Evaluation of Candidate CSL, MCUL, and SIZmax Values

Status Report

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STATUS REPORT

EVALUATION OF CANDIDATE CSL, MCUL, AND SIZ_{MAX} VALUES

This report summarizes the current status of the evaluation of candidate cleanup screening levels (CSL), minimum cleanup levels (MCUL), and maximum allowable sediment impact zone concentrations (SIZ_{MAX}). All chemicals for which definitive interim sediment quality (P2) standards have been established were evaluated. Chemicals with P2 values defined as "no value" were excluded from the analysis because the development of alternative effects criteria is subject to the same constraints as the development of the P2 standards. The attached figures illustrate the relationship between the observed concentration distribution in Puget Sound for each of these chemicals (based on data in the SEDQUAL database) and candidate values for CSL, MCUL, and SIZ_{MAX}. These figures were prepared to assess the following items:

- Patterns in effects indices illustrated by the relationship between apparent effects threshold (AET) values based on different biological tests
- Patterns in effects indices illustrated by the relationship between AET values that represent different biological test interpretation criteria
- Implications associated with setting CSL, MCUL, and SIZ_{MAX} values by alternative effects indices, illustrated by the relationship between a particular AET and the observed frequency distribution of chemical concentrations in Puget Sound.

Frequency distributions include undetected values, which are represented by detection limits.

The following discussion summarizes the definition of alternative effects indices that were assessed; general observations and constraints on the assessment (e.g., analytical, geographical); general observations; options for formulating CSL, MCUL, and SIZ_{MAX} values; general conclusions; and the rationale behind the conclusions.

DEFINITION OF ALTERNATIVE EFFECTS INDICES

The P2 value for a chemical is generally established as the lowest defined AET value for the available biological indicators. This chemical level is associated with no observable adverse effects using available biological tests. Indices described in this section are alternative values that are the chemical equivalent of a particular biological effects level.

1988 AET Values

The 1988 AET values are based on biological effects determined by a station's percent mean response relative to survey-specific reference conditions. For the three bioassay test types (amphipod mortality, oyster larvae abnormality, and Microtox® luminescence), a station is considered biologically impacted if its percent mean response is statistically different

($\alpha = 0.05$) from the percent mean response at the reference area using a comparisonwise *t*-test. For the amphipod bioassay, an initial screening was based on statistical power. Stations for which there is inadequate power (power < 0.6) to distinguish significant effects relative to reference conditions were excluded prior to generation of 1988 AET values. Of the remaining stations, only statistically significant mortality that exceeds 25 percent is considered an impact (Barrick et al. 1989). A comparisonwise significance level of $\alpha = 0.05$ is also used for determining the significance of reduced abundances of benthic infauna relative to reference conditions. In addition, only statistically significant effects ($\alpha = 0.05$) that also exceed a 50 percent reduction in major taxa abundance are considered impacts, based on an assessment of the natural variability of benthic abundances.

Nonimpacted stations that exhibited anomalously high chemical concentrations are excluded from the generation of 1988 AET values for specific biological indicators (amphipod bioassay and benthic infauna abundance). Such stations exhibit concentrations for one or more chemicals that were anomalously high (by a factor of 3) compared with those at the nonimpacted station exhibiting the next highest concentration. The purpose of this exception is to acknowledge potentially nonrepresentative data for unusual chemical matrices (e.g., slag or coal) or unusual biological conditions (e.g., extremely tolerant species under localized conditions). This exception is only applied to amphipod bioassay stations and benthic infauna stations, which are represented by numerous surveys around Puget Sound. Data for the oyster larvae and Microtox® bioassays are available only from Commencement Bay and Carr Inlet. The smaller number of stations and more limited geographic coverage for these biological indicators are considered insufficient to screen for chemical or biological anomalies.

Thirty Percent AET Values

The 30 percent "relative" AET values are based on biological effects determined by a station's percent mean response relative to survey-specific reference conditions. For the three bioassay test types (amphipod mortality, oyster larvae abnormality, and Microtox® luminescence), a station is considered biologically impacted if its percent mean response exceeds 30 percent plus the appropriate reference station's percent mean response. Statistical significance tests of each station from reference conditions were conducted to test the validity of defining an impacted station based solely on percent response. All stations that exceed a 30 percent mean response relative to reference conditions are also significantly different from that reference station (comparisonwise *t*-test, $\alpha = 0.05$). Additional review of the amphipod biological effects stations included identification of impacted stations with low power (power < 0.6) and identification of chemically anomalous nonimpacted stations (stations with concentrations of > 3 times the next highest nonimpacted station). Defining an impacted station as one that is statistically significant from reference ($\alpha = 0.05$) and that does not exhibit low power is the same definition on which the 1988 amphipod AET values are based (i.e., only the minimum percent bioassay response differs between these two kinds of AET). Neither low power stations nor chemically anomalous stations have been omitted from the calculation of the relative AET values for the Microtox® and oyster larvae test types. This approach parallels that used in calculating the 1988 AET values for the Microtox® and oyster larvae test types.

The 30 percent relative-to-reference analysis results in 44 amphipod stations, 11 Microtox® stations, and 6 oyster stations designated as biologically impacted, compared with 106, 29, and 17 impacted stations, respectively, in the 1988 AET database.

Fifty Percent AET Values

The rules for defining an impacted station for the 50 percent relative-to-reference analysis are analogous to the 30 percent relative-to-reference analysis defined above. The range of percent mean response among reference stations is 8-24 percent, requiring an impacted station to exhibit from 58-74 percent response. This definition results in only 21 amphipod stations, 3 Microtox® stations, and 2 oyster larvae stations designated as biologically impacted.

Severe Effects AET

Severe biological effects are defined as >50 percent response in a bioassay or the occurrence of statistically significant depressions (>50 percent and $\alpha=0.05$) in the abundance of more than one major taxonomic group (i.e., two or more depressions among Mollusca, Crustacea, and Polychaeta). Chemically anomalous stations were identified for amphipod and benthic infauna test types. Low power anomalies of the amphipod bioassay had no impact on this analysis (the bioassay response at stations with low power did not exceed 50 percent). The severe effects AET values are nearly identical to the 30 percent relative AET values and are based on the same assumptions for biological and chemical anomalies (i.e., exclusion of low power stations for the amphipod test, and no exclusion of chemically anomalous stations for the Microtox® and oyster larvae bioassays).

For the amphipod test type, 42 stations exhibited severe mortality, 56 stations exhibited severe benthic depressions (compared with 108 impacted benthic stations in the 1988 AET database), 3 stations exhibited severe reductions in luminescence in the Microtox® bioassay, and 4 stations exhibited severe abnormalities in the oyster larvae bioassay.

GENERAL OBSERVATIONS AND CAVEATS

The following general observations can be made regarding the patterns in the attached figures:

- Use of organic carbon normalized AET values for nonpolar organic compounds results in more values defined by a "greater than" (>) qualifier than if dry weight normalized values were used. The former normalization technique has been recommended by the U.S. Environmental Protection Agency (EPA) Science Advisory Board, but the more frequent occurrence of these qualified values for the various effects indices should be considered when determining how best to integrate such values as regulatory criteria.
- The 30 percent and 50 percent relative effects indices are frequently defined by a > qualifier. This occurrence should be considered in assessing whether these effects indices are appropriate to use as regulatory criteria.
- The identification of oyster larvae and Microtox® effects indices is constrained by the smaller number of paired chemical and biological test results relative to the amphipod bioassay or benthic infauna analyses. This constraint may explain why these effects indices are more often defined by > qualifiers, which should be considered in assessing their use as regulatory criteria.

- For individual biological effects indices, increasing predicted effects (e.g., 1988 AET, 30 percent AET, and 50 percent AET values) do not necessarily correspond to a range of increasing concentrations for a particular chemical. This further limits the utility of these alternative biological test interpretation guidelines.
- Ignoring values that are qualified by > and that are systematically less than unqualified values could be environmentally nonprotective if unqualified values are used as criteria (because it is unknown whether the particular effects occur just above the qualified value and below the unqualified value). However, the lowest unqualified value would be the lowest documented concentration above which effects were observed for a given biological indicator.
- Using values that are qualified by > and that are systematically greater than unqualified values is still environmentally protective (i.e., the values represent an effects "floor") for the particular biological indicator. These qualified values can be used as CSL, MCUL, and SIZ_{MAX} values.

In Puget Sound, the AET approach has been applied to complex mixtures of chemicals in a variety of habitats and depositional environments. Consequently, evaluations of chemical-specific effects indices and their regulatory implications were conducted recognizing several caveats:

- Some chemicals for which there are AET values may be indicators of adverse biological effects rather than direct causative agents. This possibility is characteristic of empirical approaches, and use of AET values for such chemicals would be environmentally protective. However, some technical reviewers have commented that AET values for phthalate esters are unrealistically low given their observed toxicity in laboratory experiments, and that the pattern of AET values among different phthalate esters does not reflect their relative physicochemical characteristics. Phthalate esters are also common laboratory contaminants and this factor may not be fully recognized in some historical data sets used to generate AET values. This latter concern has been addressed in the dredging program by using the highest AET for individual phthalate esters, rather than the lowest, to screen for potential biological effects. Such an exception is recommended for use in designating CSL, MCUL, and SIZ_{MAX} values.
- The characterization of the concentration distribution of several chemicals is constrained by analytical limitations associated with some of the surveys illustrated in the frequency distributions. These chemicals are described in the following section under the individual chemical groups or classes.
- 1988 AET values for antimony and chromium are recommended for the amphipod bioassay and benthic infauna indicators but not for the Microtox® or oyster larvae bioassays. Modifications of analytical procedures for metals have been instituted in Puget Sound Estuary Program (PSEP) guidelines since the available sediment data for Microtox® and oyster larvae bioassays were collected in the Commencement Bay survey. These changes were incorporated into the surveys for Elliott Bay and Everett Harbor, thereby doubling the size of the amphipod bioassay and benthic infauna data sets. By comparing tests conducted on sediment samples from Elliott Bay and Port Susan with tests

conducted on archived sediment samples from Carr Inlet (the reference area in the Commencement Bay survey), it was determined that antimony and chromium concentrations are substantially higher using the revised technique. As a result, it was concluded that AET values based on the historical chemical analyses are inefficient predictors of problem sediments. Therefore, no antimony or chromium AET values have been recommended for the Microtox® and oyster larvae bioassays, which are only based on the historical Commencement Bay survey. In addition, definitive test results for X-ray fluorescence analyses also indicate that antimony measurements by other techniques (i.e., both strong acid and total digestion) are less reliable than those for other metals. Hence, no CSL, MCUL, or SIZ_{MAX} values are recommended for antimony.

- The 1988 AET report concluded that there are no obvious geographic trends in the reliability of the amphipod or benthic infauna AET values. However, some AET values may be affected by the particular surveys that are included in the AET database. Some surveys included fewer chemicals [e.g., Duwamish River samples analyzed by the National Oceanic and Atmospheric Administration (NOAA) for the Puget Sound Dredged Disposal Analysis (PSDDA)] or had high detection limits (e.g., samples analyzed for the 48-station EIGHTBAY survey by the EPA Manchester laboratory) in comparison with the PSEP surveys in Elliott Bay and Everett Harbor and the Superfund surveys in Commencement Bay and Eagle Harbor. In particular, the 1988 report documented an unusually low sensitivity in identifying impacts at stations in the EIGHTBAY survey, although this survey included samples from the same urban areas in which high sensitivity was seen in other surveys.

OPTIONS FOR GENERATING CSL, MCUL, AND SIZ_{MAX} VALUES

The alternative biological effects levels generally, but not always, reflect higher chemical concentrations than those associated with the P2 values. For 10 of 47 chemicals evaluated, there is no difference in the chemical concentration associated with the P2 level and the next highest alternative biological effects level. In these cases, the following five options were considered for defining a range of cleanup levels above P2:

1. Require biological testing to determine whether the CSL, MCUL, or SIZ_{MAX} values have been attained (e.g., by allowing no more than minor adverse effects). This option would conceptually provide a consistent means of linking cleanup levels to a defined level of biological effects but would not provide a predictable chemical basis for defining cleanup levels and could be difficult to implement for all sediments (e.g., buried sediment).

2. Make no adjustment in the CSL, MCUL, or SIZ_{MAX} value (i.e., for these chemicals, the cleanup values would be equivalent to P2). This option would enable all CSL, MCUL, and SIZ_{MAX} values to be defined numerically on a consistent basis. Regulatory flexibility is introduced through the processes for implementing CSL, MCUL, and SIZ_{MAX} values, and through the interpretation guidelines (i.e., PSDDA Site Condition 2) for confirmatory biological testing, which allow a greater degree of biological effect(s) than the confirmatory testing specified for P2 values.

3. Use a factor elevation over P2 that reflects the maximum uncertainty in chemical measurements recommended in regional guidelines (i.e., a factor of 2 for organic compounds and a factor of 1.4 for metals, which correspond to PSEP action limits for accuracy of ±50 percent and ±25 percent, respectively). Use of such factors would imply that at concentrations greater than the factor elevation over the second lowest AET (AET2), there was confidence that the chemical measurement was clearly distinguishable from P2. This option does not provide a consistent basis for relating cleanup levels to a particular biological effects level, although application of this factor could be constrained to not exceed the highest AET value.

4. Adjust the CSL, MCUL, or SIZ_{MAX} value to a progressively higher AET value until the P2 value is exceeded. In several cases in which AET2 does not differ from P2, the third lowest AET (AET3) does. However, in at least one case, acenaphthylene, the highest AET (HAET or AET4) is equal to P2; therefore, use of Option 1 or 2 would be required to address such cases. This option provides flexibility for most chemicals but does not provide a consistent basis for defining the cleanup level in terms of a particular biological effects level.

5. Adjust the selected AET value to no more than the lowest concentration observed at an impacted station that exceeds that AET value. This alternative is equivalent to an empirical estimate of an upper bound on the uncertainty of the AET value, because it is uncertain where the AET actually lies in the range between the AET value and the lowest concentration observed at an impacted station that exceeds the AET value. This option would require additional technical analysis to be performed (to determine the chemical values) and would not necessarily provide values that could be consistently related to a particular biological effects level. The values established with this option would also be less traceable to currently published information.

The second option is recommended because it enables the CSL, MCUL, and SIZ_{MAX} values to be consistently defined using the same biological effects level for all chemicals (except for phthalate esters, for which a special exception is recommended). Application of the CSL averaging process and the MCUL sediment recovery concept, and the use of PSDDA Site Condition 2 interpretation guidelines for confirmatory biological testing, should provide adequate regulatory flexibility in establishing cleanup levels under this option.

CONCLUSIONS AND RECOMMENDATIONS

It is recommended that the CSL, MCUL, and SIZ_{MAX} values be based on the biological effects indices defined by the 1988 AET (or updates thereof). These conventional effects indices are preferred because they are consistent with existing guidelines (i.e., PSEP), programs (e.g., PSDDA), and regulatory precedence (i.e., P2 sediment quality standards). Furthermore, unlike criteria defined by factors multiplied by P2 (e.g., 1.5xP2 and 2xP2), biological effects indices can be confirmed by biological tests and will reflect the dynamic range in effects indices specific to a given chemical.

The following overall approach is recommended for setting CSL, MCUL, and SIZ_{MAX} values consistent with the 1988 AET values:

- Use AET2 to establish the chemical equivalent of minor adverse biological effects. This effects level is the minimum that can be biologically confirmed using existing tests (i.e., failure of no more than one biological test used to establish Puget Sound AET values). Phthalate esters are an exception; the CSL, MCUL, and SIZ_{MAX} values for these chemicals should be defined as the highest AET.
- Make no adjustment in the CSL, MCUL, or SIZ_{MAX} values even if the AET2 value does not differ from P2 (i.e., for these chemicals, the CSL, MCUL, and SIZ_{MAX} values would be equivalent to P2). The spatial averaging process for assessing CSL values and application of the sediment recovery principle in determining the time of compliance for MCUL values will provide a means to distinguish these cleanup levels from P2 even if the numerical values are equivalent.

Recommended values for CSL, MCUL, and SIZ_{MAX} values, their relationship to P2, and the biological test that they represent, are summarized in Table 1. The AET2 values provide protective criteria that are consistent with the PSDDA criteria for Site Condition 2. The selection of relatively protective CSL, MCUL, and SIZ_{MAX} values is appropriate because additional flexibility is incorporated into these criteria through their respective implementation processes. Sites are screened by comparing CSL to area-weighted chemical concentrations at a particular site, and the process of calculating an area-weighted average tends to lower the chemical concentration selected to represent the site. Furthermore, MCUL will be applied as inflexible cleanup levels at a 10-year point of compliance, allowing natural recovery to be considered, which may increase the remedial action cleanup level over MCUL values by a factor of 2 or more. In addition, confirmatory biological test interpretation guidelines are relaxed relative to P2 confirmatory test guidelines. The selection of relatively protective criteria is also consistent with the goals of the Puget Sound Water Quality Authority's management plan for Puget Sound.

In establishing CSL, MCUL, and SIZ_{MAX} values, it is recommended that qualified AET values (i.e., values associated with a > qualifier) not be used unless there are no other AET values that equal or exceed P2. For example, a >AET value that is between P2 and another unqualified AET value would be ignored, and the latter AET value would be considered as AET2. However, if P2 is defined as the lowest AET, and all other AET values that are available are >AET values that equal or exceed P2, then the CSL, MCUL, and SIZ_{MAX} values would be defined by the >AET value.

The results and implications of applying these recommendations to P2 chemicals is discussed in the following sections. The discussion is organized by chemical group because these groups often exhibit common patterns and are subject to similar caveats (e.g., the potential for problems associated with alternative extraction methods applies, in general, to all metals).

Metals

Most effects indices for metals are well characterized. Only the elevated effects indices (i.e., 30 percent, 50 percent, and severe effects indices) for Microtox® are routinely defined

TABLE 1. RECOMMENDED VALUES FOR CLEANUP SCREENING LEVELS, MINIMUM CLEANUP LEVELS, AND MAXIMUM ALLOWABLE CONCENTRATIONS (SIZ_{MAX})

Chemical	Value[a]	AET Order[b]	Ratio to P2
Metals (ppm DW[c])			
Arsenic	93 (A)	AET2	1.6
Cadmium	6.7 (A)	AET2	1.3
Chromium	270 (A)	AET2	1.04
Copper	390 (O,M)	AET2	1
Lead	530 (M)	AET2	1.2
Mercury	0.59 (O)	AET2	1.4
Silver	6.1 (A)	AET2[d]	1
Zinc	960 (A)	AET2	2.3
Phenols (ppm DW)			
Phenol	1.2 (M,B,A)	AET2	2.8
2-Methylphenol	0.063 (A,O)	AET2	1
4-Methylphenol	0.67 (M,O)	AET2	1
2,4-Dimethylphenol	0.029 (M,O)	AET2	1
Pentachlorophenol	0.69 (B)	AET2[e]	1.9
Other Ionic Organic Compounds (ppm DW)			
Benzyl alcohol	0.073 (O)	AET2	1.3
Benzoic acid	0.65 (M,O,B)	AET2	1
Total PCBs (ppm TOC[c])	65 (B)	AET2[f]	5.4
LPAH (ppm TOC)	780 (B)	AET2[f]	2.1
Naphthalene	170 (B)	AET2	1.7
Acenaphthylene	66 (A,B)	AET2[d,e]	1
Acenaphthene	57 (B)	AET2	3.5
Fluorene	79 (B)	AET2[f]	3.4
Phenanthrene	480 (B)	AET2[f]	4.0
Anthracene	1,200 (A)	AET2[e]	5.4
2-Methylnaphthalene	64 (B)	AET2	1.7
HPAH (ppm TOC)	5,300 (A)	AET2[f]	5.5
Fluoranthene	1,200 (B)	AET2[f]	7.5
Pyrene	1,400 (B)	AET2[e]	1.4
Chrysene	460 (A)	AET2[f]	4.2

TABLE 1. (Continued)

Chemical	Value	AET Order	Ratio to P2
HPAH (ppm TOC) (continued)			
Benz(a)anthracene	270 (A)	AET2[f]	2.5
Benzofluoranthenes	450 (A)	AET2[f]	2.0
Benzo(a)pyrene	210 (A)	AET2[f]	2.1
Indeno(1,2,3-c,d)pyrene	88 (A)	AET2[f]	2.7
Dibenzo(a,h)anthracene	33 (M)	AET2	2.7
Benzo(g,h,i)perylene	78 (A)	AET2[f]	2.5
Chlorinated Benzenes (ppm TOC)			
1,2-Dichlorobenzene	2.3 (M,O,B)	AET2	1
1,4-Dichlorobenzene	9 (A)	AET2	9
1,2,4-Trichlorobenzene	1.8 (A)	AET2	2.2
Hexachlorobenzene	2.3 (M)	AET2	6.1
Phthalate Esters (ppm TOC)			
Dimethylphthalate	53 (A,B)	HAET[d]	1
Diethylphthalate	>110 (A)	HAET	1.8
Di-*n*-butylphthalate	1,700 (B)	HAET	7.7
Butylbenzylphthalate	64 (B)	HAET	13
Bis(2-ethylhexyl)phthalate	78 (A)	HAET	1.7
Di-*n*-octylphthalate	4,500 (B)	HAET	78
Other Nonpolar Organic Compounds (ppm TOC)			
Dibenzofuran	58 (B)	AET2	3.9
Hexachlorobutadiene	6.2 (A)	AET2	1.6
N-nitrosodiphenylamine	11 (B)	--[d]	1

[a] A = amphipod bioassay; B = benthic infauna analysis; M = Microtox® bioassay; O = oyster larvae bioassay. The AET value for the biological indicator listed establishes the value shown.

[b] AET2 = second lowest AET for a range of biological indicators; HAET = highest AET.

[c] DW = value shown is normalized to dry weight of sediment (metals and ionic organic compounds); TOC = value shown is normalized to total organic carbon content of sediment (nonpolar organic compounds).

[d] No effects indices are elevated over the P2 value.

[e] One or more AET values qualified by ">" is less than the P2 value.

[f] An AET value qualified by > falls between the P2 value and the recommended CSL, MCUL, and SIZ_{MAX} values.

by > qualifiers. The log-transformed data from Puget Sound are usually normally distributed and relatively narrow in range (typically, approximately 3 orders of magnitude) compared with organic chemical distributions. Median reference area values (Pastorok et al. 1989) fall near the peak of the distribution for all metals.

Identification of AET2 for metals is straightforward because > values do not obscure interpretation. Amphipod AET values establish the recommended CSL, MCUL, and SIZ_{MAX} values for all metals except copper, lead, and mercury. Only amphipod bioassay and benthic infauna AET have been considered for chromium because of differences in the analytical techniques used to generate chromium values for the Microtox® and oyster larvae bioassays. For two metals, copper and silver, the recommended CSL, MCUL, and SIZ_{MAX} values are identical to P2.

Polycyclic Aromatic Hydrocarbons

Elevated effects indices for the Microtox® bioassay are poorly characterized for polycyclic aromatic hydrocarbon (PAH) compounds [normalized to total organic carbon (TOC)] because most of these values are qualified by >. The point where these > effects indices lie in the distribution of 1988 AET values affects their interpretation or use as regulatory criteria. The log-transformed PAH data from Puget Sound are usually normally distributed and broader in range than the data observed for metals (typically, approximately 5 orders of magnitude).

Identification of AET2 for PAH compounds is complicated by the common occurrence of > values when PAH concentrations are normalized to organic carbon content. For many PAH compounds, Microtox® AET values qualified by > fall between P2 and AET2 values. These cases are noted in Table 1. Three PAH compounds (Microtox® and oyster larvae AET qualified by > and noted in Table 1) fell below both P2 and AET2 values. The recommended CSL, MCUL, and SIZ_{MAX} values for acenaphthylene do not differ from P2. In nearly all cases, CSL, MCUL, and SIZ_{MAX} values for PAH compounds are set by amphipod or benthic infauna AET values.

The TOC-normalized AET value for 2-methylnaphthalene was inadvertently omitted from the 1988 AET report for the oyster larvae and Microtox® bioassays (although the corresponding dry weight values for these indicators were shown). SEDQUAL calculated TOC-normalized values, which are shown in the attached figure for 2-methylnaphthalene. The 1988 oyster larvae AET for dibenz(a,h)anthracene (shown in the figure) is now correct; this value had been incorrectly published as 120 parts per million (ppm) TOC (instead of 12 ppm TOC) since 1988. This correct value of 12 ppm TOC now establishes P2.

Chlorinated Benzenes

Elevated effects indices for all biological indicators except benthic infauna are poorly characterized for chlorinated benzenes because most AET values are qualified as > values. The recommended CSL, MCUL, and SIZ_{MAX} values for the different chlorinated benzene compounds are defined by Microtox® or amphipod AET values. The point where these > effects indices lie in the distribution of these 1988 AET values determines their interpretation or use as regulatory criteria. The log-transformed data for chlorinated benzenes in Puget Sound are broad in range (typically, approximately 5 orders of magnitude).

Total PCB Mixtures

For mixtures of polychlorinated biphenyls (PCBs), oyster larvae AET qualified by > fell between P2 and AET2 values. The recommended CSL, MCUL, and SIZ_{MAX} values for PCB mixtures are defined by the benthic infauna AET.

Phthalates

Based on the discussion summarized in the *General Observations and Caveats* section, the highest AET (i.e., either benthic infauna or amphipod bioassay) has been recommended for all phthalate esters. However, the highest AET for dimethylphthalate does not differ from P2.

Phenols

The AET2 values for 4-methylphenol, 2-methylphenol, and 2,4-dimethylphenol result in no difference from the P2 value.

Miscellaneous Extractable Compounds

The recommended CSL, MCUL, and SIZ_{MAX} values are clearly defined by the AET2 value for dibenzofuran and hexachlorobutadiene. The AET2 value for N-nitrosodiphenylamine is equal to P2, and significant adverse effects potentially associated with this chemical are only observed for the benthic infauna analysis (which establishes the P2 value). Based on historical data reviews, N-nitrosodiphenylamine can be misidentified in samples because of mass spectral interferences. No major source of this compound has been documented in Puget Sound.

In 1988, it was determined that the rule for chemically anomalous stations should not be applied to benzyl alcohol for amphipod bioassay results. This decision was based on best professional judgment and on concerns over random occurrences of benzyl alcohol in sediment samples. While benzyl alcohol may have a variable distribution (i.e., a high concentration at the last station in a gradient of stations exhibiting adverse biological effects but undetected or present at a much lower concentration at the most heavily impacted station in the gradient), samples from impacted stations that exceed the benzyl alcohol AET value are typically contaminated by other chemicals associated with known local sources of contamination. Application of the anomaly rule would decrease the amphipod AET for this chemical from 73 ppm TOC to 5 ppm TOC [or 870 parts per billion (ppb) dry weight to 140 ppb dry weight]. However, this change would not affect the recommended CSL, MCUL, and SIZ_{MAX} values, which are established by the oyster larvae, Microtox®, or benthic effects AET values at a lower concentration (0.65 ppm TOC).

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Appendix A:

1988 AET,
Severe Effects AET,
30% and 50% Relative AET Values

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

CHEMICAL	MEAS. BASIS	UNITS	AMPHIPOD BIOASSAY TEST TYPE			
			30% Relative	50% Relative	Severe Effects	1988 AET
1,2-DICHLOROBENZENE	TOC	PPB	5,800 G	5,800 G	5,800 G	5,800 G
1,2,4-TRICHLOROBENZENE	TOC	PPB	2,800 G	2,800 G	2,800 G	1,800
1,4-DICHLOROBENZENE	TOC	PPB	16,000	18,000 G	16,000	9,000 X
2-METHYLNAPHTHALENE	TOC	PPB	120,000 G	120,000 G	120,000 G	120,000 G
2-METHYLPHENOL	DRY	PPB	72	280	72	63
2,4-DIMETHYL PHENOL	DRY	PPB	210	210	210	72
DIBENZO(A,H)ANTHRACENE	TOC	PPB	47,000	47,000	47,000	47,000 E
DI-N-OCTYL PHTHALATE	TOC	PPB	58,000 G	96,000 G	58,000 G	58,000
4-METHYL PHENOL	DRY	PPB	3,600	26,000	3,600	3,600 X
PENTACHLOROPHENOL	DRY	PPB	690	690	690	360 X
HEXACHLOROBENZENE	TOC	PPB	9,600 G	9,600 G	9,600 G	4,500
HEXACHLOROBUTADIENE	TOC	PPB	16,000 G	16,000 G	16,000 G	6,200
ACENAPHTHENE	TOC	PPB	200,000	200,000	200,000	200,000 E
ACENAPHTHYLENE	TOC	PPB	66,000	110,000 G	66,000	66,000 X
ANTHRACENE	TOC	PPB	1,200,000	1,200,000	1,200,000	1,200,000
ARSENIC	DRY	PPM	700	700	700	93
BIS(2-ETHYLHEXYL)PHTHALATE	TOC	PPB	210,000 G	210,000 G	210,000 G	78,000
BENZ(A)ANTHRACENE	TOC	PPB	270,000	270,000	270,000	270,000
BENZO(A)PYRENE	TOC	PPB	210,000	210,000	210,000	210,000
BENZOIC ACID	DRY	PPB	6,300 G	6,300 G	6,300 G	760 E
BENZYL ALCOHOL	DRY	PPB	870 E	1,300	870 E	870 E
BENZO(G,H,I)PERYLENE	TOC	PPB	78,000	78,000	78,000	78,000
BUTYL BENZYL PHTHALATE	TOC	PPB	42,000	86,000 G	42,000	42,000 E
CADMIUM	DRY	PPM	9.6	9.6	9.6	6.7
CHROMIUM TOTAL	DRY	PPM	1,100 G	1,100 G	1,100 G	270
CHRYSENE	TOC	PPB	460,000	460,000	460,000	460,000
COPPER	DRY	PPM	1,300	1,300	1,300	1,300
DIETHYL PHTHALATE	TOC	PPB	110,000 G	110,000 G	110,000 G	110,000 G
DIBENZOFURAN	TOC	PPB	170,000 G	170,000 G	170,000 G	170,000 G
DI-N-BUTYL PHTHALATE	TOC	PPB	260,000	260,000	260,000	260,000 Z
DIMETHYL PHTHALATE	TOC	PPB	53,000	53,000	53,000	53,000
FLUORANTHENE	TOC	PPB	3,000,000	3,000,000	3,000,000	3,000,000 E
FLUORENE	TOC	PPB	380,000	380,000	380,000	360,000 E
POLYCYCLIC AROMATIC HYDROCARBON-HEAVY	TOC	PPB	5,300,000	5,300,000	5,300,000	5,300,000 E
INDENO(1,2,3-CD)PYRENE	TOC	PPB	100,000	100,000	100,000	88,000 E
LEAD	DRY	PPM	8,700 G	8,700 G	1,200	660
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT	TOC	PPB	2,200,000	2,200,000	2,200,000	2,200,000
MERCURY	DRY	PPM	2.1	2.1	2.1	2.1
NAPHTHALENE	TOC	PPB	220,000	220,000	220,000	220,000
N-NITROSO DIPHENYLAMINE	TOC	PPB	11,000 G	11,000 G	11,000 G	11,000 G
POLYCHLORINATED BIPHENYLS	TOC	PPB	190,000	190,000	190,000	190,000 E
PHENANTHRENE	TOC	PPB	690,000	690,000	690,000	690,000 E
PHENOL	DRY	PPB	1,200	2,900 G	1,200	1,200 Z

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

CHEMICAL	MEAS. BASIS	UNITS	AMPHIPOD BIOASSAY TEST TYPE			
			30% Relative	50% Relative	Severe Effects	1988 AET
PYRENE	TOC	PPB	1,000,000	1,000,000	1,000,000	1,000,000 E
SILVER	DRY	PPM	6.1	8.3 G	6.1	6.1 E
TOTAL BENZOFLUORANTHENES (B + K)	TOC	PPB	450,000	450,000	450,000	450,000
ZINC	DRY	PPM	1,600	5,900 G	1,600	960 E

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

CHEMICAL	MEAS. BASIS	UNITS	BENTHIC INFAUNA TEST TYPE Severe Effects		1988 AET	
1,2-DICHLOROBENZENE	TOC	PPB	2,300		2,300	
1,2,4-TRICHLOROBENZENE	TOC	PPB	2,800		NV	
1,4-DICHLOROBENZENE	TOC	PPB	16,000		16,000	
2-METHYLNAPHTHALENE	TOC	PPB	70,000		64,000	
2-METHYLPHENOL	DRY	PPB	72		72	
2,4-DIMETHYL PHENOL	DRY	PPB	210	G	210	E
DIBENZO(A,H)ANTHRACENE	TOC	PPB	1,200,000	G	89,000	
DI-N-OCTYL PHTHALATE	TOC	PPB	12,000,000	G	4,500,000	
4-METHYL PHENOL	DRY	PPB	26,000		1,800	
PENTACHLOROPHENOL	DRY	PPB	690		690	E
HEXACHLOROBENZENE	TOC	PPB	9,600		380	
HEXACHLOROBUTADIENE	TOC	PPB	16,000	G	6,900	
ACENAPHTHENE	TOC	PPB	200,000		57,000	
ACENAPHTHYLENE	TOC	PPB	640,000		66,000	X
ANTHRACENE	TOC	PPB	1,300,000		220,000	
ARSENIC	DRY	PPM	1,600		57	
BIS(2-ETHYLHEXYL)PHTHALATE	TOC	PPB	60,000		60,000	Z
BENZ(A)ANTHRACENE	TOC	PPB	4,500,000	G	650,000	
BENZO(A)PYRENE	TOC	PPB	6,800,000	G	1,300,000	G
BENZOIC ACID	DRY	PPB	650		650	
BENZYL ALCOHOL	DRY	PPB	870	G	870	E
BENZO(G,H,I)PERYLENE	TOC	PPB	5,400,000	G	1,200,000	G
BUTYL BENZYL PHTHALATE	TOC	PPB	410,000	G	64,000	
CADMIUM	DRY	PPM	16		5.1	
CHROMIUM TOTAL	DRY	PPM	260		260	
CHRYSENE	TOC	PPB	6,700,000	G	850,000	
COPPER	DRY	PPM	2,200		530	
DIETHYL PHTHALATE	TOC	PPB	110,000	G	61,000	
DIBENZOFURAN	TOC	PPB	170,000	G	58,000	
DI-N-BUTYL PHTHALATE	TOC	PPB	1,700,000		1,700,000	
DIMETHYL PHTHALATE	TOC	PPB	53,000		53,000	
FLUORANTHENE	TOC	PPB	6,300,000		1,200,000	
FLUORENE	TOC	PPB	640,000		79,000	
POLYCYCLIC AROMATIC HYDROCARBON-HEAVY	TOC	PPB	51,000,000	G	7,600,000	
INDENO(1,2,3-CD)PYRENE	TOC	PPB	5,200,000	G	900,000	
LEAD	DRY	PPM	1,000		450	
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT	TOC	PPB	6,200,000		780,000	
MERCURY	DRY	PPM	3.2		2.1	E
NAPHTHALENE	TOC	PPB	360,000		170,000	
N-NITROSO DIPHENYLAMINE	TOC	PPB	63,000	G	11,000	
POLYCHLORINATED BIPHENYLS	TOC	PPB	220,000		65,000	
PHENANTHRENE	TOC	PPB	3,200,000		480,000	
PHENOL	DRY	PPB	2,900	G	1,200	Z

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

CHEMICAL	MEAS. BASIS	UNITS	BENTHIC INFAUNA TEST TYPE Severe Effects		1988 AET	
PYRENE	TOC	PPB	7,300,000	G	1,400,000	
SILVER	DRY	PPM	6.1	G	6.1	G
TOTAL BENZOFLUORANTHENES (B + K)	TOC	PPB	8,000,000	G	1,500,000	
ZINC	DRY	PPM	1,600		410	E

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

CHEMICAL	MEAS. BASIS	UNITS	MICROTOX BIOASSAY TEST TYPE			
			30% Relative	50% Relative	Severe Effects	1988 AET
1,2-DICHLOROBENZENE	TOC	PPB	3,200 G	3,200 G	3,200 G	2,300
1,2,4-TRICHLOROBENZENE	TOC	PPB	5,900 G	5,900 G	5,900 G	810
1,4-DICHLOROBENZENE	TOC	PPB	16,000 G	16,000 G	16,000 G	16,000 G
2-METHYLNAPHTHALENE	TOC	PPB	64,000 G	64,000 G	64,000 G	64,000 G
2-METHYLPHENOL	DRY	PPB	72 G	72 G	72 G	72 G
2,4-DIMETHYL PHENOL	DRY	PPB	50 G	50 G	50 G	29
DIBENZO(A,H)ANTHRACENE	TOC	PPB	34,000 G	34,000 G	34,000 G	33,000
DI-N-OCTYL PHTHALATE	TOC	PPB	2,000 G	2,000 G	2,000 G	970 L
4-METHYL PHENOL	DRY	PPB	1,200	1,200	1,200	670
PENTACHLOROPHENOL	DRY	PPB	140 G	140 G	140 G	140 G
HEXACHLOROBENZENE	TOC	PPB	16,000 G	16,000 G	16,000 G	2,300
HEXACHLOROBUTADIENE	TOC	PPB	16,000 G	16,000 G	16,000 G	3,900
ACENAPHTHENE	TOC	PPB	57,000 G	57,000 G	57,000 G	57,000 G
ACENAPHTHYLENE	TOC	PPB	27,000 G	27,000 G	27,000 G	27,000 G
ANTHRACENE	TOC	PPB	79,000 G	79,000 G	79,000 G	79,000 G
ARSENIC	DRY	PPM	9,700 G	9,700 G	9,700 G	700
BIS(2-ETHYLHEXYL)PHTHALATE	TOC	PPB	68,000 G	68,000 G	68,000 G	47,000
BENZ(A)ANTHRACENE	TOC	PPB	160,000 G	160,000 G	160,000 G	160,000 G
BENZO(A)PYRENE	TOC	PPB	140,000 G	140,000 G	140,000 G	140,000 G
BENZOIC ACID	DRY	PPB	690 G	690 G	690 G	650
BENZYL ALCOHOL	DRY	PPB	61	140 G	140 G	57
BENZO(G,H,I)PERYLENE	TOC	PPB	67,000 G	67,000 G	67,000 G	67,000 G
BUTYL BENZYL PHTHALATE	TOC	PPB	9,200 G	9,200 G	9,200 G	4,900
CADMIUM	DRY	PPM	180 G	180 G	180 G	9.6
CHROMIUM TOTAL	DRY	PPM	NV	NV	37 G	NV
CHRYSENE	TOC	PPB	200,000 G	200,000 G	200,000 G	200,000 G
COPPER	DRY	PPM	11,000 G	11,000 G	11,000 G	390
DIETHYL PHTHALATE	TOC	PPB	5,300 G	5,300 G	5,300 G	5,300 G
DIBENZOFURAN	TOC	PPB	58,000 G	58,000 G	58,000 G	58,000 G
DI-N-BUTYL PHTHALATE	TOC	PPB	280,000 G	280,000 G	280,000 G	220,000 Z
DIMETHYL PHTHALATE	TOC	PPB	19,000 G	19,000 G	19,000 G	19,000 G
FLUORANTHENE	TOC	PPB	190,000 G	190,000 G	190,000 G	190,000 G
FLUORENE	TOC	PPB	71,000 G	71,000 G	71,000 G	71,000 G
POLYCYCLIC AROMATIC HYDROCARBON-HEAVY	TOC	PPB	1,500,000 G	1,500,000 G	1,500,000 G	1,500,000 G
INDENO(1,2,3-CD)PYRENE	TOC	PPB	87,000 G	87,000 G	87,000 G	87,000 G
LEAD	DRY	PPM	6,300 G	6,300 G	6,300 G	530
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT	TOC	PPB	540,000 G	540,000 G	540,000 G	540,000 G
MERCURY	DRY	PPM	52 G	52 G	52 G	0.41
NAPHTHALENE	TOC	PPB	170,000 G	170,000 G	170,000 G	170,000 G
N-NITROSO DIPHENYLAMINE	TOC	PPB	11,000 G	11,000 G	11,000 G	11,000 G
POLYCHLORINATED BIPHENYLS	TOC	PPB	46,000 G	46,000 G	46,000 G	12,000
PHENANTHRENE	TOC	PPB	160,000 G	160,000 G	160,000 G	160,000 G
PHENOL	DRY	PPB	1,200	1,200	1,200	1,200 Z

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

CHEMICAL	MEAS. BASIS	UNITS	MICROTOX BIOASSAY TEST TYPE			
			30% Relative	50% Relative	Severe Effects	1988 AET
PYRENE	TOC	PPB	210,000 G	210,000 G	210,000 G	210,000 G
SILVER	DRY	PPM	0.56 G	0.56 G	0.56 G	0.56 G
TOTAL BENZOFLUORANTHENES (B + K)	TOC	PPB	430,000 G	430,000 G	430,000 G	430,000 G
ZINC	DRY	PPM	3,300 G	3,300 G	3,300 G	1,600

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

CHEMICAL	MEAS. BASIS	UNITS	OYSTER LARVAE TEST TYPE							
			30% Relative		50% Relative		Severe Effects		1988 AET	
PYRENE	TOC	PPB	210,000	G	210,000	G	210,000	G	210,000	G
SILVER	DRY	PPM	0.56	G	0.56	G	0.56	G	0.56	G
TOTAL BENZOFLUORANTHENES (B + K)	TOC	PPB	430,000	G	430,000	G	430,000	G	230,000	
ZINC	DRY	PPM	1,600		1,600		1,600		1,600	

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

1988 AET, SEVERE EFFECTS AET, 30% AND 50% RELATIVE AET VALUES.

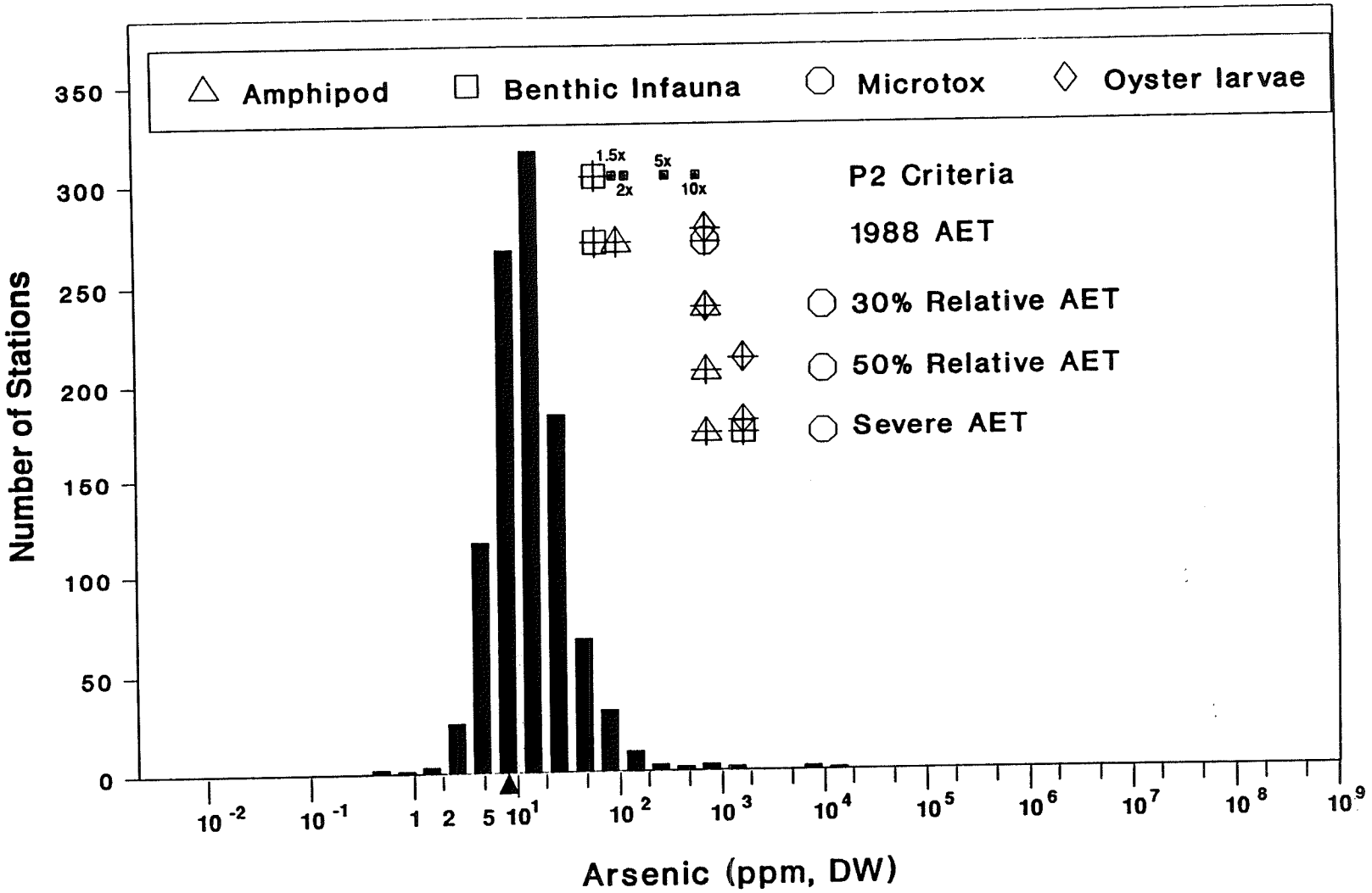
CHEMICAL	MEAS. BASIS	UNITS	OYSTER LARVAE TEST TYPE			
			30% Relative	50% Relative	Severe Effects	1988 AET
1,2-DICHLOROBENZENE	TOC	PPB	3,200 G	3,200 G	3,200 G	2,300
1,2,4-TRICHLOROBENZENE	TOC	PPB	5,900 G	5,900 G	5,900 G	2,700
1,4-DICHLOROBENZENE	TOC	PPB	16,000 G	16,000 G	16,000 G	3,100
2-METHYLNAPHTHALENE	TOC	PPB	64,000 G	64,000 G	64,000 G	38,000
2-METHYLPHENOL	DRY	PPB	72 G	72 G	72 G	63
2,4-DIMETHYL PHENOL	DRY	PPB	50 G	50 G	50 G	29
DIBENZO(A,H)ANTHRACENE	TOC	PPB	34,000 G	34,000 G	34,000 G	12,000
DI-N-OCTYL PHTHALATE	TOC	PPB	58,000 G	58,000 G	58,000 G	58,000 G
4-METHYL PHENOL	DRY	PPB	1,200	2,600	1,200	670
PENTACHLOROPHENOL	DRY	PPB	140 G	140 G	140 G	140 G
HEXACHLOROBENZENE	TOC	PPB	16,000 G	16,000 G	16,000 G	9,600
HEXACHLOROBUTADIENE	TOC	PPB	16,000 G	16,000 G	16,000 G	11,000
ACENAPHTHENE	TOC	PPB	57,000 G	57,000 G	57,000 G	16,000
ACENAPHTHYLENE	TOC	PPB	27,000 G	27,000 G	27,000 G	27,000 G
ANTHRACENE	TOC	PPB	79,000 G	79,000 G	79,000 G	79,000 G
ARSENIC	DRY	PPM	700	1,600	1,600	700
BIS(2-ETHYLHEXYL)PHTHALATE	TOC	PPB	68,000 G	68,000 G	68,000 G	60,000 Z
BENZ(A)ANTHRACENE	TOC	PPB	160,000 G	160,000 G	160,000 G	110,000
BENZO(A)PYRENE	TOC	PPB	140,000 G	140,000 G	140,000 G	99,000
BENZOIC ACID	DRY	PPB	690 G	690 G	690 G	650
BENZYL ALCOHOL	DRY	PPB	130	140 G	130	73
BENZO(G,H,I)PERYLENE	TOC	PPB	67,000 G	67,000 G	67,000 G	31,000
BUTYL BENZYL PHTHALATE	TOC	PPB	9,200 G	9,200 G	9,200 G	9,200 G
CADMIUM	DRY	PPM	9.6	16	16	9.6
CHROMIUM TOTAL	DRY	PPM	NV	NV	37 G	NV
CHRYSENE	TOC	PPB	200,000 G	200,000 G	200,000 G	110,000
COPPER	DRY	PPM	390	2,200	2,200	390
DIETHYL PHTHALATE	TOC	PPB	5,300 G	5,300 G	5,300 G	5,300 G
DIBENZOFURAN	TOC	PPB	58,000 G	58,000 G	58,000 G	15,000
DI-N-BUTYL PHTHALATE	TOC	PPB	260,000	280,000 G	280,000 G	260,000 Z
DIMETHYL PHTHALATE	TOC	PPB	22,000 G	22,000 G	22,000 G	22,000 G
FLUORANTHENE	TOC	PPB	190,000 G	190,000 G	190,000 G	160,000
FLUORENE	TOC	PPB	71,000 G	71,000 G	71,000 G	23,000
POLYCYCLIC AROMATIC HYDROCARBON-HEAVY	TOC	PPB	1,500,000 G	1,500,000 G	1,500,000 G	960,000
INDENO(1,2,3-CD)PYRENE	TOC	PPB	87,000 G	87,000 G	87,000 G	34,000
LEAD	DRY	PPM	660	1,000	1,000	660
POLYCYCLIC AROMATIC HYDROCARBON-LIGHT	TOC	PPB	540,000 G	540,000 G	540,000 G	370,000
MERCURY	DRY	PPM	1.1	3.2	3.2	0.59
NAPHTHALENE	TOC	PPB	170,000 G	170,000 G	170,000 G	99,000
N-NITROSO DIPHENYLAMINE	TOC	PPB	11,000 G	11,000 G	11,000 G	11,000 G
POLYCHLORINATED BIPHENYLS	TOC	PPB	46,000 G	46,000 G	46,000 G	46,000 G
PHENANTHRENE	TOC	PPB	160,000 G	160,000 G	160,000 G	120,000
PHENOL	DRY	PPB	1,200	1,200	1,200	420

Explanation of Qualifiers: E = Estimate; L = Value is less than value shown; G = Estimate is greater than value shown; X = Recovery correction factor applied using isotope dilution technique was greater than 10; Z = Blank corrected.

Appendix B:

Concentration Distributions in Puget Sound and Biological Effects Indices

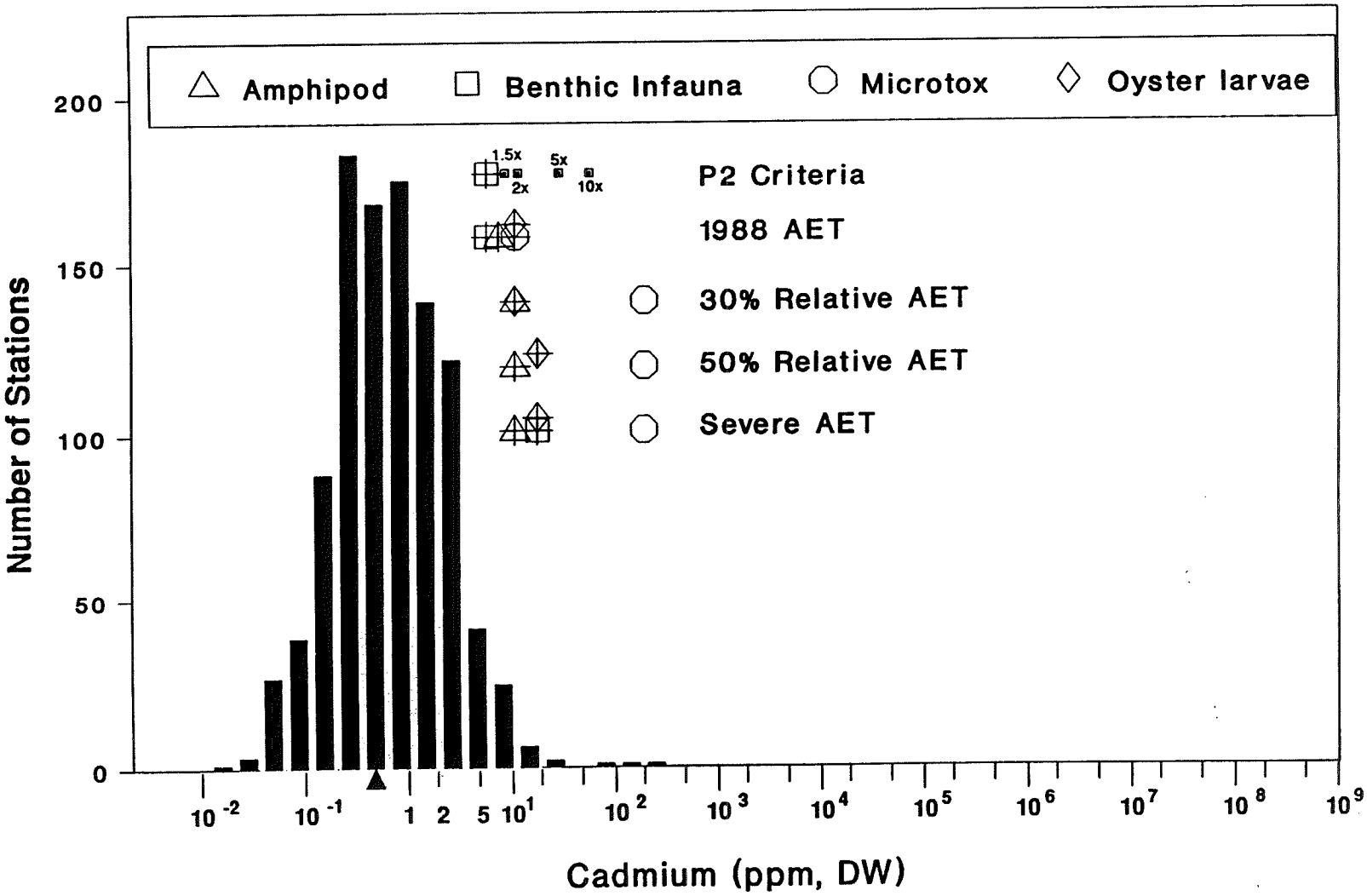
Concentration Distributions in Puget Sound and Biological Effects Indices



A '+' in center of symbol indicates a definitive AET; an open symbol indicates a 'greater than' value.

▲ Denotes the median concentration in Puget Sound reference areas (Pastorok et al. 1989)

Concentration Distributions in Puget Sound and Biological Effects Indices



A '+' in center of symbol indicates a definitive AET; an open symbol indicates a 'greater than' value.

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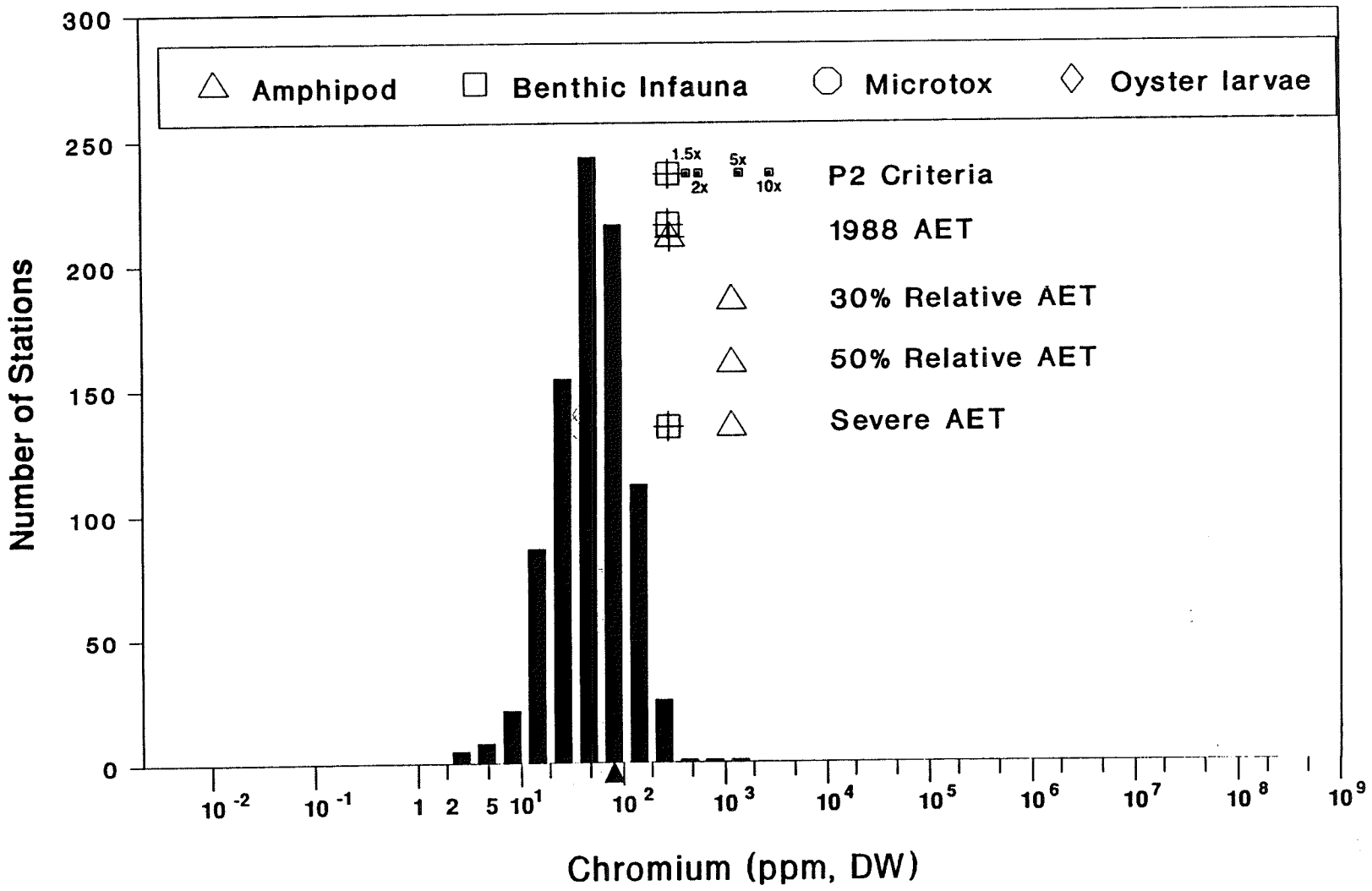
Concentration Distributions in Puget Sound and Biological Effects Indices



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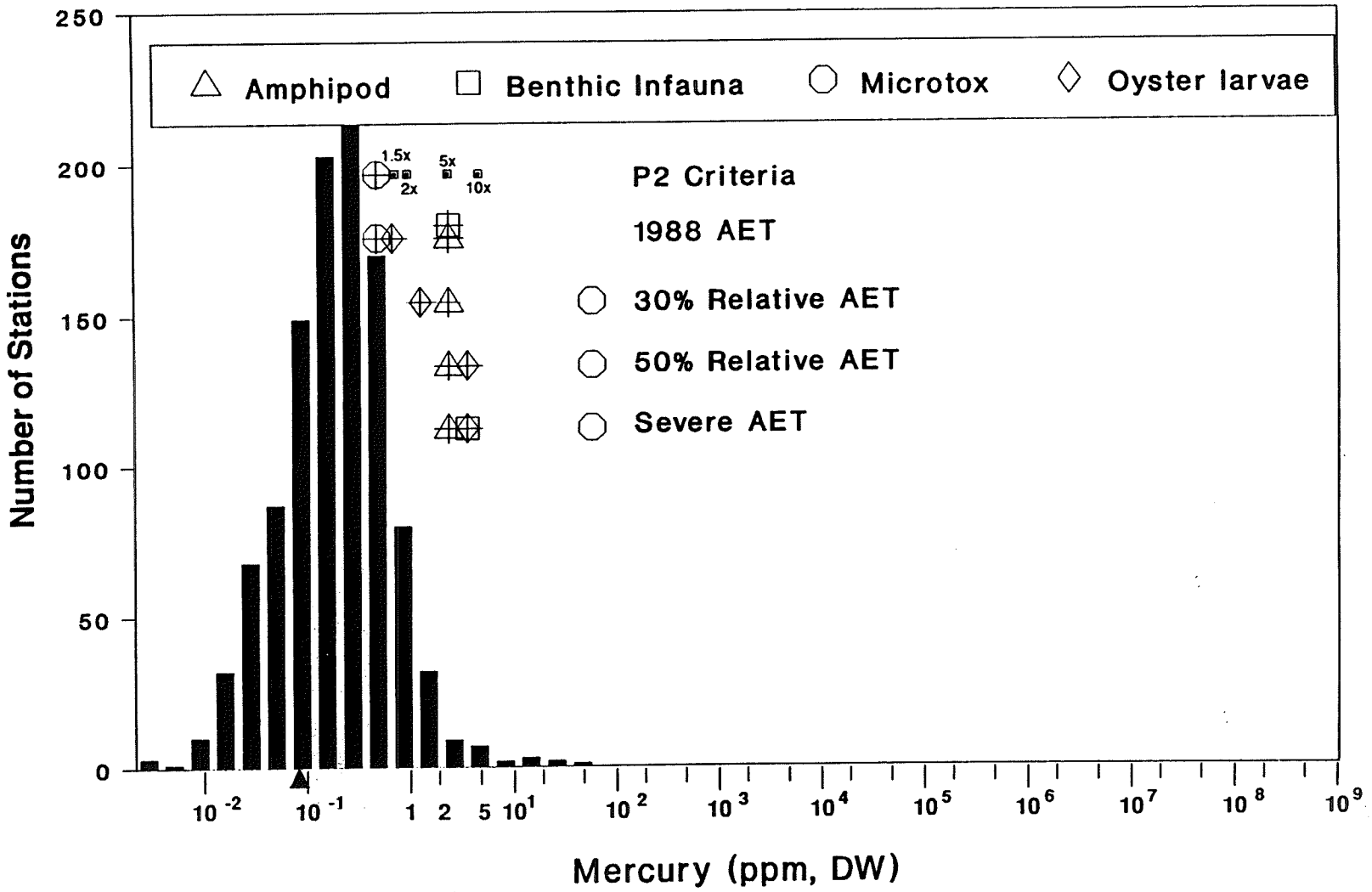
Concentration Distributions in Puget Sound and Biological Effects Indices



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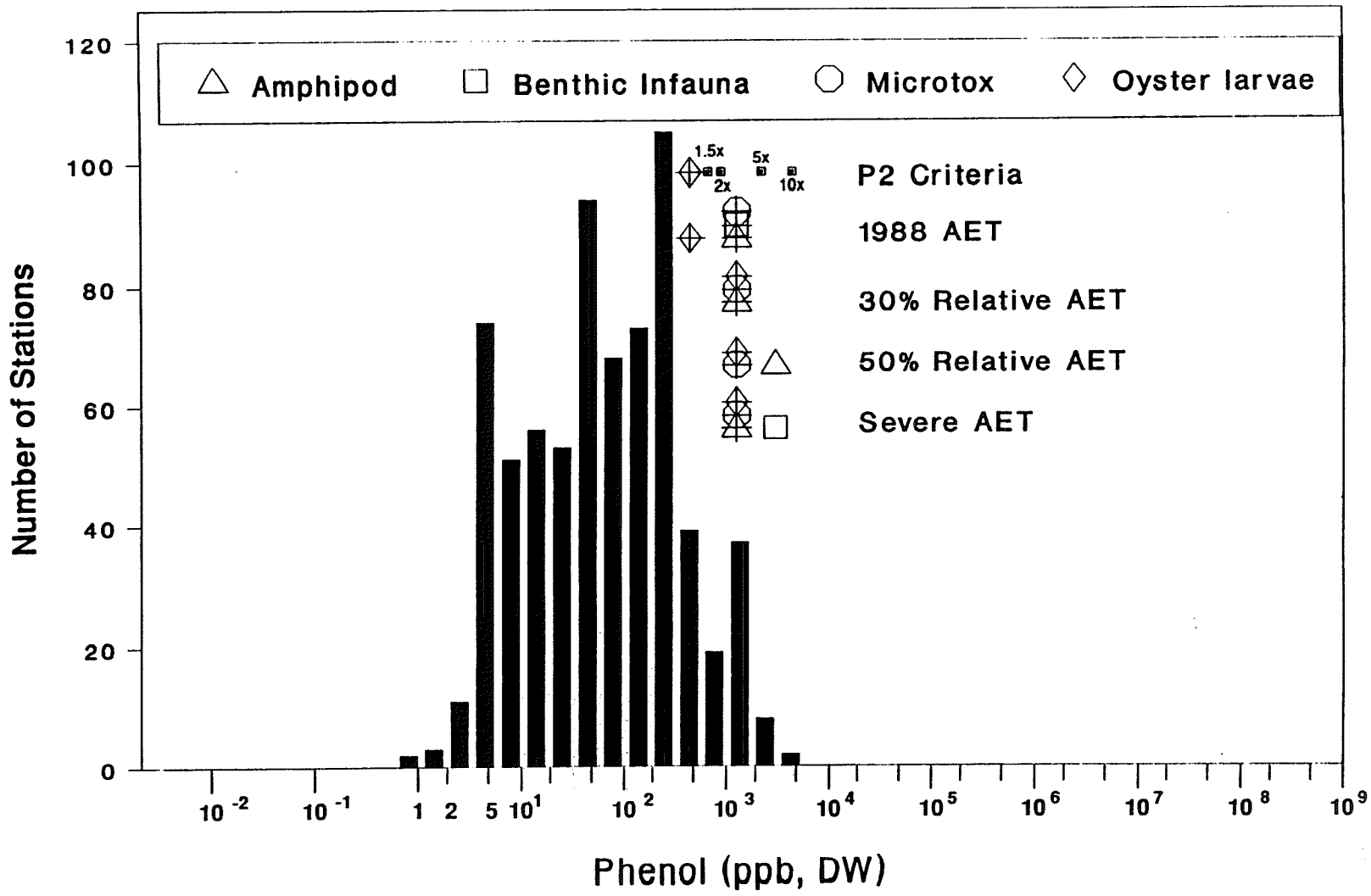
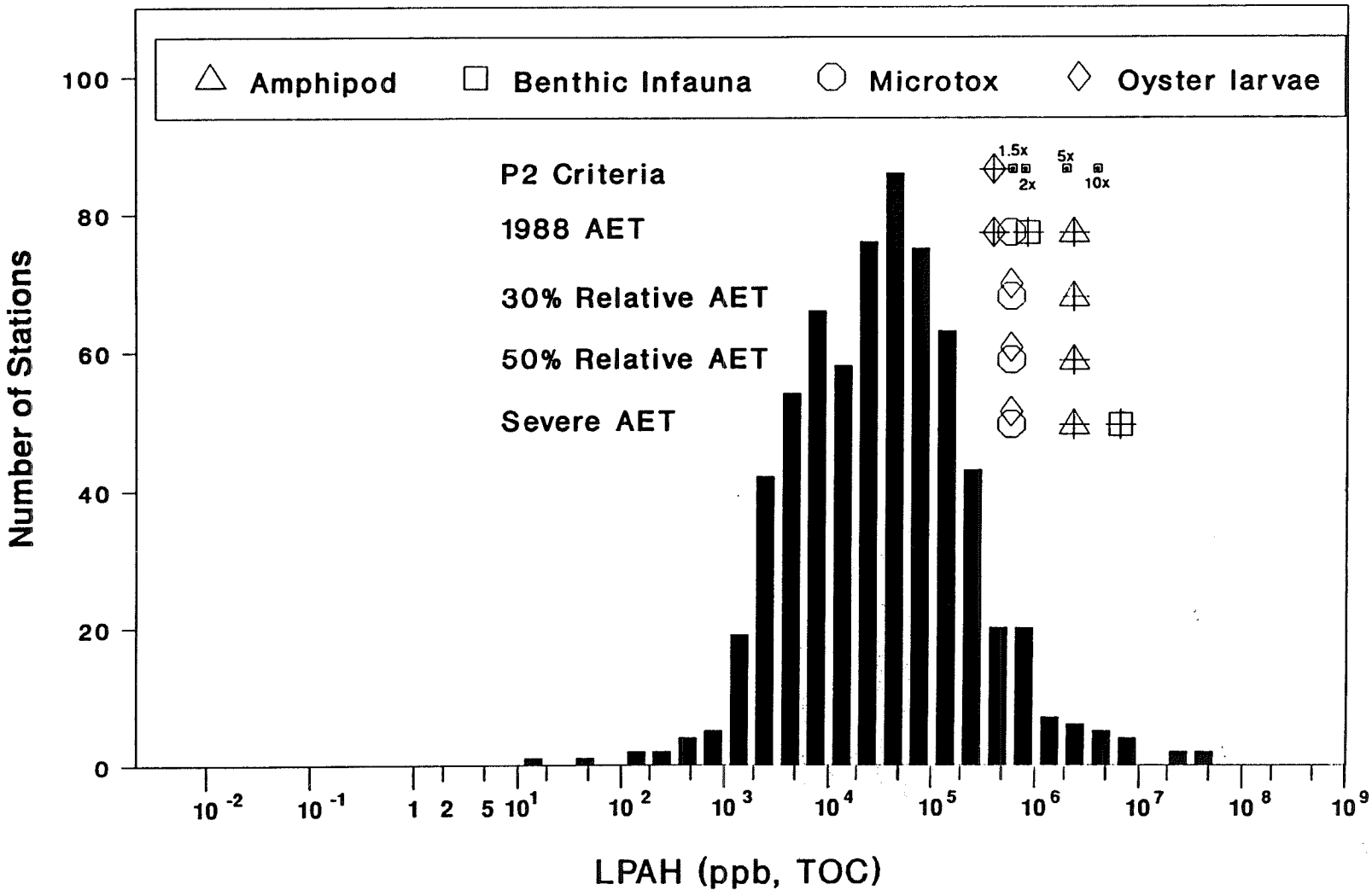
Concentration Distributions in Puget Sound and Biological Effects Indices



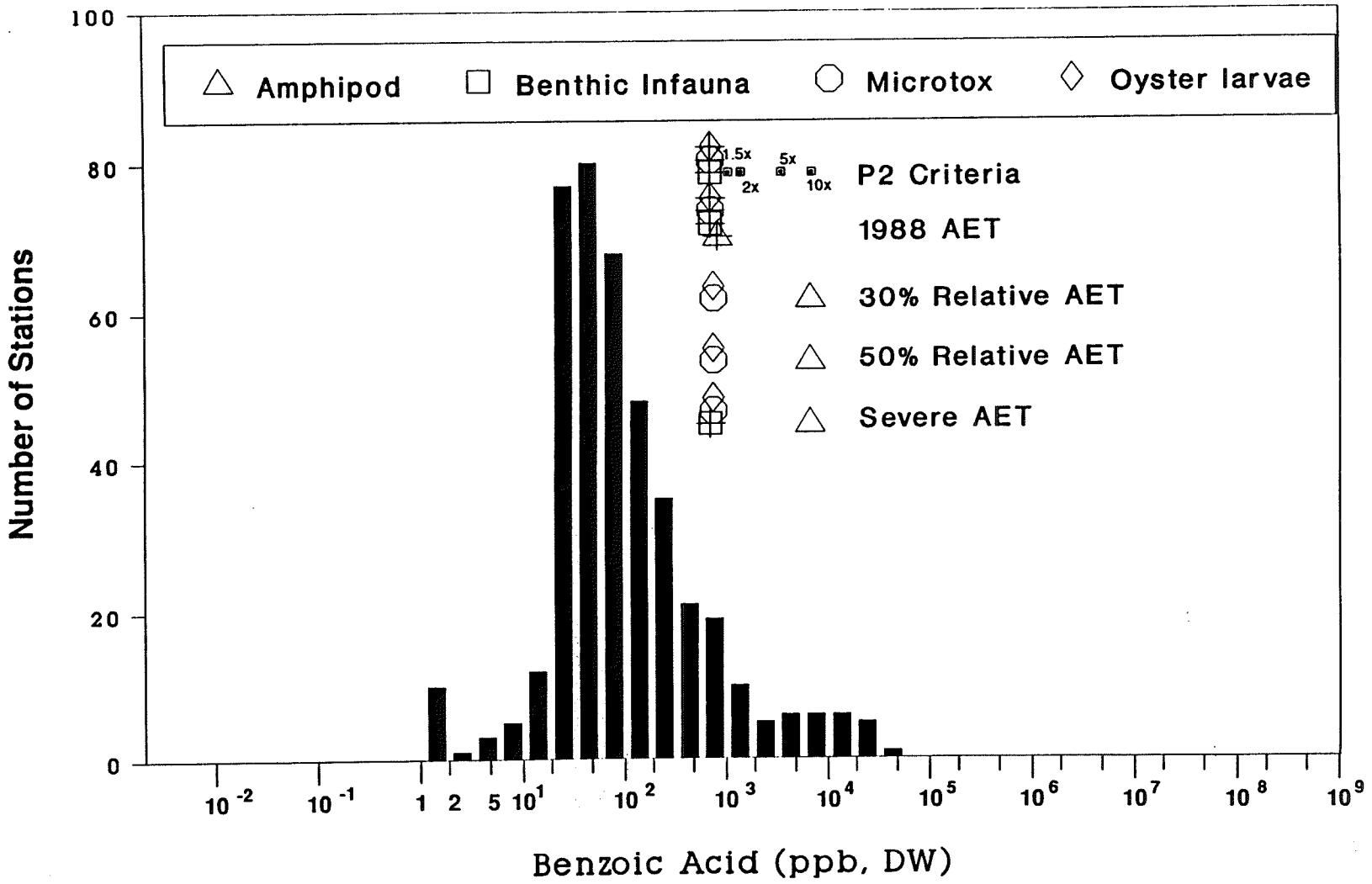
A '+' in center of symbol indicates a definitive AET; an open symbol indicates a 'greater than' value.

Concentration Distributions in Puget Sound and Biological Effects Indices



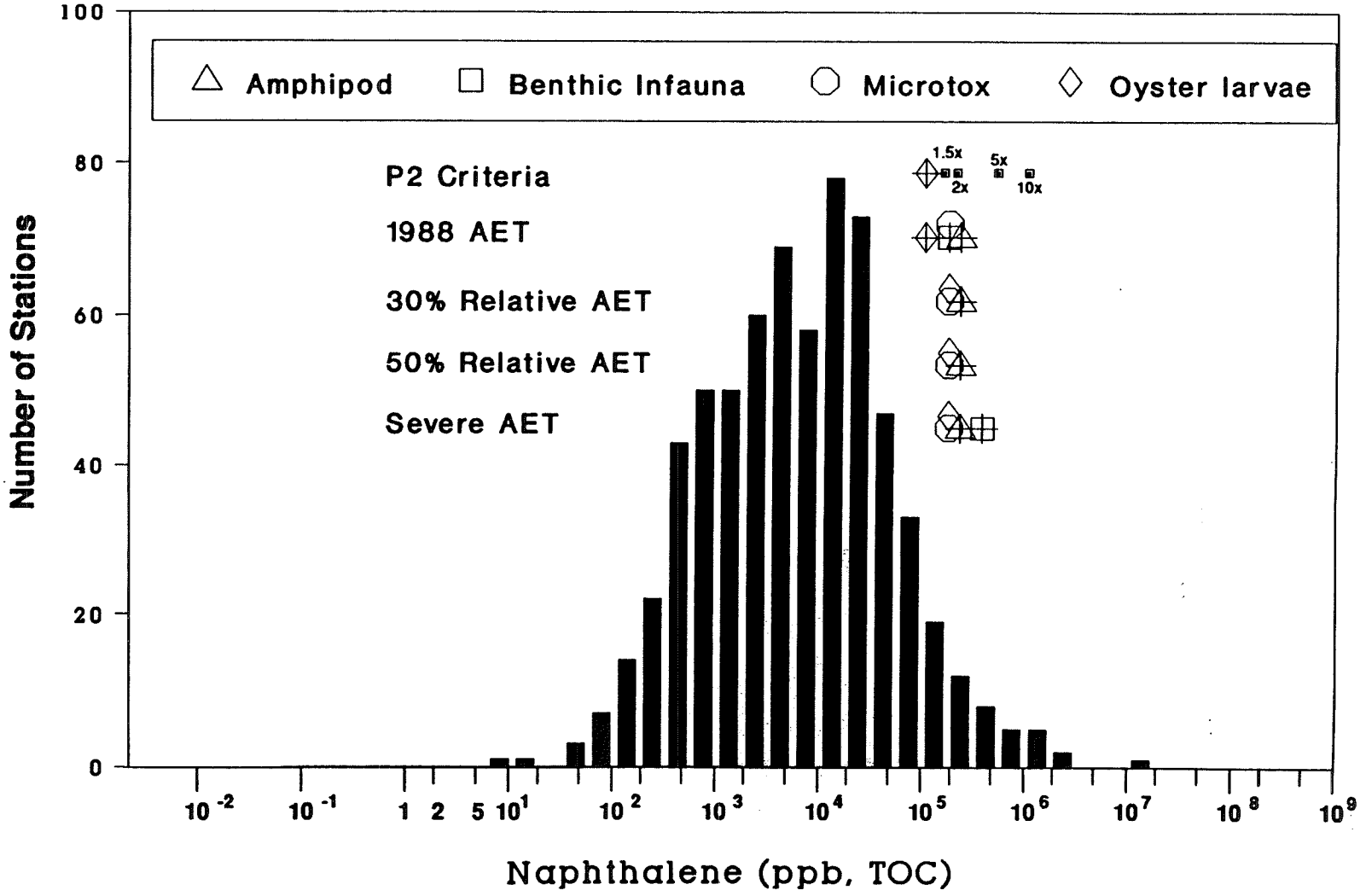
A '+' in center of symbol indicates a definitive AET; an open symbol indicates a 'greater than' value.

Concentration Distributions in Puget Sound and Biological Effects Indices



A '+' in center of symbol indicates a definitive AET; an open symbol indicates a 'greater than' value.

Concentration Distributions in Puget Sound and Biological Effects Indices



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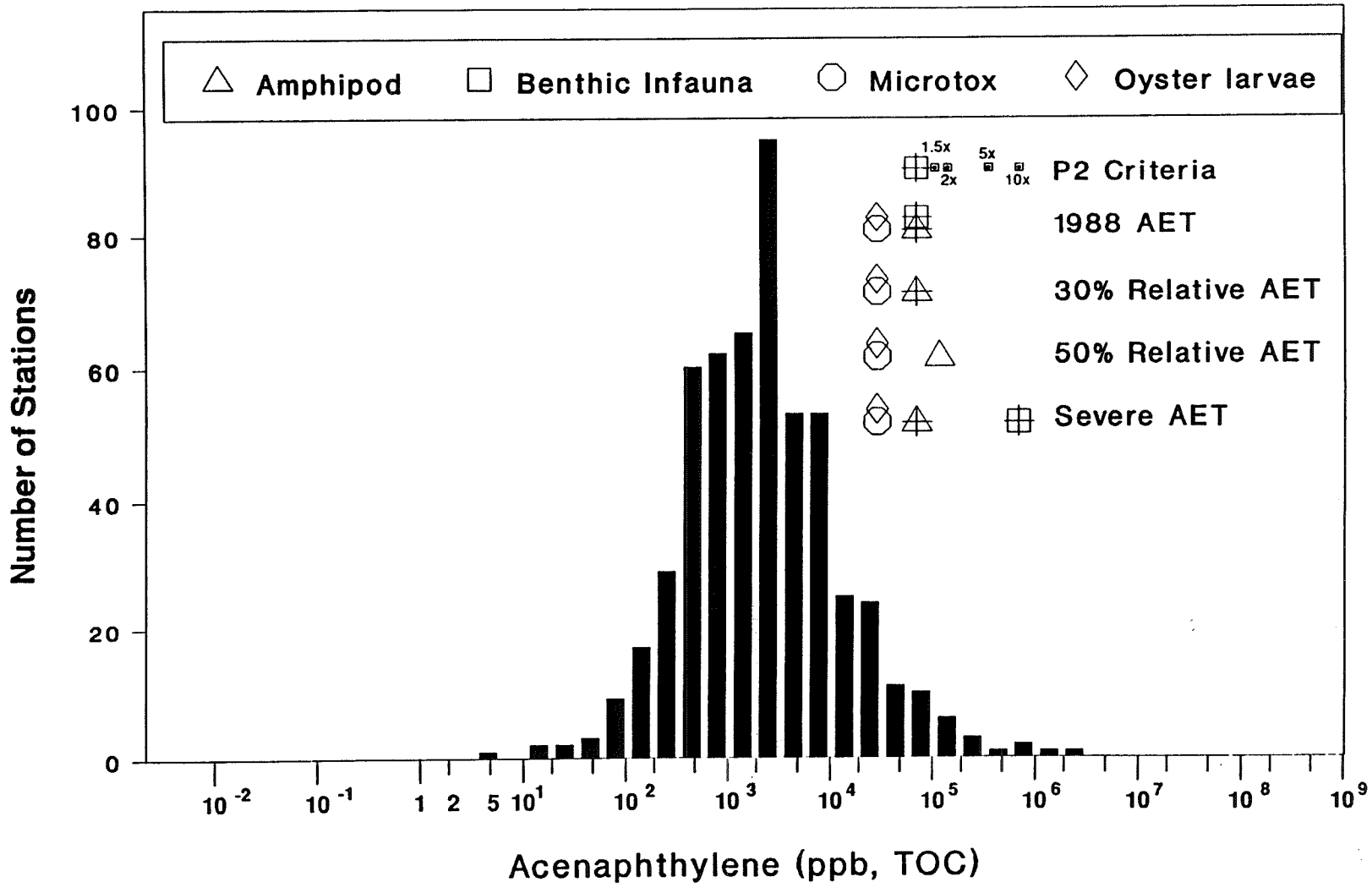
Concentration Distributions in Puget Sound and Biological Effects Indices



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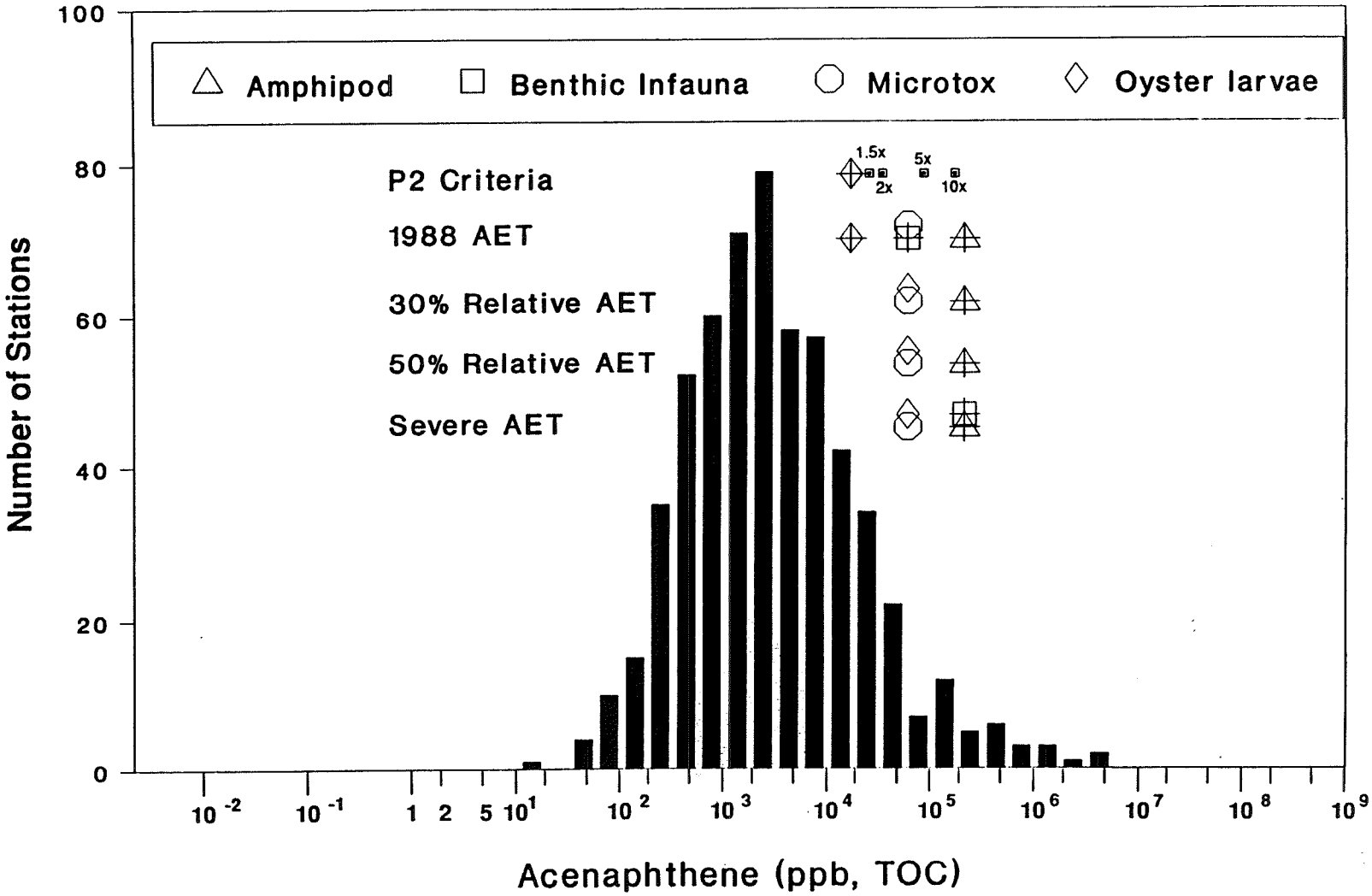

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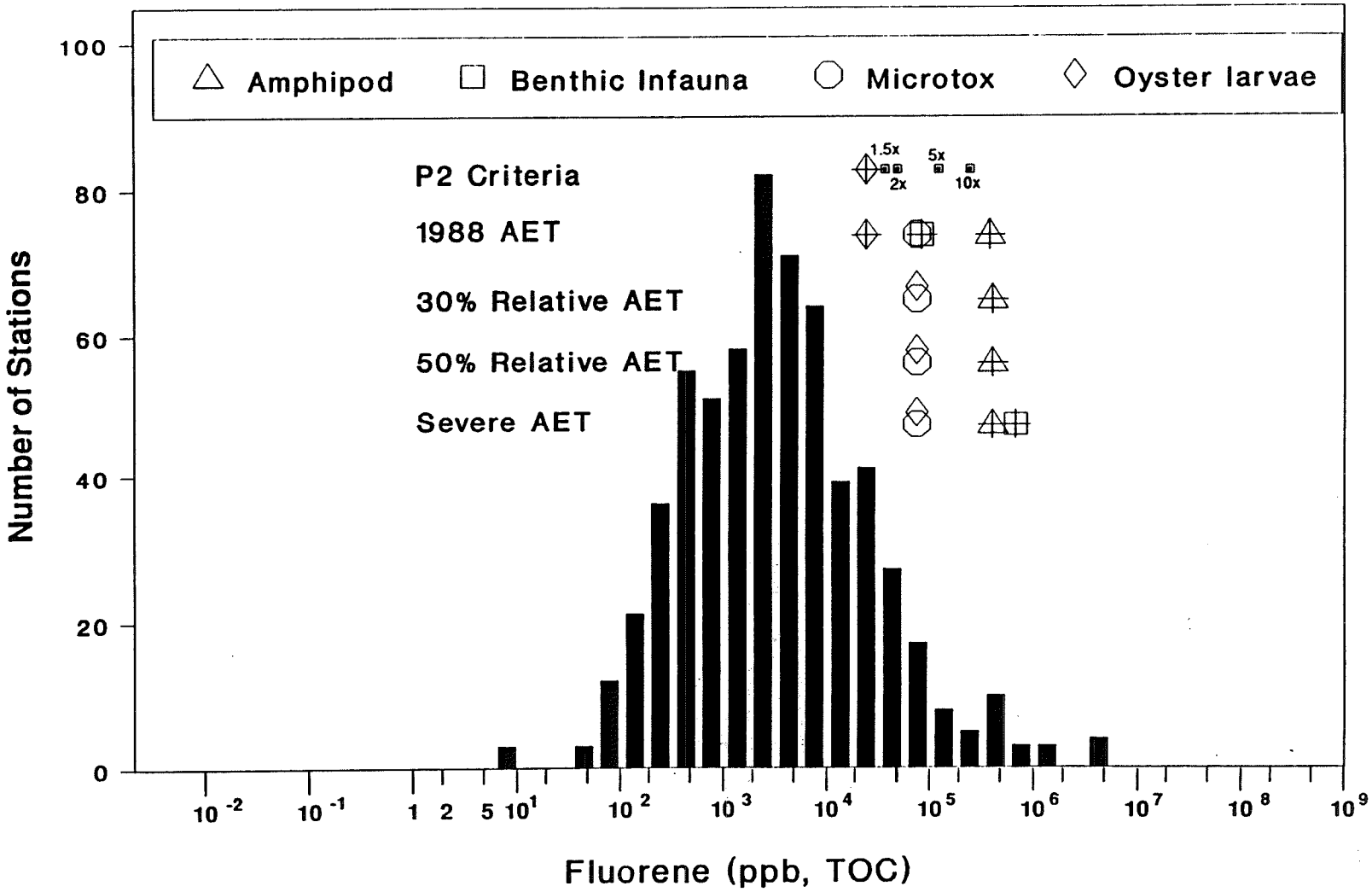

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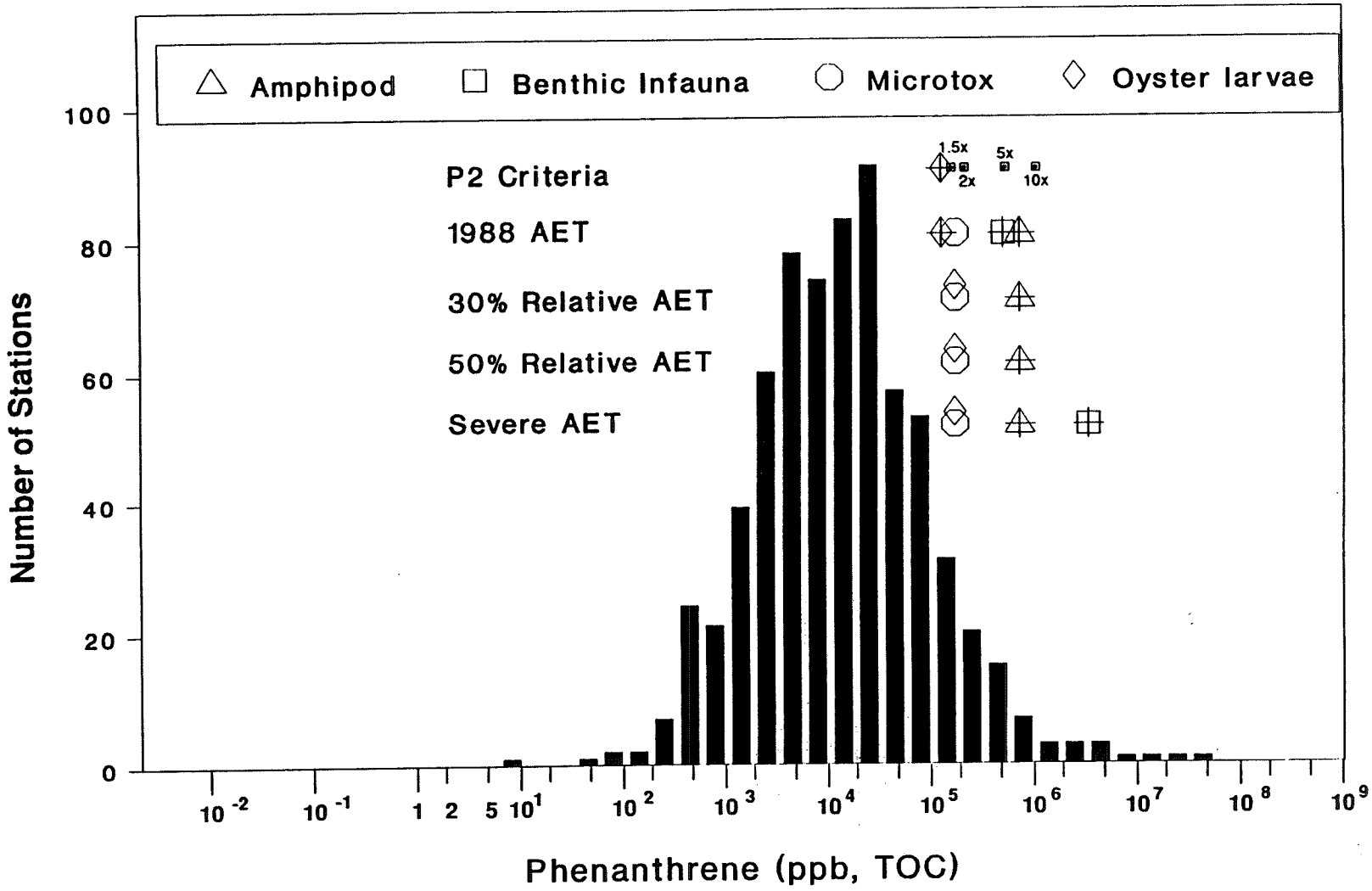

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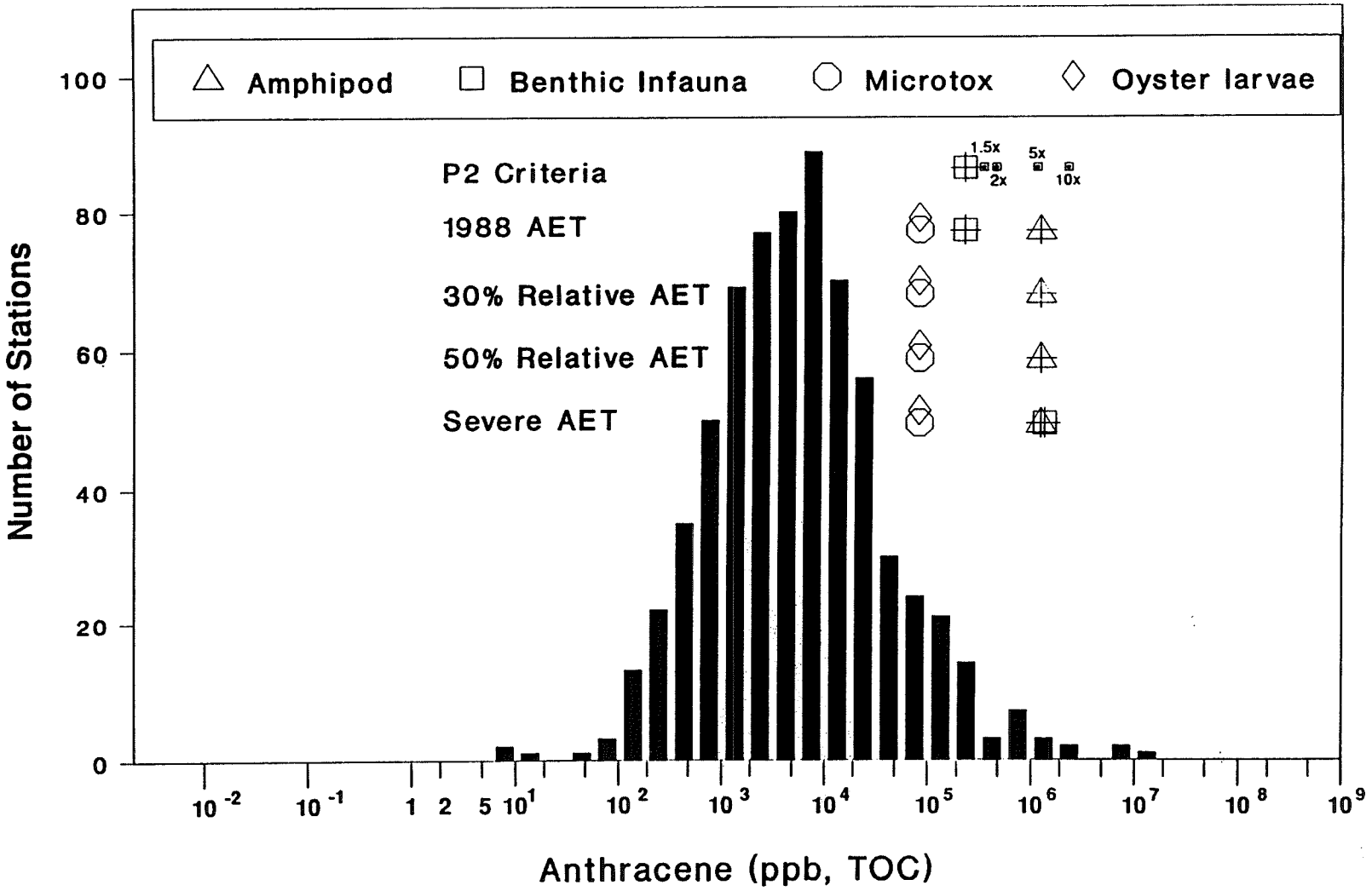

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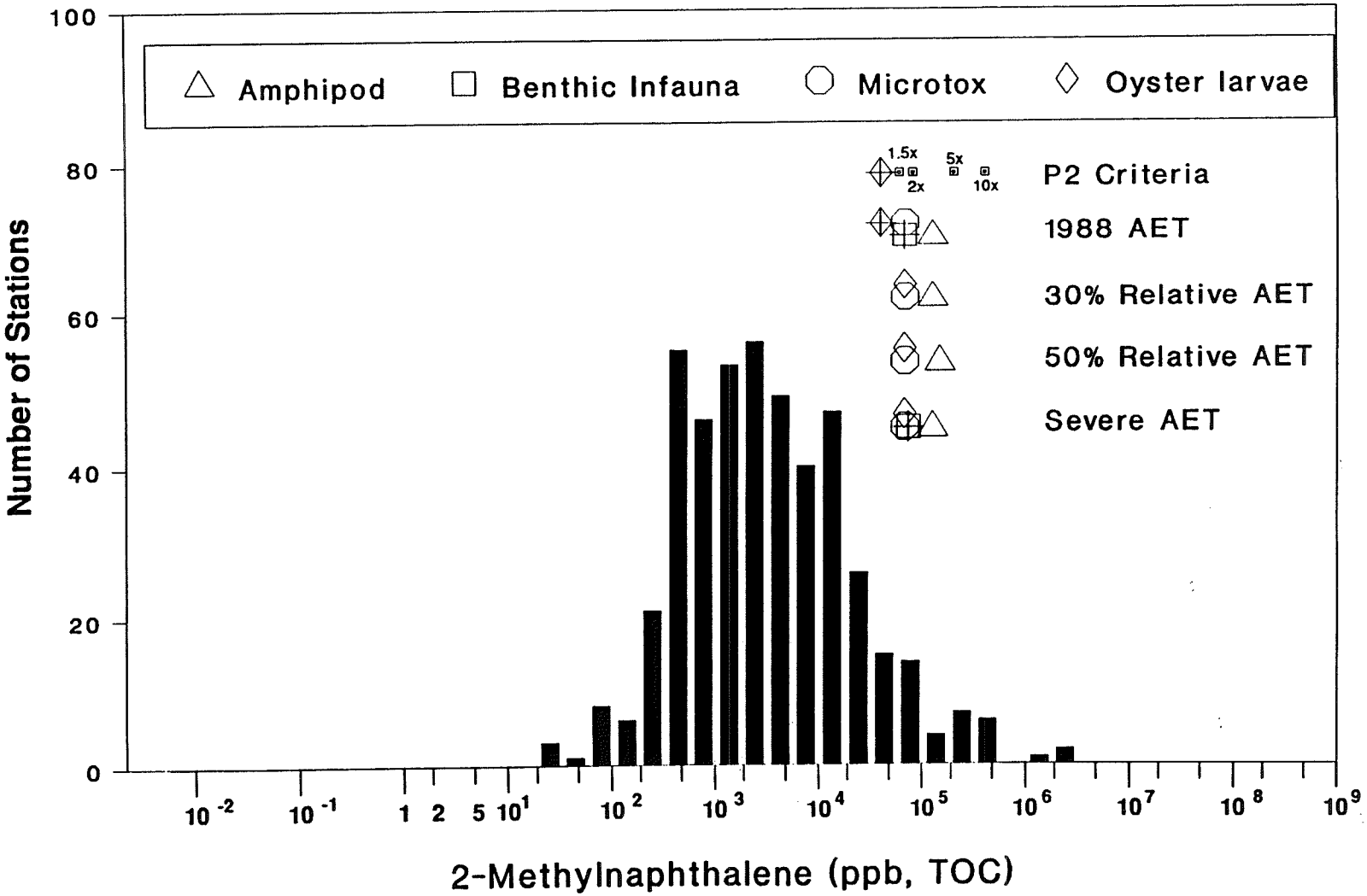

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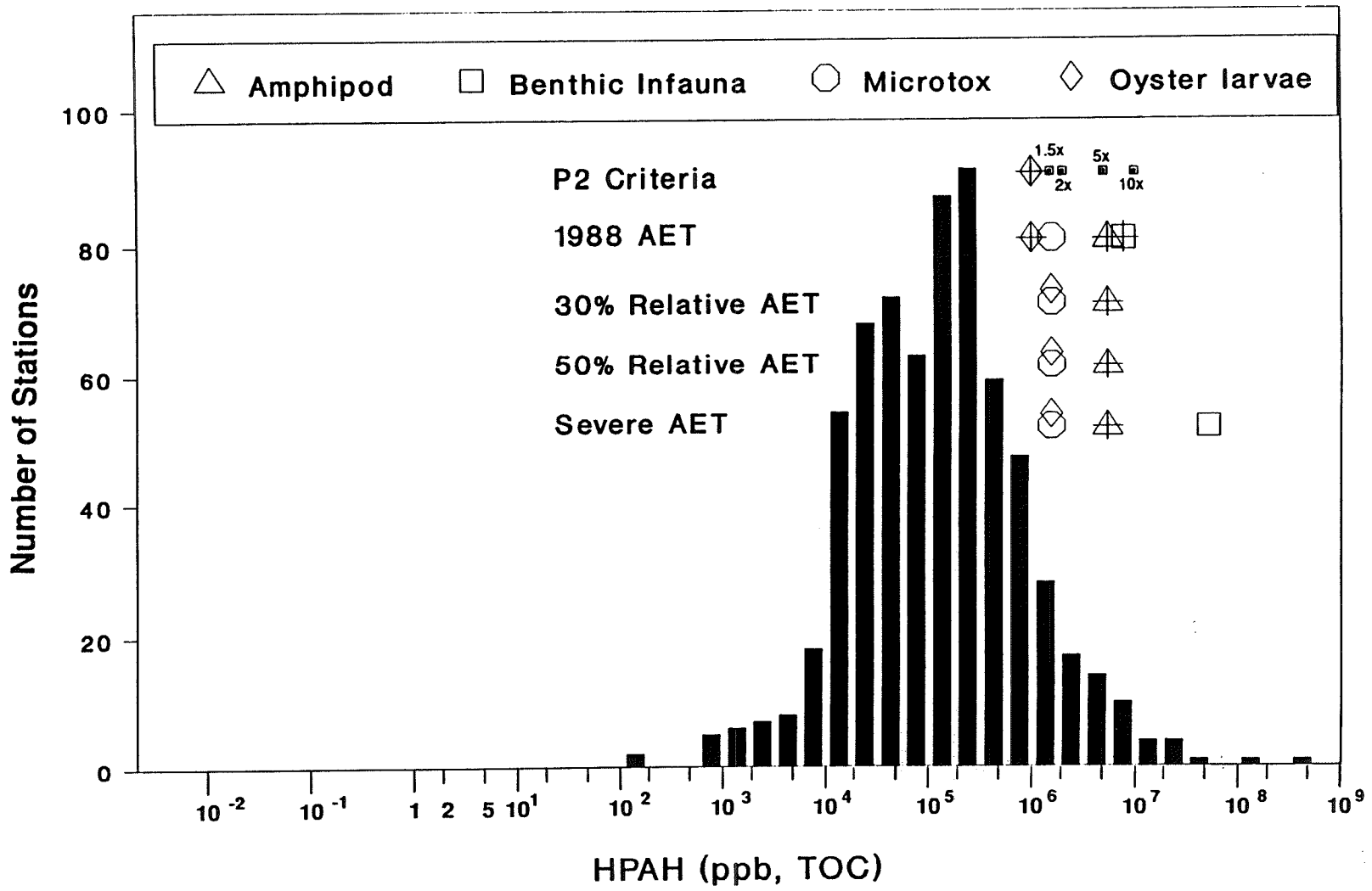

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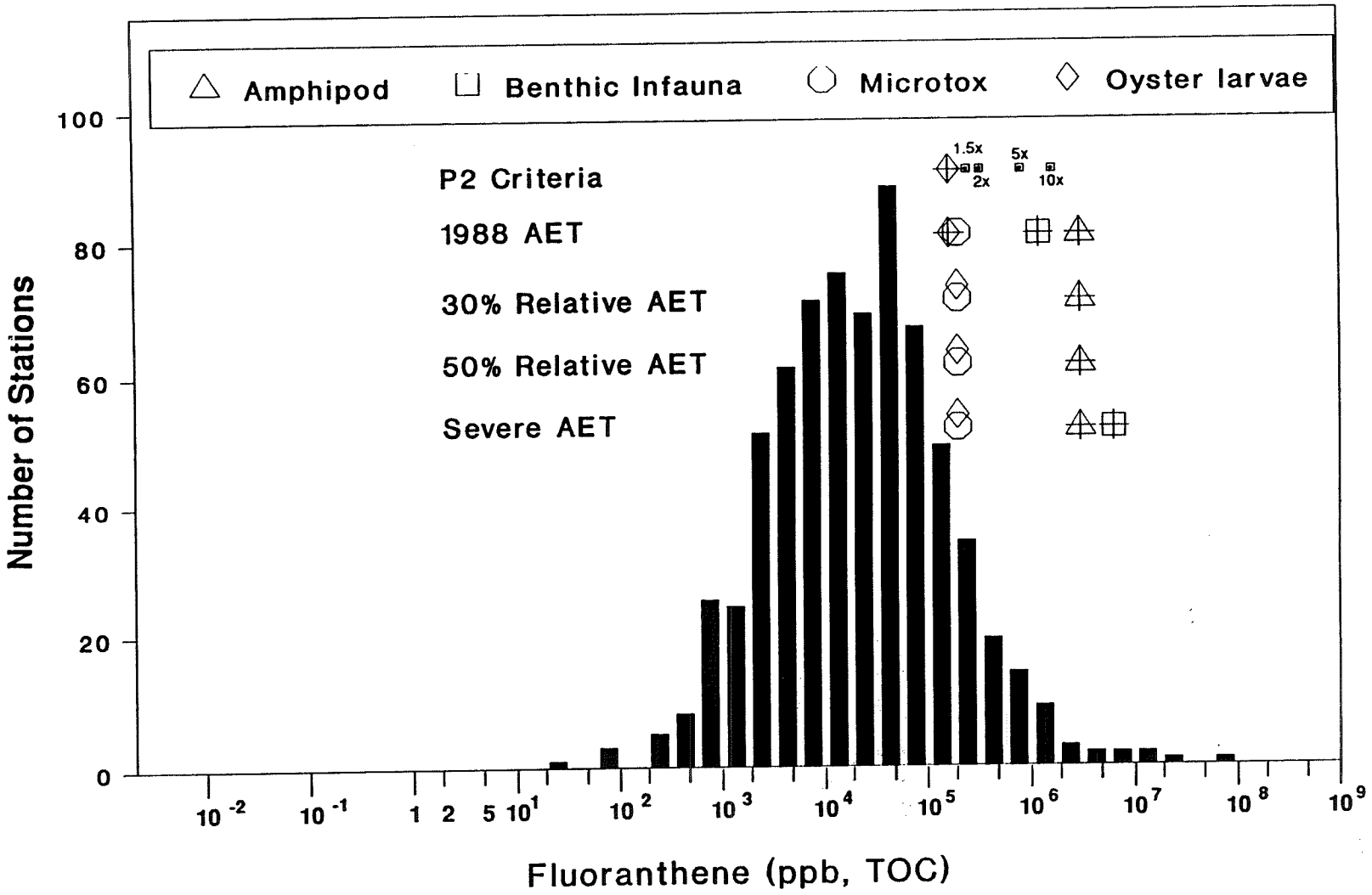

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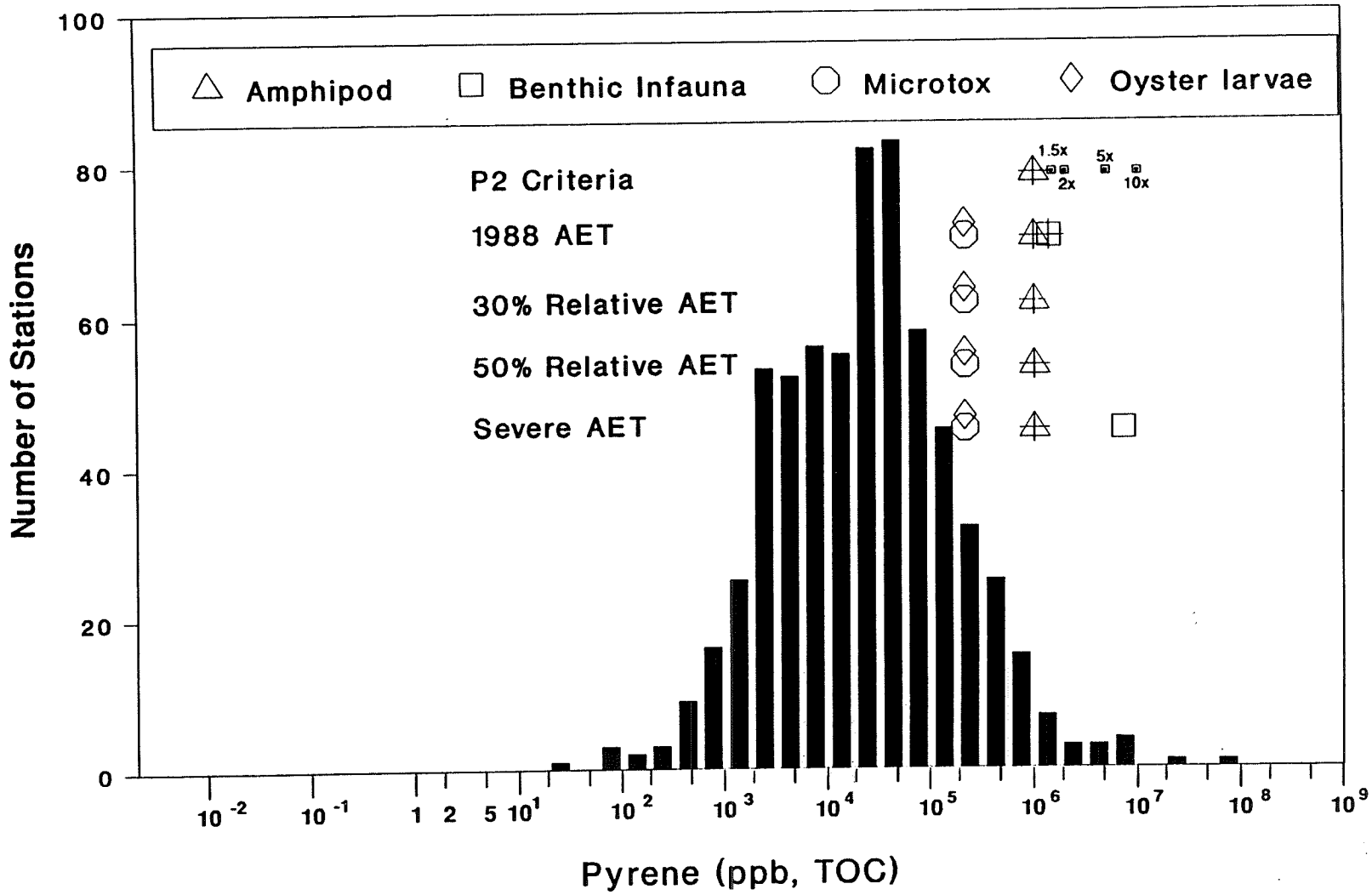

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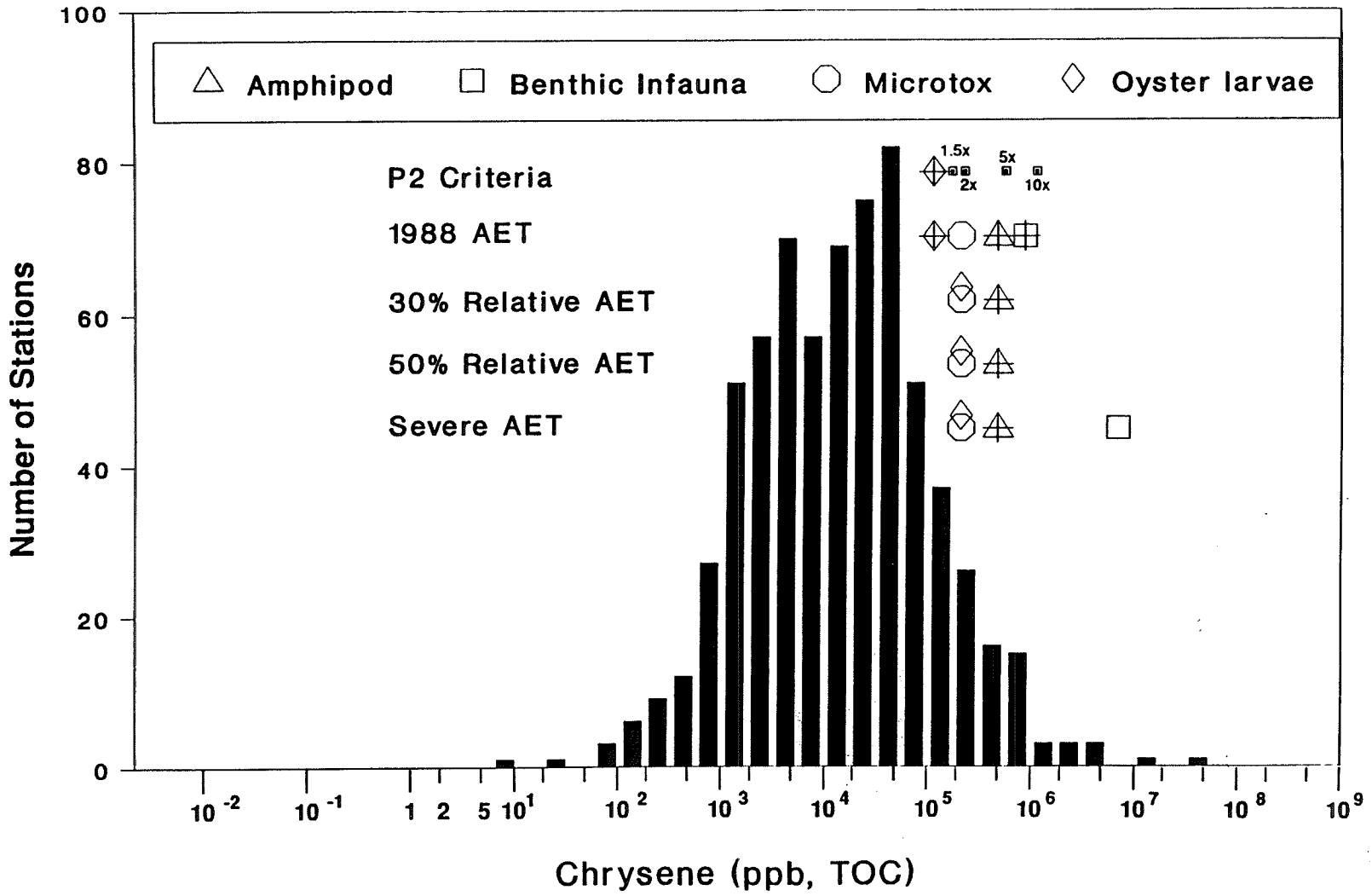

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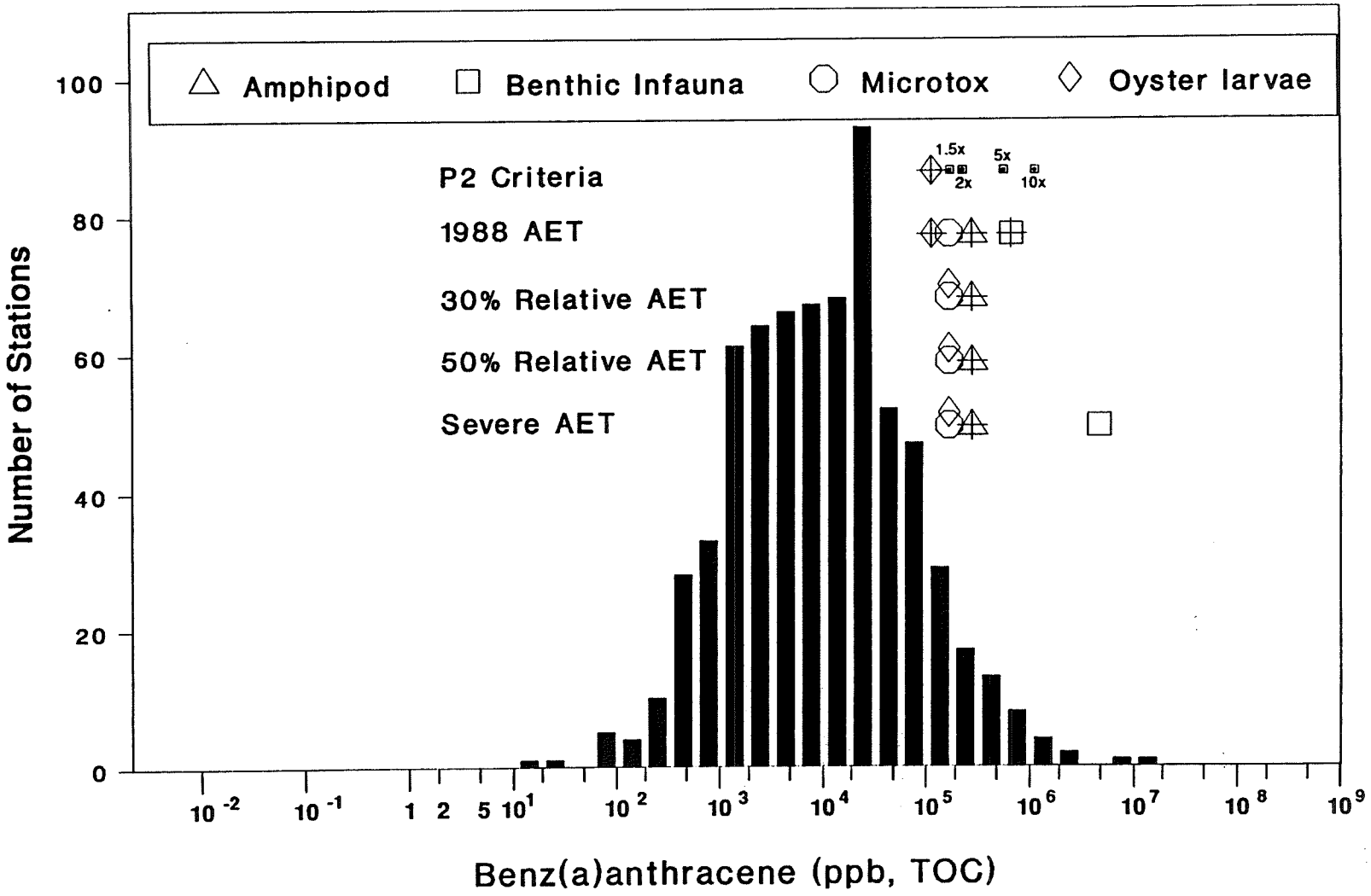

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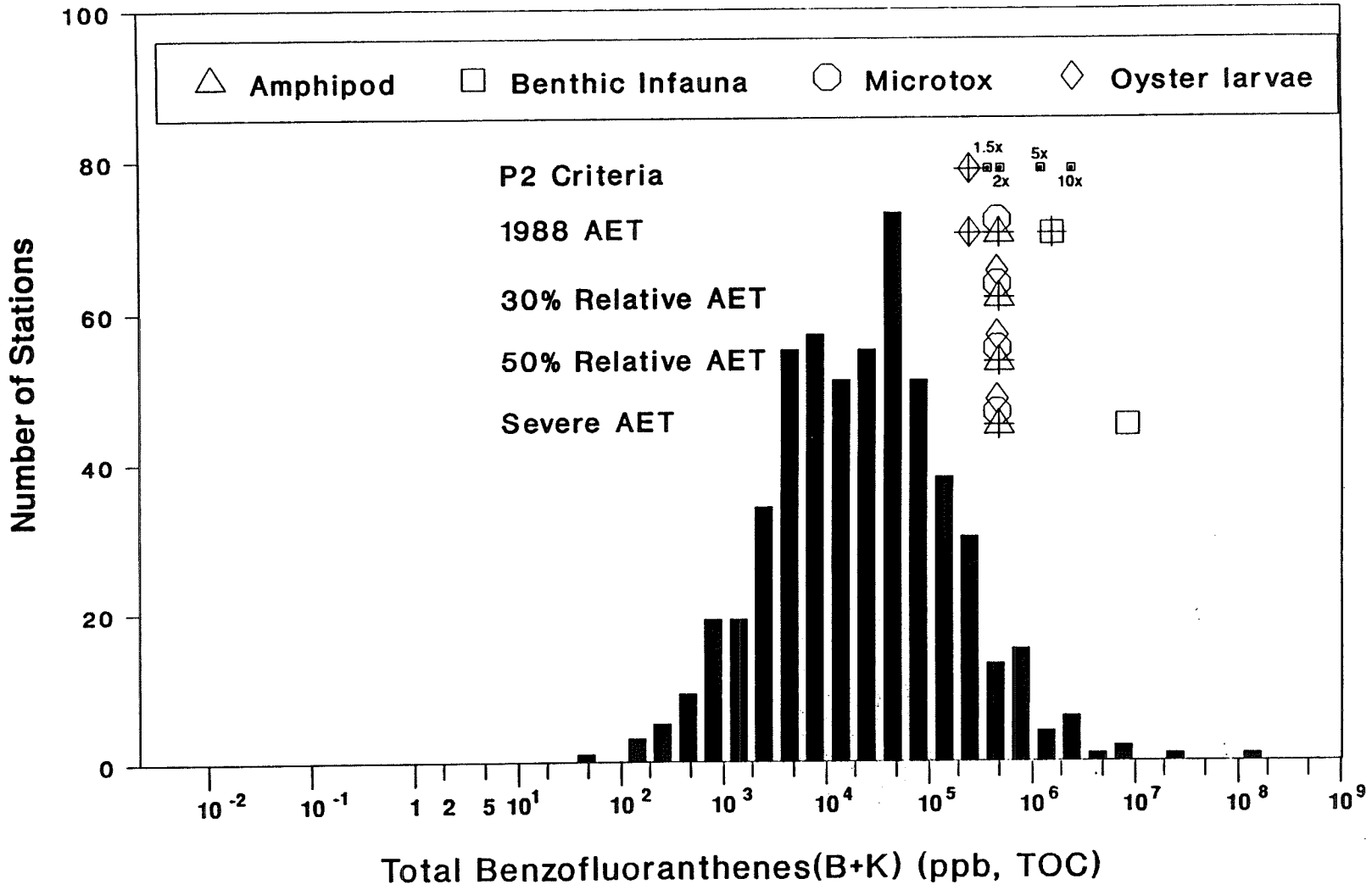

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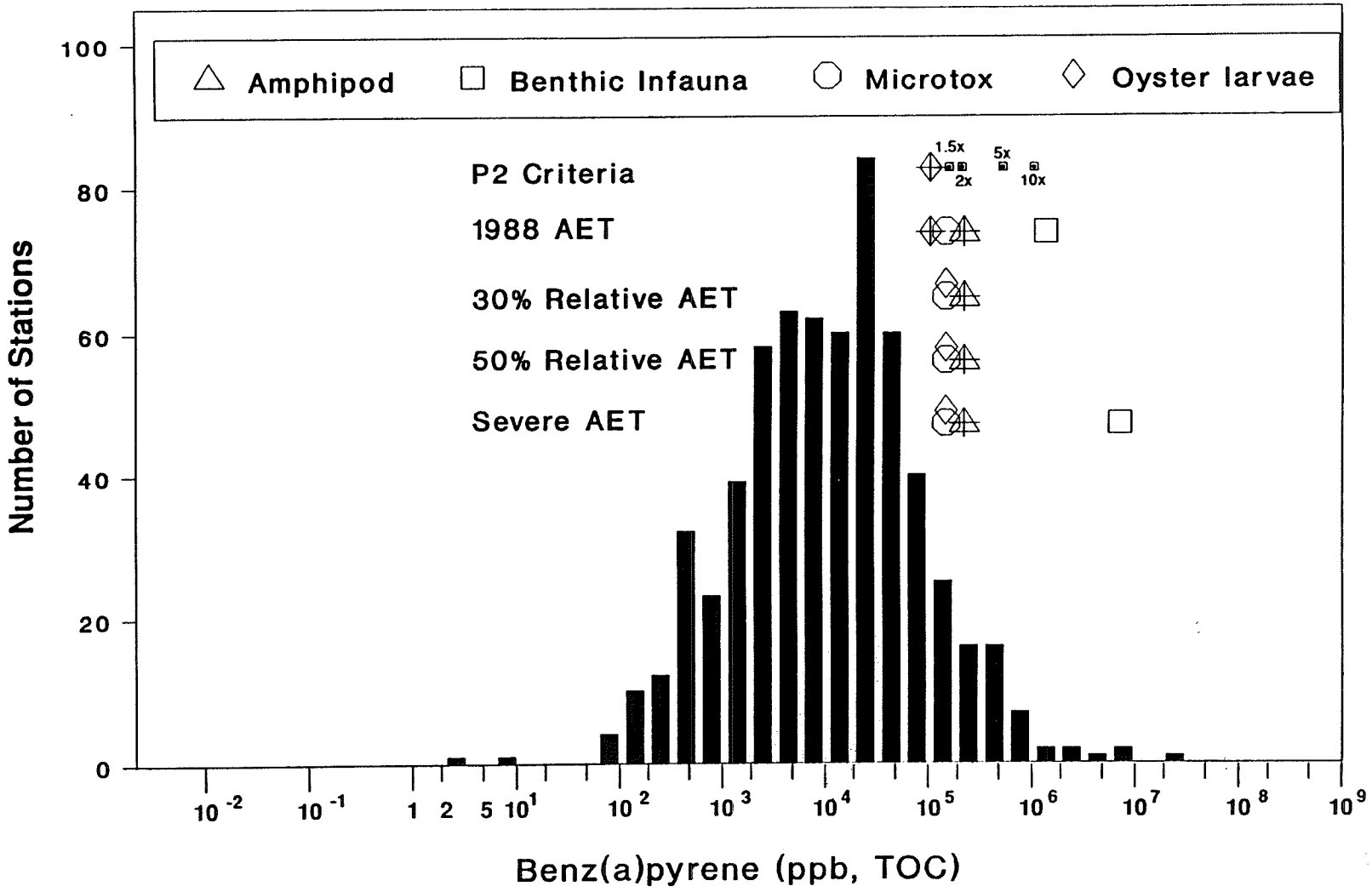

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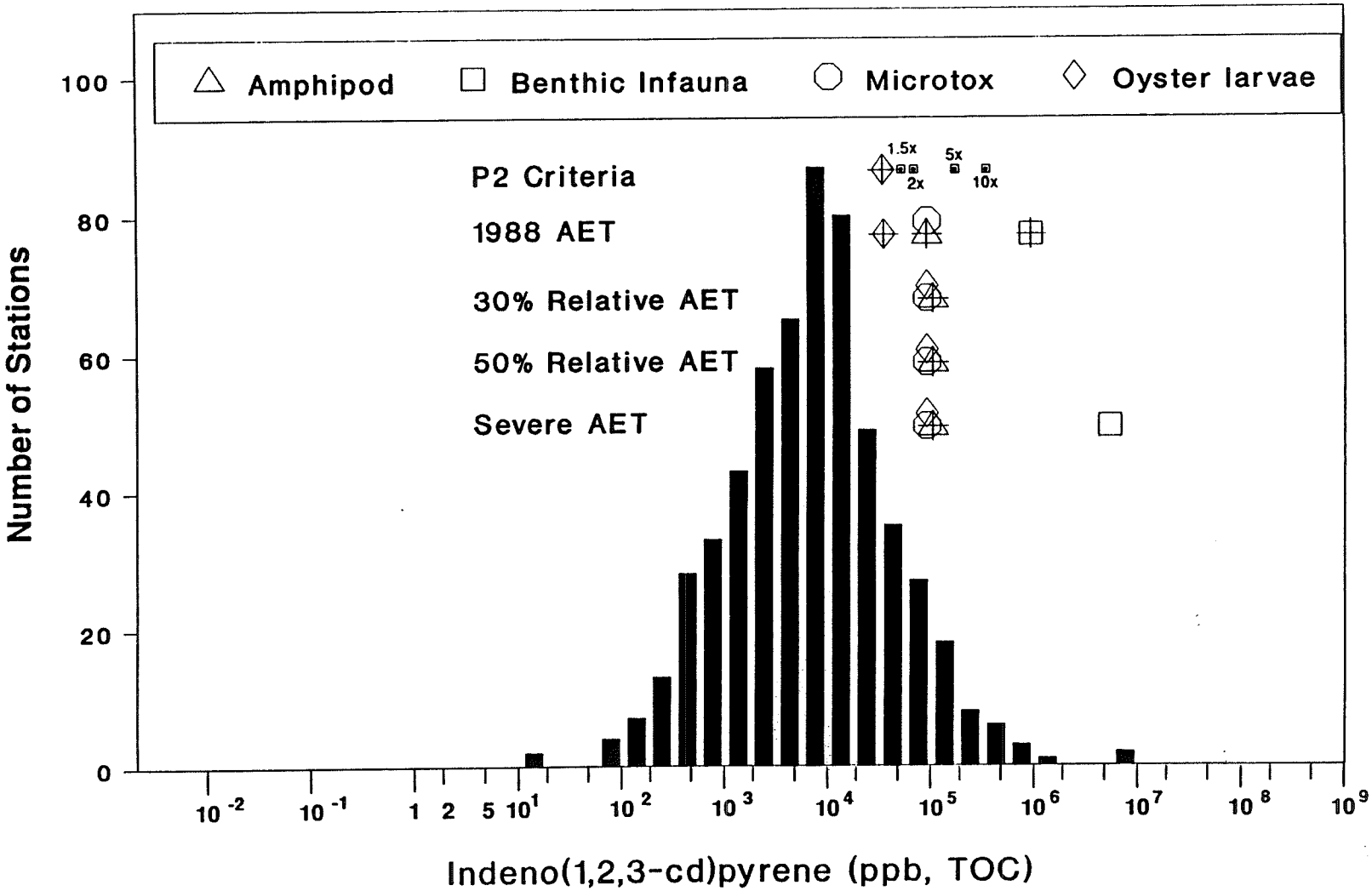

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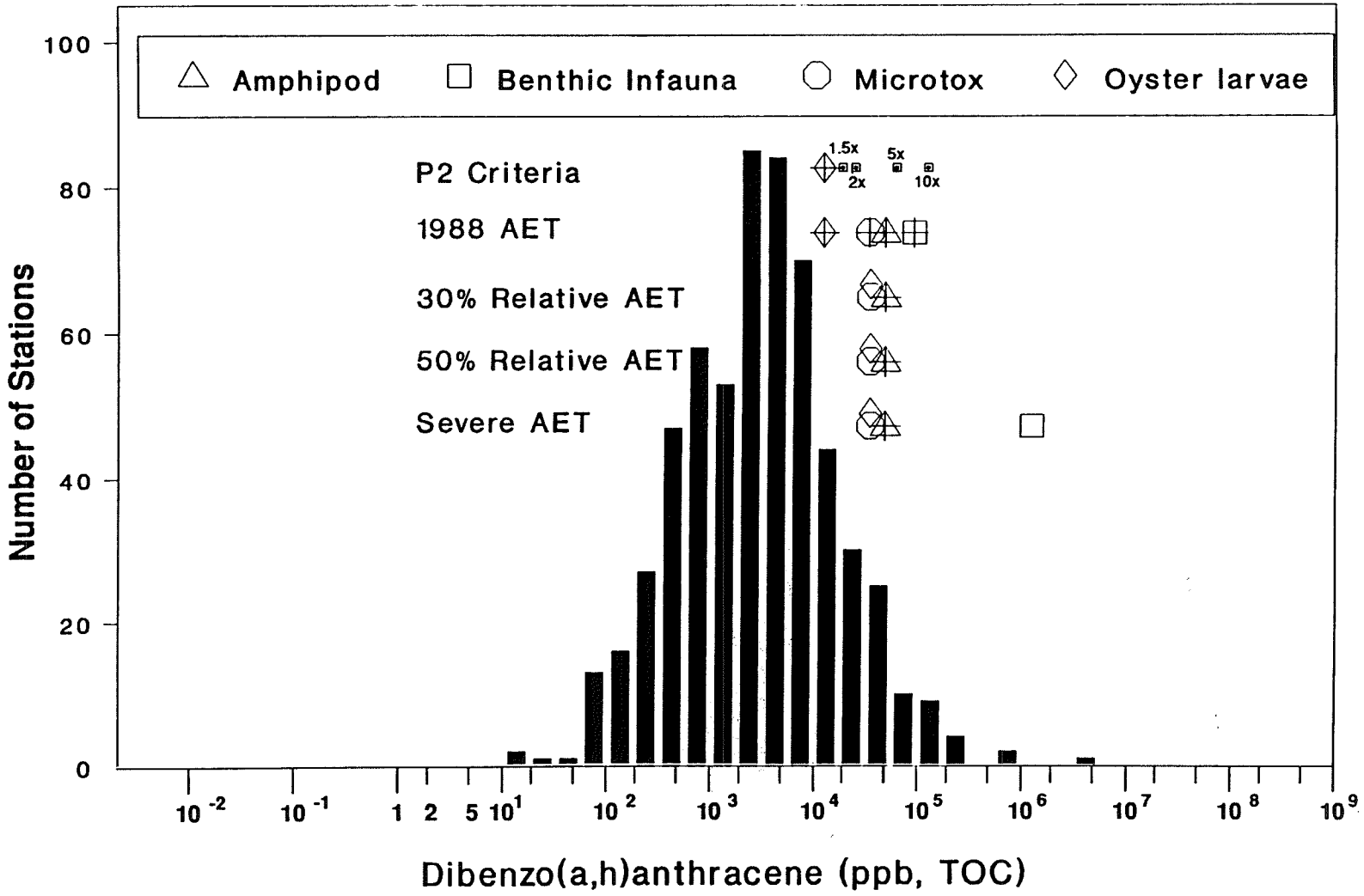

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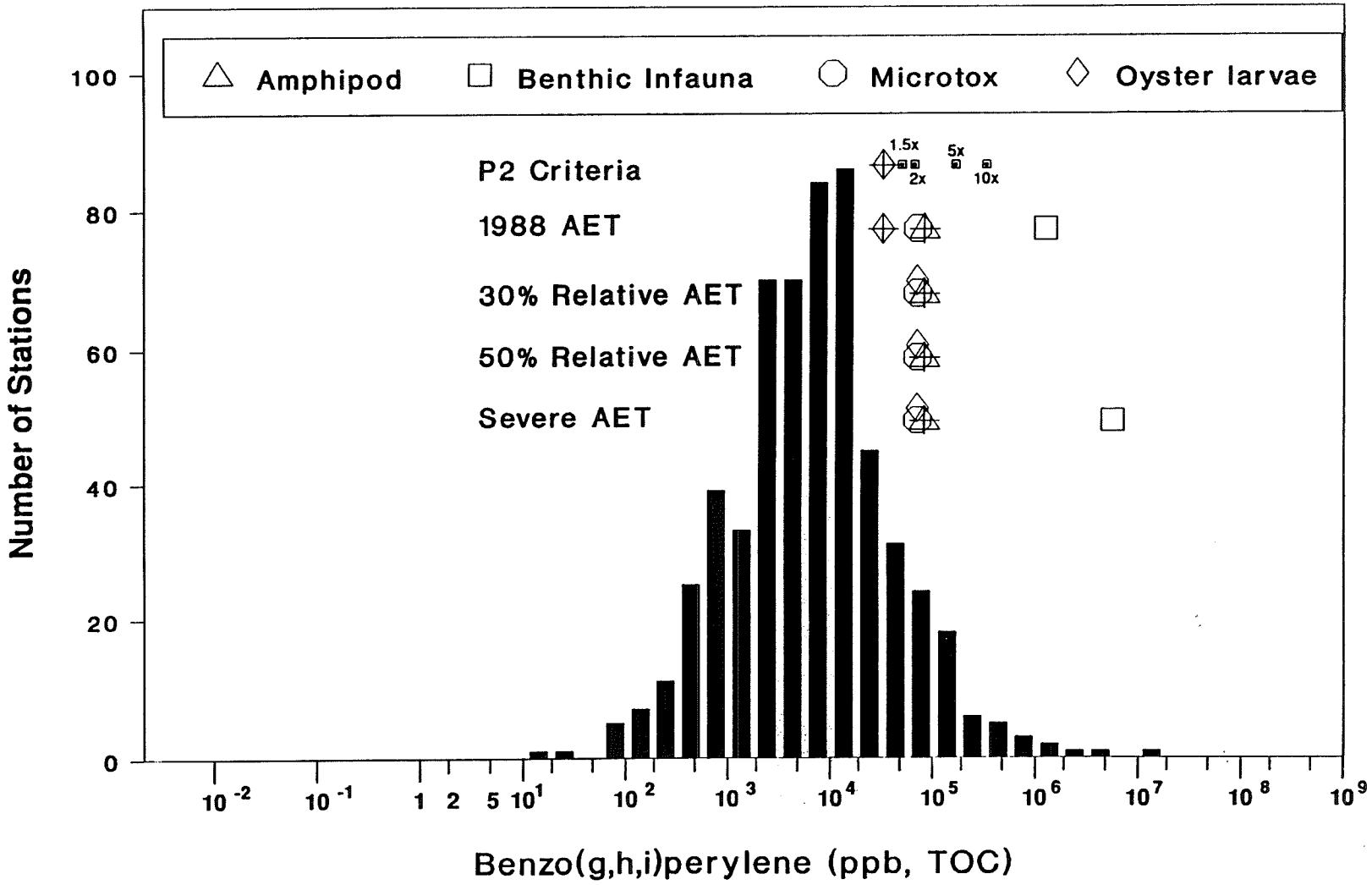

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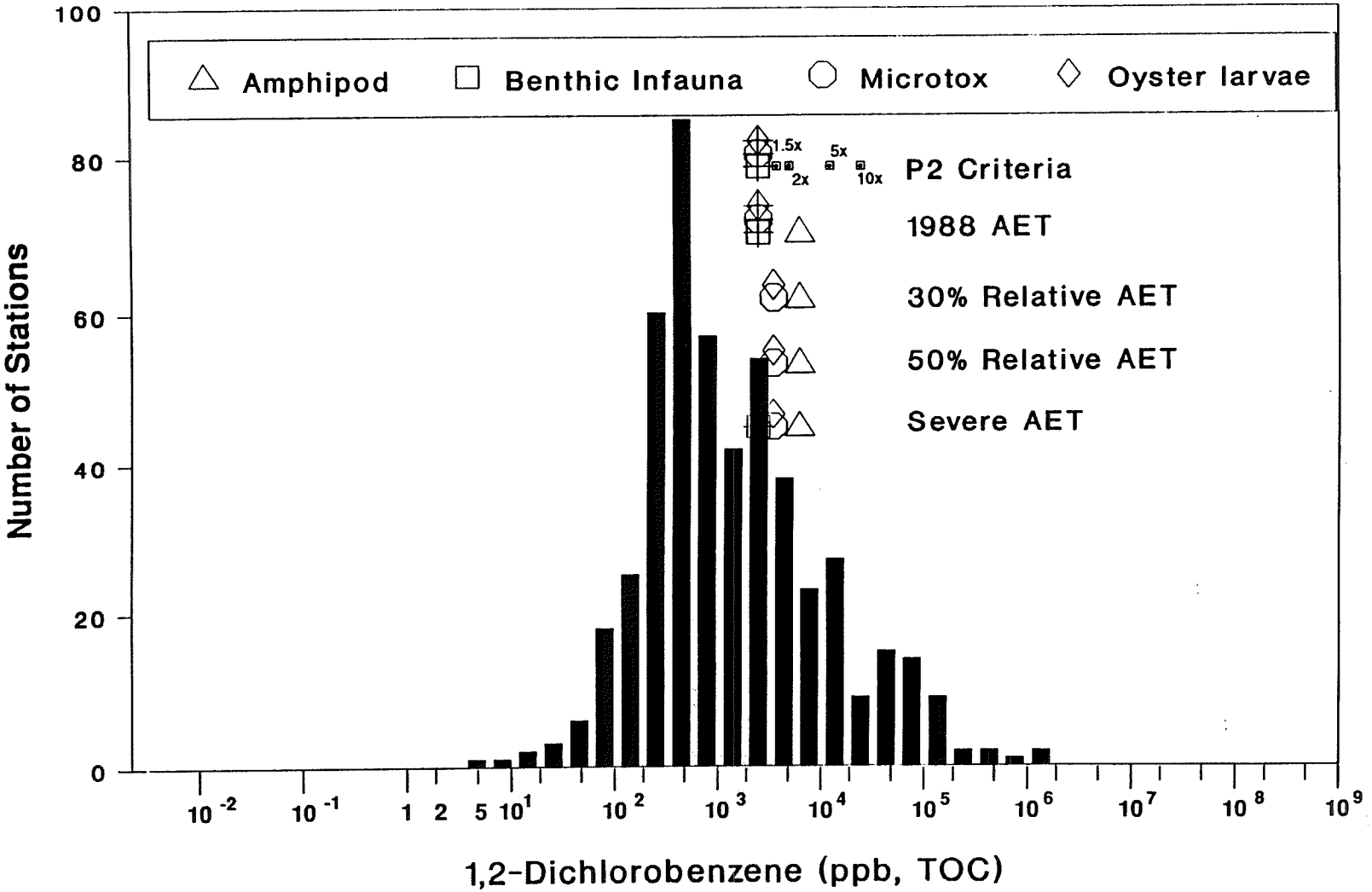

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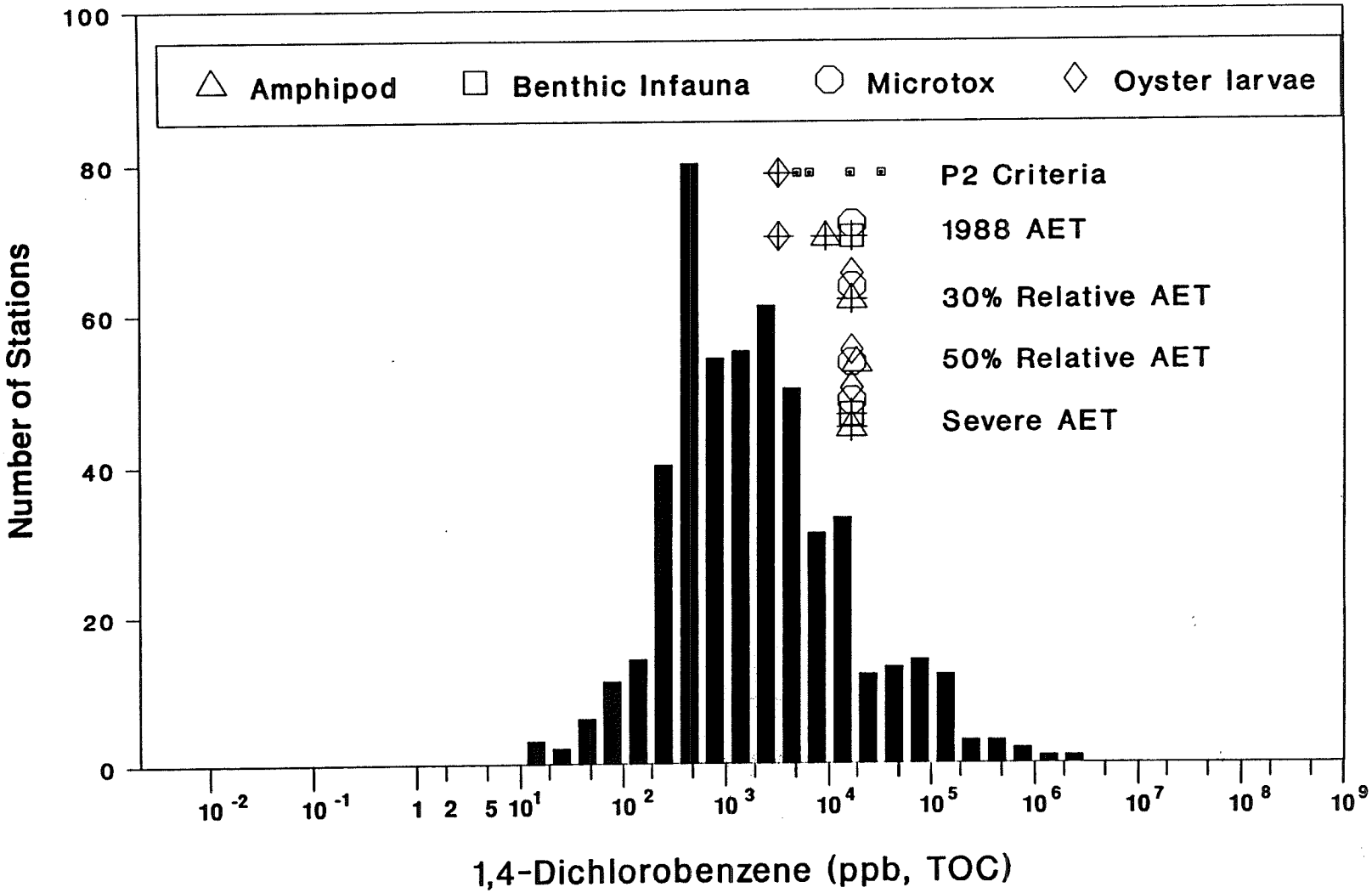

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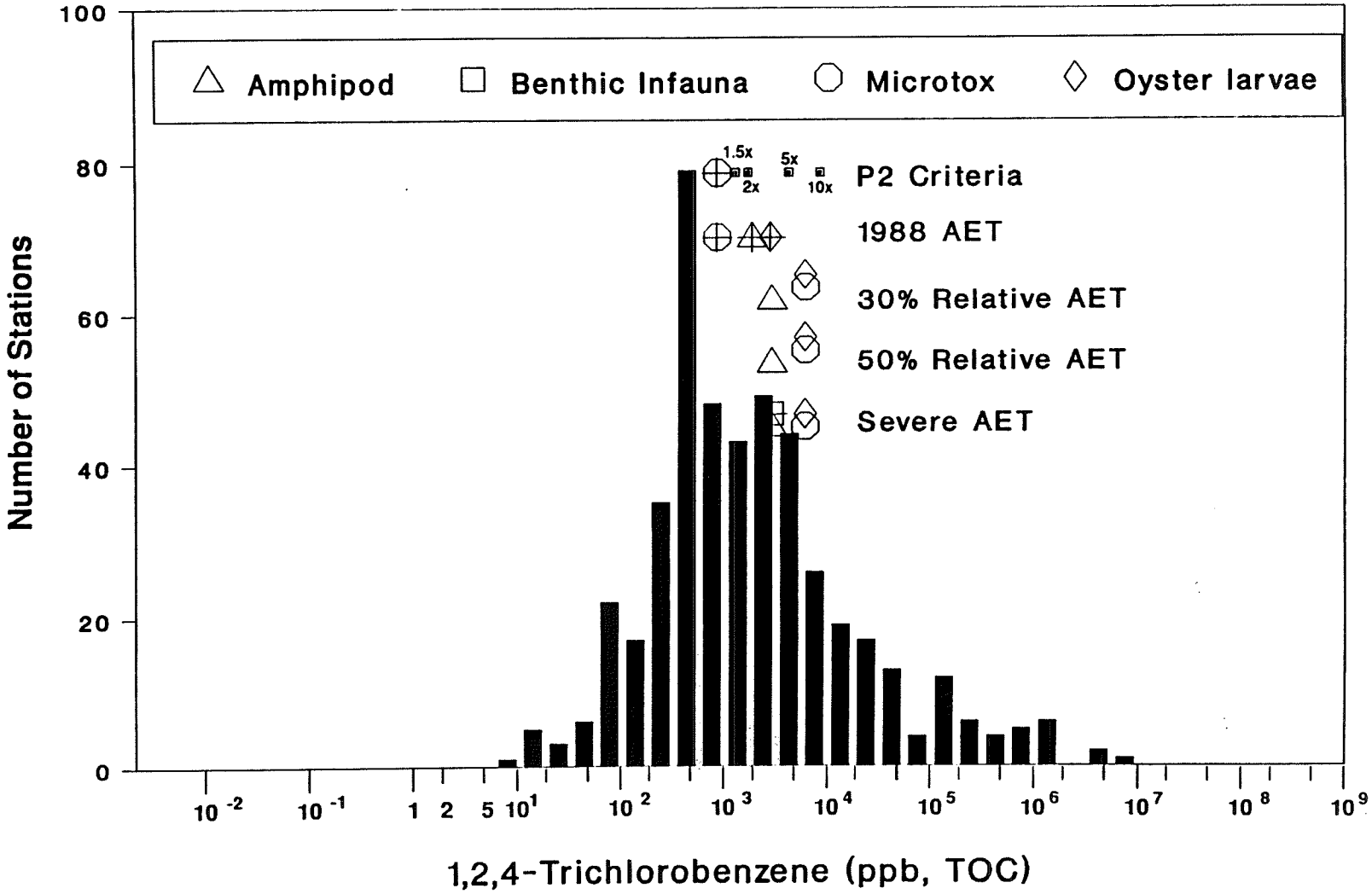

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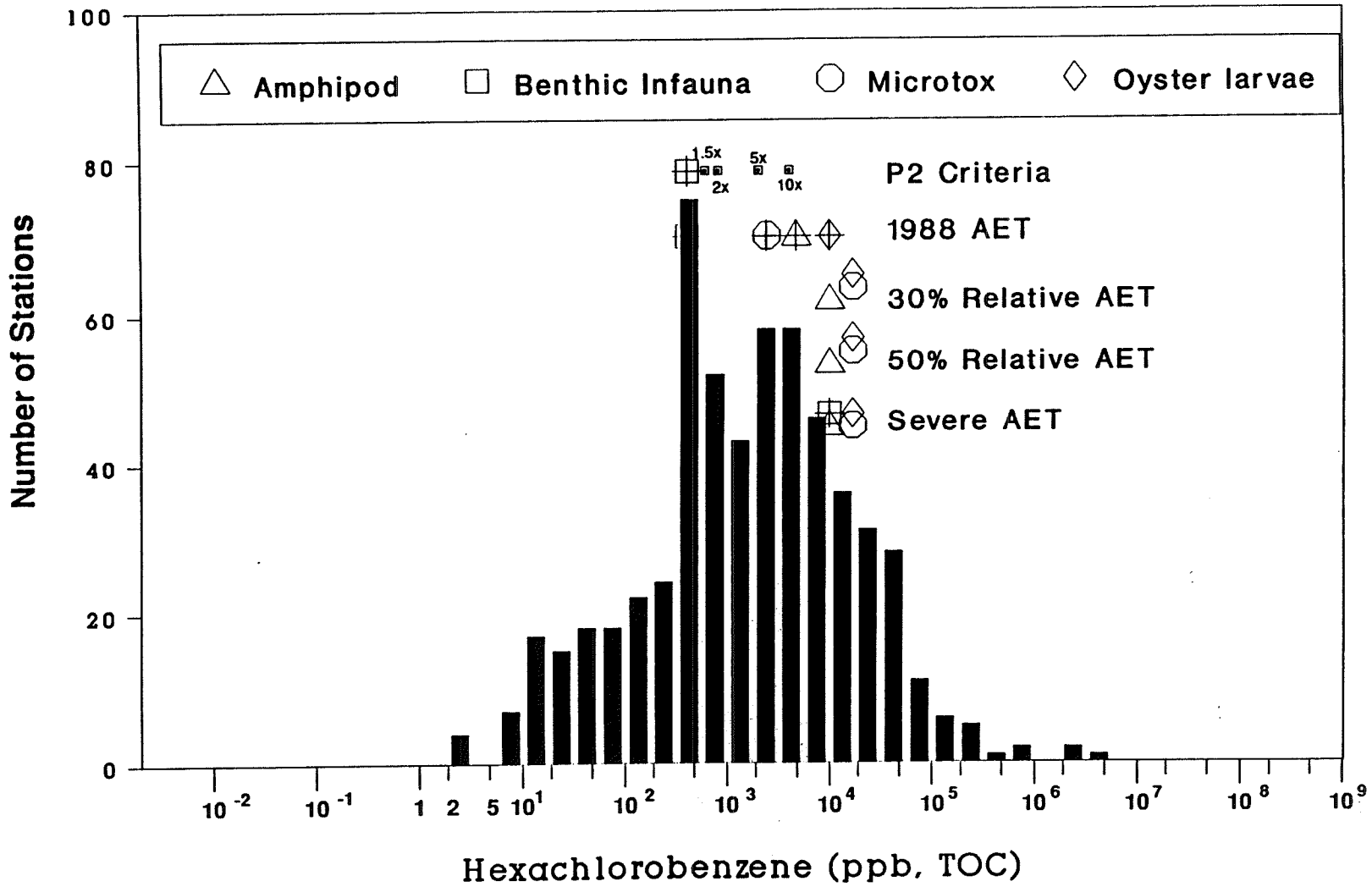

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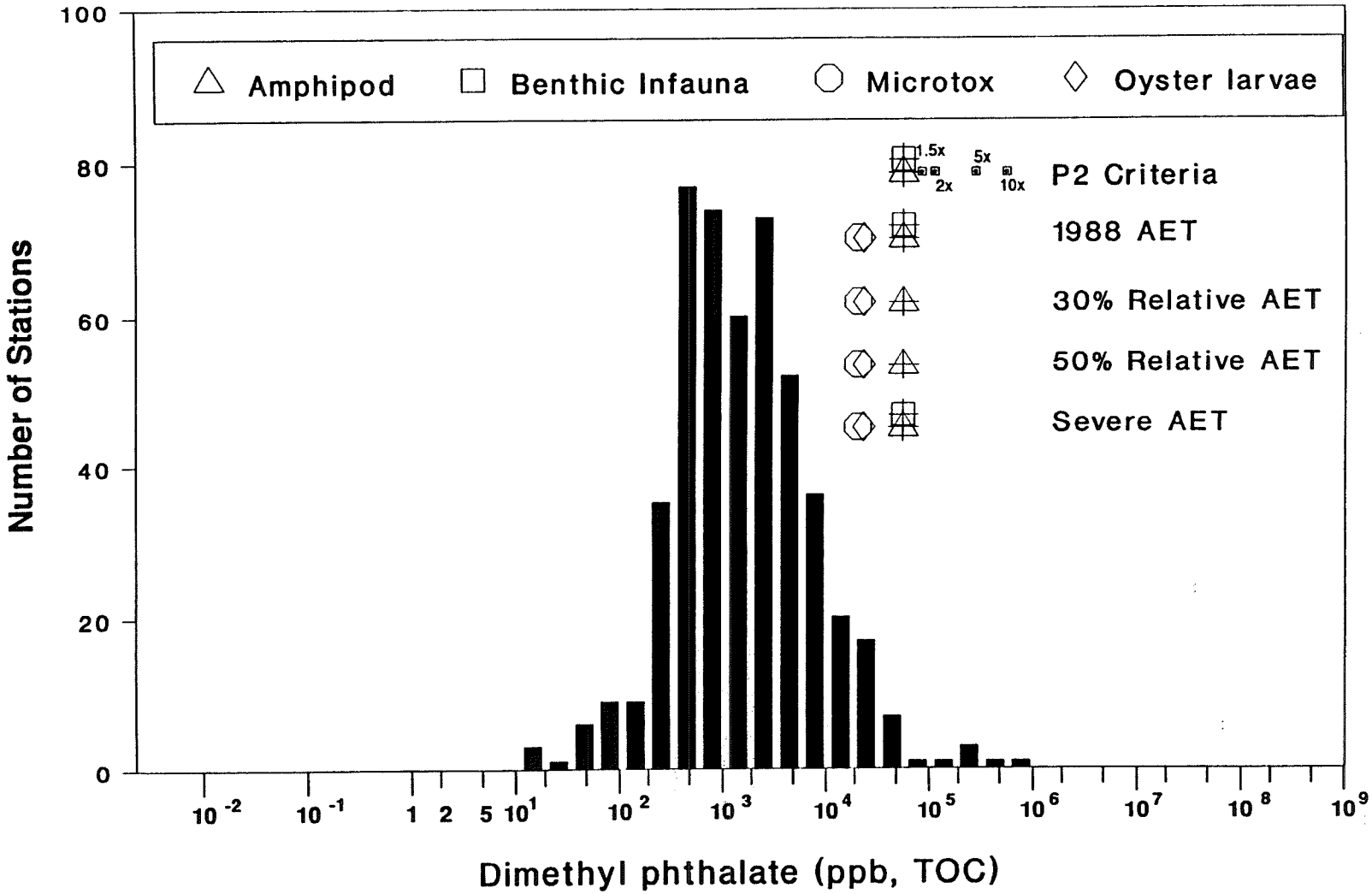

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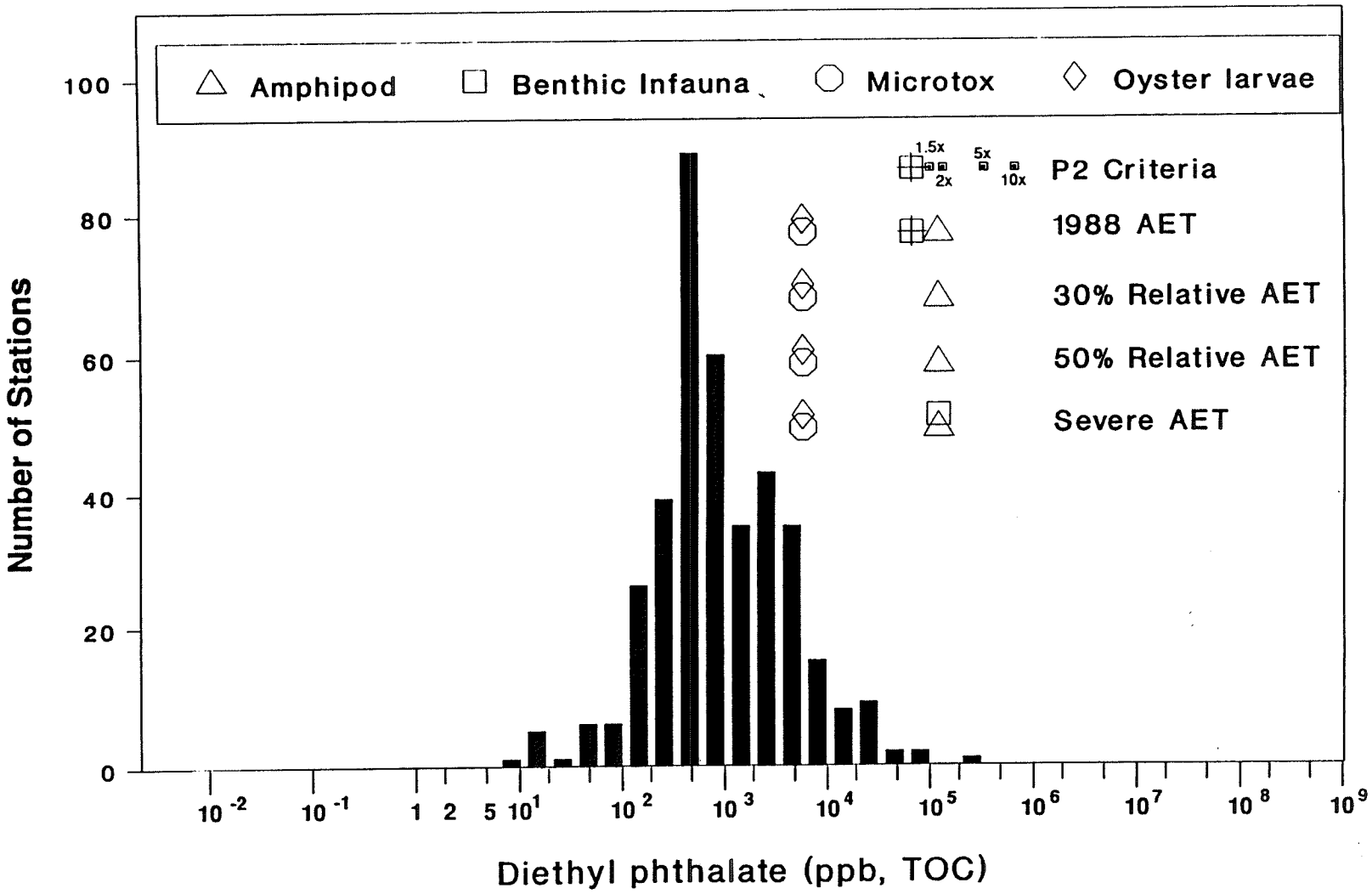

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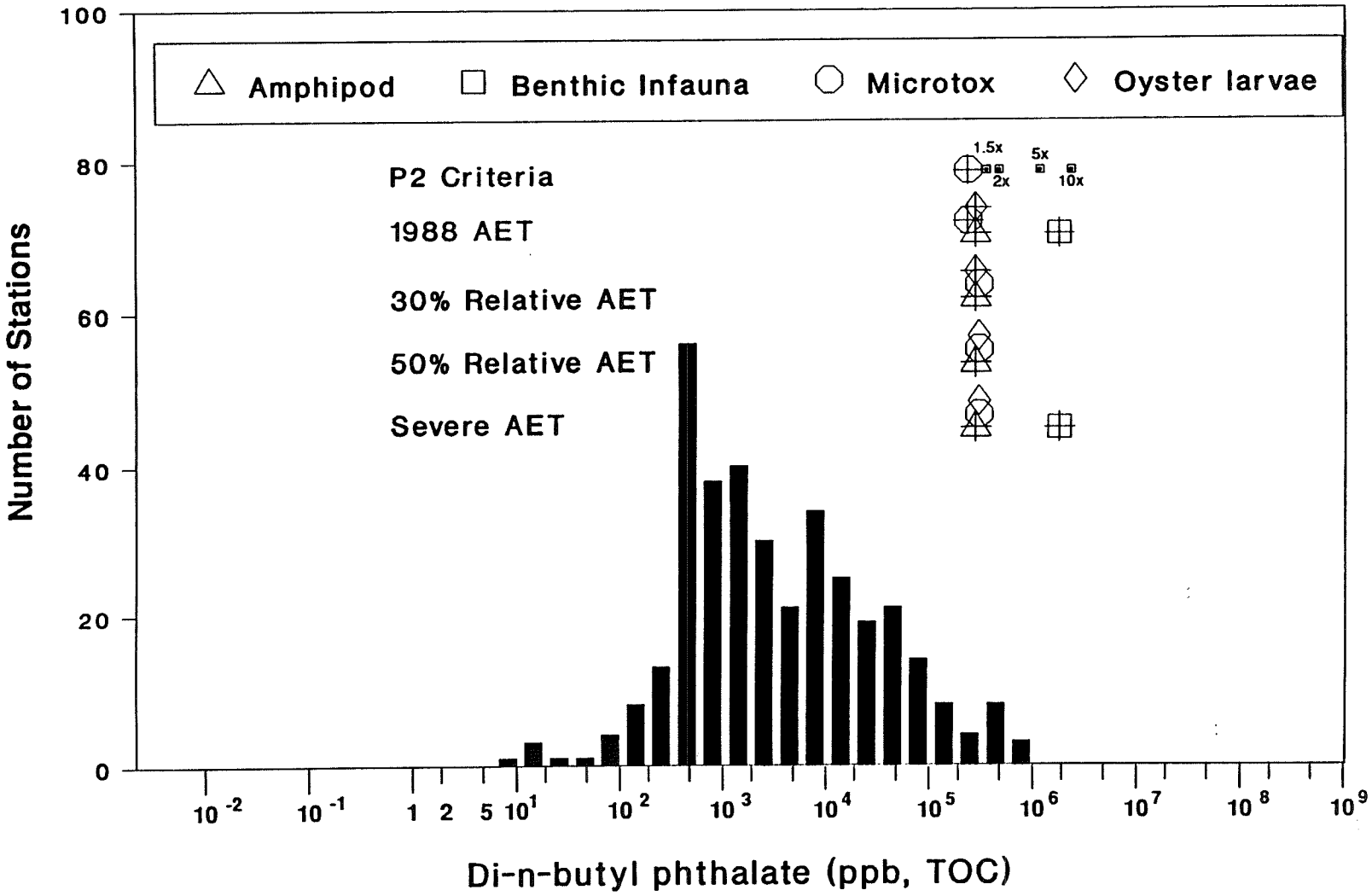

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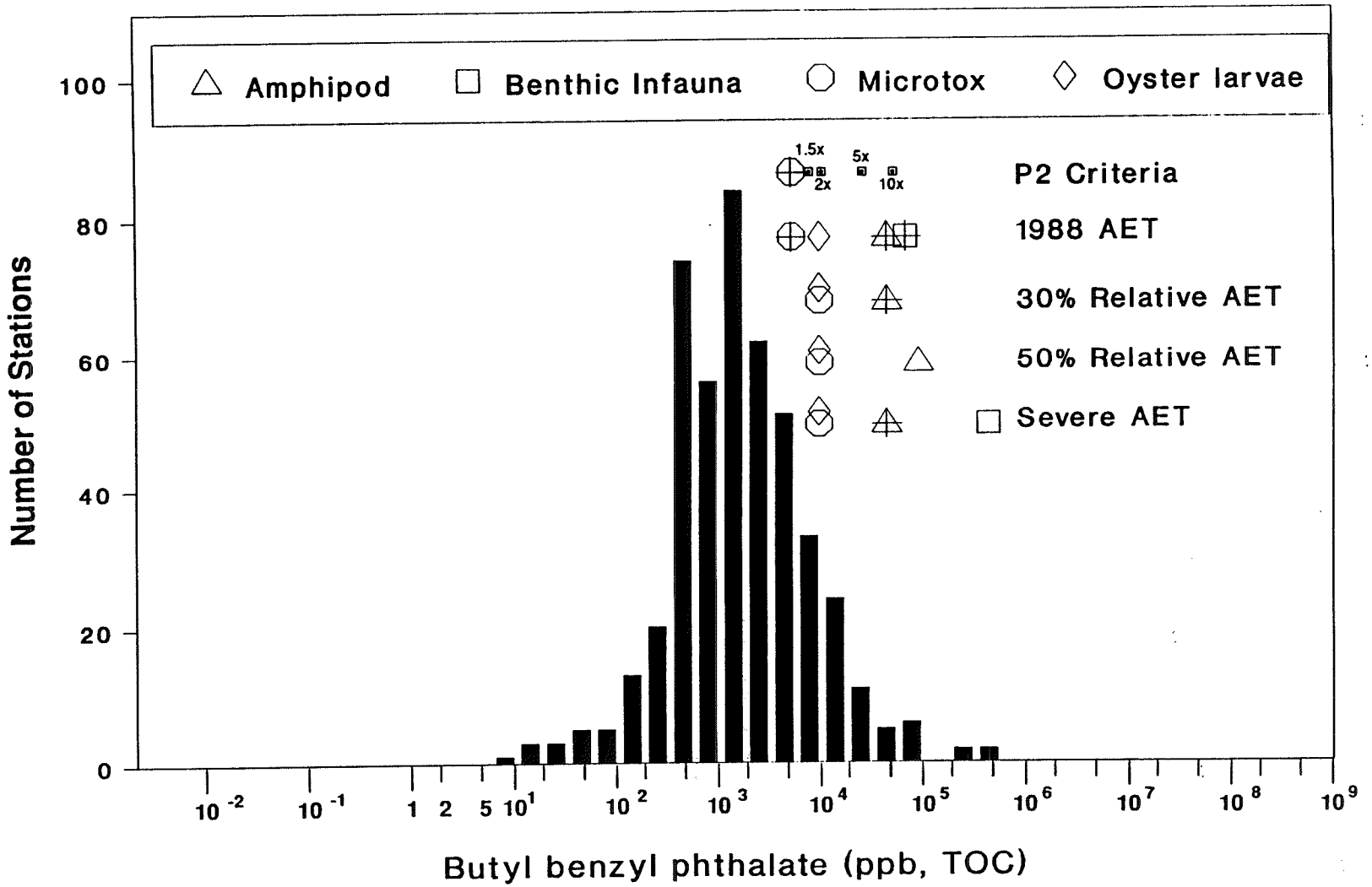

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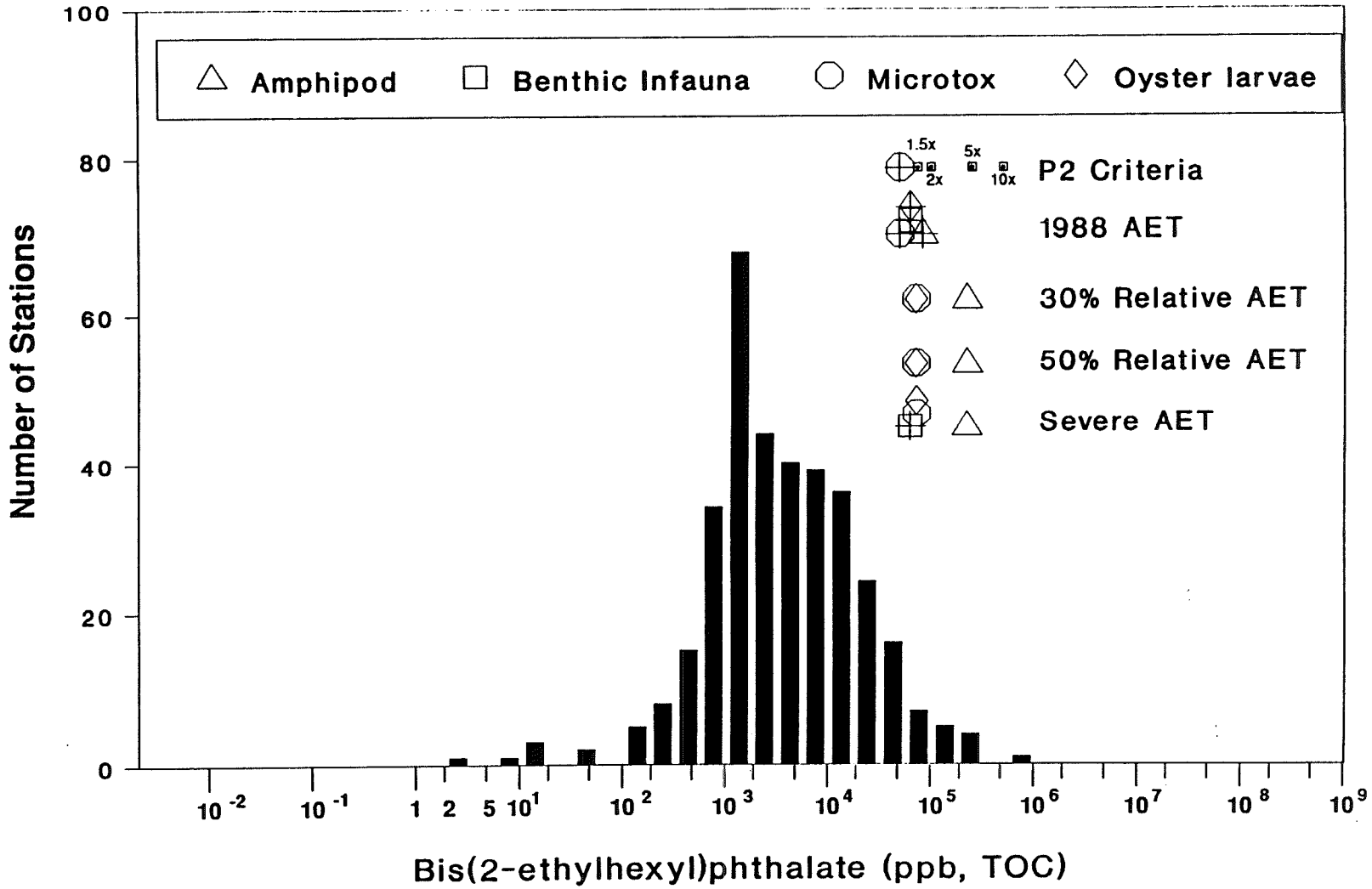

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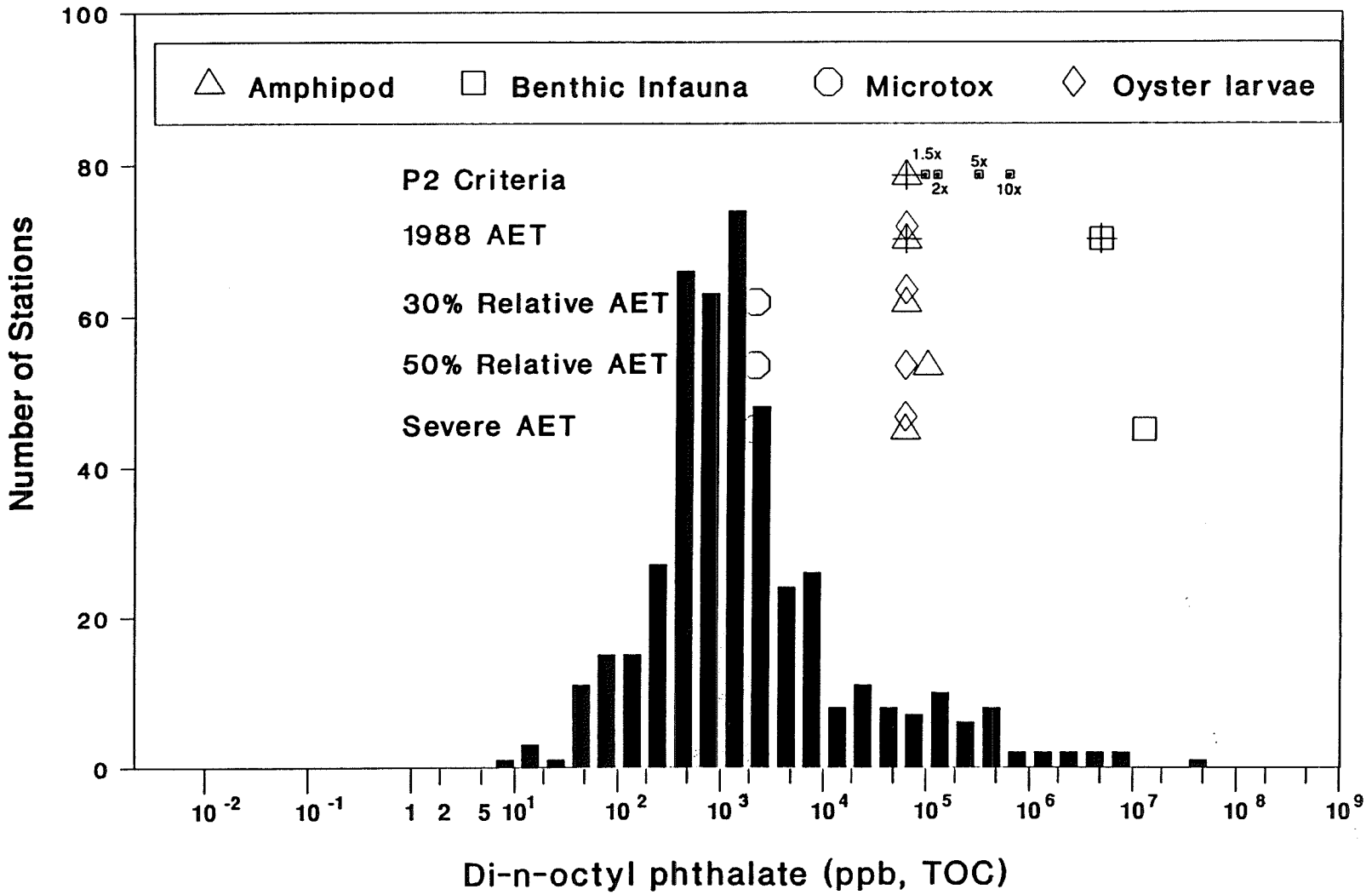

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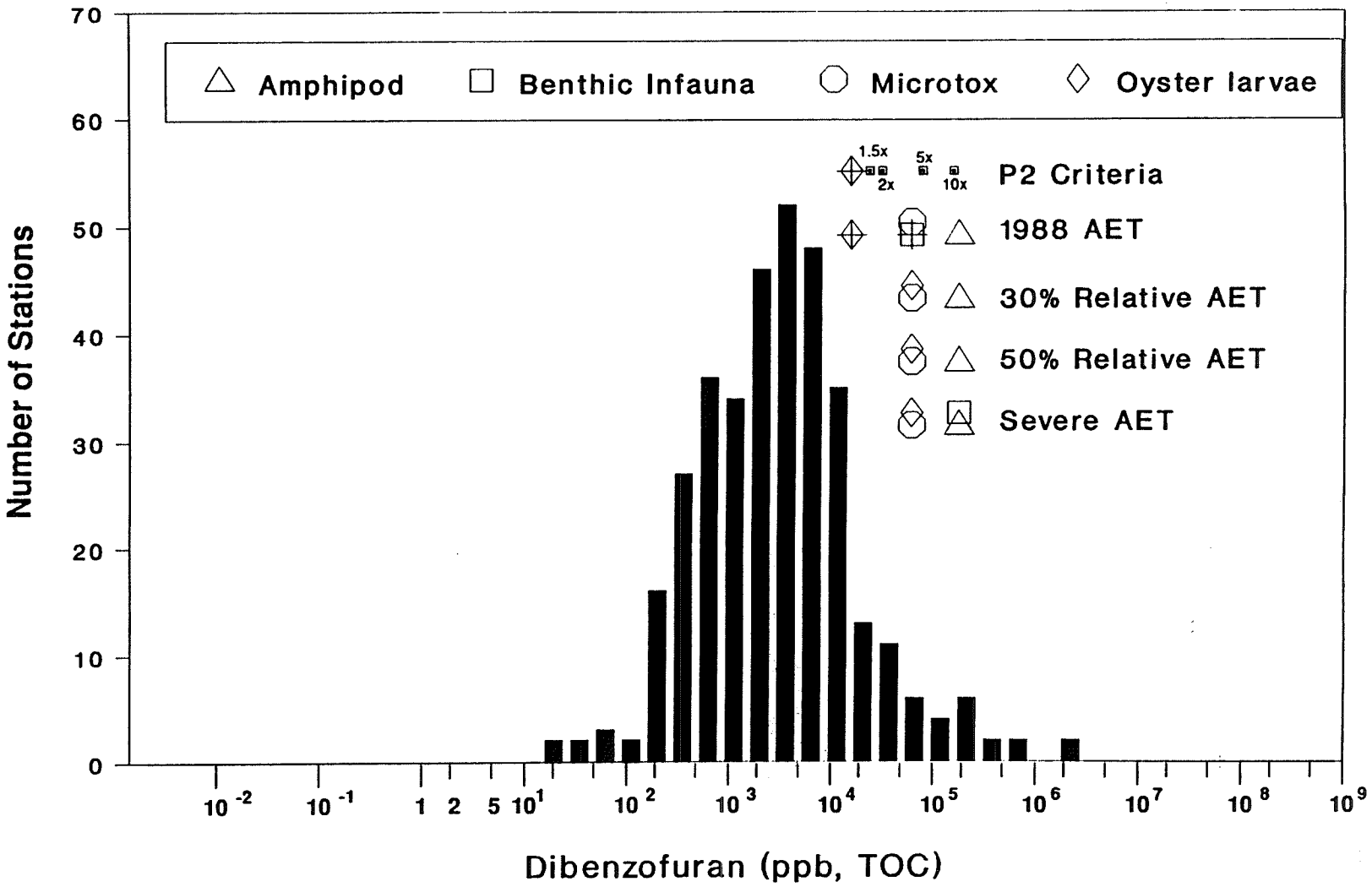

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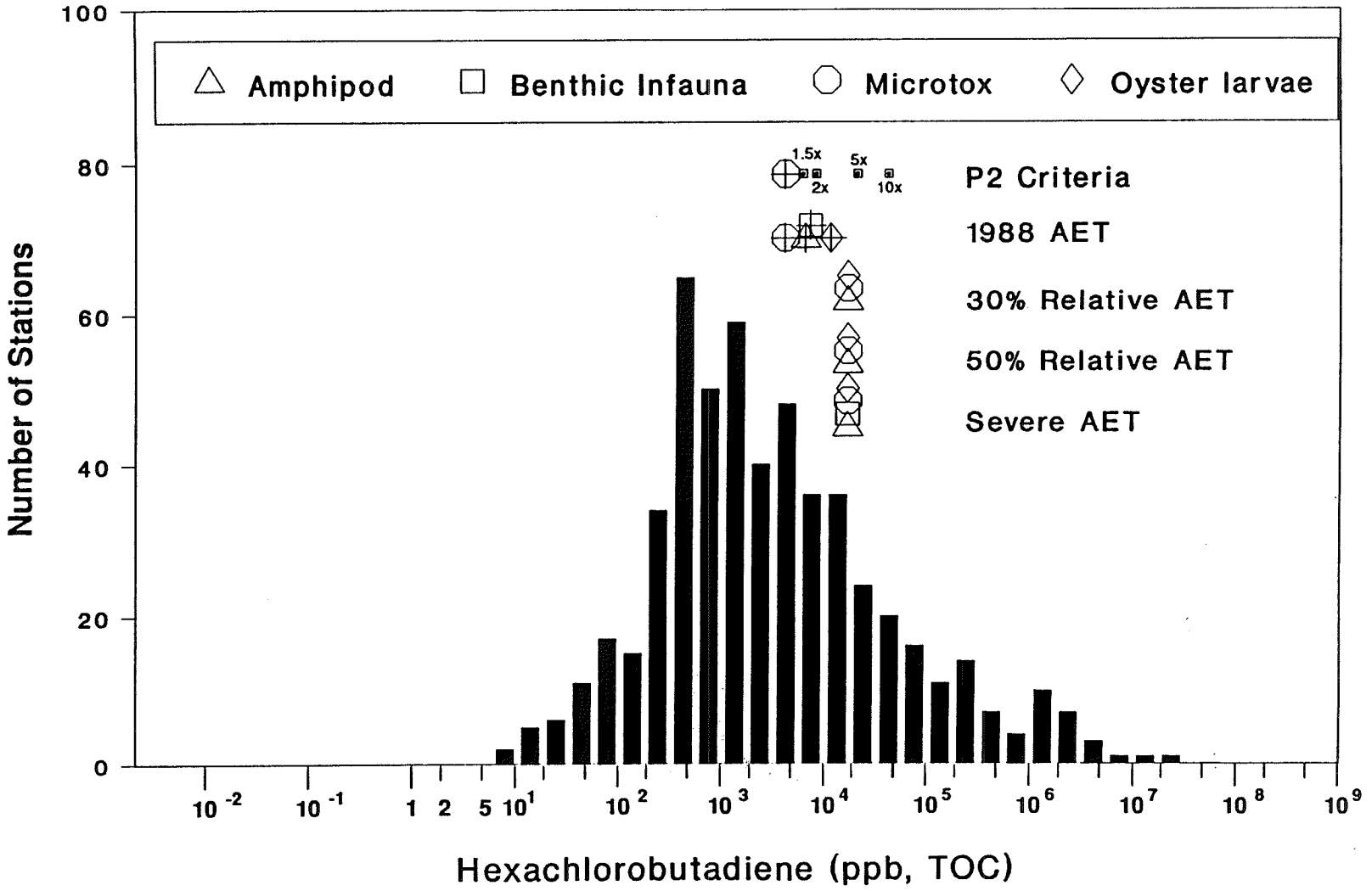

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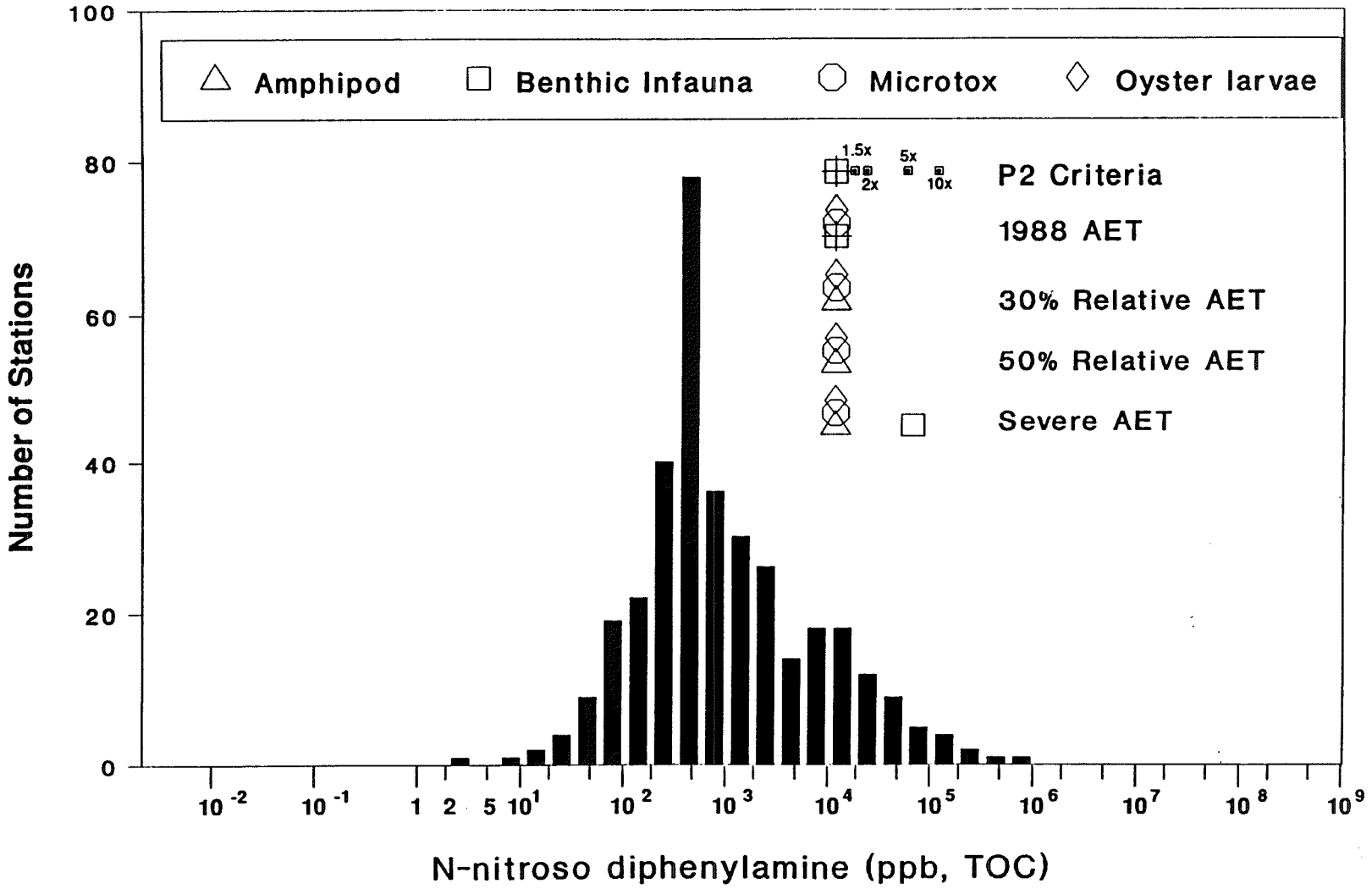

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