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ENVIRONMENTAL SERVICES

Policy Implications of Effects-Based Marine Sediment Criteria

Prepared for:

U.S. Environmental Protection Agency
Office of Policy Analysis
Washington, DC

Final Report
U.S. EPA Contract No. 68-01-7002

September 30, 1987

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POLICY IMPLICATIONS OF EFFECTS-BASED MARINE SEDIMENT CRITERIA

For

American Management Systems, Inc.
Arlington, VA

and

U.S. Environmental Protection Agency
Office of Policy Analysis
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EXECUTIVE SUMMARY

The integration of sediment criteria into environmental decision-making processes requires consideration of a wide range of policy issues. These issues derive from the differing emphases of regulatory programs as well as technical considerations. In the following report, the predicted extent and severity of potential problems posed by toxic marine sediments is demonstrated by applying Apparent Effects Threshold (AET) values to chemical monitoring data collected by the NOAA Status and Trends Program. The AET is the chemical concentration in sediments above which statistically significant biological effects are always expected for one or more effects indicator (e.g., bioassay responses, alterations of benthic macroinvertebrate communities). AET values, derived empirically from chemical and biological effects data, have been previously demonstrated to be accurate predictors of adverse effects in multiple embayments in Puget Sound of Washington State. In the present study, Puget Sound AET are used to evaluate chemical data from the east, west, and gulf coasts of the U.S.

Overall, the AET approach was useful in distinguishing NOAA Status and Trends stations and areas by degree of predicted biological effects. The relatively contaminated embayments of the Northeast Region were identified as the most impacted areas in the U.S. By contrast, most embayments in the Gulf Region were not predicted to exhibit biological effects. Predicted biological effects in the Northwest/Alaska, Southwest, and Southeast Regions were intermediate in magnitude between the effects predicted for the Northeast and Gulf Regions. Thus, the AET approach was sufficiently sensitive to discriminate among areas subjected to different degrees of chemical contamination. Confirmation of the predicted effects would require biological testing because no site-specific biological effects data were collected at sediment stations in the Status and Trends program. However, the resolution obtained in this study is important because it suggests that an effects-based approach can be used at areas removed from heavily contaminated areas (e.g., marine Superfund sites) to rank potential problem areas. This ranking effectively weights chemical concentration data according to potential biological effects, an important consideration when comparing sites of differing chemical composition.

AET are based on highly site-specific biological indicators, including sediment toxicity and in situ abundances of benthic infauna. Comparisons of fish pathology results (a less site-specific indicator) from the Status and Trends program were made with the AET predictions of sediment toxicity and benthic effects. The comparisons showed that when the AET approach predicted widespread biological effects, significantly elevated prevalences of kidney lesions were found in all cases. Prevalences of liver lesions were elevated much less frequently than prevalences of kidney lesions and showed no close relation with results of the AET analysis (similar to preliminary results for liver lesions and AET predictions in Puget Sound).

Evaluations of additional data sets from southern California and San Francisco Bay generally supported the conclusions reached from the analysis of the Status and Trends data set. That is, the AET approach discriminated among stations subjected to different degrees of chemical contamination. These latter data sets also contained site-specific biological effects information. Based on site-specific sediment chemistry results, the AET approach predicted impacted stations around sewage outfalls in southern California that were similarly defined as impacted by an independent assessment of benthic communities. Evaluations of the biological effects measured in both the southern California and San Francisco studies showed that one or more adverse effects were found at 14 of 15 stations (93 percent) where effects were predicted to occur by the AET analysis. Policy evaluations based on the results of these analyses focus on the following topics:

- Use of effects-based criteria as a tool in managing coastal regions where both nonpoint and point sources may have contributed to toxic buildup in sediments

- Application of effects-based criteria at potential marine Superfund sites

- Apparent usefulness of effects-based criteria in addressing remedial action policy issues related to "how clean is clean."

Effects-based approaches such as the AET appear to have wide applicability for problem identification at marine sites that could be considered for listing on the National Priorities List, and for monitoring changes in less contaminated coastal regions of the U.S. The NOAA Status and Trends Program focused on monitoring stations that were removed from direct sources of contamination, and several of the stations could be considered appropriate "reference" stations for marine sediments. Because AET distinguished relatively contaminated and uncontaminated areas sampled by NOAA, such an effects-based approach may provide a technical basis for cleanup criteria at remedial action sites. Confirmation of the applicability of AET (derived for the Puget Sound region) by selective field testing in other parts of the country is recommended.

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INTRODUCTION

This evaluation was conducted as a preliminary study for the U.S. Environmental Protection Agency (EPA) Office of Policy Analysis (OPA) on implications of applying effects-based sediment criteria to coastal regions of the United States.

BACKGROUND

Toxic metals and certain persistent organic compounds (e.g., PCBs) tend to accumulate in sediments. These chemicals can be transferred to the overlying water or organisms through various processes (e.g., methylation, bioconcentration, resuspension, and other physical disturbances including burrowing), causing threats to aquatic organisms and humans consuming contaminated organisms. Because of these factors, the ecology work group of the Comparative Risk Project in OPA has identified aquatic in-place pollutants as a significant problem of unknown dimensions and severity.

The assessment of risks created by toxic chemicals in marine sediments has been approached by environmental scientists in two general ways. One approach emphasizes theoretical models to predict the partitioning of sediment contaminants to interstitial water (a major exposure pathway for organisms associated with sediments). The predicted interstitial water concentrations are then compared to criteria based on laboratory measurements of biological effects. The second general approach has sought to relate empirically the results of laboratory sediment bioassays and in situ biological effects observed in organisms associated with marine sediments to chemical concentrations measured in the sediments. This latter, effects-based approach, is the basis of this report.

The effects-based approach used in this project is the Apparent Effects Threshold (AET) method, an existing tool for deriving sediment criteria. The

AET is the chemical concentration in sediments above which statistically significant biological effects are always expected for one or more biological effects indicator (see METHODS section). AET were originally developed to identify problem sediments in the Commencement Bay Nearshore/Tideflats Remedial Investigation (Barrick et al. 1985). AET have been subsequently expanded and their accuracy tested using biological and chemical data for all of Puget Sound under sponsorship of EPA Region X, Washington Department of Ecology, Washington Department of Natural Resources, and U.S. Army Corps of Engineers Seattle District (Beller et al. 1986).

OBJECTIVE

The objective of this work is to apply AET to predict biological effects from sediment chemistry data compiled by the NOAA Status and Trends Program (NOAA 1987). The NOAA results include data for sediments collected along the west, east, and gulf coasts of the United States (data for the Great Lakes were excluded). The predicted extent and severity of potential problems posed by toxic sediments will thus be demonstrated by an empirical approach to sediment criteria. The Status and Trends stations were sampled by NOAA to indicate changes over time along the U.S. coast, and are not necessarily representative of the range of contaminant conditions in each geographic area. In particular, the intent of the NOAA Status and Trends program is to monitor sediment stations that are removed from the direct influence of point discharges. Areas suspected of being heavily contaminated were generally avoided. Additional data from selected regional programs (i.e., San Francisco Bay, and southern California in the vicinity of the major municipal outfalls) have been included as available. However, none of the Puget Sound stations originally used to develop the AET are included, and the stations sampled by NOAA are outside of the heavily contaminated nearshore areas of Puget Sound.

The empirical relationships used to establish AET do not prove a cause-effect relationship between contaminants and effects. The focus of this approach is to identify concentrations of contaminants that are associated exclusively with sediments having statistically significant biological effects (relative to appropriate reference sediments). The applicability of AET in predicting biological effects has not been tested outside of Puget Sound, although a limited comparison has been conducted using biological effects data in San Francisco Bay (Chapman et al. 1986, 1987). Hence, additional chemical and biological testing would be required to confirm predictions of adverse effects summarized in this report. The purpose of this report is to evaluate implications of using effects-based sediment criteria on a national basis, not to identify specific areas for potential remedial action.

METHODS

APPARENT EFFECTS THRESHOLD APPROACH

In the AET approach, chemical data are classified according to the absence or presence of associated biological effects for a variety of indicators to determine concentrations of contaminants above which statistically significant biological effects would always be expected to occur. The AET method and accuracy tests in Puget Sound are summarized in a report prepared for the Puget Sound Dredged Disposal Analysis study (PSDDA) and Puget Sound Estuary Program (PSEP) (Beller et al. 1986). AET have been established for 64 organic and inorganic toxic chemicals using matched chemical and biological data for several biological indicators and embayments in Puget Sound. Because of patchy biological and chemical conditions in the environment, it was important that chemical analyses be performed on the same or nearly the same sediment that was used in bioassays and benthic infaunal analyses. AET were available for predicting significant effects based on the following biological indicators:

- Depressions in abundances of major taxonomic groups of benthic infauna (i.e., Crustacea, Mollusca, Polychaeta, and total abundance)
- Amphipod mortality bioassay using *Rhepoxynius abronius*
- Oyster larvae abnormality bioassay using *Crassostrea gigas*
- Microtox bioluminescence bioassay using *Photobacterium phosphoreum*.

For each chemical, a separate AET was developed for each biological indicator, resulting in four sets of AET. A list of the different AET used for predictions in this study is provided in Table A-1 (Appendix A). Derivation of AET are described in more detail in Appendix A. The AET method has been shown to be sensitive in correctly predicting impacted stations in Puget Sound, but in doing so the approach can also predict impacts at stations that do not evidence adverse effects (i.e., the approach is not completely efficient in only identifying impacted stations). Therefore, predictions in other regions that are based on AET should be verified.

DATA SOURCES

Chemical data from the NOAA Status and Trends Program (NOAA 1987), a separate NOAA Status and Trends study in San Francisco Bay (Chapman et al. 1986, 1987), and the Southern California Coastal Water Research Project (SCCWRP; Word and Mearns 1979) were compiled and compared with AET. Chemical data were available for sediment samples from 126 NOAA stations sampled in 1984. Forty-five coastal embayments are represented by this data set. The San Francisco Bay study by NOAA contained chemical data for nine samples collected in 1985. Chemical data from the SCCWRP study included 71 sediment samples collected in 1977 along the 60-m depth contour.

Data were also compiled for ancillary sediment variables (e.g., total organic carbon, sediment grain size) and other tracer variables as available (e.g., numbers of Clostridium perfringens spores). Data were transferred to a DBase III database, verified, and cross-referenced with station identifier information. The verified chemical concentration data were compared with AET values developed from the database of chemical and biological effects results for Puget Sound.

Biological effects data analogous to those used to generate Puget Sound AET were available for only some of the chemistry stations. In the NOAA Status and Trends Program, biological data were available on the prevalence of fish histopathology disorders and concentration of chemicals in mussel tissue. Mussel tissue data have not yet been evaluated. Fish histopathology data are not directly comparable to the highly site-specific bioassay and benthic infauna data supporting the Puget Sound AET. Thus, validation of the predictive accuracy of AET for this study was limited to the select data sets from California. In the SCCWRP study in southern California, benthic infaunal data were available for all stations. In the San Francisco Bay study, bioassay and benthic infauna data were available for all stations. A description of the evaluations of these biological data is provided in the following sections.

Evaluation of NOAA Status and Trends Biological Indicator Data

The only biological effect of chemical contamination evaluated by the NOAA Status and Trends Program was fish pathology. Specifically, microscopic abnormalities of the kidney and liver were evaluated in selected species of bottom-dwelling fishes captured near the stations sampled for sediment chemical contamination (Table 1). Data on spores of the bacterium *Clostridium perfringens* were also collected by NOAA, not as a biological effect but as a potential indicator of contamination by domestic sewage.

For the present study, prevalences of the lesions identified by the Status and Trends Program were compared with a prevalence of 0 percent using the G-test and Williams' correction factor. Prevalences found to be significantly different ($P \leq 0.05$) than 0 percent were considered indicative of potential adverse conditions. Because appropriate "background" conditions have not been defined for the NOAA Status and Trends data set it is uncertain what level of fish pathology in U.S. coastal waters can be considered "normal."

Sediment bioassays and measurements of in situ benthic infauna would provide the best comparison for AET predictions of biological effects at the NOAA stations but these data are not available. Use of fish pathology as an indicator of sediment chemical contamination requires several caveats. First, fish in general are not the best indicators of highly site-specific sediment contamination, because many species migrate to some extent. Second, because different fish species and age groups may exhibit different sensitivities to sediment contamination, pathology data based on different species or age groups throughout the U.S. may be influenced partly by interspecific or age-related differences in sensitivity. Finally, although strong circumstantial evidence suggests that many liver lesions and, to a lesser extent, kidney lesions, are the result of exposure to toxic chemicals, conclusive cause/effect relationships have yet to be documented in a field setting.

TABLE 1. SUMMARY OF FISH PATHOLOGY OBSERVATIONS MADE DURING 1984 BY NOAA'S NATIONAL STATUS AND TRENDS PROGRAM

Region	Species	Number of Sites	Observed Lesions: Kidney	Observed Lesions: Liver
Northeast U.S.	Winter flounder (*Pseudopleuronectes americanus*)	8	MMC[a] proliferation	Hepatic neoplasia Proliferative biliary hyperplasia
Southeast U.S./ Gulf Coast	Atlantic croaker (*Micropogodon undulatus*)	11	MMC proliferation Inflammatory necrotozing granulomas Degenerative hyalin lesions	Cholangiocellular necrosis Hepatocellular necrosis
	Spot (*Leiostomus xanthurus*)	14	MMC proliferation Inflammatory necrotizing granulomas Degenerative hyalin lesions	Cholangiocellular necrosis Hepatocellular necrosis
Northwest U.S./ Alaska	English sole (*Parophrys vetulus*)	3	Degeneration/necrosis Proliferative disorders	Foci of cellular alteration Degeneration/necrosis
	Flathead sole (*Hippoglossoides elassodon*)	4	Degeneration/necrosis Proliferative disorders	Foci of cellular alteration Degeneration/necrosis
	Starry flounder (*Platichthys stellatus*)	6	Degeneration/necrosis Proliferative disorders	Foci of cellular alteration Degeneration/necrosis
Southern California	White croaker (*Genyonemus lineatus*)	7	Degeneration/necrosis Proliferative disorders	Degeneration/necrosis Proliferative disorders
	Hornyhead turbot (*Pleuronicthys verticalis*)	5	Degeneration/necrosis Proliferative disorders	Foci of cellular alteration Degeneration/necrosis

[a] MMC = Melanin Macrophage Centers

Evaluation of Biological Indicator Data from Other Studies

Southern California--

Between 28 April and 9 August 1977, SCCWRP conducted a survey of sediment contamination and biological effects at 71 stations distributed along the 60-m isobath from Point Conception to the U.S./Mexico border (Figure 1; Word and Mearns 1979). The survey encompassed a range of sediment contamination, from reference conditions to the highly impacted conditions near the major municipal sewage outfalls of Los Angeles and San Diego.

Benthic infaunal assemblages were used by SCCWRP as the primary indicators of the biological effects of sediment chemical contamination. The chemicals measured at each station included metals, total polychlorinated biphenyls (PCBs), and total DDT.

For the present study, two kinds of benthic effects were evaluated in relation to sediment contamination. The first kind of effect was a reduction in the Infaunal Index below a value of 69. The Infaunal Index is an index of benthic alterations based on changes in the functional feeding groups of benthic taxa. The Infaunal Index can range from 0 to 100. Values lower than 69 are considered indicative of altered benthic communities (Word and Mearns 1979). The second kind of benthic effect considered in the present study was a reduction in the abundance of echinoderms below a value of 9 individuals/m^2. Echinoderms have been found to be very sensitive to environmental perturbations on the southern California Shelf. Abundances of echinoderms below a value of 9 individuals/m^2 are below the range of reference values defined for southern California (Word and Mearns 1979), and can be considered to be indicative of degraded conditions.

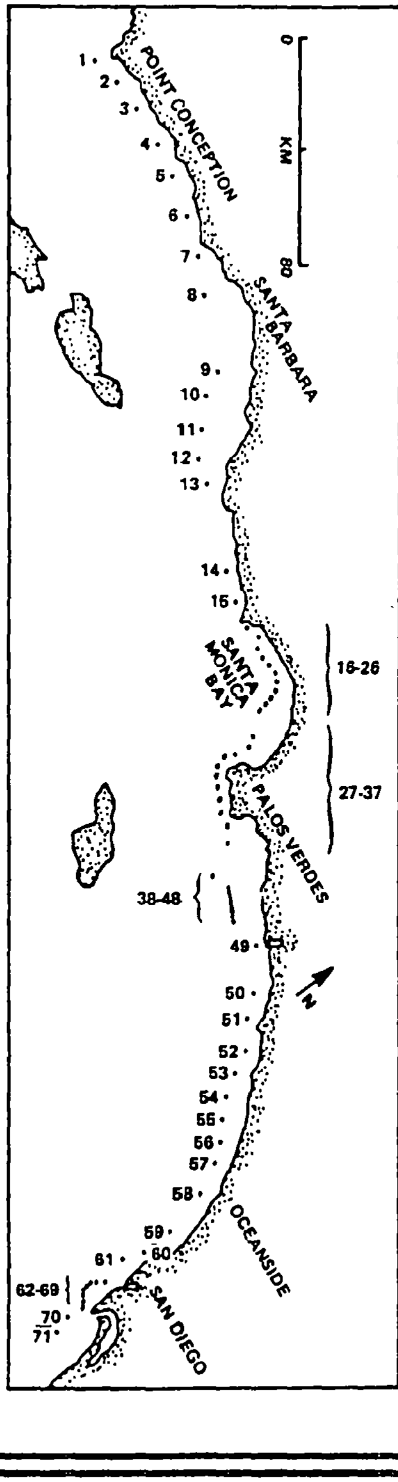

Figure 1. Locations of stations sampled in southern California along the 60 m depth contour (Source: Word and Mearns 1979)

San Francisco Bay--

In 1985, Chapman et al. (1986, 1987) conducted a survey of sediment contamination and biological effects at nine stations from San Francisco Bay (Figure 2). Three of these stations were distributed at each of three locations, representing a range of sediment contamination. A site in San Pablo Bay was used as a reference area. Contaminated areas were sampled near Oakland in the vicinity of industrial and maritime facilities and in the Islais Waterway, an industrial waterway that receives storm/sewer overflows.

Laboratory sediment bioassays and benthic infaunal assemblages were used by Chapman et al. (1986, 1987) as the primary indicators of the biological effects of sediment chemical contamination. The primary chemicals measured at each station included metals, high and low molecular weight polycyclic aromatic hydrocarbons (HPAH, LPAH), pesticides, and total sums of PCBs.

For the present study, benthic infauna and two kinds of bioassays were evaluated in relation to sediment contamination. The bioassays included the amphipod (Rhepoxynius abronius) mortality test and the mussel (Mytilus edulis) larvae abnormality test. These tests are similar to the ones used originally to determine Puget Sound AET values. Impacts, as determined by Chapman et al. (1986, 1987), included statistically significant differences ($P \leq 0.05$) from the responses observed using control sediments. Impacts to benthic invertebrates were also determined qualitatively by Chapman et al. (1986, 1987), and were based on cluster analysis and evaluations of the relative abundances of major taxa and community characteristics such as taxa richness and numerical dominance.

DATABASE SETUP AND RETRIEVAL

A DBase III database system was used to analyze data for this project. The principal functions of the database are to:

- Store sediment chemistry data and related information, including sample, station, and geographic basin identifiers.

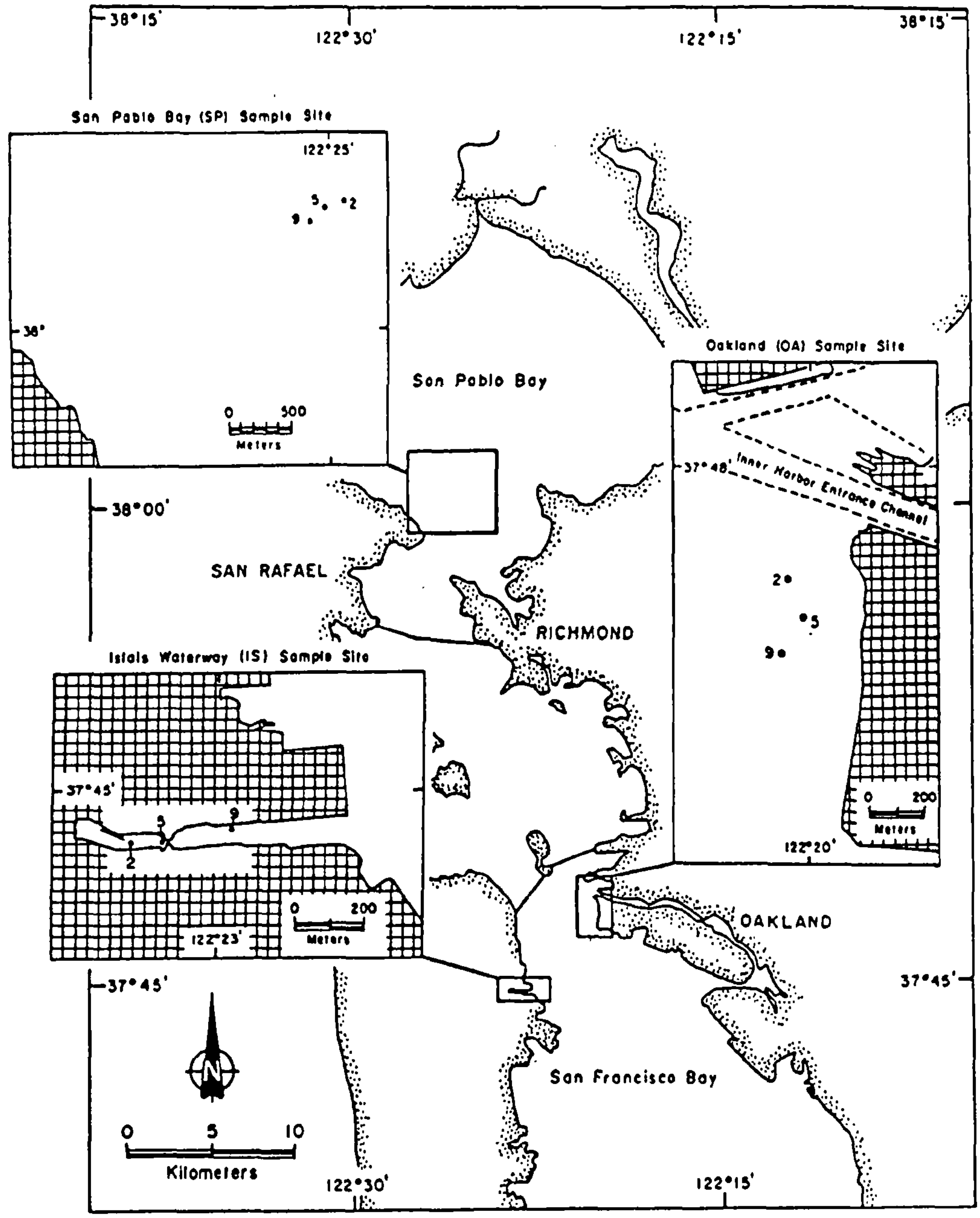

Figure 2. Locations of stations sampled in San Francisco Bay (Source: Chapman et al. 1986, 1987)

- Store the various kinds of Puget Sound AET generated for different biological effects indicators.

- Compare AET values to survey data, using AET and chemical data chosen by the user.

- Retrieve and display sediment chemistry measurements from stations and dates selected by the user.

Because the 1984 NOAA Status and Trends data, as received, did not include brief station identifiers, all identifiers used in the system were artificially generated. These identifiers were based on the geographic basin code (also synthesized), with a unique digit appended to distinguish stations. None of the chemical data were subjected to an independent quality assurance review specifically for this study.

When performing comparisons to AET values, each chemical at each station must be represented by a single number. Therefore any laboratory replicates or field replicates were averaged. Laboratory replicates were averaged first, so that field samples with different numbers of laboratory replicates were given equal weight. Any field replicates at a particular station were weighted equally.

DATA ANALYSIS

The following analyses were performed using chemical concentration data in sediments from coastal areas of the United States:

- Identification of stations exceeding specified AET values for four kinds of biological indicators

- Analyses of trends among stations, geographic regions, and predicted biological effects for stations that exceeded AET

- Interpretation of anomalous results and an assessment of which AET for a range of biological indicators appear to be most sensitive and least sensitive in identifying problem sediments.

Predictions of adverse biological effects were based on available chemical data and Puget Sound AET. These data included 9 metals and metalloids and 18 neutral organic compounds (i.e., PAH, PCBs, and miscellaneous chlorinated compounds). No sediment data were available for acid- or base- extractable organic compounds (e.g., phenol, N-nitrosodiphenylamine) because only neutral organic compounds were analyzed in the NOAA and SCCWRP studies. Data for chromium, nickel, selenium, and thallium (all EPA priority pollutants) were not included in the prediction of biological effects. These metals are predominantly naturally-occurring in Puget Sound. Preliminary AET have been established for chromium and nickel, but these AET will likely be modified after recommended chemical and biological data from a broader range of samples has been incorporated in the Puget Sound database.

In the following sections, results are summarized for comparisons of chemical concentrations to AET. The geographic distribution of predicted adverse effects is presented, followed by a comparison of predicted effects with available biological data. The most extensive biological data sets (outside Puget Sound) were collected in NOAA and SCCWRP studies conducted in California.

DISTRIBUTION OF PREDICTED EFFECTS

The broadest perspective of the national data set was achieved by grouping results on a regional scale (Figure 3). From this perspective, the highest level of chemical contamination and predicted biological effects was encountered in the Northeast Region. At least one chemical exceeded at least one of four kinds of AET (see Appendix Table A-1) at over 70 percent of the stations in that area. Five or more chemicals exceeded their AET at over 33 percent of the stations in the Northeast Region. Throughout the remainder of the U.S., five or more chemicals exceeded their AET only at stations in the Southwest Region and, in that instance, only at 1 of the 32 stations sampled (3 percent).

Results of the regional analysis suggest that the lowest level of chemical contamination and predicted biological effects was encountered in the Gulf Region. Single chemicals exceeded their respective AET at less than 25 percent of the stations in that area, and no more than four chemicals exceeded their AET at any one station. The results for the Northwest/Alaska, Southwest, and Southeast Regions were similar to one another and intermediate in magnitude to the levels observed in the Northeast and Gulf Regions.

An evaluation of which kinds of AET (i.e., Microtox AET, benthic AET, oyster larvae bioassay AET, or amphipod bioassay AET) were exceeded at each station sampled during the NOAA Status and Trends program is presented in Figure 4. The highest percentage of stations at which all four kinds of AET were exceeded was in the Northeast Region (i.e., 63 percent). By contrast, the corresponding percentages in the remaining regions ranged from 0 to 13 percent. Hence, the Northeast Region is distinguished as having the highest percentage of stations at which at least one AET is exceeded (Figure 3), the highest percentage of stations at which multiple chemicals exceed AET (Figure 3), and the highest percentage of stations at which all four AET are exceeded (Figure 4).

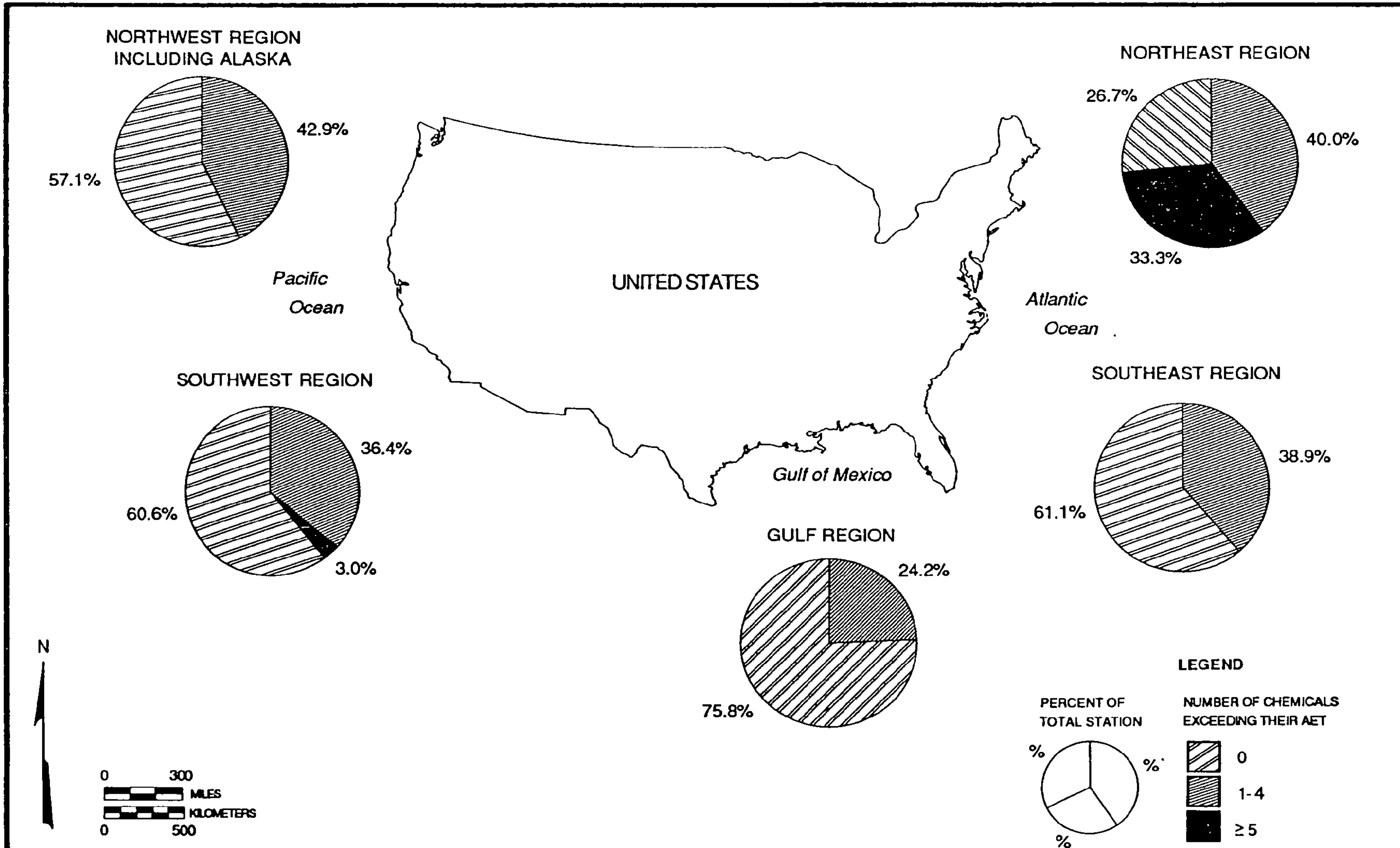

Figure 3. Summary of stations with predicted biological effects by region

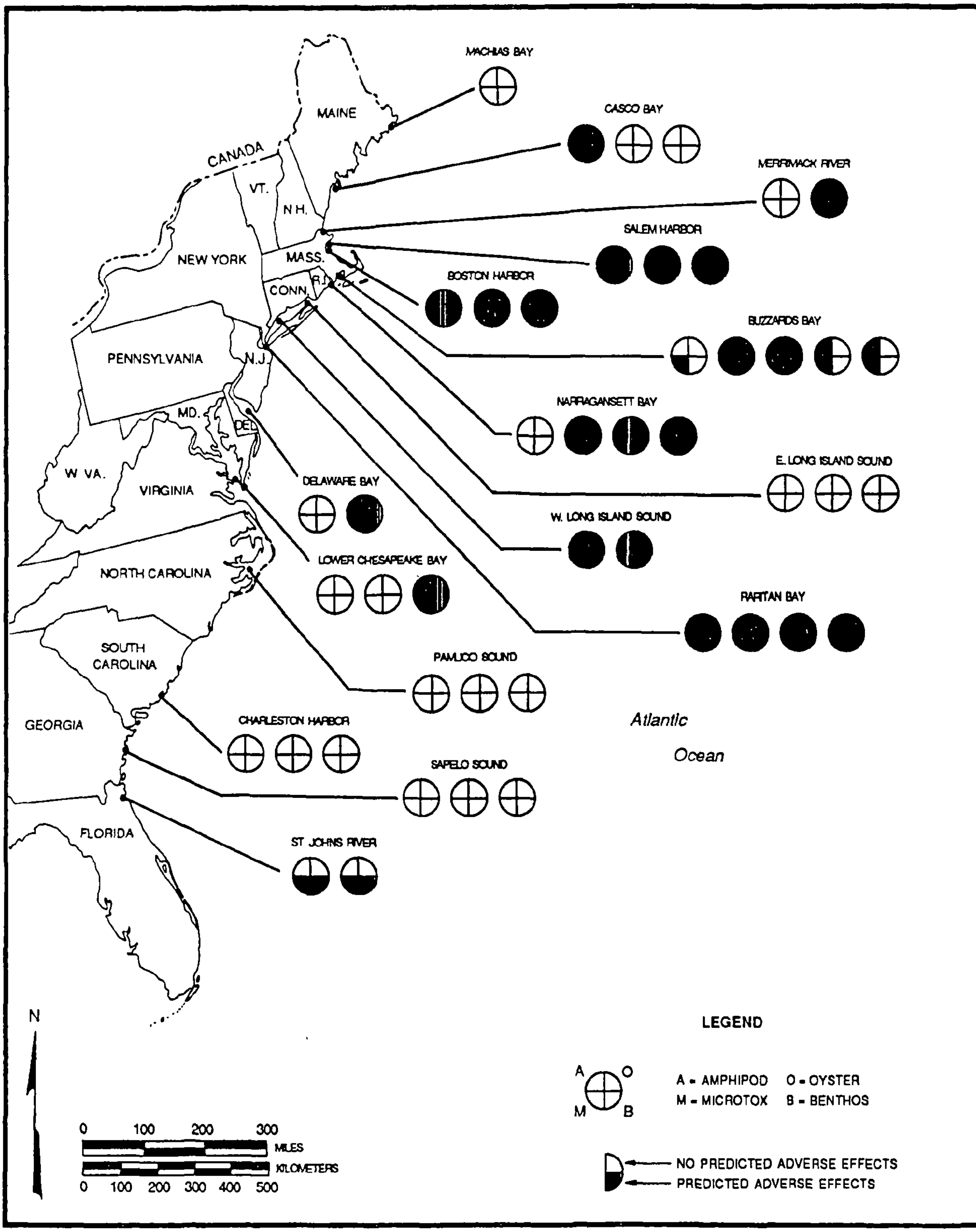

Figure 4. Summary of which kinds of AET were exceeded at NOAA Status and Trends stations

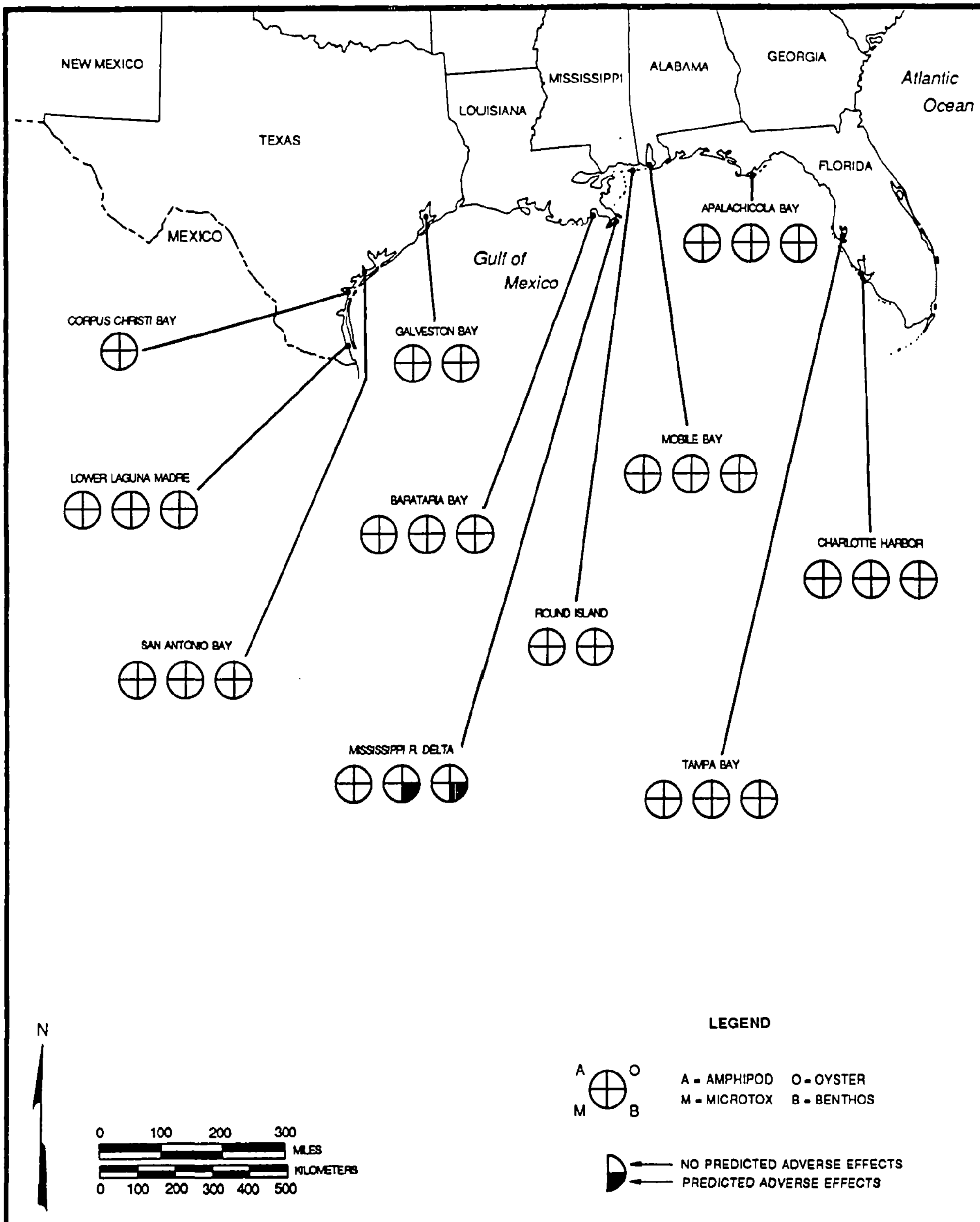

Figure 4. (continued)

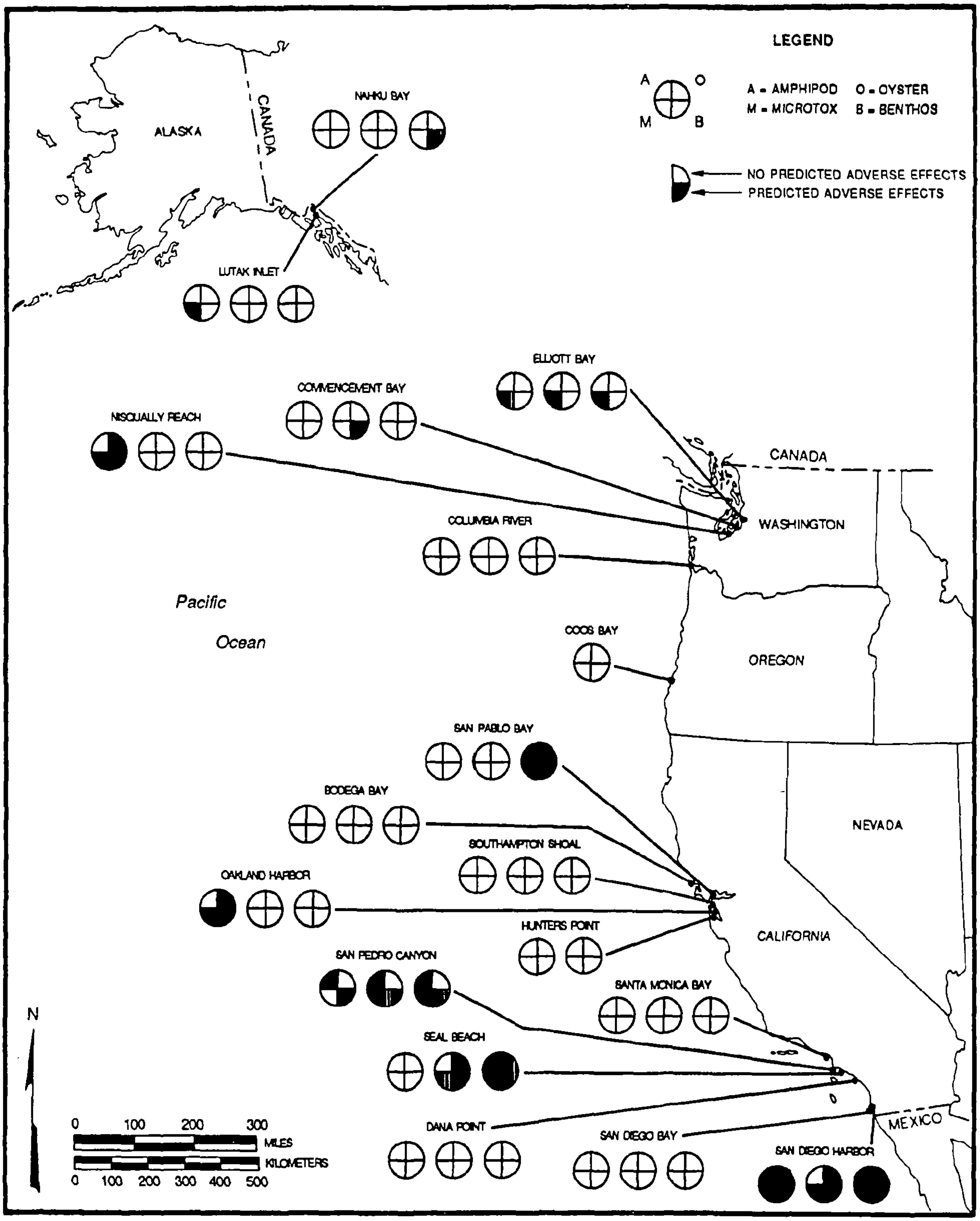

Figure 4. (continued)

AET exceedance was also more consistent among stations in each embayment in the Northeast Region than in the remainder of the U.S. All four kinds of AET were exceeded at all stations sampled in Salem Harbor, Boston Harbor, West Long Island Sound, and Raritan Bay. At no other area in the remainder of the U.S. were all four kinds of AET exceeded.

Based on the entire data set, the kind of AET exceeded most frequently was the Microtox AET (84 cases). However, the benthic AET was exceeded almost as often (77 cases). The amphipod and oyster AET were exceeded less frequently (41 and 51 cases, respectively).

With respect to chemicals, 1-methylphenanthrene was the most frequently exceeded AET (82 cases for all four AET). The exceedance rate for 1-methylphenanthrene was similar (20 - 22 cases) for each individual AET. The high exceedance rate for 1-methylphenanthrene reflects the relatively low AET for this compound (310-370 ug/kg dry weight) when compared with non-alkylated PAH (e.g., phenanthrene). Alkylated PAH such as 1-methylphenanthrene are typically found in highest abundance relative to non-alkylated PAH in fuel oils.

Concentrations of mercury, PCBs, p,p'-DDD and p,p'-DDE also frequently exceeded selected AET (>10 cases for all AET). In contrast to 1-methylphenanthrene, these chemicals displayed distinct differences in the exceedances of individual AET (Table 2). These differences suggest differential toxicity of the chemicals for the four indicators. For example, PCBs exceeded the Microtox AET at 29 stations, while the other PCB AET were exceeded at only one station each. These results suggest a relatively high sensitivity of the Microtox bioassay to PCBs (AET of 130 ug/kg dry weight). Alternatively, amphipods were relatively insensitive to PCBs, with an AET of 2,500 ug/kg dry weight. Concentrations of most of the remaining chemicals either never exceeded AET or exceeded AET at <5 stations.

Exceedances of AET by 1-methylphenanthrene concentrations in sediments were confined to the Northeast region in embayments between Casco Bay and lower Chesapeake Bay. Sediment concentrations of PCBs and mercury that exceeded AET were much more widespread. PCBs exceeded the amphipod,

TABLE 2. SUMMARY OF CHEMICALS THAT EXCEEDED THEIR AET AT NOAA NATIONAL STATUS AND TRENDS STATIONS

Chemical[a]	Number of Stations Where AET Were Exceeded Amphipod	Oyster	Microtox	Benthic	TOTAL
1-Methylphenanthrene	22	20	20	20	82
Mercury	4	19	23	12	58
PCBs	1	1	29	1	32
p,p'-DDD	1	[b]	[b]	14	15
p,p'-DDE	4	[b]	[b]	9	13
Zinc	0	0	0	8	8
Silver	[b]	[b]	[b]	7	7
Anthracene	1	2	2	1	6
p,p'-DDT	3	1	0	0	4
2-Methylnaphthalene	1	1	1	1	4
Arsenic	1	1	1	1	4
Biphenyl	1	1	1	1	4
Naphthalene	1	1	1	1	4
Pyrene	0	2	2	[b]	4
Cadmium	1	0	1	1	3
Fluoranthene	0	1	2	0	3
Phenanthrene	0	1	1	0	2
TOTAL	41	51	84	77	

[a] The following chemicals did not exceed any kind of AET: acenaphthene, fluorene, benzo(a)anthracene, chrysene, benzo(a)pyrene, dibenzo(a,h)anthracene, hexachlorobenzene, copper, and lead.

[b] The indicated AET is not yet available for this chemical.

oyster, and benthic AET only in Boston Harbor. However, the Microtox AET for PCBs was exceeded in six northeast embayments, the St. Johns River (Florida), San Diego Harbor and San Pedro Canyon (California), and the Nisqually Reach in Puget Sound. Mercury displayed a similar pattern, with AET exceedances in several northeast embayments, several areas in California, the Nisqually Reach, and Lutak Bay in Alaska.

Because of the high frequency of AET exceedances by 1-methylphenanthrene, changes were examined in the classification of stations resulting from ignoring adverse effects predicted for this chemical. By ignoring these potential effects, five stations along the east coast were no longer predicted to have adverse effects by any of the four kinds of AET. A reduction in predicted effects would occur (i.e., fewer of the four kinds of AET would be exceeded by any chemical) at 13 additional stations. All Salem Harbor, Boston Harbor, and Raritan Bay stations were still predicted to be impacted by at least three of the four kinds of AET. No changes in the classification of stations along the other U.S. coasts resulted from ignoring predictions based on 1-methylphenanthrene. The ratio of 1-methylphenanthrene concentrations to those of other hydrocarbons (e.g., phenanthrene) is substantially higher in the Northeast Region compared to data for all of the other regions of the country and may partly explain why 1-methylphenanthrene concentrations exceeded AET so frequently in that area.

The patterns of AET exceedance are examined in greater detail in Figure 5 for those areas in which one or more chemicals exceeded their AET at one or more stations. The greatest number of chemicals exceeding a particular kind of AET was found in Boston Harbor, where 20 chemicals exceeded their benthic AET. Large numbers of chemicals (i.e., >10) also exceeded their AET in Salem Harbor and Raritan Bay.

The maximum factor by which an AET was exceeded was found in Boston Harbor (PCBs exceeded their Microtox AET by a factor of approximately 400). Chemicals also exceeded their AET by a large factor (i.e., >10) in Casco Bay, Salem Harbor, West Long Island Sound, and San Pedro Canyon.

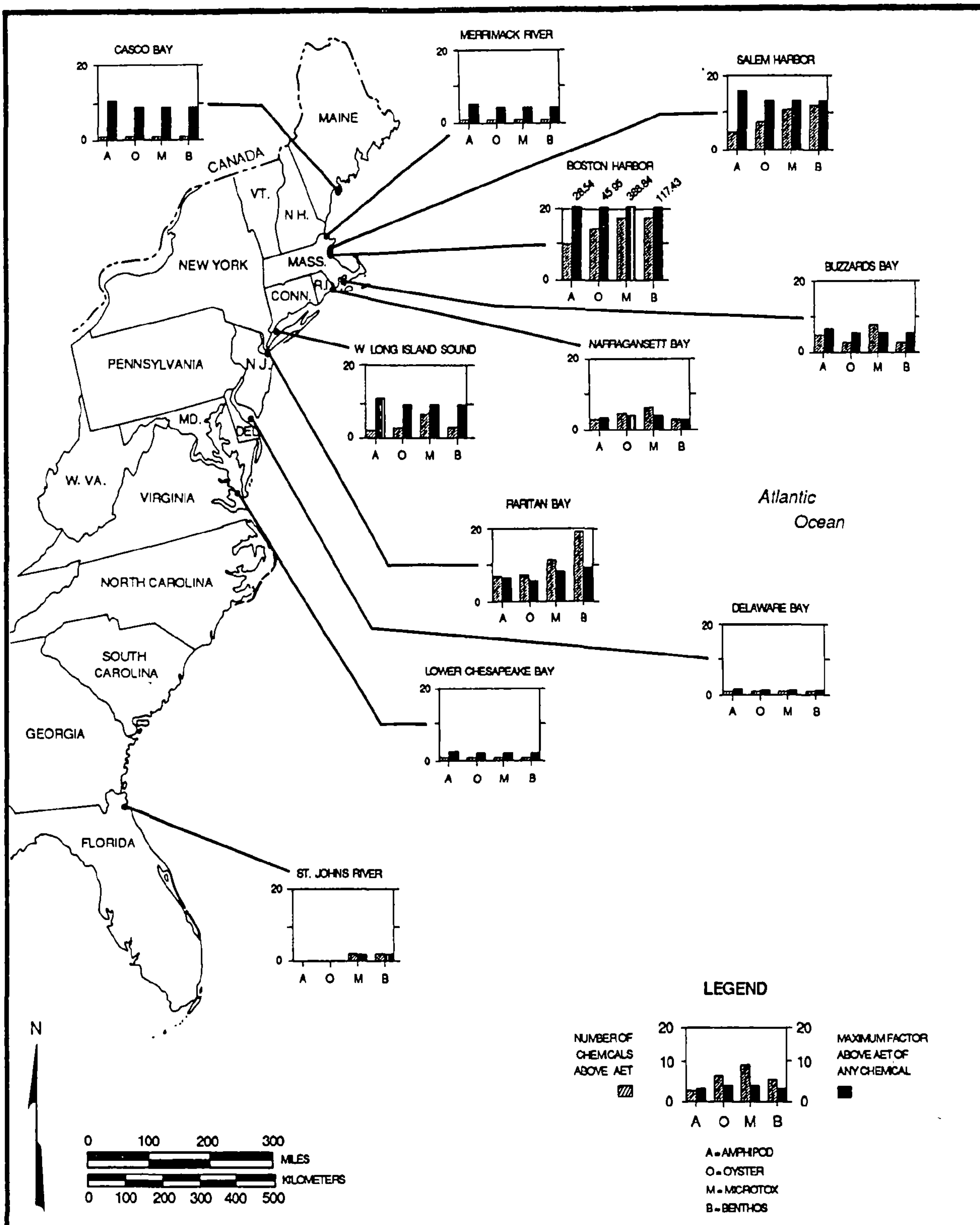

Figure 5. Summary of the number of AET exceeded and the maximum factor of exceedance

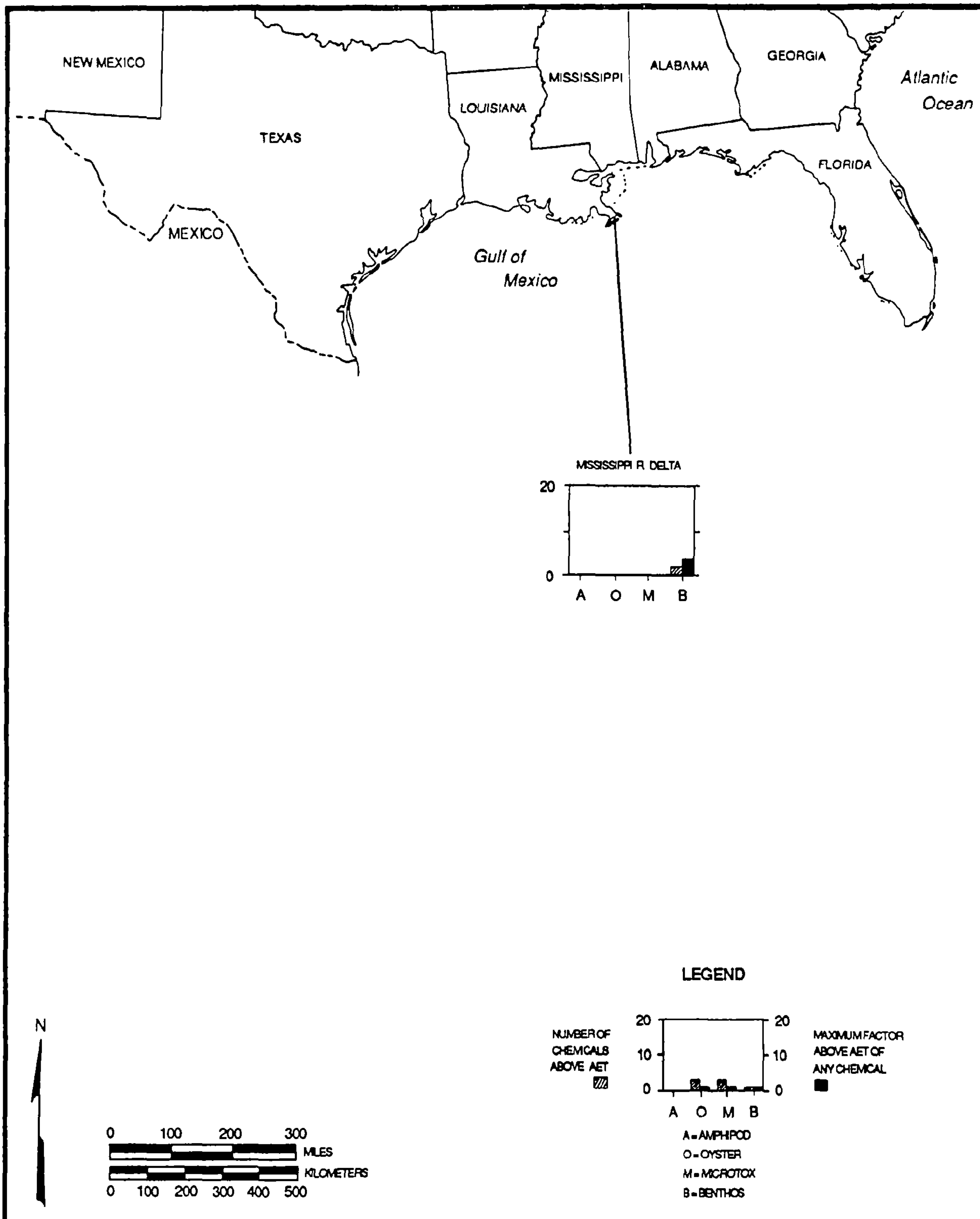

Figure 5. (continued)

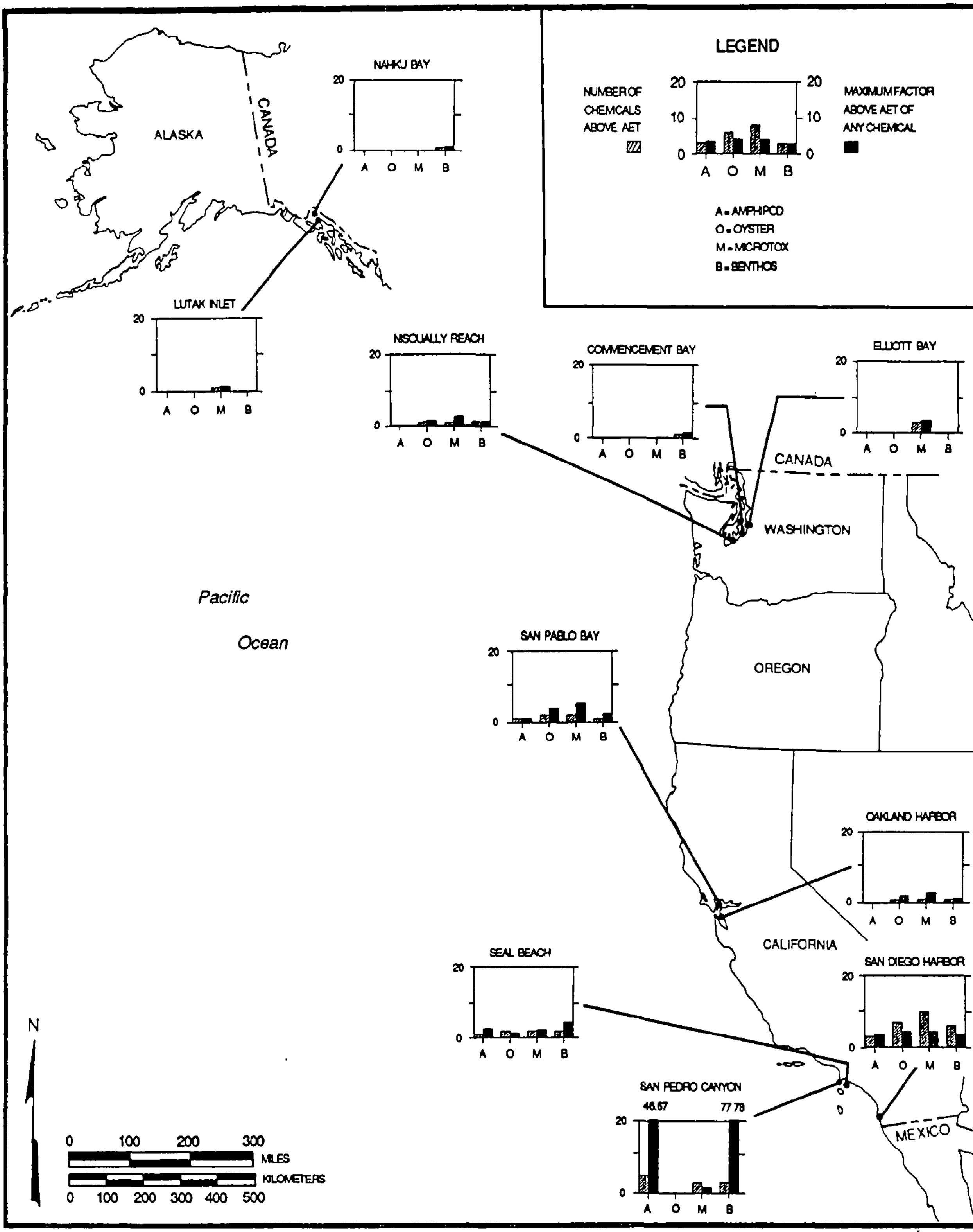

Figure 5. (continued)

The maximum AET exceedance for any chemical within a major chemical group is presented in Figure 6 and Table 3 for each kind of AET. AET were exceeded by metals over the widest area of the U.S. By contrast, AET exceedance by a chemical within the LPAH group (frequently 1-methylphenanthrene) was generally confined to the Northeast and Southeast Regions. Chemicals within the HPAH group exceeded their AET only in Salem Harbor.

Overall AET exceedance was greatest in the Northeast Region, where AET were exceeded in four of the five chemical groups in four areas (i.e., Boston Harbor, Salem Harbor, West Long Island Sound, and Raritan Bay). In other regions of the U.S., AET were not exceeded in more than three of the five chemical groups in any area.

Although many chemicals were found to be below their AET (Table 3), potential future problems area (or recently recovering areas) may be identified by establishing a "safety factor" for screening stations. For example, a factor of 0.5 times the AET could be used to identify stations approaching (or recently declining from) the AET. Using such a factor, concentrations of chemicals were near the AET in 22 study areas (Table 3). In five of those areas (i.e., Bodega Bay, Columbia River, Dana Point, Hunters Point, and Mobile Bay) there were no AET exceeded by any chemical.

COMPARISON OF PREDICTED EFFECTS AND OBSERVED EFFECTS

The AET predictions in the previous sections are based on comparisons of chemical data for NOAA stations and AET values developed from chemical-biological data in Puget Sound. In the following sections, predictions using AET are compared with actual biological effects measured by NOAA and in other programs. Measurements of the identical biological effect used to generate the various AET were available in some, but not all, studies. For example, in the NOAA Status and Trends Program, fish pathology data are used as measures of biological effects; no data were available for sediment bioassays or benthic infauna. Benthic infauna data were available in the SCCWRP and San Francisco Bay studies. Bioassay data (amphipod mortality) were available only in the NOAA San Francisco Bay study. The purpose of these comparisons was to

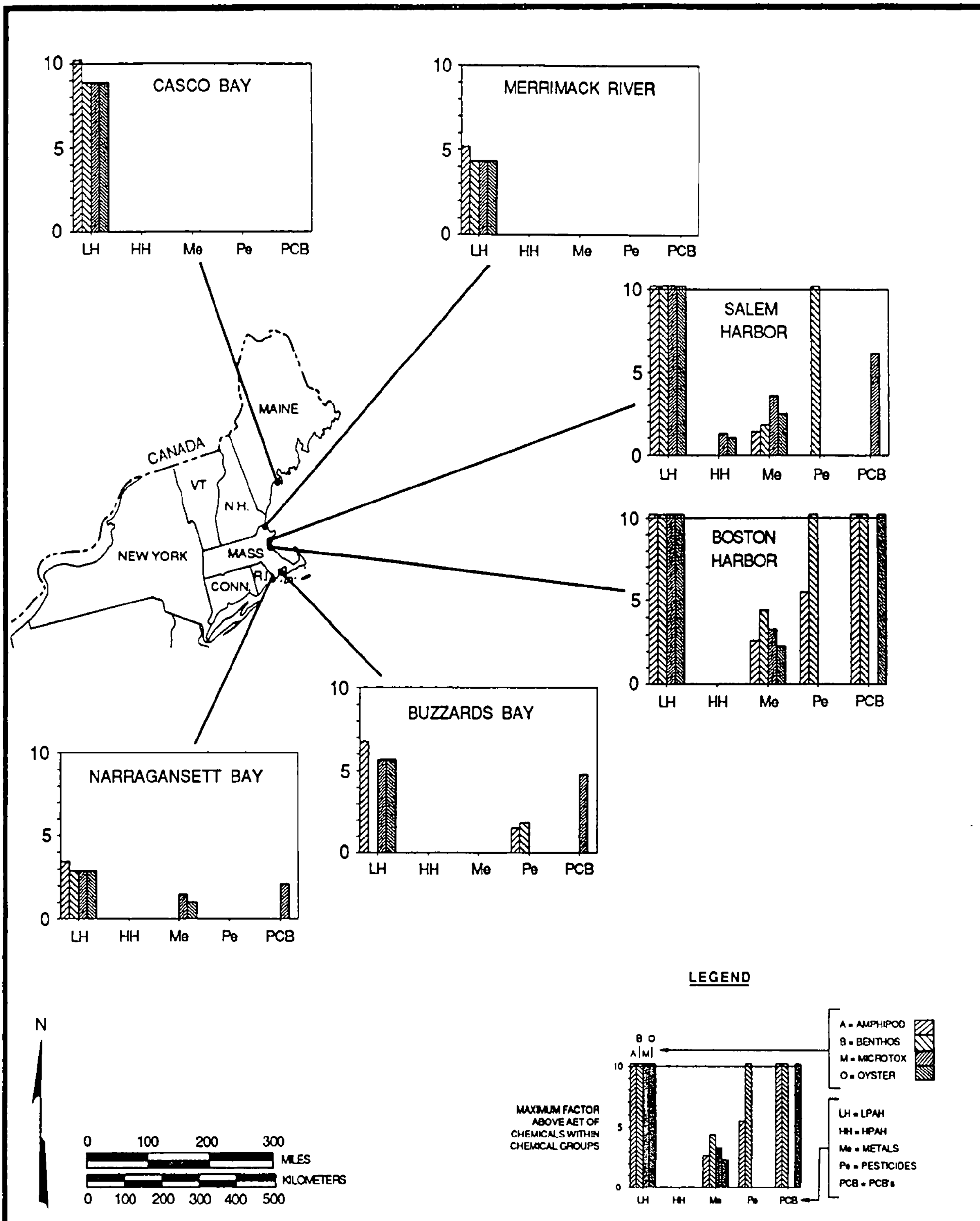

Figure 6. Summary of AET exceedance by chemical group

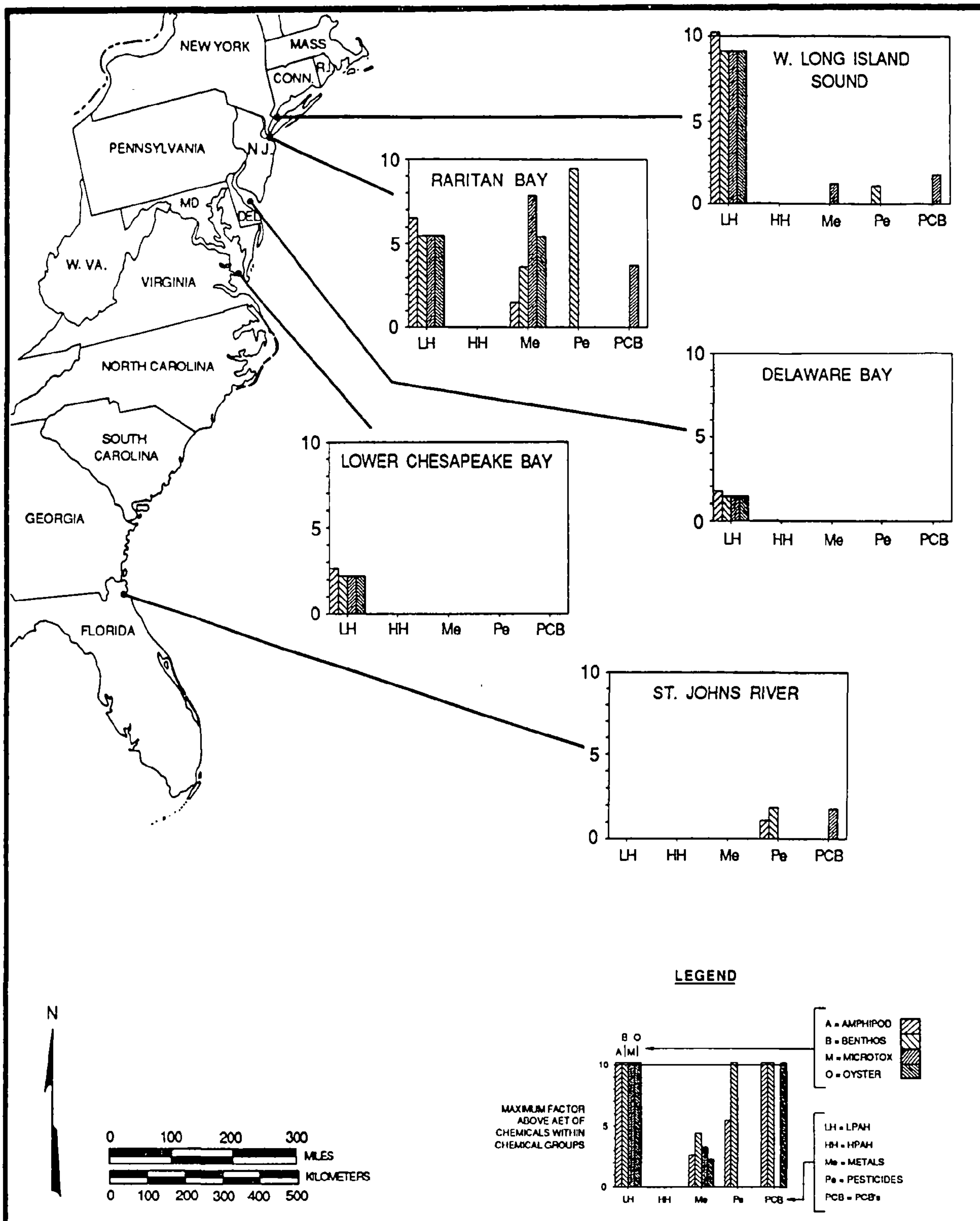

Figure 6. (continued)

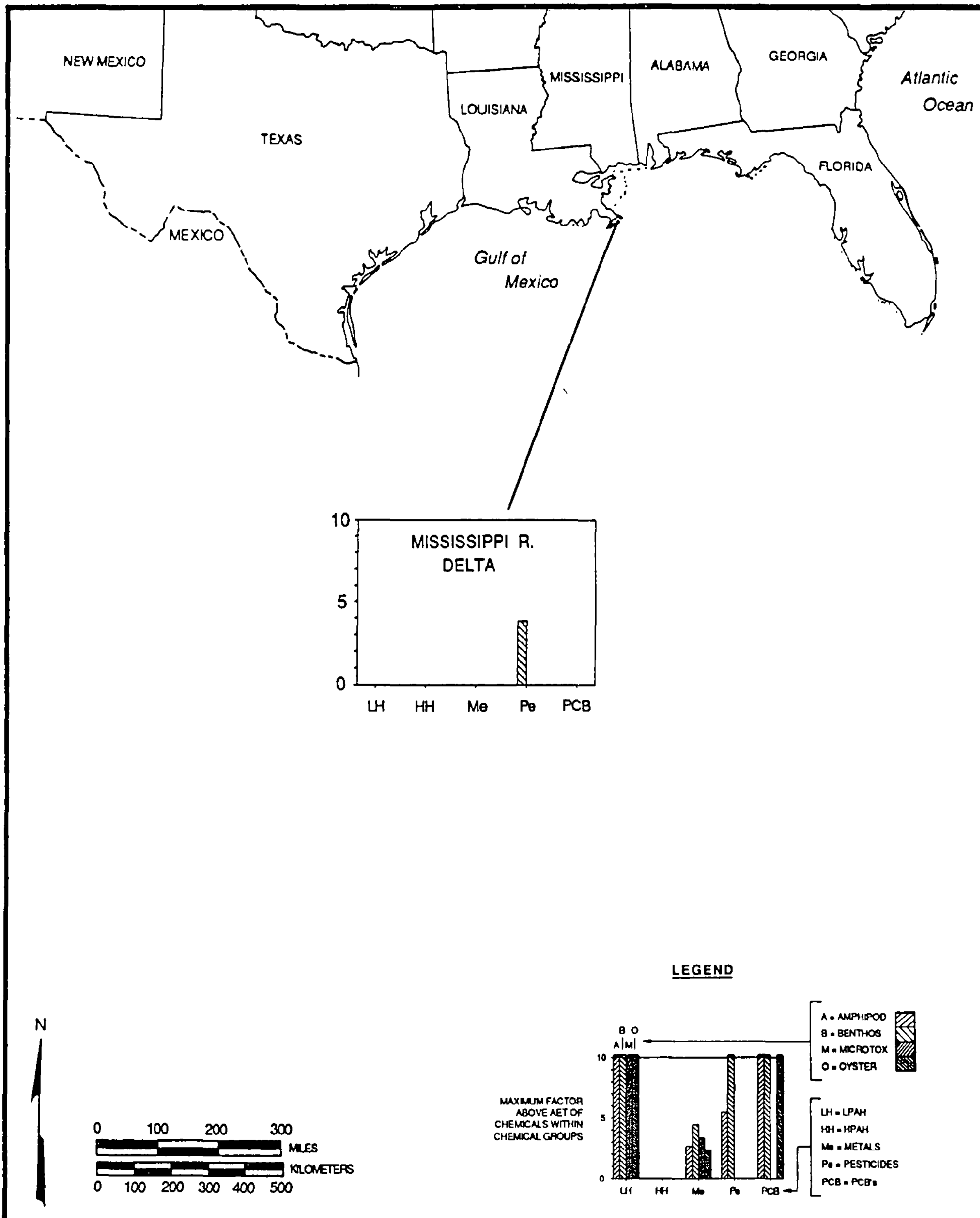

Figure 6. (continued)

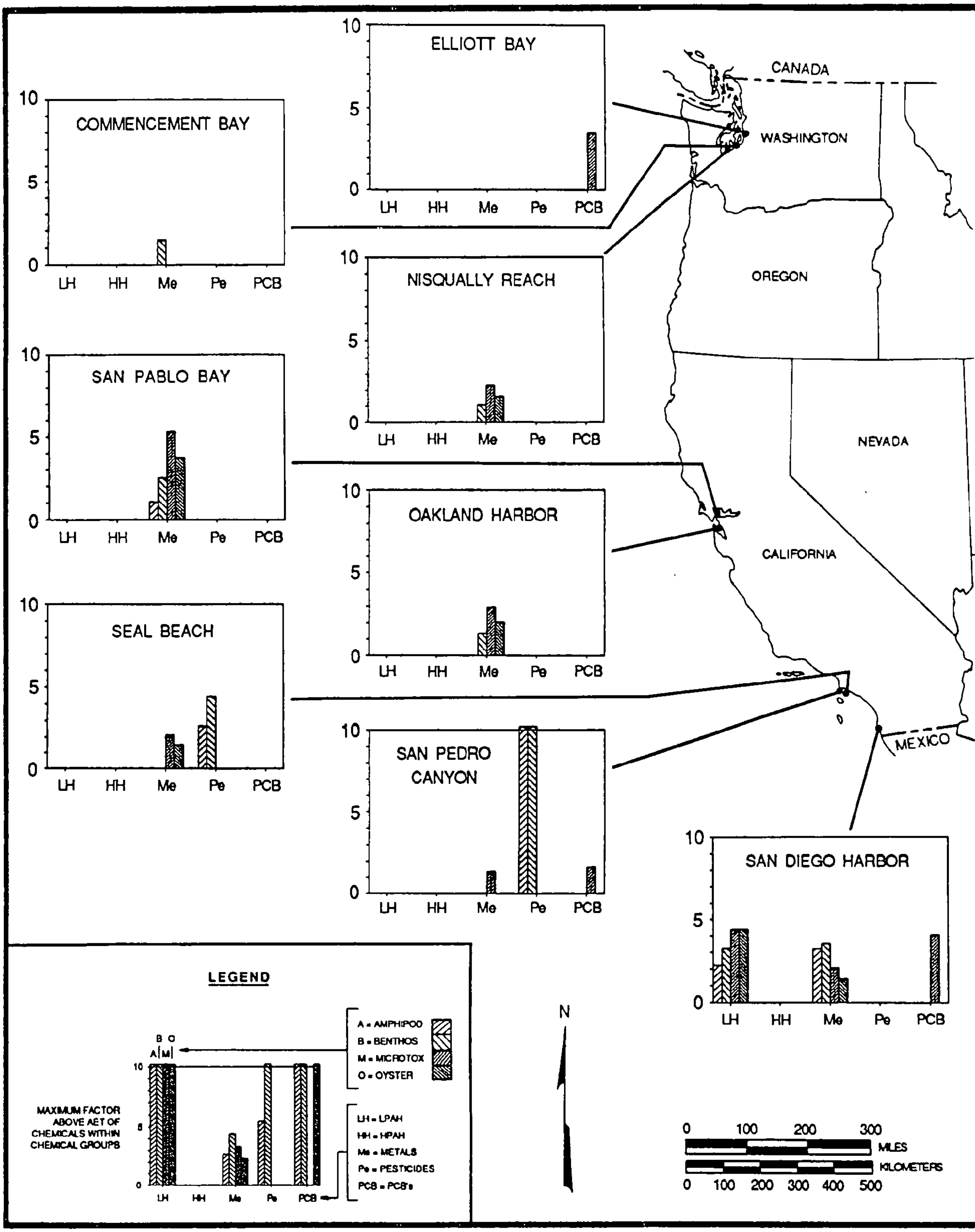

Figure 6. (continued)

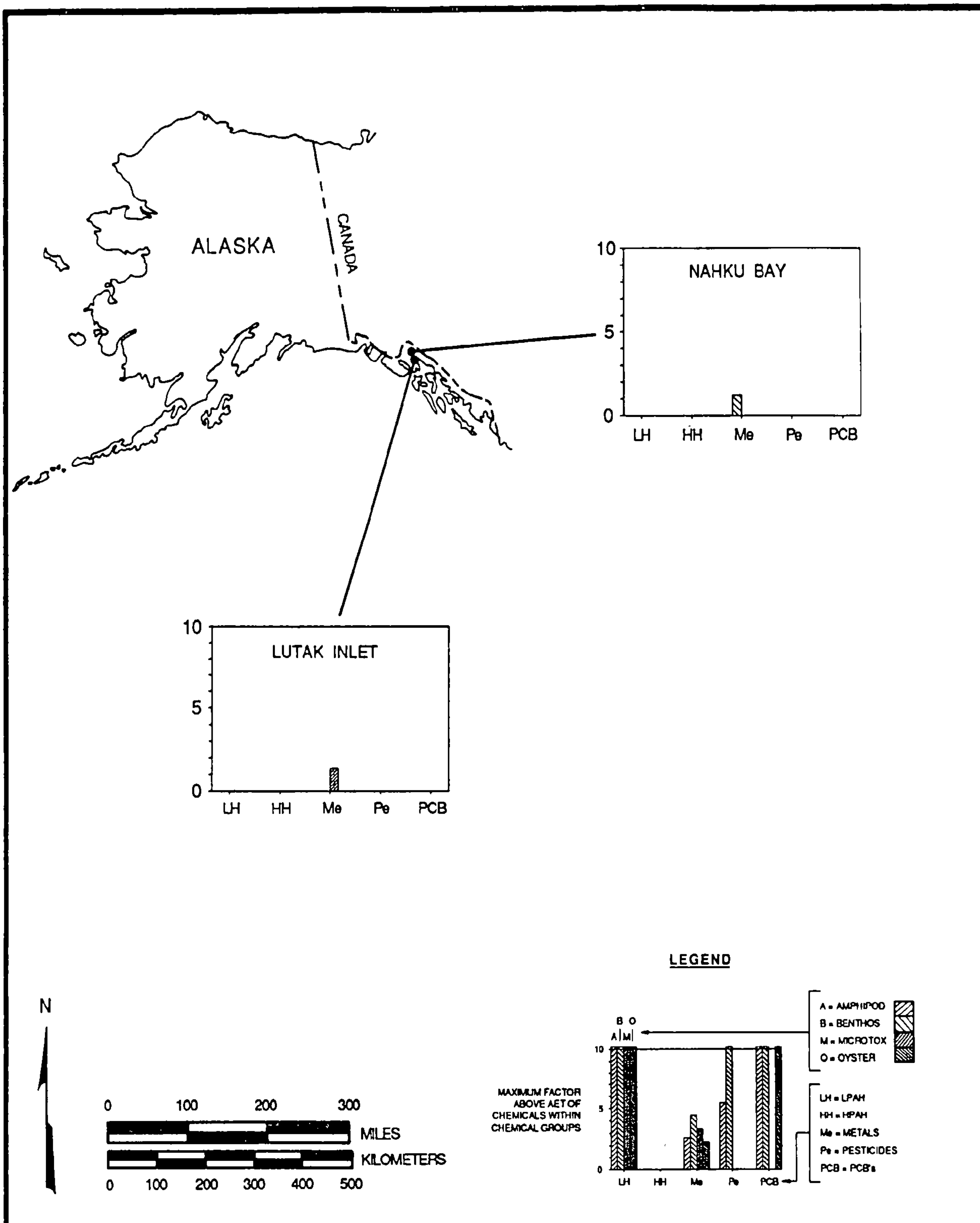

Figure 6. (continued)

TABLE 3. MAXIMUM FACTOR AT WHICH DIFFERENT AET WERE EXCEEDED[a] BY A CHEMICAL IN EACH MAJOR CHEMICAL GROUP

Area	Type of AET[b]	LPAH	HPAH	Metals	Pesticides	PCB
Appalachicola Bay	A	0.05	0.01	0.27	0.53[*]	--[c]
	B	0.04	0.02	0.42	0.02	0.01
	M	0.04	0.03	0.24	--	0.11
	O	0.04	0.03	0.17	--	0.01
Barataria Bay	A	--	--	0.10	--	--
	B	--	0.01	0.32	--	--
	M	--	0.01	0.19	--	--
	O	--	0.01	0.13	--	--
Bodega Bay	A	0.02	--	0.21	--	--
	B	0.02	--	0.34	--	0.01
	M	0.02	--	0.51[*]	--	0.05
	O	0.02	--	0.35	--	0.01
Boston Harbor	A	**28.54**	0.53[*]	**2.66**	**5.46**	**20.22**
	B	**28.54**	0.79[*]	**4.41**	**117.43**	**45.95**
	M	**28.54**	**2.94**	**3.32**	--	**388.84**
	O	**28.54**	**2.00**	**2.31**	--	**45.95**
Buzzards Bay	A	**6.76**	0.11	0.19	1.52	0.25
	B	**5.66**	0.07	0.44	1.83	0.56[*]
	M	**5.66**	0.26	0.51[*]	--	**4.77**
	O	**5.66**	0.21	0.36	--	0.56[*]
Casco Bay	A	**10.58**	0.20	0.13	--	0.04
	B	**8.87**	0.13	0.30	--	0.09
	M	**8.87**	0.46	0.34	--	0.73[*]
	O	**8.87**	0.37	0.24	--	0.09
Charleston Harbor	A	0.06	0.05	0.16	0.04	0.01
	B	0.05	0.03	0.29	0.06	0.01
	M	0.05	0.15	0.16	--	0.10
	O	0.05	0.08	0.11	--	0.01
Charlotte Harbor	A	--	0.01	0.02	--	--
	B	--	--	0.03	--	--
	M	--	0.02	0.07	--	--
	O	--	0.01	0.05	--	--
Columbia River	A	0.02	--	0.16	--	0.01
	B	0.01	--	0.45	--	0.01
	M	0.02	0.01	0.75[*]	--	0.12
	O	0.02	0.01	0.52[*]	--	0.01

TABLE 3. (Continued)

Area	Type of AET	LPAH	HPAH	Metals	Pesticides	PCB
Commencement Bay	A	0.20	0.02	0.27	0.13	0.02
	B	0.17	0.02	**1.45**	--	0.04
	M	0.17	0.10	0.14	--	0.38
	O	0.17	0.06	0.14	--	0.04
Coos Bay	A	0.05	0.11	0.12	0.03	0.01
	B	0.06	0.07	0.25	0.06	0.02
	M	0.13	0.21	0.40	--	0.17
	O	0.13	0.16	0.28	--	0.02
Corpus Christi Bay	A	--	--	0.13	--	--
	B	--	--	0.45	--	--
	M	--	--	0.20	--	--
	O	--	--	0.14	--	--
Dana Point	A	--	--	0.18	0.04	--
	B	0.01	--	0.42	0.07	0.01
	M	0.01	--	0.90*	--	0.08
	O	0.01	--	0.63*	--	0.01
Delaware Bay	A	**1.72**	0.01	0.15	0.09	--
	B	**1.44**	0.01	0.33	0.19	--
	M	**1.44**	0.02	0.24	--	0.04
	O	**1.44**	0.02	0.17	--	--
E. Long Island Sound	A	0.02	0.01	0.10	--	0.01
	B	0.02	--	0.25	--	0.02
	M	0.02	0.02	0.20	--	0.19
	O	0.02	0.02	0.14	--	0.02
Elliott Bay	A	0.23	0.25	0.28	0.15	0.18
	B	0.22	0.15	0.67*	0.11	0.41
	M	0.47	0.62*	0.27	--	**3.49**
	O	0.47	0.37	0.27	--	0.41
Galveston Bay	A	--	0.01	0.08	--	--
	B	--	--	0.23	--	--
	M	--	0.02	0.11	--	--
	O	--	0.01	0.08	--	--
Hunters Point	A	0.14	0.20	0.29	0.26	0.02
	B	0.13	0.12	0.62*	0.06	0.04
	M	0.28	0.39	0.37	--	0.38
	O	0.28	0.31	0.26	--	0.04
Lower Chesapeake Bay	A	**2.63**	--	0.13	0.12	0.04
	B	**2.21**	0.02	0.33	0.60*	0.09
	M	**2.21**	0.02	0.29	--	0.74*
	O	**2.21**	0.02	0.20	--	0.09

TABLE 3. (Continued)

Area	Type of AET	LPAH	HPAH	Metals	Pesticides	PCB
Lower Laguna Madre	A	--	--	0.14	--	--
	B	--	--	0.22	--	--
	M	--	--	0.10	--	--
	O	--	--	0.07	--	--
Lutak Inlet	A	--	--	0.22	--	0.01
	B	--	--	0.74*	--	0.01
	M	--	--	**1.38**	--	0.12
	O	--	--	0.96*	--	0.01
MACH	A	--	--	0.09	--	--
	B	--	--	0.21	--	--
	M	--	--	0.03	--	--
	O	--	--	0.03	--	--
Merrimack River	A	**5.16**	0.23	0.07	--	0.03
	B	**4.32**	0.15	0.14	--	0.07
	M	**4.32**	0.53*	0.15	--	0.63*
	O	**4.32**	0.43	0.10	--	0.07
Mississippi River Delta	A	0.04	0.03	0.15	0.18	0.03
	B	0.04	0.02	0.41	**3.81**	0.06
	M	0.04	0.09	0.19	--	0.52*
	O	0.04	0.05	0.13	--	0.06
Mobile Bay	A	0.02	0.01	0.24	0.11	--
	B	0.02	--	0.66*	0.19	--
	M	0.02	0.02	0.32	--	--
	O	0.02	0.01	0.22	--	--
Nahku Bay	A	--	0.01	0.24	--	0.01
	B	--	0.01	**1.20**	--	0.01
	M	--	0.05	0.99*	--	0.10
	O	--	0.03	0.69*	--	0.01
Narragansett Bay	A	**3.41**	0.12	0.29	0.22	0.11
	B	**2.86**	0.07	0.75*	0.78*	0.25
	M	**2.86**	0.25	**1.46**	--	**2.09**
	O	**2.86**	0.19	**1.02**	--	0.25
Nisqually Reach	A	--	--	0.45	--	--
	B	--	--	**1.07**	--	0.01
	M	--	--	**2.30**	--	0.06
	O	--	--	**1.60**	--	0.01
Oakland Harbor	A	0.04	0.10	0.57*	0.07	0.03
	B	0.05	0.07	**1.36**	0.22	0.06
	M	0.12	0.21	**2.93**	--	0.54*
	O	0.12	0.15	**2.03**	--	0.06

TABLE 3. (Continued)

Area	Type of AET	LPAH	HPAH	Metals	Pesticides	PCB
Pamlico Sound	A	--	0.05	0.16	0.09	--
	B	--	0.02	0.49	0.15	--
	M	--	0.08	0.08	--	--
	O	--	0.03	0.08	--	--
Raritan Bay	A	**6.55**	0.22	**1.53**	0.73*	0.19
	B	**5.49**	0.09	**3.65**	**9.47**	0.44
	M	**5.49**	0.45	**7.83**	--	**3.72**
	O	**5.49**	0.33	**5.44**	--	0.44
Round Island	A	--	0.01	0.14	0.01	--
	B	--	0.01	0.46	0.01	--
	M	--	0.03	0.22	--	--
	O	--	0.01	0.15	--	--
Salem Harbor	A	**15.99**	0.48	**1.41**	0.62*	0.32
	B	**13.40**	0.70*	**1.80**	**11.92**	0.73*
	M	**13.40**	**1.28**	**3.59**	--	**6.19**
	O	**13.40**	**1.01**	**2.49**	--	0.73*
San Antonio Bay	A	0.06	--	0.06	--	--
	B	0.05	--	0.20	--	--
	M	0.05	--	0.04	--	--
	O	0.06	--	0.03	--	--
Sapelo Sound	A	--	--	0.13	--	--
	B	--	--	0.19	--	--
	M	--	0.01	0.11	--	--
	O	--	--	0.07	--	--
San Diego Bay	A	--	--	0.17	--	--
	B	--	--	0.29	--	0.01
	M	--	--	0.17	--	0.08
	O	--	--	0.12	--	0.01
San Diego Harbor	A	**2.21**	0.25	**3.19**	0.33	0.21
	B	**3.23**	0.33	**3.49**	0.56*	0.48
	M	**4.38**	0.52*	**1.76**	--	**4.02**
	O	**4.38**	0.38	**1.41**	--	0.48
Seal Beach	A	0.02	0.02	0.41	**2.67**	0.03
	B	0.02	0.01	0.99*	**4.44**	0.06
	M	0.03	0.06	**2.12**	--	0.49
	O	0.03	0.03	**1.47**	--	0.06
Santa Monica Bay	A	0.01	--	0.15	0.27	0.01
	B	0.01	0.01	0.25	0.44	0.02
	M	0.03	0.02	0.07	--	0.14
	O	0.03	0.02	0.05	--	0.02

TABLE 3. (Continued)

Area	Type of AET	LPAH	HPAH	Metals	Pesticides	PCB
San Pablo Bay	A	--	0.01	**1.03**	0.02	--
	B	--	0.01	**2.47**	0.03	0.01
	M	0.01	0.02	**5.29**	--	0.08
	O	0.01	0.02	**3.68**	--	0.01
San Pedro Canyon	A	0.02	0.03	0.27	**46.67**	0.09
	B	0.02	0.02	0.64*	**77.78**	0.19
	M	0.03	0.05	**1.37**	--	**1.64**
	O	0.03	0.04	0.95*	--	0.19
Southampton Shoal	A	0.11	0.10	0.17	--	0.01
	B	0.19	0.11	0.33	--	0.02
	M	0.41	0.36	0.06	--	0.15
	O	0.41	0.25	0.06	--	0.02
St. Johns River	A	0.31	0.13	0.15	0.10	0.09
	B	0.31	0.11	0.49	**1.84**	0.21
	M	0.33	0.41	0.28	--	**1.79**
	O	0.33	0.28	0.19	--	0.21
Tampa Bay	A	--	--	0.03	--	--
	B	--	--	0.04	--	--
	M	--	0.01	0.1	--	--
	O	--	0.01	0.07	--	--
W. Long Island Sound	A	**10.88**	0.33	0.29	0.08	0.09
	B	**9.11**	0.25	0.98*	**1.13**	0.22
	M	**9.11**	0.71*	**1.27**	--	**1.82**
	O	**9.11**	0.56*	0.88*	--	0.22

[a] Factors ≤1 but ≥0.5 are identified by an asterisk.

[b] A = Amphipod mortality bioassay
O = Oyster larvae abnormality bioassay
M = Microtox bioassay
B = Benthic effects (in situ)

[c] No data were reported

the degree of correspondence between predicted and observed biological effects, even when the kinds of effects differed.

NOAA Status and Trends Data Set

Results of the fish pathology comparisons are presented in detail in Tables B1-B7 (Appendix B). Overall, significant elevations ($P \leq 0.05$) in the prevalences of liver lesions were found in 9 areas, whereas significantly elevated ($P \leq 0.05$) prevalences of kidney lesions were found in 23 areas.

A summary of the fish pathology results in relation to AET exceedance is presented in Table 4. At the 19 study areas where an AET was exceeded at one or more stations (Table 4), elevated prevalences of liver lesions were found at 5 stations (26 percent) and elevated prevalences of kidney lesions were found at 11 stations (58 percent).

Where an AET was not exceeded at any station, elevated prevalences of liver lesions were found at 3 of the 19 areas (16 percent) sampled during the NOAA Status and Trends survey. Elevated prevalences of kidney lesions were found at 8 of those 19 areas (42 percent). Conversely, elevated prevalences of liver lesions were not found at 14 areas where one or more AET were exceeded. Elevated prevalences of kidney lesions were not found at 8 areas where one or more AET were exceeded.

These data indicate that the exceedance of bioassay or benthic infauna AET at individual stations is not well correlated with the prevalence of liver or kidney lesions in the various study areas. However, elevated prevalences of kidney lesions were found at 100 percent (10 of 10) of the embayments at which AET were exceeded at multiple stations within individual embayments. These latter results suggest a good correspondence between kidney lesions and widespread contaminant effects in sediments. From this perspective, the exceedance of AET over a wide area in an embayment may be an efficient predictor of kidney lesions in fish. Additional data are required to determine whether kidney lesions are a more sensitive indicator of contamination (and therefore also occur in areas where AET are only sometimes exceeded), whether

TABLE 4. SUMMARY OF FISH PATHOLOGY AT LOCATIONS WHERE ONE OR MORE CHEMICALS EXCEEDED AN AET

Area[a]	No. Stations with an AET Exceeded	Significant Lesion Prevalence Liver[b]	Significant Lesion Prevalence Kidney[c]
Casco Bay	1		
Merrimack River	1		
Salem Harbor	3		X
Boston Harbor	3	X	X
Buzzards Bay	5		X
Narragansett Bay	3		X
W. Long Island Sound	2		X
Lower Chesapeake Bay	1		
St. Johns River	2		X
Mississippi River Delta	2	X	X
Nahku Bay	1	X	
Lutak Inlet	1		
Elliott Bay	3	X	X
Commencement Bay	1	X	X
Nisqually Reach	1		
San Pablo Bay	1		
Oakland Harbor	1		
San Pedro Canyon	3		X
Seal Beach	2		X

[a] Although Raritan Bay, Delaware Bay, and San Diego Harbor each had one or more stations at which an AET was exceeded, fish pathology determinations were not made for those areas.

[b] 3 of 19 areas (16 percent) without an AET exceeded had significantly elevated prevalences of liver lesions.

[c] 8 of 19 areas (42 percent) without an AET exceeded had significantly elevated prevalences of kidney lesions.

factors unrelated to sediment contamination influence the development of kidney lesions in less contaminated areas, or whether chemicals not measured in the Status and Trends Program could potentially account for the complete distribution of lesions.

Comparisons of spore densities of Clostridium perfringens with patterns of AET exceedance are presented in Table 5. In general, spore densities increased as an increasing number of chemicals exceeded their AET at each station. An analysis of variance (ANOVA) conducted on the log-transformed densities showed significant ($P \leq 0.05$)among the five groups of values. A posteriori comparisons showed that the groups with 0 and ≥ 5 chemicals exceeding their AET were significantly different ($P \leq 0.05$) from each other and from the other three groups. The groups with 1, 2, and 3-4 chemicals exceeding their AET were not significantly different ($P \geq 0.05$) from each other.

These patterns indicate that changes in the densities of C. perfringens were strongly associated with low, moderate, and high levels of biological effects as predicted by the number of chemicals exceeding their AET. The results do not necessarily imply that the contaminants exceeding AET are sewage-derived because there was a poor correlation between the densities of C. perfringens spores and concentrations of these chemicals at individual stations. However, the results suggest that biological effects predicted from the NOAA Status and Trends chemical data are most often associated with contamination from densely populated urban areas (which also discharge large amounts of sewage).

Southern California Data Set

One or more chemicals exceeded their AET at 13 of the 71 stations (18 percent) sampled by Word and Mearns (1979) along the coast of southern California (Table 6). All of these stations were located in the immediate vicinity of municipal sewage outfalls in Santa Monica Bay (Stations 23-26), off Palos Verdes (Stations 30-36), in San Pedro Bay (Station 45), and off Pt. Loma (Station 69).

TABLE 5. SPORE DENSITIES OF *CLOSTRIDIUM PERFRINGENS* IN RELATION TO AET EXCEEDANCE

Number of Chemicals Exceeding AET	Number of Stations	Spore Density of *Clostridium perfringens* (number/g dry wt)	
		Mean	Confidence Limits (95%)
0	61	445	176 - 714
1	32	1,535	572 - 2,498
2	7	1,514	649 - 2,379
3-4	7	3,779	977 - 6,581
≥5	11	46,259	21,895 -70,623

TABLE 6. SUMMARY OF CHEMICAL CONTAMINATION AND BIOLOGICAL EFFECTS IN SOUTHERN CALIFORNIA[a]

			Biological Effects	
Station[b]	Chemical Exceeding AET	Type of AET Exceeded[c]	Infaunal Index <69[d]	Reduced Echinoderm Abundance[e]
23	Silver	B	X	X
	PCBs	M		
24	Silver	B	X	X
	PCBs	M		
25	Silver	B	X	X
26	PCBs	M	X	X
30	PCBs	M	X	X
31	Silver	B	X	X
	Cadmium	A,O,M,B		
	Zinc	B		
	PCBs	O,M,B		
32	Cadmium	A,O,M,B	X	X
	Copper	B		
	Zinc	B		
	PCBs	A,O,M,B		
33	Silver	B	X	X
	Cadmium	A,O,M,B		
	Copper	O,M,B		
	Zinc	A,B		
	PCBs	A,O,M,B		
34	Silver	B	X	X
	Cadmium	A,O,M,B		
	Copper	O,M,B		
	Lead	M,B		
	Zinc	A,O,M,B		
	PCBs	A,O,M,B		
35	Silver	B	X	X
	Cadmium	A,O,M,B		
	Zinc	B		
	PCBs	O,M,B		

TABLE 6. (Continued)

Station[b]	Chemical Exceeding AET	Type of AET Exceeded[c]	Biological Effects: Infaunal Index <69[d]	Biological Effects: Reduced Echinoderm Abundance[e]
36	PCBs	M		X
45	PCBs	M	X	X
69	PCBs	M		

[a] Data are based on Word and Mearns (1979).

[b] No chemical exceeded an AET at the 58 stations not listed (i.e., of the 71 sampled).

[c] A = Amphipod mortality
O = Oyster larvae abnormality
M= Microtox
B = Benthic effects.

[d] 12 of the 58 stations (21 percent) not listed had Infaunal Index values <69.

[e] 8 of the 58 stations (14 percent) not listed had reduced echinoderm abundances.

Analyses of Infaunal Indices and echinoderm abundances indicate three general areas of biological effects: Santa Monica Bay (Stations 23-29), Palos Verdes Shelf (Stations 30-35), and San Pedro Bay (Stations 41-48). Biological effects were found at all but 1 (Station 69) of the 13 sites at which an AET was exceeded. The Infaunal Index was reduced below a value of 69 at 11 of the 13 sites (84 percent), whereas the abundance of echinoderms was reduced below 9 individuals/m^2 at 12 of the 13 sites (92 percent). All of the stations at which two or more kinds of AET were exceeded for one or more chemicals displayed biological effects as evidenced by both low Infaunal Indices and low echinoderm abundances. Moreover, benthic effects were always observed at stations where the benthic AET was exceeded for one or more chemicals. Station 69 was the only site in the southern California data set that exceeded an AET but did not display biological effects according to the two benthic indicators. It should be noted that the only AET exceeded at Station 69 was the Microtox value for PCBs. As was previously described, the Microtox bioassay appears to be much more sensitive to PCBs than the other biological indicators.

Biological effects were found at 13 of the 58 stations (22 percent) at which no AET was exceeded. The Infaunal Index was reduced at 12 of these stations (21 percent) and echinoderm abundance was reduced at 8 stations (14 percent). These results would be expected because of the relatively few chemicals measured in the southern California data set. For example, two of the sites with low Infaunal Indices were identified by Word and Mearns (1979) as being contaminated by petroleum from natural seeps. These sites could not be identified by AET exceedance because the investigators did not measure hydrocarbon concentrations in the sediments. Most of the remaining sites with biological effects, but without exceedance of AET, were located in San Pedro Bay in the vicinity of the Orange County Sanitation District sewage outfall. The sediments of this area are much less contaminated by PCBs and DDT (the only two organic chemicals measured) than sediments in Santa Monica Bay and the Palos Verdes Shelf. Therefore, it is reasonable to assume that benthic effects were caused by other factors such as organic enrichment or unmeasured organic chemicals.

San Francisco Bay Data Set

One or more chemicals exceeded their AET at two of the nine stations (22 percent; Table 7) sampled by Chapman et al. (1986, 1987) in San Francisco Bay. Both of these stations (IS02, IS05) are located in Islais Waterway. Biological effects were found at both of these stations. Significant amphipod mortality ($P \leq 0.05$) was found only at Station IS02. Significant mussel larvae abnormality ($P \leq 0.05$) and substantial benthic effects were found at both stations.

Biological effects were found at three of the seven stations at which no chemical exceeded its AET. All three biological indicators showed impacts at Station IS09, whereas only the mussel larvae abnormality test showed an impact at Stations OA05 and OA09.

TABLE 7. SUMMARY OF CHEMICAL CONTAMINATION AND BIOLOGICAL EFFECTS IN SAN FRANCISCO BAY[a]

Station	Chemical Exceeding AET	Type of AET Exceeded[b]	Amphipod Mortality	Mussel Larvae Abnormality	Benthic Effects
SP02	None	--			
SP05	None	--			
SP09	None	--			
OA02	None	--			
OA05	None	--		X	
OA09	None	--		X	
IS02	Mercury	M	X	X	X
	Silver	B			
	Zinc	B			
	HPAH	M			
	Anthracene	A,O,M,B			
	Chrysene	M			
	Dibenzo(a,h)-anthracene	O,M			
	Fluoranthene	O,M			
	Pyrene	M			
	PCBs	M			
IS05	Mercury	O,M,B		X	X
	Silver	M			
	Anthracene	A,O,M			
	Chrysene	M			
	Dibenzo(a,h)-anthracene	A,O,M			
	Fluoranthene	O,M			
	Pyrene	M			
	PCBs	M			
IS09	None	--	X	X	X

[a] Data are based on Chapman et al. (1986, 1987).

[b] A = Amphipod mortality
O = Oyster larvae abnormality
M= Microtox
B = Benthic effects.

EVALUATION OF POLICY IMPLICATIONS

The integration of sediment criteria into environmental decision-making processes requires consideration of a wide range of policy issues. These issues derive from the differing emphases of regulatory programs as well as technical considerations. An overview of regulatory applications of sediment criteria has recently been released by the EPA Office of Water Regulations and Standards (Battelle 1987). Examples excerpted from this report of the major legislative authority for and potential application of sediment criteria are provided in Tables 8 and 9 for perspective.

The purpose of the evaluation presented in this section is to examine the implications of applying effects-based criteria as a tool for assessing coastal sediment contamination. In addition, the implications of applying effects-based criteria developed empirically for one region to coastal sediments in other regions of the U.S. are addressed. This evaluation focuses on the following topics:

- Use of effects-based criteria as a tool in managing coastal regions where both nonpoint and point sources may have contributed to toxic buildup in sediments

- Application of effects-based criteria at potential marine Superfund sites

- Apparent usefulness of effects-based criteria in addressing remedial action policy issues related to "how clean is clean."

Many of the issues addressed in this section are also being considered by regional EPA offices, other federal, state, and local agencies, and private interest groups. Discussion of critical issues in a work group setting or the

TABLE 8. EXAMPLES OF MAJOR ENVIRONMENTAL LEGISLATION RELEVANT TO SEDIMENT CRITERIA POLICY ISSUES (Source: Battelle 1987)

Law	Purpose
Clean Water Act of 1977	Establishes authority to restore and maintain the chemical, physical, and biological integrity of the Nation's waters.
Section 115	Provides authority to identify the location of in-place pollutants with emphasis on toxic pollutants in harbors and navigable waterways.
Section 301	Establishes effluent limitations.
301(b)	Provides for effluent limitations for priority pollutants from point sources, other than publicly owned treatment works.
301(h)	Modifies discharge permits for discharge from publicly owned treatment works.
Section 402	Authorizes the National Pollution Discharge Elimination System (NPDES) for regulating the discharge of pollutants from point sources.
Section 404	Establishes permits for discharge of dredged or fill material into navigable waters of the U.S.
Clean Water Act of 1987	Establishes authority to protect the chemical, physical, and biological integrity of the Nation's waters.
Section 104	Establishes national programs for the prevention, reduction, and elimination of pollution through research, experiments, and demonstrations.
Section 118	Requires annual reports on the status of pollutants in sediments of the Great Lakes, and removal of sediments with toxic pollutants.
Section 304(a)	Authorizes development and publication of criteria reflecting the scientific knowledge on the environmental effects of pollutants.

TABLE 8. (Continued)

Marine Protection, Research, and Sanctuaries Act of 1972	Provides authority to regulate the transportation for dumping and the dumping of material into ocean waters.
Section 102	Authorizes dumping permits for sewage sludge and industrial wastes.
Section 103	Authorizes permits for transportation of dredged material for the purpose of dumping into ocean waters.
Resource Conservation and Recovery Act of 1976	Authorizes efforts to promote the protection of health and environment and to conserve valuable material and energy resources by regulating the treatment, storage, and transportation of hazardous wastes that have adverse effects on health and the environment.
Section 301	Establishes criteria for identification and listing of hazardous waste.
Toxic Substances and Control Act	Authorizes regulation of chemical substances and mixtures that present an unreasonable risk of injury to health and the environment.
Section 4(a)	Authorizes development of testing methods including toxicity testing.
Section 4(e)	Authorizes development of priority list for promulgation of procedures under Section 4(a).
Federal Insecticide, Fungicide, and Rodenticide Act	Gives authority to protect health and environment against unreasonable adverse effects from application of insecticides, fungicides, and rodenticide.
National Ocean Program Act	Confers authority to coordinate pollution programs among the federal agencies involved in marine research, monitoring, and regulations.

TABLE 9. EXAMPLES OF POTENTIAL APPLICATIONS OF SEDIMENT CRITERIA IN IMPLEMENTING KEY ENVIRONMENTAL LEGISLATION (Source: Battelle 1987)

	Dumpsite Designation	Discharge Siting	Permit Decisions	Dumpsite Monitoring	Discharge Monitoring	Clean Area Identification	Clean-Up Area Selection	Clean-Up Goal Setting	Site Restoration	EIS Preparation
Clean Water Act (1977)										
Section 104								X	X	
Section 301		X	X		X	X	X			
Section 303, 304		X	X		X		X	X		
Section 311						X	X			
Section 402			X	X						
Section 404	X		X	X						X
1987 Clean Water Act Amendments										
Section 118							X	X	X	
Section 404						X				
Section 405			X	X	X					
Section 509		X		X	X					
Ocean Dumping Act										
Section 102	X			X						X
Section 103			X							
Resource Conservation and Recovery Act (RCRA)										
Section 301							X			
Section 1006	X					X				X
Section 1008	X							X		
Section 3004								X		
Section 3004G			X							
Section 3005			X							
Section 3019	X				X	X	X	X		X
Section 7003						X	X			
Section 9003			X	X						X
Superfund Amendment and Reauthorization ACT (SARA) and Comprehensive Environmental Response and Liability Act (CERCLA)										
Section 102/103	X					X	X			
Section 105						X	X		X	X
Section 106						X	X		X	
Section 107						X	X			
Section 121	X							X	X	X
Section 205	X									

circulation of position papers may be effective in promoting an exchange of viewpoints between these groups.

MANAGEMENT OF COASTAL SEDIMENTS

The NOAA Status and Trends program is designed to monitor temporal changes at sediment stations that are generally removed from the direct influence of point discharges. Because of their location, combined effects of nonpoint sources and "far field" effects of multiple point sources of contamination can be assessed at these NOAA stations. In contrast, many stations sampled in the SCCWRP program reflect direct contributions from sewage outfalls in southern California. The potential for comparing the prediction of biological effects at both kinds of stations was an advantage of the analyses conducted for this report.

Four potential outcomes were possible from the prediction of biological effects using Puget Sound AET:

1. Adverse effects predicted at virtually all stations along the U.S. coasts

2. Adverse effects predicted at some sites, but in a random pattern

3. Adverse effects predicted at some sites and in a trend corresponding to an independent assessment of potential biological effects

4. No adverse effects predicted.

Biological results reported in the NOAA and SCCWRP studies suggest that a range of adverse effects might be expected at the monitoring stations used for predicting biological effects. Hence, Outcomes 1 and 4 would indicate that the AET approach is either too sensitive, too insensitive, or inappropriate for broad application outside of Puget Sound. Outcome 2 might also indicate that the approach was inappropriately applied, or at least that site-specific effects criteria were required to interpret the results. Outcome 3 is closest to the results reported for this study, and suggests that effects-based criteria have good potential for identifying problem sediments in coastal regions of the United States and for distinguishing contaminated and uncontaminated regions.

Overall, the AET approach was useful in distinguishing NOAA Status and Trends stations and areas by degree of predicted biological effects. The relatively contaminated embayments of the Northeast Region were identified as the most impacted areas in the U.S. By contrast, most embayments in the Gulf Region were not predicted to exhibit biological effects. Predicted biological effects in the Northwest/Alaska, Southwest, and Southeast Regions were intermediate in magnitude between the effects predicted for the Northeast and Gulf Regions. Thus, the AET approach was sufficiently sensitive to discriminate among areas subjected to different degrees of chemical contamination.

Because the NOAA program was designed to monitor changes in sediment chemistry at stations that are removed from the direct influences of point discharges, the resolution obtained in this study suggests that an effects-based approach can be used at areas removed from heavily contaminated areas (e.g., marine Superfund sites) to rank potential problem areas. The composition of chemical contamination frequently varies among stations within regions and among regions. Without consideration of potential biological effects, it is difficult to determine, for example, whether an area contaminated with 1,000 ug/kg of PCBs should be ranked higher than another area contaminated with 1,000 ug/kg of mercury. The application of an effects-based approach to sediment criteria provides a more uniform basis with which these areas can be compared (the PCB contaminated areas would be predicted to be a problem according to 1 of 4 AET indicators; the mercury contaminated area would be predicted to be a problem according to 3 of 4 AET indicators and would be ranked higher).

Comparison of the Status and Trends fish pathology results with the results of the AET analysis showed that when the AET approach predicted widespread biological effects (i.e., at multiple stations in an individual embayment), significantly elevated prevalences of kidney lesions were found in 100 percent of the cases. Therefore, in areas of widespread contamination, AET may be efficient predictors of kidney lesions. Far less correspondence was seen at embayments in which AET were exceeded at none or only one of the stations. Prevalences of liver lesions were elevated much less frequently than prevalences of kidney lesions and showed no close relation with results of the AET analysis. Given the fact that elevated prevalences of liver lesions were found in only one of the highly contaminated embayments of the Northeast Region, it appears that these abnormalities were not as sensitive to chemical contamination as were kidney lesions.

Evaluations of the additional data sets from southern California and San Francisco Bay generally supported the conclusions reached from the analysis of the Status and Trends data set. That is, the AET approach was useful in discriminating among stations subjected to different degrees of chemical contamination along a pollution gradient. Using chemical data from the southern California study, the approach identified impacted stations around sewage outfalls that were similarly defined as impacted by an independent assessment of benthic communities developed by Word and Mearns (1979). Evaluations of the biological effects measured in both the southern California and San Francisco studies showed that adverse effects almost always were found at the stations where they were predicted to occur by the AET analysis.

A range of biological effects were predicted using the 1984 NOAA Status and Trends chemical data. Hence, temporal changes in chemical concentrations at these stations can be used to evaluate the extent of improvements in areas predicted to be impacted or the potential increase in adverse effects in areas exhibiting increasing sediment contamination. In addition, selective biological monitoring could focus on those stations where changing sediment concentrations are approaching AET values. Such monitoring would serve to verify predictions and, over time, would potentially provide direct biological measurements of the transition between normal and adverse conditions.

IDENTIFICATION AND MONITORING OF POTENTIAL MARINE SUPERFUND SITES

The empirical chemical-biological relationships incorporated in effects-based criteria can provide a useful means for defining and monitoring the resolution of problems at Superfund sites. Key questions to consider at potential Superfund sites include the following:

1. Is the area contaminated?

2. Does the contamination result in adverse biological effects?

3. Is there a potential threat to public health?

4. Can the contaminant sources be identified?

5. Would remedial action reduce the environmental hazard?

Effects-based sediment criteria can be used as one of several tools to address Questions 1, 2, 3, and 5. Prior to a remedial investigation at a potential site, existing chemical data could also be assessed using such criteria as part of a hazard ranking system. Although hazard ranking under current Superfund programs focuses on human health considerations, consideration of effects-based sediment criteria would add an environmental aspect to the assessment at marine sites.

For problem identification, sensitive detection of contaminant-related problems is typically required to enable a prioritization of sites for potential remedial action. The AET approach used in this report was originally developed and tested for this purpose at the Commencement Bay Nearshore/Tideflats Superfund site in Puget Sound (Barrick et al. 1985). In addition, modified AET developed using data from throughout Puget Sound have been applied by the Puget Sound Dredged Disposal Analysis study as trigger levels for screening decisions on the need for further chemical or biological testing and evaluation of dredged sediments proposed for marine disposal. The results of the analyses conducted in the present report suggest that the AET approach has wider applicability for problem identification at marine sites that could be considered for listing on the National Priorities List. Confirmation of its applicability by selective field testing is recommended.

From a policy perspective, the use of effects-based criteria beyond initial problem definition hinges on legal defensibility (i.e., can the prediction of effects be adequately supported to implement corrective action) and the cleanup goal (discussed in the following section). In assessing the feasibility of remedial action, modification of sediment criteria to incorporate a "safety factor" or "multiplier" to either lower or raise the original criteria values may be required. "Safety factors" can be used to ensure that contaminant-related problems have been corrected, and to incorporate estimates of technical uncertainties. "Multipliers" can be used to help prioritize remedial action by identifying the worst problems (i.e., areas greatly exceeding sediment criteria) to be corrected when resources are limited. Such modifications will typically reflect site-specific needs or information. However, the procedure for assessing information and selecting appropriate modifications would likely be consistent among sites as a matter of policy. Other policy issues that frequently arise at potential marine Superfund sites (and would benefit from use of effects-based criteria) but that may require coordination with other regulatory programs include:

- Identification of "acceptable sediments" for transfer among sites (e.g., dredging and disposal programs evaluated under the Ocean Dumping Act or Section 404 of the Clean Water Act)

- Evaluation of the need for modified restrictions on discharges regulated under Section 402 of the Clean Water Act [National Pollution Discharge Elimination System (NPDES) program]

- Identification of action guidelines for chemicals registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) or Toxic Substances Control Act (TSCA).

REMEDIAL CLEANUP ISSUES

The identification of appropriate cleanup levels at remedial action sites regulated under Superfund or Resource Conservation and Recovery Act (RCRA) programs is a potential use of effects-based sediment criteria. Cleanup at a remedial action site is controversial because few objective criteria exist for quantitatively assessing more than the economic feasibility of cleanup actions. A commonly expressed concern is that cleanup criteria based solely on biological effects would likely be economically or technically infeasible. To address these concerns, the following policy questions must be addressed:

- What degree of environmental protection is desired or required? Should the degree of environmental protection vary among different regions of the country or among sites that are used for different purposes?

- What should determine an appropriate cleanup criterion? Should economic and technical feasibility be incorporated into the selection of such a criterion? If so, what procedures should apply to ensure consistency among sites?

The goal of sediment remedial action is to alleviate contamination in problem areas and thereby to eliminate associated adverse biological and human health effects. Target cleanup goals should be those sediment contaminant concentrations that are not predicted to result in adverse biological effects. The feasibility of such goals must be considered in the overall technical and economic analysis of remedial action. Nevertheless, target cleanup goals should be established based on an objective technical basis such as provided by effects-based criteria. Local or regional conditions will often influence specific cleanup decisions but a consistent process for making these recommendations is desirable. In the event that target cleanup goals for certain chemicals are found to be infeasible, then less stringent alternative criteria may be considered and their implications noted.

For example, the lowest AET for a range of biological indicators is a potential tool for establishing cleanup goals. Implementation of such goals would predict that, at concentrations below the goal, no adverse effects would be expected according to any of the four biological effects indicators used to generate AET. Comparable goals are under consideration as target sediment cleanup levels in the Commencement Bay Feasibility Study in Puget Sound (PTI, in preparation). Two sets of alternative cleanup levels (higher than the target level and predicted to be less protective) are also being evaluated.

The NOAA Status and Trends stations evaluated in this study are generally removed from direct contaminant discharges typically found at Superfund and RCRA sites. Cleanup goals based on AET could require remedial action sites to fall within the range of conditions found at the NOAA monitoring stations. Approximately 65 percent of the 126 NOAA stations meet the lowest AET (Figures 3 and 4) generated from Puget Sound data. Cleanup to such levels may be feasible for only a small portion of a remedial action site but may be warranted because of sensitive ecological concerns. A less stringent goal of not exceeding two or more AET for a range of biological indicators would be met by 71 percent of the NOAA Status and Trends stations. A still less stringent goal of not exceeding all four AET would be met by 80 percent of these stations (93 percent, if 1-methyl phenanthrene data are ignored). In addition, the number of chemicals and magnitude of concentrations exceeding cleanup goals can be used to resolve concerns over spurious results for individual chemicals driving remedial actions.

RECOMMENDATIONS FOR FIELD STUDIES

The results of this study indicate that effects-based criteria may be recommended for determining the extent and relative priority of potential problem areas to be managed nationwide. This preliminary study should be augmented by additional investigations, such as field studies under consideration by the EPA Criteria and Standard Division for verification of the theoretical equilibrium partitioning approach. It is recommended that tests be designed and conducted to expand on the assessment of the applicability of both theoretical and effects-based criteria among different geographic regions. The results of these chemical and biological tests can be used to validate the applicability of effects-based criteria in areas other than where they were developed, provide site-specific data should the criteria not be easily transferred among regions, and also provide field verification of the predictions of the theoretical approaches. Such tests will likely require the design of sampling and chemical-biological programs in selected regions of the U.S. Refinements of the Puget Sound AET and specific applications in Puget Sound are being further investigated by EPA Region X (PTI, in preparation) and cooperating federal and Washington state agencies.

The use of site-specific sediment criteria should be encouraged until adequate verification of any national sediment criteria has been completed. Use of regional criteria (e.g., criteria based on Puget Sound AET) should be supported by chemical-biological effects data in other regions as a test of their applicability. Furthermore, in designing environmental monitoring programs and interpreting monitoring results using effects-based sediment criteria, the following questions should be addressed:

- What "biological effect" is being monitored?
- What combination of biological effects is appropriate to address environmental concerns?
- To what extent can a particular combination of biological effects serve as a surrogate for other effects?

It is also recommended that a review procedure be implemented to ensure appropriate updating of the database used to set effects-based sediment criteria. One draft approach to this concern is under review by the Puget Sound Dredged Disposal Analysis study and the Puget Sound Estuary Program.

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DEVELOPMENT OF SEDIMENT QUALITY VALUES

In the Puget Sound area, a comprehensive database is available that indicates that sediment chemistry can be used for more than just providing general information on the sediment. When properly analyzed, these data can be interpreted to reveal general conclusions about chemicals present in a sediment (and their concentrations) and biological effects that are associated with the same sediments.

The AET approach has been used as one approach to develop sediment quality values based on empirical evidence of biological effects. The empirical relationships used to establish AET do not prove a cause-effect relationship between contaminants and effects. However, in validation tests using independent data sets, the approach predicted the occurrence of biological effects with a high degree of accuracy (>80 percent for most biological indicators). Of the various theoretical and empirical approaches examined, the AET (normalized to sediment dry weight) was found to be the most predictive of the sediment concentrations at which biological effects would always be expected. The efficiency of individual AET in predicting only stations that actually had biological effects was comparable to the efficiency of other approaches (approximately 33 percent).

Sources of data used to develop AET for Puget Sound are summarized in Figure A-1. Included in the database are data for sediment samples collected at the major urban areas in Puget Sound (e.g., embayments adjacent to Seattle, Tacoma, and Everett), as well as nonurban areas (e.g., "reference areas") removed from major direct sources of contaminant discharges.

The focus of the AET approach is to identify concentrations of contaminants that are associated exclusively with sediments having statistically significant adverse biological effects (relative to reference sediments). The approach can be used for any chemical and for any observable biological effects (e.g., bioassays, infaunal abundances at various taxonomic levels, bioaccumulation). By using these different indicators, application of the resulting sediment quality values enables a wide range of biological effects to be addressed in the management of contaminated sediments.

A pictorial representation of the AET approach for two chemicals is presented in Figures A-2 and A-3 for a subset of these data (for amphipod bioassay results in Puget Sound). Two subpopulations of all sediments analyzed for chemistry and biological effects are represented by bars in the figures, and include:

- Sediments that did not exhibit significant amphipod toxicity
- Sediments that exhibited statistically significant ($P<0.05$) toxicity in bioassays.

The horizontal axis in each figure represents sedimentary concentrations of contaminant of concern (i.e., lead or 4-methyl phenol) on a log scale. For the

TABLE A-1. PUGET SOUND AET FOR SELECTED CHEMICALS (DRY WEIGHT)
(ug/kg dry weight for organics; mg/kg dry weight for metals)

Chemical	Amphipod AET[b]	Oyster AET[c]	Benthic AET[d]	Microtox AET[e]
Low molecular weight PAH	5500[f,g,h]	5200	6100[h]	5200
biphenyl	260	260	270	270
naphthalene	2400[g,h]	2100	2100	2100
2-methylnaphthalene	670	670	670	670
acenaphthylene	560	>560	640[h]	>560
acenaphthene	980[g,h]	500	500	500
fluorene	1800[g,h]	540	640[h]	540
phenanthrene	5400[g,h]	1500	3200[h]	1500
anthracene	1900[f,g,h]	960	1300[h]	960
1-methylphenanthrene	310	370	370	370
High molecular weight PAH	38000[g,h]	17000	>51000[h]	12000
fluoranthene	9800[g,h]	2500	6300[h]	1700
pyrene	11,000[g,h]	3300	>7300[h]	2600
benz(a)anthracene	3000[g,h]	1600	4500[h]	1300
chrysene	5000[g,h]	2800	6700[h]	1400
benzofluoranthenes	3700	3600	8000[h]	3200
benzo(a)pyrene	2400	1600	6800[h]	1600
indeno(1,2,3-c,d)pyrene	880[g,h]	690	>5200[h]	600
dibenzo(a,h)anthracene	510[g,h]	230	1200[h]	230
benzo(g,h,i)perylene	860[g,h]	720	5400[h]	670
Chlorinated organic compounds				
Total PCBs	2500[h]	1100	1100	130
hexachlorobenzene (HCB)	130	230	230	70
p,p'-DDE	15	--	9	--
p,p'-DDD	43	--	2	--
p,p'-DDT	3.9	>6	11[h]	--
Metals				
antimony	5.3	26	3.2	26
arsenic	93	700	85	700
cadmium	6.7	9.6	5.8	9.6
copper	800[h]	390	310	390
lead	700[h]	660	300	530
mercury	2.1[h]	0.59	0.88	0.41
silver	>3.7[h]	>0.56	5.2	>0.56
zinc	870[h]	1600	260	1600

[a] ">" indicates that a definite AET could not be established because there were no "effects" stations with chemical concentrations above the highest concentration among "no effects" stations.

[b] Based on 160 stations.

TABLE A-1. (Continued)

[c] Based on 56 stations (all from Commencement Bay Remedial Investigation).

[d] Based on 104 stations.

[e] Based on 50 stations (all from Commencement Bay Remedial Investigation).

[f] A higher AET (24,000 ug/kg for low molecular weight PAH and 13,000 ug/kg for anthracene) could be established based on data from an Eagle Harbor station. However, the low molecular weight PAH composition at this station is considered atypical of Puget Sound sediments because of the unusually high relative proportion of anthracene. Thus, the low molecular weight PAH and anthracene AET shown are based on the next highest station in the data set.

[g] The value shown exceeds the Puget Sound AET established in Beller et al. (1986) and results from the addition of Eagle Harbor Preliminary Investigation data (an area of heavy creosote contamination in Puget Sound).

[h] The value shown exceeds AET established from Commencement Bay Remedial Investigation data (Barrick et al. 1985) and results from the addition of Puget Sound data presented in Beller et al. (1986).

APPENDIX A

SUMMARY OF
APPARENT EFFECTS THRESHOLD APPROACH

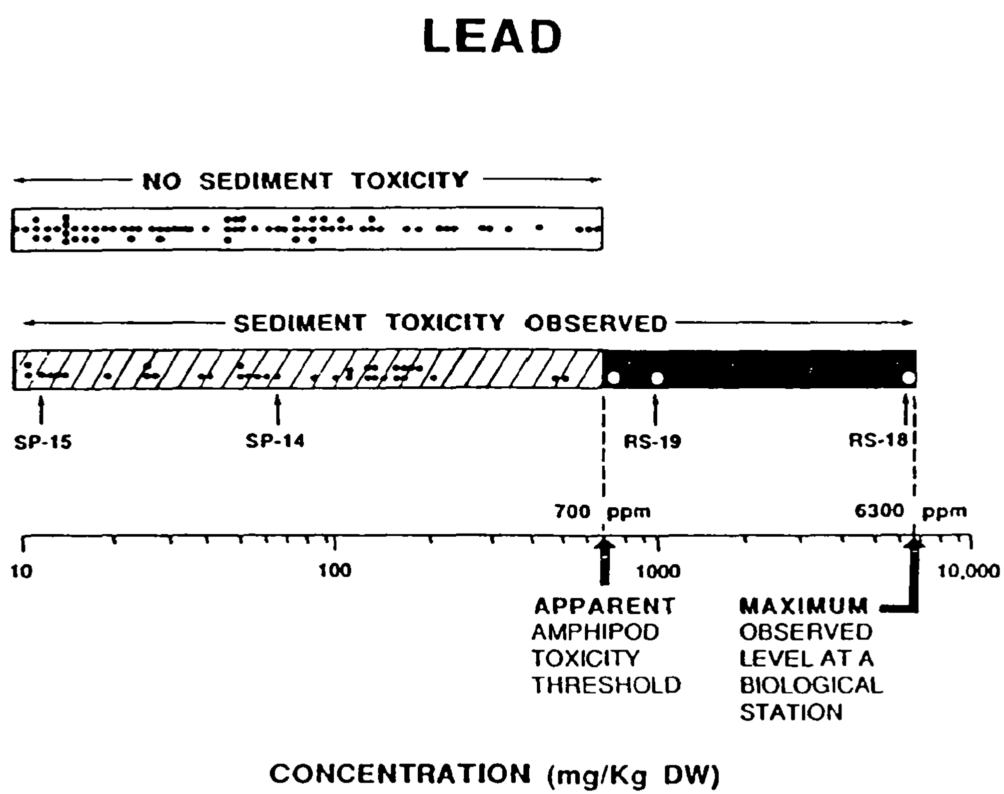

Figure A-2. The AET approach applied to sediments tested for lead concentration and amphipod mortality during bioassays.

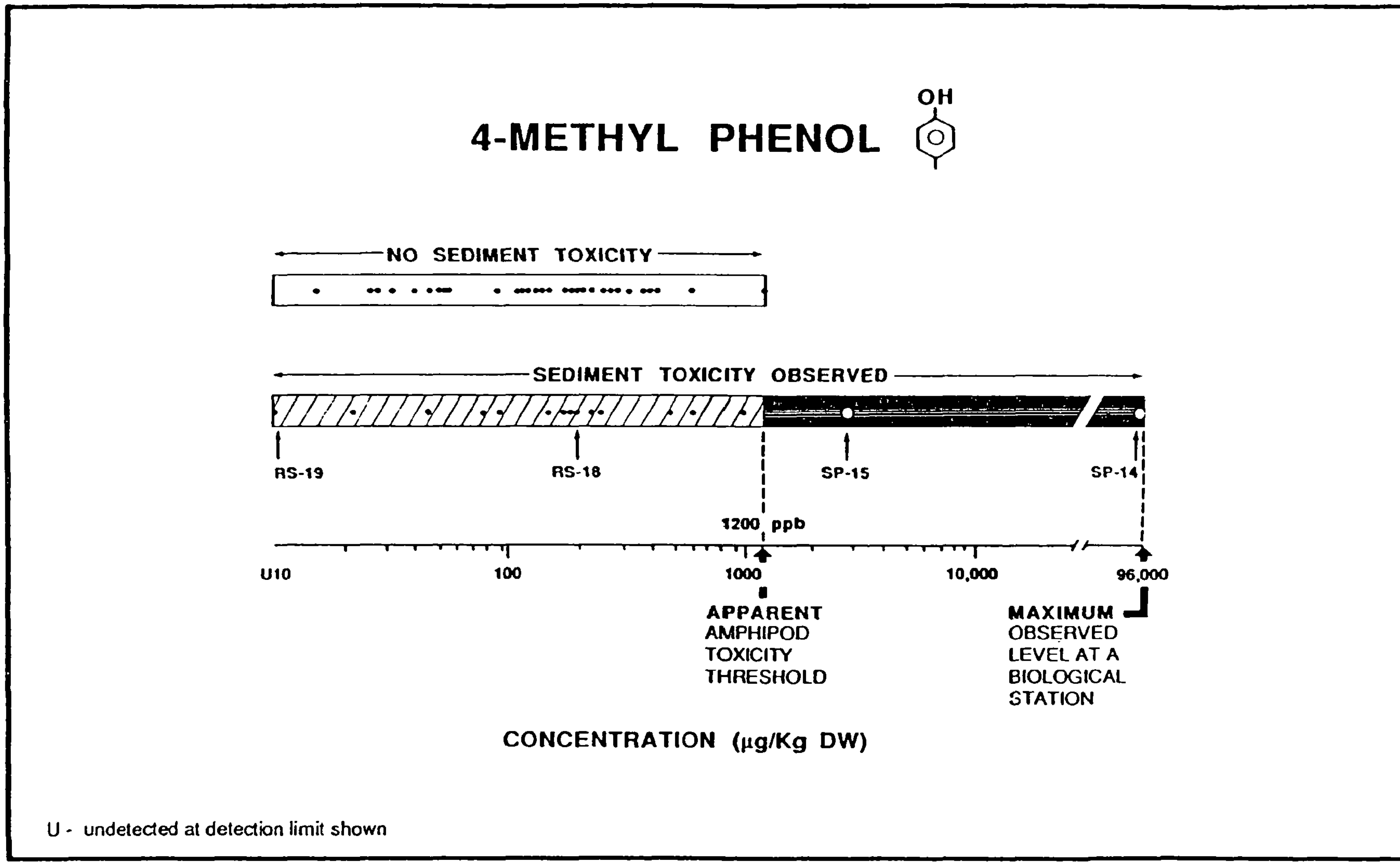

Figure A-3. The AET approach applied to sediments tested for 4-methyl phenol concentration and amphipod mortality during bioassays.

The horizontal axis in each figure represents sedimentary concentrations of contaminant of concern (i.e., lead or 4-methyl phenol) on a log scale. For the specific biological indicator under consideration, the AET for lead is the highest lead concentration corresponding to sediments that did not exhibit significant adverse effects. The AET for 4-methyl phenol were determined analogously.

The Potential Effect Threshold (Figures A-2 and A-3) is the concentration below which no statistically significant biological effects were observed in any sample. Note that this threshold for 4-methyl phenol is equal to the detection limit for the compound. The threshold is designated as "potential" because toxicity was observed in some, but not all, of the samples from stations with higher lead or 4-methyl phenol concentrations. The toxicity effects observed at these stations could have resulted from other contaminants or physical conditions (e.g., grain size). Because the potential effect threshold for a chemical cannot be related in a meaningful way to the observed biological effects, it is not used to set sediment quality values.

Apparent effects thresholds correspond to concentrations above which all samples for a particular biological indicator were observed to have adverse effects. Data are treated in this manner to reduce the weight given to samples in which factors other than the contaminant examined (e.g., other contaminants, environmental variables) may be responsible for the biological effect. For example, sediment from Station SP-14 shown in Figure A-3 exhibited severe toxicity, potentially related to a greatly elevated level of 4-methyl phenol (7,400 times reference levels). The same sediment from Station SP-14 contained a low concentration of lead that was not critical in establishing the AET for lead (Figure A-2). Despite the toxic effects displayed by the sample, sediments from other stations with higher lead concentrations than Station SP-14 exhibited no statistically significant biological effects. These results were interpreted to suggest that the effects at Station SP-14 were more likely associated with 4-methyl phenol (or a substance with a environmental distribution) than with lead. A converse argument can be made for lead and 4-methyl phenol in sediments from Station RS-18. Hence, the AET approach helps to identify different contaminants that are most likely associated with observed effects at each biologically impacted site. Based on the results for these two contaminants, effects at 4 of the 28 impacted sites shown in the figures may be associated with elevated concentrations of 4-methyl phenol, and effects at 7 other sites may be associated with elevated lead concentrations.

If an unmeasured chemical (or group of chemicals) is not distributed in the environment in the same way as a measured chemical (e.g., if a certain industrial process releases an unusual mixture of contaminants), the effect should be discerned if a sufficiently large data set is used to establish AET. Using lead and the amphipod bioassay as examples, the amphipod bioassay AET for lead is set by the highest lead concentration in samples that do not exhibit significant mortality in the amphipod bioassay. Hence, the actual AET value will not be influenced by the lead concentration in samples in which unmeasured chemicals cause amphipod mortality. (Although the lead AET would not considered to be established unless there is also at least one sample that does exhibit amphipod mortality and has a higher lead concentration than the nonimpacted sample setting the AET.)

An unmeasured toxic chemical may occur in the environment with a different spatial distribution than any of the measured chemicals. It is unlikely that the AET approach could predict impacts at stations where such a chemical is inducing toxic effects. However, the predictive success of AET can be tested in a validation using an independent field data set. Such a test conducted using Puget Sound data determined that AET identified from 82 to 94 percent of the impacted stations, when the biological indicator was oyster larvae bioassays, Microtox bioassays, or depressions in benthic infaunal abundances (Beller et al. 1986). Lower success was obtained with the amphipod bioassay (54 percent of the impacted stations were identified), which may be related to an apparent sensitivity of the amphipod bioassay to some fine-grained sediments even in the absence of contamination (Beller et al. 1986).

The precision of the AET values was also estimated in the sediment quality values work performed for the Puget Sound Dredged Disposal Analysis and Puget Sound Estuary Program (Beller et al. 1986). Several potential error components were considered, including the statistical error in incorrectly classifying one or more nonimpacted stations that determined the AET. This classification error was judged to provide a reasonable estimate of the 95 percent confidence intervals for AET values.

APPENDIX B

SUMMARY OF FISH PATHOLOGY EVALUATIONS

TABLE B1. PREVALENCE OF HISTOPATHOLOGICAL CONDITIONS IN WINTER FLOUNDER[a]

Location	Sample Size	Kidney MMC Proliferation	Proliferative Biliary Hyperplasia	Hepatic Neoplasia
Casco Bay	30	3	0	0
Merrimack River	30	3	0	3
Salem Harbor	30	40[b]	7	0
Boston Harbor	30	33[b]	10	13[b]
Buzzards Bay	30	17[b]	0	0
Narragansett Bay	30	13[b]	3	0
E. Long Island Sound	30	0	0	0
W. Long Island Sound	30	43[b]	0	0

[a] Each prevalence value was compared with 0 percent using the G-test.

[b] $P \leq 0.05$.

TABLE B2. PREVALENCES OF HISTOPATHOLOGICAL CONDITIONS IN SPOT[a]

Location	Sample Size	Kidney: Necrotizing Granulomas	Kidney: MMC Proliferation	Kidney: Hyalin Lesions	Liver: Cholangio-cellular Necrosis	Liver: Hepato-cellular Necrosis
Upper Chesapeake Bay	30	0	0	13[b]	7	0
Lower Chesapeake Bay	19	0	0	11	5	11
Pamlico Sound	30	0	0	43[b]	0	10
Charleston Harbor	30	0	0	20[b]	7	20[b]
Sapelo Sound	30	0	0	73[b]	3	10
St. John River	17	12	35[b]	12	6	6
Charlotte Harbor	30	17[b]	17[b]	70[b]	0	17[b]
Apalachicola Bay	30	7	7	30[b]	0	53[b]
Round Island	30	0	3	17[b]	3	10
Mississippi River Delta	19	0	5	21[b]	5	16
Barataria Bay	29	0	0	7	0	0
Galveston Bay	17	0	0	0	0	35[b]
San Antonio Bay	30	0	7	7	0	0
Corpus Christi Bay	29	0	0	17[b]	0	0

[a] Each prevalence value was compared with 0 percent using the G-test.

[b] $P \leq 0.05$.

TABLE B3. PREVALENCES OF HISTOPATHOLOGICAL CONDITIONS IN ATLANTIC CROAKER[a]

Location	Sample Size	Kidney: Necrotizing Granulomas	Kidney: MMC Proliferation	Kidney: Hyalin Lesions	Liver: Cholangio-cellular Necrosis	Liver: Hepato-cellular Necrosis
Upper Chesapeake Bay	21	5	0	0	10	5
Lower Chesapeake Bay	30	3	3	7	10	0
Pamlico Sound	30	3	0	3	0	3
Charleston Harbor	36	0	3	3	33[b]	14[b]
Apalachicola Bay	30	0	0	7	0	10
Mobile Bay	21	0	5	24[b]	0	10
Mississippi River Delta	30	0	0	3	40[b]	13[b]
Barataria Bay	22	0	5	0	10	5
Galveston Bay	30	0	0	3	7	20[b]
Corpus Christi Bay	30	0	0	13[b]	0	0
Lower Laguna Madre	30	0	0	7	0	3

[a] Each prevalence value was compared with 0 percent using the G-test.

[b] $P \leq 0.05$.

TABLE B4. PREVALENCES OF HISTOPATHOLOGICAL CONDITIONS IN ENGLISH SOLE AND FLATHEAD SOLE[a]

Location	Sample Size	Liver: Foci of Cellular Alteration	Liver: Degeneration/ Necrosis	Kidney: Degeneration/ Necrosis	Kidney: Proliferative Disorders
English Sole					
Elliott Bay	60	8[b]	38[b]	12[b]	15[b]
Commencement Bay	30	13[b]	10	33[b]	13[b]
Nisqually Reach	31	3	0	0	7
Flathead Sole					
Elliott Bay	60	0	3	13[b]	5
Commencement Bay	30	0	38[b]	3	13[b]
Lutak Inlet	30	0	7	0	0
Nahku Bay	30	0	17[b]	3	0

[a] Each prevalence value was compared with 0 percent using the G-test.

[b] $P \leq 0.05$.

TABLE B5. PREVALENCES OF HISTOPATHOLOGICAL CONDITIONS IN STARRY FLOUNDER[a]

Location	Sample Size	Liver		Kidney	
		Foci of Cellular Alteration	Degeneration/ Necrosis	Degeneration/ Necrosis	Proliferative Disorders
Columbia River	31	0	6	10	6
Coos Bay	30	0	0	0	3
Bodega Bay	13	0	0	0	10
Southampton Shoal	16	6	0	38[b]	0
Hunters Point	28	0	0	14[b]	7
San Pablo Bay	30	3	0	10	0

[a] Each prevalence value was compared with 0 percent using the G-test.

[b] $P \leq 0.05$.

TABLE B6. PREVALENCES OF HISTOPATHOLOGICAL CONDITIONS IN WHITE CROAKER[a]

Location	Sample Size	Liver		Kidney	
		Degeneration/ Necrosis	Proliferative Disorders	Degeneration/ Necrosis	Proliferative Disorders
Bodega Bay	37	0	0	3	5
Southampton Shoal	30	0	0	7	3
Oakland Harbor	30	0	0	7	10
Hunters Point	12	0	0	0	0
San Pedro Canyon	29	3	0	3	14[b]
Seal Beach	30	0	3	7	30[b]
Dana Point	30	3	0	13[b]	3

[a] Each prevalence value was compared with 0 percent using the G-test.

[b] $P \leq 0.05$.

TABLE B7. PREVALENCES OF HISTOPATHOLOGICAL CONDITIONS IN HORNYHEAD TURBOT[a]

Location	Sample Size	Liver: Foci of Cellular Alteration	Liver: Degeneration/ Necrosis	Kidney: Degeneration/ Necrosis	Kidney: Proliferative Disorders
Santa Monica Bay	30	3	0	10	7
San Pedro Canyon	27	4	0	7	4
Dana Point	29	0	0	10	0
Seal Beach	21	0	0	0	5
San Diego Bay	18	0	0	6	0

[a] Each prevalence value was compared with 0 percent using the G-test.

[b] $P \leq 0.05$.