Report of the Bioaccumulation Workshop

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RMP Contribution #40a

1.0 Introduction

A workshop was held on March 30, 1999 to evaluate the bioaccumulation component of the Regional Monitoring Program for Trace Substances (RMP). This evaluation was performed within the context of the revised overall program objectives that were formulated as a result of the Five-Year Review (Bernstein and O'Connor, 1997). These revised program objectives are as follows:

1. Describe patterns and trends in contaminant concentration and distribution.
2. Describe general sources and loadings of contamination to the Estuary.
3. Measure contamination effects on selected parts of the Estuary ecosystem.
4. Compare monitoring information to relevant water quality objectives and other guidelines.
5. Synthesize and distribute information from a range of sources to present a more complete picture of the sources, distribution, fates, and effects of contaminants in the Estuary ecosystem.

The revised program objectives formed the basis for revised objectives for the bioaccumulation component of the RMP, as follows:

1. Determine trends in tissue contamination.
2. Measure the bioavailable portion of contaminants in the water column.
3. Evaluate which contaminants may be transferred to higher trophic levels of the food web.
4. Determine pathways and loadings of contaminants to the Estuary.
5. Determine effects of contaminants in the Estuary.

The goal of this workshop was to provide recommendations to the Technical Review Committee on ways to improve the ability of the program to address these objectives. Consequently, discussion at the workshop included consideration of whether the transplanted bivalve method currently used to measure bioaccumulation is the most appropriate way to achieve each of these objectives, as well as ways to improve the transplanted bivalve method. Workshop participants are shown in Table 1.

The discussions at the workshop were wide-ranging and provided numerous opinions regarding the bioaccumulation component and the best ways to achieve the program objectives. Consensus on the various opinions and recommendations was not necessarily achieved at the workshop and this document seeks to synthesize the current state of knowledge concerning the transplanted bivalve method, and provides recommendations for improving and streamlining the program that are consistent with the general direction of discussions at the workshop. In some cases, recommendations are contingent upon additional information or analyses of the existing transplanted bivalve data.

Table 1. Bioaccumulation workshop participants.

Name	Affiliation
Ray Arnold	Exxon Biomedical Sciences
David Bell	Applied Marine Science
Cynthia Brown	United States Geological Survey
Jay Davis	San Francisco Estuary Institute
Jordan Gold	Applied Marine Sciences
Andy Gunther	Applied Marine Sciences
Dane Hardin	Applied Marine Sciences
Rainer Hoenicke	San Francisco Estuary Institute
Michael Kellogg	City and County of San Francisco
Henry Lee	U.S. Environmental Protection Agency
Allison Luengen	University of California at Santa Cruz
Michael May	San Francisco Estuary Institute
Michael Salazar	Applied Biomonitoring
Karen Taberski	San Francisco Bay Regional Water Quality Control Board
Bruce Thompson	San Francisco Estuary Institute
Inge Werner	University of California at Davis

2.0 Current Program Configuration

Currently, the bioaccumulation component of the RMP has the following configuration:

1. Bivalves are obtained from historically clean locations for transplantation into the Estuary. Mytilus californianus are obtained from Bodega Head, Crassostrea gigas are obtained from a commercial grower in Tomales Bay, and Corbicula fluminea were obtained from Lake Isabella, until the population crashed in 1996. Currently, resident C. fluminea are collected from RMP sampling sites for analysis, because new transplant populations have not been found in clean locations.
2. Bivalves are transplanted to 15 sites (Figure 1).
3. Bivalves are deployed for two 90-day periods each year, one during the wet season (January-April) and one during the dry season (June-September).
4. Bivalves are analyzed for condition, trace metals, and trace organic contaminants.

3.0 Recommendations for Redesign

This section is organized according to program objective. We present a brief summary of findings and recommendations for redesign associated with each objective.

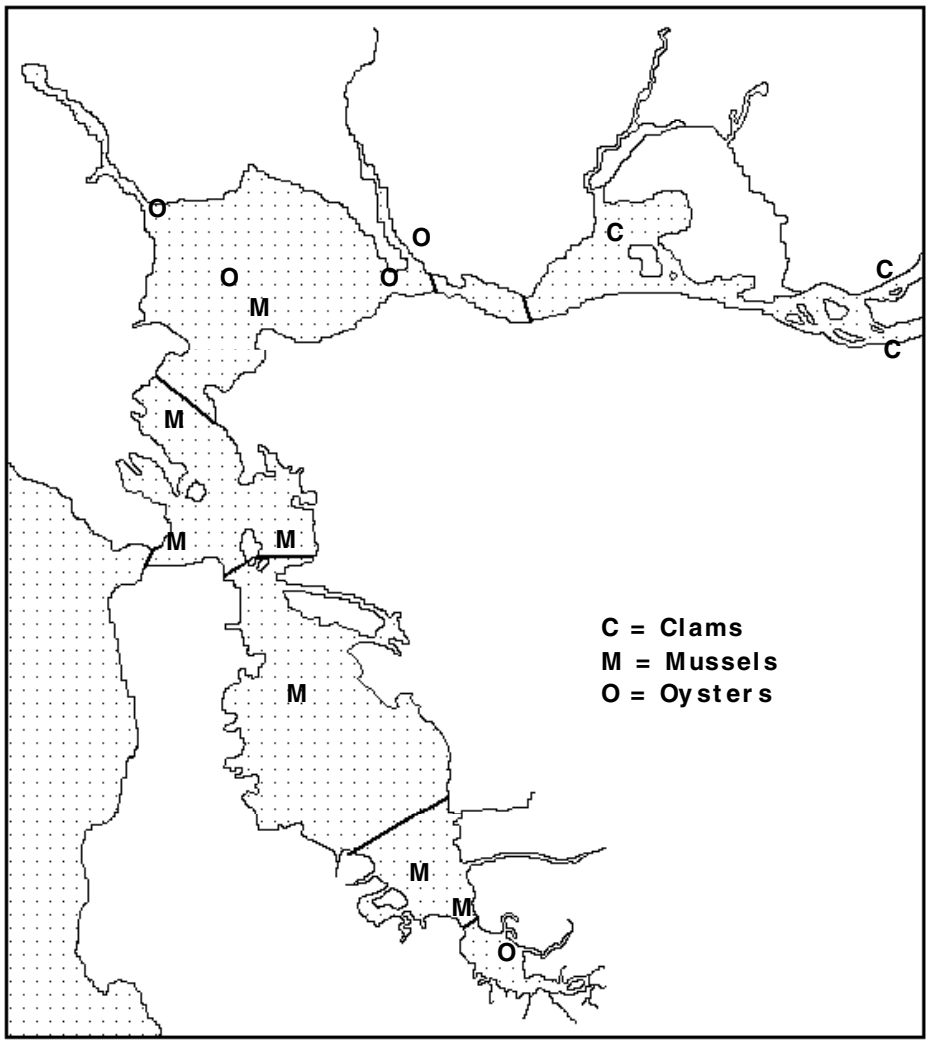

Figure 1. Sites for transplantation of bivalves.

3.1 Objective #1—Determine Trends in Tissue Contamination

Findings

Bivalves respond to changes in water concentrations of contaminants, and they integrate contaminants from the water column over time (Gunther, *et al.* 1999; Gunther and Davis, 1997; De Kock and Kramer, 1994). The State Mussel Watch (SMW) program has been in existence for almost two decades and represents an invaluable long-term database of bivalve bioaccumulation that should be continued by the RMP. The SMW program has employed mussels, *Mytilus californianus*, and clams, *Corbicula fluminea* (the latter as both transplants and residents). The RMP transplanted bivalves reveal trends that are not apparent from data on water contaminants, suggesting that bivalves may be especially valuable for tracking long-term changes in contaminant concentrations in the Estuary. For instance, recent analysis of data from 1993–1997 indicated significant increases in copper and decreases in PCBs in transplanted mussels that were not revealed in water data.

Nevertheless, these findings and interpretation of the transplanted bivalve data are complicated by several facts:

- Contaminant trends are not consistent between bivalve species. Significant estuary-wide trends in mussels were not observed in oysters.
- The mussel trends for different contaminants were more or less apparent depending on the season.
- Regression analyses suggest that non-contaminant environmental factors may affect bivalve bioaccumulation and indicators of health. Salinity, dissolved oxygen, temperature, and total suspended solids had the greatest effects, but statistical procedures allow adjustments to data to account for these effects.
- Periodic high mortality of transplanted bivalves is usually related to low salinities and high temperatures for mussels and oysters, respectively.
- Populations of *Corbicula fluminea* at clean sites recently have declined dramatically, and we do not current know of an alternate clean site to obtain clams for transplanting to the river sites.

Additional data analyses were recently undertaken using mussel data to help determine the optimum design for achieving this objective. The first step in these analyses consisted of assessing the presence of site groupings that would provide the basis for characterizing the Estuary with fewer than the current number of sampling sites (Figure 2). The Bray-Curtis similarity index (Bray and Curtis, 1957), which is normally used to determine site similarities based on organism abundances, was calculated to determine the similarities between sites based on mean concentrations of trace metals, PAHs, and PCBs. This index can range from 0.0, in which case the sites share none of the contaminants, to 100.0, in which case the sites share all of the contaminants and have identical mean concentrations. These similarities were then clustered using an unweighted pair-group method (Swartz, 1978) to graphically represent the affinities among the sites for each group of contaminants.

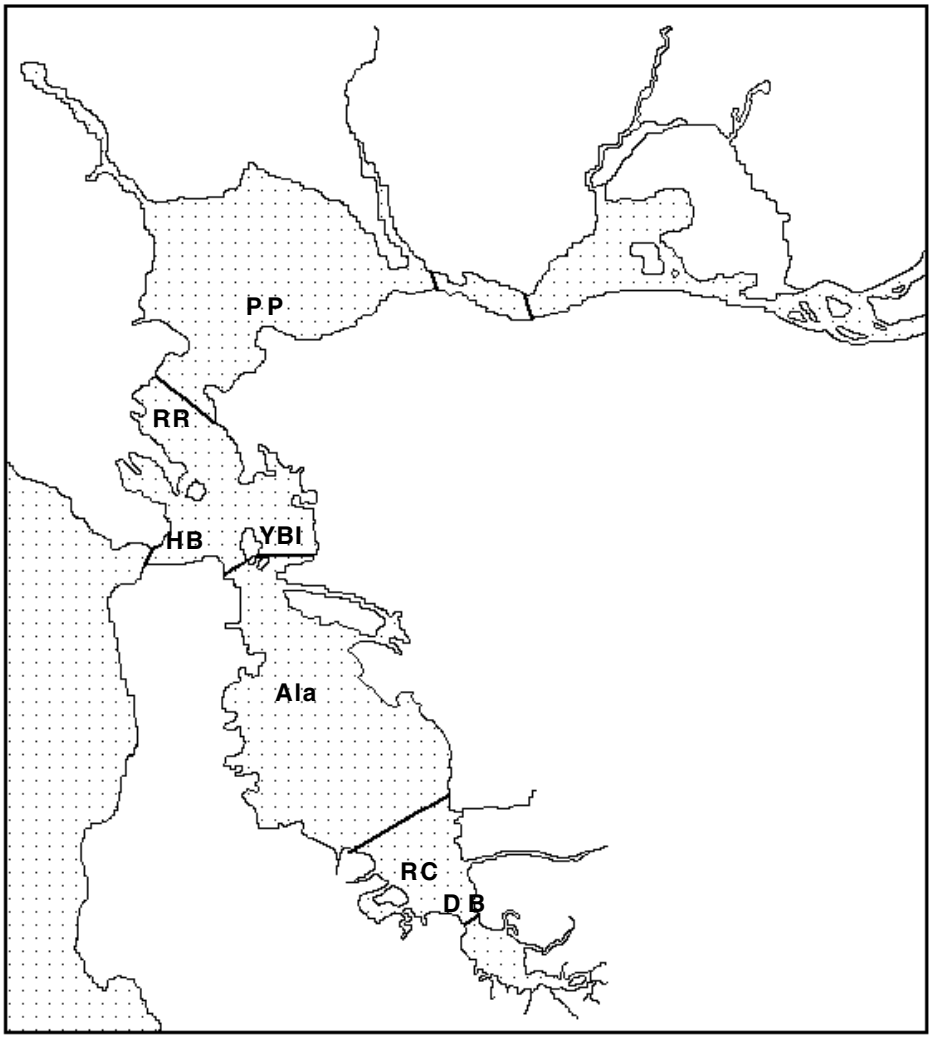

Figure 2. Mussel deployment sites. DB = Dumbarton Bridge, RC = Redwood Creek, Ala = Alameda, YBI = Yerba Buena Island, HB = Horseshoe Bay, RR = Red Rock, PP = Pinole Point.

The second step in these analyses consisted of predicting the ability of the transplanted bivalve method to detect changes over time and differences between reaches of the Estuary under various sample reduction scenarios. The percentage of change that could be detected with regression analysis over a five-year period in each reach of the Estuary was estimated for each season separately and for both seasons together using the methods of Gerrodette (1987). Gerrodette's methods for estimating the power of regression analyses to detect trends do not account for the increase in power due to analysis of replicate samples at each point in time, and we are not aware of a method that does. Nevertheless, these methods are based upon the coefficient of variation (CV, the percentage of the mean represented by the standard deviation) within sets of samples from each point in time. These methods also assume that samples are distributed over time and that the change over time (i.e., trend) is linear. The amount of difference between reaches that could be detected with analysis of variance (ANOVA) was also estimated using the method of Sokal and Rohlf (1995). Because the results of these analyses vary according to analyte, we focused our efforts on copper, mercury, nickel, selenium, total lipid-normalized PAHs and total lipid-normalized PCBs.

The cluster analyses revealed different patterns for each group of contaminants (Figures 3-5). Although delineation of clusters is somewhat arbitrary, trace metals provided relatively little definition of site groupings, with high similarities among all site/season combinations except wet-season samples from Dumbarton Bridge and Red Rock (Figure 3). Similarities based on mean concentrations of PAH analytes revealed several clusters that separated generally along seasonal and regional lines (Figure 4). Cluster 1 consisted of dry-season samples from sites between Redwood Creek and Yerba Buena Island, cluster 2 consisted of dry-season samples from Dumbarton Bridge and Pinole Point plus both seasons from Horseshoe Bay. Cluster 3 consisted of the remainder of the wet-season samples, except for Redwood Creek, and cluster 5 consisted of the Bodega Head samples. These clusters generally differed according to mean concentrations of total lipid-normalized PAHs, with the dry-season samples from each Estuary site having the highest concentrations. Similarities based on mean concentrations of PCB congeners revealed several clusters that were generally based on regions (Figure 5). Clusters 1 and 2 included both seasons for all sites from Yerba Buena Island south to Dumbarton Bridge, and cluster 3 included both seasons for all sites from Horseshoe Bay to Pinole Point. Cluster 4 included both seasons from Bodega Head. These clusters also generally differed according to mean concentrations of total lipid-normalized total PCBs, with southern dry-season samples having higher concentrations. The different clustering patterns for the three groups of contaminants suggest that there is no single strategy for delineating groups of sites that is applicable to all contaminants.

The best across-the-board strategy for grouping sites will probably be based on arbitrary geographic definitions of Estuary reaches. For the following analyses of power in regression analyses and ANOVA, the South Reach includes Dumbarton Bridge, Redwood Creek, and Alameda. The Central Reach includes Yerba Buena Island and Horseshoe Bay, and the North Reach includes Red Rock and Pinole Point (Figure 2).

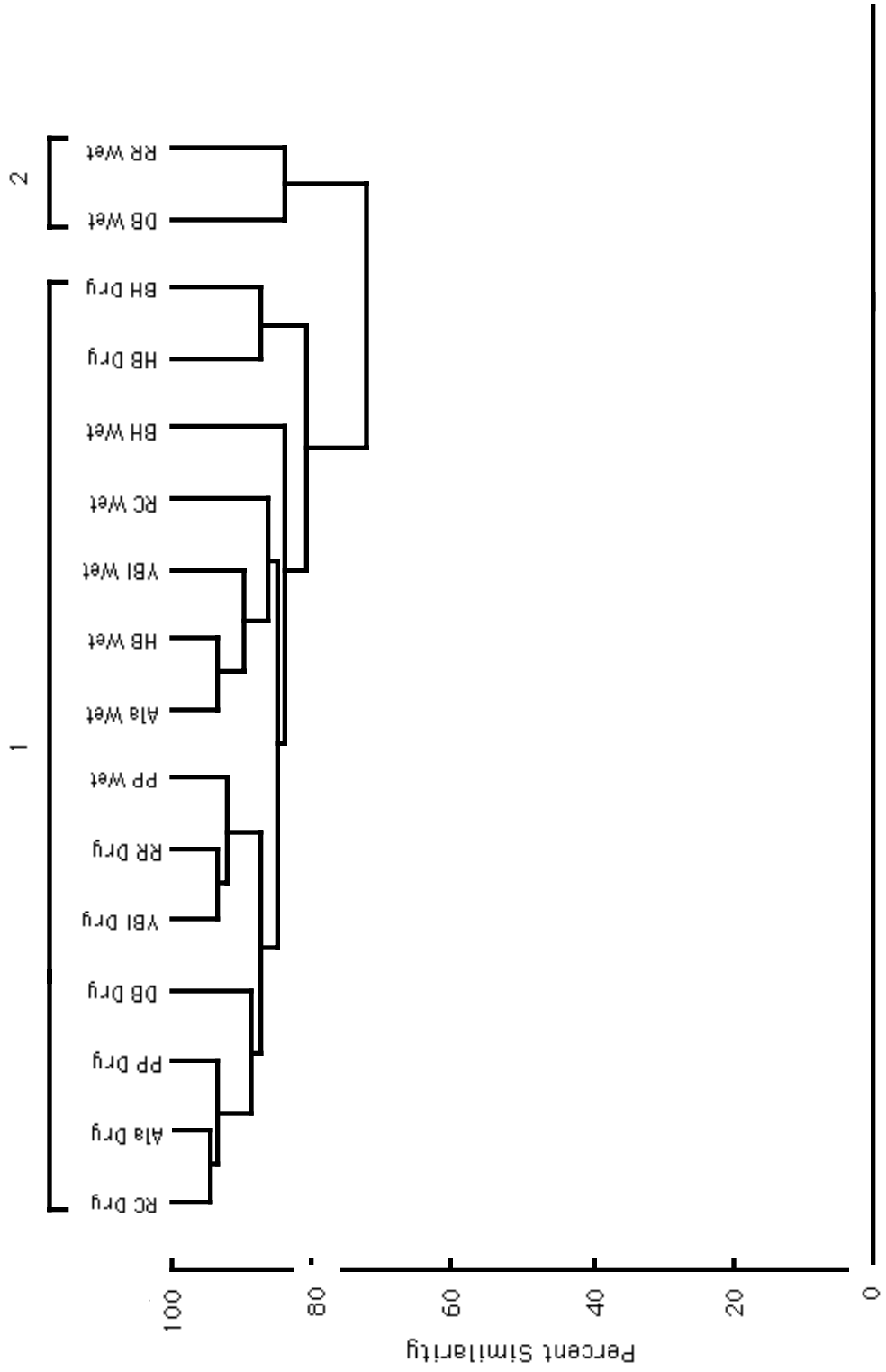

Figure 3. Clusters based on concentrations of trace metals. Ala = Alameda, BH = Bodega Head, DB = Dumbarton Bridge, HB = Horseshoe Bay, PP = Pinole Point, RC = Redwood Creek, RR = Red Rock, YBI = Yerba Buena Island.

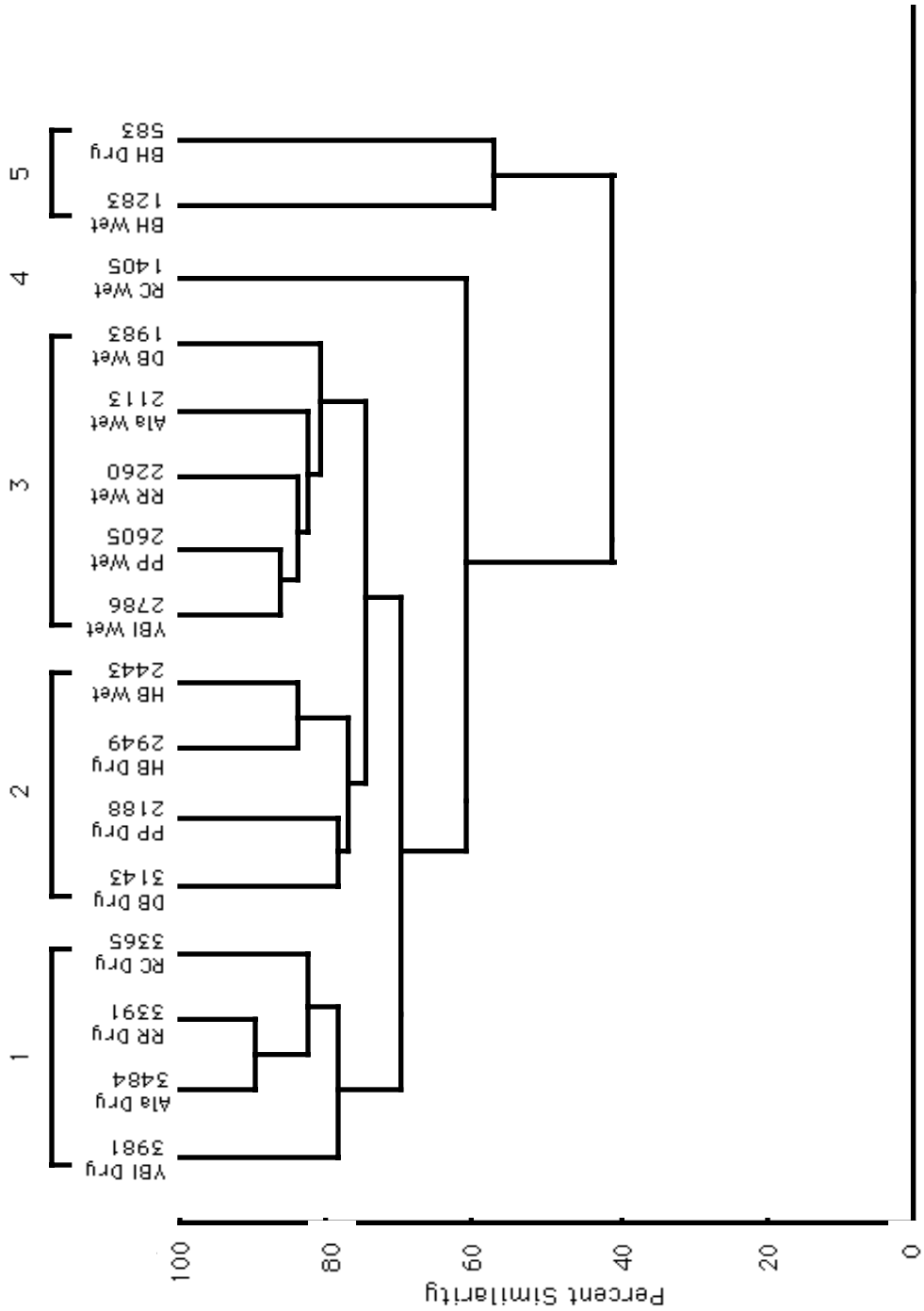

Figure 4. Clusters based on concentrations of PAH analytes. Ala = Alameda, BH = Bodega Head, DB = Dumbarton Bridge, HB = Horseshoe Bay, PP = Pinole Point, RC = Redwood Creek, RR = Red Rock, YBI = Yerba Buena Island. Numbers are lipid-normalized concentrations of total PAHs (micrograms of PAH/kilogram of lipid).

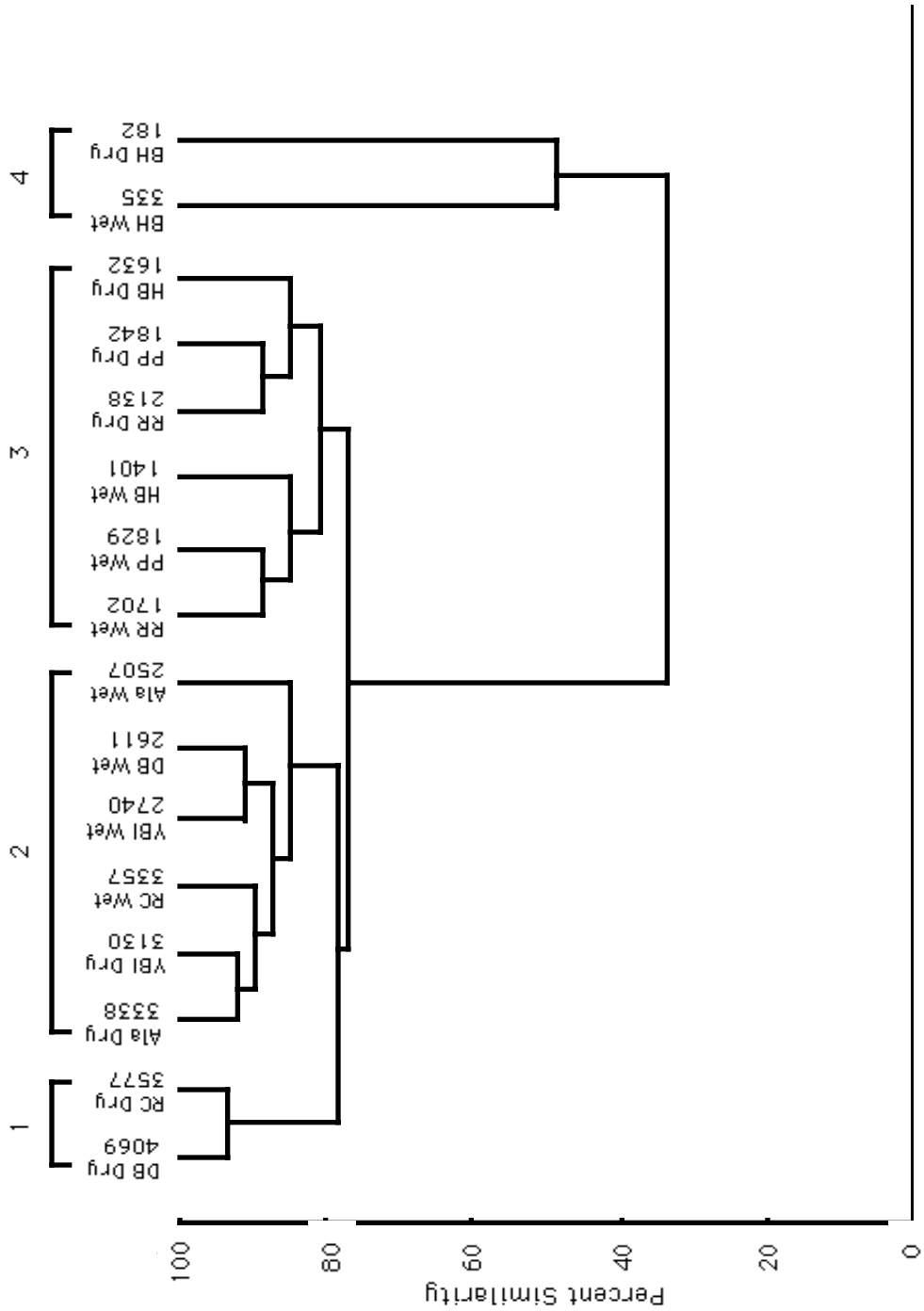

Figure 5. Clusters based on concentrations of PCB congeners. Ala = Alameda, BH = Bodega Head, DB = Dumbarton Bridge, HB = Horseshoe Bay, PP = Pinole Point, RC = Redwood Creek, RR = Red Rock, YBI = Yerba Buena Island. Numbers are lipid-normalized concentrations of total PCBs (micrograms of PCB/kilogram of lipid).

Based on the average CV within sampling periods, the predicted percentage change that might be detectable with five samples (e.g., annual samples over five years) varied from 6.48% in wet season mercury from the Central Reach to 78.46% in wet season nickel from the North Reach (Table 2). The combination of wet and dry season samples to provide 10 samples over time decreased the estimated percentage change that could be detected for each analyte in each reach, often by substantial amounts. With 10 samples, the predicted percentage change that might be detectable ranged from 4.78% for mercury in the Central Reach to 20.50% for nickel in the North Reach.

The differences in predicted detectable percentage change for wet season and dry season samples varied inconsistently among reaches and analytes. There were six cases in which high power (i.e., <15% predicted detectable change) was indicated for wet season samples and one case in which high power was indicated for dry season samples. Nevertheless, the predicted results were often not reflected in the actual regressions, because trends did not always accompany low predicted detectable percentage changes. In these cases, the low CVs indicate that all the sites within the reach had similar concentrations of contaminants, but the concentrations either varied irregularly through time or did not vary with time. Moreover, the actual regression results indicated several cases in which very significant regressions occurred when the predicted detectable percentage change was high (e.g., dry season PAHs in every reach), indicating especially strong trends. There were eight and 10 cases in which significant actual regressions (P<0.10) occurred for wet and dry seasons, respectively. There were seven significant regressions for both seasons combined. These results suggest that there is not an optimum season for detecting trends that applies to all contaminants, but that sampling in both seasons might not always improve detection of actual trends.

Although the influence of replicate samples was not determined for the analysis of predicted detectable percentage change, actual regression results were used to evaluate this issue. The inclusion of 3, 2, and 2 sites to characterize the South, Central, and North reaches, respectively, resulted in the detection of numerous significant regressions (Table 2). But when individual sites were analyzed for seasonal copper and total PAHs, the two analytes with the strongest actual regressions, few significant regressions occurred (Table 3). Only in the case of wet season copper in the Central Reach and dry season copper in the North Reach did both sites exhibit significant regressions consistent with the overall trend for that reach. Moreover, where significant reach-wide regressions occurred, the probability was always lower than for any individual site. These results suggest that five-year trends in reaches cannot generally be adequately described using single sites.

The ability to detect differences between reaches using ANOVA is also strongly affected by the number of sites analyzed per reach. In the case of ANOVA comparisons, each site represents a replicate sample within its reach. The predicted percentage differences between reaches that could be detected for each analyte was substantially less (i.e., greater power) for three samples than for two samples (Table 4). The percentage difference that can be detected using three samples ranged from 37.23 for wet season mercury to 150.85 for wet season nickel.

Table 2. Results of statistical analysis to determine the predicted minimum percentage change detectable over the period covered by the samples using regression analysis (i.e., statistically significant trends over time), compared to actual regression results. The predicted results are the minimum percentage change detectable because they do not account for the increase in power due to analyzing multiple replicate samples (i.e., more than one site) from each sampling time. The predicted results also assume that the change is linear with time and that the samples are spread over time. Actual regression results are based on analysis of three samples per time for the South Reach and two samples per time for the Central Reach and North Reach.

				Predicted Results		Actual Regression Results	
Analyte	Estuary Reach	Season	Average C.V.	N[a]	Minimum % Change Detectable	R^2	*P*
Copper	South	Wet	13.4	5	14.97	0.441	0.0259**
		Dry	33.2	5	37.09	0.568	0.0019***
		Both	23.3	10	9.20	0.373	0.0012***
	Central	Wet	11.6	5	12.96	0.576	0.0177**
		Dry	19.3	5	21.56	0.297	0.1033
		Both	15.4	10	6.08	0.291	0.0170**
	North	Wet	33.2	5	37.09	0.031	0.7049
		Dry	21.4	5	23.91	0.697	0.0070***
		Both	27.3	10	10.78	0.135	0.1216
Mercury	South	Wet	25.4	5	28.38	0.379	0.0437**
		Dry	29.3	5	32.73	0.136	0.1939
		Both	27.3	10	10.78	0.076	0.1832
	Central	Wet	5.8	5	6.48	0.554	0.0214**
		Dry	18.5	5	20.67	0.302	0.0997*
		Both	12.1	10	4.78	0.297	0.0158**
	North	Wet	9.7	5	10.84	0.608	0.0386**
		Dry	35.7	5	39.88	0.045	0.4849
		Both	22.7	10	8.97	0.031	0.4596
Nickel	South	Wet	50.0	5	55.86	0.079	0.4029
		Dry	39.8	5	44.46	0.0003	0.9527
		Both	44.9	10	17.73	0.007	0.6863
	Central	Wet	44.9	5	50.16	0.022	0.7027
		Dry	30.6	5	34.18	0.118	0.3303
		Both	37.8	10	14.93	0.012	0.6557
	North	Wet	70.5	5	78.76	0.004	0.8990
		Dry	33.3	5	37.20	0.004	0.8512
		Both	51.9	10	20.50	0.008	0.7185

Table 2. Continued.

Analyte	Estuary Reach	Season	Average C.V.	Predicted Results Minimum % Change Detectable N[a]	Actual Regression Results R^2	*P*
Selenium	South	Wet	20.7	5	23.12	0.099	0.3454
		Dry	8.2	5	9.16	0.262	0.0614*
		Both	14.4	10	5.69	0.041	0.3339
	Central	Wet	20.6	5	23.01	0.003	0.8864
		Dry	14.3	5	15.98	0.333	0.0808*
		Both	17.4	10	6.87	0.131	0.1278
	North	Wet	23.4	5	26.14	0.014	0.8018
		Dry	25.7	5	28.71	0.263	0.0734*
		Both	24.5	10	9.68	0.145	0.0974*
Total PAHs	South	Wet	58.4	5	65.24	0.019	0.7062
		Dry	27.0	5	30.16	0.624	0.0022***
		Both	42.7	10	18.66	0.307	0.0075**
	Central	Wet	12.0	5	13.41	0.114	0.4136
		Dry	24.3	5	27.15	0.697	0.0099***
		Both	18.1	10	7.15	0.111	0.2080
	North	Wet	33.7	5	37.65	0.091	0.5609
		Dry	36.4	5	40.66	0.630	0.0106**
		Both	35.0	10	13.82	0.255	0.0549*
Total PCBs	South	Wet	28.0	5	31.30	0.509	0.0205**
		Dry	22.7	5	25.36	0.416	0.0235**
		Both	25.3	10	9.99	0.256	0.0162
	Central	Wet	46.0	5	51.39	0.387	0.0997*
		Dry	42.9	5	47.93	0.182	0.2917
		Both	44.4	10	17.54	0.238	0.0553*
	North	Wet	8.5	5	9.50	0.883	0.0053**
		Dry	16.4	5	18.32	0.132	0.3369
		Both	12.4	10	4.90	0.144	0.1630

[a] = N is the number of sampling times, not the number of replicate samples in each time.
* = Regression is significant at the 0.10 level.
** = Regression is significant at the 0.05 level.
*** = Regression is significant at the 0.01 level.

Table 3. Significance of regressions for each site compared with those for sites combined into reaches.

Analyte	Site or Reach	Regression *P* for Each Season Wet	Dry
Copper	South Reach	0.0259**	0.0019***
	Dumbarton Bridge	0.0648*	0.0820*
	Redwood Creek	0.2527	0.1553
	Alameda	0.8134	0.2368
	Central Reach	0.0177**	0.1033
	Yerba Buena Island	0.0565*	0.1002
	Horseshoe Bay	0.0576*	0.3031
	North Reach	0.7049	0.0070***
	Red Rock	0.7505	0.0429**
	Pinole Point	0.3290	0.0449**
Total PAHs	South Reach	0.7062	0.0022***
	Dumbarton Bridge	0.5592	0.2213
	Redwood Creek	0.8146	0.2925
	Alameda	0.1473	0.0626*
	Central Reach	0.4136	0.0099***
	Yerba Buena Island	0.6939	0.1094
	Horseshoe Bay	0.5839	0.0952*
	North Reach	0.5609	0.0106**
	Red Rock	0.0106**	0.1177
	Pinole Point	-[a]	0.2072

[a] = Only two points available for regression.
* = Regression is significant at the 0.10 level.
** = Regression is significant at the 0.05 level.
*** = Regression is significant at the 0.01 level.

Table 4. The predicted percent difference detectable between reaches of the Estuary based upon analysis of variance using two or three sites (i.e., N) per reach.

Analyte	Season	Average C.V.	N	Predicted % Difference Detectable
Copper	Wet	19.4	3	53.11
			2	80.71
	Dry	24.6	3	67.35
			2	102.34
Mercury	Wet	13.6	3	37.23
			2	56.57
	Dry	27.8	3	76.11
			2	115.65
Nickel	Wet	55.1	3	150.85
			2	229.22
	Dry	34.6	3	94.72
			2	143.94
Selenium	Wet	21.6	3	59.13
			2	89.86
	Dry	16.1	3	44.08
			2	66.98
Total PAHs	Wet	34.7	3	95.00
			2	144.35
	Dry	29.2	3	79.94
			2	121.47
Total PCBs	Wet	27.5	3	75.29
			2	114.40
	Dry	27.3	3	74.74
			2	113.57

The percentage difference that can be detected using two samples ranged from 56.57 for wet season mercury to 229.22 for wet season nickel. The decrease in the predicted detectable percentage difference was proportional to the number of samples, with three samples being able to detect a difference that was two-thirds the difference detectable with two samples.

Recommendations

In order to track trends, the RMP should maintain sites and methods comparable to SMW and the last six years of RMP data collection. Although long-term trends are more apparent in the dry season than in the wet season, the low CVs in many wet season samples suggest that the bivalves are responding to real phenomena that vary from year-to-year on a non-linear basis. While this wet season information is useful for determining processes and pathways for entry of contaminants into the Estuary (see Objective #4), transplanting bivalves in the wet season could perhaps be suspended without seriously affecting the program's ability to achieve Objective #1. Bivalves should be deployed at more than one site to characterize trends within and differences among reaches, and three sites are recommended. These sites should be distributed as widely as possible to adequately represent all the variation within the reach. Reaches should be defined using geographical criteria.

One species should be deployed at all sites to eliminate the difficulty of interpreting data from different species. If deployment of bivalves in both the wet season and dry season is maintained, side-by-side deployments of several species should be continued for several years to determine whether a suitable species is available for deployment in the wet season at all sites west of Carquinez Strait. CTD profiles should be recorded during each visit to deployment sites to allow further examination of the effects of non-contaminant factors on bioaccumulation and bivalve health. If cost savings are required while maintaining deployments in both seasons, elimination of mid-deployment maintenance cruises should be examined.

3.2 Objective #2—Measure the Bioavailable Portion of Contaminants in the Water Column

Findings

Many trace metals do not appear to accumulate much above concentrations measured in the "clean" populations used as sources for transplants. It is not known whether the low accumulations in the transplants are due to poor bioaccumulation or ambient concentrations that are similar between the source locations and the Estuary. Nevertheless, trends apparent for tissue concentrations of some metals, such as copper, suggest that ambient conditions within the Estuary are being reasonably well represented by the transplants.

In the case of mercury, however, there is evidence that bivalves may not be the best indicators of bioavailability, especially of the most toxic form of this element. Mercury is a contaminant of concern that is found in very high concentrations in many fishes in the Estuary, most likely in the methylated form. Mercury concentrations in fishes are sufficiently high that health advisories have been issued warning people to limit the amount of fish they consume from the Estuary. Although mercury concentrations have declined significantly in mussels since 1993, primarily in the wet season, it does not occur in very high concentrations in the transplanted bivalves, and the best available information suggests that mussels are not efficient accumulators of methylated mercury.

The transplanted bivalve method, as it is currently employed, also does not seem to capture ecologically important short-term trends in organo-selenium presence in the Estuary. Although RMP data indicate that increases in dry season selenium are approaching statistical significance, U.S. Geological Survey data from resident bivalves near Carquinez Strait suggest that selenium

fluxes to the Estuary may occur over periods of less than one month. The time-integration design used in the RMP transplanted bivalve program (90–100 day deployments) does not capture such short-term events. The current design also can meet the objective of assessing the bioaccumulation potential of substances heretofore not identified. At least three workgroups have proposed recommendations related to new pollutant identification or diagnostic monitoring.

Recommendations

Some analytes should no longer be analyzed in bivalves. Mercury and arsenic, in particular, do not appear to provide information that is helpful to environmental or risk managers. While trends in mercury have been noted in the transplanted bivalves, it would be prudent to add a resident or transplanted bivalve component that is more sensitive to methylated mercury and the temporal scales of selenium fluctuation. The frequency of analysis of metals not on the 303(d) or the Regional Board's "pollutants of concern" list should be reduced to once every 3-5 years in order to maintain the trend database.

Assemble a database on known bioaccumulative substances and the current state of knowledge on environmental effects (e.g., flame retardants). Identify peaks on existing chromatograms according to Bob Risebrough's proposal and determine what is known about potential environmental effects of those compounds still in use today. Determine which (potential) pollutants that are currently not on the RMP analyte list ought to be tracked. This would add a proactive element to the RMP which would enable the Regional Board to work with other agencies (U.S. Environmental Protection Agency pesticide registration, Department of Health Services, etc.) to determine whether or not additional studies are needed prior to use restrictions.

3.3 Objective #3—Evaluate which Contaminants May Be Transferred to Higher Trophic Levels of the Food Web

Findings

The findings for Objective #2 also apply to this objective. Use of the California Mussel, *Mytilus californianus*, as the primary organism for the transplanted bivalve component may also limit achievement of this objective because this species does not normally occur in the Estuary and it has no natural position within the food web. The Bay Mussel, on the other hand, does occur throughout the Estuary and may survive at a broader range of salinities than does *M. californianus*. If the current side-by-side deployments indicate that it is a suitable transplant organism, the Bay Mussel may improve achievement of this objective. Nevertheless, deployment of transplanted bivalves in the water column may not adequately represent transfer of contaminants from the sediments into benthos and higher trophic levels. Other types of organisms, such as benthos or fishes, may be the best way to assessing the transfer of contaminants to higher trophic levels of the food web.

Recommendations

Develop additional ways to assess transfer of contaminants to higher trophic levels. These should include a benthic bivalve, other invertebrates, or fishes to evaluate bioavailability and transfer of sediment contaminants to higher trophic levels.

3.4 Objective #4—Determine Pathways and Loadings of Contaminants to the Estuary

Findings

Bivalve measurements are able to discern differences in contaminants over spatial scales ranging from tens of meters to kilometers and over temporal scales from months to years. They can be used to assess the relative magnitude of contaminant problems at the terminus of watersheds and in front of outfalls or other point sources. Bivalves may also be used within this context to measure the response to clean-up efforts or other management action within watersheds that have been identified as pollutant contributors to the Estuary.

The patterns in contaminant concentrations indicated by Figures 4 and 5 suggest that substantial seasonal and spatial differences exist in contaminant input or build-up in the Estuary. Although additional analyses should be performed to determine whether the high PAH concentrations in dry season samples from Yerba Buena Island to Redwood Creek are primarily petrogenic or pyrogenic, they suggest the importance of aerial fallout from the busy motor vehicle corridors that border this part of the Estuary. The regional differences in PCB congeners may also indicate contaminant sources that vary spatially.

The current configuration of the transplanted bivalve component limits its ability to achieve this objective. The high variability of salinity in the Estuary, especially during the wet season, necessitates deployment of three different species for bioaccumulation measurements. Because bivalve species differ in their bioaccumulation characteristics, site comparisons are limited to those with the same species and sites with the same species do not necessarily overlap with the geographic definition of reach. Side-by-side deployments of multiple species currently being performed may determine whether there is a single species suitable for wet season deployment at all sites west of Carquinez Strait.

Recommendations

One species should be deployed at all sites to eliminate the difficulty of interpreting data from different species. If deployment of bivalves in both the wet season and dry season is maintained, side-by-side deployments of several species should be continued to determine whether a suitable species is available for deployment at all sites in the wet season. If a single species cannot be found that survives at all sites during the wet season, a subset of sites with more limited salinity variation should be used. If cost savings are required while maintaining deployments in both seasons, elimination of mid-deployment maintenance cruises should be examined.

As the examination of contaminant pathways into the Estuary focuses on smaller spatial scales, methods other than transplanted bivalves may be more appropriate. For instance, tracing PCBs to upstream sources may be best accomplished by using sediment sampling.

3.5 Objective #5—Determine Effects of Contaminants in the Estuary

Findings

Although the RMP bivalve monitoring component operates under the assumption that the bivalve species used are unlikely to be affected by contaminant levels found in the Estuary, this assumption has not been tested. Significant correlations exist between concentrations of tissue contaminants and indicators of bivalve health, but it has not been determined how either of these factors affects the other. Investigators in other areas have found significant biological effects of contaminants on bivalves, but it is not known how non-contaminant environmental factors affect these biological indicators.

Other organisms, such as fishes or birds, may be better indicators of contaminant effects in the Estuary. Previous studies have suggested that contaminants in the estuary are at or above

the threshold for effects on some vertebrates (Spies *et al*., 1988; Spies and Rice, 1988; Davis 1997; Davis *et al*., 1997).

Recommendations

Bivalve growth may be the best indicator of contaminant effects in the current transplanted bivalve program. Tissue dry weight is measured as part of the condition measurements and changes in tissue weight can be easily determined from differences in tissue weight between the T-0 (pre-deployment) bivalves and post-deployment bivalves. Tissue growth and contaminant concentrations that have been adjusted for the effects of environmental factors can be statistically compared to determine whether contaminants might be affecting growth.

Although bivalve growth may be an indicator of contaminant effects, fishes, birds, and mammals may be more suitable for this purpose. These forms are more likely to show effects than are bivalves because they occupy higher positions in the food web and will contain higher concentrations of contaminants that biomagnify. A special study should be developed to examine the effects of contaminants on fishes, birds, or mammals.

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