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REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION

Pete Wilson
Governor

Staff Report

AMBIENT CONCENTRATIONS OF TOXIC CHEMICALS IN SAN FRANCISCO BAY SEDIMENTS

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This report is intended to provide information to staff to assist in evaluating sediment data and enhance the decision-making process. This report does not constitute a regulation and the thresholds presented herein are not promulgated criteria or standards. The information contained in this report will be periodically updated.

Summary

This report summarizes the results of the statistical evaluation of ambient concentrations of chemical compounds found in the San Francisco Bay sediments. We recommend that the ambient level threshold for routine use be based upon an 85th percentile (P=0.85) for 100% fines, the grain size fraction less than 62.5 µm. We define the upper point of the ambient population (reference) as the ambient *threshold*. Above the threshold concentration, a sediment would be considered contaminated.

The ambient concentrations in sediments were calculated by a consulting statistician (Robert Smith, EcoAnalysis, Inc.) in order to support the development of guidance on management of contaminated sediments. Staff within the Regional Board's Planning and Policy Unit managed this project using several sources of funding. In this report, we summarize and place into context the levels of chemicals found in shallow bay sediments. We address chemicals found in San Francisco Bay sediments that are commonly referred to as "toxic pollutants", because at certain concentrations they pose a threat to human health and the environment. Contamination by so-called "conventional" pollutants, such as sulfur compounds, ammonia, degrading organic material, bacteria or viruses are outside the scope of this project.

Introduction

This project began because several Regional Board programs are involved in the assessment and management of contaminated sediments (Table 1). Staff expressed a need for threshold and reference concentrations of chemicals with which to evaluate sediment pollution problems. San Francisco Bay and other estuarine sediments have been studied by scientists for many decades. Yet, despite the fact that there is ample national guidance on creating a decision-making process, there is a scarcity of guidance and criteria on which to base regulatory decisions. As a result, staff have had difficulty determining chemical concentrations that are of concern and that may require corrective actions.

The experience of the Regional Board staff, in both regulatory and policy functions, makes us uniquely qualified to develop sediment concentration thresholds for toxic pollutants. Staff from various programs exchange information through our Contaminated Sediment Committee, as well as with outside committees and groups, such as the Biological and Technical Advisory Group (BTAG) and the Dredged Material Management Office (DMMO).

TABLE 1

PROGRAMS AT THE REGIONAL BOARD THAT REGULATE CONTAMINATED SEDIMENT

Activity	Regulatory Program	Advisory and Policy Forum
Dredging and Dredged Material Disposal	Section 401 Water Quality Certification	Long Term Management Strategy for dredging (LTMS) Studies and Programmatic EIR
Department of Defense Base Closure and Realignment (BRAC)	Review and approval of investigation and remediation under federal Superfund process	Biological and Technical Advisory Group (BTAG)
Bay Protection and Toxic Cleanup Program (BPTCP)	Site Screening and Confirmation for Identification of Toxic Hot Spots. Cleanup Plans are for High Priority Sites. Database of Sites.	Development of sediment bioassay thresholds, staff active in state Monitoring and Surveillance Task Force
Shoreline Development	Waste Discharge and Site Cleanup Orders issued to Property Owner, may also include on-shore soil contamination, also may include Cleanup under State Hazardous Substances Control Act and CERCLA-Superfund	Underground Storage Tank and Groundwater Protection Policies (e.g. Resolution # 68-16)
NPDES Permit Program	Local Effects Monitoring (Outfall) for POTW	Basin Plan

Ambient Values

Although bay sediments can be severely polluted, such as at a state listed "toxic hot spot" [1], more often the sediments in question are moderately contaminated and fall into a "gray zone". Ambient concentrations for these compounds may be higher than those for historic background. Given the scientific literature and available assessment tools, the sediments may represent an unquantifiable threat if the concentrations are somewhat elevated above background. We may question sediment quality at a site because elements, compounds or classes of compounds are detected at what seem to be elevated levels, as compared to some "control" sediment. Since San Francisco Bay sediments are not totally free of anthropogenic and naturally occurring pollutants, it is important to define the typical range of concentrations that one would expect to find in them. In accordance with terminology already in use, we will refer to this condition as "ambient." True pre-industrialization levels of contaminants will be termed "background" and are discussed below.

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[1] As defined in section 13393.5 Porter-Cologne Water Quality Act and Guidance on Development of Proposed Regional Toxic Hot Spot Cleanup Plans, October 1997.

Apart from the question of contaminant toxicity and bioavailablity, it is often crucial to know how a given sediment sample compares to the rest of the Bay. This is especially true for habitat restoration projects, where, for example, a newly restored intertidal wetland would be subject to an influx of suspended sediments from the daily tides. There would be little to gain from insisting that sediment concentrations in a restored wetland be lower than ambient levels because the new marsh substrate will be comprised of sediment deposited by re-suspension from surrounding sources. Data used to calculate these ambient concentrations were collected by the Regional Monitoring Program for Trace Substances and the Bay Protection and Toxic Cleanup Program (Table 2).

Sediment Dynamics / Sample Type

It is important to consider that the results in the database for this project are from monitoring programs that sample the upper five centimeters of the benthic substrate. This is generally known as the "oxic layer" due to the presence of oxygen in the sediments; in most instances this translates to the sediment horizon that is most biologically active. Contaminants located below the oxic layer are thought to be much less "bioavailable" due both to chemical form and physical isolation. In most cases, a "Van Veen" sampling device is used to retrieve the sample. Therefore, the samples represent the in-place sediments, of which only a portion may be periodically resuspended. Monitoring of the water column using unfiltered water samples is one approach to measuring contaminant concentration in suspended sediments. Again, water column data are available but such analysis was outside the scope of this project. The bay system is extremely dynamic and complex. Resuspension of fine-grain material by wind waves is a dominant force in shallower regions while current-driven bed-load transport of coarse material is common in the deep channels. In shallow areas where the benthic substrate is fine grained, there is typically a loose or "fluff" layer which hovers over the firm sediments.

Background Values

We are interested in determining the chemical concentrations of sediments prior to the region's industrialization. For the sake of clarity, these pre-industrialization levels are referred to as "background" values. Prior to the Gold Rush of the 1850's, there was no industrial discharge. However, industrial activities carried out in and after the late nineteenth century have had a profound effect on much of the San Francisco Bay Estuary. Two notable examples are the enormous discharge of silt resulting from hydraulic mining in the foothills of the Sierra mountains and the direct discharge of petroleum hydrocarbon waste from early industry such as coal-fired power plants and refineries. Industrial discharges continued uncontrolled until the enactment of the of the Clean Water Act in the 1960s. Since then, point source discharge of contaminants have steadily decreased.

Recent analysis of deep sediment cores by the United States Geological Survey (USGS) has provided valuable information on pre-industrial levels of several metals: copper, lead, mercury, silver and zinc (Hornberger, et al. *in press*). Other metals also discussed in this report included chromium, nickel and vanadium. Their analysis examines the trends in metal concentrations and reflects on historical industrial activity along the shoreline. Along with deposition rate analysis, their dating techniques also distinguish between "natural" and background levels due to geologic conditions and anthropogenic inputs. For example, the Bay Area is home to mercury deposits at both ends of the Estuary that have been mined since the 1800's (e.g. New Almaden Mine in the Guadalupe River watershed). Discharge of mercury used in the processing of gold-containing ore is thought to have also contributed to elevated levels Bay sediments. In addition, recently published data of typical heavy metals concentrations in various soil series may prove helpful to those reviewing metals contamination in the region (Bradford et al. 1996).

As compared to the background values found in deeper, pre-industrialized sediments, the surficial sediments contain elevated metal concentrations. This may be due in part to both historical (i.e., early industrialization) and current point and non-point discharges, as well as atmospheric deposition. Other factors controlling chemical concentrations of surficial sediments are bioturbation (mixing of sediments by benthic organisms) and resuspension of sediments by wave and current action. The ambient values found in this report represent Bay sediments considered to be the least contaminated or most "clean". The ambient, or *normal,* contemporary, chemical concentrations can be compared to project sediments to determine whether project sediments are elevated. For clarity's sake, we define the "ambient threshold" value are distinct from the *pre*-industrialization "background" values discussed above.

Toxicity Considerations

The 1995 Basin Plan addresses toxic chemicals by stating that waters shall be "...free of toxic substances in concentrations that are lethal to or that produce other detrimental responses in aquatic organisms" (Toxicity Narrative Standard page 3-4). In other words, it is a presumed that there can, and usually will be, potentially toxic chemicals detected at some concentrations. However, one must observe a toxic effect to consider this a failure of the standard. We know from the literature that toxic compounds in the water column may be, and perhaps often are, present at low levels without any observable toxic effect (non-acute). With some very toxic compounds, the dioxin 2,3,7,8 TCDD for example, toxicity may even occur at chemical concentrations too low for most laboratories to measure. Perhaps more troubling is the fact that there are thousands of organic, synthetic chemicals discharged into the environment for which we have little toxicological information. These compounds are not part of current monitoring programs and are therefore not included in this study. For example, research has shown that toxic organic compounds contained in household detergents (quaternary ammonium compounds) are released through the municipal treatment process (Fernandez et al. 1991). Also, potentially very toxic natural substances can be released during algal blooms, including so-called "red tides" (Gribble 1992, Carmichael 1994). In large part because chemical analyses can not accurately predict the actual toxicity of a discharge, federal and state regulations may require toxicity testing of effluent.

Likewise, sediments may also exhibit toxicity even though the toxic chemicals analyzed are found at low levels. However, there are no national standards for toxic chemicals in sediment and there are few widely accepted guidelines or state criteria. Perhaps because of the complex nature of the sediment matrix, the body of knowledge for sediment toxicity lags far behind our understanding of the effects of the same toxins in water. This is especially true of the interpretation of toxicological measures which are often mired by confounding effects.

Effects-Ranges

One notable benchmark that has come into wide use is the "effects-ranges" for potential toxic effects published by Dr. Long of the National Oceanic and Atmospheric Administration (Long et al. 1995, Long and Morgan 1991). The effects-ranges were developed using a "co-effects analysis" of data from bulk chemical and bioassay tests. These were derived from a large database spanning hundreds of data points, taken from numerous projects located across the country. The cutoff points corresponding to the effects ranges, the *low,* or "ER-L" and *median* or "ER-M", are presented along with the corresponding ambient values in Table 3. The intent of the ranges is to predict the *likelihood* of a toxic effect in sediment based upon bulk chemical concentrations. The predictive power of effects-ranges is enhanced when quotients and sums of quotients are used to analyze site chemistry. In this approach, a hazard quotient is calculated by dividing a measured concentration in sediment by the corresponding effects range level. If the hazard quotient is greater than one, there may be a potential for adverse effects. The sum of the individual quotients is then used to account for potential additive toxicological effects. This is similar to the approach used to calculate a hazard quotient in human health studies. The cause of toxicity in sediment may be the result of additive effects by multiple toxic chemicals. Note that the ambient values for several metals are well above the ER-L and the nickel ambient value is greater than the ER-M.

Data Sources and Considerations

Data used in the ambient analysis were from sites that represent the least impacted portions of the Bay (Table 2). The "ambient" sampling stations are located away from point and non-point pollution sources. In this context, we did not consider the Delta to be a "source" of discharge. The database used in this analysis is made up of data from the 1991 Pilot and ongoing Regional Monitoring Program and the Bay Protection and Toxic Cleanup Program's 1995 Reference Site study. Some of the Pilot RMP "bay" stations suspected of being proximate to sources (e.g. marinas) were removed from the database. None of the "marsh" stations from the Pilot RMP are included in the database because many Bay Area marshes are subject to urban runoff and other non-point discharges. The remaining data set consists of 81 records containing data on the following chemical substances:

- Polynuclear aromatic hydrocarbons (PAHs)
- Polychlorinated biphenyls (PCBs)
- Heavy metals and metalloids
- Selected chlorinated pesticides

Organotins were not included in the database because they are not part of routine sediment monitoring programs in the San Francisco Estuary. Likewise, volatile organic compounds (e.g. benzene), other light-fraction hyrocarbons and fuel additives (MTBE) are unlikely to be found in bay sediments and so are rarely quantified. The survey stations where sediments were collected for chemical analyses are all within the San Francisco Estuary. We did not include data from reference stations located outside San Francisco Bay (e.g. Tomales Bay) in the analysis. The characteristics of the Bay-Delta watershed are unique and so data from other separate water bodies, such as Tomales Bay were not included in the database. The station names are listed, as well as the dates of collection, in the table below. River stations ("BG" series) are located within the Central Valley RWQCB's jurisdiction (See Figure 1).

Table 2. Stations-Surveys

The numbers in the cells of the table indicate the number of field or location replicates taken. Blank cells indicate no data.

Location	Station#	Site	Data Source	Year: 1991 Month: 08	92 03	92 04	92 05	93 03	93 09	94 02	94 04	94 08	95 02	95 03	95 04	95 08
South Bay	20013	N. South Bay Ref.	REFERENCE SURVEY											3		
South Bay	20014	S. South Bay Ref.	REF SURV											3		
South Bay	BA20	Extreme South Bay	BPTCP SEDQUAL 3	1	1											
South Bay	BA21	South Bay	SFB RMP					1	1	1		1	1			1
South Bay	BA30	Dumbarton Bridge	SFB RMP	1	1			1	1	1		1	1			1
South Bay	BB15	San Bruno Shoal	SFB RMP							1		1	1			1
South Bay	BB30	Oyster Point	SFB RMP					1	1	1		1	1			1
South Bay	BB70	Alameda	SFB RMP							3		3	1			1
Central Bay	BC10	Yerba Buena Island	BPTCP SEDQUAL 3	1	1											
Central Bay	BC11	Yerba Buena Island	SFB RMP					1	1	1		1	1			1
Central Bay	BC21	Horseshoe Bay	SFB RMP					1	1	3		3	1			1
Central Bay	BC31	Richardson Bay	BPTCP SEDQUAL 3		1											
Central Bay	BC32	Richardson Bay	SFB RMP					1	1	1		1	1			1
Central Bay	BC41	Point Isabel	SFB RMP					1	1	1		1	1			1
Central Bay	BC50	Staufer	BPTCP SEDQUAL 3	1	1											
Central Bay	BC60	Red Rock	SFB RMP							1		1	1			1
North Bay	BD15	Petaluma River	SFB RMP										1			1
North Bay	BD20	Petaluma River Lt. 18	BPTCP SEDQUAL 3	1	1											
North Bay	BD22	San Pablo Bay	SFB RMP					1	1	1		1	1			1
North Bay	BD30	Pinole Point	BPTCP SEDQUAL 3	1	1											
North Bay	BD31	Pinole Point	SFB RMP					1	1	1		1	1			1
North Bay	BD40	Davis Point	BPTCP SEDQUAL 3	1												
North Bay	BD41	Davis Point	SFB RMP					1	1	3		3	1			1
North Bay	BF10	Pacheco Creek	SFB RMP	1		1		1	1	1		1	1			1
North Bay	BF20	Grizzly Bay	BPTCP SEDQUAL 3	1		2										
North Bay	BF21	Grizzly Bay	SFB RMP													
North Bay	BF40	Honker Bay	SFB RMP													
River	BG20	Sacramento River	SFB RMP													
River	BG21	Sacramento River In Sherman Lake	BPTCP SEDQUAL 3	1		1		1	1	1		1	1			1
River	BG30	San Joaquin River	SFB RMP					1	1	1		1	1			1
River	BG31	San Joaquin River At Kimball Island South	BPTCP SEDQUAL 3	1												
River	BG32	San Joaquin River At Kimball Island Southwest	BPTCP SEDQUAL 3			1										
North Bay	GD12	Pt. Pinole pilings, shallow	BPTCP SEDQUAL 3				5									
Central Bay	SF01-1	Paradise Cove	REF SURV								3			1		
North Bay	SF02-3	San Pablo Bay-Island #1	REF SURV								3				1	
North Bay	SF03-1	San Pablo Bay-Tubbs Is.	REF SURV								3				1	

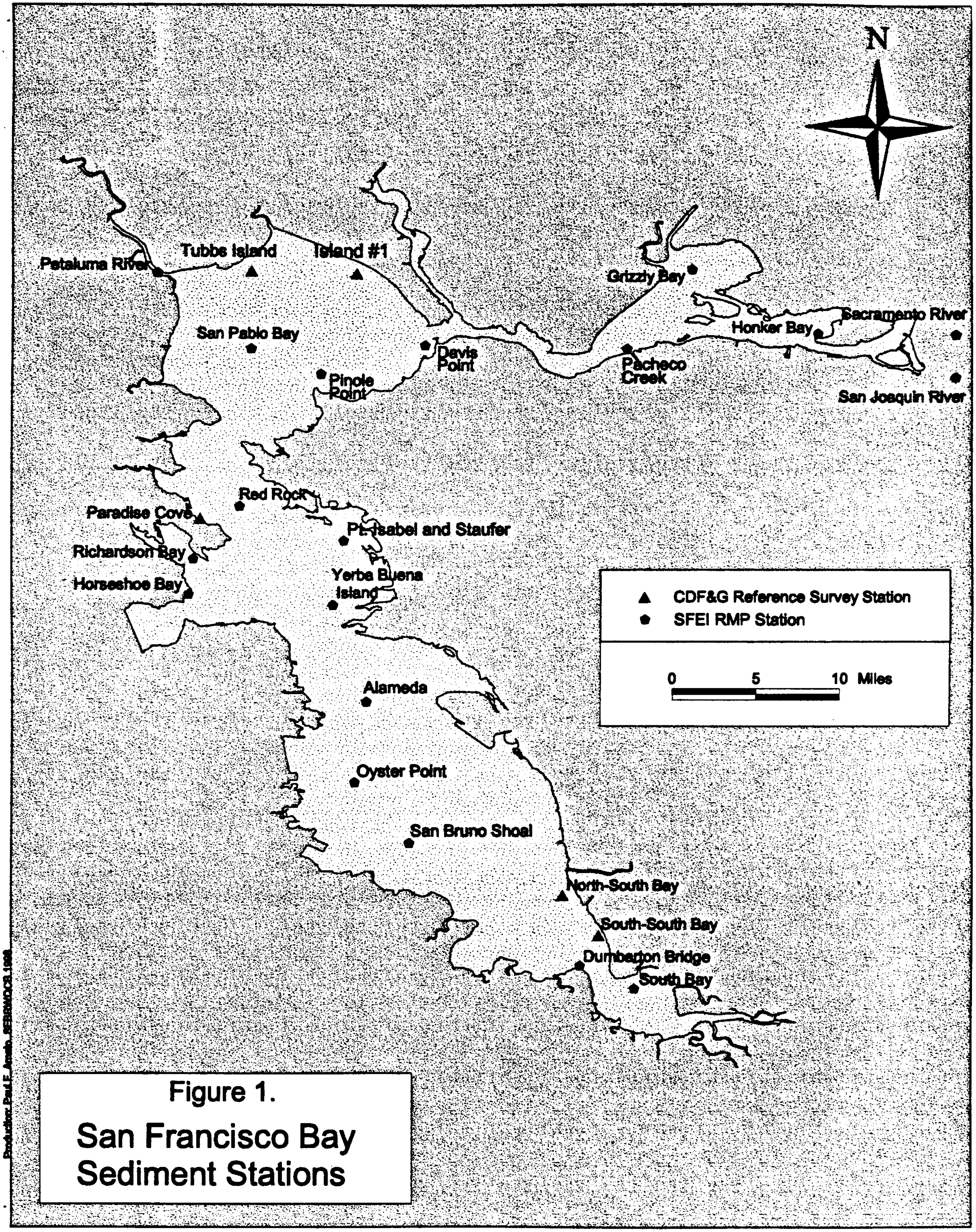


Figure 1.

San Francisco Bay Sediment Stations

Removal of Outliers

Outliers were removed from the data set by deleting points in the scatter plots that were above obvious breaks in the clustering. The placement of these "breaks" in the data then determined the rules used to pull the results from the statistical analysis. Nineteen stations were subject to outlier removal. For PAHs, several outliers were indicative of elevated concentrations of other PAH compounds. Four of the nineteen stations that were subject to outlier removal are attributable to generally elevated PAH levels. Outlier removal should not be confused with exclusion of entire stations due to potential contamination from local inputs which was done prior to outlier removal. Relatively extreme measurement values (compared to the rest of the values) can greatly affect the computed tolerance interval bounds, because those values can result in unreasonably high upper bounds. Hence, the usefulness of the upper bound as a screening tool for regulatory compliance could be questionable. The analytical approach for the determination of outliers is outlined in the box below.

RULES FOR IDENTIFYING AND REMOVING OUTLIERS

1. For the coarse sediment (<40% fines), a maximum measurement that was 2.9 times the next highest value, and if the second highest value was 3 times the next highest value, then it was removed.
2. For the finer sediment (>40% fines), a maximum measurement that was 1.4 times the next highest value, or if the second or third highest value was 1.8 times the next highest value, then it was removed.
3. The procedure outlined above was only performed once, i.e., the procedure was not redone to the remaining data after the first set of outliers was removed.

(Discarded data is described in Appendix A of the report by Smith and Riege, EcoAnalysis, Inc.)

Statistical Approach for the Determination of Upper Bounds

This report will present only a brief overview of the statistical data analysis employed. For a complete description of the statistical methods employed, the reader is encouraged to review the analysis, described in *San Francisco Bay Sediment Criteria Project*, Ambient Analysis Report, (Smith and Riege 1998). Copies may be obtained from the Regional Board's Planning and Policy Section. A common approach to defining chemical concentrations in soil and sediment data has been to derive a mean concentration and calculate an upper bound based on the standard deviation and the sample size with the following equation (EPA, 1989).

$$UCL = X_{av} + K\sigma$$

Where: UCL = Upper Confidence level
Xav = arithmetic mean
σ = standard deviation
K = One sided normal tolerance factor

Such an approach is only appropriate for randomly and normally distributed data.

Reference information, such as the ambient threshold values, can be of great help in assessing potentially contaminated sites. However, deriving a mean value is not ideal when the sampling scheme is non-random. Also, the assumption of normal distribution for the data is not always true. In our case the sampling spans several years of time and sampling sites were predetermined (fixed monitoring stations). Therefore, we needed a different statistical approach. The distribution of the data as a function of particle size and some results of the statistical analysis are shown in the attached scatter plots. In addition, the thresholds for a *P*-value of 0.85 are listed in Table 3. This information may prove helpful for making site-specific and project-specific comparisons of sediment quality.

The objective of this project was to statistically define the upper bound or "threshold value" for the bay reference or *ambient* sediments. Several physical factors and chemical factors, such as TOC, particle surface area and particle size distribution, are known to correlate with chemical concentrations in sediments. Grain size was selected as the main cofactor for the data analysis as it is easily measured. This is in part due to the lack of data for these other parameters (TOC, surface area and cation exchange capacity), as well as the interrelationship of these factors with grain size. After careful analysis of the distributions with respect to particle size, three statistical models were employed. The model used was consistent for each class of chemicals: heavy metals distributions fell under one model, PAHs fell into a second, and PCBs and pesticides fell into yet a third model. The three models are simply different equations that fit the three different distributions of concentrations. Data were analyzed either directly or after a log transformation. Upper bounds were then calculated using these equations following parametric methods for normal data distributions. When the distribution of the data could not be shown to be normal, upper bounds were calculated using non-parametric statistics.

Treatment of Censored Data (Non-detects)

In the database, all concentrations less than the analytical detection limit were recorded as a value of zero. For PAHs and metals (models 1 and 2), the values of zero were replaced by a value equal to one half the smallest concentration detected for each chemical. For the metals, a constant of 1 was added to all values for chemicals where the minimum value was less than one. For the chemicals with a minimum value of zero, the addition of the constant prevented indeterminate values when applying the log transformation. In addition, for the chemicals with a minimum value of less than one, addition of the constant made all log transformed values positive, which in turn helped increase the linearity of the relationship between the transformed data and percent fines. These constants are simple data manipulations that do not affect the quality of the resulting upper bounds, and need not be considered in order to compare the calculated upper bounds to sediment data.

Heterogeneity

Bias in the data set due to changes over time was accounted for by the statistical methods. We qualitatively assessed the trends and bias due to geographic location of samples by coding the samples according to bay segment (south, central, north and river) and looking for patterns. No obvious trend or pattern was observed based on location or sampling event (time). As previously mentioned, sediment contaminant concentration is partially a function of sediment texture. Since coarse-grained sediments occur in various locations throughout the Estuary, contaminant concentrations are probably distributed as a function of hydrodynamic energy in addition to proximity to natural and man-made sources.

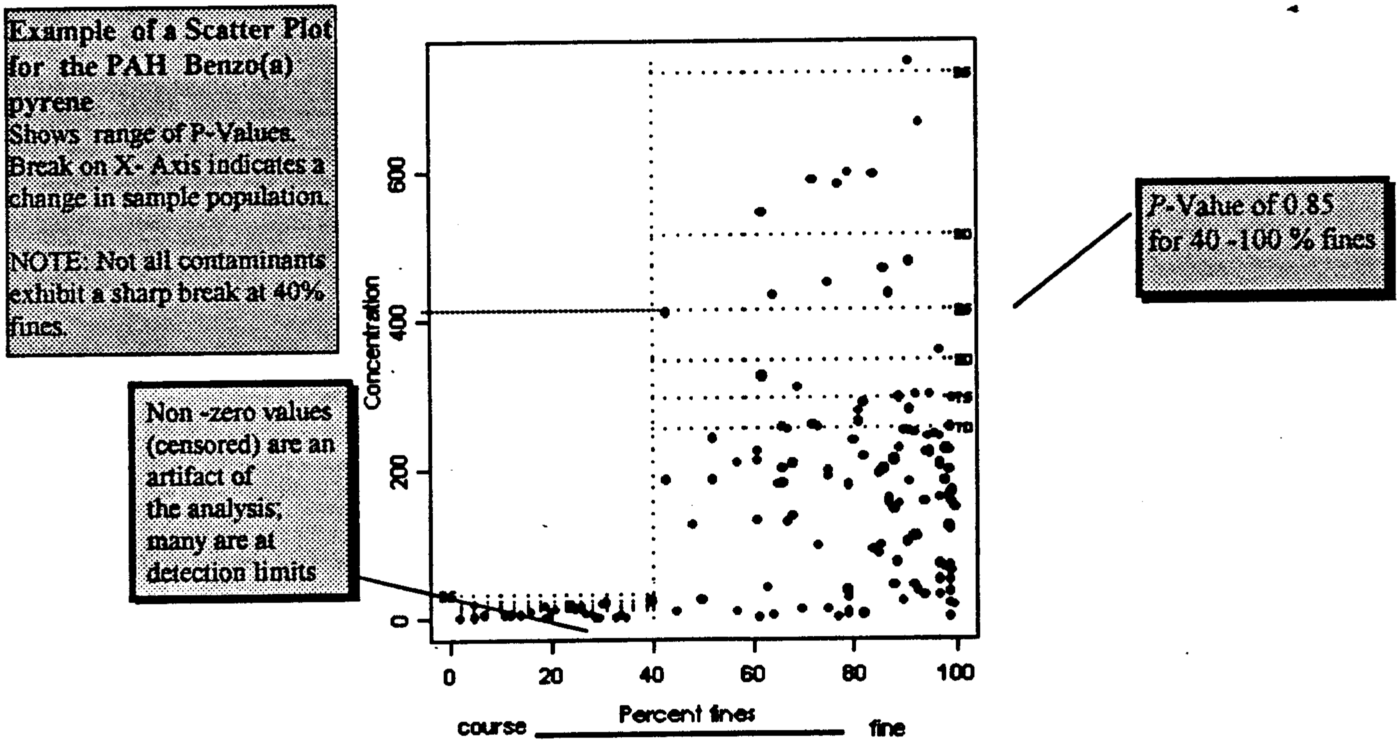
Setting *P*- and Alpha Values

The *P*-value is the percentile of the ambient population that will have a concentration less than the upper bound calculated using this *P*-value. Alpha is the confidence level that the calculated upper bound is correct. Selection of an appropriate *P*-value is a policy decision: there is no mathematical approach to setting these values. However, one of our objectives was to find a *P*-value that best "fit" the data clusters so as to strike a balance between resource protection and characterization of an impacted environment. Initially, several *P*-values ranging from 0.70 to 0.95 were generated from the data. After careful consideration, we concluded that a *P*-value of 0.85 is an appropriate bound for this data set and should be set as the threshold for screening purposes.

Confidence levels, or alpha values, in environmental data analysis are typically set at a level of 0.05 resulting in 95% confidence in the calculated threshold value. We adopted this confidence level, or alpha, so as to be consistent with other work done in the field. Increasing alpha will have the effect of increasing the upper bound, while decreasing alpha decreases the upper bound.

Polynuclear Aromatic Hydrocarbons

We generated threshold values for Polynuclear Aromatic Hydrocarbons (PAHs) for grain sizes less than 40% fines and between 40 and 100 % fines (Table 3). The example plot below shows the influence of grain-size upon contaminant concentration under this model. The plots indicate that there are actually two populations of data for each PAH compound. The data above and below 40% fines was analyzed separately resulting in two upper bounds for fine (> 40 % fines) and coarse (< 40 % fines) grained sediments. Percent fines is the grain size fraction that is less than 62.5 m mean diameter.



Example of a Scatter Plot for the PAH Benzo(a) pyrene
Shows range of P-Values.
Break on X- Axis indicates a change in sample population.

NOTE: Not all contaminants exhibit a sharp break at 40% fines.

Non -zero values (censored) are an artifact of the analysis; many are at detection limits

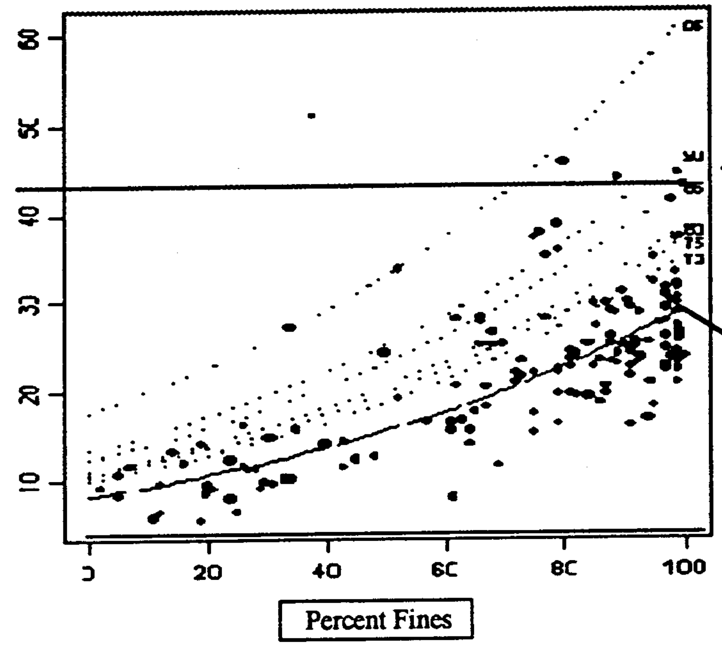
P-Value of 0.85 for 40 -100 % fines

Metals and Chlorinated Hydrocarbons

Deriving bounds for metals and chlorinated hydrocarbons was more complicated than for the other contaminant classes. The additional complication resulted from analyte concentrations that are continuously dependent upon grain size (i.e., heavily biased) rather than two distributions for coarse and fine material that we see in the PAHs. Separate models were applicable to these two classes of compounds although both increased in concentration with increasing percent fines. The relationship between chemical concentration and percent fines is a complex function of the differences in surface area, ion exchange capacity, organic carbon content and mineralogy.

The statistical analyses did not consider the measurement error associated with grain size determinations. As this error can be significant, this report proposes the use of two upper bounds numbers: the upper bound for 40% fines and for 100% fines for coarse grain and fine grain sediments, respectively.

Example Scatter Plot for lead
Shows concetration as a function of percent fines.



Bound at P-value of 0.85 at 100% fines

Regression line (solid)

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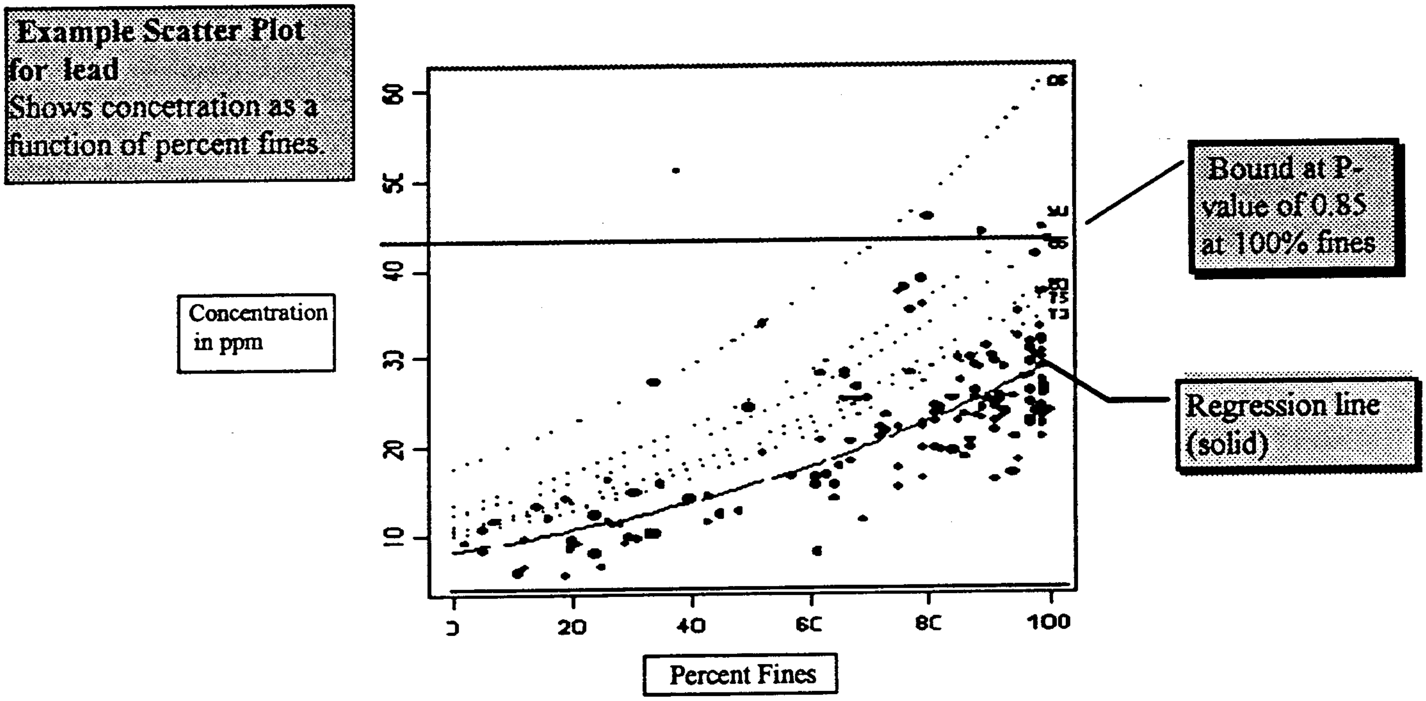

TABLE 3. Sediment Thresholds

Analyte	ER-L [1995] (dry wt.)	ER-M [1995] (dry wt.)	S.F. Estuary Sediment Ambient Concentration (dry wt.) [p=85]		USACE Bay Area Marsh Study (C.R. Lee, et.al) (wet wt.)	
			<40 % fines	<100 % fines	Mean	Range
Metals (ppm) (HNO3/HCl Digestion)						
Arsenic	8.2	70	13.5	15.3	14.8	(5.29-23.7)
Cadmium	1.2	9.60	0.25	0.33	0.34	(0.14-0.56)
Chromium	81	370	91.4	112	181	(110-224)
Copper	34	270	31.7	68.1	63.7	(24.2-90.6)
Lead	46.7	218	20.3	43.2	35.4	(13.7-85.6)
Mercury	0.15	0.71	0.25	0.43	0.33	(0.059-0.515)
Nickel	20.9	51.6	92.9	112	105.4	(32.2-145.2)
Selenium			0.59	0.64	0.32	(>0.14-0.91)
Silver	1	3.7	0.31	0.58		
Zinc	150	410	97.8	158	143.3	(88.5-166.1)
Organic Compounds (ppb)						
Chlordanes, total			0.42	1.1		
Dieldrin			0.18	0.44		
HCH, total			0.31	0.78		
HCB, total			0.19	0.48		
DDTS, total of 6 isomers	1.58	46.1	2.8	7		
PCBs, total	22.7	180	5.9	14.8		
PCBs, total (SFEI 40 list)			8.6	21.6		
1-Methylnaphthalene			6.8	12.1		
1-Methylphenanthrene			4.5	31.7		
2,3,5-Trimethylnaphthalene			3.3	9.8		
2,6-Dimethylnaphthalene			5	12.1		
2-Methylnaphthalene	70	670	9.4	19.4		
Acenaphthene	16	500	11.3	26.6		
Acenaphthylene	44	640	2.2	31.7		
Anthracene	85.3	1100	9.3	88		
Benz(a)anthracene	261	1600	15.9	244		
Benzo(a)pyrene	430	1600	18.1	412		
Benzo(b)fluoranthene			32.1	371		
Benzo(e)pyrene			17.3	294		
Benzo(g,h,i)perylene			22.9	310		
Benzo(k)fluoranthene			29.2	258		
Biphenyl			6.5	12.9		
Chrysene	384	2800	19.4	289		
Dibenz(a,h)anthracene	63.4	260	3	32.7		
Fluoranthene	600	5100	78.7	514		
Fluorene	19	540	4	25.3		
Indeno(1,2,3-c,d)pyrene			19	382		
Naphthalene	160	2100	8.8	55.8		
Perylene			24	145		
Phenanthrene	240	1500	17.8	237		
Pyrene	665	2600	64.6	665		
High molecular weight PAHs, total	1700	9600	256	3060		
Low molecular weight PAHs, total	552	3160	37.9	434		
PAHs, total	4022	44792	211	3390		

Discussion and Recommendations

We recommend that the ambient level *threshold* for routine use be based upon the bound for the 85th percentile (P=0.85) as derived for sediments at the 100% fines level. The ambient thresholds are presented in Table 3. Most projects encountered by Regional Board staff involve sediments that are greater than 40% fines. Given the uncertainties of the data, It is appropriate that the threshold values for metals, chlorinated hydrocarbons and pesticides be based upon the bound for 100% fines. Very coarse-grained ambient sediments are essentially devoid of chlorinated compounds.

We have also included Effects-Range levels (ER-L, ER-M) and metals data from the USACOE marsh study in the table for comparative purposes. The ambient threshold is the point at which one can say with confidence that a given concentration is either within the ambient (reference) population or elevated above it. The threshold is not a sort of "average" around which there is a region of uncertainty (error bar); rather, it is the "edge" of the reference "envelope". As discussed above, the ambient thresholds do not speak to the potential toxicity of these chemical at low levels. Toxicity of chemicals at ambient levels is a question well outside the scope of this study. However, sediments that are swept into dredged channels or on to newly formed marsh surfaces would be expected to contain chemical concentrations as high as the ambient concentrations presented in this report.

Most projects subject to regulatory scrutiny involve fine grained sediments (e.g. dredging and military base closure). Therefore, the thresholds for fine material should prove more useful to agency staff. Very coarse material should be compared to the ambient value for coarse sediments.

In various site-specific sediment investigations, we have seen concentrations of chlorinated organic compounds above the ambient thresholds. Some of these investigations were conducted in locations that are well off-shore and remote from suspect sources. The fact that these sites have levels of chlorinated organic compounds above the ambient is, in some cases, a reflection of the relatively low detection limits used in the monitoring programs. In other words, the detection of the chlorinated organic compounds is at or near the limits of detection and their occurrence in these mostly off-shore sediments is heterogeneous. Therefore, the comparison of project sediments to ambient thresholds for compounds such as PCB and HCH may be, essentially, a comparison to non-detection. This can be contrasted to the detection of heavy metals and PAHs which are based upon a wider distribution. The resultant ambient thresholds for those two classes are well above detection limits.

Several metals are found at levels exceeding some guidelines and thresholds (e.g., ER-Ls). This is due in large part to the geologic conditions in the Estuary's watershed. Many of the stations included in this analysis are located offshore in the San Francisco Bay far from potential sources of contamination. Metals concentrations may be even higher in certain locations due to geology; these data are not covered in our analysis. For example, mercury concentrations are elevated in North Bay tributaries as compared to the mid-bay stations used in this study. We found the threshold in fine sediment for mercury to be 0.43 ppm. However, sediment samples taken in the Napa River and Novato Creek watersheds show numerous samples in the 2 ppm to 4 ppm range with a peak of 9 ppm (Regional Board Case Files: Corps of Engineers, Dredging applications, Napa River Flood Control Project). Again, data from peripheral locations, such as marshes, creeks, and other tributaries were not analyzed in this project. Much of these data are not readily available in electronic form.

In Table 3 we include the ER-L and ER-M values; as well as, metals data from a survey of marsh stations performed by the U.S. Army Corps of Engineers (Lee et al. 1992). Though these are included for comparative purposes, it should be note that the Corps of Engineers data, is in wet weight, whereas all other values provided are in dry weight. The reason is that the Corps collected the sediment data as a part of a larger study of plant and animal bioaccumulation, the endpoint for which is expressed in wet weight.

The ambient concentration plots and thresholds (calculated tolerance interval bounds at the 85th percentile) should be used in site comparisons and in concert with other measurements and endpoints. If toxicity testing or bioassay data is available, those data should also be considered during the decision making process. In the case of sites for which there is little reason to suspect polluted sediments, these ambient thresholds may prove most useful as a "first-level screen" in the decision-making process. In this way, ambient concentrations can serve to define what is "elevated" relative to the suspended sediments distributed throughout the Bay. For projects involving sediment concentrations well above the ambient thresholds, more sophisticated measurements of toxicity and estimates of bioavailability should be considered.

It is believed that the ambient values presented in this report will be valid for a number of years. RMP data collected over a four year period shows that the concentrations of contaminants in sediments at these mid-bay sites does not change substantially from one year to the next. For this reason we recommend that the database be updated and the thresholds recalculated on a triennial basis.

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9. United States Environmental Protection Agency. 1989. *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities,* February 1989 (PB89-151047)

Related Reading

1 *Review of Sediment Quality Investigations in San Francisco Bay,* NOAA Technical Memorandum NOS ORCA 116

2 *Contaminated Sediments in Ports and Waterways,* National Science Foundation, 1997

3 USEPA and USCOE. 1992. *Evaluation of Dredged Material Proposed for Ocean Disposal, Testing Manual,* United States Environmental Protection Agency / U.S. Army Corps of Engineers, February 1992.

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5. San Francisco Estuary Institute (SFEI). 1993. Regional Monitoring Program for Trace Substances, San Francisco Estuary Institute

6. SFEI. 1994. Regional Monitoring Program for Trace Substances, San Francisco Estuary Institute

7. SFEI. 1995. Regional Monitoring Program for Trace Substances, San Francisco Estuary Institute

Primary Data Sources

1. Regional Monitoring Program for Trace Substances - Data can be found in Annual reports 1993-1995
2. San Francisco Estuary Pilot Regional Monitoring Program: Sediment Studies, Final Report, July 1994, Submitted to: San Francisco Bay Regional Water Quality Control Board, State Water Resources Control Board
3. Evaluation of Sediment Toxicity Tests and Reference Sites in San Francisco Bay, Final Report, 1998

Attachments

1. Table of Chemical Analytes
2. Data plots for Analytes showing thresholds for course and fine grained sediments (bound @ P=0.85)

Attachment 1.

Chemical Analytes

Chemical #[2]	Chemical Class	Chemical Name
1	PAH	1-METHYLNAPHTHALENE
2	PAH	1-METHYLPHENANTHRENE
3	PAH	2,3,5-TRIMETHYLNAPHTHALENE
4	PAH	2,6-DIMETHYLNAPHTHALENE
5	PAH	2-METHYLNAPHTHALENE
6	PAH	ACENAPHTHENE
7	PAH	ACENAPHTHYLENE
8	PAH	ANTHRACENE
9	PAH	BENZ(A)ANTHRACENE
10	PAH	BENZO(A)PYRENE
11	PAH	BENZO(B)FLUORANTHENE
12	PAH	BENZO(E)PYRENE
13	PAH	BENZO(GHI)PERYLENE
14	PAH	BENZO(K)FLUORANTHENE
15	PAH	BIPHENYL
16	PAH	CHRYSENE
17	PAH	DIBENZ(A,H)ANTHRACENE
18	PAH	FLUORANTHENE
19	PAH	FLUORENE
20	PAH	INDENO(1,2,3-CD)PYRENE
21	PAH	NAPHTHALENE
22	PAH	PERYLENE
23	PAH	PHENANTHRENE
24	PAH	PYRENE
25	PAH	SUM OF HEAVY PAHS
26	PAH	SUM OF LIGHT PAHS
27	PAH	TOTAL PAH
28	Pest/PCBs	SUM OF PCBS - NST 18 LIST
29	Pest/PCBs	SUM OF PCBS - SFEI 40 LIST
30	Pest/PCBs	DIELDRIN
31	Pest/PCBs	HEXACHLOROBENZENE
32	Pest/PCBs	SUM OF CHLORDANES
33	Pest/PCBs	SUM OF DDT
34	Pest/PCBs	SUM OF HCH
35	Metal	Silver
36	Metal	Arsenic
37	Metal	Cadmium
38	Metal	Chromium (aqua regia digest only)
39	Metal	Nickel
40	Metal	Selenium
41	Metal	Copper
42	Metal	Mercury
43	Metal	Lead
44	Metal	Zinc

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[2] Chemical number was assigned for convience. i.e., not conventional.

ATTACHMENT 2

ATTACHMENT 2

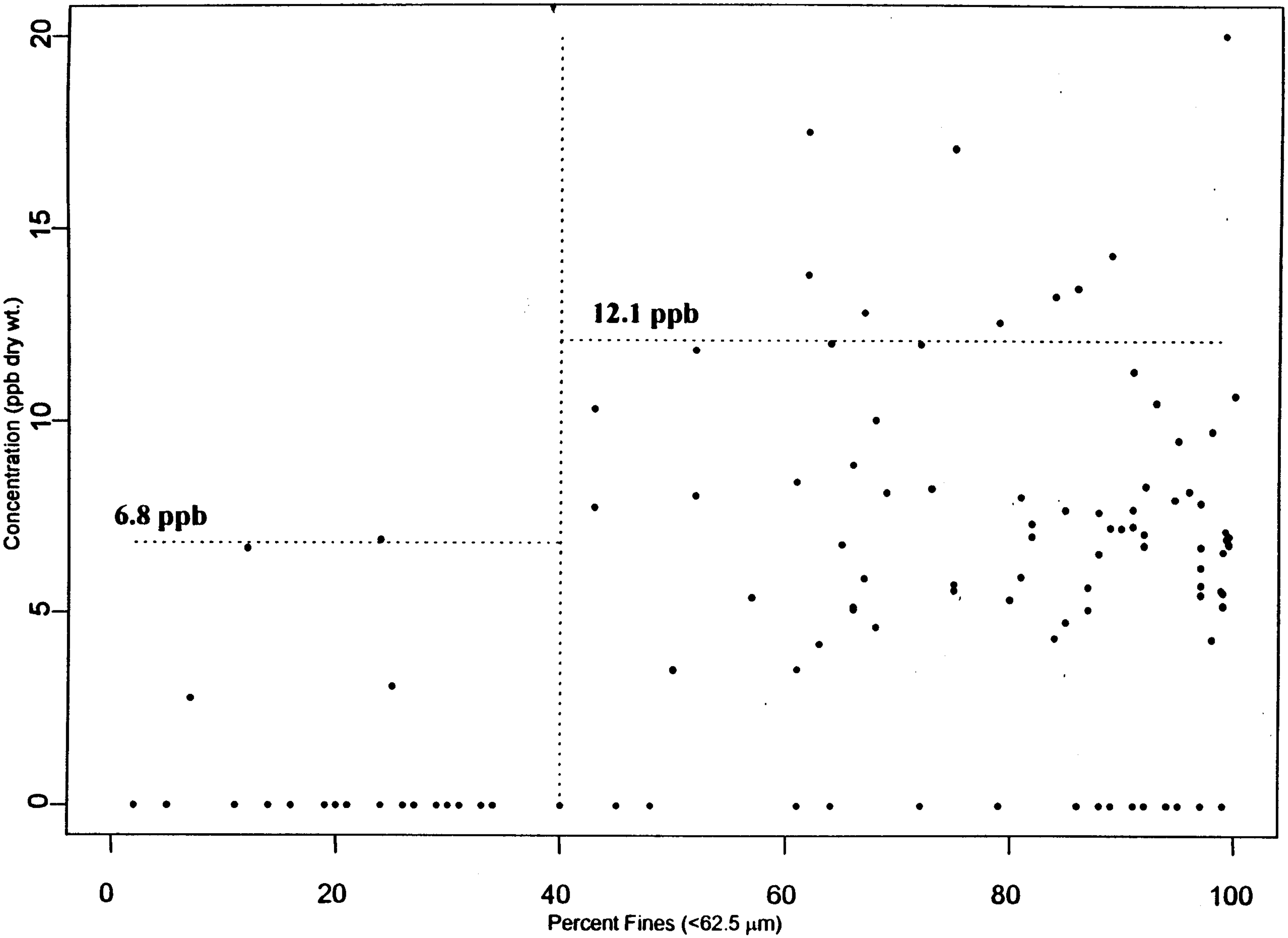

Figure 1. 1-Methylnaphthalene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

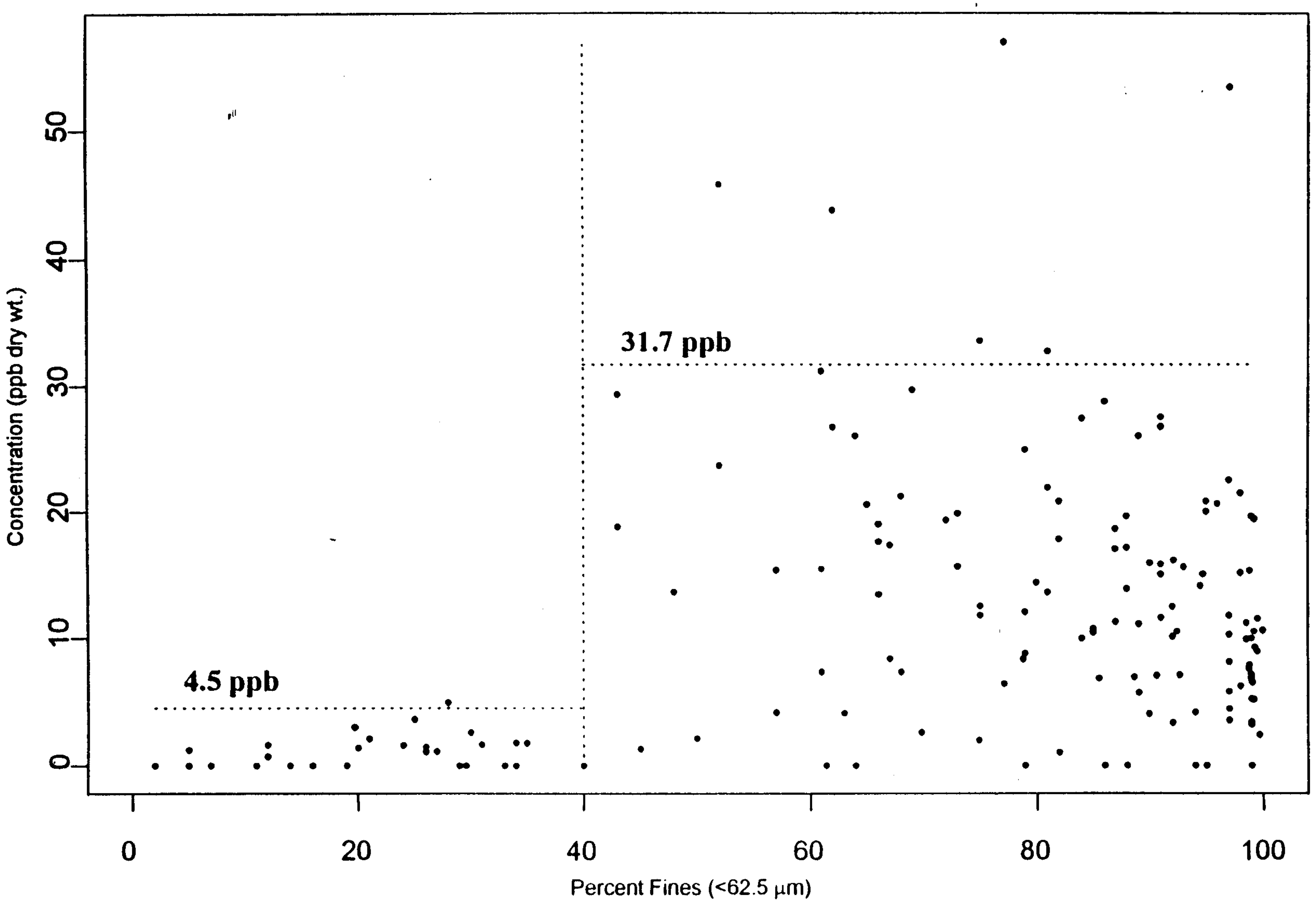

Figure 2. 1-Methylphenanthrene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

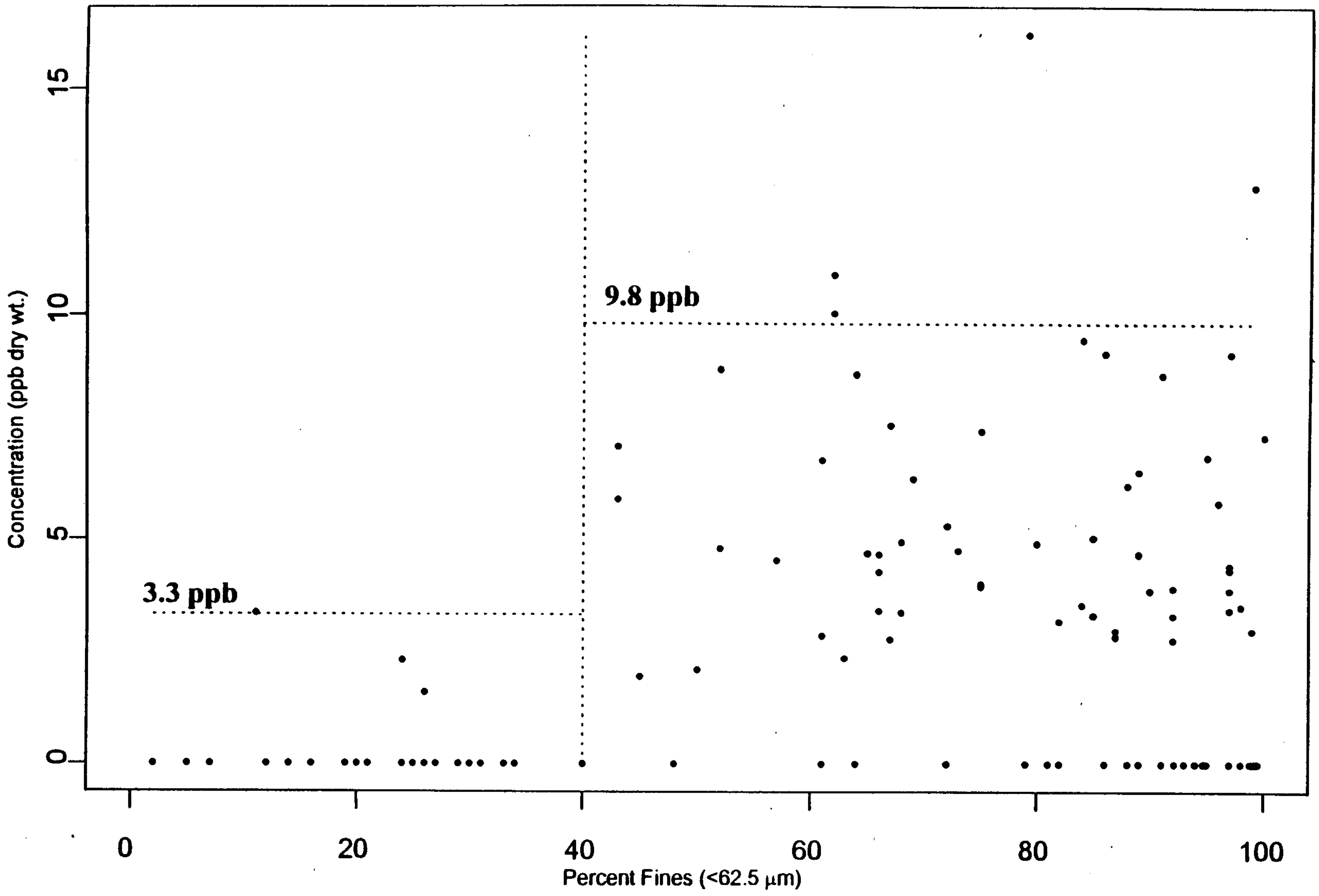

Figure 3. 2,3,5-Trimethylnaphthalene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

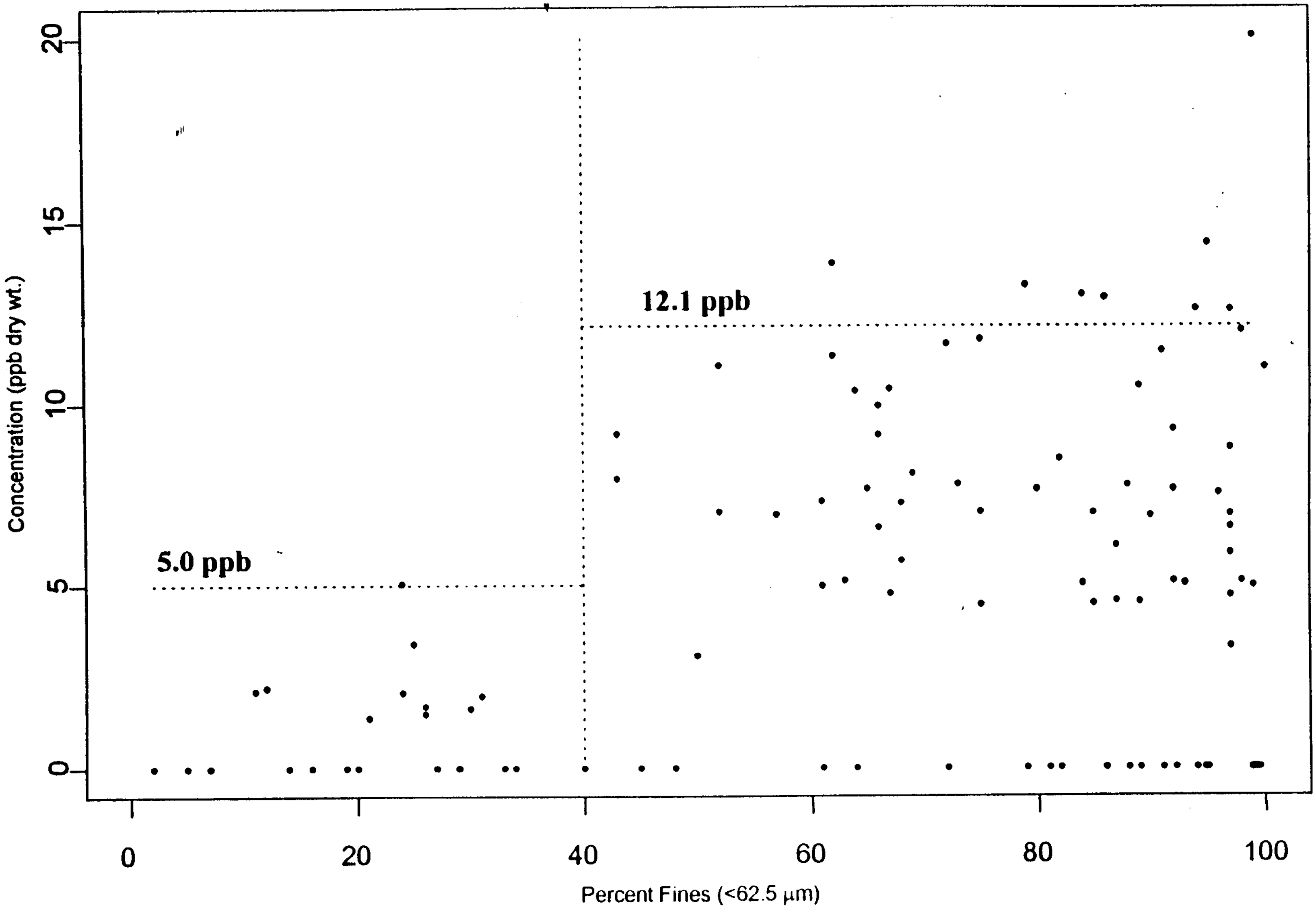

Figure 4. 2,6-Dimethylnaphthalene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

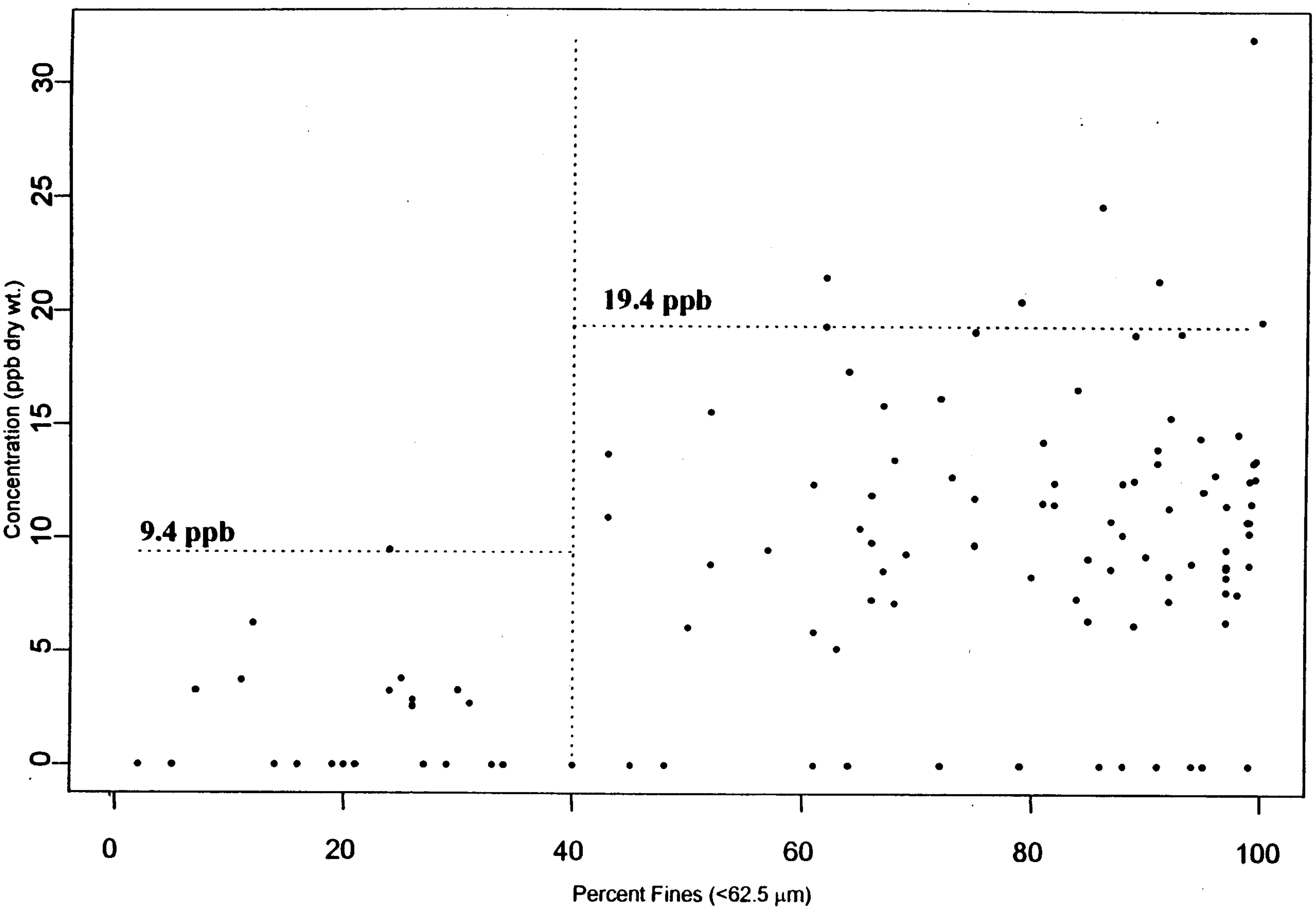

Figure 5. 2-Methylnaphthalene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

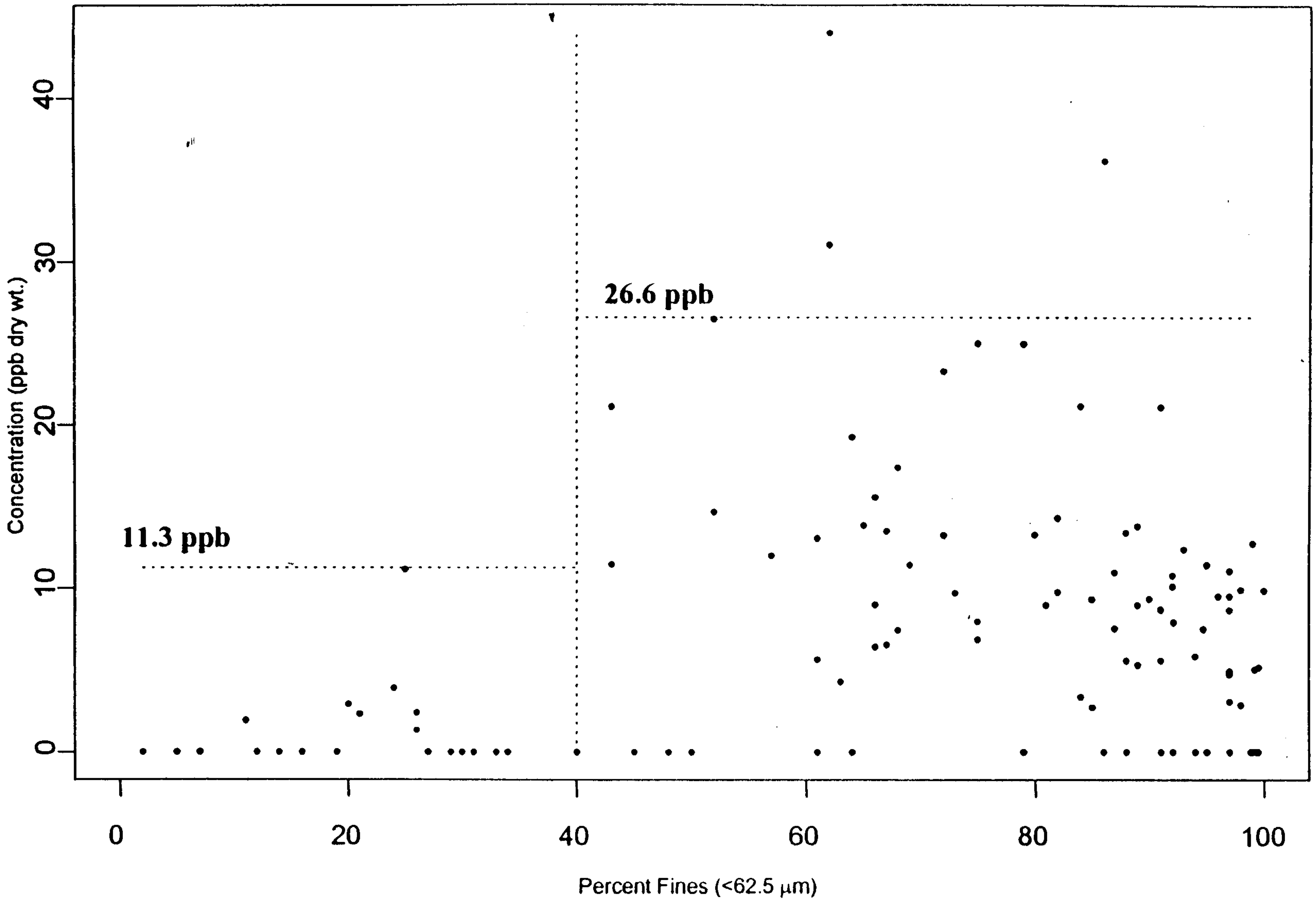

Figure 6. Acenaphthene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

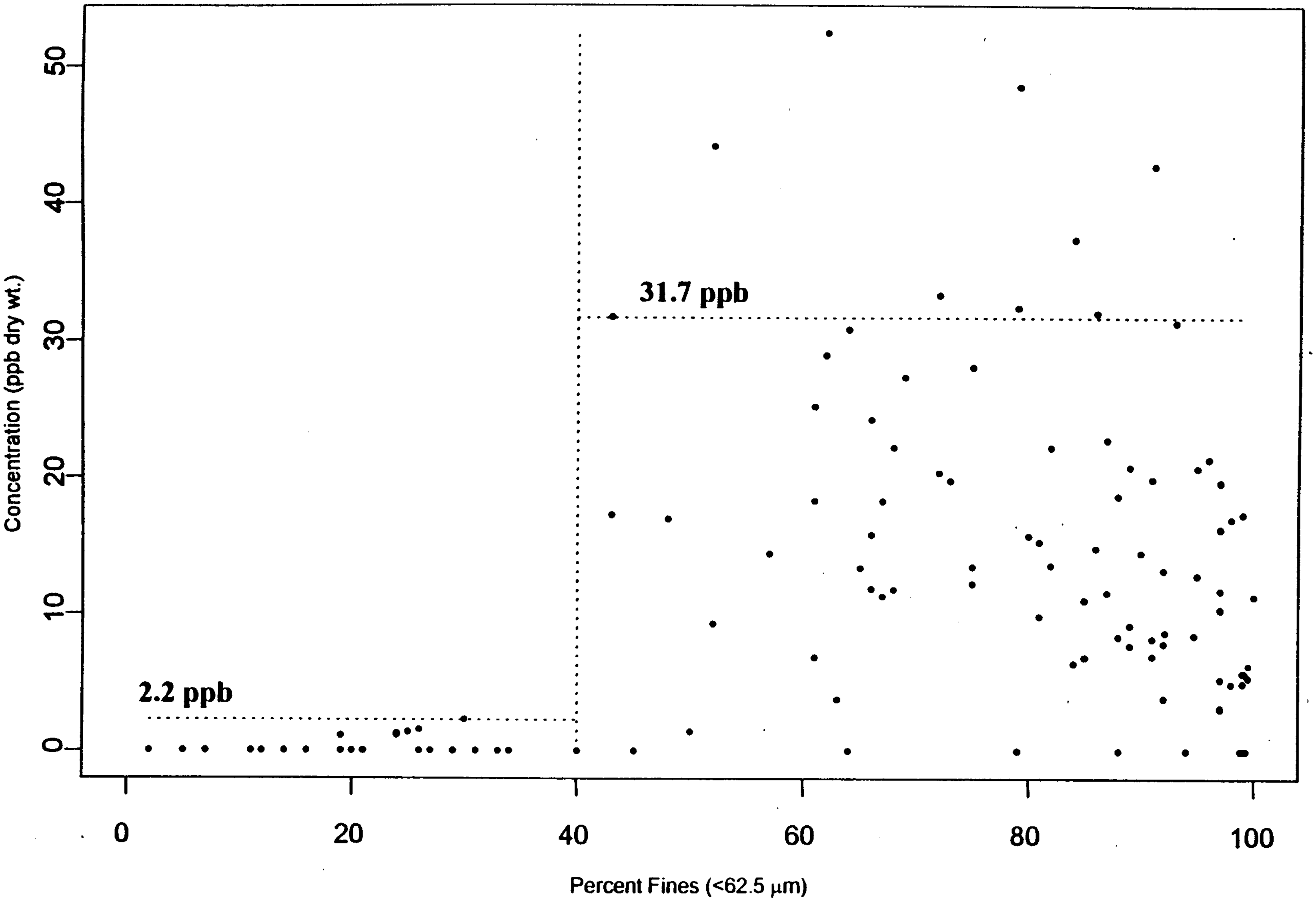

Figure 7. Acenaphthylene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

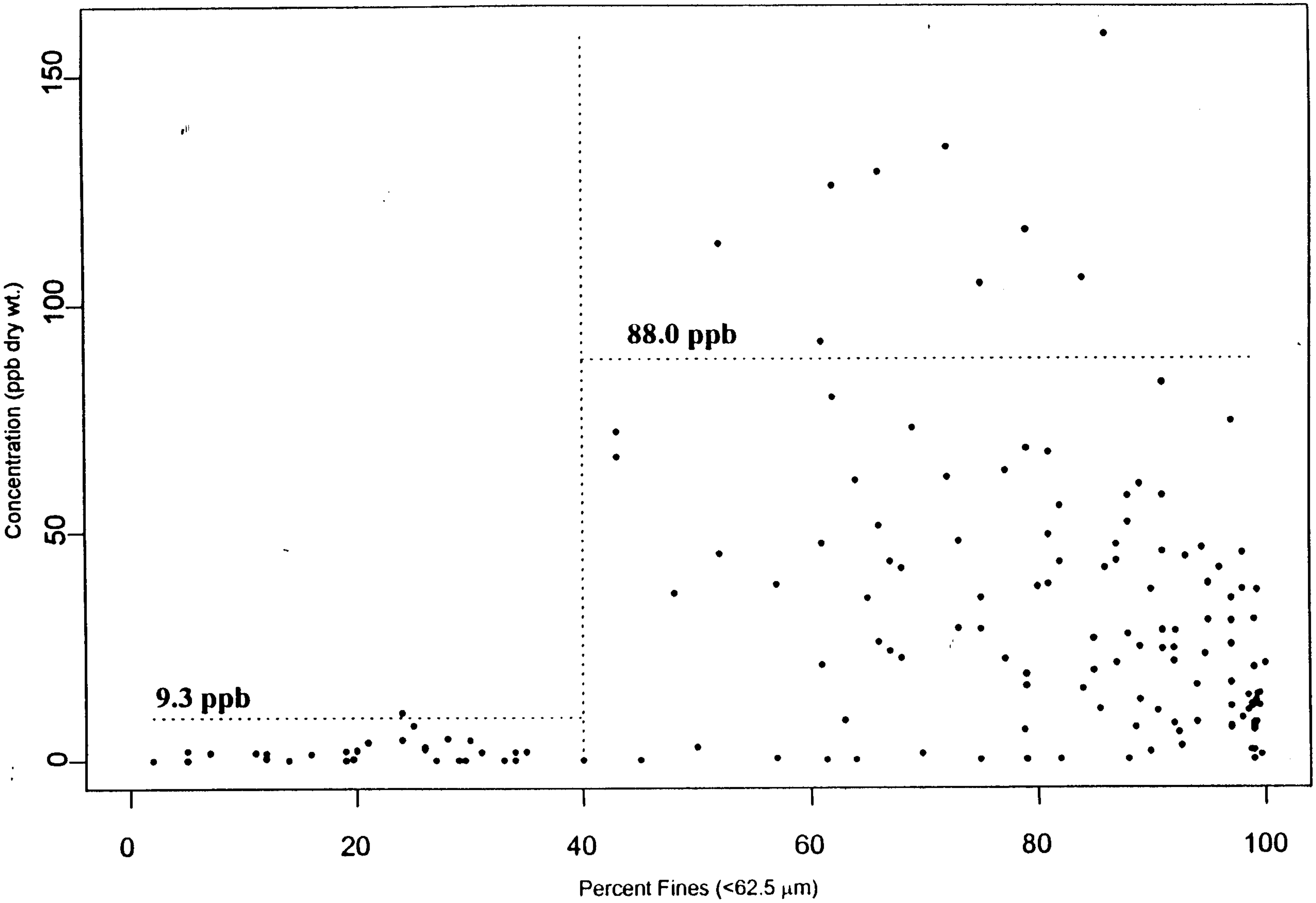

Figure 8. Anthracene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

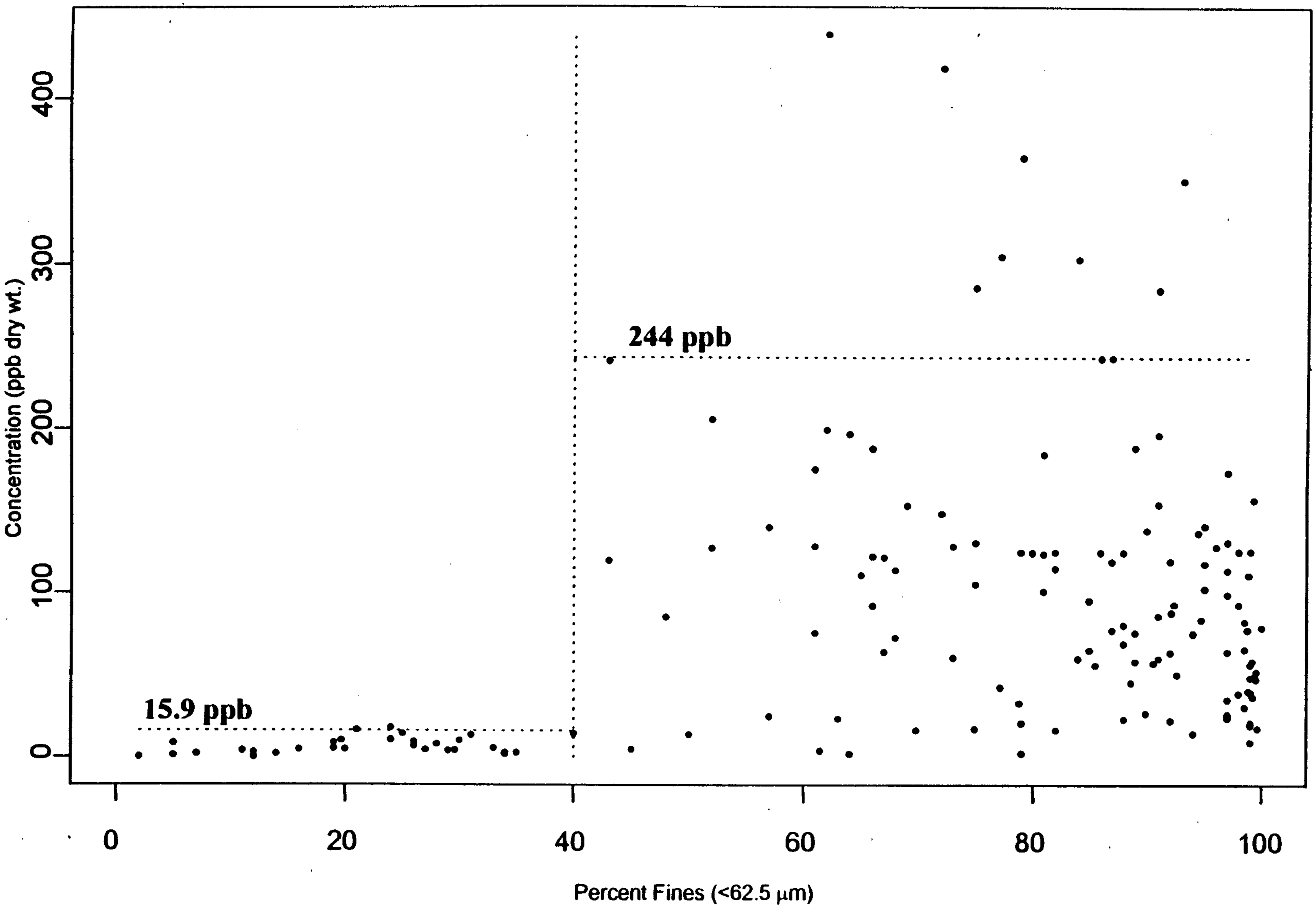

Figure 9. Benz(a)anthracene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

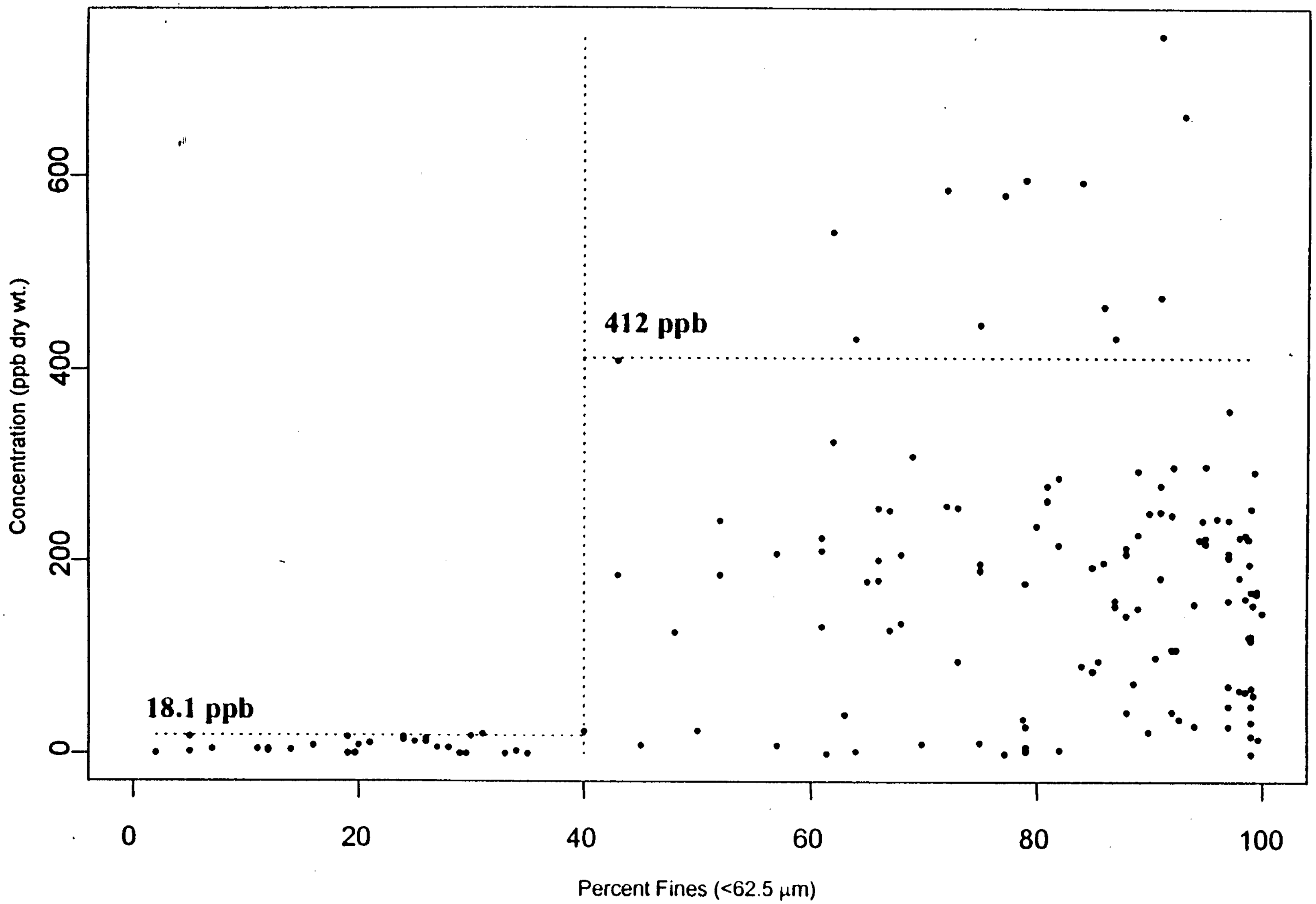

Figure 10. Benzo(a)pyrene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

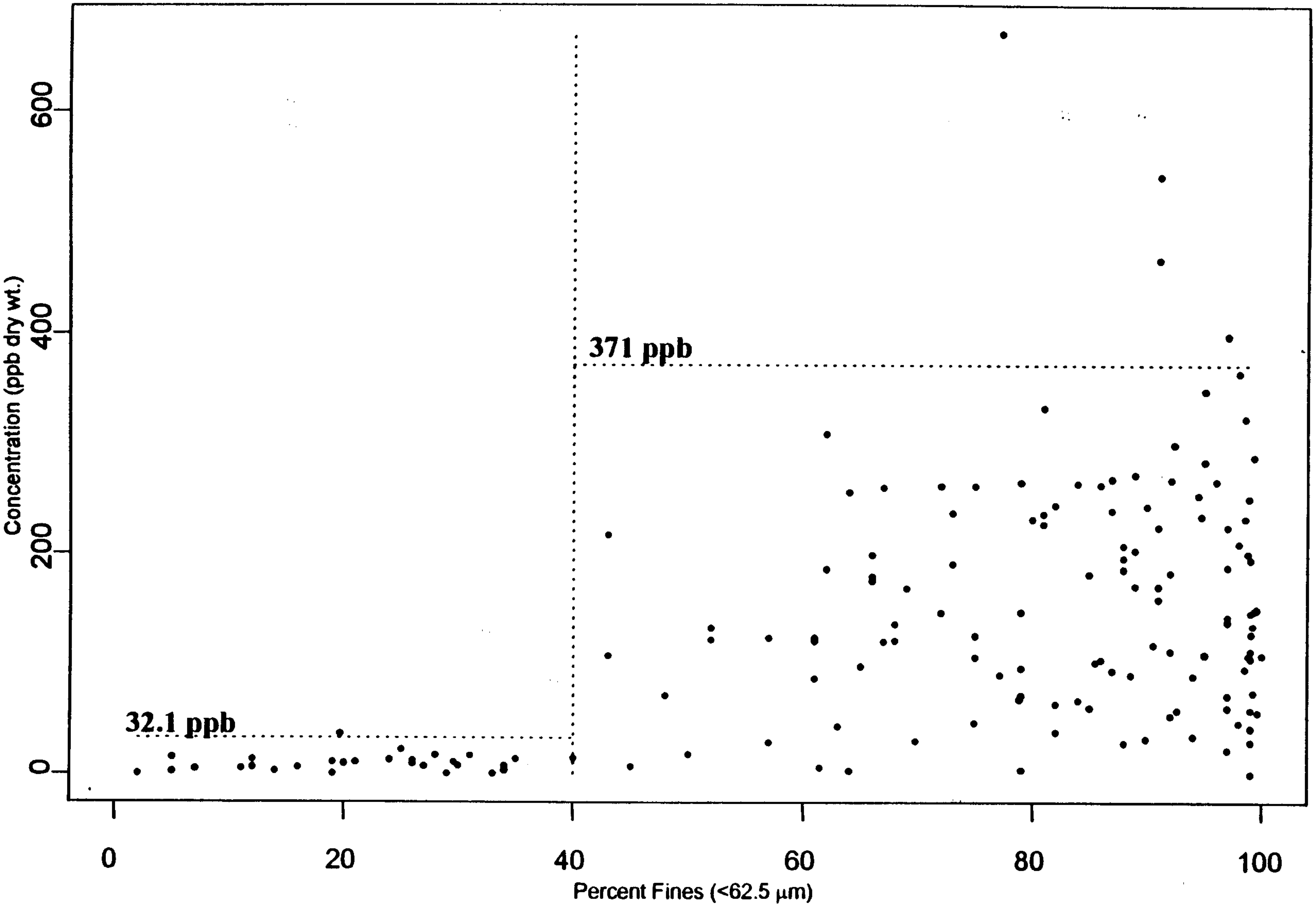

Figure 11. Benzo(b)fluoranthene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

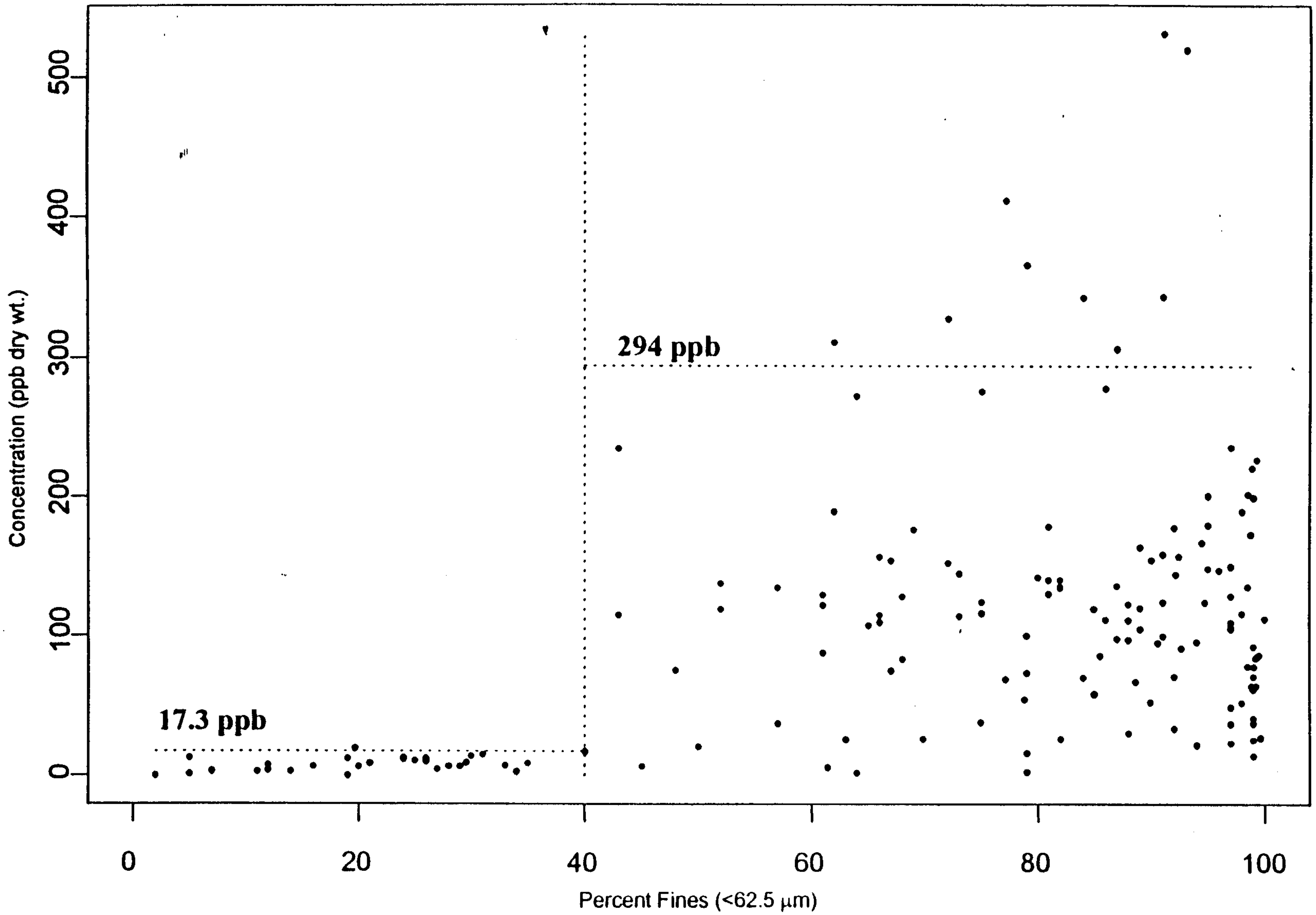

Figure 12. Benzo(e)pyrene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

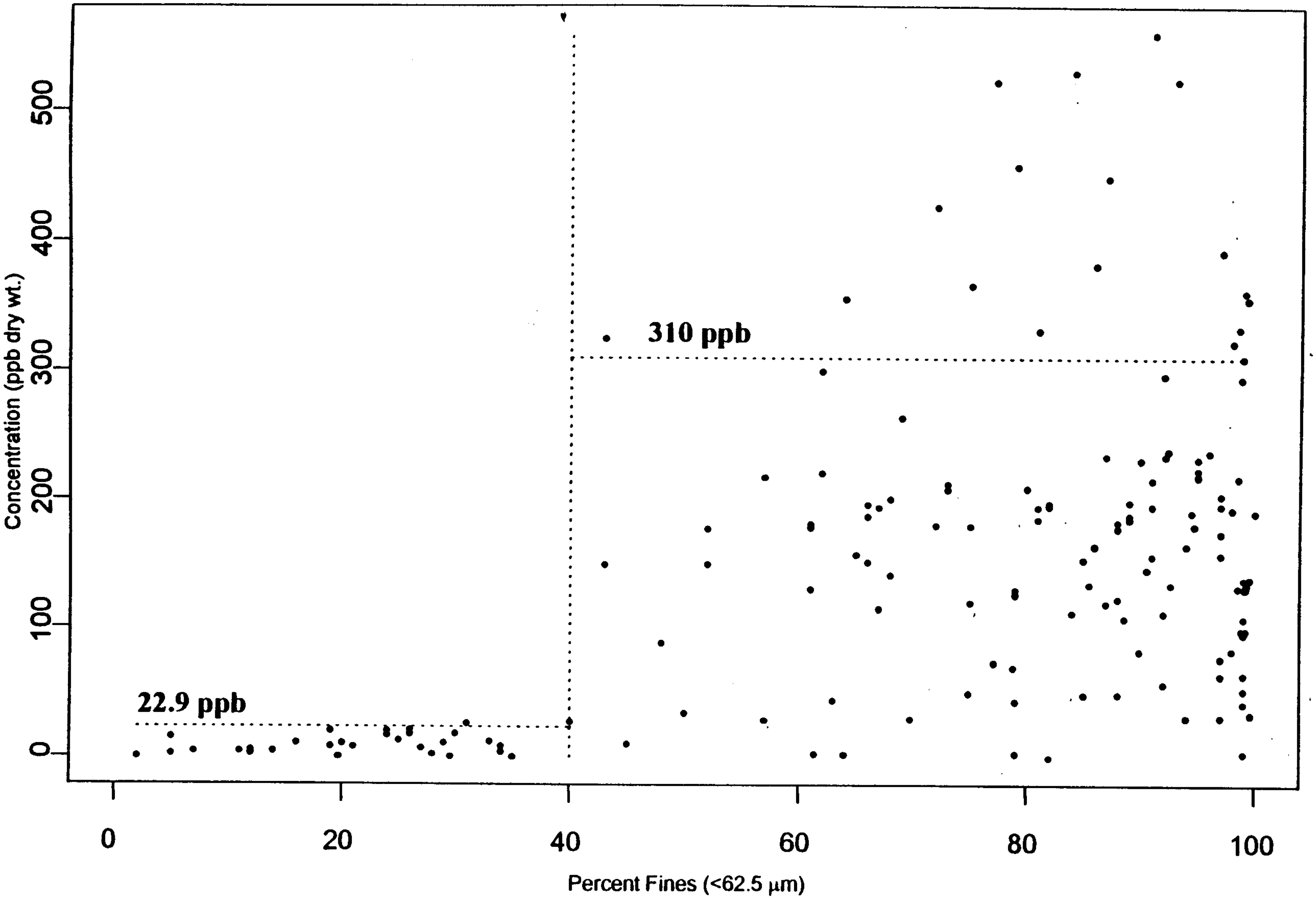

Figure 13. Benzo(g,h,i)perylene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

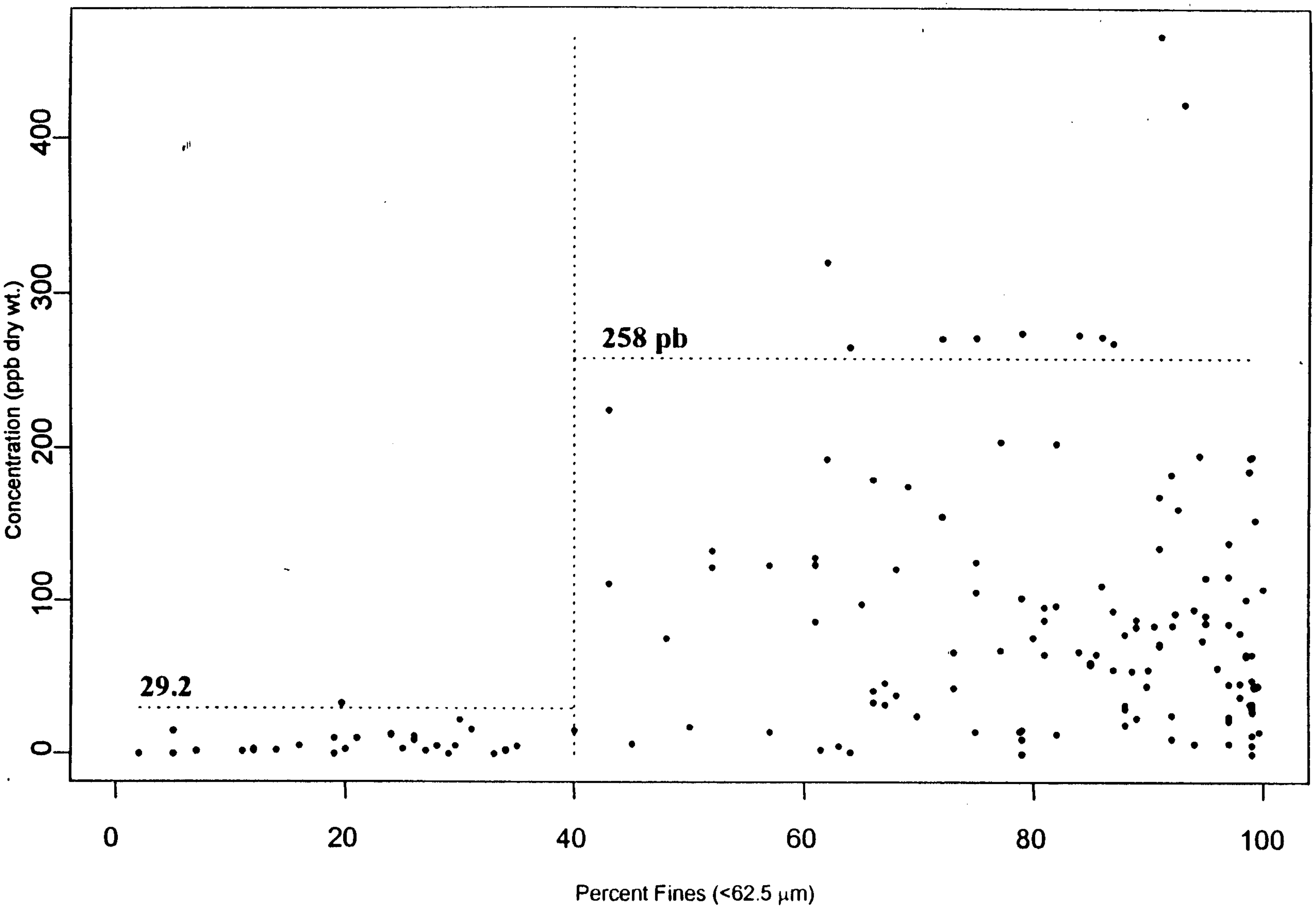

Figure 14. Benzo(k)fluoranthene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

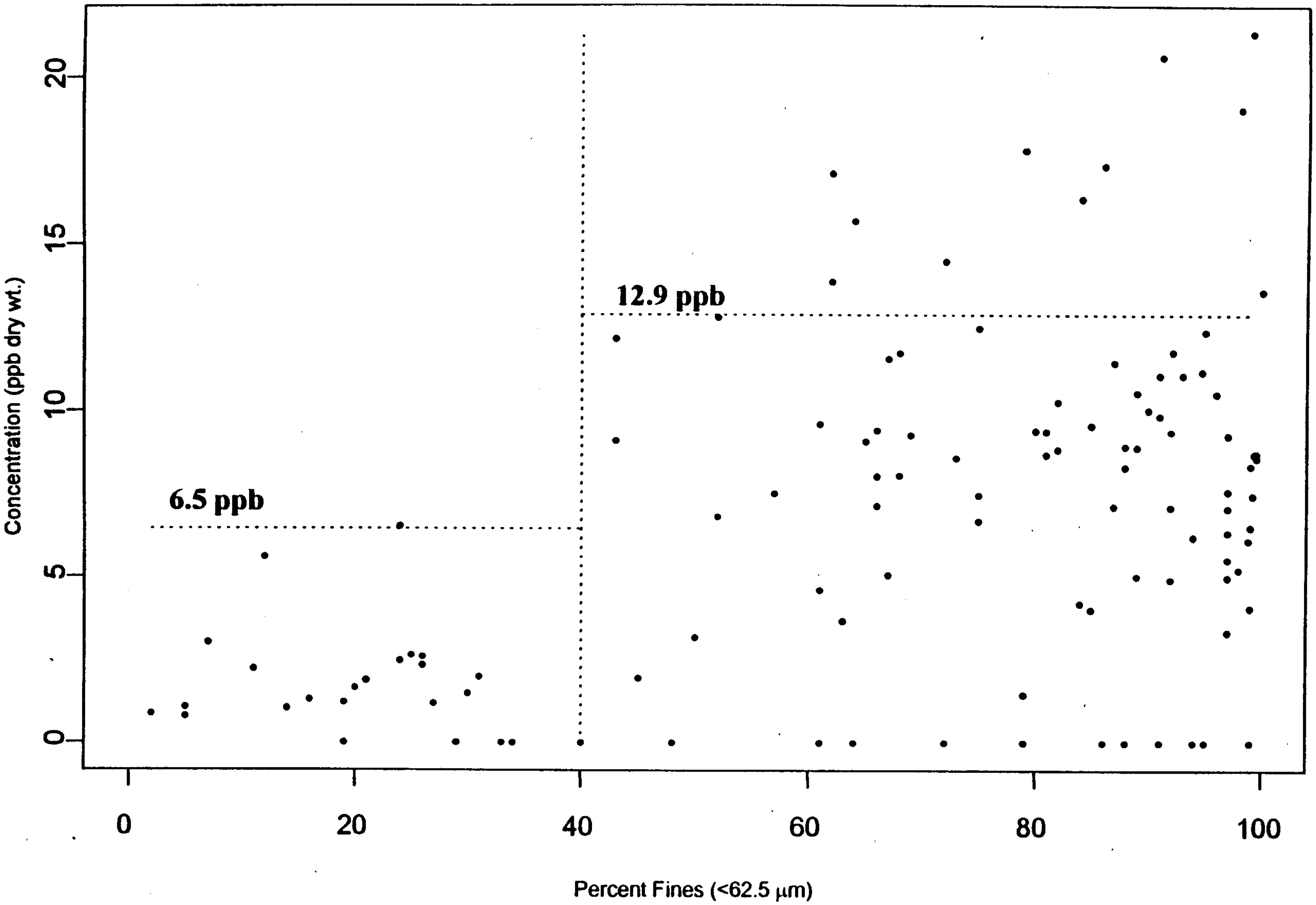

Figure 15. Biphenyl Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

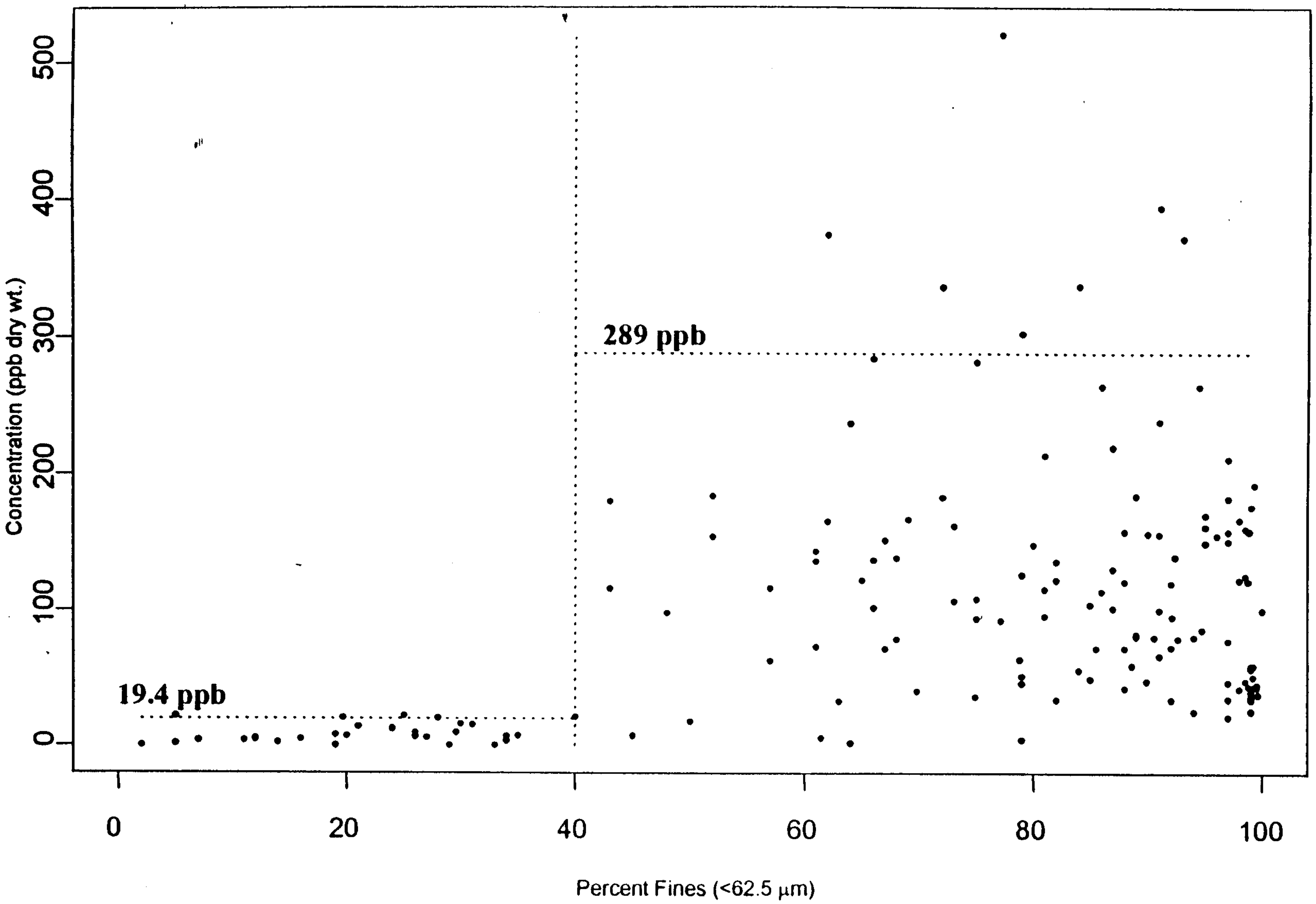

Figure 16. Chrysene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

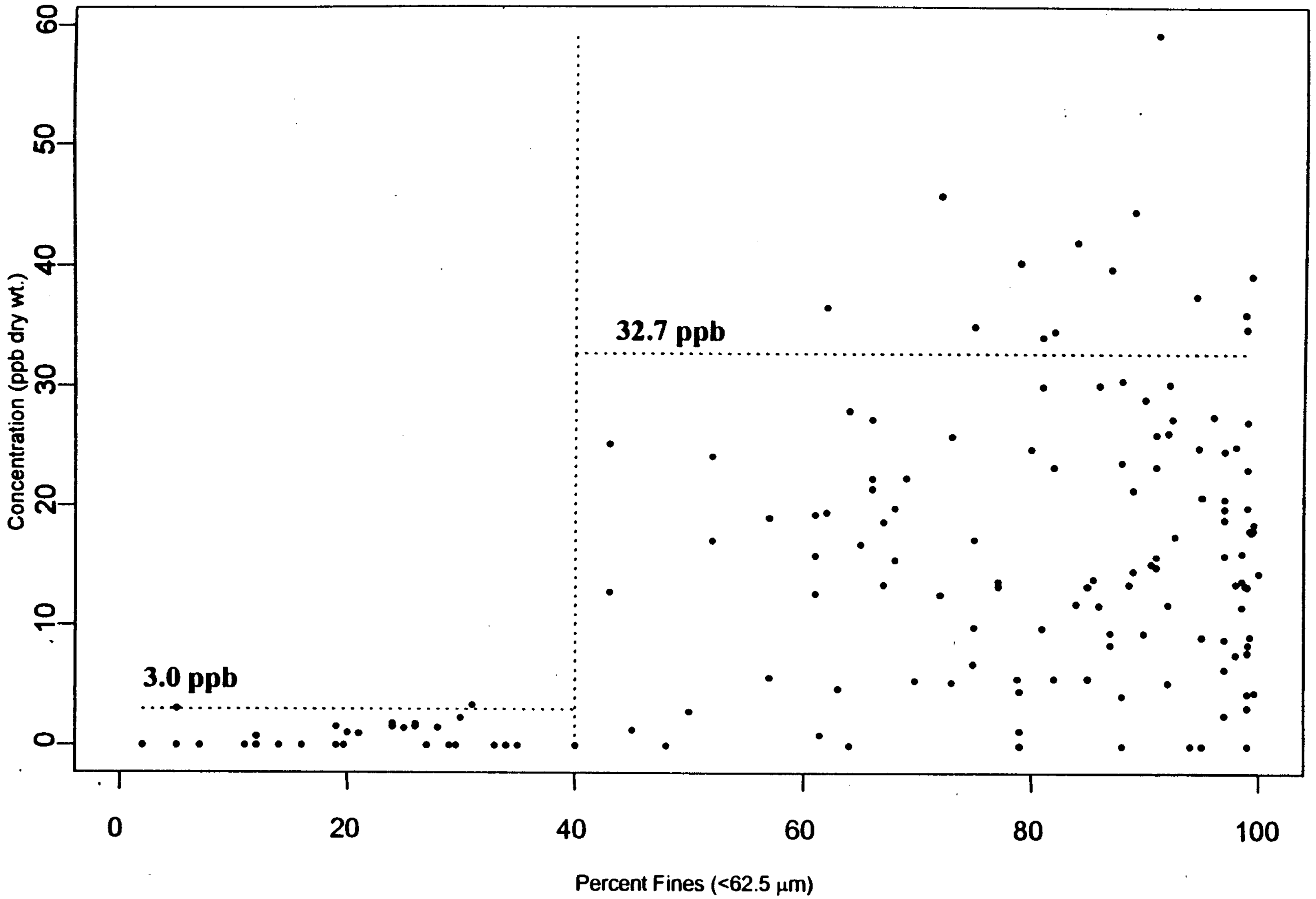

Figure 17. Dibenz(a,h)anthracene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

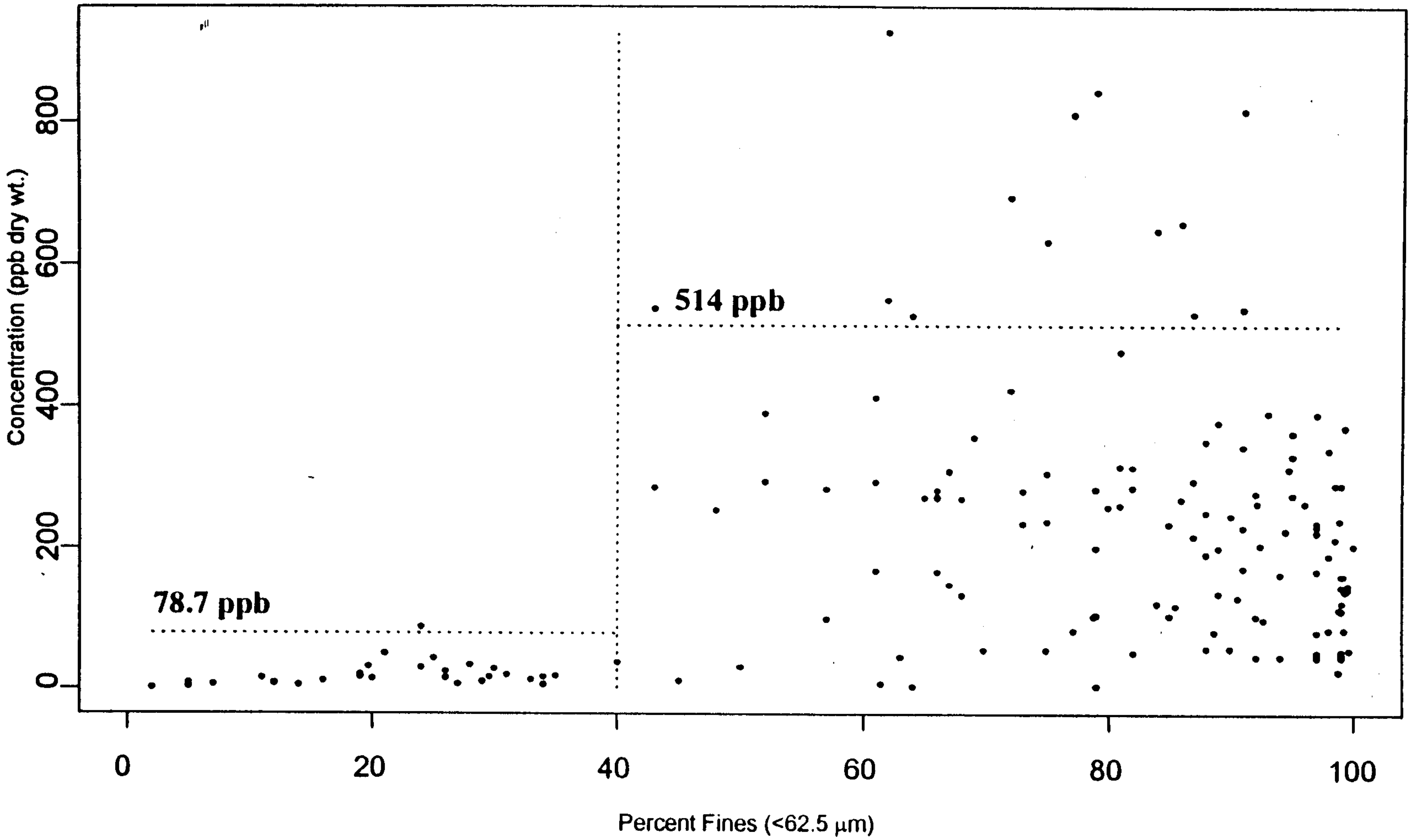

Figure 18. Fluoranthene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

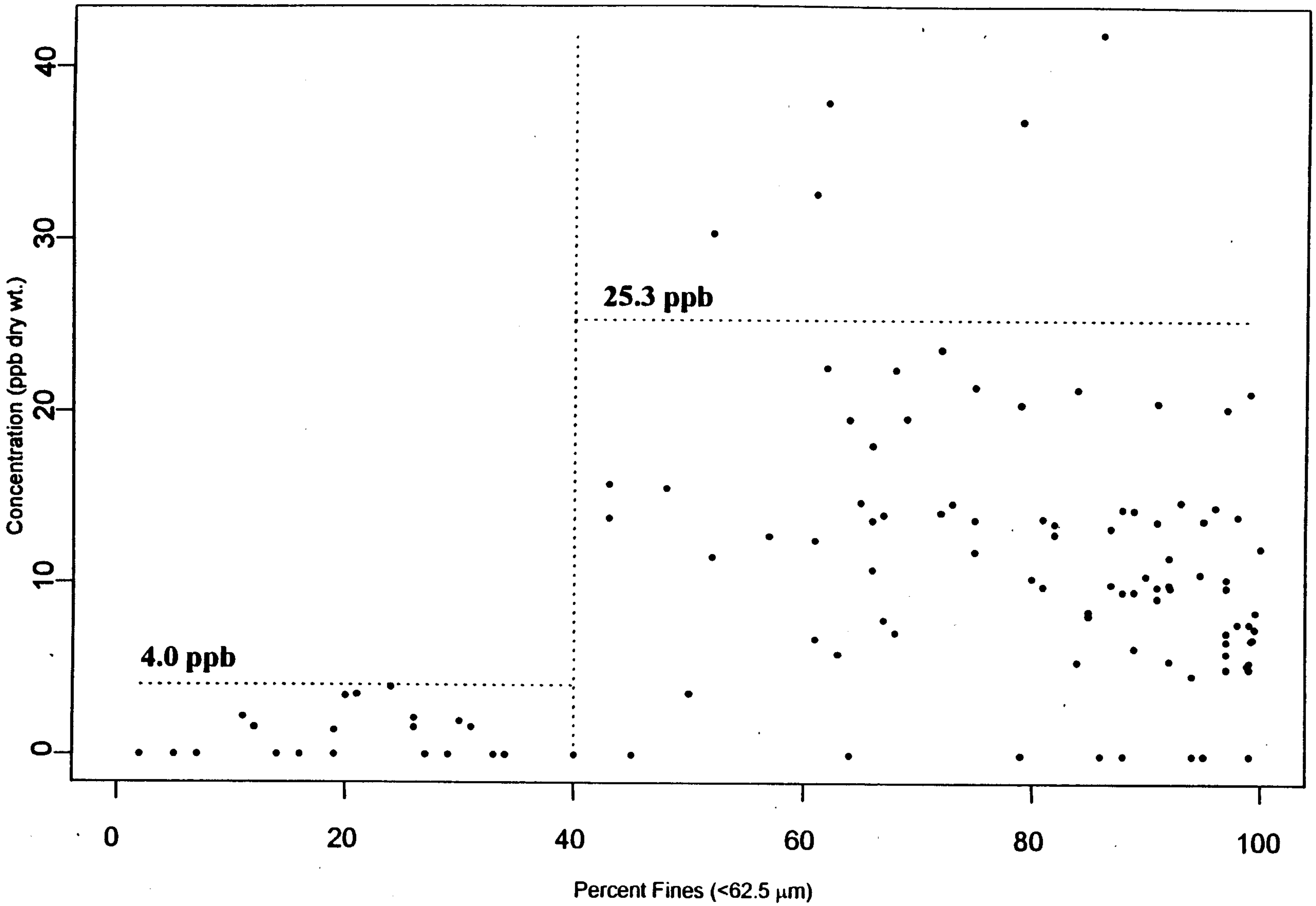

Figure 19. Fluorene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

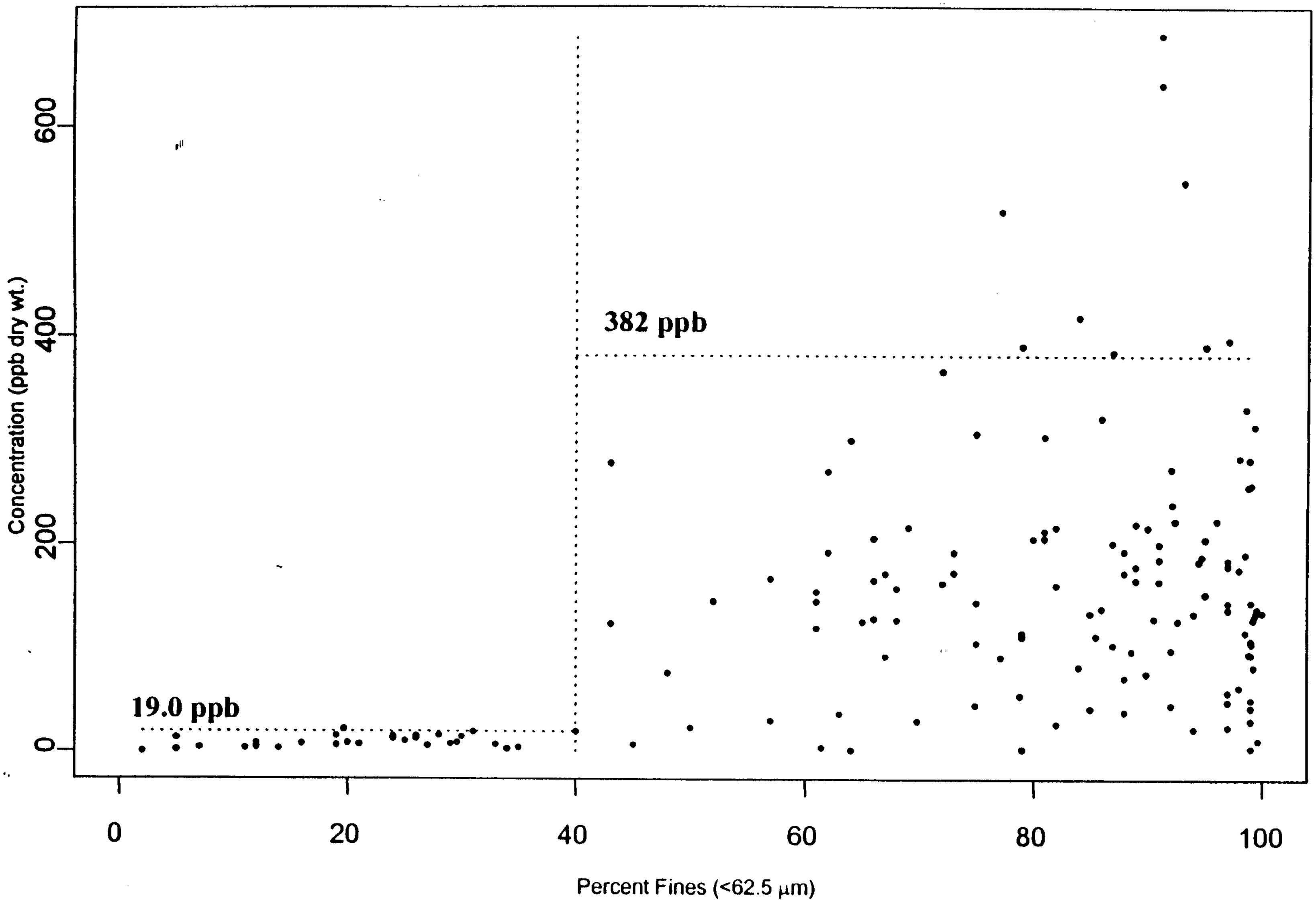

Figure 20. Indeno(1,2,3-cd)pyrene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

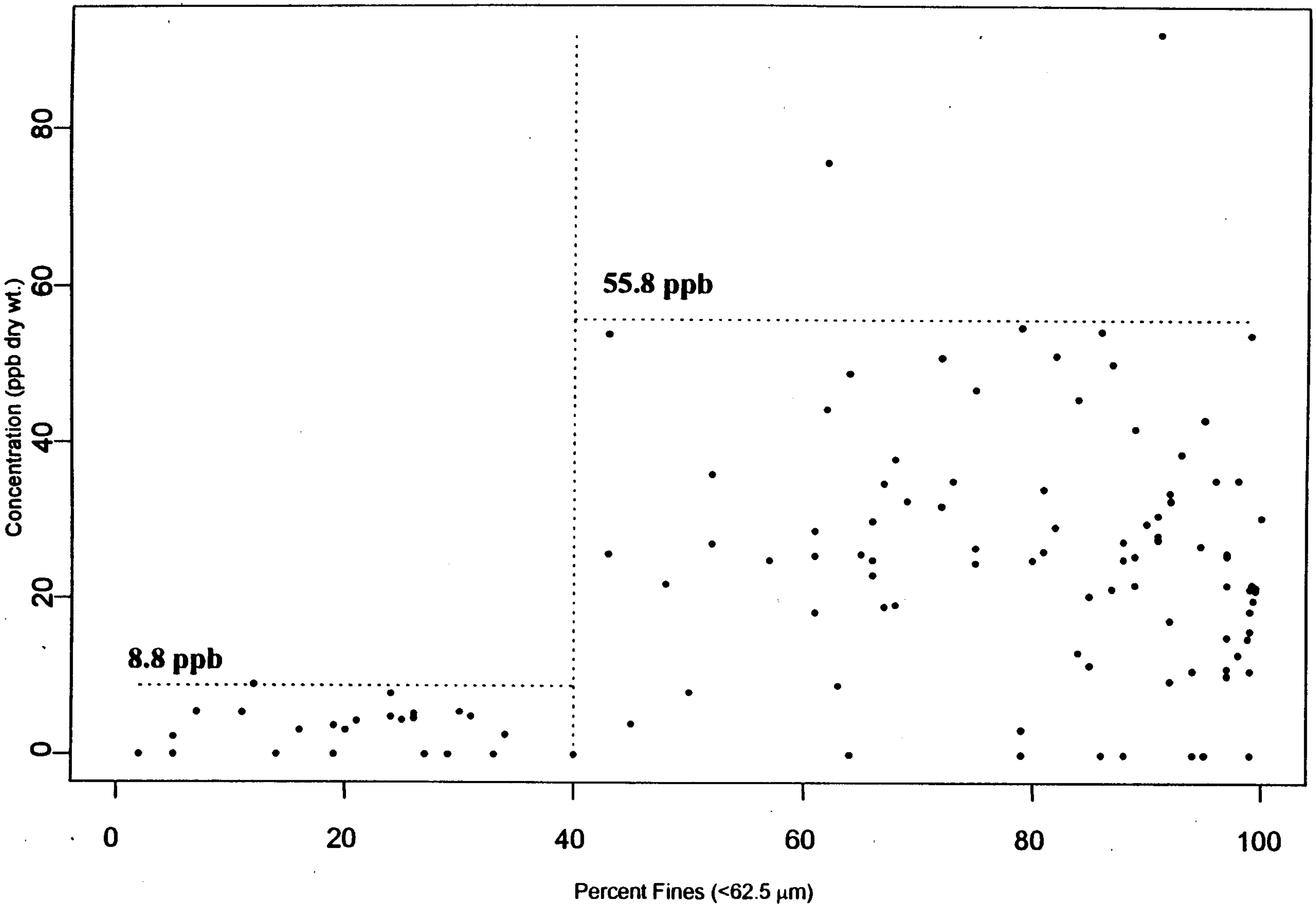

Figure 21. Naphthalene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

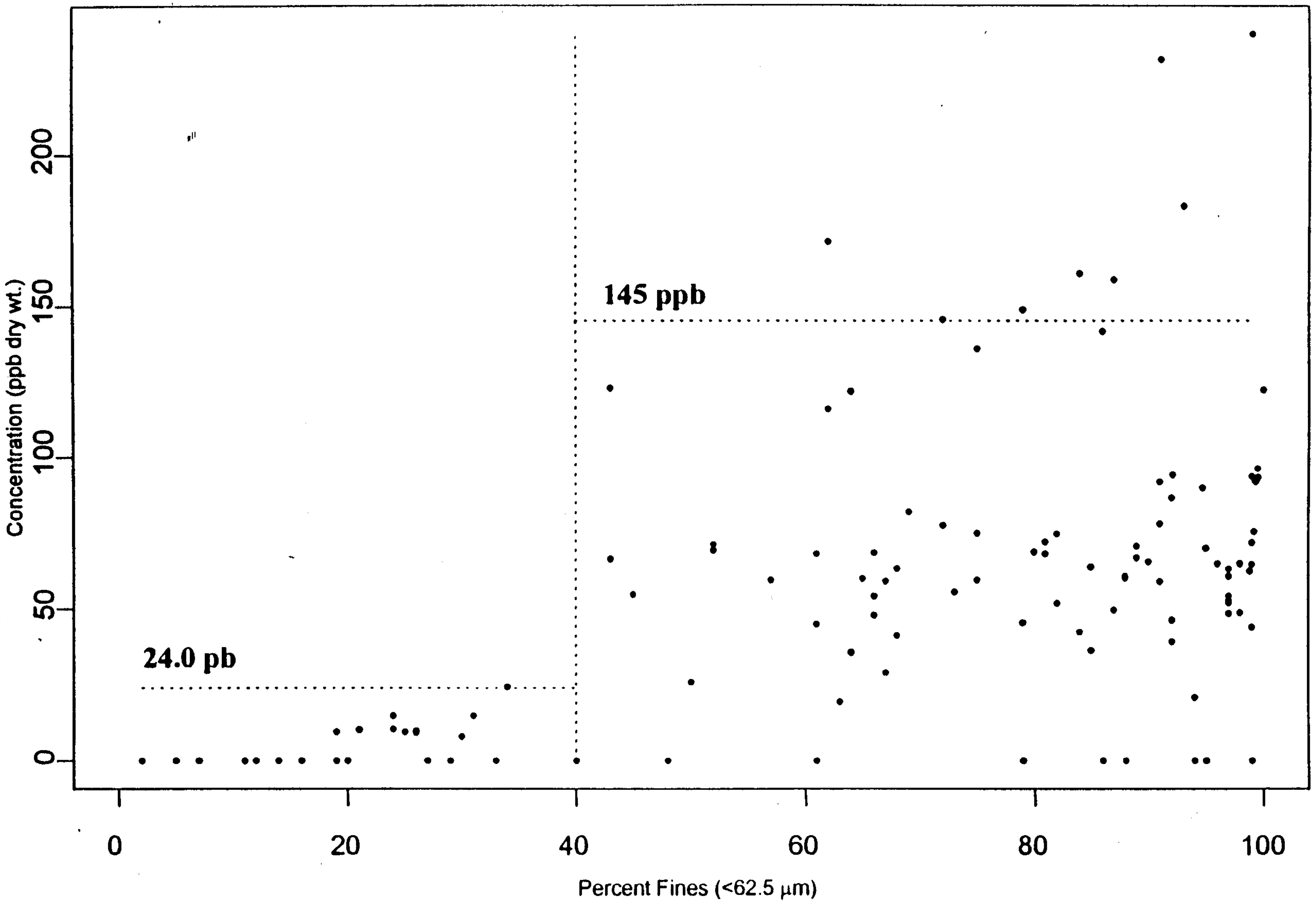

Figure 22. Perylene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

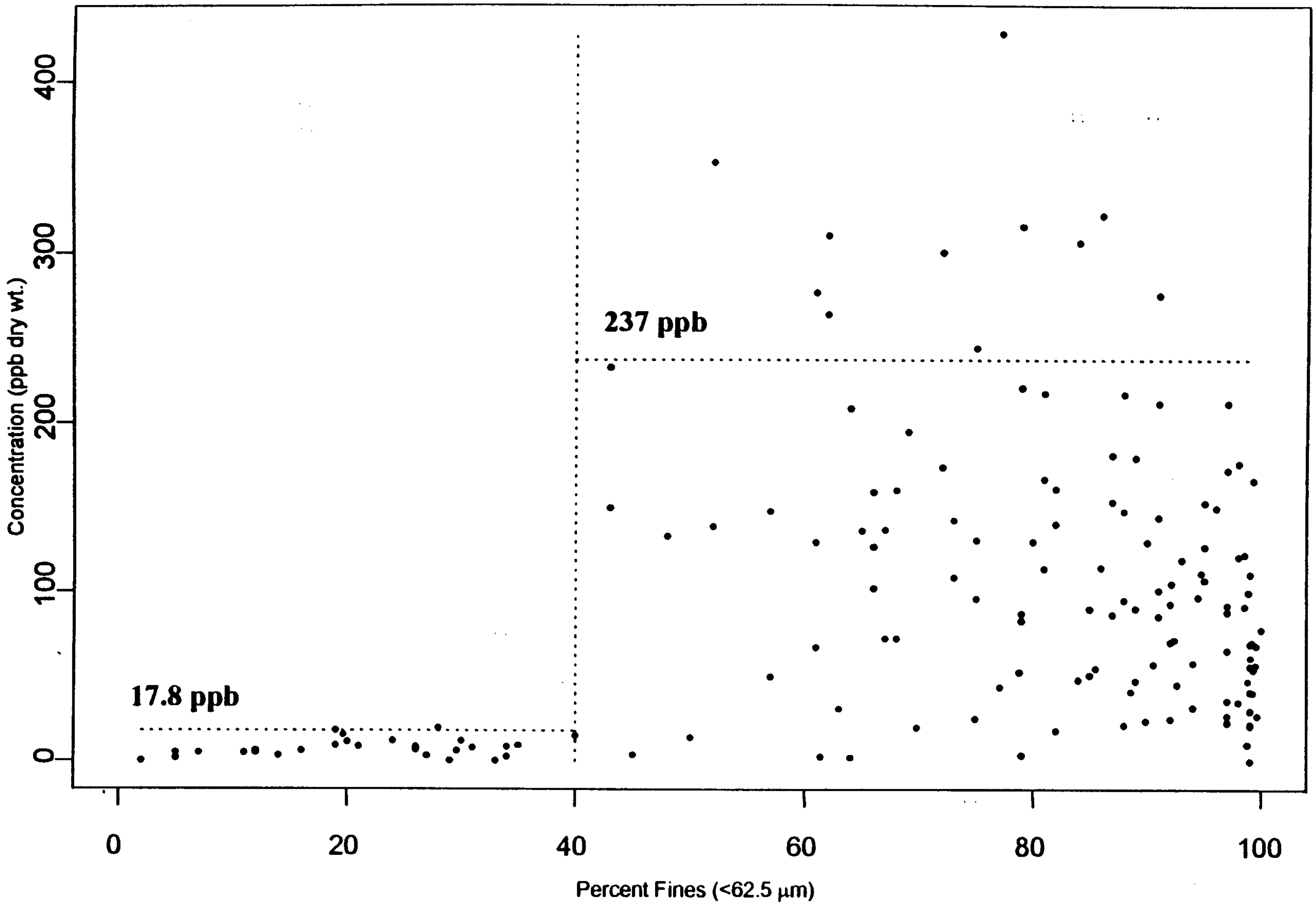

Figure 23. Phenanthrene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

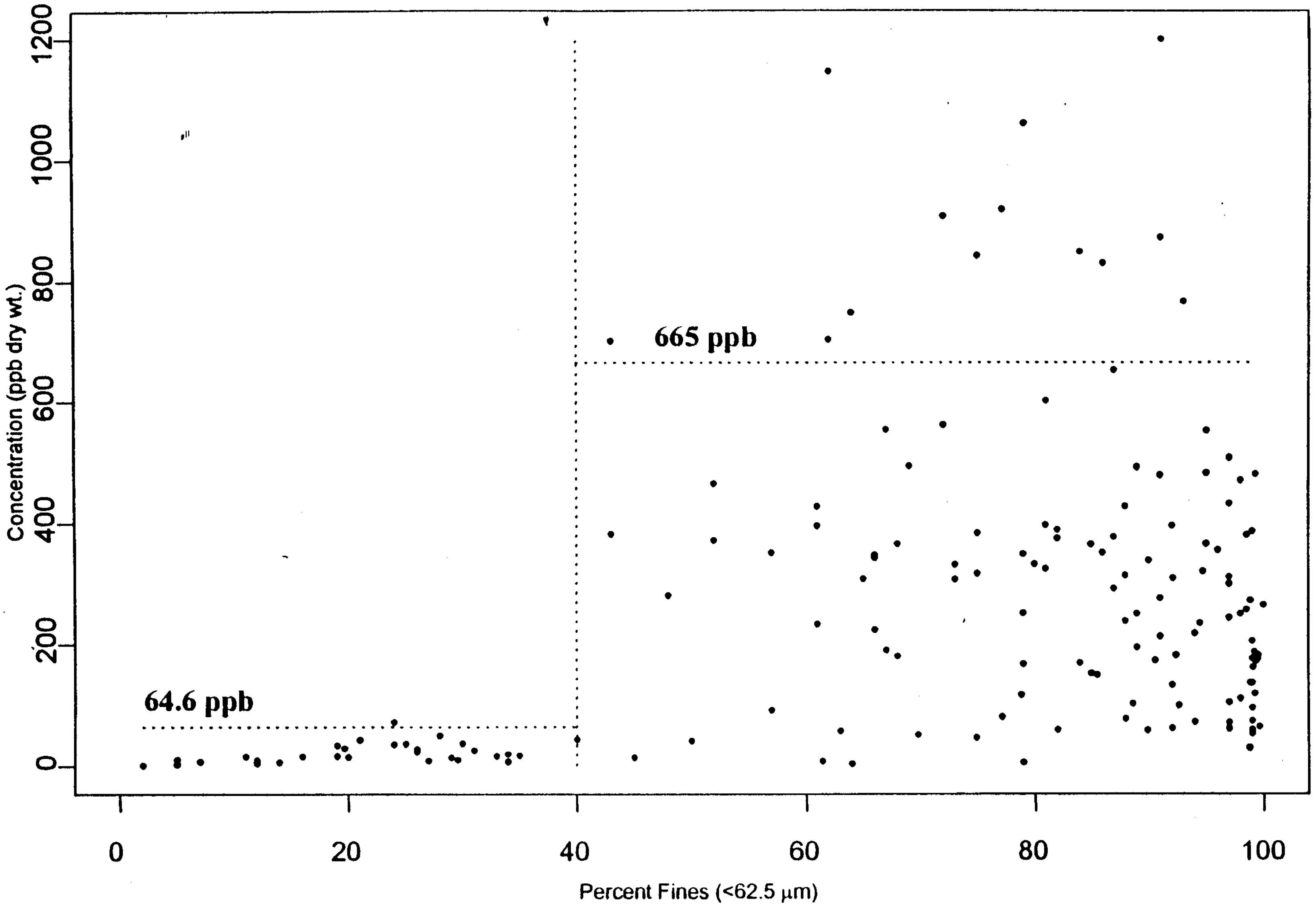

Figure 24. Pyrene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

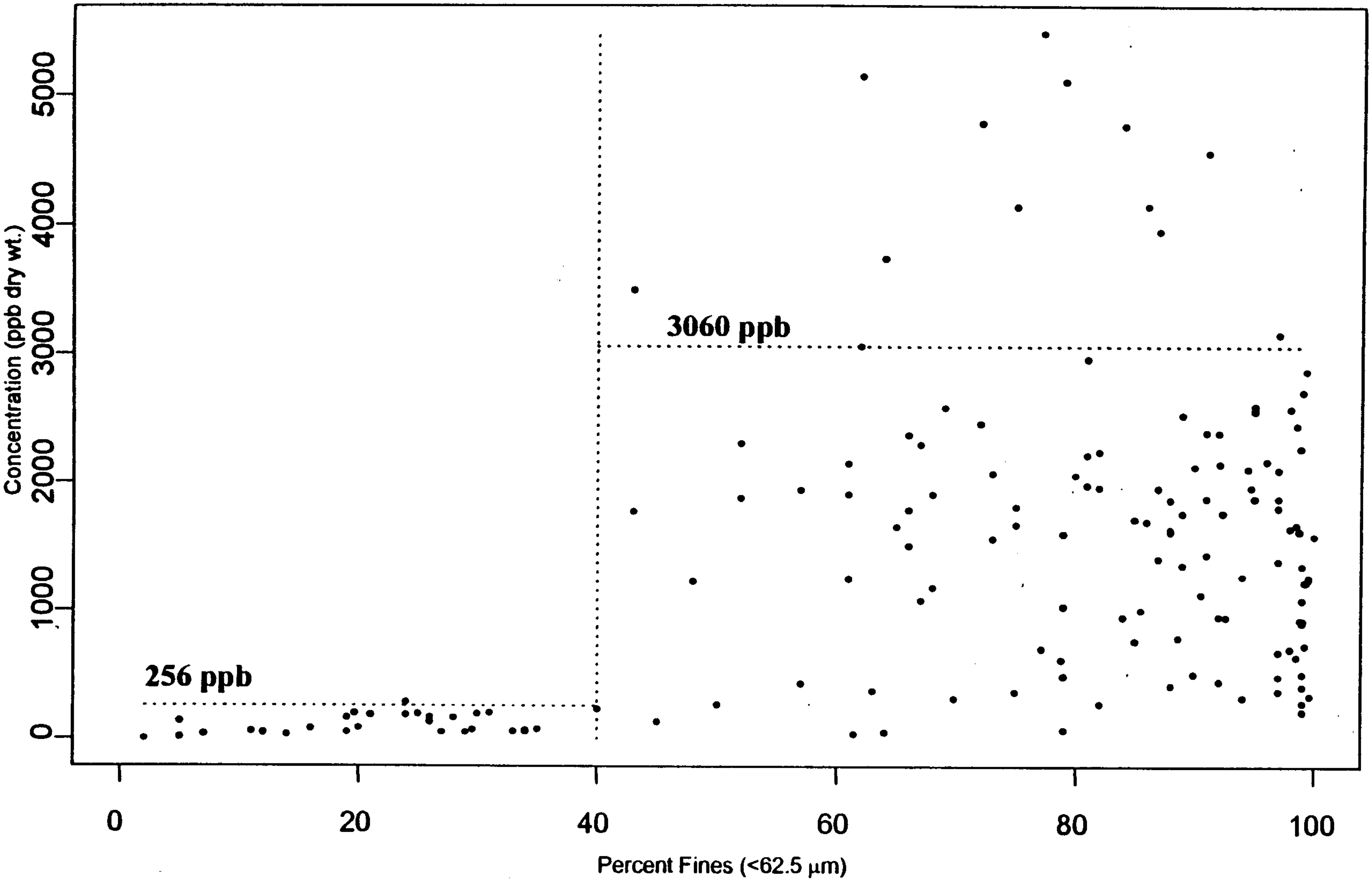

Figure 25. Sum of Heavy Polynuclear Aromatic Hydrocarbons Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

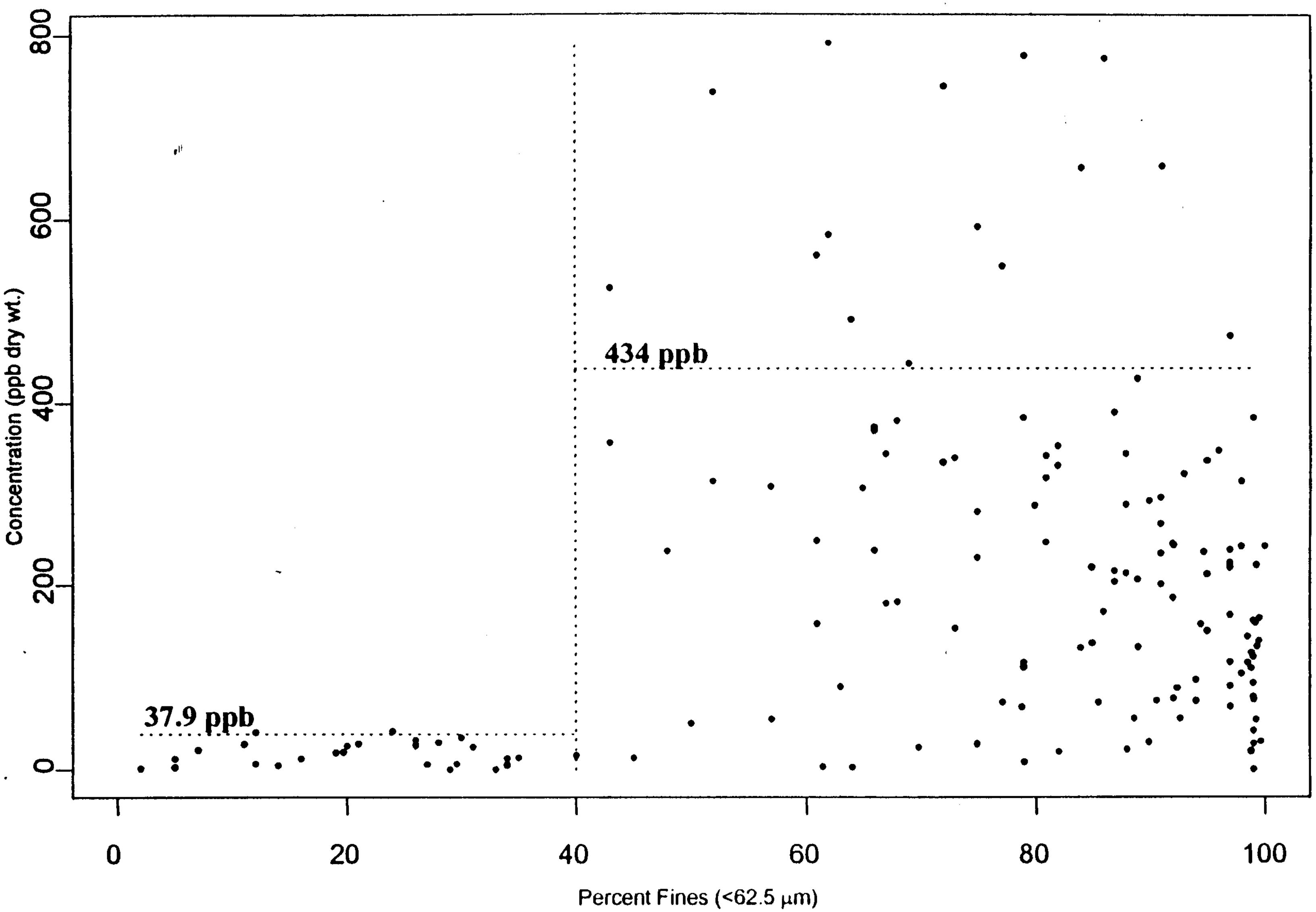

Figure 26. Sum of Light Polynuclear Aromatic Hydrocarbons Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

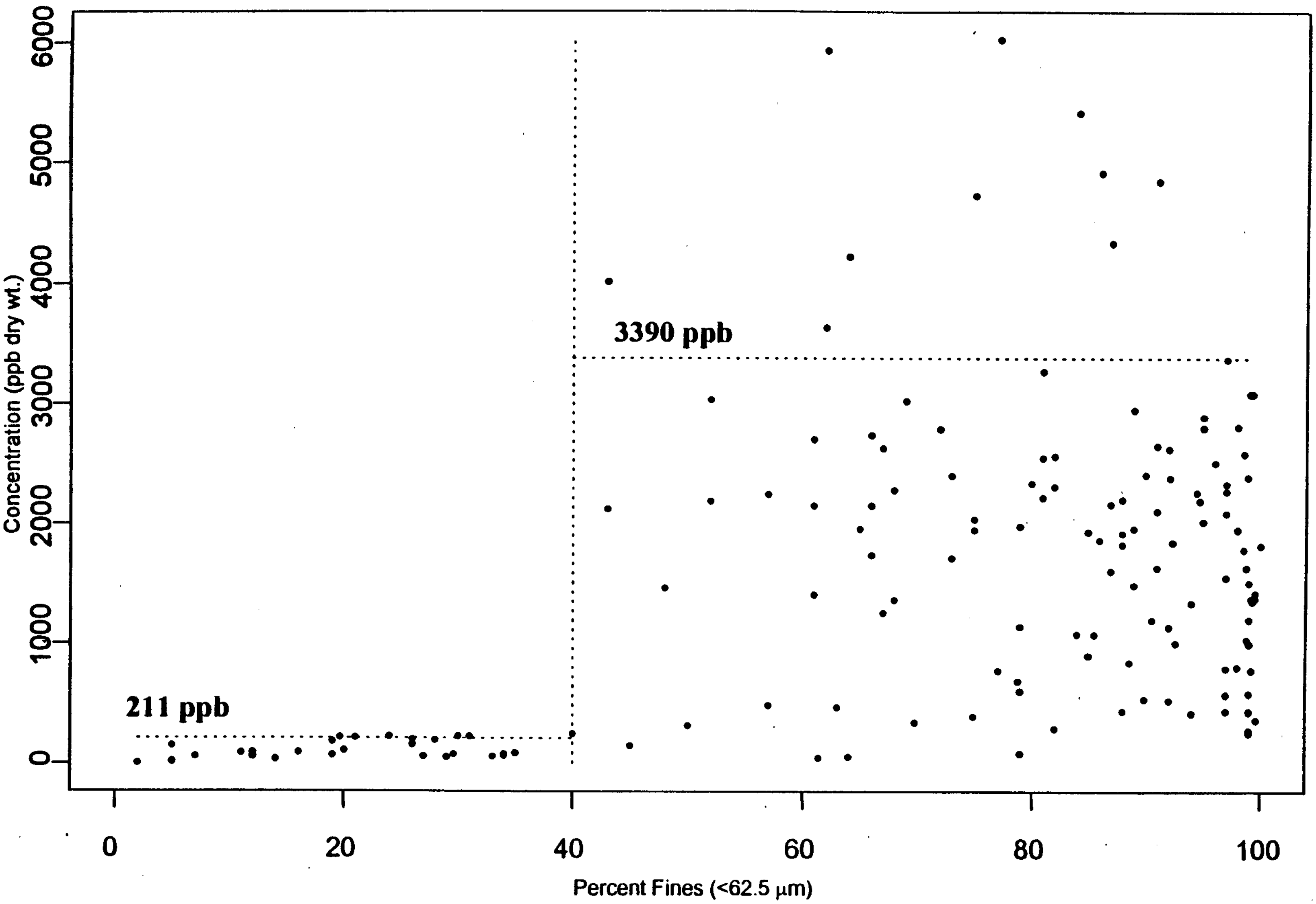

Figure 27. Sum of Total Polynuclear Aromatic Hydrocarbons Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bounds.

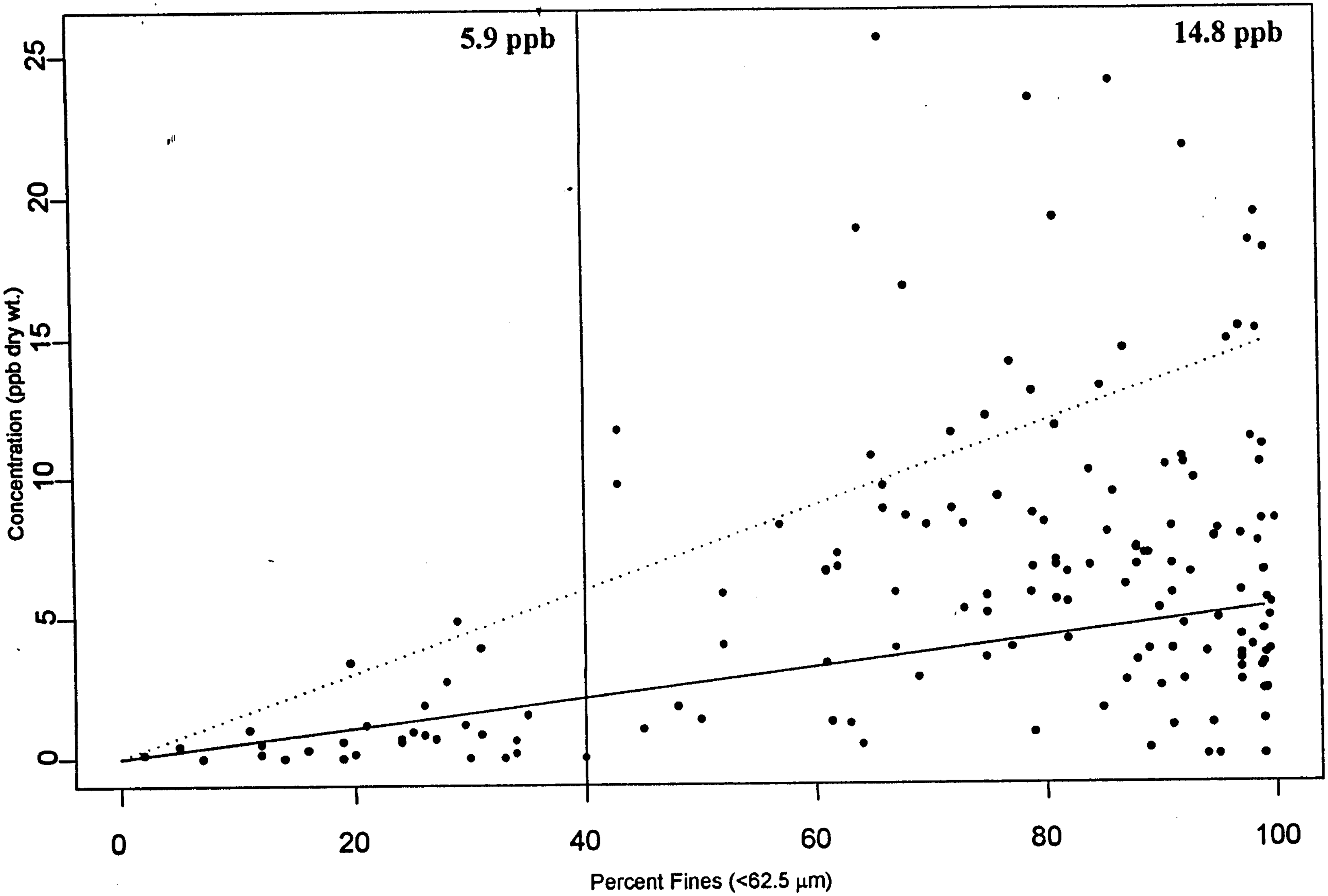

Figure 28. Sum of PCB Congener (NST List) Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

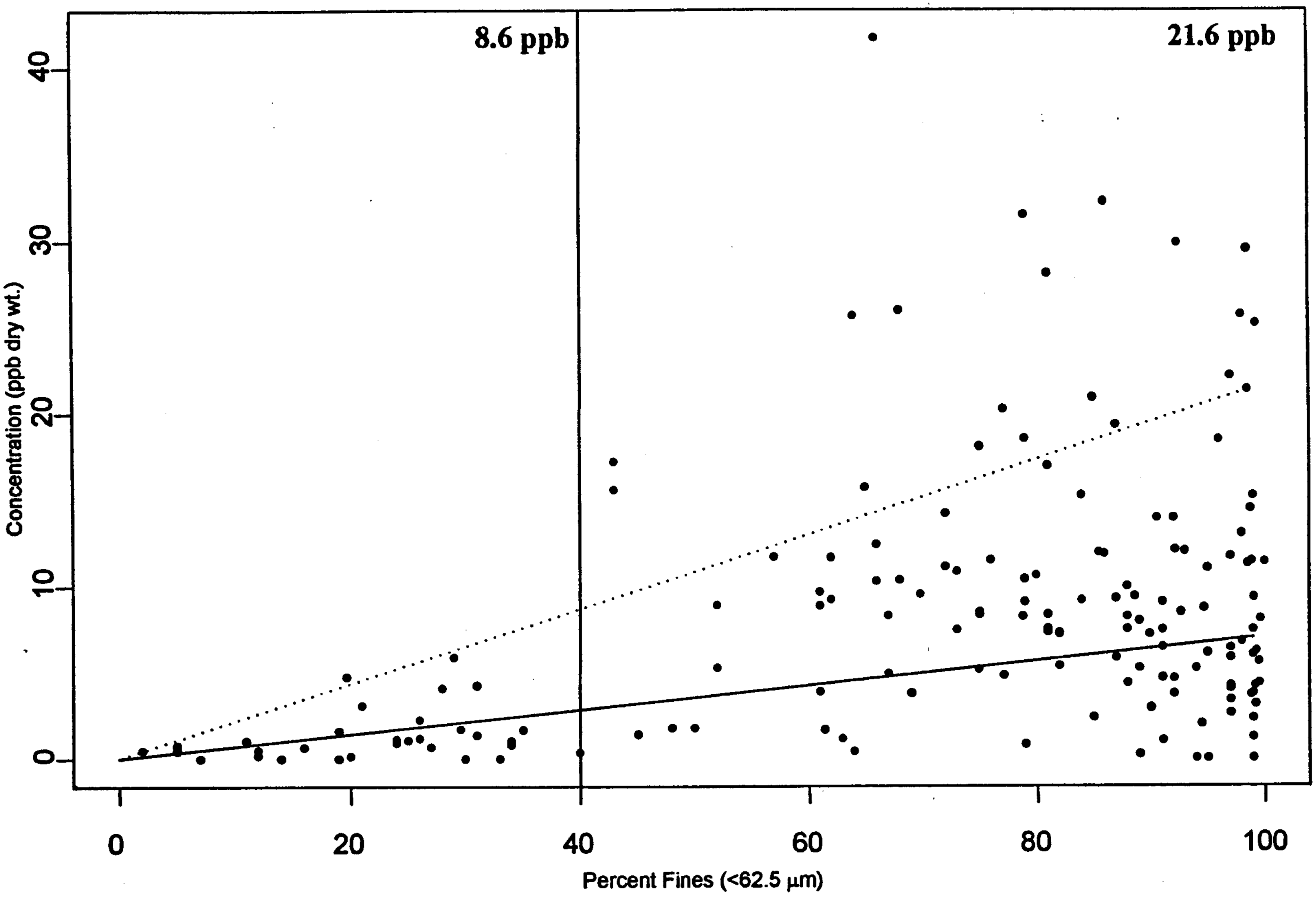

Figure 29. Sum of PCB Congener (SFEI List) Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

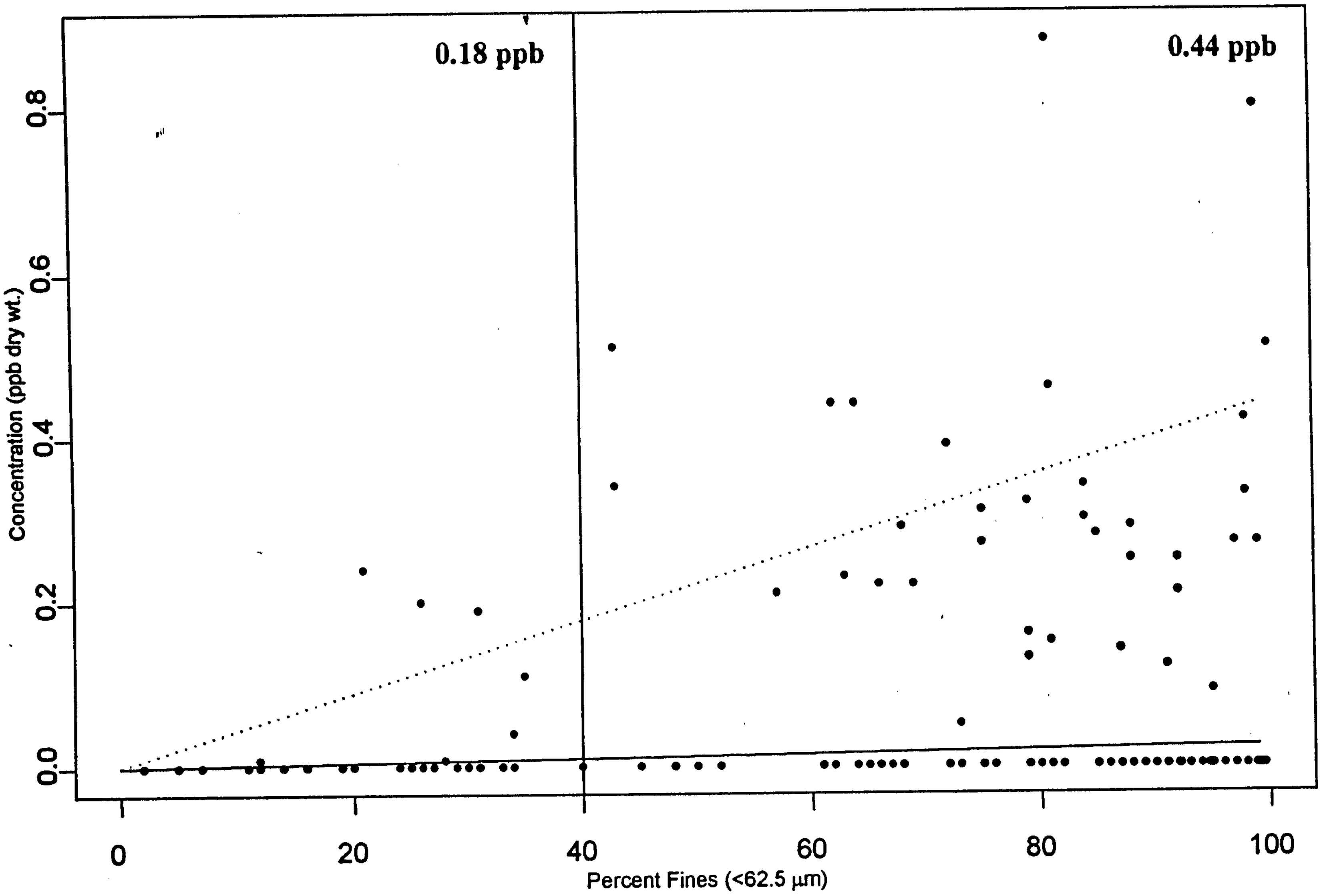

Figure 30. Dieldrin Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

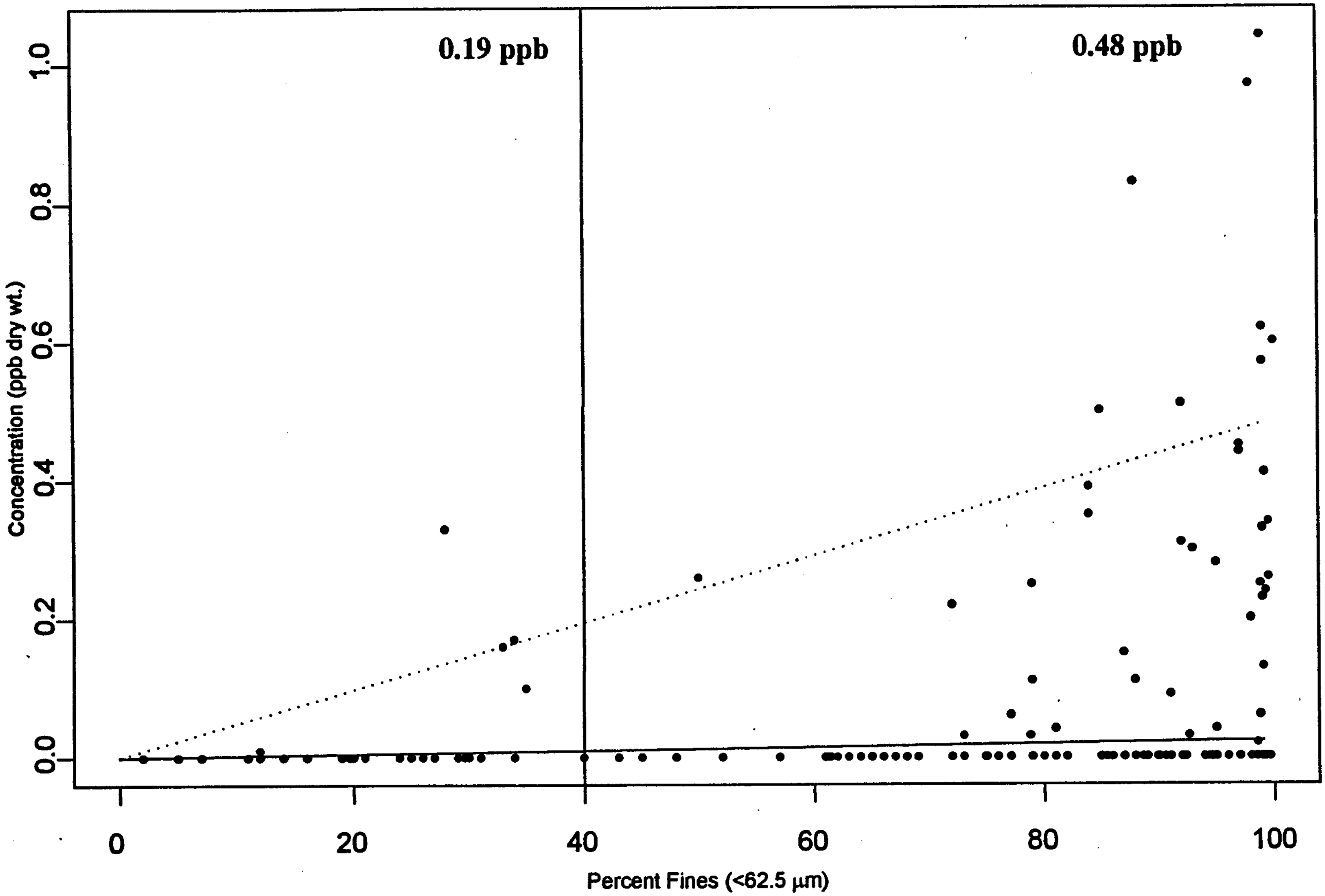

Figure 31. Hexachlorobenzene Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

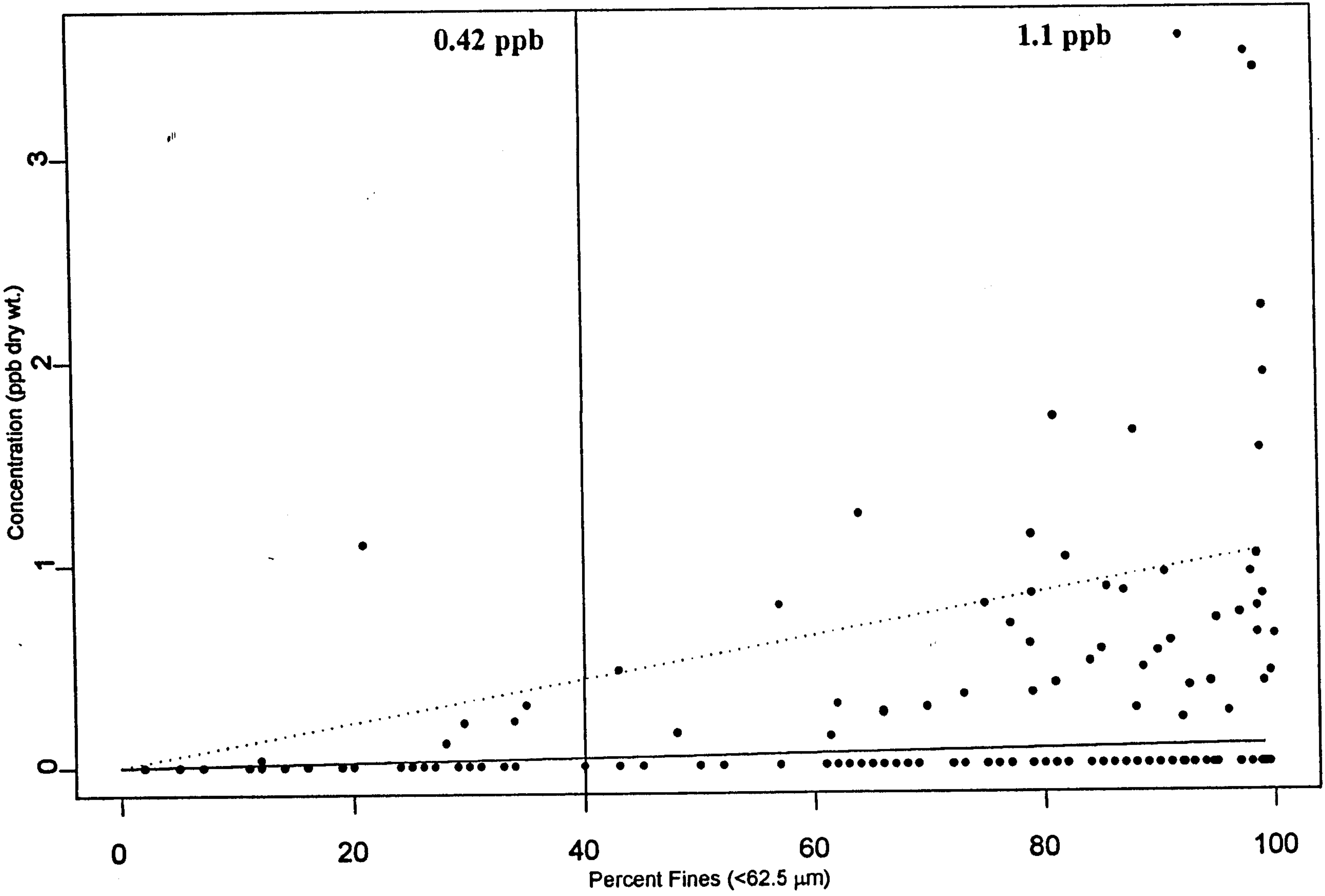

Figure 32. Sum of Chlordanes Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

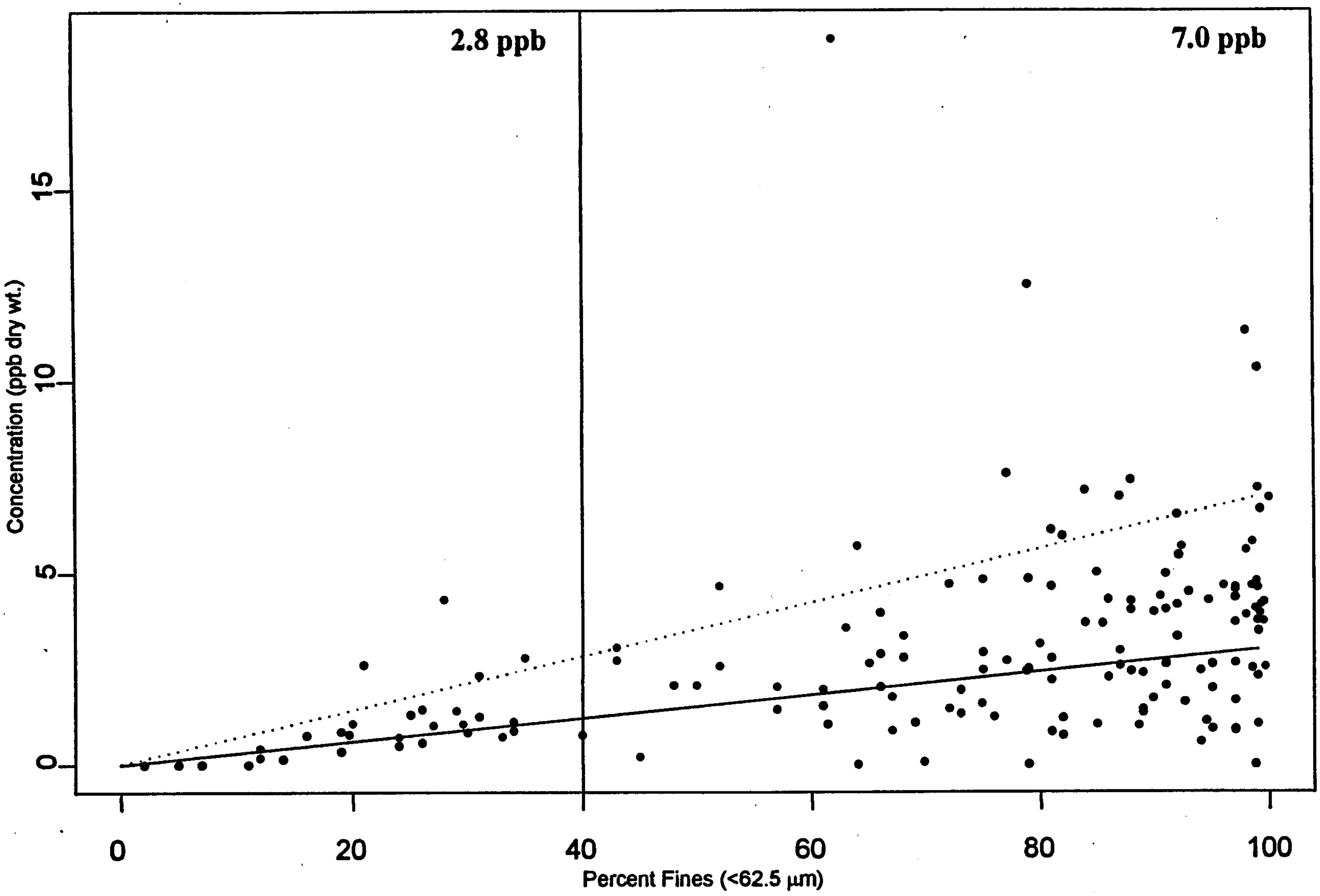

Figure 33. Sum of DDT, DDEs and DDDs Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

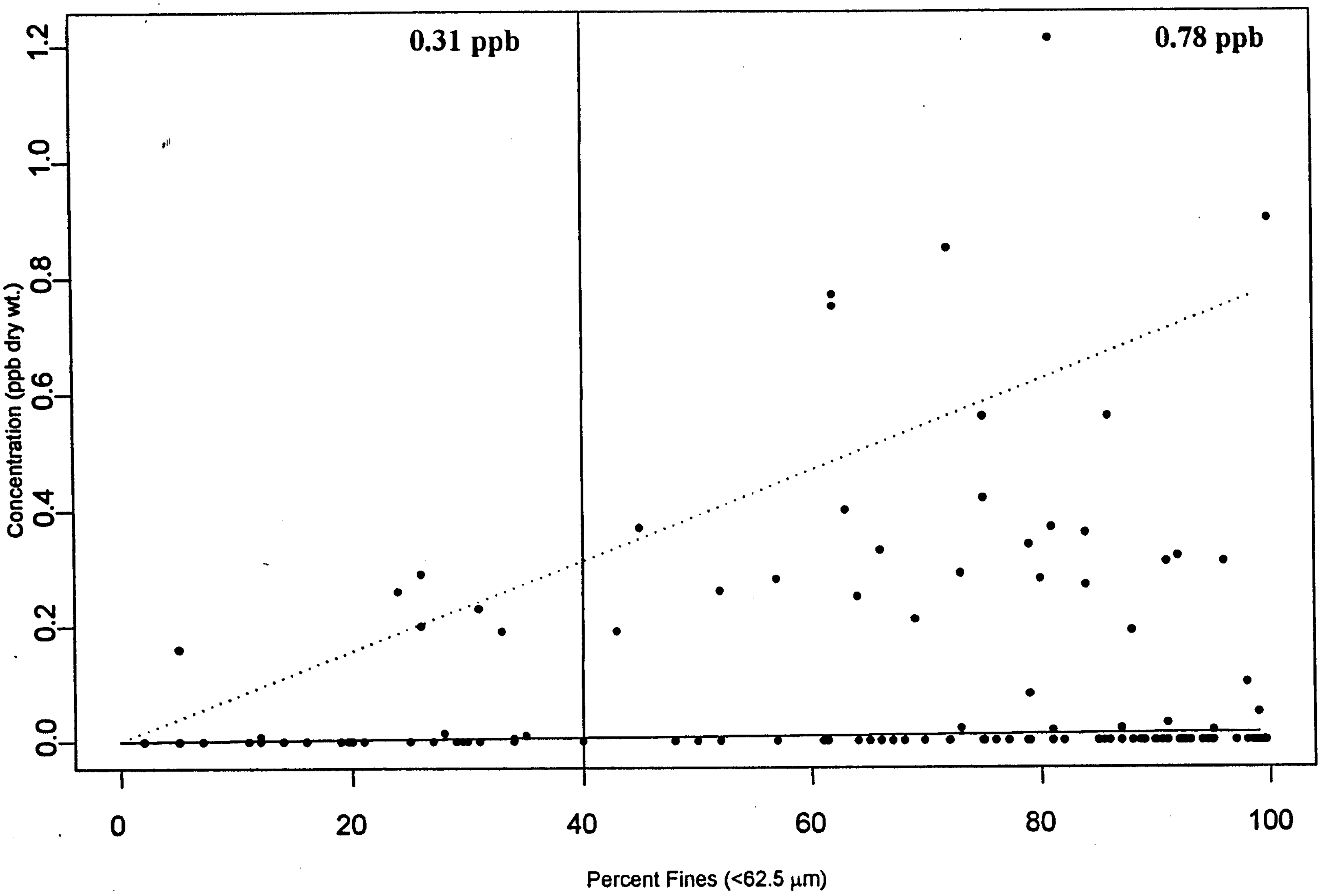

Figure 34. Sum of HCH Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

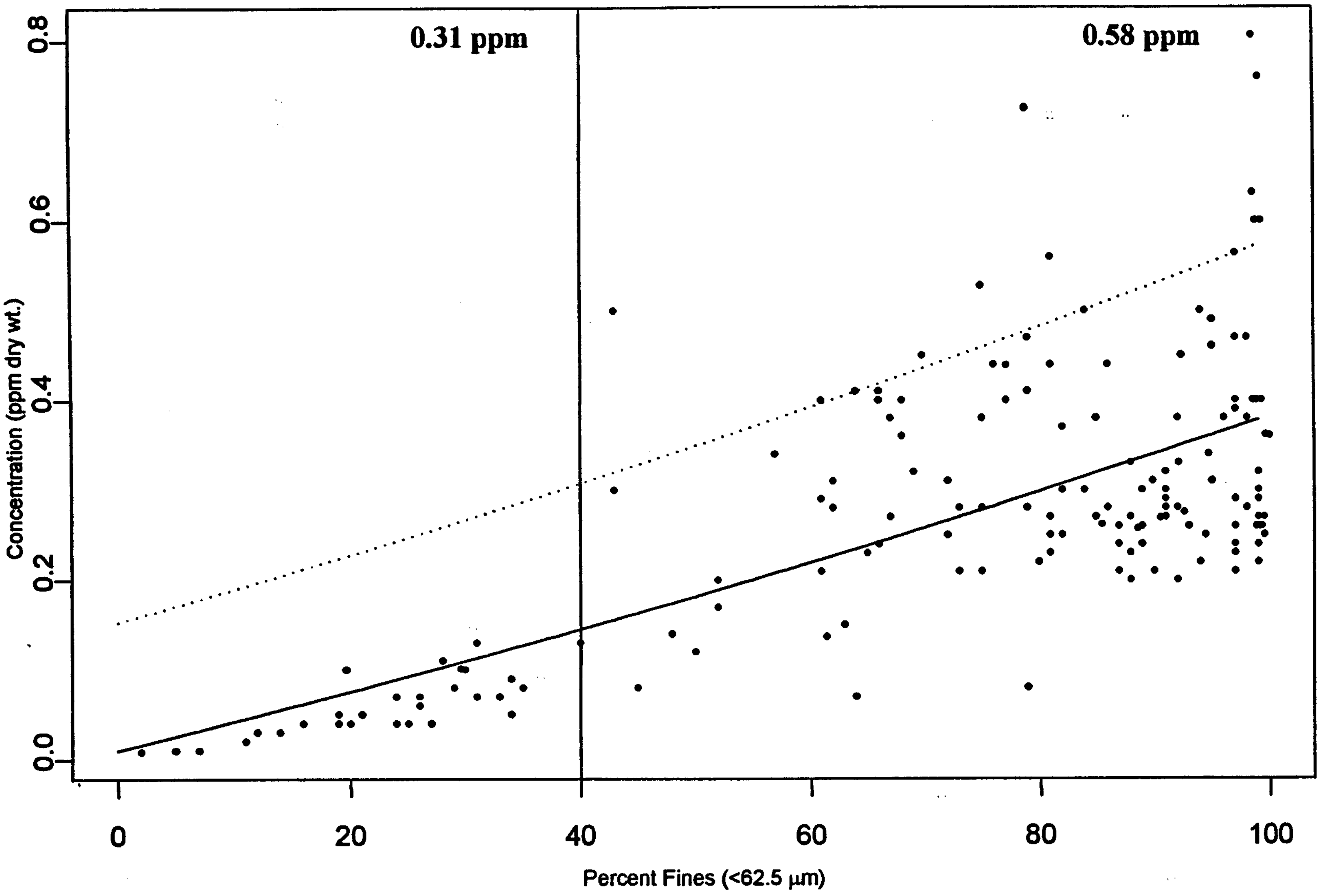

Figure 35. Silver Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

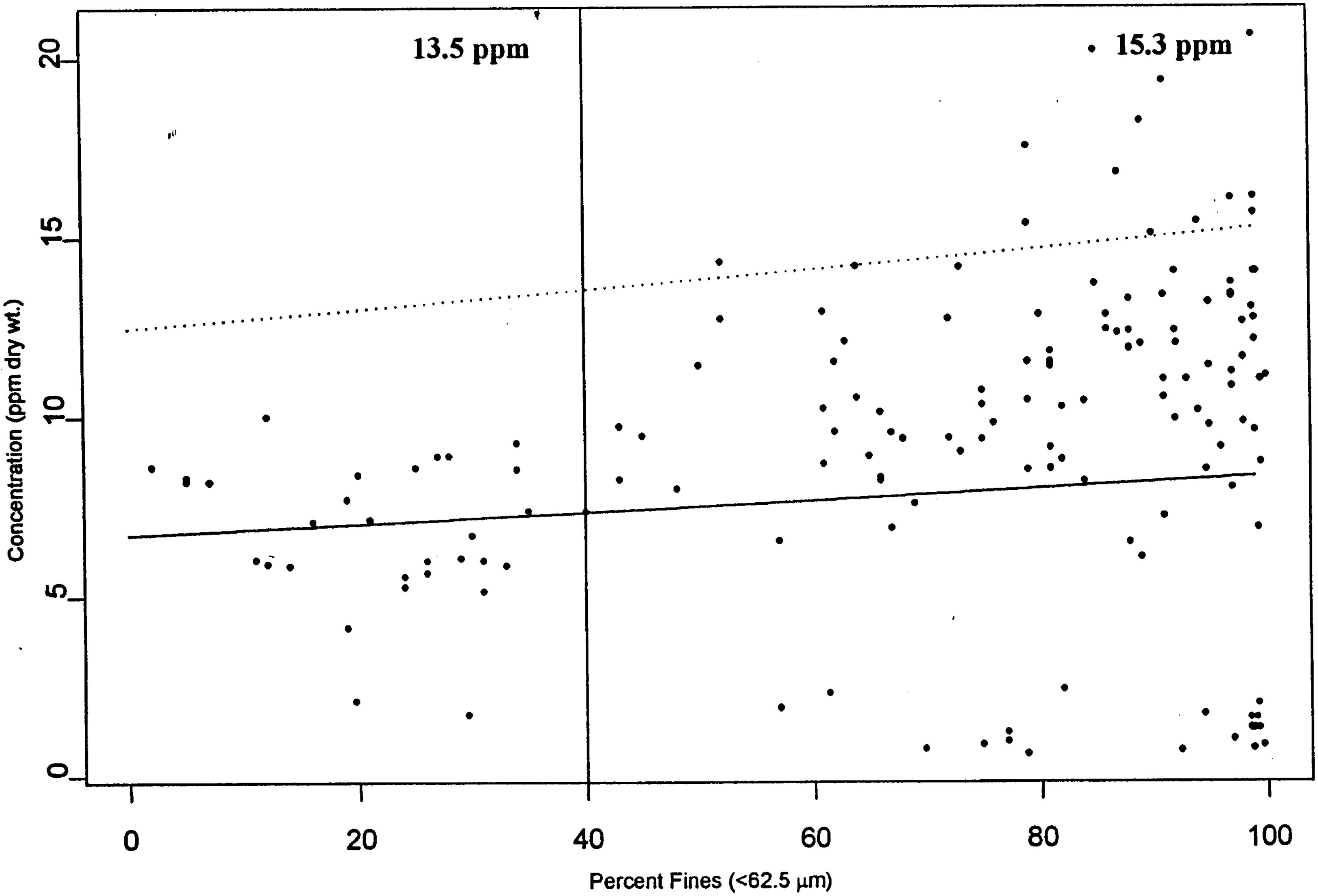

Figure 36. Arsenic Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

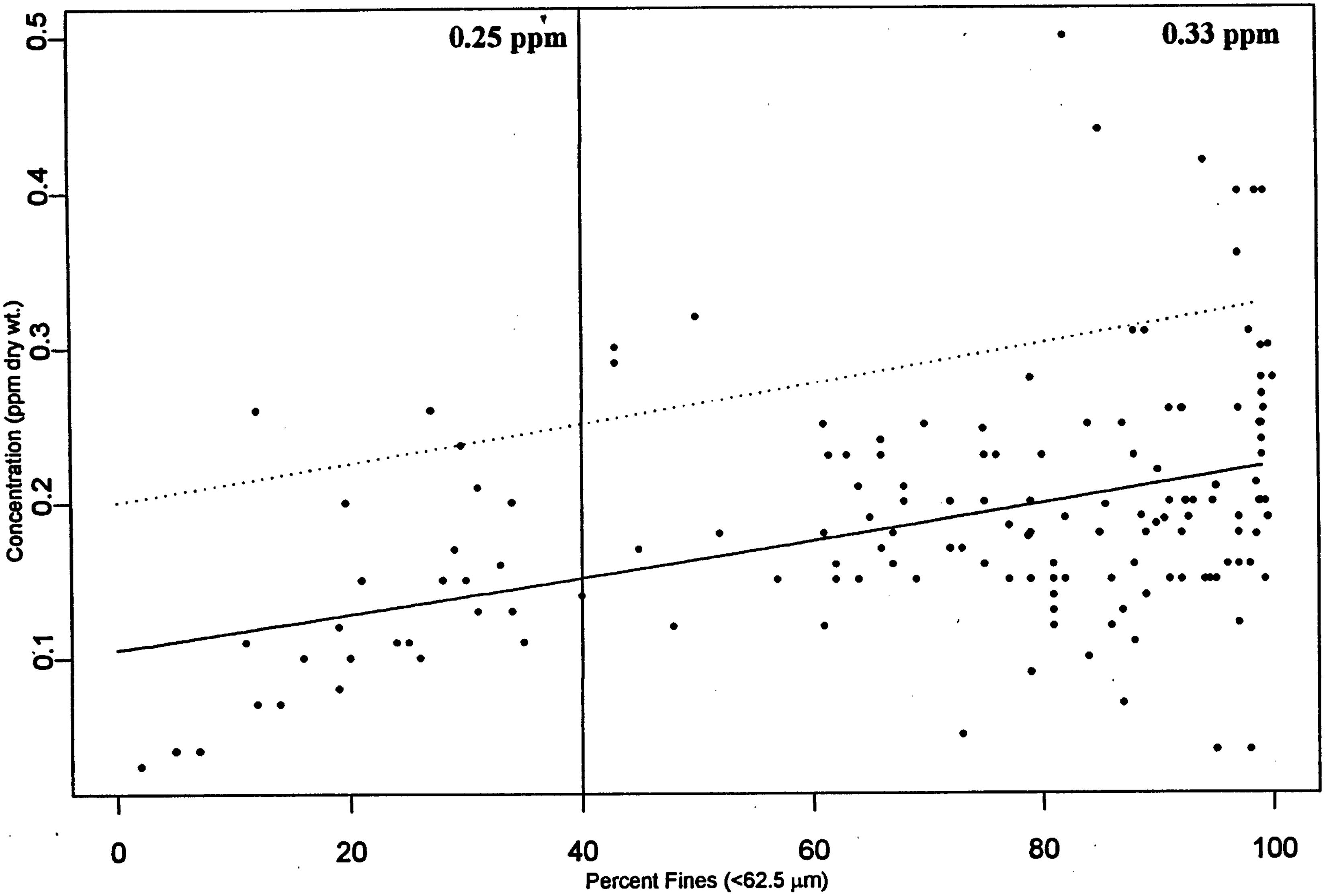

Figure 37. Cadmium Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

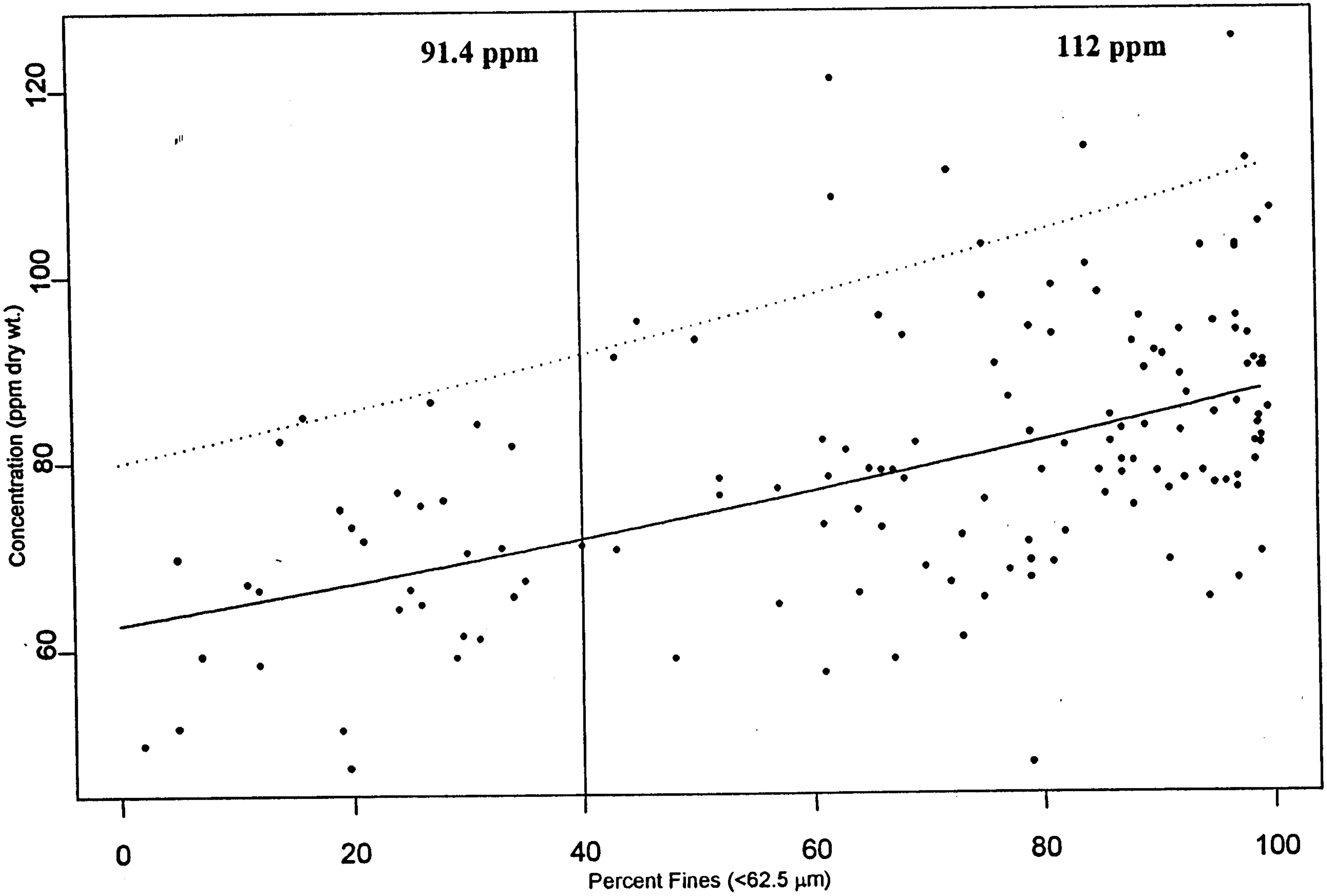

Figure 38. Chromium Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

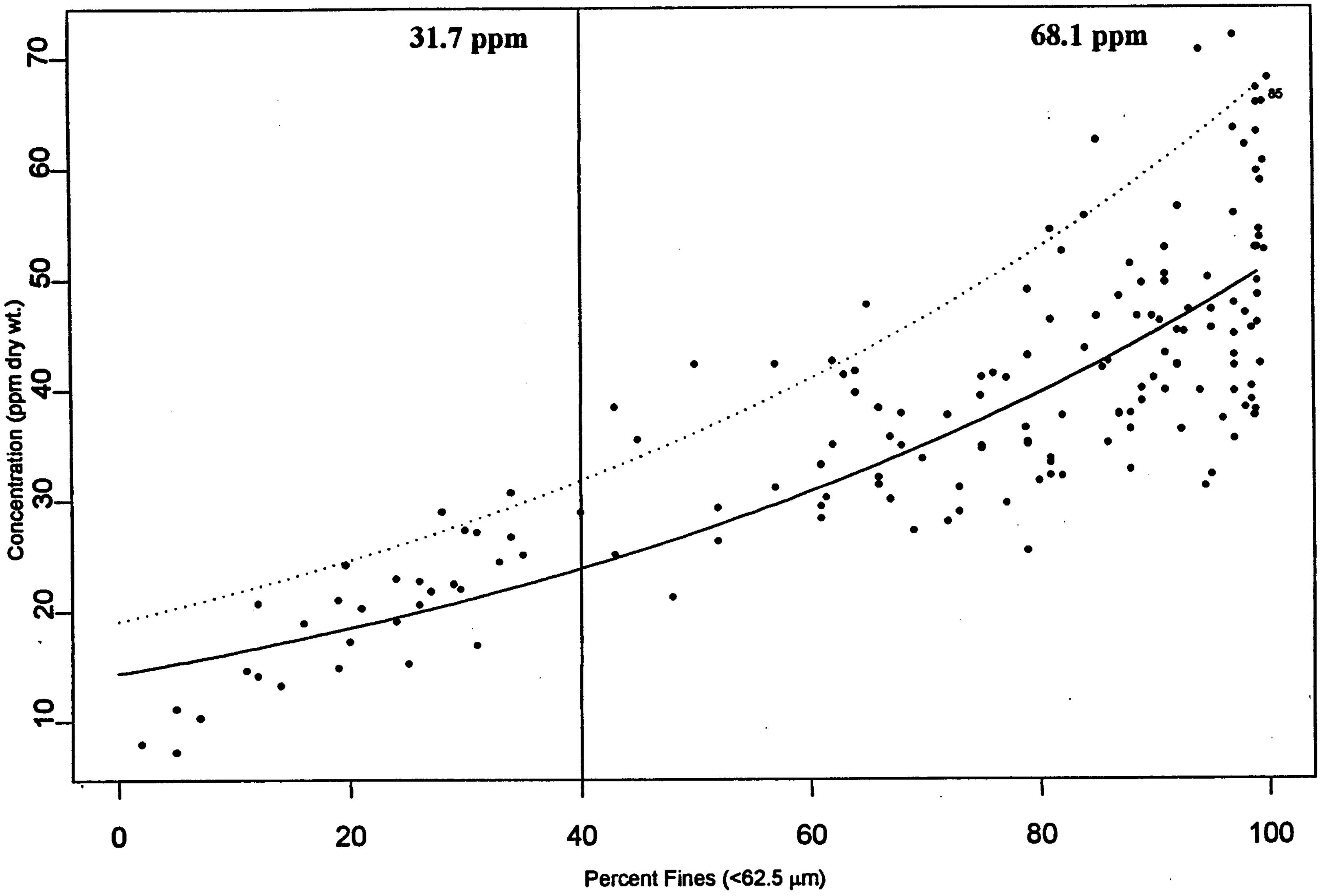

Figure 39. Copper Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

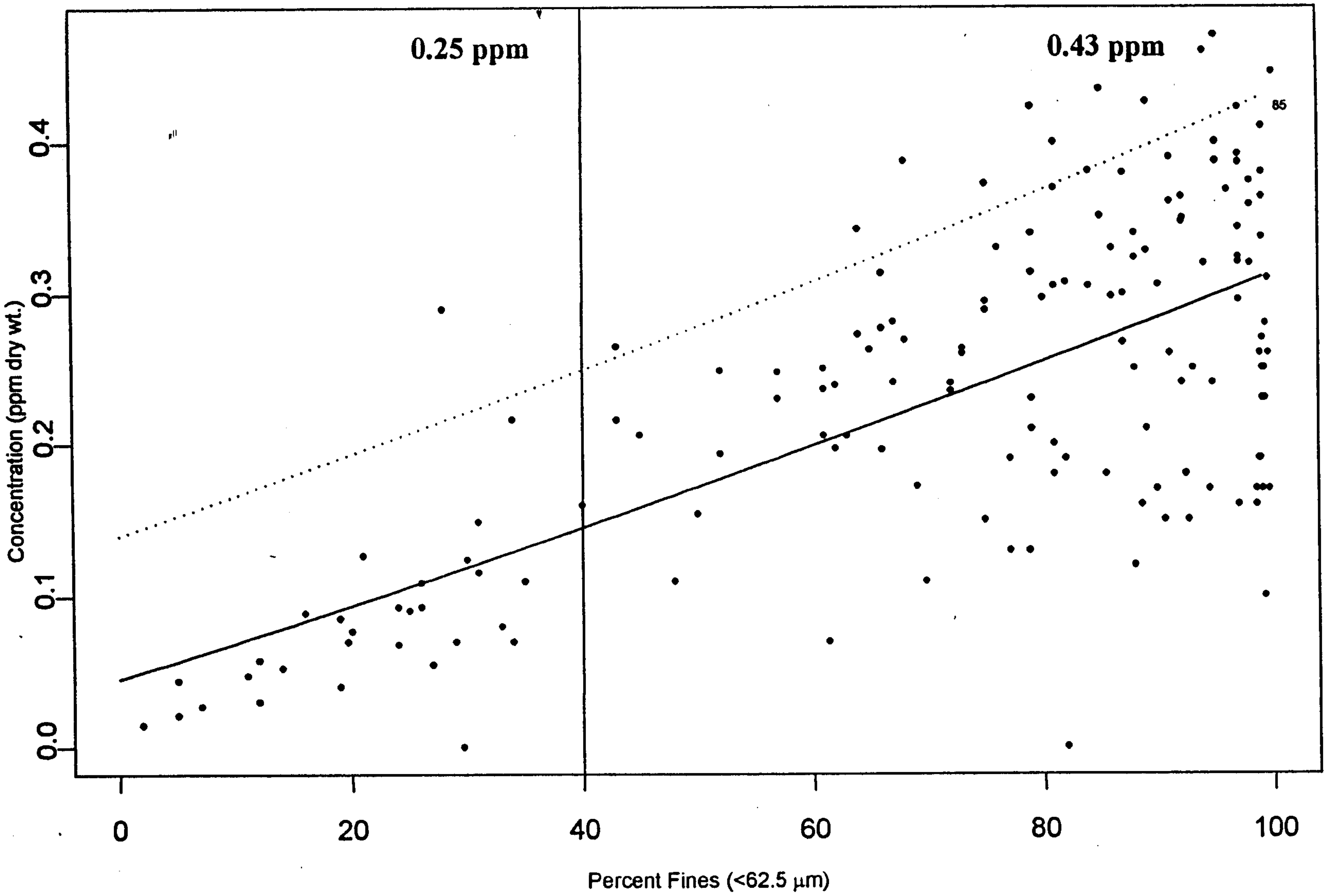

Figure 40. Mercury Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

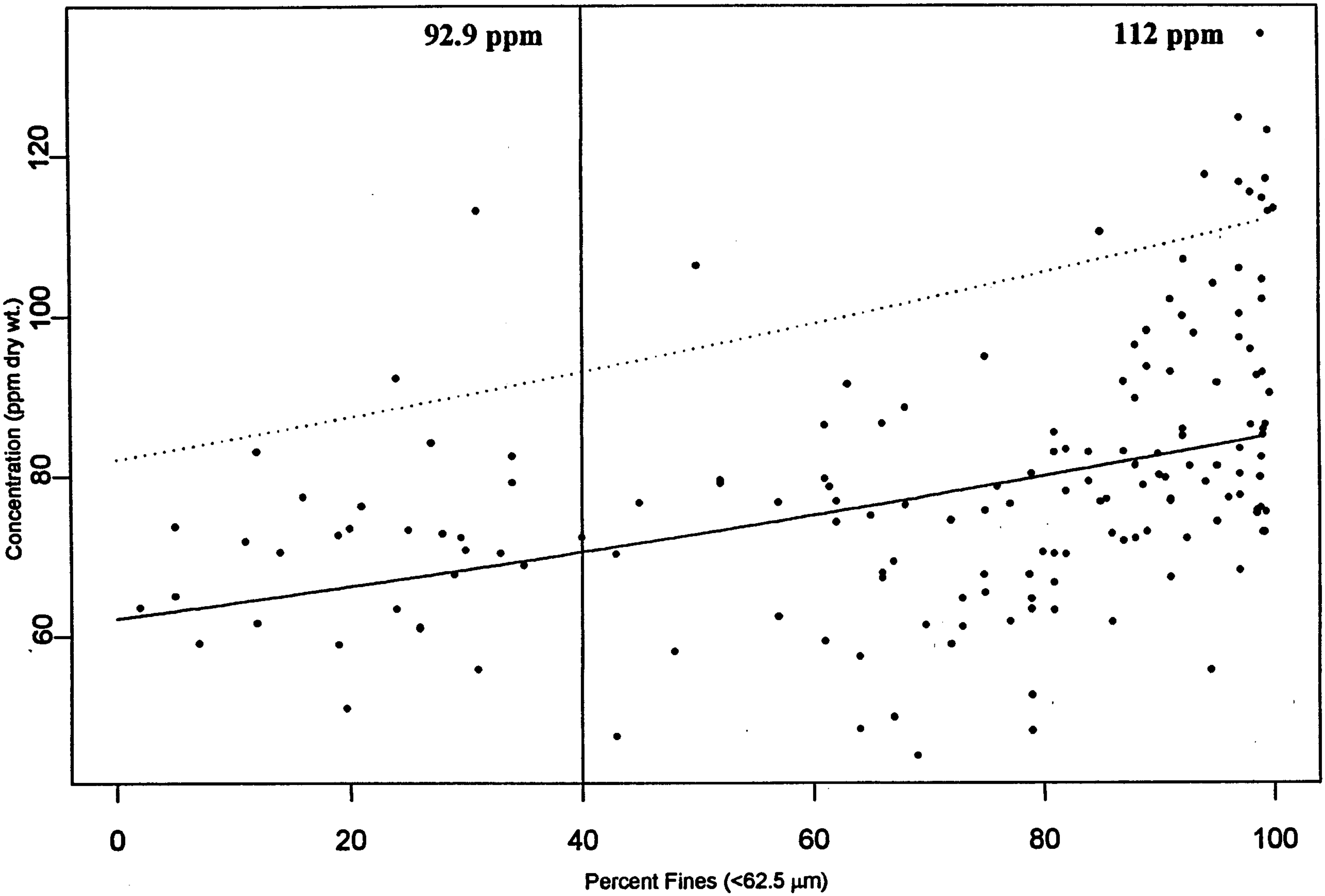

Figure 41. Nickel Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

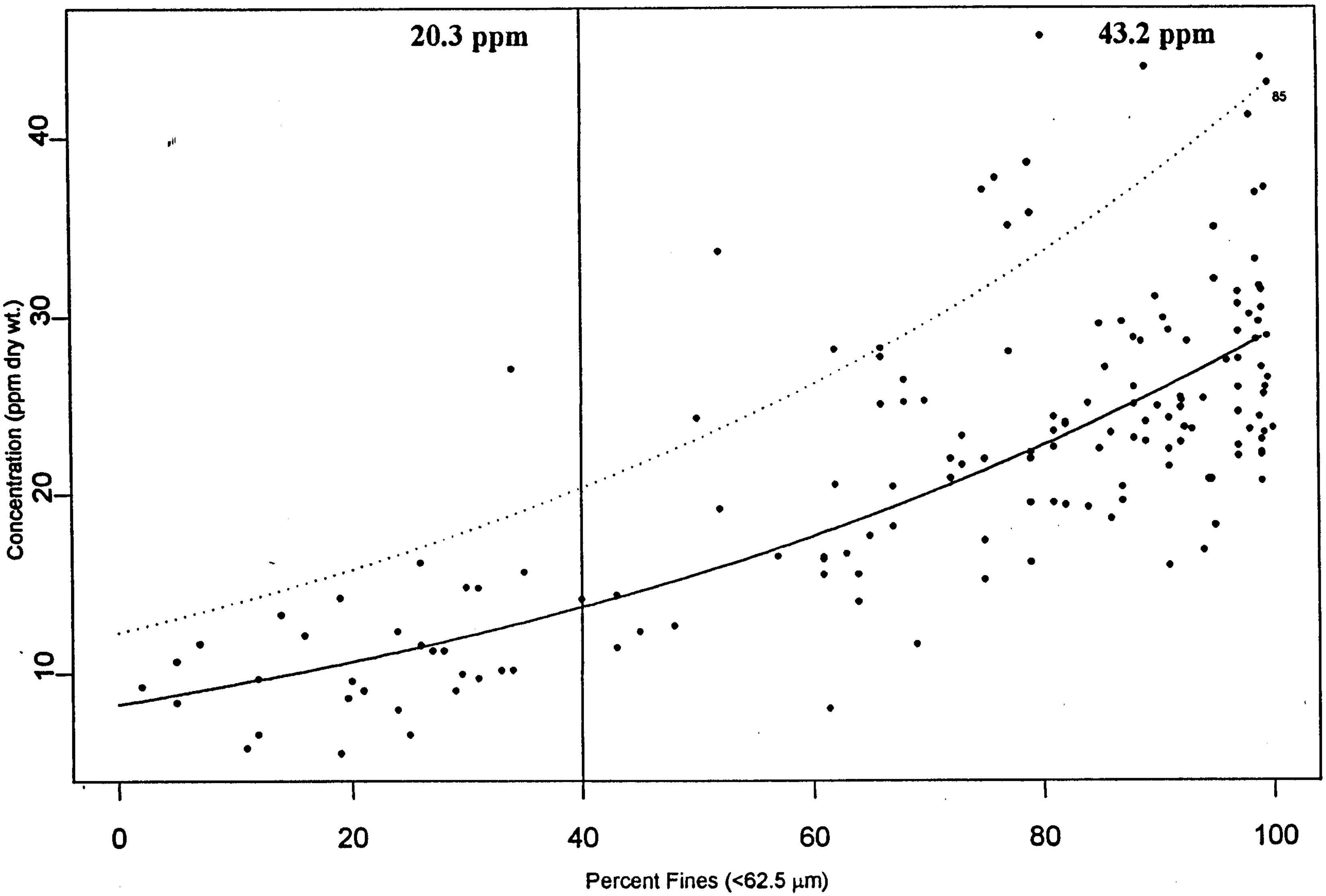

Figure 42. Lead Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

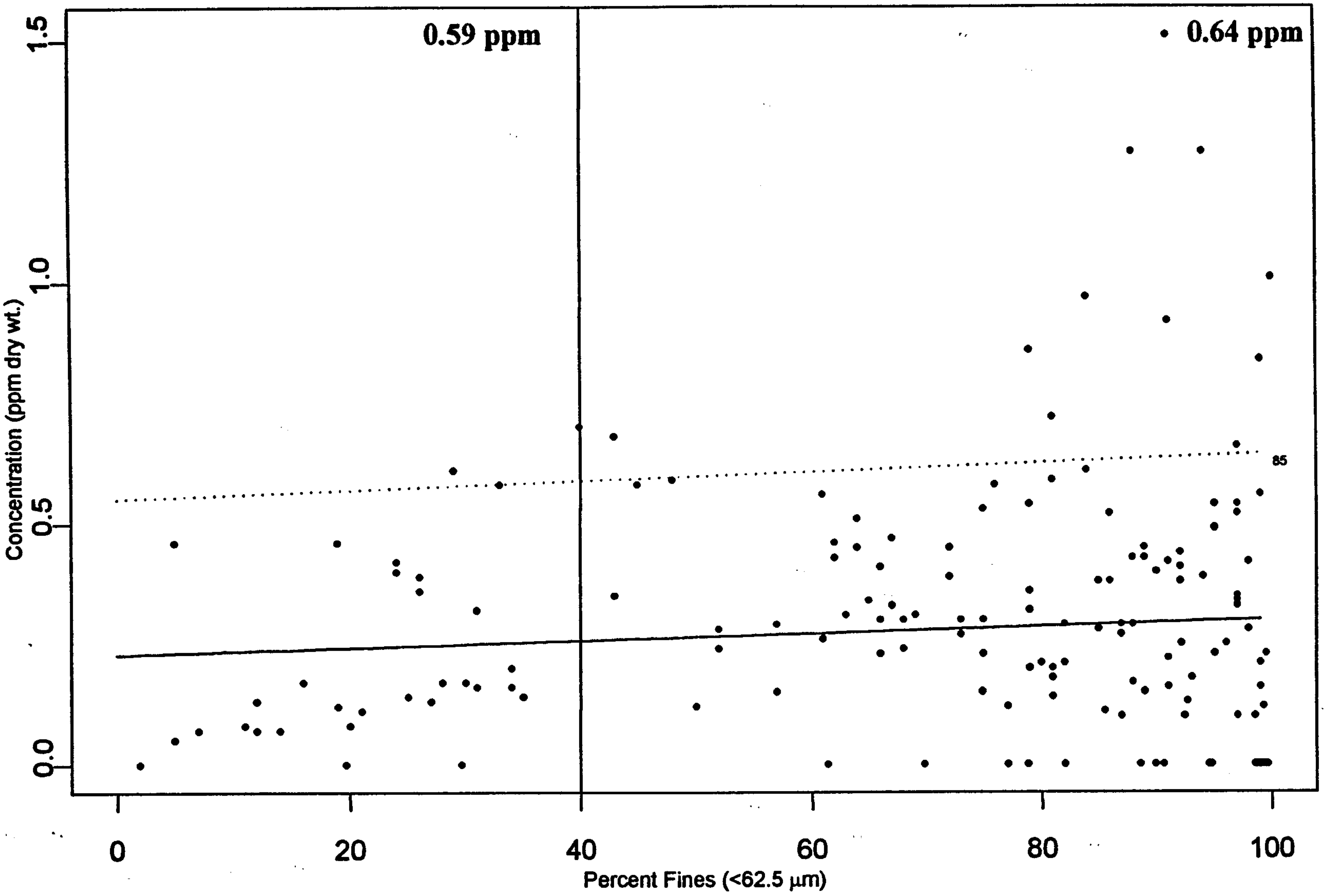

Figure 43. Selenium Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.

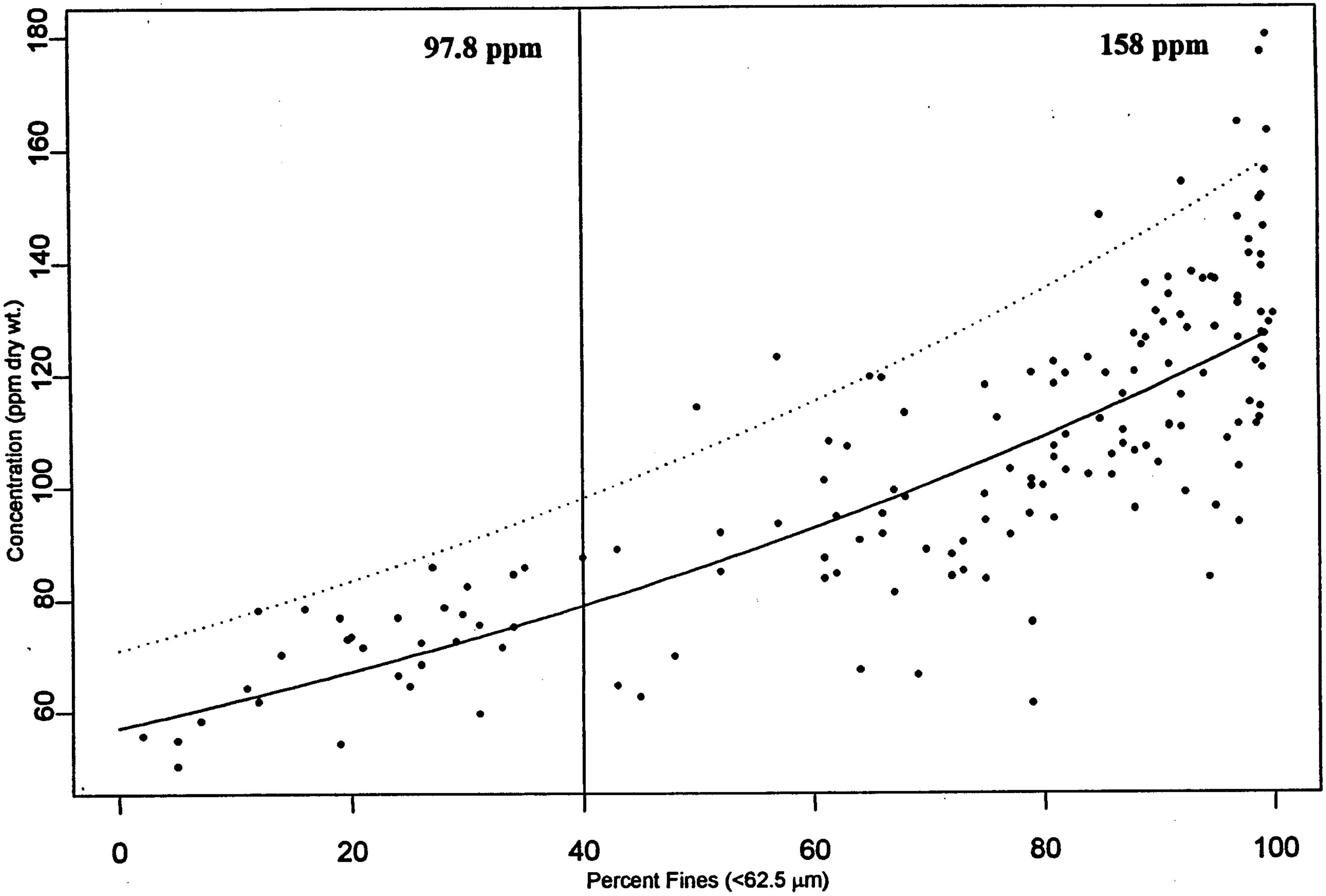

Figure 44. Zinc Concentrations in San Francisco Bay Sediments and the 85th Percentile Upper Bound.