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The mission of the Puget Sound Water Quality Authority includes the dissemination of the results of research on issues pertinent to the health of the Sound and its inhabitants and to the management of its resources. Periodic research conferences have been by far the most significant and successful means of achieving this goal. In 1988, 1991 and 1995, these conferences brought together scientists from agencies, universities and consulting firms, resource managers and other decision-makers, and members of the interested public to review the current findings of the day. The conferences, and the accompanying proceedings, have highlighted the latest trends in basic and applied research, and brought to a wider audience many studies and findings that otherwise might have been confined to relative obscurity in an institution's or department's "grey literature."

Presented by the Puget Sound Water Quality Authority and co-sponsored by state and federal agencies, universities, and private businesses, the third conference on research in Puget Sound, *Puget Sound Research '95*, was held on January 12-14, 1995, at the Meydenbauer Center in Bellevue Washington. It featured speakers from both sides of the border and the latest research on water quality and habitat issues in the Puget Sound/Strait of Georgia region. Over 700 attendees joined speakers in a variety of presentation formats, including plenary and luncheon addresses, concurrent paper sessions, panel discussions of special issues, and student and poster sessions.

Here, in two volumes, are the proceedings of the conference, including panel and plenary sessions transcribed verbatim. You are encouraged to contact the authors/presenters for further information and updates on any of the subjects discussed in these pages.

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CONTAMINANT MONITORING IN FISH: OVERVIEW OF THE PUGET SOUND AMBIENT MONITORING PROGRAM FISH TASK

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INTRODUCTION

Concerns over declining water quality in Puget Sound, and the potential consequences to fish, wildlife, and humans, resulted in the formation of the Puget Sound Ambient Monitoring Program (PSAMP), a multi-agency effort to assess the environmental health of Puget Sound (Monitoring Management Committee (MMC), 1988). As a participating PSAMP agency, the Washington Department of Fish and Wildlife (WDFW) was charged with implementing the PSAMP Fish Task, a study of contaminant levels in Puget Sound marine fishes. The PSAMP Fish Task is only one component of PSAMP and was designed and implemented (Stern, 1989) and modified (Washington Department Fisheries, 1992) to meet the overall PSAMP goals that were relevant to fish monitoring including: characterizing the condition of Puget Sound, providing a temporal record of changes in key environmental indicators, measuring the success of water quality programs, and supporting research activities (MMC, 1988).

The PSAMP Fish Task objectives are to:

- document current tissue contaminant levels in fish and, where possible, relate these contaminant levels to sediment contamination measured at nearby stations;
- determine the spatial and temporal trends in tissue contamination;
- assess the impact of fish contamination on human health;
- document the prevalence of liver disease in English sole, relating these disorders to fish tissue contamination and sediment contamination measured at nearby stations, and assess the impact of liver disease on fish health; and
- determine the spatial and temporal trends in liver disease for target fish species.

WDFW began the PSAMP Fish Task in 1989 and fully implemented the program in 1991. The PSAMP Fish Task monitors contaminants in six species to give a broad overview of contamination in Puget Sound marine fishes: English sole *(Pleuronectes vetulus)*, copper rockfish (*Sebastes caurinus*), quillback rockfish (*S. maliger*), chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*) and Pacific cod (*Gadus macrocephalus*). These species are important to recreational or commercial fisheries and represent a wide range of life histories and feeding patterns. Tissue contamination in these fishes has been monitored as a measure of contaminant accumulation in the marine food web, and the threat to human health from eating fish (MMC, 1988). All contaminant data collected by the PSAMP Fish Task are evaluated by the Washington Department of Health to determine whether consuming Puget Sound marine fishes may be harmful to humans. Prevalence of liver disease is measured as an indicator of the potential impact of contamination on fish health. This paper highlights data synthesis on contaminants in Puget Sound fishes for all data collected from 1989 through 1993 to identify factors correlated with the accumulation of contaminants and so addresses the first objective of PSAMP Fish Task. Where possible, spatial differences are discussed (second PSAMP Fish Task objective). Temporal trends are not discussed as there are insufficient data for statistical analysis. The implications of our results are discussed. More extensive analyses of tissue contaminant data, data on prevalence of liver disease in English sole, and the effect of contamination on fish health will be presented in WDFW (in prep.).

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MATERIAL AND METHODS

Species and Station Locations

English sole were collected with a 400-mesh eastern otter trawl in April and May at 37 stations throughout Puget Sound in 1989 and 1991-1993, the most recent data that have undergone quality assurance review and interpretation (Figure 1). Nine of the 37 stations were "fixed" stations sampled annually. A third of the remaining 28 "rotating" stations were sampled annually so that a rotating station was sampled once in three years (Figure 1). The Department of Ecology (DOE) also collected sediment chemistry samples near most of the English sole stations (Tetra Tech, 1990; Dutch et al., 1993; DOE, 1994; DOE, unpub. data).

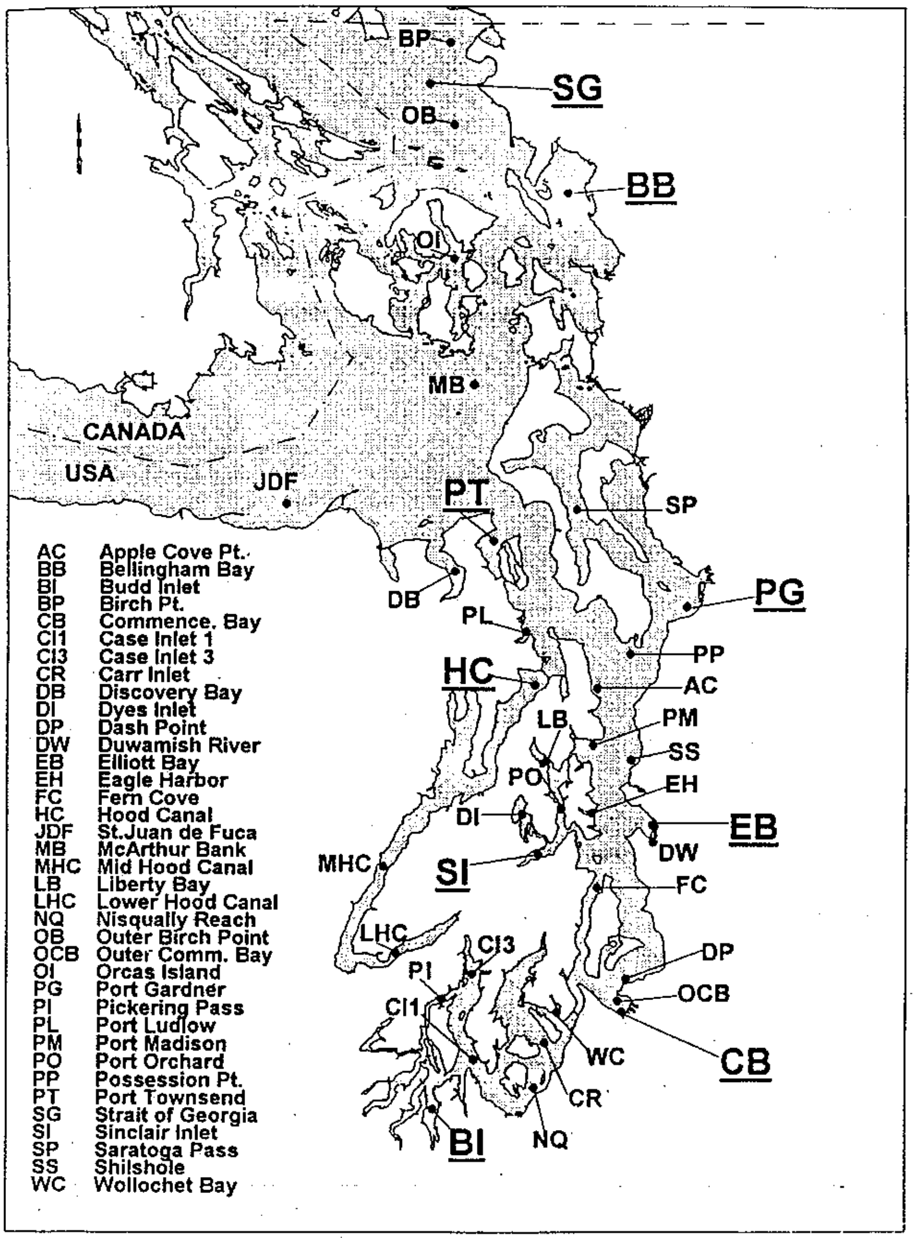

Figure 1. Location of fixed (underlined) and rotating English sole stations sampled by the PSAMP Fish Task from 1989 through 1993

Coho and chinook salmon were caught with a commercial purse seine or purchased from licensed fish buyers and treaty tribal fishermen in the late summer and early fall of 1992 and 1993. Sampling areas included six nearshore marine areas or river mouths where the origins of the fish were presumed ("terminal areas") and three offshore marine areas where the fish origins were unknown ("mixed stock areas," Figure 2). Only three salmon stations, Nooksack River, Skagit River and the Duwamish/Green River, were sampled in both years. Mixed stock areas were not sampled in 1993.

In the fall of 1989 to 1993, quillback and (less frequently) copper rockfish were sampled at five stations using hook and line or by scuba divers with spear guns. Quillback, the targeted species, was consistently sampled at only three stations, San Juan Islands, Double Bluff and Blakely Rock (1991 through 1993). Pacific cod taken as bycatch were purchased from a commercial bottom trawler fishing in the Admiralty Inlet area in March of 1990, 1992 and 1993, and from Alden Bank in 1992 and 1993 (Figure 2).

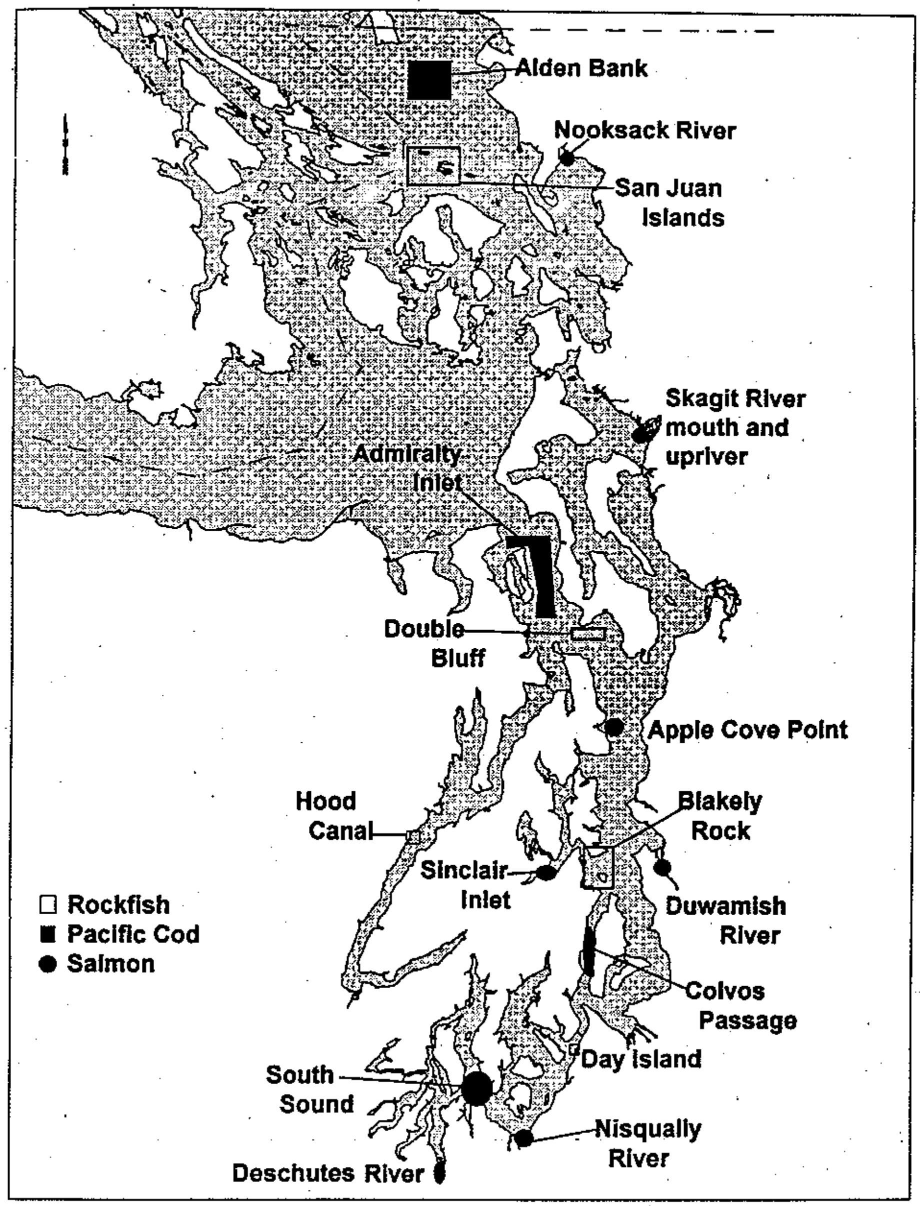

Figure 2. Location of rockfish, Pacific cod and Pacific salmon stations sampled by the PSAMP Fish Task from 1989 through 1993

General Sampling Methodology

On board the boat, English sole were measured (total length), sexed and tagged. Except for 1989, samples of liver tissue were removed and placed in pre-cleaned jars. English sole were then wrapped in aluminum foil, placed in individual zip-lock bags, stored on ice and transferred to the laboratory, where the muscle tissue samples were taken. Rockfish were treated similarly to English sole muscle tissue samples. Purchased salmon and cod were transported on ice to the laboratory and were then tagged, wrapped in aluminum foil, placed in plastic bags and returned to ice until they were processed.

Within 10 days of collection, all fish were weighed and measured (fork length for Pacific salmon and total length for all other species), and the sex was determined. Gill interopercula, otoliths and scales were removed for later age determination of English sole, rockfish, and Pacific salmon, respectively. Pacific cod were not aged. Samples of skinned lateral muscle were placed in pre-cleaned jars. For rockfish, chinook and coho salmon and Pacific cod, muscle tissue samples from five fish were combined to make one composite sample, and usually six composites were collected at each station. Three composite muscle tissue samples were collected at each English sole station, but the number of fish per composite varied among years from five to 20 individuals. Starting in 1991, three composite liver tissue samples were also collected at the English sole stations, but for some stations all three composites were combined if there was insufficient weight of tissue for chemical analysis.

Chemical Analysis

Generally, chemical analyses for organic compounds were conducted according to the Puget Sound Estuary Program's (PSEP) recommended guidelines (1989a). Organic compounds were extracted from fish samples by soxhlet extraction (1989 and 1990) or sonication with a methylene chloride and acetone mix (1991, 1992 and 1993). Starting in 1991, all extracts were "cleaned" with gel permeation chromatography (GPC). Base/neutral/acid (BNA) organic compounds were analyzed by gas chromatography/mass spectroscopy with a DB5-625 column. Pesticides and PCBs were analyzed using gas chromatography and electron capture detection (GC/ECD) with aroclor mixtures used as standards for quantifying PCB concentrations. In 1989 and 1990 a dual megabore column was used on the GC/ECD, but in 1991, 1992 and 1993 a dual narrowbore column (0.25 mm) better suited to analyzing low concentrations was substituted. Starting with the 1992 rockfish samples (fall 1992), new chromatography software was used for quantification of the pesticides and PCBs, allowing laboratory chemists to more accurately quantify low concentrations of pesticides and PCBs.

The laboratory modifications initiated in 1991 and 1992 improved the accuracy and precision of the pesticide and PCB analysis. Consequently, pesticide and PCB data from 1989 and 1990 (all species) and the 1991 rockfish samples were excluded from data analysis in this report. PCB data for the first set of English sole liver samples, collected in 1991, were also excluded from data analysis due to insufficient quality assurance/quality control documentation (e.g., unconfirmed matrix-based detection limits).

Analyses for inorganic elements followed the PSEP recommended guidelines (1989b). Mercury was analyzed by the cold vapor atomic absorption method. Arsenic and copper were extracted using nitric acid/hydrogen peroxide and analyzed by inductively coupled argon plasma spectrophotometry. Lead was analyzed by the graphite furnace atomic absorption method. Arsenic data for all of the 1989 samples were qualified as estimated values and excluded from data analysis. All chemistry data were reported as the concentration per wet weight of tissue.

Data Analyses

Mean age, mean length and mean percent lipids were computed for the fish comprising each composite sample. Hence, all contaminant analyses were conducted using mean composite age (MCA), mean composite length (MCL) and mean composite percent lipids (MCPL).

Detection limits for particular compounds were similar within fish species among years, and detection limit values were used for all non-detected compounds, except as noted below. PCB detection limits varied for the English sole liver samples from 1992 to 1993, and for statistical analyses, the values of all non-detected arochlors were assumed to be zero. PCB detection limits for the DOE sediment samples also varied among years, and all non-detected arochlors were assumed to be 1 for statistical purposes. Total PCBs were calculated by summing the values of the routinely detected arochlors (1248, 1254 and 1260). Total DDT was calculated by summing the values for 4,4-DDT, 4,4-DDD and 4,4-DDE.

For comparison of fish species, station or year means, data were first assessed for normality, homoscedasticity of variance and quality of residuals. All data met assumptions for parametric analysis, except for minor violations of the homoscedasticity assumption. If necessary, PCB data were log-transformed to linearize data. One-way analysis of variance with Tukey multiple range comparisons (STSC, 1991) was used to identify station location-differences in parametric means.

Linear regression analysis was used to model accumulation of contaminants, with stepwise (forward) variable selection (STSC, 1991). Variables modeled included sediment concentration (English sole only) MCA, MCL, and MCPL. For the rockfish and Pacific salmon data, dummy variables (Kleinbaum and Kupper, 1978) were used to model the accumulation of contaminants due to station effects.

RESULTS

PCBs, DDT metabolites, mercury, arsenic, copper, and lead were the main contaminants detected in Puget Sound fishes. An overview of these results are presented here; more detailed analyses will be presented in WDFW (in prep.). Except for phthalates, benzyl alcohol, and benzoic acid, which were detected intermittently, BNAs were not detected in Puget Sound fishes. These results will also be detailed in WDFW (in prep.).

PCBs

Mean PCB concentration was higher in English sole liver samples than any muscle tissue samples (Table 1). For the muscle samples, the highest PCB concentration was detected in chinook salmon, followed by coho salmon, English sole, quillback rockfish, Pacific cod, and copper rockfish (Table 1). Except for Pacific cod, PCB concentrations within a species varied considerably among some station locations. PCBs were never detected in Pacific cod from Alden Bank and were detected in only two of 12 Admiralty Inlet samples at 18.7 and 15.6 ug/kg, values near the detection limit (15 ug/kg).

PCBs were present in most muscle tissue samples of English sole, with individual composite concentrations ranging from 6.9 ug/kg (the limit of detection) in fish from non-urban areas (e.g., Birch Bay, Hood Canal and Discovery Bay) to 159 ug/kg in fish from the very urbanized Duwamish Waterway (Table 1). The highest mean concentration of PCBs was detected in fish from the Duwamish Waterway (110 ug/kg) followed by Sinclair Inlet (54 ug/kg), Elliott Bay (49 ug/kg), and Commencement Bay (44 ug/kg). At the fixed stations with multiple years of data, PCB concentration in English sole muscle tissue were significantly higher in fish from urbanized areas (Sinclair Inlet, Elliott Bay and Commencement Bay) than non-urbanized areas (ANOVA on logged [PCB], $p<0.0001$, d.f.=8; Figure 3). Stepwise linear regression testing the relative effects of fish age, fish length, percent lipids, and sediment PCB concentration indicated that sediment PCBs accounted for 39 percent of the variation observed at the fixed stations, and fish age accounted for 6 percent ($p<0.001$).

All chinook salmon samples and most (55 of 66) coho samples had detectable concentrations of PCBs with concentrations in individual composites ranging from 11.5 to 216 ug/kg for chinook and 4.7 (the detection limit) to 107 ug/kg for coho (Table 1). Mean concentrations of total PCBs were higher for chinook (50 ug/kg) and coho (27 ug/kg) than English sole muscle tissue (20 ug/kg; Table 1) but were lower than in English sole liver tissue (546 ug/kg; Table 1). Percent lipid values were also lower in salmon samples than in English sole liver samples (Table 1).

Overall, PCBs were detected at higher mean concentrations in salmon from mixed stock areas than terminal areas, but the concentrations detected in Puget Sound salmon were approximately 10 times lower than mean concentration detected in salmon collected from Lake Michigan (Figure 4). Chinook and coho collected in mixed stock areas had higher percent lipids (4.3 percent and 2.1 percent) than chinook and coho in terminal areas (2.6 percent and 2.05 percent). Based on skin coloration, fish in terminal areas were closer to

Table 1. Summary of contaminant data for Puget Sound marine fish sampled by PSAMP Fish Task, 1989 - 1993. Results are grand mean values for Mean Composite % Lipid (MCPL), Mean Composite Lenght (MCL), Mean Composite Age (MCA), trace metals, PCBs, and DDT.

Species		MCPL	MCL	MCA	Arsenic (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	PCB (ug/kg)	DDT (ug/kg)
English sole (muscle)	Mean	0.32	286.63	5.54	8.26	0.31	0.03	0.06	19.67	4.41
	Std	0.16	34.42	1.92	3.08	0.27	0.01	0.02	21.91	0.77
	Max	0.87	392.00	10.40	20.00	3.60	0.11	0.14	159.00	9.40
	Min	0.09	214.00	2.00	2.90	0.14	0.03	0.02	6.00	3.90
	N	96	192	192	162	192	192	177	161	161
English sole (liver)	Mean	4.16	288.78	5.63	9.43	7.27	0.56	0.09	546.21	12.50
	Std	0.89	31.00	1.86	7.65	2.94	0.58	0.04	1173.75	34.12
	Max	6.30	365.40	9.80	48.00	14.00	3.50	0.23	7100.00	250.00
	Min	2.60	235.60	2.20	2.00	2.60	0.06	0.04	0.00	0.00
	N	27	102	102	77	77	77	77	68	62
Chinook (muscle)	Mean	2.95	749.33	3.62	1.05	0.49	0.03	0.10	49.98	22.17
	Std	3.61	82.03	0.56	0.31	0.07	0.00	0.03	37.36	11.17
	Max	22.20	898.60	5.00	1.80	0.65	0.04	0.16	216.00	58.80
	Min	0.24	530.00	2.00	0.60	0.32	0.02	0.06	11.50	6.27
	N	66	66	66	66	66	66	66	66	66
Coho (muscle)	Mean	2.07	534.08	2.99	0.75	0.50	0.03	0.05	26.67	10.10
	Std	1.53	49.09	0.04	0.24	0.08	0.00	0.02	19.90	3.47
	Max	8.95	604.40	3.00	1.60	0.84	0.04	0.11	107.00	18.50
	Min	0.20	402.00	2.80	0.40	0.40	0.02	0.03	4.70	3.80
	N	66	66	66	66	66	66	66	66	66
Quillback rockfish (muscle)	Mean	0.41	314.04	12.72	2.41	0.25	0.03	0.22	11.44	1.68
	Std	0.33	38.04	6.07	1.11	0.12	0.01	0.11	11.63	1.02
	Max	2.29	410.00	32.40	6.60	1.10	0.09	0.51	69.00	6.50
	Min	0.17	247.20	5.40	1.00	0.10	0.02	0.06	4.00	1.00
	N	38	67	67	61	67	67	67	38	38
Copper rockfish (muscle)	Mean	0.43	316.95	5.37	2.16	0.23	0.03	0.11	9.23	1.47
	Std	0.20	44.05	2.05	0.69	0.04	0.01	0.05	2.47	0.27
	Max	0.79	398.00	12.20	4.80	0.30	0.09	0.30	16.00	2.00
	Min	0.21	234.00	3.20	1.50	0.13	0.02	0.04	6.60	1.30
	N	12	28	28	20	25	28	28	12	12
Pacific cod (muscle)	Mean	0.11	517.95		3.83	0.24	0.03	0.11	11.08	3.10
	Std	0.13	47.89		1.85	0.04	0.00	0.03	4.43	0.92
	Max	0.49	628.00		8.80	0.33	0.03	0.18	18.70	4.00
	Min	0.01	450.00		1.30	0.20	0.02	0.06	6.60	2.20
	N	22	29		24	26	29	29	24	24

spawning. At all sampling areas, PCB concentrations were consistently higher in chinook than coho salmon (Figure 4).

Chinook salmon had a higher mean PCB concentration than coho salmon, and were generally older and had higher percent lipids (Table 1). Data for the Nooksack River, Skagit River and the Duwamish River (the only terminal stations sampled in both years of the study) were further analyzed to determine the factors associated with bioaccumulation of PCBs. At these stations, PCB tissue concentration was positively correlated with percent lipids. However, chinook salmon had higher concentrations of PCBs than coho salmon, even after accounting for differences in lipid content (Figure 5).

Variation in percent lipids explained 35 percent of the variation in PCB concentration observed in chinook salmon from the Nisqually, Skagit, and Duwamish rivers (stepwise linear regression; $p<0.0001$). Chinook PCB concentration was not correlated with length, age or site location. Similarly, PCB concentra-

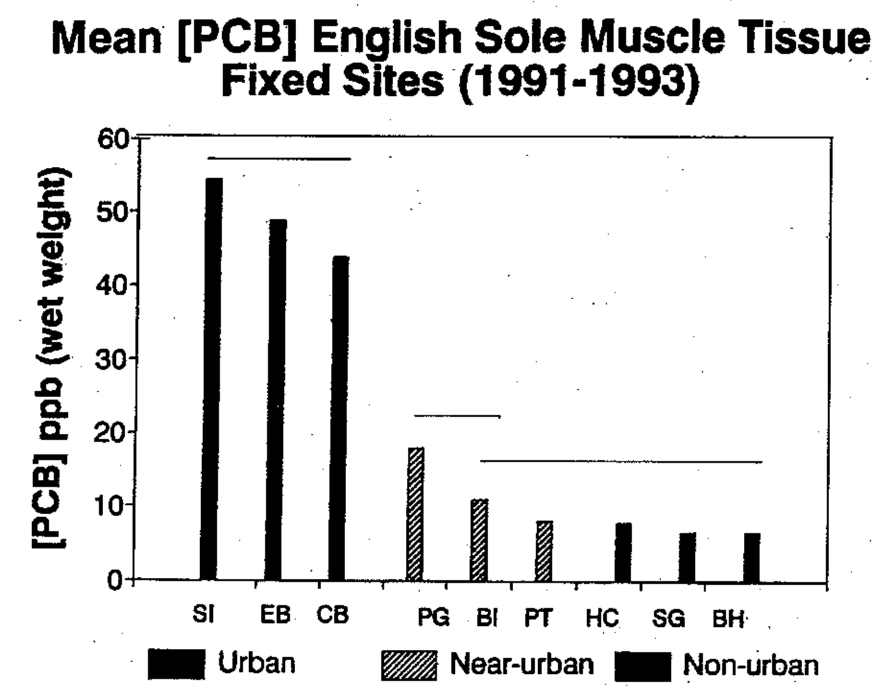

Figure 3. Mean PCB concentrations (ug/kg wet weight) detected in English sole sampled by the PSAMP Fish Task at fixed stations from 1989 through 1993. Horizontal lines indicate means that were not significantly different from each other.

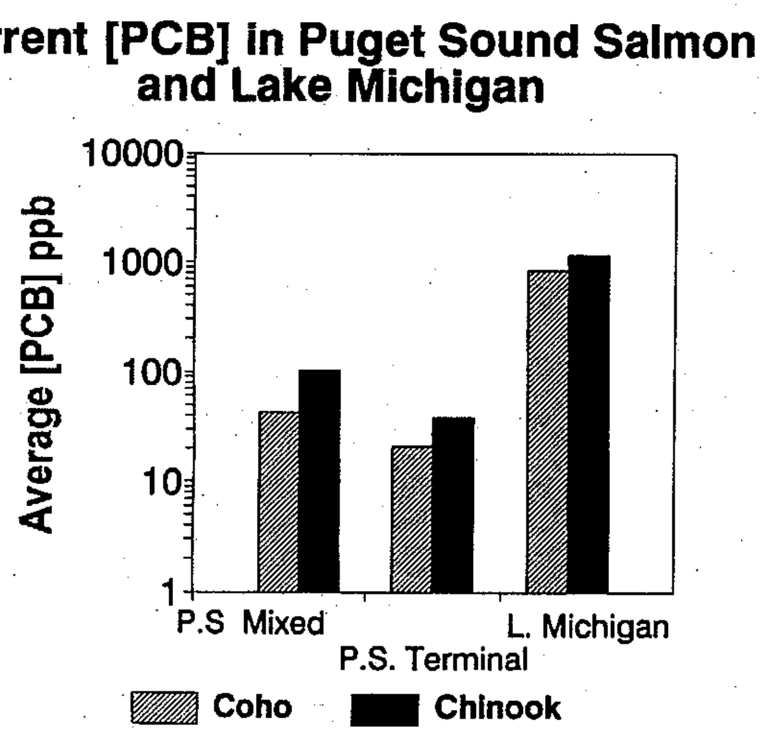

Figure 4. Mean PCB concentrations (ug/kg wet weight) detected in chinook and coho salmon from mixed stock and terminal areas of Puget Sound (sampled by PSAMP Fish Task from 1989 through 1993) and Lake Michigan (Stow et al., 1994)

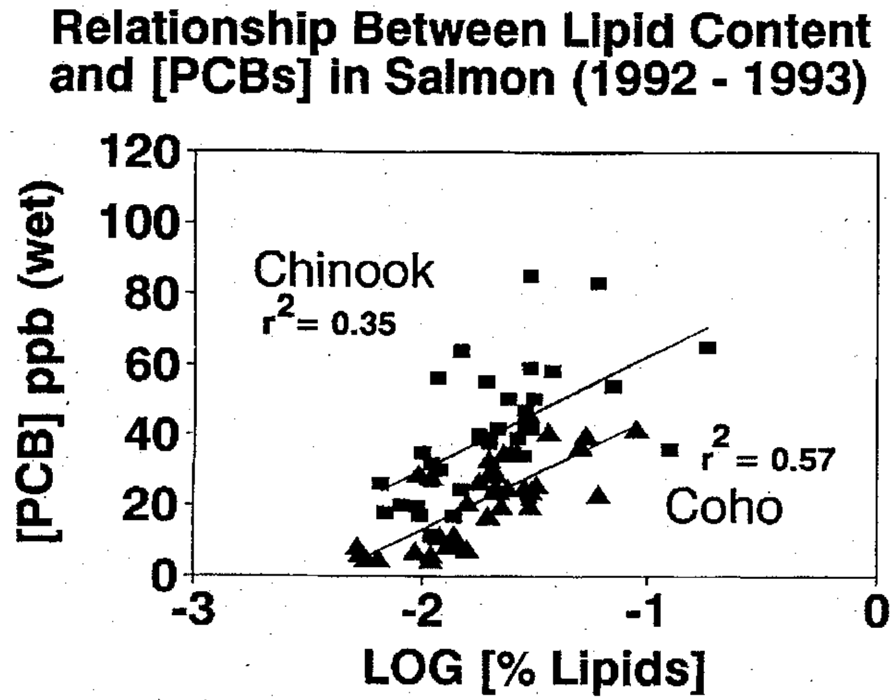

Figure 5. Relationship between lipid content and PCB concentration (ug/kg wet weight) in chinook and coho salmon sampled in Puget Sound by the PSAMP Fish Task from 1989 through 1993 .

tion in coho was mostly correlated with percent lipids but, unlike chinook, the Duwamish River had a significantly higher PCB concentration ($p<0.00001$) than the other stations. Together, percent lipids and site location explained 68 percent of the observed variation in coho PCB concentration at the Nisqually, Skagit and Duwamish rivers.

PCBs were detected in all the copper rockfish samples and 36 out of 38 of the quillback rockfish samples; composite concentrations ranged from 6 to 16 ug/kg and 4 to 69 ug/kg, respectively. Data from Blakely Rock, the San Juan Islands and Double Bluff were further analyzed by West and O'Neill (this volume) to identify factors correlated with the bioaccumulation of PCBs in quillbacks. Briefly, those results indicated that PCB concentration (as aroclor 1260) was positively correlated with fish age, and station location (stepwise linear regression; $p<0.0001$). Age contributed significantly to within station variation; older fish contained higher contaminant loads. However, Blakely Island samples had a higher PCB concentration than expected based on fish age.

DDT

Mean DDT concentration in muscle tissue was higher in chinook (22 ug/kg) than coho (10 ug/kg) salmon and was seldom detected or was detected only at very low levels in the other fish species (Table 1). DDT concentrations in individual composite samples ranged from 6.3 to 58.8 ug/kg for chinook and from 3.8 to 18.5 ug/kg for coho salmon.

Like PCBs, DDT concentrations in chinook and coho were positively correlated with lipid content. Variation in percent lipids explained 33 percent of the variation in DDT concentration among the samples from the Nisqually, Skagit and the Duwamish rivers (stepwise linear regression; $p<0.0002$). For coho, percent lipids and fish length together accounted for 45 percent of the variation in PCB concentrations at these sites. Mean DDT concentrations in English sole liver samples were comparable to values detected in coho salmon (Table 1).

Mercury

Mean mercury concentration was highest in quillback rockfish, followed by Pacific cod, copper rockfish, chinook salmon, English sole livers, English sole muscle and coho salmon (Table 1). Mercury concentrations in composite samples ranged from 0.06 to 0.51 mg/kg for quillback and 0.04 to 0.30 mg/kg for copper rockfish. Data from Blakely Rock, the San Juan Islands and Double Bluff were further analyzed by West and O'Neill (this volume). Briefly, those results indicated that a length and age interaction (presumably representative of growth rate) was the primary determinant of mercury concentration in quillback rockfish, accounting for 76 percent of the variation (stepwise linear regression; $p<0.001$).

Mercury was present in all English sole muscle and liver samples with a slightly higher mean concentration in the liver samples (Table 1). Stepwise linear regression analysis indicated that mercury concentration in liver tissue was positively correlated with the fish age, which accounted for 66 percent of the variation, and with the concentration of mercury in the associated sediments, which accounted for 14 percent of the variation ($p<0.001$).

Mercury was detected in all Pacific cod samples ranging from 0.06 to 0.18 mg/kg (Table 1). Fish length, which is correlated with Pacific cod age, was positively correlated with mercury concentration (O'Neill, 1995; WDFW, in prep).

Mercury concentrations in composite samples of chinook and coho salmon ranged from 0.06 to 0.16 mg/kg and 0.03 to 0.11 mg/kg, respectively. Data for the Nooksack, Skagit and Duwamish rivers (the only terminal stations sampled in both years of the study) were further analyzed by stepwise linear regression (WDFW, in prep). At these stations, mercury concentrations in chinook salmon were positively correlated with fish age, accounting for 44 percent of the variation ($p<0.001$). For coho, station location and fish

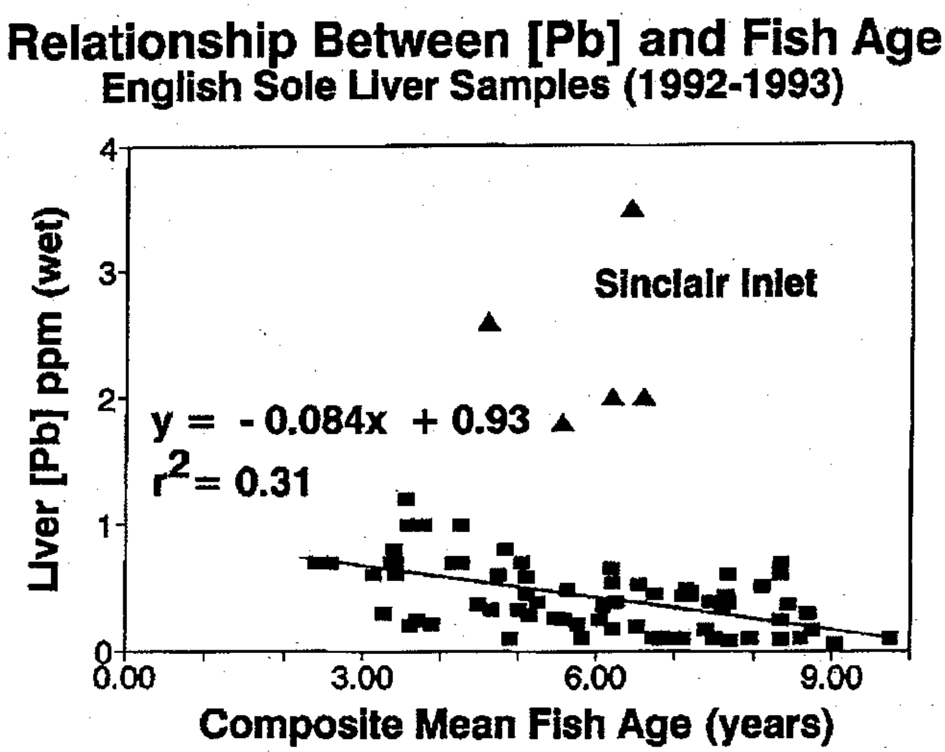

Figure 6. Relationship between fish age and lead concentration (mg/kg wet weight) in English sole liver samples collected by the PSAMP Fish Task from 1989 through 1993. Regression line excludes samples collected at Sinclair Inlet.

length by station location interaction accounted for 43 percent of the variation in mercury concentration ($p<0.001$). Almost all coho from the Nooksack, Skagit and Duwamish rivers were three years old, but the Skagit River coho were larger and had higher mercury concentrations (WDFW, in prep).

Lead

Mean lead concentration was highest in English sole liver samples (Table 1). Lead was never detected in the muscle tissue of the salmon, rockfish or Pacific cod. Very low concentrations of lead, at or near the detection limit (0.03 mg/kg), were consistently detected in English sole muscle samples from Sinclair Inlet but not in English sole from other stations. Excluding data from Sinclair Inlet, stepwise linear regression analysis indicated that lead in English sole liver samples was negatively correlated with fish age (Figure 6). Concentration of lead in nearby sediments was not correlated with lead concentration in English sole liver samples.

Arsenic

Arsenic concentrations were highest in English sole, followed by Pacific cod, rockfish, and salmon (Table 1). However, within a species, factors such as fish age, fish length, percent lipids and site location were not generally correlated with arsenic concentration (WDFW, in prep.).

Copper

Similar copper concentrations were observed in the muscle tissues of English sole, Pacific cod and quillback and copper rockfish (Table 1) and generally did not vary among stations within a species (WDFW, in prep.). Higher copper concentrations were detected in chinook and coho salmon than in the other fish species (Table 1). Copper concentrations in English sole were higher in samples of liver than in muscle tissue, and concentration in either tissue generally was not correlated with sediment copper concentration fish age, fish length or percent lipid (WDFW, in prep.).

DISCUSSION

The purposes of the PSAMP Fish Task were to document contaminant levels in selected fish species from locations throughout Puget Sound and to determine the factors responsible for variation among and within locations. PCBs, DDT metabolites and mercury bioaccumulate in English sole, chinook and coho salmon, and quillback and copper rockfish. Copper and arsenic bioaccumulate in all Puget Sound fishes, but lead seldom accumulates. Except for phthalates, benzyl alcohol and benzoic acid, which were detected intermittently, BNAs were not detected in Puget Sound fishes. In general, we documented contaminant levels comparable to those detected in previous studies. Furthermore, we identified abiotic factors (sediment concentrations of contaminants) and biotic factors (fish age, size at age, and lipid content) that explained much of the variation in levels of these contaminants. An understanding of the factors affecting accumulation of particular contaminants is essential to tracking spatial and temporal changes in contaminant levels in the species monitored by the PSAMP Fish Task.

The ranges of PCBs, DDT metabolites, mercury, lead, arsenic, and copper contaminant concentrations detected in Puget Sound fishes were comparable to or lower than those detected in other Puget Sound studies (Gahler et al., 1982; Malins et al., 1982, 1984; Galvin et al., 1984; Romberg et al., 1984; Tetra Tech, 1985; Landolt et al., 1987; Tetra Tech, 1988; PTI, 1990). PCB levels detected in English sole were similar those reported by Landolt et al. (1987), but English sole sampled in the late 1970s and early 1980s (Malins et al., 1980, 1982) had substantially higher concentrations. The levels of DDT detected in fish in our study were generally lower than those reported in previous studies (Gahler et al., 1982; Galvin et al., 1984; Landolt et al., 1987). This observation is consistent with results reported by Matta et al. (1986) and Mearns et al. (1988), who showed that organochlorine pesticides and their metabolic breakdown products have decreased in fish from Elliott Bay over time.

PCBs

PCBs were used extensively as coolants and frequently mixed with oils and greases in electrical transformers. Although their manufacture has been banned since 1977, PCBs are ubiquitous in aquatic systems (Phillips, 1994) and have been transported to remote polar ecosystems via atmospheric processes (Hammer, 1989). Exposure to PCB-contaminated sediments, coupled with subsequent exposure through the food chain, affects the accumulation of PCBs in fish (Varanasi et al., 1992).

Our results are consistent with other studies showing that proximity to PCB-contaminated sediments, lipid content, fish age and growth rate affect the accumulation of PCBs in fish (Jensen et al., 1982; Masnado, 1987; Larsson et al., 1991; Varanasi et al., 1992, 1993; Hammar et al., 1993; Loizeau and Abarnou, 1994; Stow et al., 1994). In our study, mean PCB concentrations in muscle tissue samples were higher in chinook and coho salmon than all other species and were correlated with biotic factors like lipid content and fish age. After accounting for variation in percent lipids, PCB concentration in chinook salmon did not vary among terminal stations. Furthermore, the total body burdens of PCBs in chinook smolts leaving the contaminated estuary of the Duwamish River (Varanasi et al., 1993) were much lower than in adult chinook salmon returning to the Duwamish River, suggesting that PCBs were accumulated primarily in marine waters of Puget Sound and the north Pacific (WDFW, in prep). Salmon are likely exposed to low concentrations of PCBs in their food, but because of their high lipid content, salmon readily retain these lipophilic contaminants.

Differences in PCB concentration between chinook and coho are likely affected by variation in diet (chinook tend to eat more fish; Beacham, 1986), age (the chinook sampled were older), and life history (coho spend more time in fresh water). Chinook and coho caught in mixed stock areas had higher contaminant levels of PCBs and DDT than conspecifics caught in terminal areas. This probably resulted from the lower lipid content in fish caught in terminal areas, related to the more advanced state of maturation of salmon ascending rivers. PCB concentrations might be even lower in fish caught in up-river terminal fisheries if lipid concentrations were also lower.

Unlike chinook and coho salmon, benthic fish like English sole are closely associated with marine sediments, potentially exposing them to higher contaminant levels. English sole in urbanized embayments are exposed to higher PCB concentrations than salmon, as the liver samples contained much higher PCB concentrations despite having comparable percent lipids. Higher PCB concentrations accumulated in the muscle tissue of English sole associated with PCB contaminated sediments than English sole from uncontaminated areas (Figure 1), but because of their very low lipid content, the concentrations in English sole from urban areas were similar to the mean PCB concentration observed in chinook salmon.

Fish age, especially for long-lived species like rockfish, affected PCB concentration. Although the mean PCB concentration in composite quillback rockfish samples was lower than in chinook, coho, and English sole muscle samples, older individual rockfish could have significantly higher concentration. Future monitoring of individual rockfish, especially older fish, is needed to document maximum concentration of PCBs.

Mercury

We demonstrated that most (66 percent) of the spatial and temporal variation in mercury concentrations in English sole liver tissue was explained by variation in fish age. For chinook salmon we observed higher mercury concentrations in older fish (accounting for 44 percent of the variation). Chinook salmon had higher mercury concentrations than coho salmon, perhaps related to the greater total age, diet and duration of marine residence of chinook salmon. We documented that location-specific growth rates also appear to affect accumulation of mercury in quillback rockfish, and that one of the composite samples had mercury concentrations higher than that recommended for human consumption by the World Health Organization (0.5 mg/kg). Virtually all (95 percent) of the mercury present in fish is mono methyl mercury (Bloom 1993), which is toxic. Thus, within Puget Sound, long-lived fishes like quillback and copper rockfish, lingcod (Ophiodon elongatus) and dogfish (Squalus acanthias) may accumulate very high levels of mercury that is toxic to humans.

Our results are consistent with other studies noting the importance of age or growth rate on the accumulation of mercury in fish tissue (Braune, 1987; Monteiro and Lopes, 1990; Larsson et al., 1991; Monteiro et al., 1991). However, fewer studies have demonstrated that proximity to contaminant sources affect accumulation in fish (Leah et al., 1991). In WDFW (in prep), we also demonstrate that at those stations where the ages of English sole did not vary significantly among stations, proximity to mercury contaminated sediment accounted for 67 percent of the observed variation. English sole are benthic feeders and although they are not as long-lived as quillback rockfish, exposure to mercury contaminated sediments, especially for older individuals, may exacerbate the accumulation of mercury in their tissues.

Lead

Our results are consistent with other studies that have shown that lead generally does not accumulate in skeletal muscle due to the very low binding rate of lead to sulfhydryl groups in the muscle tissue (Sorensen, 1991). Lead is a non-essential element that is absorbed by the epithelium of the fish's gills and intestine and rapidly metabolized in the liver (Sorensen, 1991). We observed higher lead concentrations in English sole liver samples than in muscle tissues. With the exception of English sole from Sinclair Inlet, older English sole had lower lead concentrations in their liver than younger fish, suggesting that older fish can more readily metabolize lead (Figure 6).

In Sinclair Inlet, English sole may be exposed to a higher lead loading because lead is somehow more bioavailable at this site or because the lead concentration in sediments is higher than that indicated by the sediment chemistry samples collected at that station. Exposure to heavily contaminated sediments, like those at Sinclair Inlet, may surpass English sole's ability to regulate the body burden of lead. To further define the extent of lead contamination at Sinclair Inlet, other marine species should be monitored, especially invertebrates, for which trace elements may be more readily bioavailable.

Copper

In general, copper concentrations did not vary greatly among fish species nor among stations within a species and were not correlated with the abiotic and biotic factors we tested. Copper and other essential elements like zinc are actively regulated by fish. Consequently, the tissue concentrations are maintained within specific ranges and do not always reflect environmental levels (Phillips and Rainbow, 1989). The liver actively processes and stores large amounts of copper (Sorensen, 1991) and then transports the required amounts of this elements to muscle tissue and other organs as needed. Only if fish are exposed to excessive copper levels does the regulatory mechanism break down and toxicity occur (Phillips and Rainbow, 1989; Sorensen, 1991).

Arsenic

As with the copper analysis, the abiotic and biotic factors that we tested for were not correlated with arsenic in English sole samples. Mean concentration of arsenic was highest in English sole samples suggesting that bottom-feeding fish, such as English sole, accumulate higher arsenic levels than pelagic fish (LeBlanc and Jackson, 1973; Kennedy, 1976).

Arsenic is ubiquitous in seafood, occurring mainly as an organic penta-valent form that is non-toxic (Edmonds and Francesconi, 1993), suggesting that it is readily accumulated in muscle tissue of marine species and is not usually a health concern. Natural sources of arsenic, including oceanic water, rivers, and shoreline erosion contribute over ten times more arsenic to Puget Sound than do anthropogenic sources (Dexter et al., 1981; Landolt et al., 1987). Crecelius (1985) concluded that arsenic body burden in Puget Sound flatfishes was not related to anthropogenic sources.

SUMMARY AND RECOMMENDATIONS

Our results have demonstrated that various abiotic (proximity to contaminated sediments) and biotic factors (fish age, length, growth rate and % lipids) affect the bioaccumulation of contaminants in English sole, chinook and coho salmon, Pacific cod, and quillback rockfish. By statistically accounting for these various factors (stepwise linear regression), we were able to document spatial differences in the accumulation of

PCBs, mercury and lead. Ongoing monitoring should carefully composite fish of similar size and age, or monitor individuals, so that temporal trends in contaminant levels are easier to detect.

PSAMP was designed to include a full programmatic review every five years, with the first review to take place in the summer and fall of 1995. As part of the review, the PSAMP Fish Task is considering the following recommendations: (1) adding additional species, including important forage fish like Pacific herring (*Clupea harengus* pallasi) that have lipid-rich muscle and roe tissue; (2) monitoring individual rockfish and other long-lived fish such as lingcod and dogfish to determine whether contaminant loadings are a human health concern; and (3) discontinuing monitoring BNAs as they are seldom detected in Puget Sound fishes and considering monitoring other contaminants not currently monitored.

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