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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.

Conference Manager: Timothy W. Ransom, Ph.D.
Editor: Elizabeth Robichaud
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ACCUMULATION OF MERCURY AND POLYCHLORINATED BIPHENYLS IN QUILLBACK ROCKFISH (*Sebastes maliger*) FROM PUGET SOUND, WASHINGTON

James E. West and Sandra M. O'Neill[1]

INTRODUCTION

Ecotoxicological impacts of persistent pollutants (PPs) in aquatic ecosystems have received much attention in the past few decades. These nondegradable, nonnutritive contaminants are taken up by organisms faster than they are released, resulting in bioaccumulation over time. Metal poisoning of fish by mercury from industrial and agricultural sources has been well documented (Sorensen, 1991), as has contamination by polychlorinated biphenyls (PCBs). PCBs are unusually ubiquitous in aquatic systems (Phillips, 1994), being transported to even remote polar ecosystems via atmospheric processes (Hammar, 1989).

In aquatic ecosystems, persistent pollutants reach high levels in carnivores primarily through the food chain (see Hammar et al., 1993). A number of fish life history and ecological parameters have also been associated with accumulation of PPs in marine fishes. Fish age and size were shown to be important in determining the mercury concentration in muscle tissue of two species of scorpionfish (Monteiro et al., 1991), Atlantic herring (Braune, 1987), swordfish (Monteiro and Lopes, 1990), and the catadromous European eel (Larsson et al., 1991). Larsson et al. (1991) also identified body fat content as an important factor to consider for uptake of lipophilic compounds such as PCBs. Thomson (1985) demonstrated the importance of fish size on concentration of mercury in muscle tissue in some marine species, yet warned that lack of correlation of fish size to mercury concentration in others he tested precluded the use of fish size as a universal, multi-species predictive tool.

The Fish Task Unit of the Puget Sound Ambient Monitoring Program (PSAMP) monitors levels of more than 100 pollutants in five species of marine and anadromous fish from Puget Sound (PSQWA, 1993). The primary goal of the Unit is to monitor average conditions in Puget Sound fishes in terms of temporal and spatial changes in their contaminant levels. The quillback rockfish (*Sebastes maliger*) is one of two *Sebastes* monitored by PSAMP. This species is a long-lived (>50 years), relatively slow-growing, non-migratory, benthic carnivore that inhabits rocky subtidal substrates from California to Alaska. These life history characteristics provide an excellent opportunity to study bioaccumulation of PPs in marine ecosystems. Quillback rockfish is also one of the most abundant *Sebastes* in Puget Sound, and it contributes substantially to Washington's sport-fishing industry as a popular food item for marine anglers.

In this paper, we (1) summarize three years of PSAMP data for mercury and PCBs in quillback rockfish; (2) compare muscle tissue concentrations of these contaminants for three locations in the Puget Sound; (3) assess the importance of fish age, size, lipid content and location on the bioaccumulation of PPs in quillback rockfish; and (4) describe these relationships using linear regression models.

METHODS

Quillback rockfish were collected from Blake Island (BI), Double Bluff (DB), and San Juan Islands (SJ) in 1991, 1992, and 1993 (Figure 1). Fish were taken using hook-and-line gear from September to December, and collection depths ranged from 30 m to 120 m. Upon landing, fish were immediately wrapped individually in aluminum foil, labeled, sealed in plastic bags, and placed on ice. In the laboratory, fish were measured, weighed and sexed. Sagittal otoliths were removed for age estimation. Muscle tissues were excised from skinned lateral muscles in the lab within 10 days of collection. Approximately 50 g of tissue from each of five rockfish was combined to create a single composite-sample. Six composite

[1] Washington Department of Fish and Wildlife, Marine Fish Division, 600 Capitol Way N., Olympia, WA 98501-1091

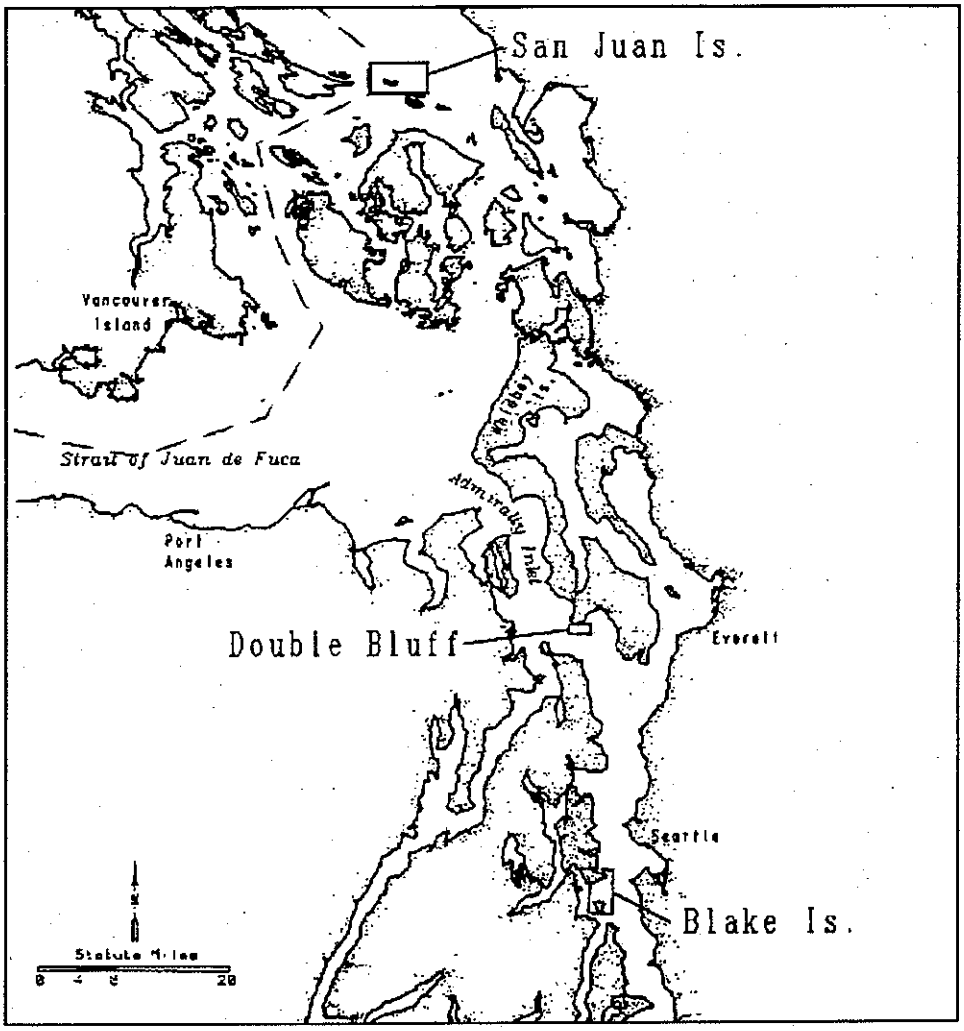

Figure 1. Location of collection sites for quillback rockfish

samples (representing 30 fish) were processed from each location in each year. Composite-samples of muscle tissue were placed in pre-cleaned jars and frozen for later analysis.

Total mercury concentration of composite-samples was determined by cold vapor atomic absorption after digestion with the nitric acid/sulfuric method (PSEP, 1989). PCBs were analyzed using gas chromatography-electron capture detection with a 0.25 mm column (PSEP, 1989). Because of modifications in laboratory procedures in 1992, PCB data from the 1991 muscle samples were excluded from PCB data analysis in this report.

Mean age, mean length and mean %lipids were computed for the five fish that constituted each composite-sample. Hence, all contaminant analyses were conducted using mean composite age (MCA), mean composite total length (MCTL) and mean composite %lipids (MCPL). In 1992 and 1993, we grouped fish in composites based on similarity of size. (1991 fish were not grouped in this manner.)

For comparison of 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. One-way analysis of variance with Tukey multiple range comparison (STSC, 1991) was used to identify year- or location-differences in parametric means.

Least squares Model I linear regression analysis using dummy (Z) variables (Kleinbaum and Kupper, 1978) were used to model accumulation of PPs and to separate station effects. Values of dummy variables were Z_1=1, Z_2=0 (BI); Z_1=0, Z_2=1 (DB); Z_1=0, Z_2=0 (SJ). For regressions with two stations, only one dummy variable was required (Z=1 for BI and Z=0 for DB). Stepwise (forward) variable selection (STSC, 1991) was conducted with a confidence level of 95%. A log transformation of PCB concentrations was performed to linearize data.

Location-specific growth rates were modeled using the von Bertalanffy length-at-age growth equation (Ricker, 1975) for individual (pre-composited) fish:

$$Length = L_\infty(1 - e^{-k(Age - t_0)})$$

where L_∞ = the asymptotic length,
k = the growth rate constant, and
t_0 = age at length 0 (intercept).

Non-linear least squares analysis (SAS, 1988) was used to generate parameters for fitting von Bertalanffy curves.

Individual (pre-composited) fish length and weight were highly correlated for all locations (sites pooled, n=264, r^2=0.98, p<0.0001). Hence, for all subsequent analyses, length was used as the sole descriptor of fish size.

RESULTS

Mercury

Mercury was detected in all quillback rockfish composite-samples for the three years of this study. Concentrations ranged from 0.10 mg/kg to 0.51 mg/kg. Station mean values (± standard deviation) were 0.25±0.10 mg/kg (BI), 0.24±0.08 mg/kg (DB) and 0.22±0.14 mg/kg (SJ–Table 1). All three stations had at least one composite-sample with a concentration of mercury greater than 0.40 mg/kg. We observed no significant trends in mean mercury concentration between years (ANOVA, p=0.53, stations pooled), or between stations (ANOVA, p=0.81, years pooled).

Mercury concentration increased with age of rockfish for all locations (Figure 2a). Using stepwise multiple linear regression analysis regressing [Hg] with age and location, we computed a mercury age model

$$[Hg] = \beta_1(MCA) + \beta_2 Z_2 + \beta_0,$$

where [Hg] = mercury concentration in mg/kg,
β_i = factor coefficient,
MCA = Mean Composite Age, and
Z_2 = location identifier dummy variable.

Table 1. Summary of contaminant data for quillback rockfish from three stations in Puget Sound, Wash. Results are grand mean values for mean composite ages, mean composite total lengths, and mean composite % lipids

Location		MCA	MCTL	MCPL*	Mercury (mg/kg)	Aroclor 1260 (µg/kg)
	Mean	15.6	296	0.4	0.25	12.9
Blake	Std Dev	6.6	22	0.5	0.10	15.8
Island	Min	9.0	258	0.05	0.10	2.3
	Max	32.4	338	2.3	0.47	65.0
	n	17	17	12	17	17
	Mean	11.9	321	0.3	0.24	4.4
Double	Std Dev	3.7	22	0.2	0.08	3.1
Bluff	Min	7.8	283	0.01	0.10	2.3
	Max	22.4	360	0.6	0.41	15.0
	n	18	18	12	18	18
San	Mean	13.5	341	0.3	0.22	2.8
Juan	Std Dev	7.1	43	0.2	0.14	1.8
Islands	Min	6.4	276	0.1	0.10	2.0
	Max	28.0	400	0.5	0.51	8.9
	n	18	18	12	18	18

* lipid data from 1992 and 1993 only

With this procedure we identified two statistically significant ($p<0.01$) model parameters (Table 2). The mercury age model adjusts [Hg] for age effects common to all locations (β_1), and unmeasured effects specific to Double Bluff (β_2).

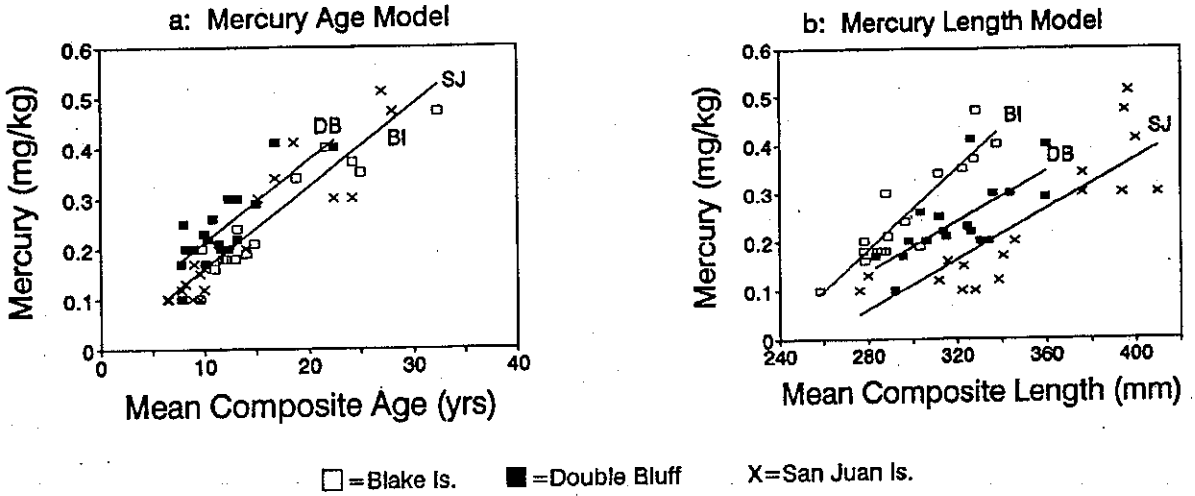

Figure 2. Fitted regression lines for two linear regression models, (a) mercury age model and (b), mercury length model. Model equations and statistics are presented in Table 2.

Table 2. Parameters for full (age-length) and restricted linear regression models used to describe bioaccumulation of mercury in quillback rockfish from three locations in Puget Sound, Wash.

	Mercury Age·Length Model			Mercury Age Model			Mercury Length Model		
	Variable	Coeff.	p value	Variable	Coeff.	p value	Variable	Coeff.	p value
β_0	intercept	0.0249	0.14	intercept	-0.0008	0.96	intercept	-0.726	0.09
β_1	(Z_1)MCTL	0.00013	0.015	MCA	0.0162	<0.001	MTCL	0.0028	<0.001
β_2	(Z_2)MCTL	0.00020	0.0001	Z_2	0.0522	<0.001	Z_2	0.0836	0.021
β_3	MCA·MCTL	0.00004	<0.0001				(Z_1)MCTL	0.0005	<0.001
R^2		0.815			0.811			0.707	
p		<0.0001			<0.0001			<0.001	
Model	$[Hg]=MCTL(\beta_1 Z_1+\beta_2 Z_2+\beta_3 \cdot MCA)+\beta_0$			$[Hg] = \beta_1(MCA)+\beta_2 Z_2+\beta_0$			$[Hg] = MCTL(\beta_1+\beta_3 Z_1)+\beta_2 Z_2+\beta_0$		

Using coding for dummy variables described in Methods above and model coefficients from Table 2, individual simplified equations for each location are:

SJ: [Hg] = 0.0162(MCA)-0.001
DB: [Hg] = 0.0162(MCA)+0.051
BI: [Hg] = 0.0162(MCA)-0.001.

The mercury age model indicates that mercury concentration is strongly associated with fish age from all locations (r^2=0.81), and that fish from all three locations accumulated mercury at an equal rate. In addition, quillback rockfish from Double Bluff exhibited a slightly higher offset in mercury concentration (0.052 mg/kg); however, the difference was associated with an unmeasured parameter.

Mercury concentration also increased with size of rockfish (Figure 2b) at all locations. We used stepwise multiple linear regression analysis regressing [Hg] with fish length and location to compute a mercury length model,

$$[Hg] = MCTL(\beta_1+\beta_3 Z_1)+\beta_2 Z_2+\beta_0,$$

where [Hg] = mercury concentration in mg/kg,
β_i = factor coefficient,
MCTL = Mean Composite Total Length, and
Z_1 & Z_2 = station identifier dummy variables.

With this procedure we identified three statistically significant ($p<0.05$) model parameters (Table 2). The mercury length model adjusts [Hg] for fish length effects common to all locations (β_1), unmeasured effects specific to Double Bluff (β_2), and fish length effects specific to Blake Island (β_3). The model accounted for 70.7% of the variability in mercury concentration observed in these data.

Using coding for dummy variables described in Methods and model coefficients from Table 2, individual simplified equations for each location are:

SJ: [Hg] = 0.00257(MCTL)-0.660
DB: [Hg] = 0.00257(MCTL)-0.582
BI: [Hg] = 0.00417(MCTL)-0.984.

Unlike the age model, uptake patterns of [Hg] with fish size differed significantly among all three locations (Table 2, Figure 2b). The rate of [Hg] uptake was higher at BI than at the other two locations, and significant [Hg] offsets occurred for each location. Hence, for a given length, predicted [Hg] was highest at BI, followed by DB and SJ.

We also compared all measured parameters (length, age, and %lipids) together for all locations in a stepwise multiple linear regression analysis to test their relative effects on [Hg] in quillback rockfish. This model indicates that only age, length and age·length interactions represented significant effects ($p<0.0001$), accounting for 81.5% of observed [Hg] variability. The following mercury age·length model adjusts for these location-specific age and length effects:

$$[Hg] = MCTL(\beta_1 Z_1+\beta_2 Z_2+\beta_3 \cdot MCA)+\beta_0$$

where [Hg] = mercury concentration in mg/kg,
β_i = factor coefficient,
MCA = mean composite age,
MCTL = mean composite total length and
Z_1 & Z_2 = location identifier dummy variables.

The procedure resulted in three statistically significant ($p<0.05$) model coefficients (Table 2, Age-Length Model). Substituting codes for dummy variables described previously in the Methods section, individual simplified equations for each station are:

SJ: [Hg] = MCTL(0.00004 · MCA)+0.0249
DB: [Hg] = MCTL(0.00020+0.00004 · MCA)+0.0249
BI: [Hg] = MCTL(0.00013+0.00004 · MCA)+0.0249

Mercury concentration at each location is defined in this model primarily by the age-length product, indicating that growth rate was an important contributor to the variability in [Hg] for all locations. BI and DB locations have additional slope (Hg uptake) components attributable to location-specific differences in fish length (β_1 and β_2, respectively, Table 2). The age-length model specified no parameters attributable to unmeasured location-specific effects.

Quillback rockfish were significantly larger at SJ than BI (ANOVA of MCTLs with Tukey Multiple Range Test, $p=0.0002$, d.f.=52), even though there were no significant differences in fish age between these locations (ANOVA, $p=0.16$, d.f.=52). This location-specific growth rate difference is illustrated by von Bertalanffy growth curves fitted for these samples (Figure 3). Both the growth rate constant (k) and the asymptotic length (L_∞) increased from BI → DB → SJ. Equations for the lines fitted in Figure 3 are as follows:

$$BI{:}Length = 350(1 - e^{-0.052(Age+21.8)})$$

$$DB{:}Length = 372(1 - e^{-0.096(Age+9.6)})$$

$$SJ{:}Length = 416(1 - e^{-0.119(Age+3.6)})$$

Mercury concentration in quillback rockfish estimated with the age-length model is higher at BI than at SJ for the age and length ranges of our data, which is converse to the trend in growth rate we observed between these two locations (Figure 3). Hence, the fastest-growing fish accumulated mercury at a slower rate than the slowest-growing population. The highest [Hg] of the three locations as estimated by the age-length model was from DB. Growth rate of fish from this location was intermediate between SJ and BI (Figure 3), however, overlap in the 95% confidence intervals for (L_∞), k and T_0 for DB and BI (Table 3).

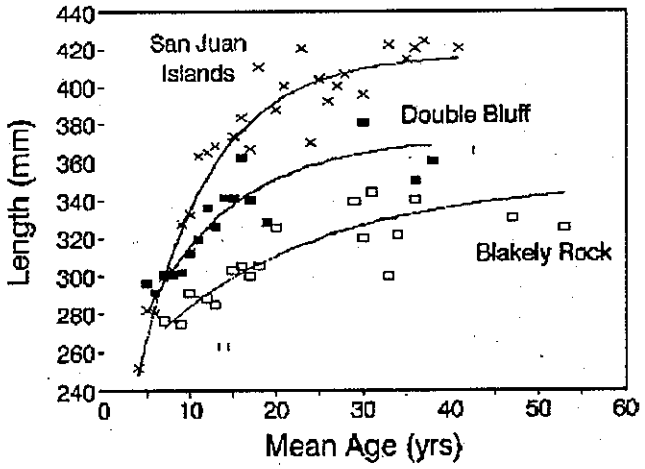

Figure 3. von Bertalanffy growth curves for quillback rockfish from three locations in Puget Sound, Wash. Curves were fitted using raw (non-composited) age and length data (n=264); however, observed data are presented as means in order to simplify graph.

PCBs

PCBs, as Aroclor 1260 congeners, were present in quillback rockfish from 1992 and 1993 samples from all three stations in Puget Sound. Individual sample-composite concentrations ranged from 2.0 µg/kg (the limit of detection) at SJ to 65 µg/kg at BI (Table 1). Mean station concentrations (± standard deviation, years pooled) ranged from 2.8±1.8 µg/kg at SJ to 12.9±15.8 µg/kg at BI. The mean concentration of PCBs was significantly higher at BI than SJ, and there was no significant difference in mean PCB concentration at DB (4.4±3.1 µg/kg) versus SJ or BI (ANOVA of log

[PCB], $p<0.0001$, d.f.=35, with Tukey Multiple Range Test).

Most Aroclor 1260 concentrations were at or near the detection limit (2.0 µg/kg) in samples from SJ; only two composites of 18 exceeded 3 µg/kg (5.9 µg/kg and 8.9 µg/kg) at that location. These two composites also represented the oldest and largest fish from SJ. Because of this, SJ samples were excluded from the following regression analyses.

Like mercury, [Aroclor 1260] increased with fish age (Figure 4a). Stepwise linear regression analysis testing the relative effects of fish length, age, location, and %lipids on [Aroclor 1260] indicates that only age and an unmeasured location-specific parameter contributed significantly to [Aroclor 1260] in quillback rockfish ($p<0.0001$). The following PCB age model, which adjusts for age effects (both locations) and an unmeasured effect specific to the BI location (β_2), accounted for 75.7% of the variability in log-transformed Aroclor 1260.

$$\text{Log [Aroclor 1260]} = \beta_1(\text{MCA})+\beta_2 Z+\beta_0,$$

where β_i = factor coefficient,
MCA = mean composite age, and
Z = dummy (station identifier) variable.

Individual station equations from the PCB age model are:

DB: Log [Aroclor 1260] = 0.044(MCA)+0.163
BI: Log [Aroclor 1260] = 0.044(MCA)+0.356.

The stepwise linear regression for this model showed that age was the primary variable affecting [Aroclor 1260] in quillback rockfish, and that [Aroclor 1260] at BI was elevated as a result of an unmeasured parameter (β_2, Table 3).

Concentration of Aroclor 1260 also increased with size of fish (Figure 4b). A log-linear regression model testing the effects of only length and location on [Aroclor 1260] provided a positive correlation ($p<0.0001$).

The following PCB length model accounted for 57.8% of the variability in log [Aroclor 1260] from BI and DB:

$$\text{Log [Aroclor 1260]} = \text{MCTL}(\beta_1+\beta_2 \cdot Z)+\beta_0,$$

where β_i = factor coefficient,
MCTL = Mean Composite Total Length, and
Z = dummy (station identifier) variable.

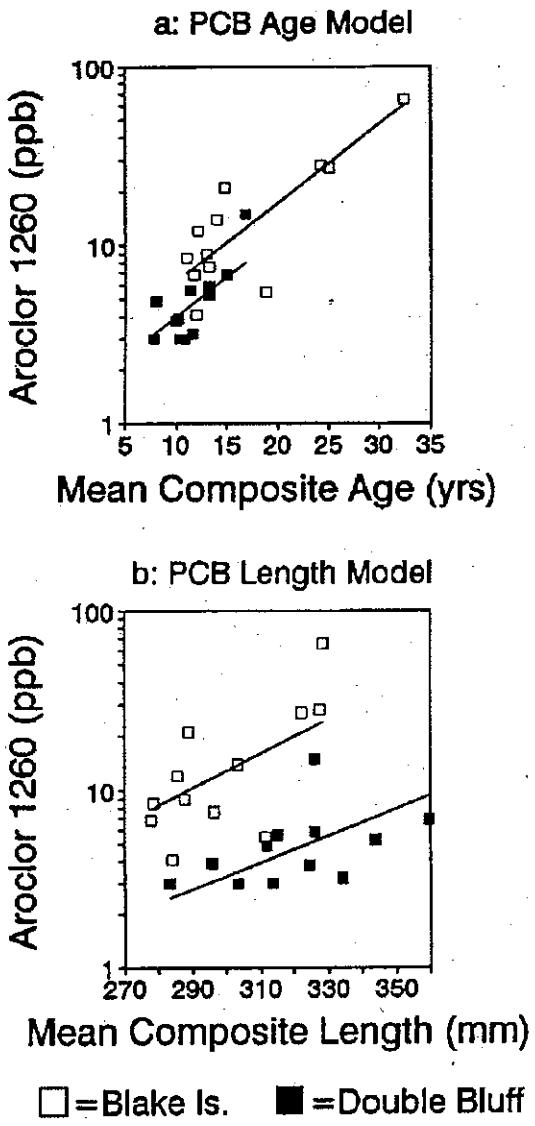

Figure 4. Fitted regression lines for the (a) PCB age model and (b) PCB length model. The y axes are presented in log scales to linearize data. Model equations and statistics are presented in Table 3.

Table 3. Parameters for full (Age) and restricted (Length) linear regression models used to describe bioaccumulation of Aroclor 1260 in quillback rockfish from three locations in Puget Sound, Wash.

	PCB Age Model			PCB Length Model		
	Variable	Coeff.	p value	Variable	Coeff.	p value
β_0	intercept	0.163	0.109	intercept	-1.763	0.032
β_1	MCA	0.044	<0.001	MCTL	0.0076	0.005
β_2	Z	0.193	0.027	MCTL · Z	0.0020	<0.001
R^2		0.778			0.614	
p		<0.001			<0.001	
Model	Log [Aroclor 1260] = β_1(MCA)+β_2Z+β_0			Log [Aroclor 1260] = MCTL(β_1+β_2· Z)+β_0		

This model resulted in simplified individual station equations,

DB: Log [Aroclor 1260]=0.0076(MCTL)-1.763
BI: Log [Aroclor 1260]=0.0096(MCTL)-1.763.

In the PCB Length Model, size of quillback rockfish was a significant determiner of [Aroclor 1260] (MCTL·β_1) for both locations, and BI showed a significantly greater rate of accumulation than DB as the result of an unmeasured parameter (β_2·Z).

DISCUSSION

Both mercury and Aroclor 1260 accumulated in quillback rockfish from all locations we sampled. Mercury exhibited a strong linear relationship with age and size. This is similar to results obtained for two confamilial scorpionfishes (Monteiro et al., 1991), in which both exhibited a strong, positive (exponential or multiplicative) relationship with age. Aroclor 1260 exhibited a moderately strong positive log-linear relationship with age, indicating that a relatively slow rate of uptake for young fish increased with fish age.

The mercury age·length model indicated that most of the variability in mercury concentration among locations can be explained by differences in location-specific growth rate (age·length interactions). Indeed, we observed different growth patterns between the locations, illustrated by the von Bertalanffy growth curves (Figure 3). It is unknown why quillback rockfish exhibited this gradient of growth rates from SJ>DB>BI. Possible explanations include differences in location-specific (1) environmental conditions (e.g., temperature), (2) diet, (3) habitat quality, (4) levels of fishing pressure, and (5) interspecific resource competition.

A significant question remains as to whether contaminants have affected growth rate or growth rates have affected contaminant uptake. Growth "dilution," where faster-growing fish accumulate PPs at a slower rate than slow-growing fish (see Hammar et al., 1993), has been suggested as a factor controlling bioaccumulation of PPs in Atlantic herring (Braune, 1987), two species of Atlantic scorpaenid (Monteiro, 1991) and the catadromous European eel (Larsson et al., 1991) as well as a number of freshwater fishes (Jensen et al., 1982; Thomann and Connolly, 1984; Hammar et al., 1991; Borgmann and Whittle, 1992; Stow et al., 1993). Growth rate has also been suggested as a factor to account for differences observed in mercury concentration between conspecific sexes; however, no one has yet distinguished this from the confounding effects of sexual differences in elimination of PPs through gametes (Monteiro and Lopes, 1990; Monteiro et al., 1991). In any case, the different age- or size-specific Hg and PCB levels and

bioaccumulation rates we observed among our sampling locations is particularly important because they suggest that any predictive models for mercury or PCB concentration in quillback rockfish from Puget Sound should account for population- or location-specific growth or other factors.

The PCB age model indicated that of the input variables tested in the stepwise regression (age, length, %lipids and location), age was the only significant factor that affected [Aroclor 1260]. The model also indicated that an unmeasured factor resulted in the higher [Aroclor 1260] at BI. A simple explanation for the higher [Aroclor 1260] at BI is a source difference of the contaminant at that location. Unfortunately, contaminants are not currently measured at the PSAMP rockfish stations because of the hard-bottom substrate typical of their habitats. However, proximity to source of contaminants has been described as an important factor in uptake of persistent pollutants in flounders (Kiørboe et al., 1983), dogfish and flatfish (Leah et al., 1991), and migrating juvenile salmon (McCain et al., 1990). This effect has also been demonstrated experimentally in a marine shrimp (Palmer and Presley, 1993).

Fat, or lipid content of fish, is an important factor controlling accumulation of lipophilic pollutants in other species (Larsson et al., 1991); however, they were not an important factor in accumulation of mercury or Aroclor 1260 in quillback rockfish. We found low levels of lipids in quillback rockfish (≤0.6%) in all but one case. One composite with a lipid value of 2.3% had the highest concentration of PCB, suggesting that lipids may become important in this species at higher levels.

Composite-samples consisted of an average PP concentration for a group of five fish of varying lengths and ages. Because of this, it is impossible to determine the full range of variability in [PP]s for individual rockfish. At least one composite (from SJ) exceeded the World Health Organization action limit (WHO, 1976) of 0.5 mg/kg mercury, and is close to the U.S. Environmental Protection Agency's screening value (U.S. EPA, 1993) of 0.6 mg/kg. Fish from that composite ranged in age from 9 to 37 years and in length from 330 to 424 mm (the regression was computed using a mean age of 28 years and mean length of 397 mm). If the largest non-composited ages and lengths from this group are applied to the mercury age-length model, resulting [Hg] estimates exceed 0.6 mg/kg. Six composites from BI and one from DB exceeded the U.S. EPA screening value for PCBs. If the oldest individual age (53 years) of quillback rockfish we collected is applied to the PCB age model, the resulting [Aroclor 1260] estimate exceeds 490 µg/kg.

These projections are useful only in estimating potential PP concentrations for individual fish and rely on the assumption that uptake continues in a linear fashion for fish beyond the range of ages and lengths described in our models. Growth in quillback rockfish, however, slows substantially as adults reach their asymptotic length (Figure 3), likely resulting in an increase in rate of uptake of PPs as a fish ages. This increased rate of uptake with age has been described in a confamilial scorpionfish (*Helicolenus dactylopterus*; Monteiro et al., 1991).

Compositing samples of long-lived fish for contaminants that accumulate with age (although more cost-effective for monitoring studies) may mask the effects of important physiological factors (e.g., age), thereby reducing the accuracy of bioaccumulation models. We also did not try to sample very large (or old) quillback rockfish. Maximum length for this species is reported at 61 cm (Hart, 1973), which is substantially larger than any individual we collected. The largest specimen from BI, the location with the greatest rate of uptake of both mercury and Aroclor 1260, was 400 mm. Hence, quillback rockfish with higher PP concentrations than measured in this study likely exist in Puget Sound.

Age and length are both important factors to consider in understanding the accumulation of PPs in quillback rockfish from Puget Sound. Uptake of PPs is undoubtedly nonlinear over the entire lifespan of these fish; however, linear or log-linear models were adequate to describe uptake within the age and length ranges of our data. Location-specific differences in growth rates of fish populations and in factors we did not measure also make it imperative to consider where fish were collected when modeling or estimating PPs in this species. We suggest that a study designed specifically to assess bioaccumulation is warranted to define more clearly the range of mercury and PCB concentrations in quillback rockfish from Puget Sound, and to model more completely and accurately the relationships we have identified here.

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