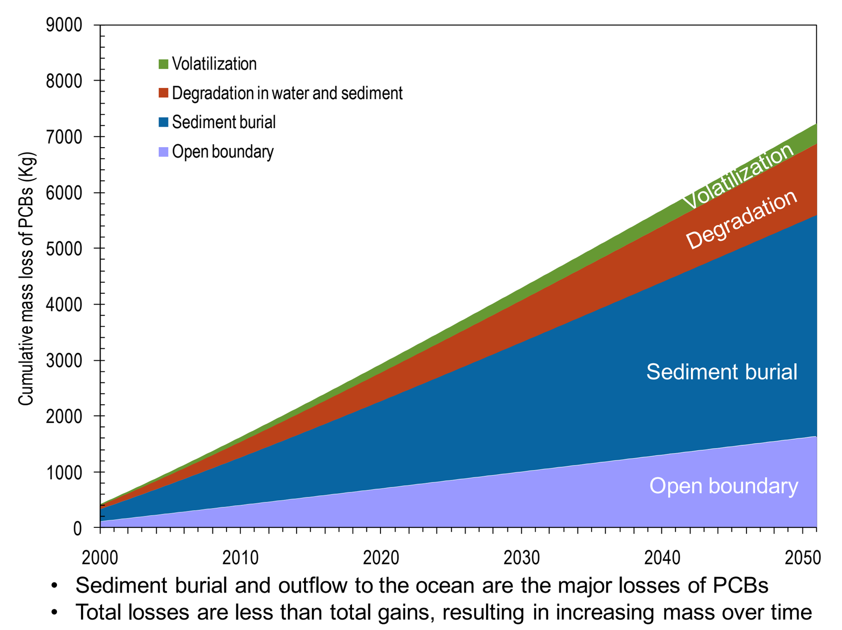

Fig. 9. Cumulative mass losses of PCBs.

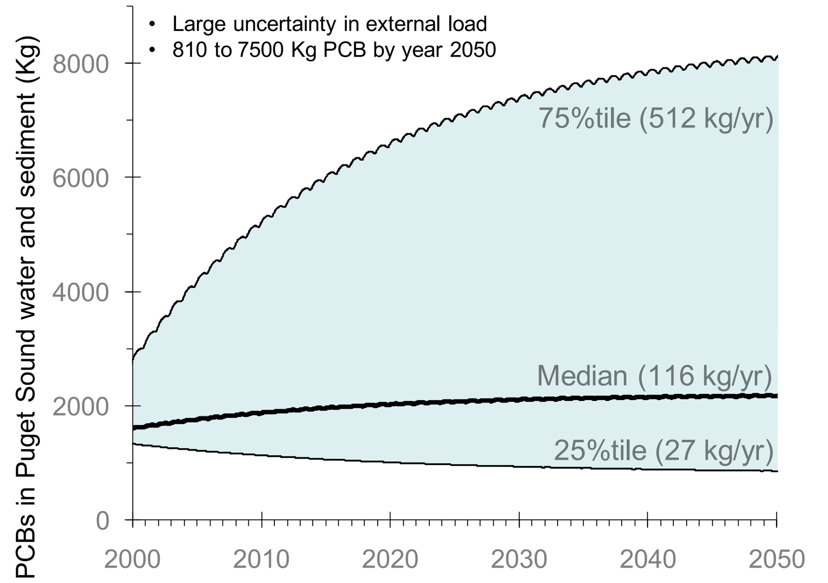

Fig. 10. Sensitivity to external load of PCBs.

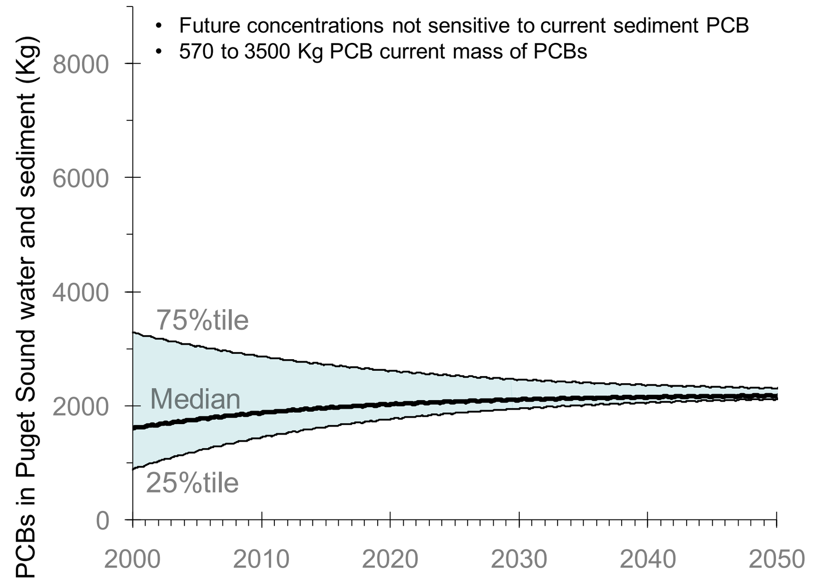

Fig. 11. Sensitivity to initial PCBs.

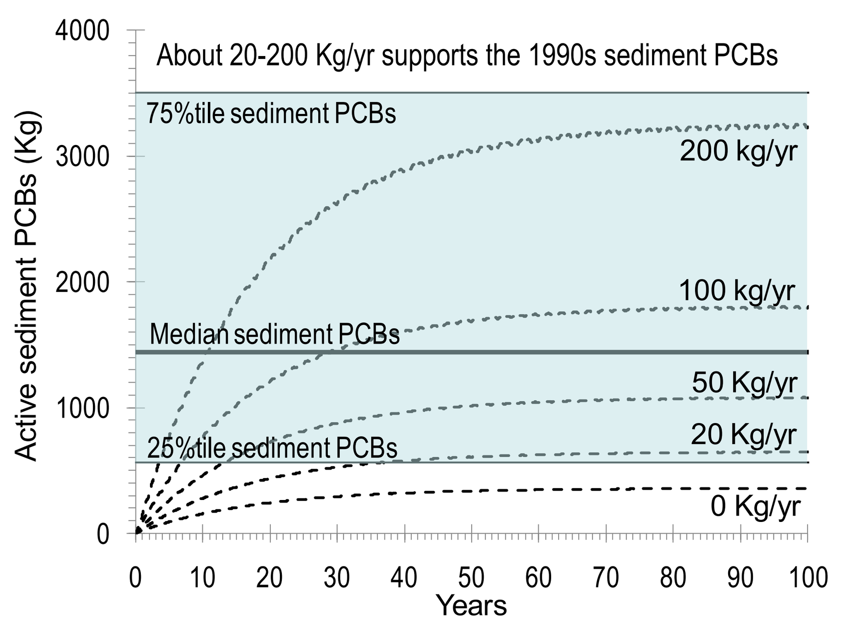

Fig. 12. Plausible range of watershed PCB loading.

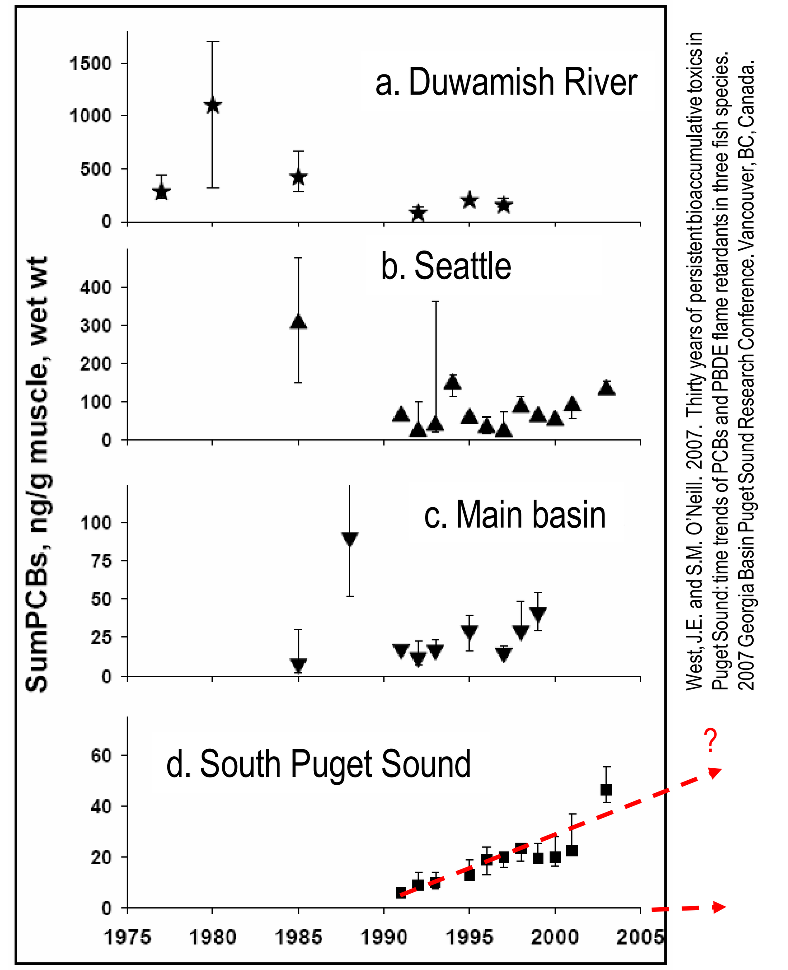

Fig. 13. Observed PCBs in English sole.

Recommendations

- **External loads**. External loading should be reduced to prevent an increase, and possibly decrease PCB concentrations in the water, sediment, and biota of Puget Sound. Data should be collected to estimate PCB loads from forest, residential, commercial/industrial, and agricultural land covers of each region. Sediment cores would also be useful to examine historical trends.
- **Marine boundary**. Data should be collected to describe toxic contaminants in the water column at the marine (salt-water) boundary to improve the accuracy of the models.
- **Water column toxics**. Toxic contaminants at various locations within Puget Sound should be monitored. The lack of water column data using methods that are capable of detecting the low concentrations present is a major data gap.
- **Biota concentrations**. Data gaps should be filled concerning the concentrations of toxics in various species of biota of the Puget Sound regions, including several trophic layers within the food web. Measurements of toxics in whole body samples are preferable if practical, or lipid measurements where it is not practical (e.g., harbor seals). These additional data will allow improvement of the model of food web bioaccumulation across all regions of Puget Sound and throughout the entire food web.
- **Other endpoints**. The modeling framework for this project focused on the endpoint of concentrations in water, sediment, and the tissue in biota of the aquatic food web. The model does not address adverse effects to the exposed wildlife. Modeling of other endpoints in near-shore biota, such as reduced fecundity and reduced age to sexual maturity, or other endpoints specific to endocrine disruptors, is also needed.

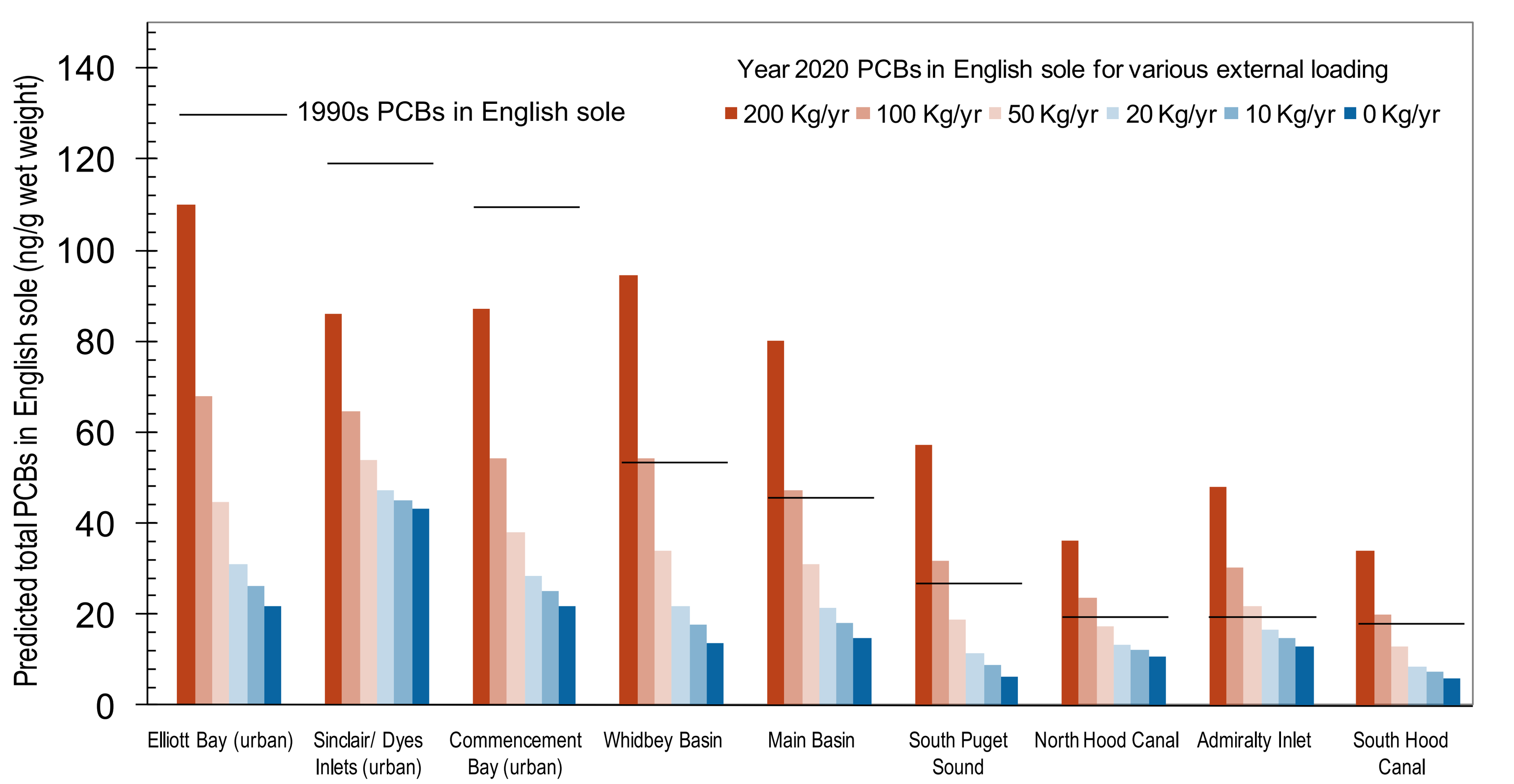

Fig. 14. Predicted changes in PCBs in English sole for the year 2020 for alternative scenarios of loading.

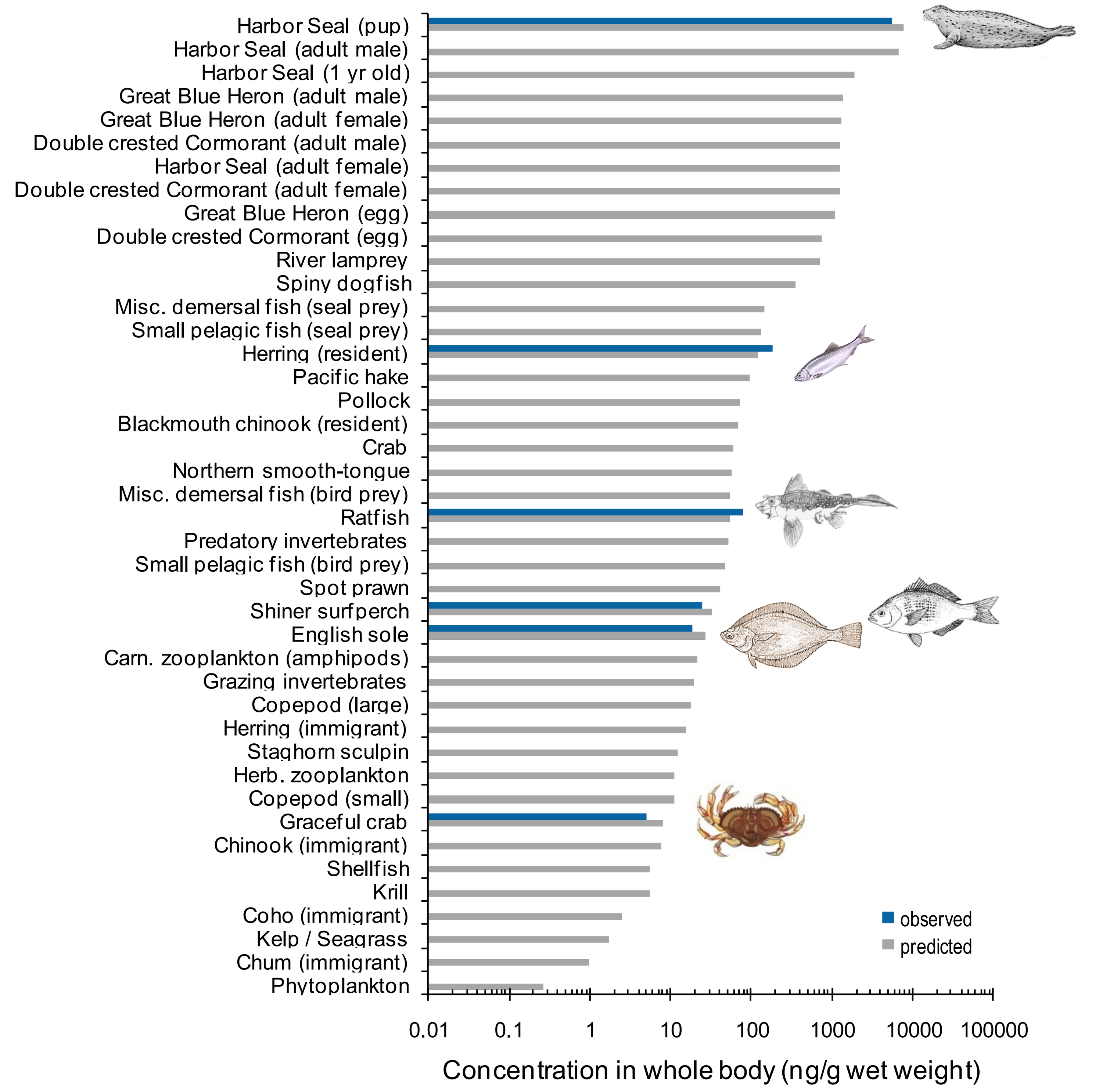

Fig. 15. Predicted and observed PCBs in biota in South Puget Sound (whole body, sum of congeners).

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Learn more about this study at:
www.ecy.wa.gov/biblio/0903015.html

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