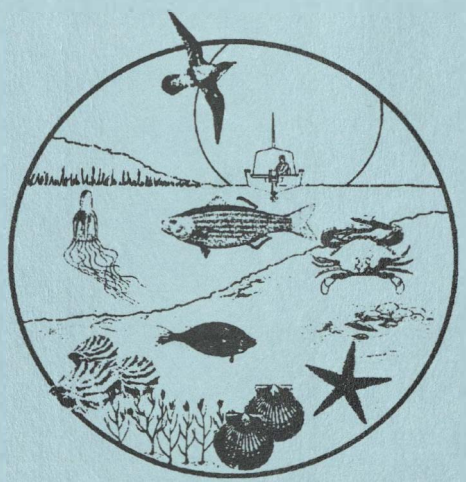
Final Report

Year Two Demonstration Project Studies in the Carolinian Province by Marine Resources Research Institute: Results and Summaries

January, 1997

A Study Sponsored Jointly by the Environmental Protection Agency and the National Oceanic and Atmospheric Administration's "National Status and Trends Program."

A. H. Ringwood, R. F. Van Dolah, A. F. Holland, M. E. DeLorenzo, C. Keppler, P. Maier, J. Jones, M. Armstrong-Taylor



submitted by

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South Carolina Department of Natural Resources
217 Fort Johnson Road
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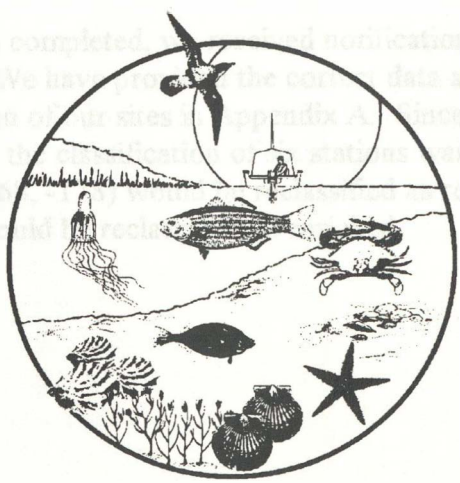

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Authors' Note

After this report was completed, we received notification that there were errors in the chlordane concentrations. We have provided the correct data as well as how these changes would affect the classification of our sites in Appendix A. Since the corrected values were lower than the original data, the classification of six stations was affected. Four of the enriched stations (CP95163, -165, -168, -178) would be reclassified as reference and 2 of the degraded stations (CP95164, -175) would be reclassified as enriched.

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SUMMARY

The second year of sampling for the full implementation of EMAP in the Carolinian Province was conducted during the summer of 1995. Core indicators (dissolved oxygen and other water quality parameters, sediment characteristics, sediment contaminants, sediment toxicity tests, benthic communities, and nektonic assemblages) were evaluated at 86 sites from Cape Henry, VA to Indian River Lagoon, FL. Summaries of EMAP activities conducted by Marine Resources Research Institute (MRRI) for the Year 2 Demonstration Project are provided in this report. MRRI personnel were responsible for sampling at 21 core sites and 11 supplemental sites in South Carolina and Georgia. MRRI was also responsible for conducting amphipod toxicity tests using *Ampelisca verrilli,* Microtox tests, and seed clam growth assays using juvenile *Mercenaria mercenaria* for all core stations and most supplemental stations, and compiling data for the amphipod toxicity tests using *Ampelisca abdita* (conducted by SAIC). Two new toxicity tests were conducted, an amphipod feeding test (using *Ampelisca verrilli*) and a bivalve fertilization assay, for a subset of core and supplemental sites.

Hydrolab Datasonde 3s were deployed *in situ* for $\geq$ 24 hr for continuous records of water quality data (temperature, salinity, pH, dissolved oxygen, and depth), and instantaneous readings were taken at the time of sampling. Continuous records provide a better indication of the daily variation observed in critical components such as salinity, pH, and dissolved oxygen (DO). Bottom readings taken during instantaneous measurements were never as low as the minimum values (typically observed during late night or early morning low tides) recorded during continuous measurements. Although 24 hour deployments usually provide a good estimate of the potential for DO stress, longer records are encouraged. Extended data were collected for 8 sites, but did not alter the conclusions drawn from the 24 hour data. Three sites (Hampton River, GA, CP95167; a site located near the Charleston Naval Base, SC, CP95NV2; and Shipyard Creek, SC, CP95SPY) were characterized as experiencing acute DO stressed, and there was evidence of chronic DO stress at a number of other sites (CP95DIE, CP95KOP, CP95153, CP95166, CP95NMK, CP95FOS).

The top 2 cm of sediments from multiple grabs were composited and used for a variety of analyses (sediment contaminants, toxicity, sediment characterization). Sediments are the primary sink for contaminants that are introduced into estuarine ecosystems, and are an important indicator of potential pollutant exposure. Only one core station (Ashley River, CP95152) had a PAH analyte (pyrene) that exceeded ER-M values, and no supplemental stations had PAH concentrations that exceeded ER-M values. Only two core stations had ER-L exceedances (South Santee, CP95150; Ashley River, CP95152). Several of the supplemental stations in the Charleston Harbor area had ER-L exceedances (Diesel Creek, Koppers, and New Market Creek), and sites sampled around the Charleston Naval Base (CP95NV1 and CP95NV2) also had ER-L exceedances.

PCBs were detected at all stations, at concentrations ranging from 2.22 - 80.88 ppb for core stations and up to 216 ppb at supplemental stations. No core stations and only one supplemental station (New Market Creek) had PCB concentrations that exceeded ER-M

values. Exceedances of ER-L values for PCBs were observed at 5 core stations (Chowan River, CP95103; Little Alligator River, P95109; Rattan Bay, CP95138; St. Johns River, CP95171; and Doctors Lake, CP95172), and at 5 supplemental sites (Diesel Creek, Koppers Creek, Navy Base North, Navy Base South, and Shipyard Creek). Maximal PCB concentrations were higher than the maximal value measured in the Louisianian Province (38 ppb), but lower than that measured in the Virginian Province (1040 ppb).

Chlordane concentrations ranged from 0 - 66.61 ppb for core and supplemental sites. The highest concentration was measured at a core site, Mud River in GA (CP95166), and there was a total of 6 core sites and 1 supplemental site in the province that exceeded the ER-M value. The highest concentrations were higher than those measured in the Carolinian Province in 1994. Concentrations of DDT and DDT related analytes (DDD and DDE) were also higher in 1995, and there were more ER-M or PEL exceedances (6 core sites and 1 supplemental site exceeded these criteria). Numerous exceedances of ER-L or TEL levels of chlordane, 4-4' DDD, 4-4' DDE, 4-4' DDT, and total DDT were found. Overall, pesticide concentrations were higher than those measured in either the Louisianian or Virginian Provinces.

There were no core stations that had metal concentrations exceeding ER-M values, but sediments from one supplemental station (Shipyard Creek) contained extremely high Cr concentrations that exceeded the ER-M value. There were numerous ER-L exceedances at core as well as supplemental sites. Arsenic, Cr, and Ni were the most commonly elevated elements. One problem with using ER-L and ER-M guidelines is that there is no way of correcting for variations in background concentrations associated with different sediment types. Therefore, aluminum normalization techniques were also used to determine the degree of metal enrichment and to generate metal enrichment factors (MEFs). Metal enrichment factors are the measured concentrations divided by the metal concentrations expected in a given sediment type. Most of the average MEFs were around one, indicating no metal enrichment, but MEFs > 2 were observed for numerous sites. Based on the MEF analyses, ERL or ERM values may overestimate or underestimate metal contamination, depending on the sediment type.

In additional to single contaminant criteria, methods for classifying stations with enriched concentrations of multiple contaminants were developed. These multiple contaminant criteria were based on the summed proportional concentrations (i.e. analyte concentrations divided by ER-L or ER-M concentrations). Using this approach, a single numerical index is generated that summarizes the extensive suite of analytes, and facilitates ranking of stations. Likewise MEFs may be averaged over a suite of metal contaminants, yielding an overall index of metal enrichment. The stations were classified as reference, enriched, or degraded based on sediment contaminants.

Laboratory toxicity tests have been used in EMAP and other monitoring programs as indicators of potential impacts on the biota and as indirect indicators of contaminant bioavailability. The amphipod (*Ampelisca abdita*) assay was the primary test of potential toxicity for the Virginian and Louisianian Provinces. For the Year 2 Demonstration Project in

the Carolinian Province, whole sediment bioassays were conducted with four tests: the ampeliscid acute toxicity assay with both *Ampelisca abdita* and *A. verrilli,* and two sublethal assays (Microtox® and seed clam growth). Only one of the 86 core stations tested with *A. abdita* resulted in significant mortality relative to the performance controls based on the EMAP criteria of survival < 80% of the controls and $p < 0.05$. The station which caused significant mortality to *A. abdita* (CP95178) was located in North Carolina and was classified as enriched based on sediment contaminant levels. This station also had extremely high concentrations of total ammonia (120.0 mg/L as NH_3-N) and unionized ammonia (2.63 mg/L) which exceeded the No Observable Effect Concentration (NOEC) of 30 mg/L total ammonia and 0.4 mg/L unionized ammonia for this species, respectively (USEPA, 1994). Therefore, it is likely that toxicity would have occurred even with no contaminants present.

The assays conducted using *A. verrilli* showed slightly greater sensitivity than the *A. abdita* assays, but use of this species still resulted in only three core stations being coded as toxic. All three sites (CP95103, CP95108, CP95178) were located in North Carolina, but only CP95103 was classified as degraded based on sediment chemistry. As noted for *A. abdita*, the very high ammonia concentrations noted at CP95178 are likely to have accounted for most of the *A. verrilli* mortality based on an estimated NOEC of 45 mg/L and an LC_{50} of 88 mg/L total ammonia obtained for this species in 10-day spiked sediment tests recently completed by the MRRI.

Microtox assays, based on the attenuation of light production by the photoluminescent bacteria *Vibrio fischeri*, were conducted at all core and 18 of 20 supplemental stations. Because of the strong sediment bias associated with the solid-phase assay, the silt-clay data must be used to identify sites that caused significant toxicity. One approach that was developed (and used for the 1994 EMAP data as well as this year's data) is that sites with < 20% silt-clay are classified as toxic if the EC50s < 0.5, and sites with > 20% silt-clay were classified as toxic when the EC50s < 0.2. When these criteria were applied, 4 reference sites (9.5% of reference sites), 5 enriched sites (35.7% of enriched sites), and 16 degraded sites (53.3% of degraded sites) were identified as toxic based on the Microtox assay.

Seed clam assays using juvenile *Mercenaria mercenaria* were conducted with sediments from 85 core stations and all 20 supplemental stations. The seed clam growth assay was the most sensitive assay tested, and has a number of desirable attributes. This is a sublethal assay based on growth as an indicator of potential sediment toxicity, and so it may represent the potential for chronic as well as acute effects. There were 47 stations characterized as toxic, composed of 20 degraded stations, 23 reference stations, and 4 enriched stations. Silt-clay content has often been found to be an important variable that affects the performance of sediment bioassays, as was demonstrated for the Microtox assay. Seed clams demonstrated good growth in all sediment types, ranging from very sandy to very silty. Therefore, in addition to the positive features, such as 7-day duration and sublethal endpoint, the seed clam growth assay has applicability over a broad range of sediment types, a very important attribute.

Seed clam growth was inversely correlated to ammonia concentrations. The no observed effects concentration (NOEC) for juvenile *M. mercenaria* was in the range of 14 - 16 mg/L total ammonia. Many of the false positives could be explained by ammonia toxicity. This value is substantially lower than the ammonia NOEC of 30 mg/L for *Ampelisca abdita*. However the incidence of stations that had ammonia concentrations exceeding 16 mg/L was relatively rare. Eighteen of 105 stations (17%) had ammonia concentrations greater than 16 mg/L, and 12 of these were from reference sites. Generally, sites with high porewater ammonia concentrations were characterized as sandy, as 16 of the 18 sites had < 25% silt-clays.

The potential importance of other porewater parameters, pH and salinity, to seed clam toxicity were also considered and some interesting patterns were observed. When porewater pHs were < 7.3 or salinities were < 15 ‰ in conjunction with contaminants, toxicity was more commonly observed. All degraded stations with seed clam growth < 80% of controls had low pH and/or low salinity porewaters. On the other hand, 21 of the 24 false negatives were characterized by pHs > 7.3 and salinities > 15 ‰. When pHs and salinities are low, contaminants are more likely to desorb from the sediments and porewater concentrations of contaminants should increase, presenting higher proportions of labile contaminants to the bioassay system, i.e. increased bioavailability potential. When porewater pHs and salinities are high, contaminants may tend to remain more tightly bound to the sediments, reducing bioavailability. Frequently, false negatives are assumed to be related to differences in bioavailability, and these results support that notion. Furthermore, these results also indicate the importance of pore water measurements (ammonia, pH, salinity) to the interpretation of toxicity tests and sediment contaminant data.

Two new candidate indicators were evaluated during Year 2 Demonstration Project, the *A. verrilli* feeding-inhibition assay and the bivalve fertilization assay. Forty sediment samples, representing both degraded and non-degraded sites, were tested using the feeding assay. Mean chlorophyll-a uptake was <80% of control values at 13 of the 30 sites designated as degraded or enriched, but due to high variance only three of the sites also showed statistically significant differences ($p<.05$). Six of the 10 reference sites showed false positive results (based on chlorophyll-a uptake of <80% of controls) and 17 of the degraded and enriched sites showed false negative results. Despite the variance problem, this assay showed evidence of being more sensitive than the ten-day acute assay, and modifications of some of the methods may expand the utility of this approach. For the bivalve fertilization assay, problems with gamete viability were encountered and many experiments were considered invalid, so any definitive statements regarding its utility as a sediment bioassay are precluded. The bivalve fertilization assay may be developed as a valid sediment toxicity bioassay, but clearly more basic research is needed. The results do indicate that significant toxicity was more frequently observed with sediments from degraded sites. Toxicity was observed at only 1 out of 14 reference sites, no enriched sites, and 4 out of 10 degraded sites.

The assemblages of organisms that comprise the benthic communities were characterized from grabs taken at each station. Evaluation of the core and supplemental stations in SC and GA indicated that there was a tendency for degraded stations to be

characterized by lower abundances and fewer numbers of species. Salinity and sediment characteristics are two important types of environmental variables that may affect benthic assemblages. Another variable that tends to covary with salinity is pH, a parameter that can profoundly affect physiological and cellular processes as well as sediment processes. Plots of the relationships between benthic community parameters (number of species and abundance) and sediment parameters (% silt-clay and % total organic carbon) or water quality parameters (salinity and pH) suggested that salinity and pH are the most important variables affecting benthic communities.

Trawls were conducted at each core station in SC and GA to evaluate the nektonic assemblages. The mean number of species at reference sites was not significantly greater than that of degraded or enriched sites, and the mean number of individuals caught at degraded stations and enriched stations were higher than that of the reference stations. The penaeid shrimp, *Penaeus setiferus*, was the most commonly caught species, occurring as the dominant taxa at 16 of the 21 stations. At present, trawl data appear to have limited utility for discriminating degraded sites from reference sites. No pathologies were observed in any of the fish caught during the 1995 Year 2 Demonstration Project. "Cotton disease" was observed in a few penaeid shrimp (more commonly in *Penaeus setiferus*) at 1 reference site and 1 degraded site.

Monitoring programs strive to identify sites with evidence of stress, so that areal or trend estimates can be generated. Exposure and condition indicators should cross-validate each other, and should provide an accurate assessment of habitat condition. Since it is likely that any indicator will sometimes yield false-positives or false-negatives, it is important to incorporate a variety of indicators that represent various levels of organization to provide the most reliable evaluations. Estuaries are complex multidimensional resources that require a multidisciplinary approach and a robust suite of indicators to identify areas under stress. We must continue to develop tools that enable us to recognize habitats in early, possibly reversible, stages of degradation as well as those that would require more costly efforts to remediate.

CHAPTER 1. INTRODUCTION

BACKGROUND

EMAP (Environmental Monitoring and Assessment Program) is a comprehensive nationwide program designed to: (1) estimate the status and trends in condition of the nation's ecological resources on a regional basis; (2) identify associations between human-induced stress and ecological condition; and (3) provide periodic statistical summaries and interpretative reports on status and trends to environmental managers and the public. Both EPA and NOAA have mandates to assess the effects of pollution impacts on estuarine environments. EPA planned and initiated EMAP, and NOAA played a major role in the planning and development of EMAP for marine and estuarine environments. EMAP was implemented in the Virginian Province (northeast region) in 1990 and in the Louisianian Province (Gulf of Mexico region) in 1991. EMAP was extended into the Carolinian Province (southeast region, from Cape Henry, VA to the end of the Indian River Lagoon, FL) with pilot studies conducted by Marine Resources Research Institute (MRRI) in 1993. Whereas EPA was responsible for day-to-day operations in the Virginian and Louisianian Provinces, NOAA/NOS functions as the lead agency in the Carolinian Province. EMAP was implemented on a full scale in the Carolinian Province as the Year 1 Demonstration Project during summer 1994 through the cooperative efforts of state and university personnel. Eighty-four sites were sampled by researchers from University of North Carolina at Wilmington, Florida Department of Natural Resources, and Marine Resources Research Institute (MRRI) of the South Carolina Department of Natural Resources. The same structure was used for implementation of Year 2 Demonstration Project during summer 1995. For Year 2, 86 core stations were sampled: 1 was located in Back Bay, VA, 46 stations were sampled in NC, 12 in SC, 9 in GA, and 19 in FL.

A suite of indicators was measured at each site so that degraded habitats could be distinguished from those that show no adverse signs of anthropogenic impacts. The choice of indicators for Carolinian Province assessments was based on the indicator framework previously developed in the Virginian and Louisianian Provinces. Since the EMAP-Estuaries program does not have the resources to monitor all of the ecological parameters of concern, the limited resources available must be focused on the system attributes that are of greatest concern ecologically, and best address program objectives. Indicator data should be comparable with those from other provinces and contribute to a national assessment of the environmental condition of estuarine resources.

Results from the Virginian and Louisianian studies indicate that the present methodologies can be used to effectively discriminate between highly degraded and undegraded areas. However, it is not so clear that the present methodologies are effective for identifying those areas which are experiencing less severe, more chronic stress, which if unmitigated may progress towards more severe status. Therefore, the selection of indicators is an ongoing process, requiring continued validation of established indicators, as well as

development of new indicators that are biologically relevant and take advantage of technological advancements. The reliability of new indicators must be validated and the effects of natural habitat variations must be evaluated. It is desirable to have sufficient overlap in the indicators so that relationships between old and new indicators can be established. Indicators that are selected and developed should:

- Relate to ecological condition in a way that can be quantified and interpreted.
- Apply across a range of habitats.
- Be a concern of and valued by society.

Furthermore, indicators should possess the following attributes:

- Quantifiable in a standardized manner with a high degree of repeatability.
- Balanced sensitivity, i.e. be sufficiently sensitive to enable identification of stressful conditions, but not hypersensitive to natural environmental variables or sampling methodologies.
- Methods that can be applied on a regional scale, incorporating local modifications.
- Balanced costs, i.e. minimal incremental costs but high insight value.

Parameters that serve as indicators of ecological condition have been organized into various categories. Some confusion results from the fact that the nomenclature has gone through various modifications and the Virginian and Louisianian Provinces are using slightly different category schemes (Summers et al., 1993; Macauley et al., 1994; Schimmel et al., 1994). The categories of indicators discussed in this report are habitat, exposure, and biotic condition.

Habitat indicators describe the physical and chemical conditions of sample sites, and provide basic information about the overall environmental setting. Examples include depth, salinity, temperature, sediment characteristics, pH, water clarity, etc. Habitat indicators are frequently used to normalize exposure and response indicators across natural environmental gradients.

Exposure indicators provide measures of the magnitude and extent of pollution exposure. Measures of potential pollutant exposure include physical, chemical, and biological parameters that quantify pollution exposure, habitat degradation, or other causes of degraded ecological condition. Measurements related to this category include dissolved oxygen concentrations, sediment toxicity, and sediment contaminant concentrations.

Biotic condition indicators are characteristics of the environment (i.e. biological responses) that provide quantitative evidence of the status of ecological resources and biotic integrity. These measurements quantify the integrated responses of ecological resources to individual and multiple stressors. Measurements related to this category are benthic community parameters, fish and shellfish community parameters, incidences of gross pathology or disease, and tissue concentrations of contaminants.

A fourth indicator category used by EMAP is "stressors." Stressor indicators are economic, social, engineering, and landscape measures that can be used to estimate pollutant loadings to coastal waters and identify their sources. Examples include land use patterns, point source discharge estimates, freshwater inflows, and pesticide use along a watershed. These parameters are not measurable as part of the annual EMAP sampling efforts but represent data derived from other agencies. This category was not evaluated by MRRI.

1995 PROGRAM OVERVIEW AND STATION LOCATIONS

Summaries of EMAP activities conducted by MRRI for the Year 2 Demonstration Project are provided in this report. The indicators measured by MRRI during the second year of full implementation of EMAP in the Carolinian Province are listed in Table 1-1. The core indicators are those that were evaluated in the other provinces and during pilot year studies. These indicators were evaluated at all 86 core sites and are expected to be used in the province-wide assessment. MRRI personnel were responsible for sampling at 21 sites in South Carolina and Georgia. MRRI was also responsible for contracting or conducting the various toxicity assays with sediments from all core stations: the amphipod toxicity assay using *Ampelisca abdita* (conducted by SAIC), the Microtox® assay, the amphipod toxicity assay using *Ampelisca verrilli*, and the seed clam toxicity assay using *Mercenaria mercenaria*. The research indicators listed in Table 1-1 were evaluated at some of the core as well as supplemental stations to determine their potential value as regional-scale indicators of habitat quality.

In addition to activities conducted at the core stations, some core as well as research indicators were evaluated at a number of supplemental stations. Most of the supplemental stations were suspected or known from previous studies to be degraded. Some of the sites previously characterized during 1993 pilot year studies and 1994 Year 1 Demonstration Project were used as supplemental sites in the 1995 assessment to facilitate the evaluation of new indicator approaches. It is important that existing and potential indicators of habitat quality are tested at both reference and degraded sites so that their efficacy can be evaluated. The goal of the research components is the development of potential indicators of estuarine health for future monitoring activities.

The sites that were sampled in GA and SC are listed in Table 1-2, and mapped in Figure 1-1 (SC stations) and Figure 1-2 (GA stations). All of the sites sampled in SC and GA are small estuaries as defined by EMAP (surface area < 260 km^2 but ≥ 2.6 km^2). For the probabilistic sampling design to provide an unbiased estimate of condition, it is important to sample as close as possible to the sites defined by the list frame. The actual coordinates that are listed in Table 1-2 vary only slightly from the coordinates specified in the list frame provided by the Carolinian Province Office (CPO). Generally, there were no major problems except that bad weather associated with hurricanes (Erin and Felix) and tropical depression, Jerry required frequent modifications of our sampling plans.

Table 1-1. List of indicators measured at sites sampled in SC and GA by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995.

INDICATOR CATEGORY	CORE INDICATORS	RESEARCH INDICATORS
Habitat	Salinity Temperature pH Depth Water Clarity Sediment Characteristics % Silt-Clays % Water % Total Organic Carbon	Chlorophyll a Porewater Ammonia
Exposure	Dissolved Oxygen Sediment Contaminants Amphipod Toxicity (*Ampelisca abdita*) Microtox®	Amphipod Toxicity (*Ampelisca verrilli*) Seed Clam Growth Feeding-inhibition (*A. verrilli*) Bivalve Fertilization
Biotic Condition	Benthic Species Composition and Abundance Fish and Shellfish Assemblages Gross Pathology of Fish and Shellfish Tissue Contaminants in Fish and Shellfish	

Table 1-2. Station information for sites sampled in SC and GA by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995. Coordinates are the actual sampling location and depths are the maximum depths recorded from continuous Datasonde records.

State	Station #	Code	Station Name	Area (sq. km)	Date	Depth (m)	Latitude	Longitude
South Carolina	CP95149	WIN	Winyah Bay	60.9	Aug-18	6.1	33° 20.48'	79° 16.14'
	CP95150	SAN	S. Santee River	9.0	Aug-18	4.5	33° 09.30'	79° 21.22'
	CP95151	ASH1	Ashley River	13.4	Aug-2	8.9	32° 47.08'	79° 57.91'
	CP95152	ASH2	Ashley River 2	13.4	Aug-2	9.1	32° 47.05'	79° 57.72'
	CP95153	HAM	Hamlin River	3.5	Aug-3	4.6	32° 46.98'	79° 48.28'
	CP95154	PAR	Parrot Point Creek	7.5	Aug-4	2.2	32° 43.87'	79° 52.92'
	CP95155	NED	N. Edisto River	39.7	July-31	11.7	32° 36.11'	80° 14.21'
	CP95156	SED	S. Edisto River	27.1	July-31	7.2	32° 35.46'	80° 23.88'
	CP95157	BUL	Bull River, SC	11.2	Aug-16	10.7	32° 31.99'	80° 34.27'
	CP95158	COO	Coosaw River	42.0	Aug-15	5.3	32° 30.66'	80° 36.35'
	CP95159	PTR	Port Royal Sound	40.1	Aug-28	11.3	32° 15.92'	80° 41.64'
	CP95160	SKU	Skull Creek	3.6	Aug-29	4.2	32° 14.91'	80° 45.14'
Georgia	CP95161	TYB	Tybee Roads	48.0	Aug-30	5.4	32° 04.82'	80° 52.79'
	CP95162	SCH	South Channel	6.3	Aug-29	4.0	32° 01.54'	80° 54.69'
	CP95163	BRG	Bull River, GA	8.5	Aug-29	8.4	32° 59.15'	80° 55.74'
	CP95164	OGE	Ogeechee River	29.2	Aug-22	9.3	31° 51.68'	81° 06.50'
	CP95165	NEW	N. Newport River	28.1	Sept-8	8.0	31° 41.39'	81° 11.51'
	CP95166	MUD	Mud River	10.4	Sept-7	5.3	31° 29.60'	81° 17.61'
	CP95167	HMP	Hampton River	12.5	Sept-5	5.8	31° 15.45'	81° 19.55'
	CP95168	JOI	Jointer Creek	25.5	Sept-6	7.6	31° 04.32'	81° 29.66'
	CP95169	CUM	Cumberland River	27.3	Sept-7	6.3	30° 55.60'	81° 27.71'

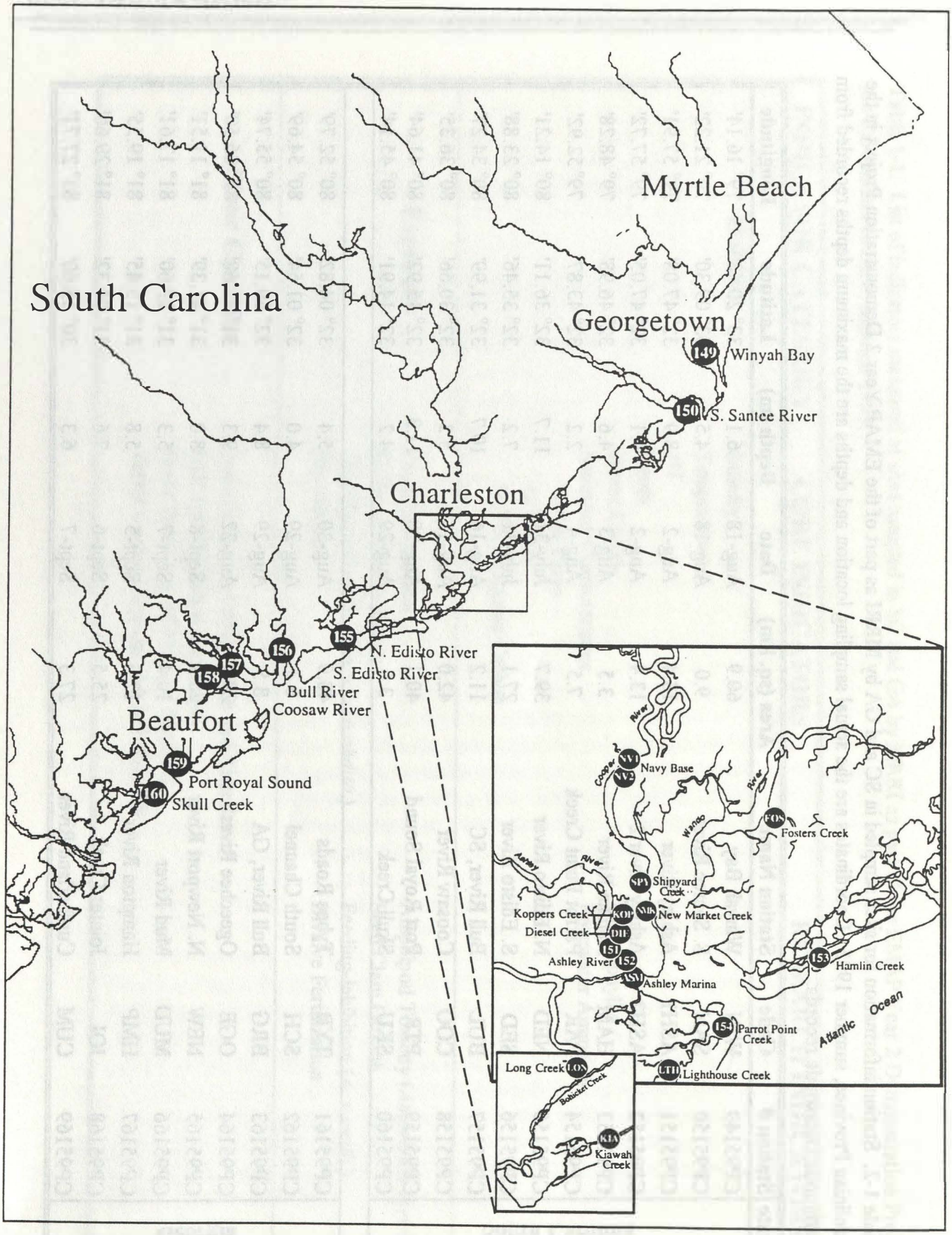


Figure 1-1. Map of sites sampled in SC in the Carolinian Province during summer, 1995.

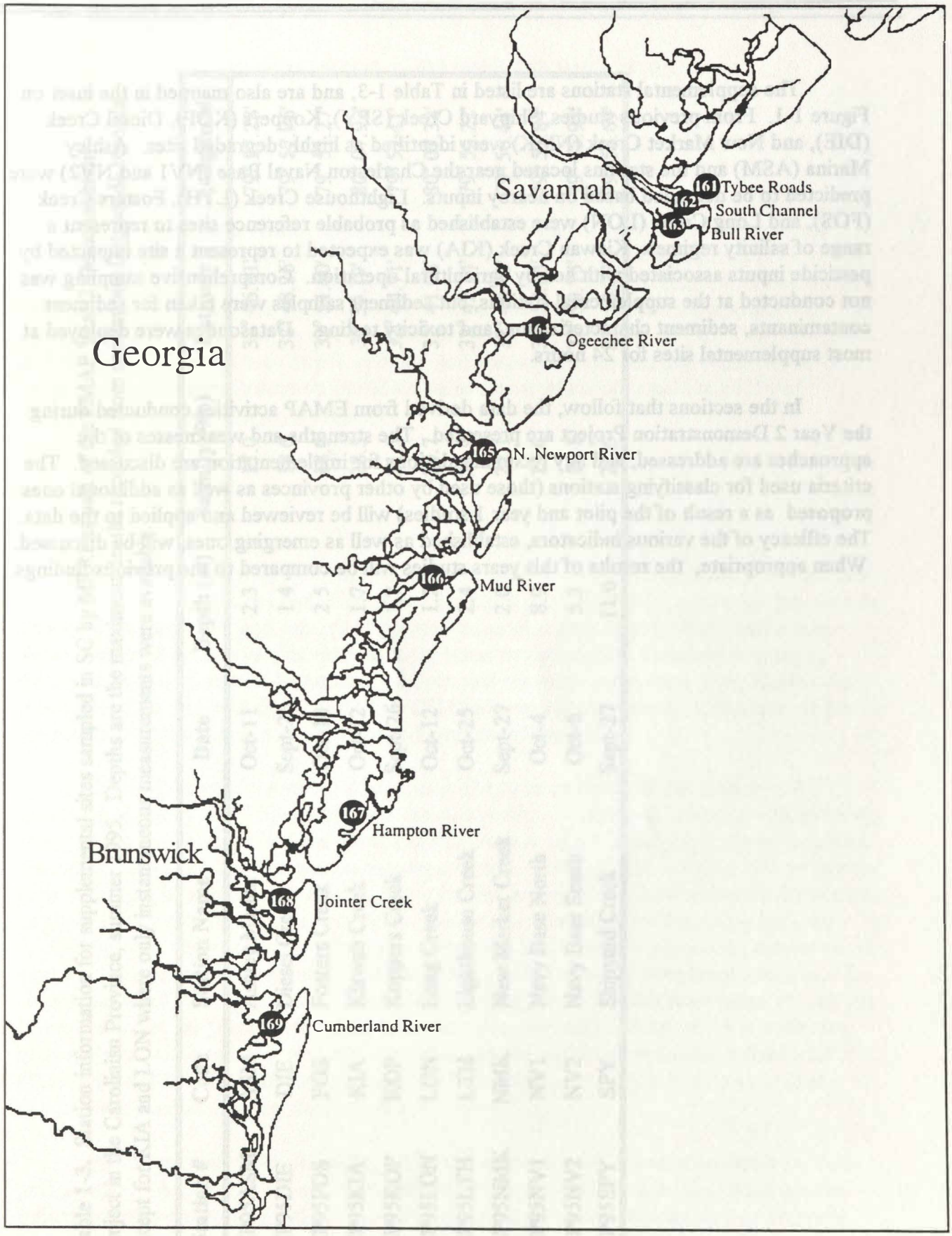


Figure 1-2. Map of sites sampled in GA in the Carolinian Province during summer, 1995.

The supplemental stations are listed in Table 1-3, and are also mapped in the inset on Figure 1-1. From previous studies, Shipyard Creek (SPY), Koppers (KOP), Diesel Creek (DIE), and New Market Creek (NMK) were identified as highly degraded sites. Ashley Marina (ASM) and the stations located near the Charleston Naval Base (NV1 and NV2) were predicted to be degraded based on nearby inputs. Lighthouse Creek (LTH), Fosters Creek (FOS), and Long Creek (LON) were established as probable reference sites to represent a range of salinity regimes. Kiawah Creek (KIA) was expected to represent a site impacted by pesticide inputs associated with nearby agricultural operation. Comprehensive sampling was not conducted at the supplemental stations, but sediment samples were taken for sediment contaminants, sediment characterization, and toxicity testing. Datasondes were deployed at most supplemental sites for 24 hours.

In the sections that follow, the data derived from EMAP activities conducted during the Year 2 Demonstration Project are presented. The strengths and weaknesses of the approaches are addressed, and any recommendations for implementation are discussed. The criteria used for classifying stations (those used by other provinces as well as additional ones proposed as a result of the pilot and year 1 studies) will be reviewed and applied to the data. The efficacy of the various indicators, established as well as emerging ones, will be discussed. When appropriate, the results of this years studies will be compared to the previous findings.

Table 1-3. Station information for supplemental sites sampled in SC by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995. Depths are the maximum depths recorded from continuous Datasonde records, except for KIA and LON where only instantaneous measurements were available.

Station #	Code	Station Name	Date	Depth (m)	Salinity (‰)	Latitude	Longitude
CP95ASM	ASM	Ashley Marina	Oct-11	2.3	17.0	32° 46.81'	79° 57.28'
CP95DIE	DIE	Diesel Creek	Sept-26	1.4	18.6	32° 48.26'	79° 57.96'
CP95FOS	FOS	Fosters Creek	Oct-10	2.5	18.9	32° 51.60'	79° 51.27'
CP95KIA	KIA	Kiawah Creek	Oct-12	1.7	28.5	32°36.19'	80° 07.92'
CP95KOP	KOP	Koppers Creek	Sept-26	1.7	21.5	32° 44.71'	79° 57.41'
CP95LON	LON	Long Creek	Oct-12	1.2	20.7	32° 41.08'	80° 07.38'
CP95LTH	LTH	Lighthouse Creek	Oct-25	2.4	26.9	32° 42.14'	79° 55.22'
CP95NMK	NMK	New Market Creek	Sept-27	2.0	22.1	32° 48.43'	79° 56.44'
CP95NV1	NV1	Navy Base North	Oct-4	8.9	13.6	32° 52.03'	79° 57.84'
CP95NV2	NV2	Navy Base South	Oct-6	5.3	16.1	32° 50.75'	79° 55.91'
CP95SPY	SPY	Shipyard Creek	Sept-27	11.0	21.6	32° 50.33'	79° 56.69'

CHAPTER 2. HABITAT INDICATORS

INTRODUCTION

Water quality parameters and sediment characteristics provide important information about the environmental setting of the sites. These parameters describe the physical and chemical conditions, and are often very important for normalizing other indicators to environmental gradients. Grain size, percent silt-clays and organic content of sediments, as well as salinity and temperature are important environmental parameters that affect the distribution and species composition of biota (Remane and Schlieper, 1971). Other environmental variables such as pH, sulfides, and redox potential also affect numerous physical and biological processes, including contaminant availability and the ability of organisms to compensate physiologically.

METHODS

Salinity, temperature, pH, and water depth were measured readily with the Hydrolab Datasonde 3s. Datasondes were first secured inside a protective PVC tube and a pinger was attached. A concrete weight and float system was used at deep sites (> 3 m), and a pole deployment system was used in more shallow water environments. Datasondes were deployed for a minimum of 24 hours at all sites, and readings were taken every 30 minutes. Pre-deployment and post-deployment QA/QC checks were conducted to insure the validity of the readings (Kokkinakis et al., 1994 Field Operations Manual).

Secchi-disk readings were taken at each site as an estimate of water clarity. A limnological Secchi disc (20 cm diameter, black and white) connected to a rope with markings every 10 cm was lowered into the water and the depth at which it disappeared was recorded. However, turbid conditions are a natural characteristic of SC and GA estuaries due to factors such as large tidal ranges, high detritus and sediment loadings, etc. Low water clarity is often interpreted as a sign of degraded conditions, but in many southeastern estuarine systems, Secchi disk data must be carefully interpreted because turbid waters may not be indicative of degraded conditions. Therefore, MRRI field crews collected water samples at some sites for determination of chlorophyll. For these measurements, 50 ml samples were taken at each site (3 replicates per site) and filtered onto Whatman glass microfibre filters which were frozen until analysis. Chlorophyll a was extracted with acetone and measured using a fluorometer (Turner Model 10-AU). Readings were taken before and after acidification with HCl and results were expressed as μg chlorophyll a /L.

Sediments were collected using a 1/25-m^2 stainless steel Young-modified Van Veen grab sampler. All samples for sediment characteristics were taken as subsamples from the sediment composite, which was composed of the top 2 cm of approximately 8 to 10 grabs.

Water content, % total organics, and % silt-clays were determined using standard EMAP protocols (EMAP, Laboratory Methods Manual, 1993). The % water content of sediments was calculated as a loss in weight after drying, and the values were corrected for salt content. These dried sediment samples were then ashed in a muffle furnace at 500°C for 4 hours. Percent total organics were then computed as the loss in weight after ashing divided by dry weight. For silt-clay analyses, sediment samples were first dispersed with sodium hexametaphosphate and sieved through a 63-μm screen. Sediments retained on the screen were dried and weighed, and a 40-ml subsample of the filtrate was then dried and used to estimate % silt-clays. Although EMAP requires only one 40 ml subsample, 3 subsamples were taken and averaged. Because these all came from the same sediment sample, they represent pseudo-replicates. Therefore the average number was used to estimate % silt-clay, but no standard deviations were computed.

Total organic carbon (TOC) content of sediments was determined using a Perkin Elmer CHNS analyzer (PE 2400, Series II). Sediment samples (2-5 g) were dried, pulverized, and acidified with H_3PO_4. Acidified sediments were then filtered onto precombusted GF/F filters, rinsed with decarbonated distilled water (boiled and gased with nitrogen), and dried. Sediment samples (approximately 20 mg, 4 replicates per station) were combusted (975°C) in the CHNS analyzer, and the results were expressed as % total organic carbon per gram of dried sediment (preacidified weight). Cystine standards and standard reference sediments (BCSS-1, marine sediments) were also analyzed with each batch of samples. The samples were processed in 7 batches, and control charts for the BCSS standards were maintained for both total carbon and total organic carbon (carbon remaining after removal of carbonates by acidification. The certified value for % total carbon of the BCSS standard was 2.19 ± 0.09. The mean concentration for % total carbon of the BCSS standard measured over all batches (n=26) was 2.19 ± 0.06; and the mean % organic carbon was slightly lower, 1.84 ± 0.14.

The program for analyzing carbon concentrations of sediments also yielded a sulfur concentration, so these data for SC and GA stations are presented. When sulfur is present as acid volative sulfides (AVS), the bioavailability of metal contaminants is believed to decrease as AVS concentrations increase. Although the sulfur data presented here may be of limited value, they may be related to the potential AVS concentrations. The certified value for % sulfur of the BCSS standard was 0.36 ± 0.05. The mean concentration for % sulfur of the BCSS standard measured over all batches (n=26) was 0.32 ± 0.04.

RESULTS AND DISCUSSION

Salinity

Mean salinities of the South Carolina and Georgia core stations ranged from 0.8 to 32.0 ‰ (Table 2-1). Two stations had a mean salinity of < 10 ‰; 5 stations were in the 10 - 20 ‰ range; 11 stations were in the 20 - 30 ‰ range; and 3 stations had salinities

Table 2-1. Salinities (‰) recorded from Hydrolab Datasonde 3s deployed at sites sampled by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995. Summaries are based on 24 hr deployments (na = not available).

State	Station		CONTINUOUS DEPLOYMENT			INSTANTANEOUS PROFILE		
			Mean ± Std	Minimum	Maximum	Surface	Bottom	Depth (m)
South Carolina Core Stations	CP95149	WIN	15.4 ± 1.7	12.8	18.9	12.8	16.6	5.9
	CP95150	SAN	0.8 ± 1.1	0.1	4.0	2.2	3.8	4.2
	CP95151	ASH1	23.7 ± 1.6	21.4	27.2	21.8	22.1	7.4
	CP95152	ASH2	23.5 ± 1.7	20.8	27.0	22.8	22.9	9.0
	CP95153	HAM	32.0 ± 0.8	31.2	34.6	34.3	34.3	3.2
	CP95154	PAR	31.4 ± 0.7	30.2	32.4	31.7	31.9	1.2
	CP95155	NED	30.2 ± 1.6	27.6	32.6	27.1	31.8	11.4
	CP95156	SED	11.9 ± 4.8	5.3	20.0	9.5	12.5	6.7
	CP95157	BUL	23.7 ± 1.4	20.8	26.0	22.4	23.1	10.6
	CP95158	COO	24.5 ± 0.5	23.6	25.2	23.8	23.7	4.8
	CP95159	PTR	27.6 ± 1.7	22.4	29.9	28.9	29.3	11.1
	CP95160	SKU	25.9 ± 1.0	24.2	27.4	25.6	26.0	2.1
Georgia Core Stations	CP95161	TYB	19.8 ± 3.1	14.1	25.7	21.3	26.4	5.3
	CP95162	SCH	9.5 ± 2.6	7.0	14.4	11.3	12.1	3.5
	CP95163	BRG	23.5 ± 1.6	21.1	26.4	26.1	26.2	8.4
	CP95164	OGE	23.1 ± 2.7	19.6	28.0	19.0	20.4	6.6
	CP95165	NEW	20.0 ± 2.3	16.5	23.8	23.0	23.9	8.0
	CP95166	MUD	20.2 ± 1.1	18.2	22.5	19.5	21.0	2.0
	CP95167	HMP	18.3 ± 3.1	12.7	22.8	13.1	14.7	3.5
	CP95168	JOI	23.2 ± 1.4	20.4	25.4	25.6	25.5	7.1
	CP95169	CUM	23.0 ± 2.1	19.9	26.5	26.2	26.7	6.0
South Carolina Supplemental Stations	CP95ASM	ASM	16.2 ± 3.3	9.4	21.8	16.2	17.0	0.8
	CP95DIE	DIE	17.7 ± 2.6	11.8	22.2	18.0	18.6	1.2
	CP95FOS	FOS	17.1 ± 1.0	16.2	18.9	18.8	18.9	2.5
	CP95KOP	KOP	17.1 ± 1.3	13.9	18.8	21.1	21.5	1.7
	CP95LTH	LTH	24.2 ± 0.6	28.3	25.9	na	na	2.4
	CP95NMK	NMK	18.3 ± 2.6	12.3	22.0	21.6	22.1	1.7
	CP95NV1	NV1	15.3 ± 3.5	9.5	20.5	10.6	13.6	8.1
	CP95NV2	NV2	17.3 ± 3.0	12.8	21.3	14.4	16.1	3.0
	CP95SPY	SPY	25.7 ± 1.3	23.6	27.9	17.9	21.6	2.5

greater than 30 ‰. Most of the supplemental stations had salinity regimes in the 10 - 20 ‰ range. During 1995, the dominant salinity classes were the 10 - 20 ‰ range and the 20 - 30 ‰ range, whereas stations sampled during 1994 were predominantly in the two higher classes, the 20 - 30 ‰ and > 30 ‰ ranges (Figure 2-1). The differences between years may

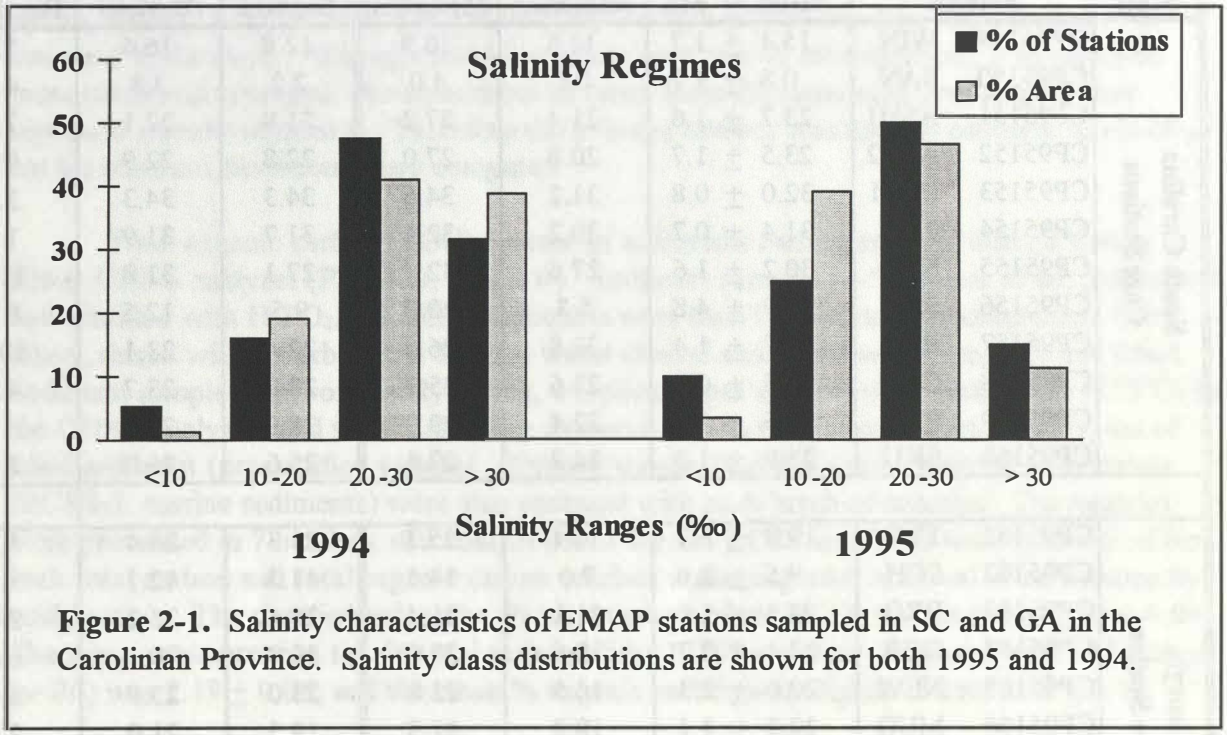


Figure 2-1. Salinity characteristics of EMAP stations sampled in SC and GA in the Carolinian Province. Salinity class distributions are shown for both 1995 and 1994.

be explained by differences in annual rainfall. Rainfall in the coastal regions of SC and GA was approximately one to seven inches below the August normal for 1994. However during 1995, rainfall values were approximately one to ten inches above the August normal (Climatological Data, Environmental Data and Information Service, NOAA). There was also a general perception that the sampling sites in 1995 were located further up into the estuaries and more likely to be affected by drainage processes, whereas may of the sampling sties in 1994 were located near inlets. The median distance of sites from oceanic inlets was calculated to be 4.5 nautical miles for 1995 and 2.0 nautical miles for 1994.

The results of the salinity measurements taken during the instantaneous profiles are also shown in Table 2-1. As an indicator of stratification, the instantaneous measurements indicate that only 1 station (CP95161, Tybee Roads) had surface to bottom range deviations of $\geq$ 5 ‰. However, the continuous readings indicate a greater degree of salinity variation. Based on minimum and maximum values measured during continuous deployment, the range deviations of bottom water salinities were $\geq$ 5 ‰ at 15 of 21 stations (or 83.2% of the SC and GA area). Therefore, the continuous records indicated that a greater number of sites were experiencing wider ranges of salinity regimes than would be indicated by the instantaneous data.

Temperature

Mean temperatures (based on the continuous records) of the core stations ranged from 24.9 - 31.5 °C (Table 2-2). The temperature ranges measured at each station during the instantaneous profiles typically did not exceed 2°C, except for Mud River (CP95166), and indicate similar temperatures throughout the water column. In general, continuous records also indicated that temperatures during this sampling period were consistently high with very little variation.

pH

Mean pH values of core stations ranged from 6.98 to 7.88 (Table 2-3). There were eight core stations with mean pHs below 7.5, and six of these had minima below 7.2. Low pH values can be explained in part by the low salinities that occurred at these stations, since pH decreases with decreasing salinity. From the pilot studies, it was suggested that a pH range deviation (maximum minus minimum) of 0.5 pH units may be a means of identifying sites experiencing pH stress or those that may be more susceptible to other stressors due to fluctuating pHs. Eight sites are suspect using this criteria: Winyah Bay (CP95149), South Santee (CP95150), South Edisto (CP95156), Tybee Roads (CP95161), South Channel (CP95162), Bull River (CP95163), North Newport River (CP95165), Hampton River (CP95167), Jointer Creek (CP95168), Cumberland River (CP95169). Shifts in pH are one of the most important physicochemical factors affecting bioavailability of contaminants. Changes in pH will affect adsorption - desorption processes in sediments, as well as membrane transport and enzyme-mediated functions of the organisms (Erickson et al., 1994; Simkiss and Taylor, 1995). The importance of pH shifts to bioavailability of metals is generally expected. Bioavailability of organic contaminants may also increase if pH conditions cause a shift from ionized to neutral forms, because neutral forms of organic contaminants cross lipid membranes more readily than charged forms (Erickson et al., 1994). Therefore organisms living in habitats characterized by pH shifts may be more susceptible to contaminant stress.

Secchi Depth and Chlorophyll a

The Secchi depth measurements ranged from 0.3 m to 1.3 m (Table 2-4). In many cases, it was difficult to get an accurate measurement because the strong tidal currents tended to move the disc in a horizontal direction so that vertical measurements were difficult to obtain. Chlorophyll a concentrations (also listed in Table 2-4) ranged from 6.27 to 37.06 ug/L. The highest chlorophyll concentrations were measured at sites sampled in the Ashley River (CP95151 and CP95152), which were identified as degraded (see Chapter 3 for description of station classification). There was no significant correlation between Secchi depth and chlorophyll a concentrations (Figure 2-2, r^2=0.04), or between Secchi depth and station depth (r^2=0.16). The slightly better agreement between Secchi depth and station depth rather than chlorophyll a would suggest that turbidity rather than productivity may be a

Table 2-2. Temperatures (°C) recorded from Hydrolab Datasonde 3s deployed at sites sampled by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995. Summaries are based on 24 hr deployments (na = not available).

State	Station		CONTINUOUS DEPLOYMENT			INSTANTANEOUS PROFILE		
			Mean ± Std	Minimum	Maximum	Surface	Bottom	Depth (m)
South Carolina Core Stations	CP95149	WIN	30.3 ± 0.1	30.1	30.5	31.6	30.4	5.9
	CP95150	SAN	31.0 ± 0.3	30.6	31.6	31.8	30.8	4.2
	CP95151	ASH1	29.7 ± 0.3	29.3	30.3	30.0	30.3	7.4
	CP95152	ASH2	29.7 ± 0.2	29.3	30.1	29.4	30.0	9.0
	CP95153	HAM	29.3 ± 0.5	28.6	30.2	28.6	28.6	3.2
	CP95154	PAR	29.8 ± 0.5	28.8	30.7	28.7	28.9	1.2
	CP95155	NED	30.1 ± 0.3	29.6	30.7	29.8	29.6	11.4
	CP95156	SED	30.3 ± 0.2	29.7	30.5	29.5	30.0	6.7
	CP95157	BUL	31.1 ± 0.5	30.4	32.3	30.7	30.8	10.6
	CP95158	COO	31.5 ± 0.5	30.8	32.7	30.7	30.9	4.8
	CP95159	PTR	28.0 ± 0.2	27.7	28.2	28.1	28.1	11.1
	CP95160	SKU	27.7 ± 0.4	27.1	28.3	27.6	27.9	2.1
Georgia Core Stations	CP95161	TYB	27.7 ± 0.4	27.0	29.0	27.1	27.5	5.3
	CP95162	SCH	26.9 ± 0.3	26.4	27.2	26.1	26.3	3.5
	CP95163	BRG	27.8 ± 0.3	27.2	28.2	27.3	27.2	8.4
	CP95164	OGE	29.6 ± 0.2	29.3	29.9	29.6	29.6	6.6
	CP95165	NEW	25.8 ± 0.3	25.3	26.9	24.7	25.4	8.0
	CP95166	MUD	25.5 ± 0.3	24.7	26.1	25.5	29.9	2.0
	CP95167	HMP	26.1 ± 0.6	25.2	27.1	26.5	27.0	3.5
	CP95168	JOI	24.9 ± 0.2	24.6	25.3	24.5	25.4	7.1
	CP95169	CUM	25.4 ± 0.2	25.1	25.7	24.9	25.2	6.0
South Carolina Supplemental Stations	CP95ASM	ASM	25.3 ± 0.2	25.2	25.7	25.1	25.2	0.8
	CP95DIE	DIE	23.6 ± 0.4	22.8	24.9	23.2	23.5	1.2
	CP95FOS	FOS	24.8 ± 0.4	24.2	25.4	24.6	24.6	2.5
	CP95KOP	KOP	26.9 ± 0.5	25.5	28.8	23.7	23.9	1.7
	CP95LTH	LTH	27.3 ± 0.8	25.9	28.2	na	na	2.4
	CP95NMK	NMK	24.4 ± 0.5	23.4	25.6	24.2	24.2	1.7
	CP95NV1	NV1	25.5 ± 0.1	24.3	24.7	24.5	24.3	8.1
	CP95NV2	NV2	24.5 ± 0.1	24.3	24.6	24.7	24.5	3.0
	CP95SPY	SPY	24.7 ± 0.1	24.6	24.9	24.0	24.3	2.5

Table 2-3. Summaries of pH measurements (based on 24 hr deployments) recorded from Hydrolab Datasonde 3s deployed at sites sampled by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995 (na = not available).

State	Station		CONTINUOUS DEPLOYMENT			INSTANTANEOUS PROFILE		
			Mean ± Std	Minimum	Maximum	Surface	Bottom	Depth (m)
South Carolina Core Stations	CP95149	WIN	7.50 ± 0.13	7.27	7.68	8.25	7.76	5.9
	CP95150	SAN	6.98 ± 0.15	6.78	7.34	8.08	7.61	4.2
	CP95151	ASH1	7.78 ± 0.11	7.58	7.94	7.72	7.69	7.4
	CP95152	ASH2	7.85 ± 0.11	7.62	8.00	7.69	7.65	9.0
	CP95153	HAM	7.87 ± 0.07	7.75	7.99	7.96	7.94	3.2
	CP95154	PAR	7.88 ± 0.13	7.69	8.06	7.81	7.80	1.2
	CP95155	NED	7.79 ± 0.13	7.57	8.00	7.80	7.89	11.4
	CP95156	SED	7.33 ± 0.20	7.01	7.68	7.34	7.31	6.7
	CP95157	BUL	7.52 ± 0.10	7.32	7.66	7.38	7.33	10.6
	CP95158	COO	7.42 ± 0.05	7.33	7.51	7.41	7.40	4.8
	CP95159	PTR	7.80 ± 0.05	7.75	7.95	7.74	7.81	11.1
	CP95160	SKU	7.58 ± 0.05	7.49	7.67	7.59	7.54	2.1
Georgia Core Stations	CP95161	TYB	7.61 ± 0.18	7.25	7.85	7.63	7.78	5.3
	CP95162	SCH	7.14 ± 0.22	6.84	7.46	7.61	7.54	3.5
	CP95163	BRG	7.64 ± 0.18	7.40	7.94	7.84	7.82	8.4
	CP95164	OGE	7.57 ± 0.14	7.37	7.85	7.37	7.37	6.6
	CP95165	NEW	7.36 ± 0.15	7.16	7.67	7.53	7.59	8.0
	CP95166	MUD	7.27 ± 0.11	7.14	7.48	7.44	7.22	2.0
	CP95167	HMP	7.46 ± 0.26	7.12	7.88	7.18	7.20	3.5
	CP95168	JOI	7.46 ± 0.16	7.29	7.83	7.44	7.42	7.1
	CP95169	CUM	7.57 ± 0.11	7.41	7.79	7.74	7.75	6.0
South Carolina Supplemental Stations	CP95ASM	ASM	7.51 ± 0.14	7.29	7.76	7.51	7.48	0.8
	CP95DIE	DIE	7.29 ± 0.12	7.02	7.53	7.51	6.50	1.2
	CP95FOS	FOS	7.35 ± 0.16	7.08	7.56	7.52	7.53	2.5
	CP95KOP	KOP	7.22 ± 0.13	6.93	7.40	7.57	7.51	1.7
	CP95LTH	LTH	7.83 ± 0.15	7.57	8.03	na	na	2.4
	CP95NMK	NMK	7.38 ± 0.18	7.00	7.58	7.67	7.66	1.7
	CP95NV1	NV1	7.56 ± 0.13	7.37	7.74	7.42	7.44	8.1
	CP95NV2	NV2	7.67 ± 0.10	7.50	7.81	7.56	7.56	3.0
	CP95SPY	SPY	7.89 ± 0.04	7.82	7.96	7.52	7.51	2.5

Table 2-4. Secchi depth and chlorophyll a concentrations measured at sites sampled in SC and GA by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995 (na = not available).

State	Station		Secchi Depth (m)	Chlorophyll a (ug/L) (Mean ± Std)
South Carolina Core Stations	CP95149	WIN	0.6	8.63 ± 2.59
	CP95150	SAN	na	14.58 ± 3.36
	CP95151	ASH1	0.7	37.06 ± 2.70
	CP95152	ASH2	0.6	21.63 ± 14.7
	CP95153	HAM	0.3	8.95 ± 5.93
	CP95154	PAR	0.6	7.43 ± 5.71
	CP95155	NED	0.7	10.36 ± 4.98
	CP95156	SED	0.3	na
	CP95157	BUL	1.0	7.5 ± 1.35
	CP95158	COO	0.4	10.61 ± 4.46
	CP95159	PTR	0.9	17.03 ± 1.53
	CP95160	SKU	0.6	8.33 ± 1.03
Georgia Core Stations	CP95161	TYB	0.3	18.57 ± 4.93
	CP95162	SCH	0.4	7.41 ± 1.06
	CP95163	BRG	0.8	17.15 ± 2.93
	CP95164	OGE	1.3	17.68 ± 6.84
	CP95165	NEW	0.3	9.23 ± 3.77
	CP95166	MUD	0.8	12.26 ± 2.45
	CP95167	HMP	0.4	8.67 ± 1.22
	CP95168	JOI	0.7	6.51 ± 0.56
	CP95169	CUM	0.7	6.27 ± 0.96

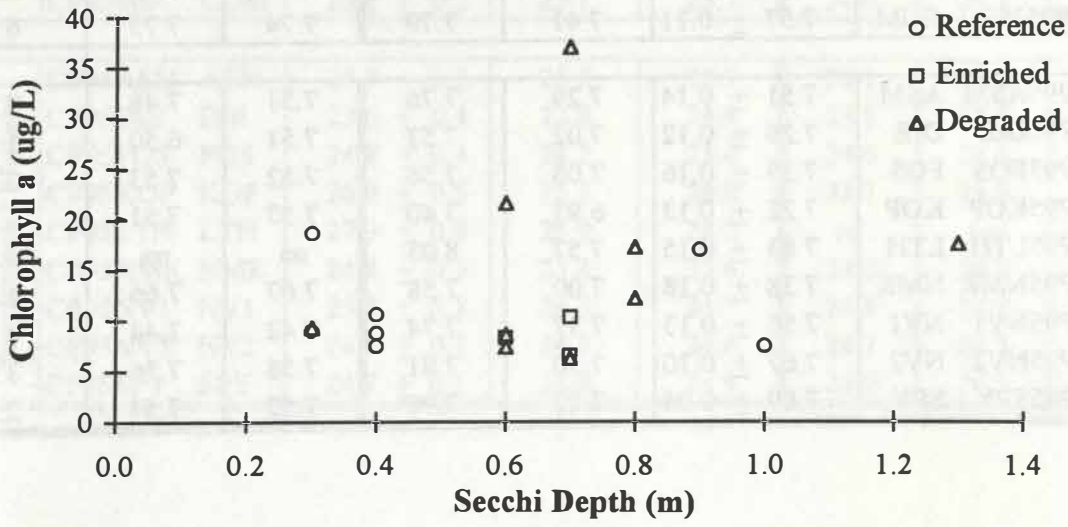


Figure 2-2. Plot of the chlorophyll a concentrations vs secchi depth for SC and GA stations sampled during theYear 2 Demonstration Project in the Carolinian Province.

more important factor affecting water clarity. It is our opinion that water clarity has little value as an indicator of ecological condition in southeast estuaries. In other provinces, poor water clarity has been defined as waters in which "...waders would not be able to see their toes in waist deep water" (Macauley et al., 1994). Since clarity and turbidity vary with depth, wave activity, etc., as well as with phytoplankton abundances, the significance of this parameter is difficult to interpret and may have little ecological significance. If the purpose is to identify areas that are experiencing eutrophication or blooms of nuisance algae, then measurements of nutrients, chlorophyll a, or taxonomic analyses of phytoplankton would be more appropriate.

Sediment Characteristics

The results of the sediment characterization analyses for core and supplemental stations are summarized in Table 2-5. Regression analyses of various combinations of these parameters indicate that many of these variables (TOC, % organics, % sulfur) co-vary with % silt-clay as expected (Figure 2-3A and C). There is a very good relationship (r^2=0.90) between the cruder measure of organic content (i.e. total organics as estimated from combustion) and TOC (Figure 2-3B). This suggests that total organics is an acceptable measure of organic content if data on TOC are not available. Generally, degraded stations were characterized by high silt-clay contents, high TOC concentrations, and high sulfur concentrations.

An acidification procedure is used in the TOC analyses to remove inorganic carbon. The question was raised regarding whether the additional processing time associated with the acidification steps was worth the effort, or if performing total carbon analyses on un-acidified sediments was sufficient. Unacidified as well as acidified sediments were analyzed and there was a good correlation between the total carbon (TC) concentrations and the TOC concentrations (Figure 2-4). Therefore, if a sufficient database of paired data exists, the TOC concentrations could be predicted from TC concentrations, eliminating the time and materials required for the acidification step.

Sediment parameters provide important means of correcting for variations in habitat type with respect to other indicators. The available surface area for adsorption of contaminants is considered to be a function of grain size, so sandy sediments have a lower tendency for accumulation of contaminants than muddy sediments. Silt-clay content of sediments is often a determining factor in the composition of the benthic community, and sediment composition factors such as aluminum concentration are also important in the evaluation of the sediment chemistry data. Organic matter, particularly TOC, is an important nutritional component that cycles in estuaries, and also plays important roles in modulation of binding and bioavailability of contaminants. Some of these parameters will be incorporated as normalizing factors in later chapters. The sediment parameters described in this chapter are measurable with a high degree of repeatability at minimal costs, and provide valuable information regarding system characteristics.

Table 2-5. Characteristics of sediments collected at sites sampled by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995.

State	Station		% Water	% Silt-Clay	% TOC	% Organics	% Sulfur
South Carolina Core Stations	CP95149	WIN	53.43	46.40	2.16	6.62	0.37
	CP95150	SAN	42.22	15.39	0.33	3.44	0.08
	CP95151	ASH1	43.58	19.04	0.77	3.91	0.35
	CP95152	ASH2	54.30	33.73	0.65	6.34	0.33
	CP95153	HAM	28.09	4.29	0.09	1.59	-0.02
	CP95154	PAR	60.89	45.88	1.47	8.30	0.83
	CP95155	NED	21.74	2.38	0.24	1.09	0.11
	CP95156	SED	72.55	77.38	3.32	10.82	1.30
	CP95157	BUL	28.40	2.42	0.06	0.41	0.02
	CP95158	COO	28.25	6.19	0.35	1.72	0.04
	CP95159	PTR	20.17	1.40	0.04	0.58	0.03
	CP95160	SKU	47.11	19.82	0.55	3.41	0.29
Georgia Core Stations	CP95161	TYB	24.78	2.81	0.09	0.63	0.06
	CP95162	SCH	24.85	1.23	0.10	0.63	-0.02
	CP95163	BRG	24.14	5.18	0.11	1.16	0.04
	CP95164	OGE	23.04	1.46	0.05	0.40	0.02
	CP95165	NEW	26.70	3.41	0.11	0.74	-0.01
	CP95166	MUD	68.32	64.21	1.76	8.20	1.45
	CP95167	HMP	32.74	8.72	0.43	1.83	0.13
	CP95168	JOI	36.90	5.90	0.24	1.46	0.11
	CP95169	CUM	46.76	25.35	0.82	4.72	0.59
South Carolina Supplemental Stations	CP95ASM	ASM	54.80	33.50	0.89	5.67	0.68
	CP95DIE	DIE	76.84	94.59	4.09	12.84	1.94
	CP95FOS	FOS	53.06	28.89	1.21	4.70	0.62
	CP95KIA	KIA	51.73	37.18	1.72	6.37	0.43
	CP95KOP	KOP	80.09	92.68	4.57	15.49	1.38
	CP95LON	LON	43.47	20.10	1.43	3.97	0.32
	CP95LTH	LTH	28.32	3.06	0.17	0.73	0.00
	CP95NMK	NMK	65.91	46.67	3.06	10.45	1.59
	CP95NV1	NV1	43.90	19.45	0.99	3.73	0.28
	CP95NV2	NV2	78.69	93.26	2.92	12.53	1.27
	CP95SPY	SPY	40.76	14.26	2.20	4.58	0.18

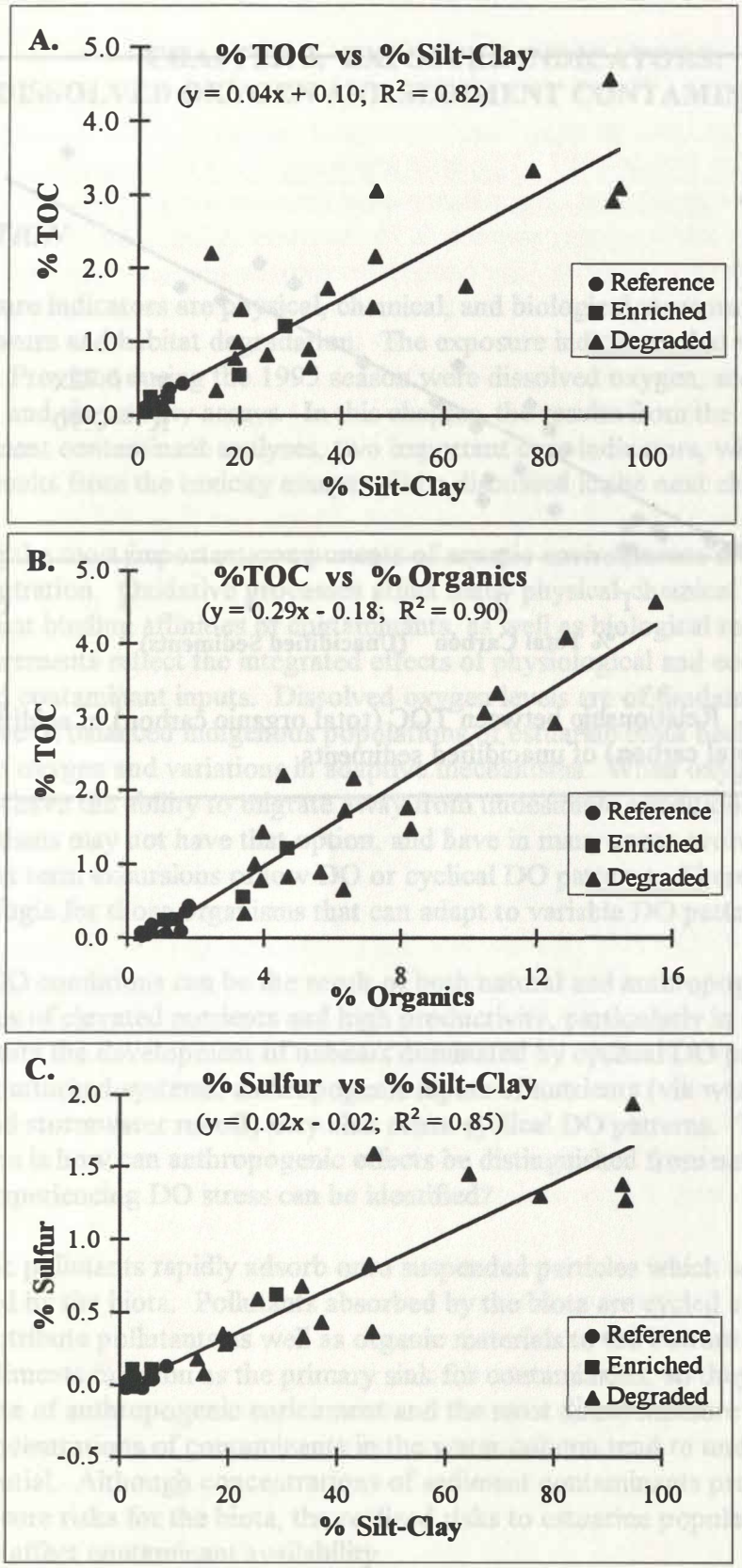


Figure 2-3. Plots of the relationships between various sediment parameters. **A.** %TOC vs % Silt-Clay; **B.** %TOC vs % Organics; **C.** % Sulfur vs % Silt-Clay.

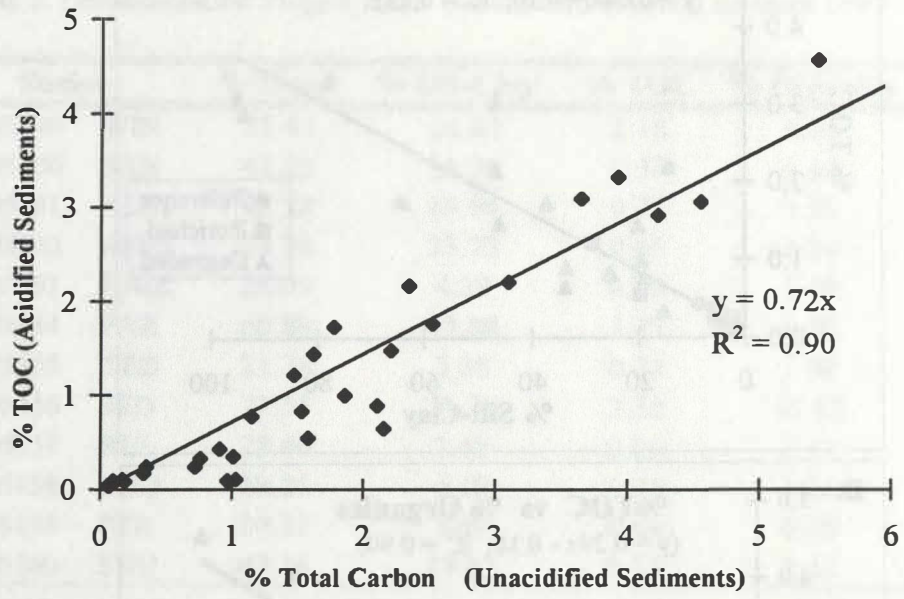


Figure 2-4. Relationship between TOC (total organic carbon) of acidified sediments and TC (total carbon) of unacidified sediments.

CHAPTER 3. EXPOSURE INDICATORS: DISSOLVED OXYGEN AND SEDIMENT CONTAMINANTS

INTRODUCTION

Exposure indicators are physical, chemical, and biological measurements that indicate pollutant exposure and habitat degradation. The exposure indicators that were evaluated in the Carolinian Province during the 1995 season were dissolved oxygen, sediment contaminants, and six toxicity assays. In this chapter, the results from the dissolved oxygen data and sediment contaminant analyses, two important core indicators, will be presented and discussed. Results from the toxicity assays will be discussed in the next chapter.

One of the most important components of aquatic environments is the dissolved oxygen concentration. Oxidative processes affect many physical-chemical processes such as pH and sediment binding affinities of contaminants, as well as biological responses. Dissolved oxygen measurements reflect the integrated effects of physiological and ecological processes to nutrient and contaminant inputs. Dissolved oxygen levels are of fundamental importance to the maintenance of balanced indigenous populations of estuarine biota because of the essential requirement of oxygen and variations in adaptive mechanisms. When oxygen levels are low, mobile species have the ability to migrate away from undesirable conditions. Sessile or low mobility organisms may not have that option, and have in many cases evolved mechanisms to cope with short term excursions of low DO or cyclical DO patterns. Therefore, estuaries can function as refugia for those organisms that can adapt to variable DO patterns.

Low DO conditions can be the result of both natural and anthropogenic factors. Natural sources of elevated nutrients and high productivity, particularly in shallow tidal systems, facilitate the development of habitats dominated by cyclical DO patterns (Holland et al, 1996). In perturbed systems, anthropogenic inputs of nutrients (via wastewater discharges, agricultural and stormwater runoff) may also cause cyclical DO patterns. Therefore the critical question is how can anthropogenic effects be distinguished from natural variations so that systems experiencing DO stress can be identified?

Aquatic pollutants rapidly adsorb onto suspended particles which settle to the bottom, or are absorbed by the biota. Pollutants absorbed by the biota are cycled as wastes or detritus which also contribute pollutants as well as organic materials to the bottom sediments. Therefore, sediments function as the primary sink for contaminants, so they provide a more reliable estimate of anthropogenic enrichment and the most direct measure of exposure potential. Concentrations of contaminants in the water column tend to underestimate exposure potential. Although concentrations of sediment contaminants provide estimates of potential exposure risks for the biota, the realized risks to estuarine populations are controlled by factors that affect contaminant availability.

METHODS

Instantaneous readings as well as continuous records of DO were taken at each core site using a Hydrolab Datasonde 3. This instrument employs a polarographic-type sensor, fitted with a LoFlow membrane. For instantaneous measurements, profiles of water column measurements were taken at approximately 0.5 m intervals for sites less than 3 m, and at 1.0 intervals for sites greater than 3 m. For continuous records, measurements were taken at 30 minute intervals for $\geq$ 24 hours. Each instrument was calibrated the morning before deployment, and had to function within an acceptable range for the measured parameters. Pre-deployment and post-deployment QA/QC checks were conducted to insure the validity of the readings (Kokkinakis et al., 1994 Field Operations Manual). There were some cases in which the Datasondes were exposed during low tides, but other parameters such as salinity and depth can be used to identify invalid records. These records were removed from the data set before any statistical analyses were conducted. Means and standard deviations were calculated and time series plots were generated.

Composite sediments were collected for determination of metal and organic contaminants. Sediments for metals analyses were placed in polyethylene jars, and sediments for organic contaminants were placed in glass jars with Teflon caps. The sediments were frozen until analysis by Texas A&M. A total of 16 inorganic metals were measured by FAA , GFAA, or CVAA (for Hg); 44 PAHs and Total PAHs were measured by GC/MS-SIM; 28 aliphatic hydrocarbons were measured by GC/FID; 24 pesticide contaminants were measured by GC/EID; 18 PCB congeners and Total PCBs were measured by GC/ECD. The classes of contaminants are listed in Table 3-1. One new PCB congener, PCB 118, was measured in 1995 that was not measured in 1994; and three congeners were measured in 1994 that were not measured in 1995 (77/110, 188/108/149, 126). Although QA/QC procedures indicated that overall the data were acceptable, there were some problems with measurements of a few specific analytes. For example, PCB congener 170/190 exceeded acceptable limits of recovery from standard sediments, and there were sometimes high concentrations measured in the blanks, suggesting that there may be wide-spread contamination or some other background measurement problem. Also some pesticide analytes, such as endrin and dieldrin, did not meet defined detection limits, such that detection limits were sometimes above the current ER-L guidelines. All concentrations were based on sediment dry weight.

The concentrations of metals in sediments are highly dependent on the concentration of fine grain materials. Therefore the degree of enrichment at each site was determined using aluminum normalization techniques (Windom et al., 1989; Hanson et al., 1993). Reference sites were used to generate Al-normalized plots, regressions and prediction intervals (data with residuals > 2 were removed), and then the remaining sites were overlaid. Al-normalized regressions were generated using Al data expressed as percent as well as log-log regressions.

Table 3-1. List of metal and organic analytes measured in sediments collected as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995.

Metals	PAHs	Aliphatics	Pesticides	PCBs
Ag	Naphthalene	C10	Hexachlorobenzene	PCB 8/5
Al	C1-Naphthalenes	C11	Alpha HCH	PCB 18/17
As	C2-Naphthalenes	C12	Beta HCH	PCB 28
Cd	C3-Naphthalenes	C13	Gamma HCH	PCB 52
Cr	C4-Naphthalenes	C14	Delta HCH	PCB 44
Cu	Biphenyl	C15	Heptachlor	PCB 66
Fe	Acenaphthylene	C16	Heptachlor Epoxide	PCB 101/90
Mn	Acenaphthene	C17	Oxychlordane	PCB 118
Ni	Fluorene	C18	Gamma Chlordane	PCB 153/132
Pb	C1-Fluorenes	C19	Alpha Chlordane	PCB 105
Sb	C2-Fluorenes	C20	Trans-nonachlor	PCB 138/160
Se	C3-Fluorenes	C21	Cis-nonachlor	PCB 187
Si	Phenanthrene	C22	Aldrin	PCB 128
Sn	Anthracene	C23	Dieldrin	PCB 180
Zn	C1-Phen-Anthr	C24	Endrin	PCB 170/190
Hg	C2-Phen-Anthr	C25	2,4' DDE	PCB 195/208
	C3-Phen-Anthr	C26	2,4' DDE	PCB 206
	C4-Phen-Anthr	C27	4,4' DDE	PCB 209
	Dibenzothio	C28	2,4' DDD	Total PCBs
	C1-Diben	C29	4,4' DDD	
	C2-Diben	C30	2,4' DDT	
	C3-Diben	C31	4,4' DDT	
	Fluoranthene	C32	Endosulfan II	
	Pyrene	C33		
	C1-Fluoran-Pyr	C34		
	Ben(a)Anthracene	Pristane		
	Chrysene	Phytane		
	C1-Chrysenes	Total Alkanes		
	C2-Chrysenes			
	C3-Chrysenes			
	C4-Chrysenes			
	Ben(b)Fluoran			
	Ben(k)Fluoran			
	Ben(e)pyrene			
	Ben(a)pyrene			
	Perylene			
	1123c,d-Pyrene			
	DBahAnthra			
	BghiPerylene			
	2-Methylnaph			
	1-Methylnaph			
	2,6-DiMethylnaph			
	1,6,7-TriMethylnaph			
	1-Methylphen			
	Total PAHs			

RESULTS and DISCUSSION

Dissolved Oxygen (DO)

The DO concentrations recorded during continuous deployments and the instantaneous profile are listed in Table 3-2. All data were considered to be valid based on QA/QC checks. Bottom readings taken during instantaneous measurements at all sites were never as low as the minimum values recorded during continuous measurements. As in the previous studies (1993 pilot studies and Year 1 Demonstration Project, 1994), the lowest DO readings tended to coincide with late night or early morning low tides, so instantaneous profiles should not be used to estimate minima. Also, consistent with previous studies, some sites had cyclical DO patterns that tended to be related to tidal and diurnal cycles (Figure 3-1).

Although EMAP protocols only require 24 hour records, an effort was made to leave the Datasondes deployed at some sites for longer periods when possible. Extended records were collected at the following stations: Parrot Point Creek (CP95154, 72 hrs), Ashley Marina(CP95ASH, 123 hrs), Diesel Creek (CP95DIE, 144 hrs), Koppers Creek (CP95KOP, 120 hrs), Lighthouse Creek (CP95LTH, 174 hrs), New Market Creek (CP95NMK, 120 hrs), Navy Base North (CP95NV1, 49.5), Navy Base South (CP95NV2, 47.5). Conclusions regarding DO conditions drawn from 24 hour records were not significantly altered when more extended records were examined. A time frame of 3 - 5 days would be preferred, because past studies have indicated that extended records will occasionally reveal a greater potential for stress than 24 hr deployments. However in most cases, a minimal 24 hr deployment provides a good representation for DO patterns so this time period is acceptable and is certainly much more valuable than instantaneous readings.

A number of criteria for identifying sites experiencing DO stress have been used in various EMAP programs. For the sites sampled in SC and GA, the following criteria for anoxic and severe hypoxic conditions, as well as chronic DO stress, were used to identify sites with evidence of dissolved oxygen stress.:

ACUTE DO STRESS

DO < 0.3 mg/L at any time
DO < 1.0 mg/L at least 10% of the time
DO < 2.0 mg/L at least 20% of the time

CHRONIC DO STRESS

DO maximum < 5.0 mg/L
DO range deviation > 3.5 mg/L
DO change rate > 0.5 mg/L/hr

The acute criteria and the chronic criterion of DO concentrations that never exceed 5.0 mg/L are the more traditional indicators of DO stress. Because, many southeastern estuaries are characterized by cyclical patterns with at least some periods below 5.0 mg/L (Table 3-2; Ringwood et al., 1995), we need to be able to identify truly stressful conditions in these

Table 3-2. Dissolved oxygen concentrations (mg/L) recorded from Hydrolab Datasonde 3s deployed at sites sampled by MRRI as part of the EMAP Year 2 Demonstration Project in the Carolinian Province, summer 1995. Summaries are based on 24 hr deployments.

State	Station		CONTINUOUS DEPLOYMENT			INSTANTANEOUS PROFILE		
			Mean ± Std	Minimum	Maximum	Surface	Bottom	Depth (m)
South Carolina Core Stations	CP95149	WIN	5.60 ± 0.36	4.77	6.14	7.91	6.77	5.9
	CP95150	SAN	6.82 ± 0.45	5.92	7.68	7.66	6.81	4.2
	CP95151	ASH1	5.95 ± 0.40	4.88	6.72	6.18	5.74	7.4
	CP95152	ASH2	5.78 ± 0.47	4.34	6.34	6.02	5.79	9.0
	CP95153	HAM	6.04 ± 0.86	3.86	7.70	6.66	6.63	3.2
	CP95154	PAR	6.39 ± 0.82	5.10	7.97	5.93	5.95	1.2
	CP95155	NED	5.55 ± 0.54	4.48	6.44	6.09	5.62	11.4
	CP95156	SED	5.37 ± 0.43	4.29	6.06	6.82	4.79	6.7
	CP95157	BUL	4.65 ± 0.48	3.62	5.22	5.26	4.11	10.6
	CP95158	COO	4.71 ± 0.53	3.95	5.76	5.82	4.56	4.8
	CP95159	PTR	6.00 ± 0.08	5.80	6.22	6.23	6.27	11.1
	CP95160	SKU	5.45 ± 0.27	4.78	5.87	6.30	5.22	2.1
Georgia Core Stations	CP95161	TYB	5.52 ± 0.59	4.25	6.53	6.72	5.80	5.3
	CP95162	SCH	5.16 ± 0.51	4.20	6.38	6.56	5.88	3.5
	CP95163	BRG	5.42 ± 0.57	4.50	6.39	6.15	6.02	8.4
	CP95164	OGE	5.33 ± 0.40	4.86	6.18	6.44	5.25	6.6
	CP95165	NEW	4.61 ± 0.59	3.59	5.75	6.92	5.78	8.0
	CP95166	MUD	4.01 ± 0.78	2.45	5.19	6.29	4.84	2.0
	CP95167	HMP	5.05 ± 1.27	0.04	7.03	4.86	4.17	3.5
	CP95168	JOI	5.16 ± 0.79	4.26	7.03	6.27	5.15	7.1
	CP95169	CUM	5.50 ± 0.47	4.56	6.41	6.39	6.23	6.0
South Carolina Supplemental Stations	CP95ASM	ASM	5.64 ± 0.35	4.79	6.52	7.90	6.80	0.8
	CP95DIE	DIE	4.36 ± 0.46	3.27	4.88	7.32	7.27	1.2
	CP95FOS	FOS	5.07 ± 1.12	2.93	6.52	5.73	5.73	2.5
	CP95KOP	KOP	3.82 ± 0.73	2.13	4.75	6.44	5.80	1.7
	CP95LTH	LTH	5.94 ± 0.7	4.45	7.17	na	na	2.4
	CP95NMK	NMK	4.24 ± 0.93	1.32	5.22	6.37	5.92	1.7
	CP95NV1	NV1	5.72 ± 0.11	5.40	5.94	6.94	5.64	8.1
	CP95NV2	NV2	3.73 ± 2.43	0.00	5.73	6.29	6.11	3.0
	CP95SPY	SPY	0.06 ± 0.01	0.04	0.11	8.01	6.29	2.5

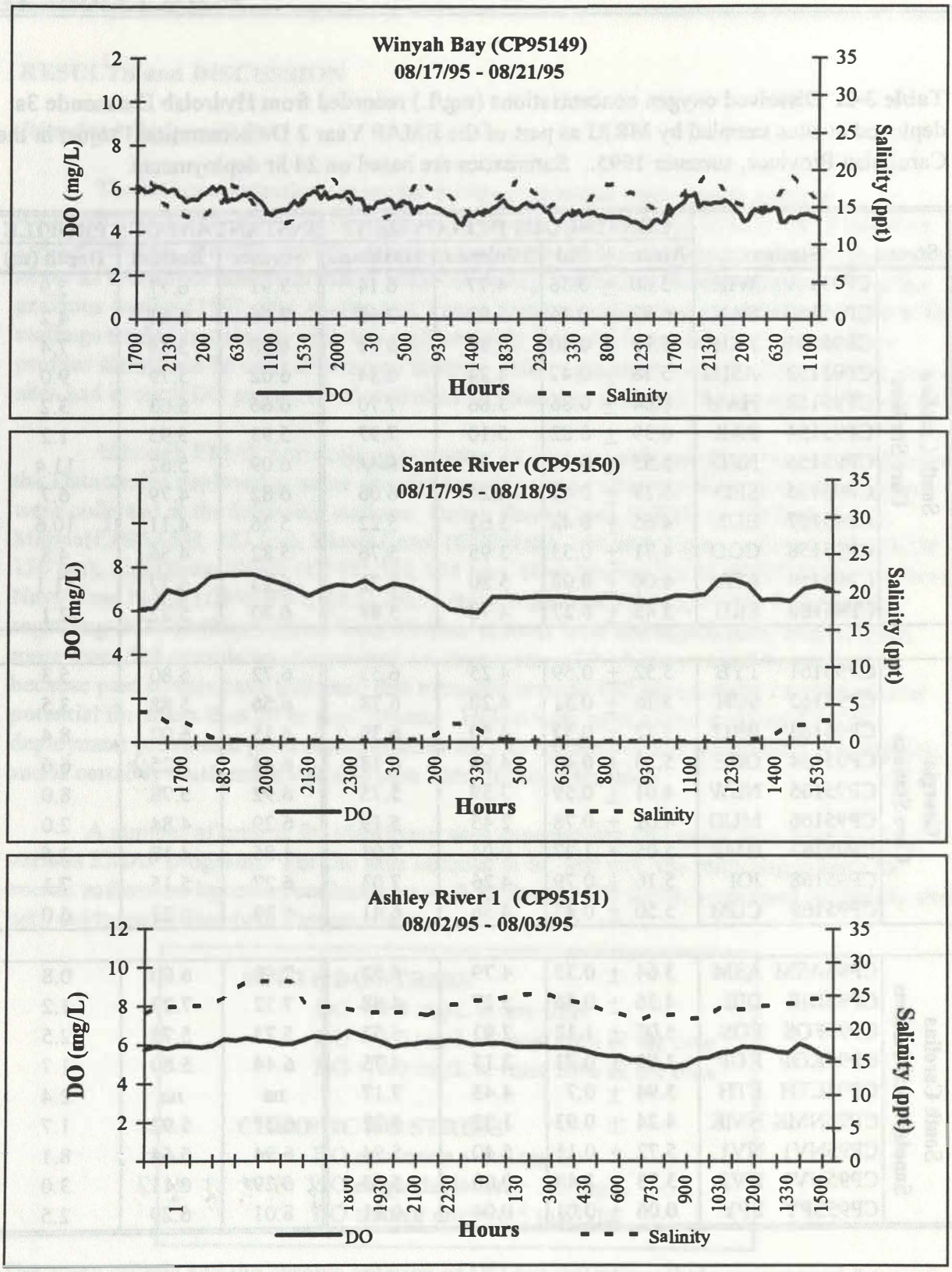
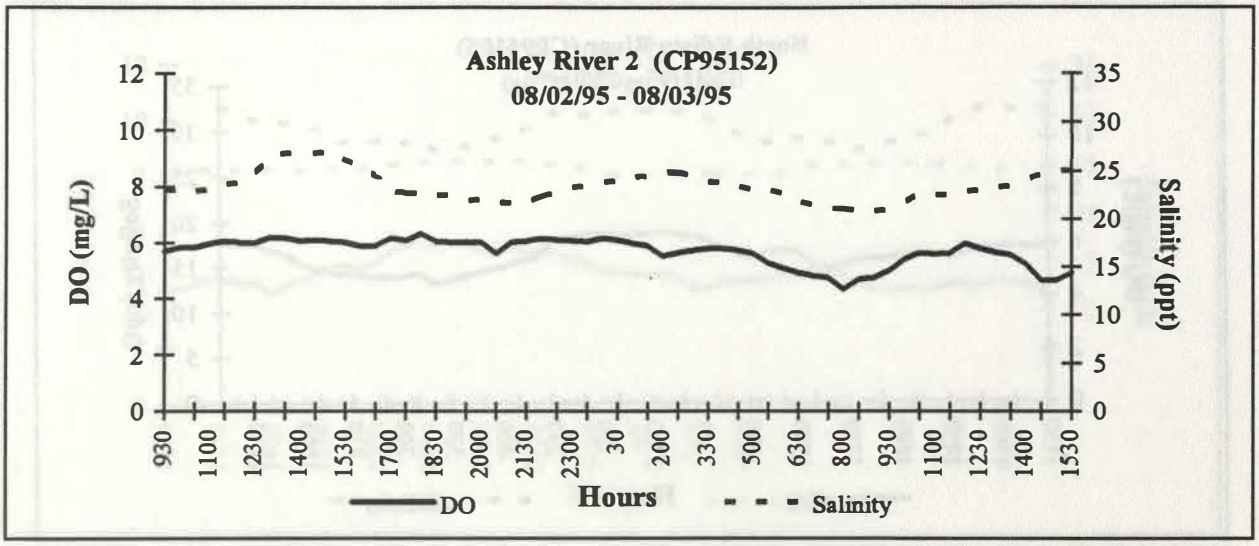
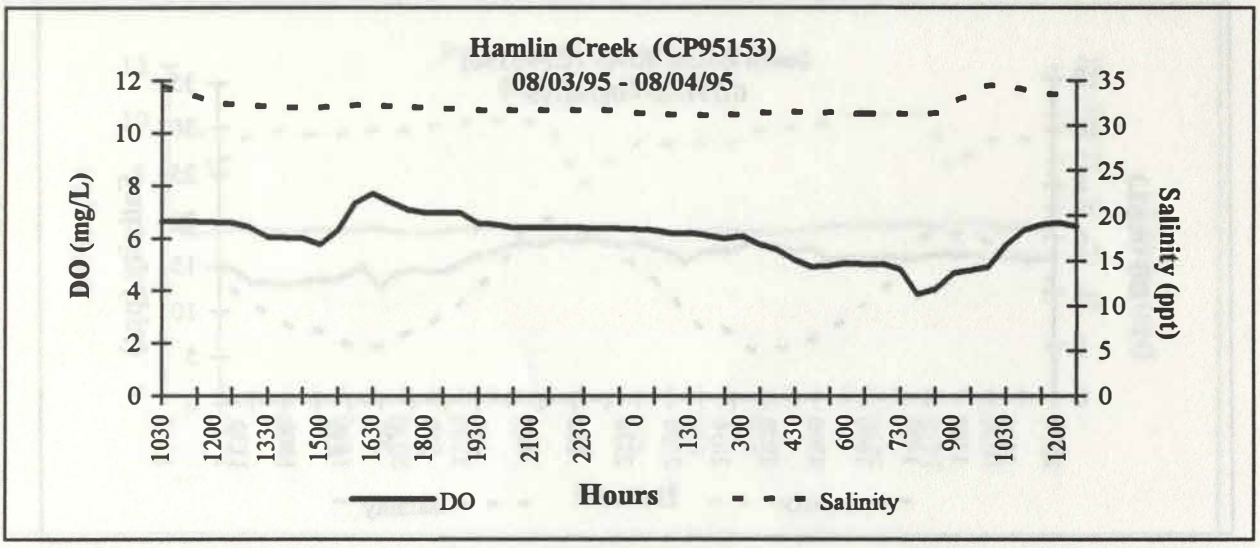
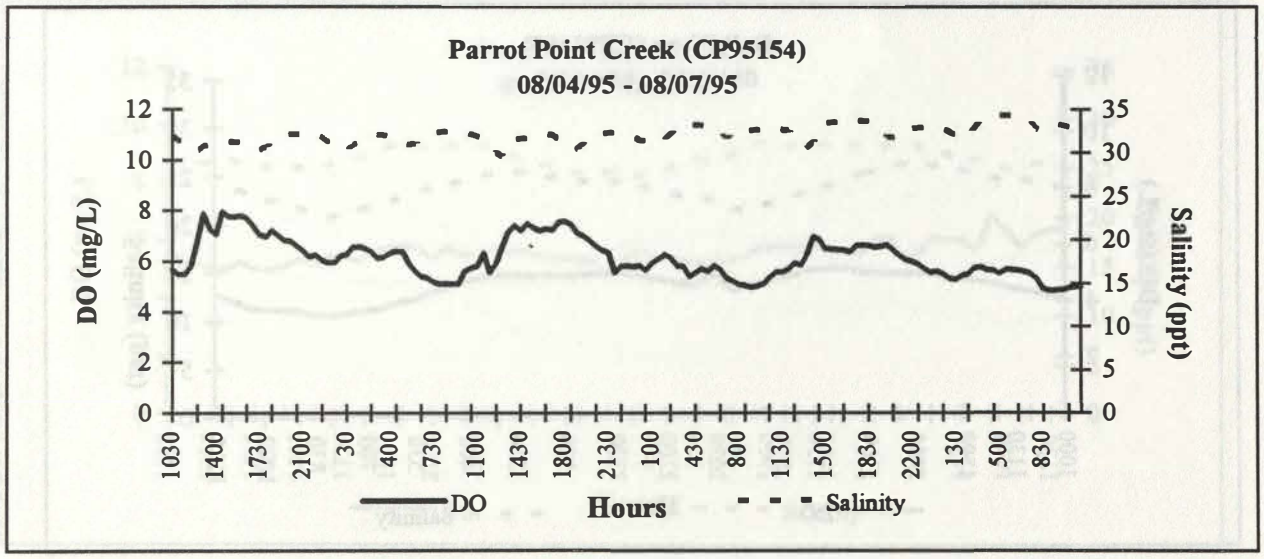


Figure 3-1. Plots of the dissolved oxygen and salinity records from Datasondes deployed for ≥ 24 hours at SC and GA sites sampled in the Carolinian Province, summer 1995.







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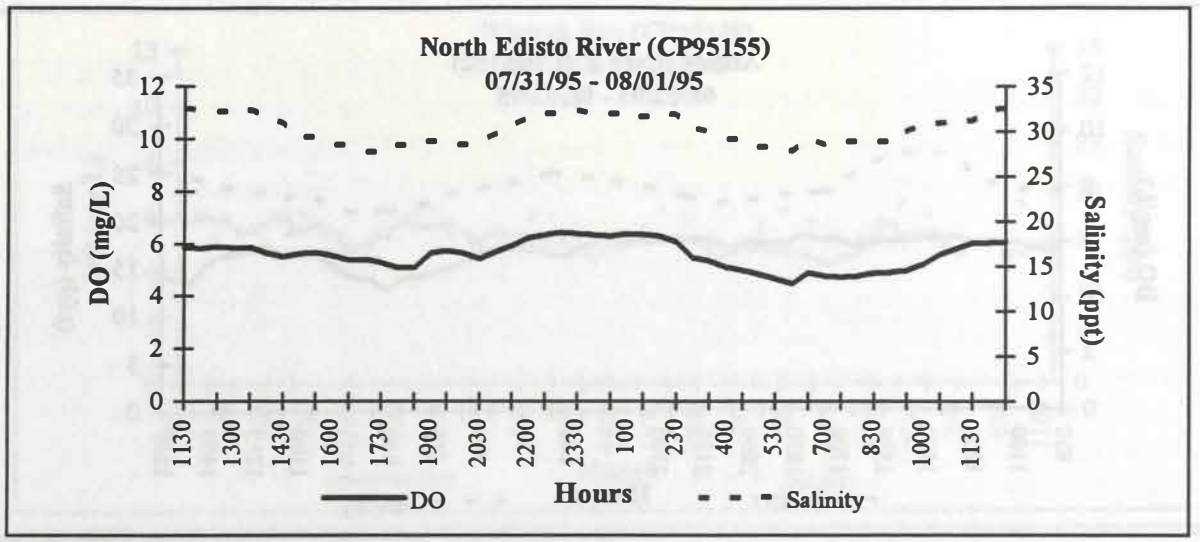

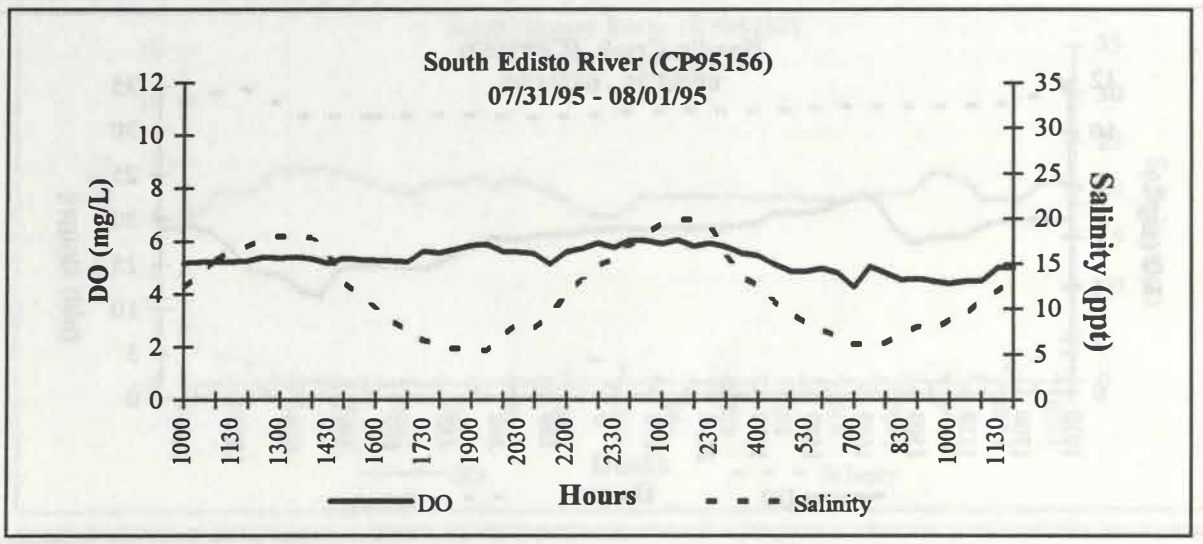

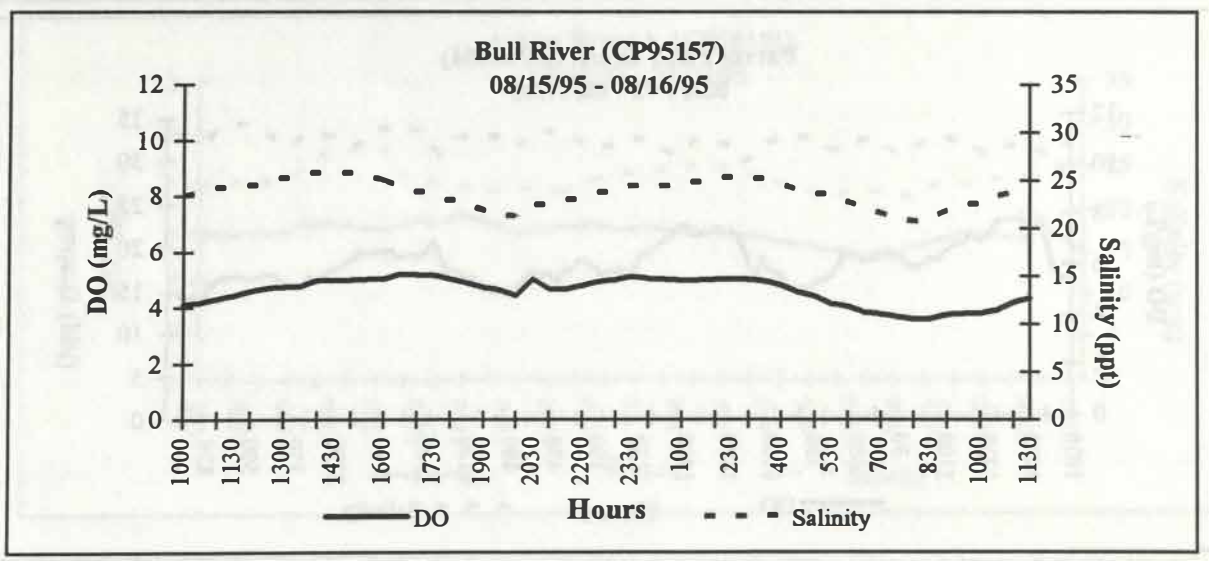

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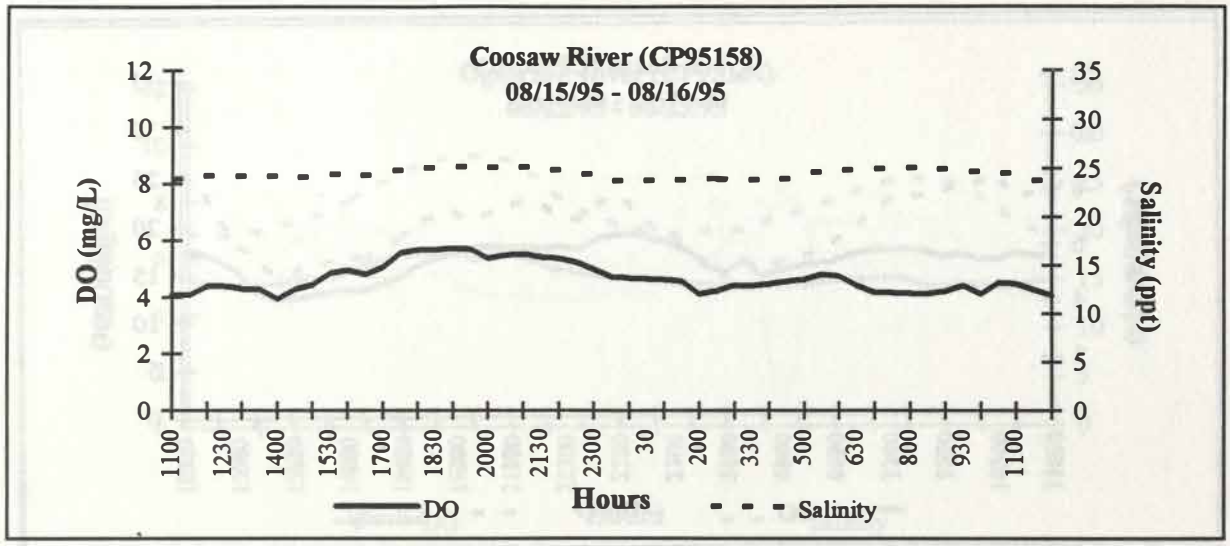

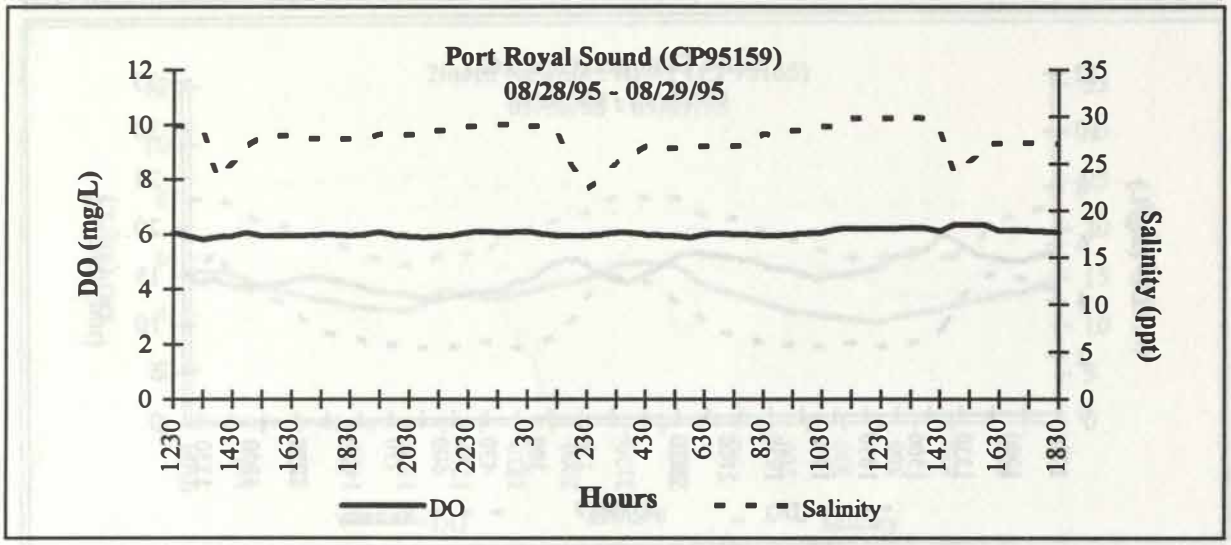

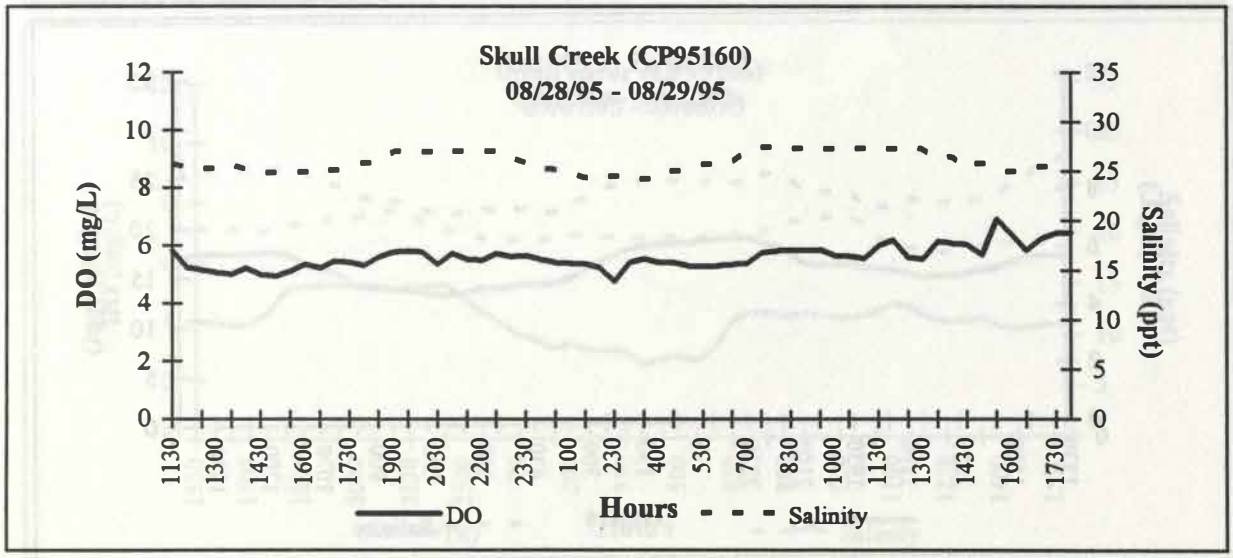

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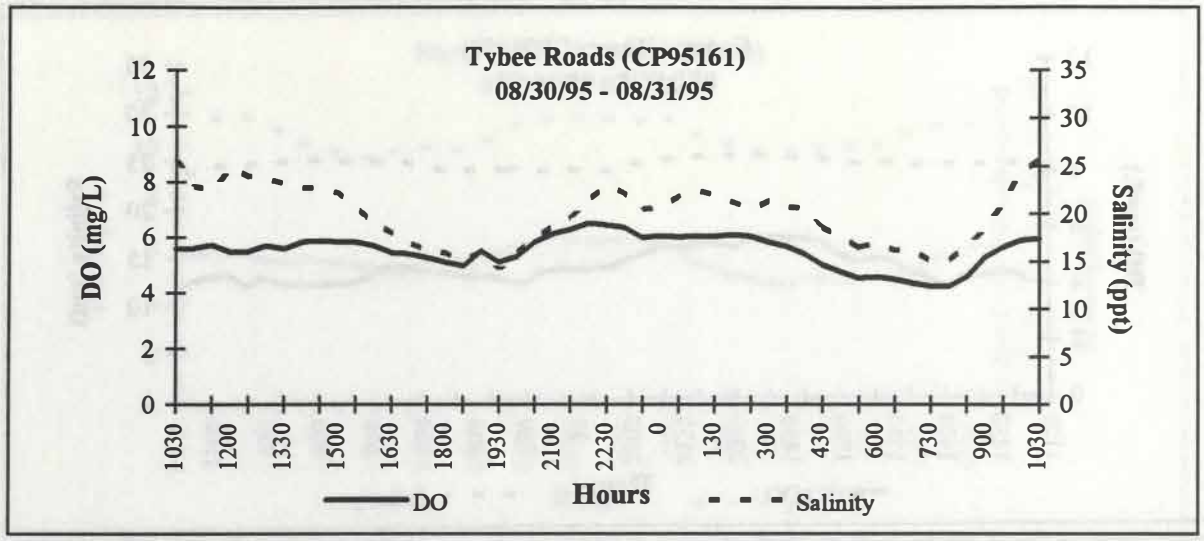

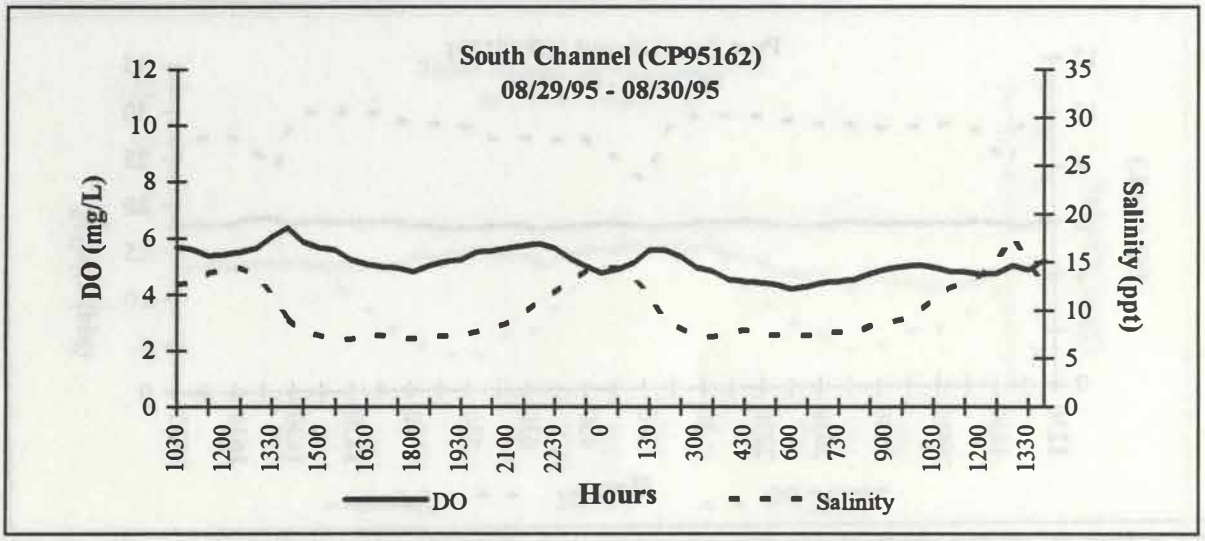

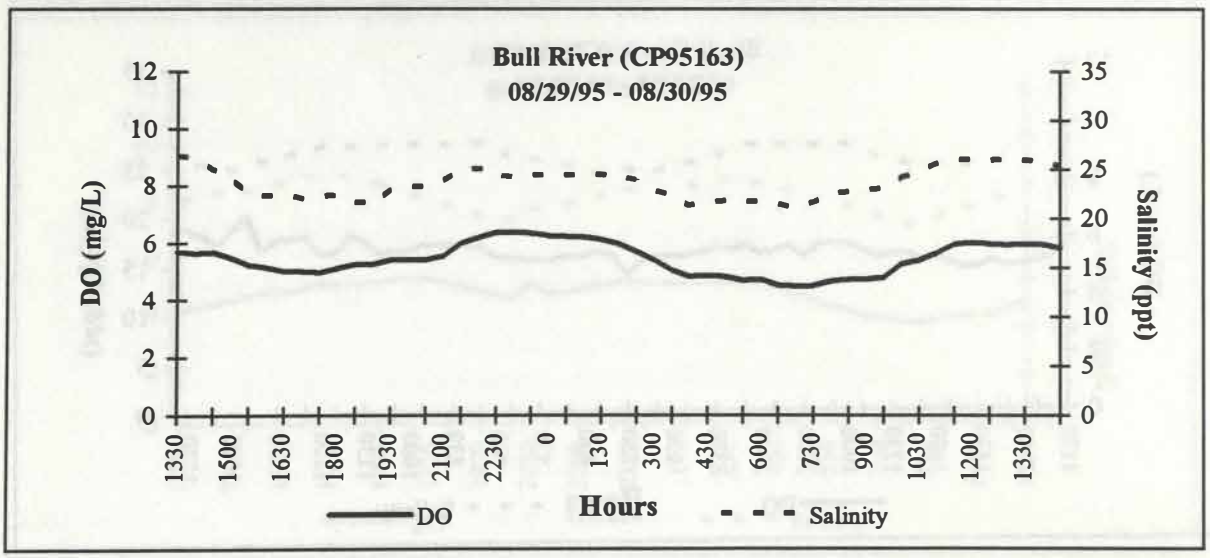

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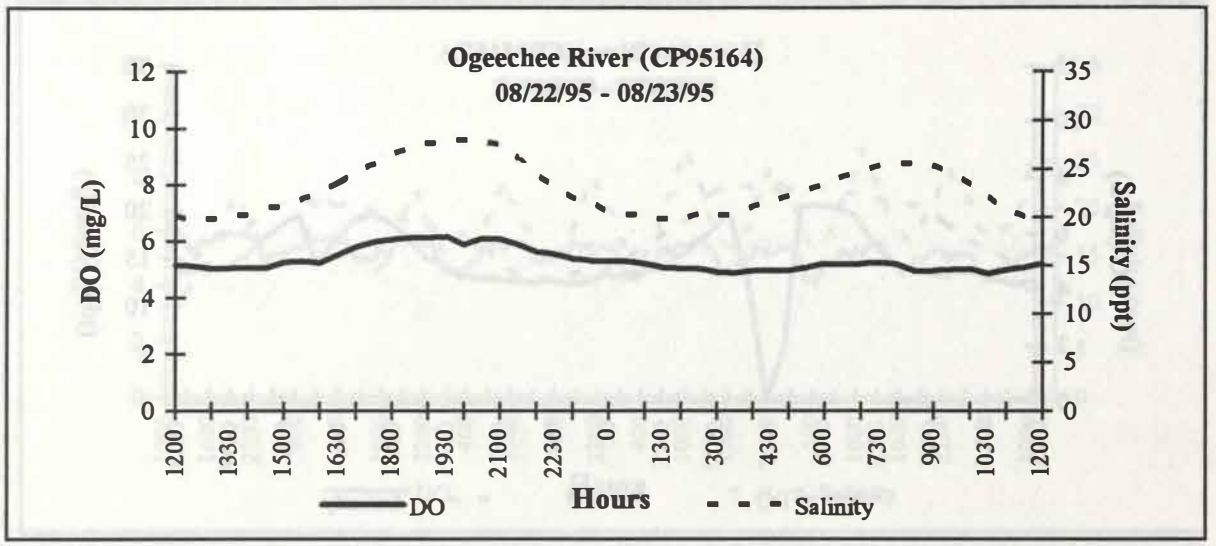

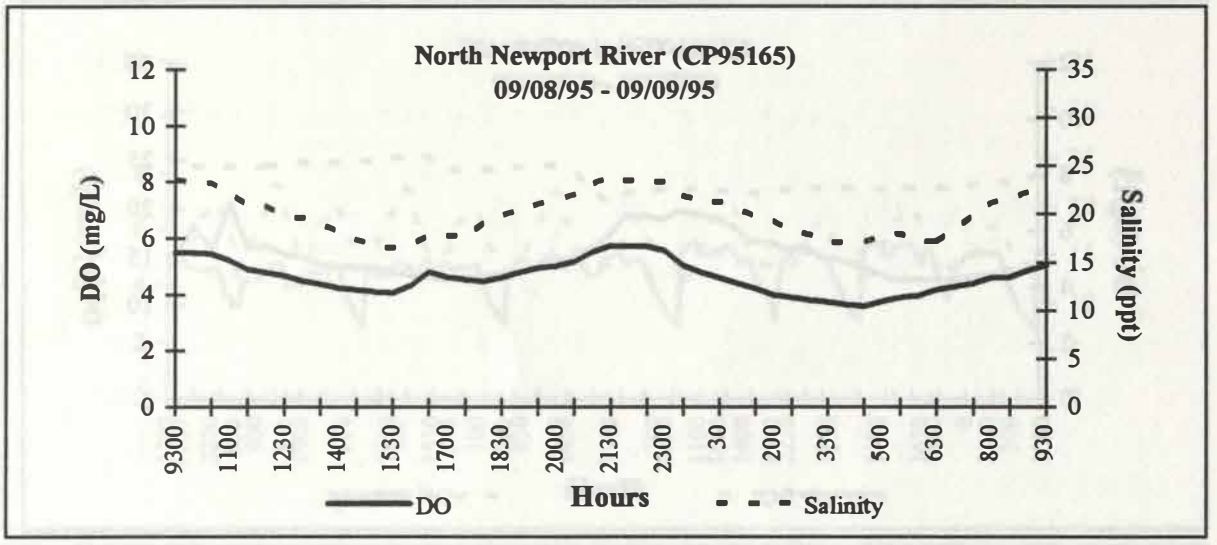

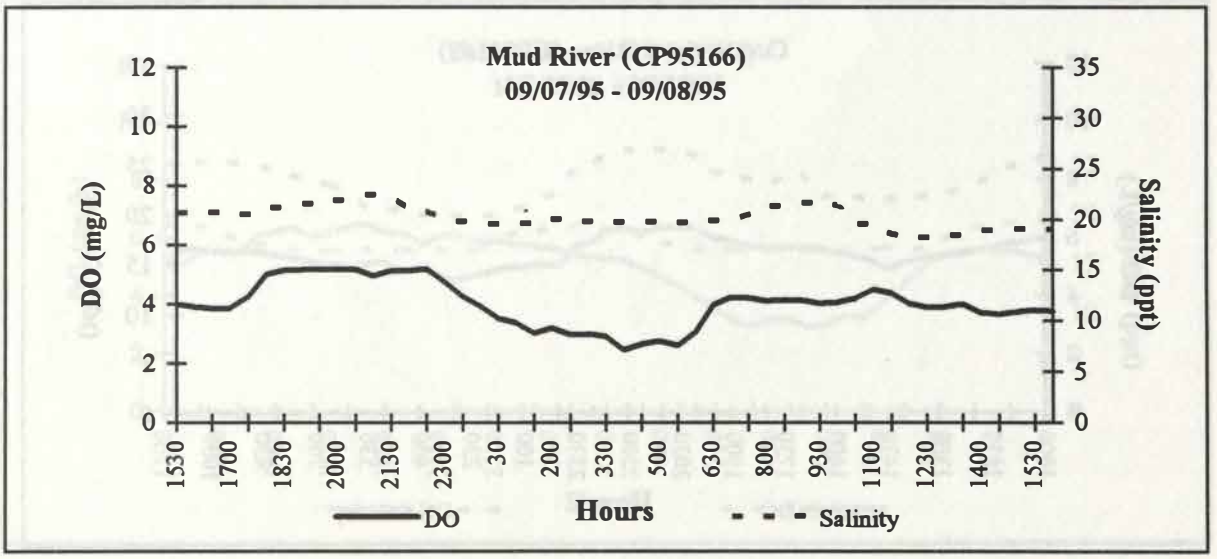

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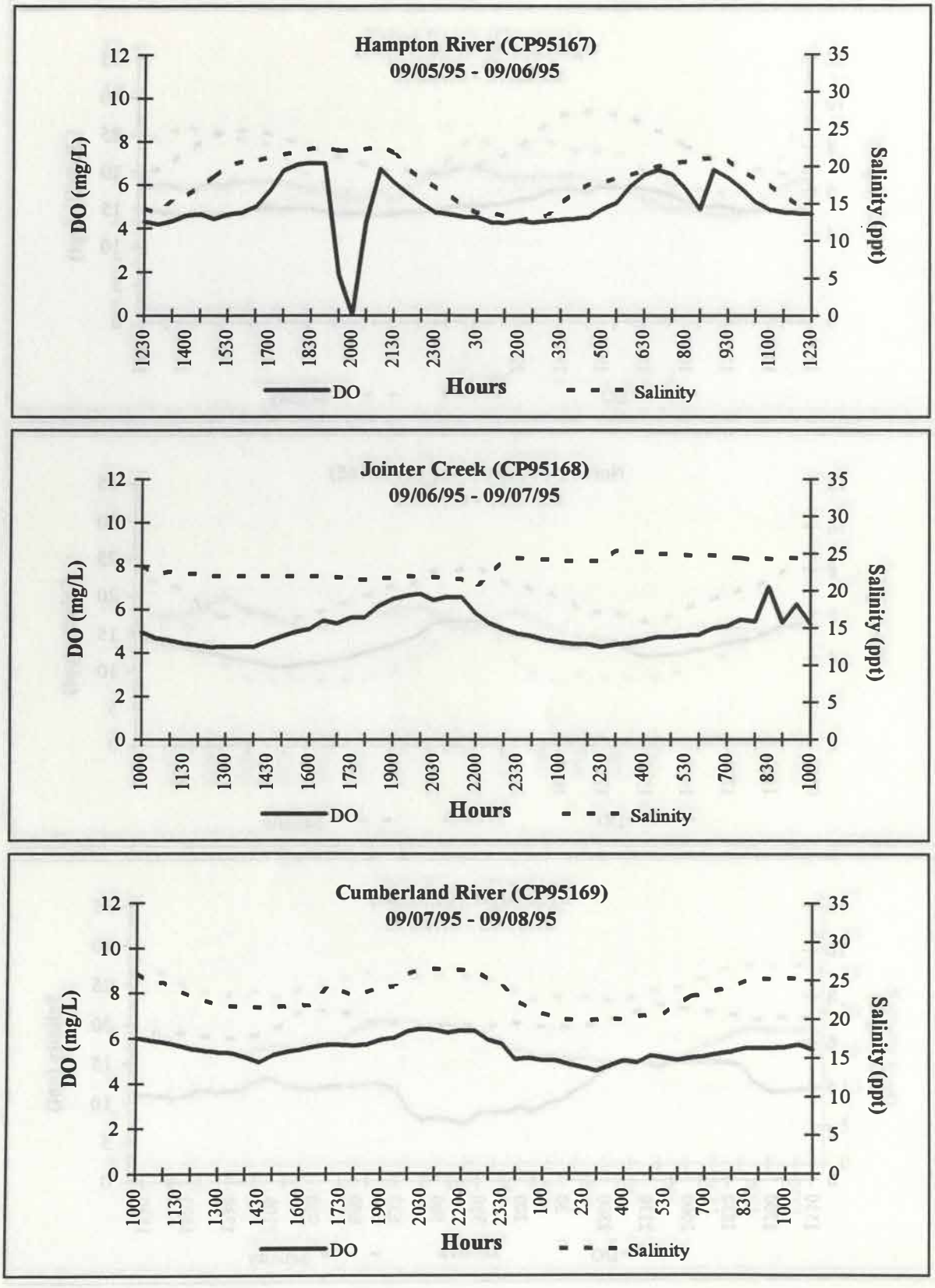

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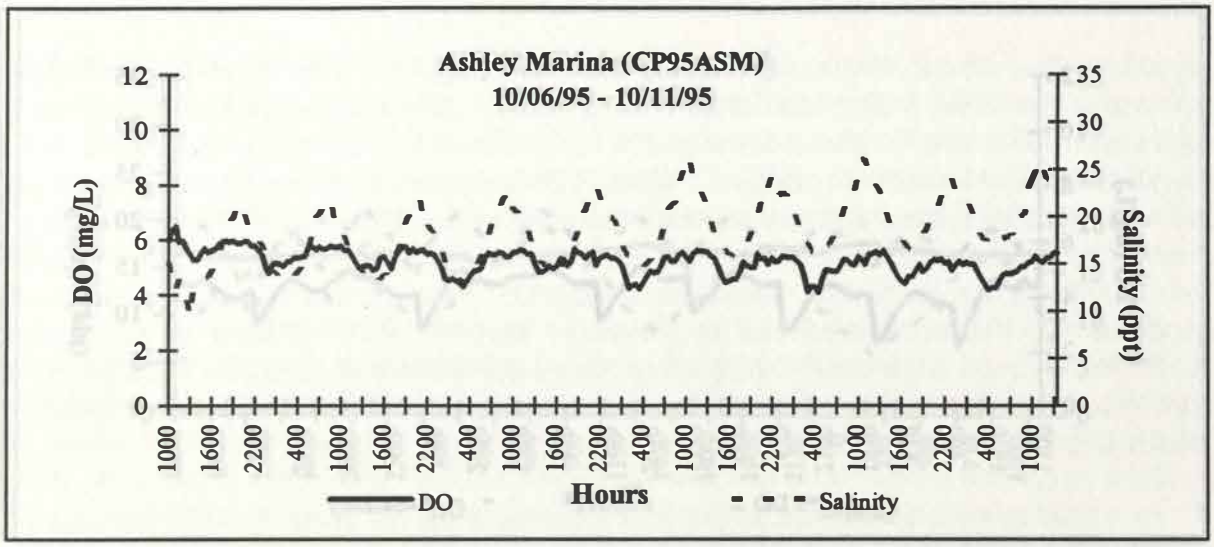

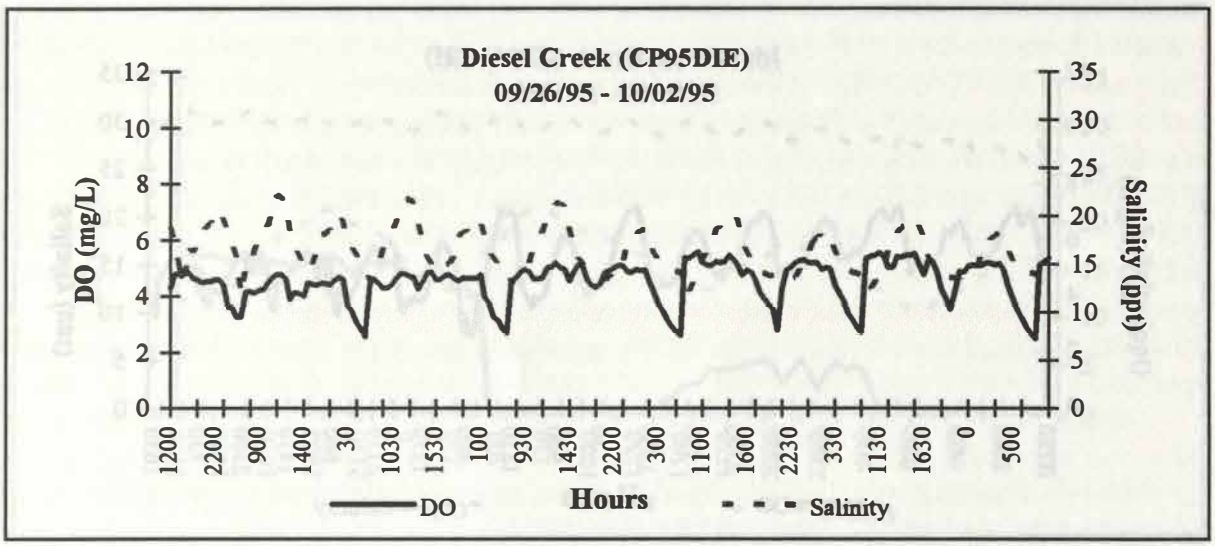

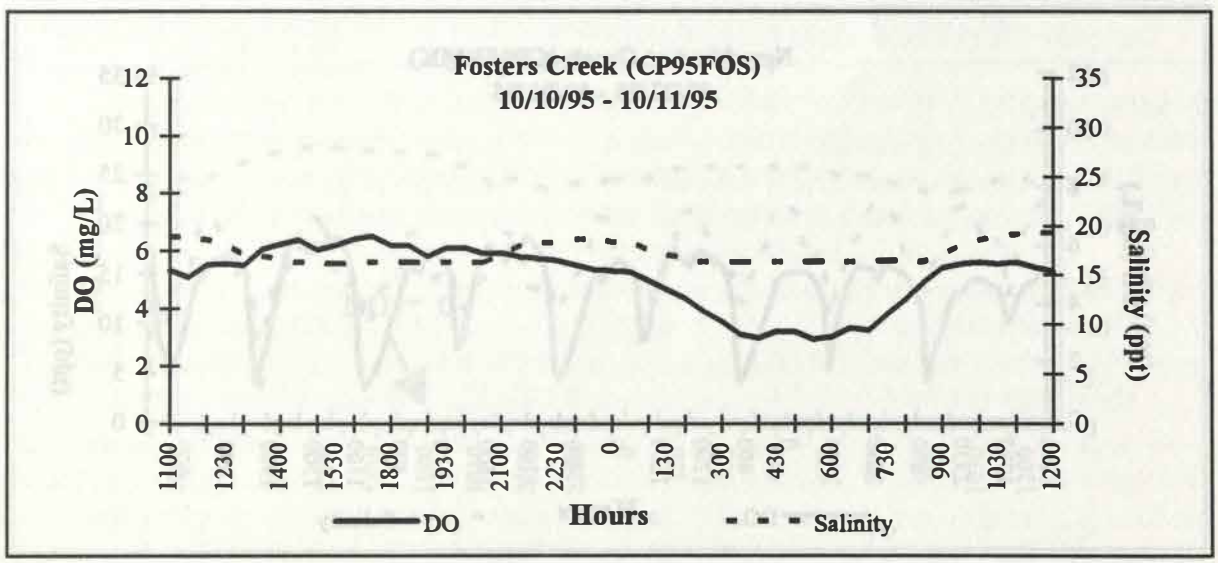

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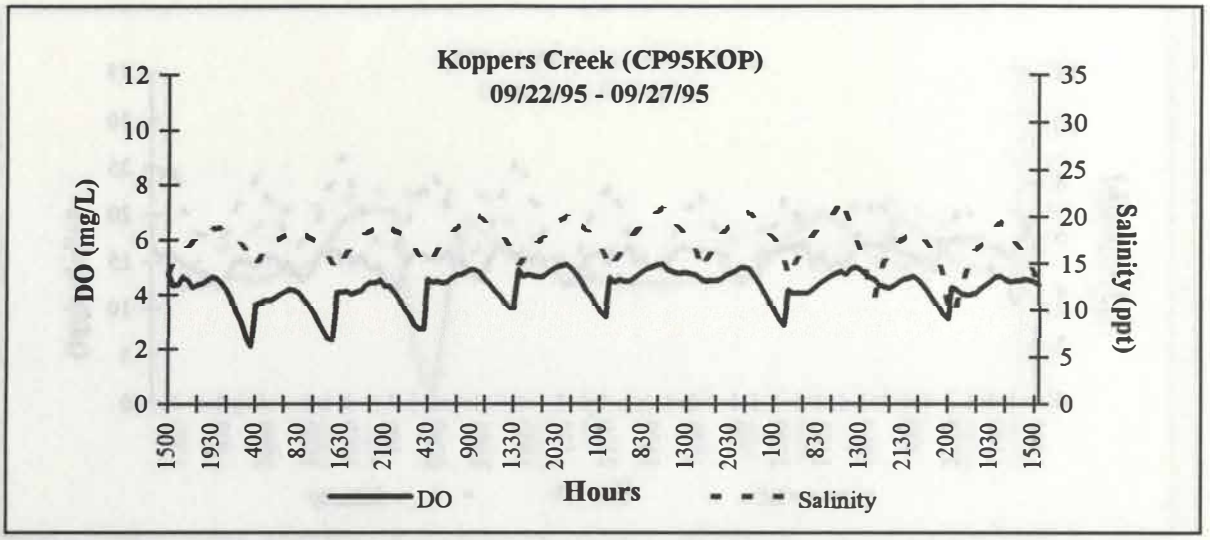

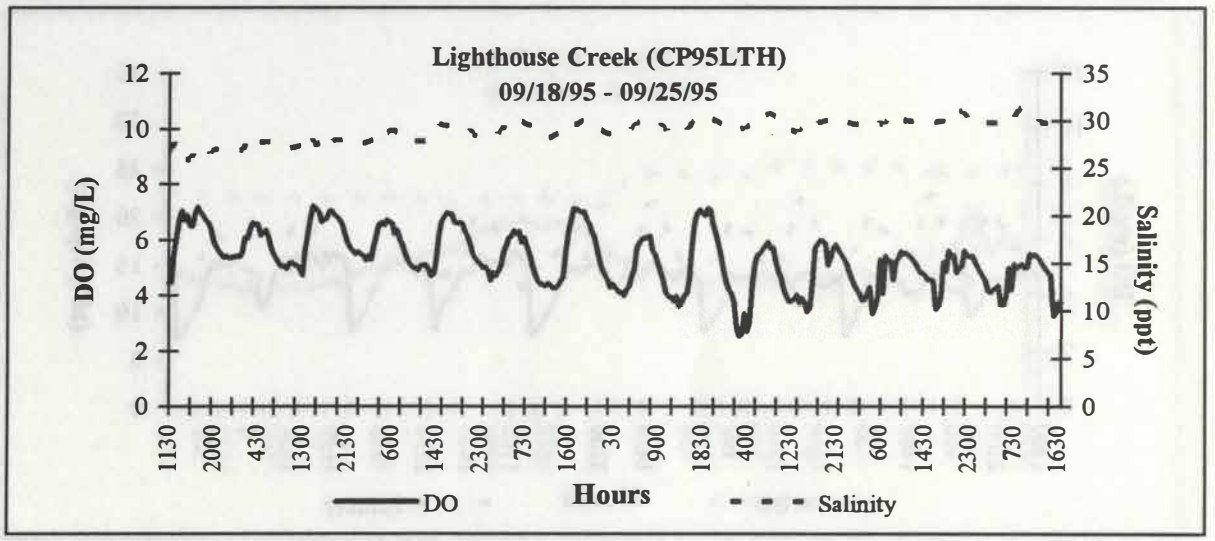

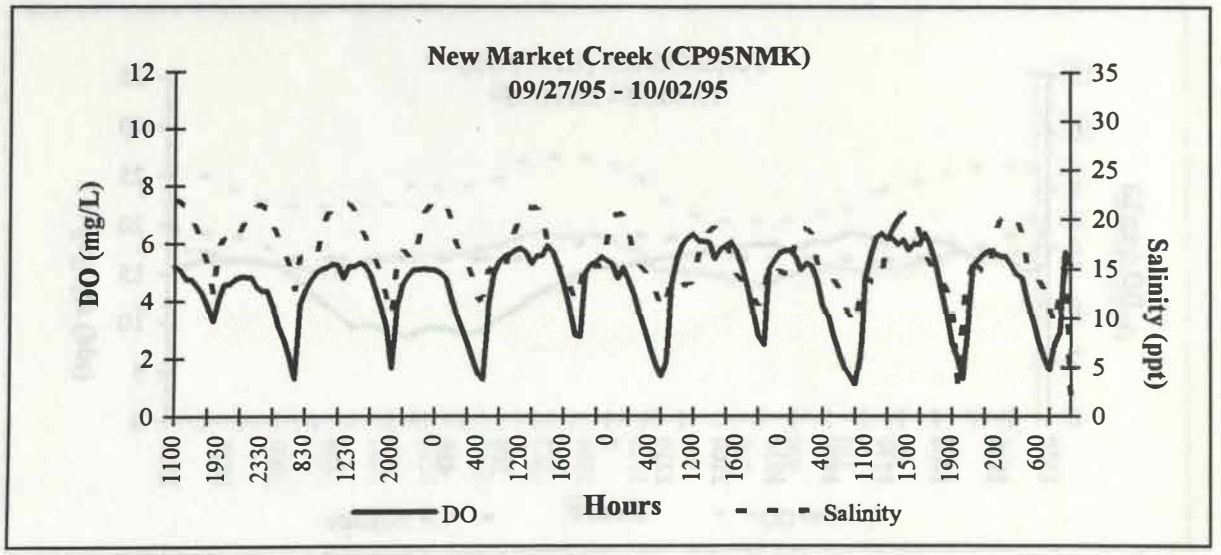

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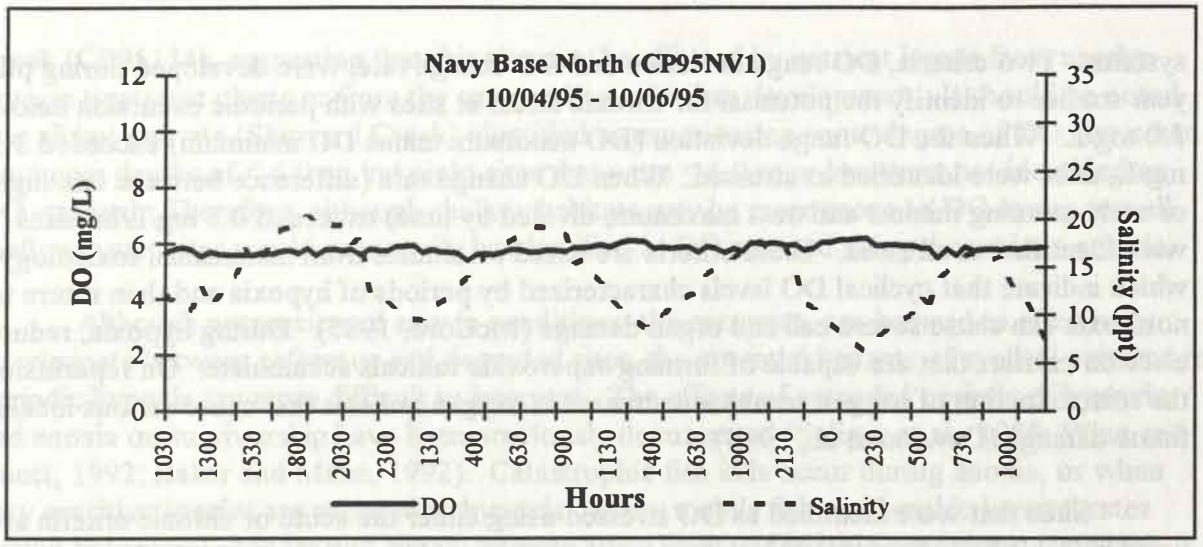

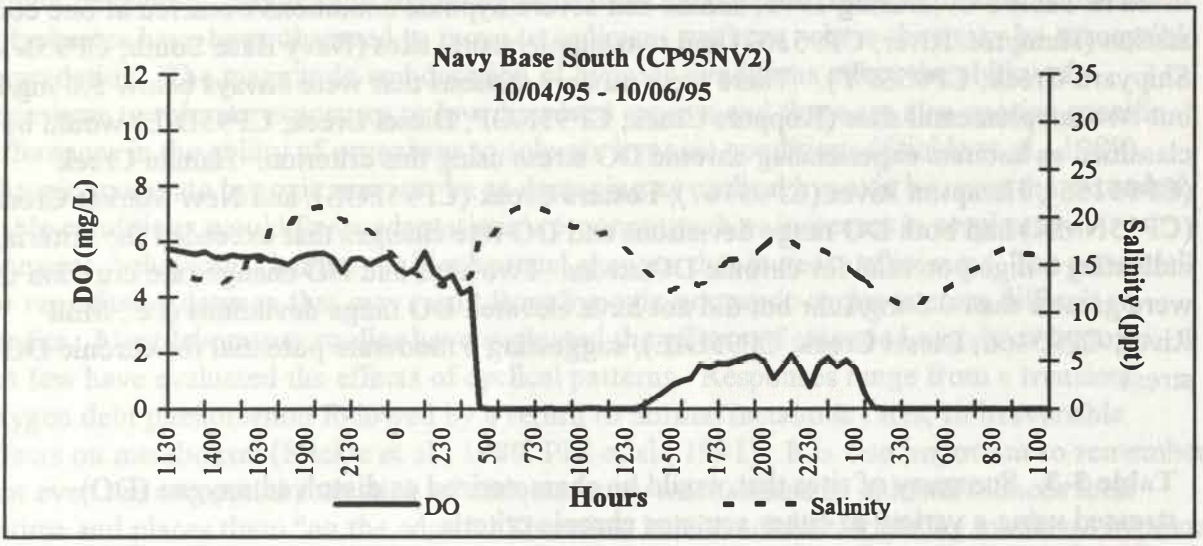

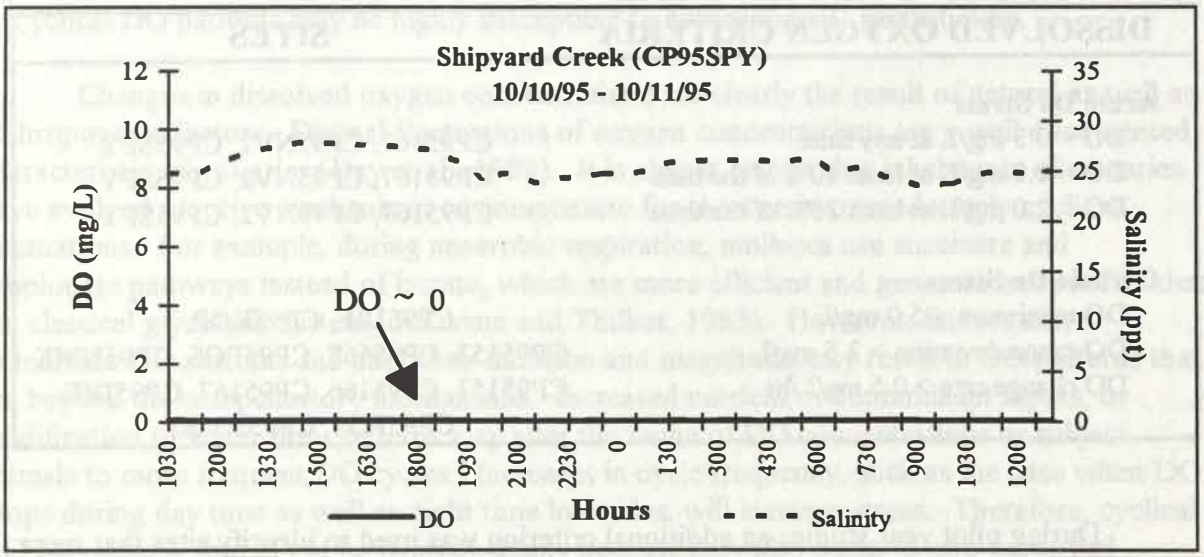

(Figure 3-1 continued)

systems. Two criteria, DO range deviation and DO change rate, were developed during pilot year studies to identify the potential for chronic stress at sites with periodic excursion below 5.0 mg/L. When the DO range deviation (DO maximum minus DO minimum) exceeded 3.5 mg/L, sites were identified as stressed. When DO change rate (difference between late night or early morning minima and next maximum, divided by time) exceeded 0.5 mg/L/hr, sites were identified as stressed. These criteria are based on studies from mammalian toxicology which indicate that cyclical DO levels characterized by periods of hypoxia and then return to normoxia can cause severe cell and organ damage (McCord, 1985). During hypoxia, reduced electron carriers that are capable of forming superoxide radicals accumulate. On reperfusion, the reintroduction of oxygen results in increases in oxygen radicals that cause serious localized tissue damage (Dawson et al., 1993).

Sites that were identified as DO stressed using either the acute or chronic criteria are listed in Table 3-3. During 1995, anoxic and severe hypoxic conditions occurred at one core station (Hampton River, CP95167) and two supplemental sites (Navy Base South, CP95NV2; Shipyard Creek, CP95SPY). There were no core stations that were always below 5.0 mg/L, but two supplemental sites (Koppers Creek, CP95KOP; Diesel Creek, CP95DIE) would be classified as habitats experiencing chronic DO stress using this criterion. Hamlin Creek (CP95153), Hampton River (CP95167), Fosters Creek (CP95FOS), and New Market Creek (CP95NMK) had both DO range deviations and DO rate changes that exceeded the criteria, indicating a high potential for chronic DO stress. Two sites had DO change rate criterion that were greater than 0.5 mg/L/hr but did not have elevated DO range deviations (i.e., Mud River, CP95166; Diesel Creek, CP95DIE), suggesting a moderate potential for chronic DO stress.

Table 3-3. Summary of sites that would be characterized as dissolved oxygen (DO) stressed using a variety of either acute or chronic criteria.

DISSOLVED OXYGEN CRITERIA	SITES
Acute Do Stress	
DO < 0.3 mg/L at any time	CP95167, CP95NV2, CP95SPY
DO < 1.0 mg/L at least 10% of the time	CP95167, CP95NV2, CP95SPY
DO < 2.0 mg/L at least 20% of the time	CP95167, CP95NV2, CP95SPY
Chronic Do Stress	
DO maximum < 5.0 mg/L	CP95DIE, CP95KOP
DO range deviation > 3.5 mg/L	CP95153, CP95167, CP95FOS, CP95NMK
DO change rate > 0.5 mg/L/hr	CP95153, CP95166, CP95167, CP95DIE, CP95FOS, CP95NMK

During pilot year studies an additional criterion was used to identify sites that were supersaturated (DO > 8.0 mg/L). In those studies maximal DO concentrations > 8.0 mg/L were observed at a number of sites, all known to receive substantial inputs of treated wastewater from sewage treatment plants. The only site that approached this level was Parrot

Creek (CP95154), suggesting that this site may be affected by nutrient inputs from nearby sewage treatment plants or from the surrounding suburban development. It should be noted that all but one site (Shipyard Creek) identified as experiencing some degree of DO stress had maximum depths of < 6.0 m; but eight sites that were ≤ 6.0 m or less were not identified as DO stressed. Therefore, although shallow habitats may be more prone to DO stress, not all shallow water sites would necessarily be identified as DO stressed using the various criteria.

Although normoxic and anoxic conditions, the extremes, can be used to effectively discriminate between reference and degraded sites, the potential impacts of cyclical patterns or periodic hypoxia are more difficult to interpret. The effects of extended periods of hypoxia and anoxia on survivorship have been previously documented (Seliger et al., 1985; Winn and Knott, 1992; Baker and Mann, 1992). Catastrophic fish kills occur during anoxia, or when very sensitive species are exposed to hypoxia. Many mobile fish and benthic invertebrates exhibit behavioral changes and simply migrate away from undesirable conditions. Infaunal polycheates have been observed to move to sediment surfaces, where they may be susceptible to predation. The magnitude and duration of hypoxic conditions affect the ability of organisms to tolerate exposures to low dissolved oxygen and there are also species specific differences in the ability of organisms to tolerate hypoxic conditions (Stickle et al., 1989). Chronic moderate hypoxia may not be as damaging as cyclical hypoxia because the extended stable conditions would favor adaptational responses such as increases in respiratory pigments, behavioral changes, or biochemical changes that increase efficiency. The potential for reperfusion damage that may result from hypoxic-normoxic cycles is more difficult to predict. Most laboratory studies have evaluated the effects of extended anoxia or hypoxia, but few have evaluated the effects of cyclical patterns. Responses range from a transient oxygen debt phenomenon followed by a return to normal metabolic rates, to irreversible effects on metabolism (Stickle et al., 1989; Pihl et al., 1991). It is also important to remember that even the successful activation of compensatory mechanisms by animals reduces their optima and places them "on the edge." Therefore habitats characterized by moderate hypoxia or cyclical DO patterns may be highly susceptible to anthropogenic perturbation.

Changes in dissolved oxygen concentrations are clearly the result of natural as well as anthropogenic factors. Diurnal fluctuations of oxygen concentrations are a well documented characteristic of estuaries (Day et al., 1989). It is almost certain that inhabitants of estuaries have evolved adaptive mechanisms to compensate for short term or moderately cyclical fluctuations. For example, during anaerobic respiration, molluscs use succinate and propionate pathways instead of lactate, which are more efficient and generate more ATPs than the classical glycolysis system (deZwann and Thillart, 1985). However, factors that exacerbate DO patterns and alter their duration and magnitude may result in DO patterns that are beyond the compensatory mechanisms. Increased nutrient or contaminant inputs, or modification of water flow patterns may alter the range of DO concentrations or subject animals to more frequent DO cycles. Increases in cycle frequency, such as the case when DO drops during day time as well as night time low tides, will increase stress. Therefore, cyclical DO phenomena should not be ignored simply because they also occur in non-perturbed systems. The combined effects of DO cycles and anthropogenic perturbations may range from periodic catastrophic mortalities to more chronic effects on growth and reproduction.

Sediment Contaminants

Determination of contaminant concentrations that are likely to have adverse effects on the biota is still an emerging science. Long and Morgan (1990) and MacDonald (1993) produced important studies regarding the development of sediment guidelines based on biological effects. These investigators have recently combined their efforts and published modifications of the ER-L and ER-M values (Long et al., 1995). These two guideline values delineate three concentrations ranges. Concentrations below ER-L values were defined as the minimal-effects range in which effects would be rarely observed. Contaminant concentrations > ER-L but < ER-M indicate a possible-effects range, and those > ER-M represent a probable-effects range.

Polycyclic aromatic hydrocarbons occur naturally as products of fossil fuels such as oil and coal. Low molecular weight PAHs are generally associated with petroleum, whereas the high molecular weight PAHs are combustion products. The major mode of toxicity for low molecular weight PAHs is believed to be due to interference with cellular membrane function and membrane associated enzyme systems (Neff, 1984). Higher weight PAHs are frequently found to be very carcinogenic. Tumorigenic, teratogenic, and mutagenic effects as well as immunosuppressive effects have been demonstrated (Eisler, 1987; Faisal and Huggett, 1993). Metabolic transformations can occur that result in intermediates that may also be highly toxic. Cytochrome P-450 mixed function oxidases can detoxify some PAHS, but others result in the production of even more toxic compounds (Neff, 1984). Toxicity generally increases as molecular weight increases.

The aliphatic and aromatic hydrocarbon data for those analytes which have ER-L and ER-M values are listed in Table 3-4 for all stations sampled over the Carolinian Province during 1995. The supplemental stations are listed in the last section of the table and the ER-L and ER-M values are also provided for reference. Only one core station (Ashley River, CP95152) had an analyte (pyrene) that exceeded ER-M values, and no supplemental stations had PAH concentrations that exceeded ER-M values. Only two core stations had ER-L exceedances (South Santee, CP95150; Ashley River, CP95152). Several of the supplemental stations in the Charleston Harbor area had ER-L exceedances (Diesel Creek, CP95DIE; Koppers Creek, CP95KOP; New Market Creek, CP95NMK), and sites sampled around the North Charleston Naval Base (CP95NV1 and CP95NV2) also had ER-L exceedances.

Polychlorinated biphenyls (PCBs) are highly toxic compounds that are very stable and persistent in the environment. Although PCBs are no longer manufactured in the US and their existing uses are being phased out, their long-term persistence presents on-going environmental concern (Laws, 1993). There is a general tendency for PCBs to accumulate in lipid-rich tissues, and adverse effects on reproduction and development in birds and mammals have been reported (Maugh, 1972 and 1975). Although PCBs are not pesticides, they are often discussed together due to their many similarities to chlorinated hydrocarbon pesticides. Chlordane, dieldrin, and DDT are also banned products, that tend to have a high degree of persistence in the environment, and tend to accumulate in lipid tissues. The chlorinated hydrocarbons are the most notorious of the synthetic chlorinated organic pesticides, and are

Table 3-4. The concentrations of aliphatic and aromatic hydrocarbons measured at EMAP sites sampled in the Carolinian Province during summer 1995. Only those with ER-L/ER-M values are listed. Units are ng/g dry sediment weight. Values shaded in gray are ER-L exceedances; values shaded in black are ER-M exceedances. ER-L and ER-M values are listed at the end for reference.

STATION	Napthalene	Acenapthylene	Acenapthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo (a) Anthracene	Chrysene	Benzo (a) Pyrene	Dibenzo (a,h) Anthracene	2-Methylnapthalene	Total PAHs
CP95101	2.7	0.4	0.2	4.6	3.2	1.1	8.6	6.3	2.1	3.1	2.9	0.7	1.3	101.0
CP95102	1.8	0.2	0.3	1.2	1.7	0.7	6.3	5.8	1.3	2.1	1.7	0.3	0.7	120.8
CP95103	38.6	22.2	3.7	11.1	32.2	12.5	142.3	191.2	67.4	86.7	82.0	12.0	10.3	5933.0
CP95104	1.3	0.2	0.1	0.1	0.3	0.1	0.6	0.8	0.3	0.4	0.4	0.1	0.4	22.9
CP95105	1.5	0.1	0.1	0.1	1.0	0.3	1.8	1.5	0.7	1.1	0.8	0.3	0.2	31.7
CP95106	1.7	0.2	0.3	0.5	0.8	0.3	2.1	1.7	0.5	0.7	0.7	0.2	0.4	43.3
CP95107	8.1	6.7	0.8	1.8	11.7	3.7	45.9	66.3	18.6	28.2	28.0	5.7	3.1	533.0
CP95108	1.6	0.2	0.1	0.1	0.7	0.2	1.8	2.4	0.6	0.9	0.8	0.2	0.3	33.4
CP95109	13.9	25.4	2.5	8.2	46.9	16.3	266.9	325.4	76.5	112.6	127.7	17.8	4.4	2173.7
CP95110	2.3	0.4	0.2	0.4	0.4	0.2	1.3	1.5	0.4	0.5	0.7	0.1	0.9	29.7
CP95111	3.7	2.5	0.3	0.5	4.6	1.9	39.9	39.1	19.7	18.9	22.3	2.9	1.3	321.3
CP95112	1.1	0.1	0.0	0.3	0.7	0.4	0.8	1.5	0.2	0.3	0.2	0.0	0.2	18.1
CP95113	1.4	0.1	0.2	0.2	0.3	0.1	0.5	0.6	0.1	0.3	0.3	0.1	0.1	20.8
CP95114	7.6	2.5	0.6	1.5	5.5	2.8	16.4	17.7	6.5	9.7	11.0	1.9	1.5	264.5
CP95115	2.9	0.8	0.5	0.5	1.0	0.3	2.7	3.1	1.3	1.9	1.8	0.3	0.9	48.5
CP95116	14.5	7.3	2.7	3.7	33.3	7.1	95.1	88.9	41.5	47.5	50.6	7.6	6.3	913.6
CP95117	8.1	5.4	1.2	1.8	10.7	2.3	29.0	36.3	12.7	17.6	19.4	2.8	3.8	376.7
CP95118	1.6	0.4	0.5	0.5	0.7	0.5	0.8	0.8	0.4	0.4	0.2	0.1	0.3	13.8
CP95119	5.4	3.0	0.6	1.2	6.1	1.6	22.6	27.4	12.7	13.4	16.0	2.2	2.9	276.9
CP95120	8.2	6.3	0.6	3.3	11.4	5.0	40.3	46.4	14.9	22.6	27.5	4.6	3.0	565.6

(Table 3-4 continued)

STATION	Napthalene	Acenapthylene	Acenapthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo (a) Anthracene	Chrysene	Benzo (a) Pyrene	Dibenzo (a,h) Anthracene	2-Methylnapthalene	Total PAHs
CP95121	14.7	8.5	1.6	5.2	18.8	7.2	61.0	76.0	28.4	43.9	44.2	7.5	8.1	817.6
CP95122	8.8	5.9	0.6	2.7	12.7	4.3	49.8	56.5	21.0	30.8	33.2	5.9	3.3	609.5
CP95123	1.9	0.1	0.1	0.2	0.8	0.3	2.4	2.4	1.3	1.5	1.7	0.3	0.3	35.1
CP95124	10.9	5.8	0.7	2.5	13.8	3.7	48.3	60.7	20.6	30.7	33.4	5.4	3.3	603.7
CP95125	2.2	0.1	0.1	0.2	0.4	0.1	0.5	0.6	0.2	0.3	0.3	0.1	0.4	21.7
CP95126	2.1	0.0	0.1	0.2	0.3	0.0	0.3	0.5	0.1	0.1	0.1	0.0	0.5	21.8
CP95127	2.5	0.0	0.1	0.1	0.4	0.1	0.2	0.3	0.1	0.2	0.1	0.0	0.4	18.0
CP95128	2.1	0.3	0.1	0.3	0.9	0.3	3.2	3.4	1.5	2.0	1.9	0.3	0.6	51.4
CP95129	3.5	0.1	0.2	0.3	0.5	0.2	0.6	0.8	0.1	0.3	0.2	0.0	0.5	33.6
CP95130	12.9	0.6	0.6	1.0	2.0	0.5	2.4	3.5	1.0	1.8	1.2	0.2	2.7	111.0
CP95131	5.5	2.3	0.3	1.2	5.5	1.2	15.9	19.2	7.5	9.7	8.6	1.5	1.7	214.2
CP95132	3.2	0.1	0.1	0.2	0.5	0.1	0.4	0.5	0.1	0.2	0.1	0.1	0.7	26.8
CP95133	3.6	0.1	0.3	0.2	0.6	0.1	0.4	0.4	0.1	0.2	0.1	0.0	0.8	25.0
CP95134	5.1	0.2	0.2	0.4	0.8	0.2	0.4	0.9	0.1	0.3	0.2	0.0	1.0	50.0
CP95135	4.8	0.2	0.2	0.5	0.8	0.1	0.4	0.5	0.2	0.2	0.1	0.1	1.2	43.3
CP95136	13.4	11.7	0.9	3.8	19.8	6.1	92.8	106.9	51.2	57.9	53.8	8.7	4.4	1053.1
CP95138	2.1	0.1	0.2	0.4	4.4	0.3	2.1	1.7	0.2	0.4	0.2	0.0	0.7	65.4
CP95139	13.3	7.4	2.2	4.7	16.7	5.6	62.9	71.6	28.5	35.7	30.4	7.1	4.7	875.9
CP95140	23.3	0.7	1.4	1.8	5.8	4.1	34.3	34.8	15.1	23.4	17.0	2.4	0.2	347.3
CP95141	4.0	1.0	0.3	1.1	3.1	1.5	9.6	8.8	2.5	4.1	4.3	0.6	1.4	153.3
CP95142	4.1	3.7	1.2	4.6	25.5	23.7	92.7	63.6	33.4	46.4	33.5	4.9	1.5	645.3
CP95143	4.8	2.0	0.4	1.5	6.1	3.1	22.5	18.2	8.3	11.8	11.4	1.8	1.7	230.5

(Table 3-4 continued)

STATION	Napthalene	Acenapthylene	Acenapthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo (a) Anthracene	Chrysene	Benzo (a) Pyrene	Dibenzo (a,h) Anthracene	2-Methylnapthalene	Total PAHs
CP95145	2.8	0.9	0.3	1.0	2.0	1.4	6.3	6.0	1.6	2.9	2.8	0.5	1.1	83.4
CP95146	2.2	0.1	0.2	0.2	0.6	0.6	1.4	4.5	0.4	0.4	0.3	0.3	0.6	35.4
CP95147	3.8	0.6	0.9	0.8	1.2	0.6	2.2	2.2	0.6	0.8	0.7	0.1	1.5	57.0
CP95148	3.3	0.4	0.5	0.3	0.8	0.2	0.7	0.5	0.0	0.2	0.2	0.1	0.5	25.6
CP95149	7.8	1.1	1.0	1.9	8.6	1.6	14.7	13.9	3.5	5.5	4.6	0.8	1.8	170.5
CP95150	3.1	1.7	0.3	0.7	1.9	3.5	229.5	198.7	301.5	164.7	103.2	8.1	0.6	1952.1
CP95151	19.0	18.3	7.9	11.8	36.7	48.9	122.8	477.7	114.5	212.0	226.0	29.7	2.9	2939.8
CP95152	39.9	56.3	53.2	45.6	114.6	142.4	701.6	3855.4	333.2	620.5	685.9	71.4	12.0	12307.9
CP95153	1.8	0.2	0.2	0.2	0.5	0.4	1.0	0.9	0.7	1.6	1.0	0.2	0.4	25.2
CP95154	9.2	6.2	1.6	2.7	11.3	10.8	61.2	62.5	37.5	48.0	47.0	7.2	2.3	647.8
CP95155	1.9	0.1	0.3	0.2	0.6	0.2	1.5	1.6	0.5	0.5	0.2	0.1	0.5	29.7
CP95156	8.0	1.5	0.6	2.4	5.2	2.6	16.3	15.4	7.9	11.5	9.0	1.4	1.8	204.2
CP95157	1.6	0.1	0.1	0.1	0.3	0.2	0.3	0.4	0.1	0.1	0.1	0.0	0.2	13.4
CP95158	2.1	0.2	0.1	0.2	0.4	0.2	0.9	0.9	0.3	0.6	0.5	0.1	0.6	21.6
CP95159	1.5	0.0	0.1	0.1	0.2	0.1	0.1	0.3	0.0	0.0	0.0	0.0	0.2	10.4
CP95160	3.3	0.3	0.1	0.3	1.3	0.9	3.2	3.2	1.2	1.6	1.6	0.3	0.7	47.4
CP95161	2.9	0.1	0.1	0.1	0.5	0.2	0.6	0.7	0.2	0.2	0.2	0.0	0.3	28.9
CP95162	1.9	0.1	0.1	0.3	1.2	0.3	2.5	2.0	0.3	0.8	0.3	0.1	0.3	25.4
CP95163	1.7	0.2	0.1	0.2	0.6	0.3	1.3	1.3	0.5	0.7	0.6	0.1	0.2	22.7
CP95164	1.6	0.0	0.1	0.1	0.3	0.1	0.3	0.3	0.0	0.1	0.1	0.0	0.1	14.6
CP95165	1.5	0.1	0.1	0.1	0.4	0.1	0.3	0.4	0.1	0.2	0.2	0.0	0.3	14.6
CP95166	6.3	1.6	0.4	1.2	6.0	1.4	14.6	12.2	4.8	5.4	5.5	1.0	1.2	159.2

(Table 3-4 continued)

STATION	Napthalene	Acenapthylene	Acenapthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo (a) Anthracene	Chrysene	Benzo (a) Pyrene	Dibenzo (a,h) Anthracene	2-Methylnapthalene	Total PAHs
CP95167	2.3	0.2	0.2	0.2	0.6	0.2	1.2	1.1	0.3	0.7	0.5	0.1	0.4	28.5
CP95168	1.9	0.3	0.1	0.2	0.6	0.2	1.2	1.1	0.3	0.5	0.5	0.1	0.4	23.6
CP95169	3.4	0.6	0.2	0.5	2.0	0.6	4.8	4.4	1.9	2.6	2.6	0.6	0.7	75.8
CP95170	2.2	0.2	0.1	0.2	0.8	0.3	1.7	1.3	0.3	0.4	0.3	0.1	0.3	21.1
CP95171	21.5	20.0	7.9	13.6	55.0	48.3	247.0	252.7	108.4	160.3	143.4	24.5	8.7	2462.0
CP95172	30.4	21.2	8.4	17.7	45.9	30.6	195.4	215.9	88.4	110.5	118.2	20.0	11.1	2482.4
CP95173	3.2	0.7	0.3	0.5	2.3	1.4	10.8	10.1	3.5	5.2	5.2	1.0	0.7	125.0
CP95174	6.2	8.0	4.1	4.6	63.1	15.3	326.3	288.6	139.9	225.9	256.4	43.3	2.2	2972.6
CP95175	1.9	0.1	0.1	0.2	0.7	0.2	0.7	0.5	0.1	0.3	0.2	0.1	0.4	22.1
CP95176	1.7	0.1	0.1	0.2	0.3	0.2	0.6	0.5	0.1	0.3	0.2	0.1	0.4	15.0
CP95177	1.4	0.1	0.3	0.2	0.5	0.3	0.9	0.9	0.2	0.4	0.3	0.1	0.6	9.1
CP95178	1.7	0.3	0.1	0.3	2.0	0.5	10.6	8.8	2.9	7.2	6.7	1.3	0.4	108.8
CP95179	2.1	0.2	0.4	0.3	1.1	0.3	4.6	4.1	2.1	3.5	3.6	0.7	0.5	46.4
CP95180	4.6	1.7	0.9	0.8	2.4	1.9	12.0	10.5	5.5	6.7	7.7	1.8	1.8	125.6
CP95181	5.2	4.7	0.9	3.2	7.2	5.8	39.1	33.6	18.0	27.0	28.4	6.7	2.5	422.3
CP95182	1.8	0.3	0.4	0.6	0.8	0.3	2.8	2.4	1.4	1.7	2.3	0.4	0.6	35.0
CP95183	2.0	0.5	0.3	0.4	0.3	0.2	0.8	0.8	0.4	0.9	0.5	0.2	0.8	13.0
CP95184	2.1	0.3	0.3	0.9	1.0	0.6	5.6	5.1	3.1	4.2	4.2	0.7	0.9	74.3
CP95185	2.4	0.3	1.2	0.7	0.9	0.4	3.4	3.6	2.2	2.9	3.0	0.6	1.2	42.4
CP95186	1.9	0.3	0.5	0.1	0.3	0.0	0.4	0.7	0.3	0.3	0.4	0.1	0.6	9.2
CP95187	2.9	0.3	0.2	0.8	0.9	0.3	2.0	1.8	0.4	1.0	0.6	0.2	1.1	19.1
CP95188	2.0	0.7	0.9	1.0	1.5	1.0	7.3	5.9	3.2	3.8	3.8	0.8	1.2	74.0

(Table 3-4 continued)

STATION	Napthalene	Acenapthylene	Acenapthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo (a) Anthracene	Chrysene	Benzo (a) Pyrene	Dibenzo (a,h) Anthracene	2-Methylnapthalene	Total PAHs
CP95ASM	11.9	22.6	4.5	6.4	29.7	39.3	166.7	281.1	109.2	179.9	170.4	31.0	6.7	2258.6
CP95CB_	3.1	0.5	0.6	2.6	2.3	1.3	4.6	3.4	1.1	1.8	1.4	0.3	2.6	80.1
CP95CF_	9.6	8.5	2.3	3.8	9.0	7.4	63.4	95.1	64.9	61.1	85.5	11.6	5.2	1167.2
CP95DIE	27.4	78.9	10.6	13.9	49.1	120.8	221.2	718.7	181.4	250.4	515.1	86.3	9.9	5809.7
CP95FOS	4.9	2.0	0.9	1.6	3.3	3.3	18.6	16.6	6.8	9.0	10.3	1.8	1.6	194.3
CP95KIA	4.2	2.8	1.3	1.9	7.6	4.3	30.0	26.4	26.9	20.4	27.3	5.4	1.5	363.4
CP95KOP	38.0	68.9	85.5	94.7	269.8	353.1	868.8	796.6	553.1	682.2	457.2	81.0	26.3	8287.0
CP95LON	2.8	0.9	0.5	0.8	1.3	0.9	5.7	5.2	3.1	2.5	2.5	0.6	1.3	76.9
CP95MI_	1.6	0.4	0.4	0.3	0.3	0.4	0.6	0.6	0.1	0.2	0.1	0.1	0.4	7.7
CP95NMK	207.3	45.1	73.9	73.1	341.0	159.5	905.3	683.3	656.8	829.3	434.6	78.7	362.3	10708.9
CP95NV1	44.1	7.4	28.8	34.8	246.0	100.2	612.2	503.6	203.3	253.6	208.7	27.9	18.4	4312.7
CP95NV2	18.7	83.4	13.2	66.5	166.0	442.8	677.9	829.5	569.5	846.6	631.9	93.2	14.0	8803.5
CP95PR1	2.4	3.5	0.1	0.5	3.4	2.1	67.7	63.2	46.3	46.7	60.9	10.4	0.6	664.9
CP95PR2	7.8	4.9	1.0	2.5	10.1	3.9	35.0	41.1	14.8	19.8	23.4	5.0	4.0	420.4
CP95PR3	15.6	15.9	2.1	7.8	33.9	13.7	117.8	159.1	47.0	73.9	71.3	15.8	8.0	1446.1
CP95PR4	10.8	13.7	1.5	4.2	23.1	8.3	73.2	88.5	32.7	43.0	48.9	11.0	5.2	1023.2
CP95PR5	13.4	12.2	1.7	5.3	27.5	11.8	108.8	120.2	52.5	66.4	74.2	16.3	9.8	1296.4
CP95RC_	2.1	0.2	0.2	0.3	0.6	0.3	1.5	0.9	0.5	0.5	0.4	0.1	0.3	10.3
CP95SPY	58.9	9.7	13.2	15.1	53.3	34.9	174.3	173.8	76.3	121.6	84.9	15.0	18.6	2041.6
CP95ZI_	2.3	0.6	0.2	0.5	1.1	0.4	1.7	1.8	0.8	1.0	1.0	0.2	1.5	23.5

ER-L	**160**	**44**	**16**	**19**	**240**	**85**	**600**	**665**	**261**	**384**	**430**	**63**	**70**	**4022**
ER-M	**2100**	**640**	**500**	**540**	**1500**	**1100**	**5100**	**2600**	**1600**	**2800**	**1600**	**260**	**670**	**44792**

recognized as carcinogens. Chlordane is still used on a restricted basis as treatment for termites and with some non-food plants (Brattstein et al., 1986; Laws, 1993).

The PCB and pesticide data for those analytes which have ER-L and ER-M values or TEL and PEL values (MacDonald, 1994) are listed in Table 3-5 for all stations sampled over the Carolinian Province during 1995. PCBs were detected at all stations, at concentrations ranging from 2.22 - 80.88 ppb for core stations and up to 216 ppb at supplemental stations. No core stations and only one supplemental station (New Market Creek, CP95NMK) had PCB concentrations that exceeded ER-M values. Exceedances of ER-L values for PCBs were observed at 5 core stations (Chowan River, CP95103; Little Alligator River, P95109; Rattan Bay, CP95138; St. Johns River, CP95171; and Doctors Lake, CP95172), and at 5 supplemental sites (Diesel Creek, CP95DIE; Koppers Creek, CP95KOP; Navy Base North, CP95NV1; Navy Base South, CP95NV2; Shipyard Creek, CP94SPY). Maximal PCB concentrations were higher than the maximal value measured in the Louisianian Province (38 ppb), but lower than that measured in the Virginian Province (1040 ppb).

Chlordane concentrations ranged from 0 - 66.61 ppb for core and supplemental sites. The highest concentration was measured at a core site, Mud River (CP95166), and there were a total of 6 core sites and 1 supplemental site that exceeded the ER-M value. The highest concentrations were higher than those measured in the Carolinian Province in 1994. Concentrations of DDT and DDT related analytes (DDD and DDE) were also higher in 1995, and there were more ER-M or PEL exceedances (6 core sites and 1 supplemental site). Numerous exceedances of ER-L or TEL levels of chlordane, 4-4' DDD, 4-4' DDE, 4-4' DDT, and total DDT were found (Table 3-5). The previously published ER-L values for dieldrin and endrin are now regarded as too low (E. Long, personal communication to J. Hyland). The ER-L values were below the required detection limits (0.1 ng/g) for these analytes, and the ability to measure such low concentrations accurately is questionable. Moreover, the actual detection limits for endrin were in many cases much higher than the required limits, so some of the values would not be acceptable based on QA/QC criteria. Therefore, the PEL/TEL criteria were used to evaluate the potential for biological effects due to dieldrin, but no PEL/TEL criteria are available for endrin. Exceedances of PEL values for dieldrin were observed at 5 core stations, 6 stations had concentrations that exceeded TEL values. For lindane, 10 stations had concentrations that exceeded PEL values, and 5 other stations had TEL exceedances. Overall, pesticide concentrations were higher than those measured in either the Louisianian or Virginian Provinces.

Metals are introduced naturally into marine environments due to weathering and erosion of rocks and soils. Metals are important as components of a variety of materials commonly found in modern society. Anthropogenic enrichment occurs due to localized mining and discharges associated with urbanization (industrial discharges, sewage treatment discharges, street run-off, aerial fall-out, etc.). Some metals such as Zn, Cu, Fe and others (including As) are recognized as essential micronutrients, while others such as Hg, Pb, Cd have no known biological function. Toxicity occurs when animals are exposed to pollutant metals or essential metals in excess. Environmental concentrations in the field that are as high as those observed in laboratory studies to cause acute toxicity are rarely observed, but toxicity

Table 3-5. The concentrations of PCBs and Pesticides measured at EMAP sites sampled in the Carolinian Province, summer 1995. The analytes listed are only those that have ER-L/ER-M or TEL/PEL[a] values (listed at the end). Units for both PCBs and pesticides are ng/g sediment dry weight. Values shaded in gray are ER-L or TEL exceedances; values shaded in black are ER-M or PEL exceedances.

Station	PCB	Dieldrin	Endrin	Chlordane	4,4' DDD	4,4' DDE	4,4' DDT	Total DDT	Lindane
CP95101	3.44	0	0	0.14	0.18	0	0.42	0.6	0
CP95102	2.83	0	0	0.08	0.06	0	0.21	0.27	0
CP95103	32.3	1.35	0	4.75	8.54	0	4.76	18.06	0
CP95104	2.79	0	0	0	0.09	0	0	0.09	0
CP95105	2.78	0	0	0	0	0	0	0	0
CP95106	2.91	0	0	0	0	0	0	0	0
CP95107	6.26	0	0	0.27	0.84	0	0.42	1.63	0
CP95108	5.27	0.06	0	0.15	0	0	0	0	0.38
CP95109	33.78	3.66	0	1.03	150.91	0	24.63	213.17	0
CP95110	2.29	0.03	0	0.03	0.33	0.36	0.17	0.92	0
CP95111	3.39	0.03	0	0.07	0.28	0.29	0	0.59	0
CP95112	2.68	0	0	0	0	0	0	0	0
CP95113	3.19	0	0	0	0	0	0	0	0
CP95114	7.56	1.55	1.15	4.36	1	2.46	0.77	5.24	1.85
CP95115	2.22	0	0	0	0	0	0	0	0
CP95116	10.91	0	0	0.45	0.68	1.72	0.29	2.76	0.68
CP95117	4.33	0.09	0	0.15	0.19	0.32	0	0.67	0
CP95118	2.33	0	0	0	0	0.01	0	0.01	0
CP95119	3.88	0	0	0	0.11	0.22	0	0.33	0
CP95120	16.63	1.81	2.23	6.86	1.35	3.33	1.65	7.64	2.06
CP95121	17.78	0.19	0	0.86	1.73	3.67	0.47	6.29	0
CP95122	6.82	0	0	0	0.61	2.13	0.36	3.48	0
CP95123	2.68	0	0	0	0	0	0	0	0
CP95124	5.74	0	0	0	0.47	1.05	0	1.52	0
CP95125	2.29	0	0	0	0	0	0	0	0
CP95126	2.23	0	0.04	0	0	0	0.02	0.34	0
CP95127	2.48	0	0	0	0	0	0	0	0
CP95128	2.32	0	0	0	0	0.07	0	0.23	0
CP95129	2.47	0	0	0	0	0.11	0	0.11	0
CP95130	4.18	0	0	0	0	0	0	0.55	0
CP95131	2.33	0	0	0	0	0.14	0.23	0.36	0
CP95132	2.26	0	0	0	0	0	0	0	0
CP95133	2.46	0	0	0	0	0	0	0	0
CP95134	5.35	0	0	0.4	0	0.18	0	0.65	0.04
CP95135	2.43	0	0	0	0	0	0	0	0
CP95136	5.09	0	0	0.02	0.4	1.81	0	3.68	0.28
CP95138	72.82	15.22	20.54	27.36	19.34	24	18.38	78.07	13.1
CP95139	9.52	0	0	0.53	0.47	2.22	0	2.68	0
CP95140	9.96	0.09	0	0.69	0.36	0.76	1.33	3.04	0.07
CP95141	3.8	0.12	0	0.16	0	0.18	0.33	0.64	0.11

(Table 3-5 continued)

Station	PCB	Dieldrin	Endrin	Chlordane	4,4' DDD	4,4' DDE	4,4' DDT	Total DDT	Lindane
CP95142	4.32	0.13	0	0.19	0.18	0.29	0.23	0.81	0.03
CP95143	6.37	0.04	0.3	0.26	0.07	0.69	0.28	1.59	0.05
CP95145	3.49	0.3	0.44	1.27	0.05	0.31	0.24	0.77	0.76
CP95146	2.87	0.23	0.26	0.01	0.02	0.01	0	0.15	0
CP95147	2.61	0	0	0	0	0.02	0	0.02	0
CP95148	2.34	0	0	0	0	0	0	0	0
CP95149	7.64	0	0	0.11	0.07	0.14	0.12	0.65	0.1
CP95150	6.01	0.14	0	0.32	0.03	0.08	0.03	0.17	0.06
CP95151	12.39	0	0	0.93	0.27	0.23	0.1	0.66	0.06
CP95152	17.92	0	0	1.4	1.47	0.62	0.37	2.66	0.07
CP95153	2.66	0	0.07	0.24	0.01	0.02	0	0.15	0.04
CP95154	10.94	0	0	0.33	0.18	0.57	0.4	1.55	0.2
CP95155	5.06	0.02	0.01	0.28	0.04	0.13	0.01	0.32	0.01
CP95156	7.77	0	0	0.16	5.18	1.52	0.12	7.46	0.08
CP95157	2.65	0	0	0.16	0.01	0.01	0	0.1	0.06
CP95158	4.07	0	0	0.2	0.01	0.03	0	0.06	0.04
CP95159	3.25	0	0	0.08	0.01	0.02	0	0.03	0.02
CP95160	3.74	0	0.07	0.33	0.07	0.04	0	0.2	0.02
CP95161	2.65	0	0.19	0.1	0.03	0.05	0	0.18	0.03
CP95162	2.97	0.01	0	0.2	0.01	0.05	0.01	0.08	0.03
CP95163	3.25	0.15	0.11	1.94	0.03	0.09	0	0.12	1.27
CP95164	4.43	7.92	7.12	17.52	6.23	6.69	6.05	20.68	8
CP95165	4.44	0.76	0.59	3.38	0.31	0.5	0.28	1.27	2.07
CP95166	20.7	38.53	36.92	66.61	35.65	34.16	35.01	127.31	30.52
CP95167	4.58	0	0	0.21	0	0.02	0	0.13	0.05
CP95168	6.87	0.19	0.15	0.66	0.13	0.14	0.1	0.49	0.39
CP95169	16.74	33.32	33.14	54.67	33.71	31.61	34.72	121.91	25.27
CP95170	3.14	0	0.04	0.01	0	0	0	0	0.01
CP95171	42.21	0.53	0	3.22	0.8	1.08	0	3.55	0.31
CP95172	80.88	1.74	3.52	4.25	2.62	4.28	1.39	12.77	0.87
CP95173	10.97	0.07	0.05	0.06	0.09	0	0.21	0.76	0.02
CP95174	21.14	0.12	0	0.62	1.41	2.09	0.31	4.6	0.11
CP95175	6.05	9.82	8.83	21.41	7.26	7.71	6.83	24.78	11.8
CP95176	3.36	0	0.29	0.03	0	0	0	0.15	0.02
CP95177	3.2	0	0	0.06	0	0	0	0.17	0
CP95178	4.84	0.45	0.3	3.21	0.09	0.23	0.06	0.81	2.58
CP95179	3.94	0	0	0.76	0.05	0.11	0.1	0.39	0
CP95180	4.86	0	0	0.5	0.02	0.07	0	0.33	0
CP95181	7.35	0	1.01	1.67	0.01	0.12	0	1.07	0
CP95182	4.4	0	0	0.7	0	0	0	0.17	0.01
CP95183	3.55	0	0	0.3	0	0	0	0	0
CP95184	5.45	0	0.08	0.42	0	0.05	0	0.25	0
CP95185	3.4	0	0	0.26	0	0.04	0	0.05	0
CP95186	4.11	0	0.04	0.52	0	0	0	0	0
CP95187	3.67	0	0	0.16	0	0.01	0.04	0.06	0
CP95188	5.02	0	0	0.35	0	0.06	0	0.06	0

(Table 3-5 continued)

Station	PCB	Dieldrin	Endrin	Chlordane	4,4' DDD	4,4' DDE	4,4' DDT	Total DDT	Lindane
CP95ASM	21.03	0.15	0	1.19	0.51	1.13	0.22	2.01	0.17
CP95CB_	3.14	0.04	0	0.09	0.2	0.13	0	0.35	0
CP95CF_	11.95	0.29	0	0.83	0.28	0.46	0	0.74	0
CP95DIE	44.85	1.26	0	2.11	0.44	2.56	0.59	3.91	0.37
CP95FOS	5.65	0.11	0	0.22	0.05	0.21	0.14	0.54	0.08
CP95KIA	7.2	0.07	0	0.53	0.07	0.34	0.23	0.83	0.03
CP95KOP	30.59	0.67	0.11	3.78	1.05	1.71	0.33	5.43	0
CP95LON	7.11	0.43	0	5.9	6.59	18.85	12.13	44.24	0
CP95MI_	2.33	0	0	0.02	0	0	0	0	0
CP95NMK	216	4.72	0	27.46	6.91	8.78	2.25	21.71	0.76
CP95NV1	166.4	0	0	5.12	5.5	7.06	2.19	20.05	0.51
CP95NV2	72.11	0.17	0	3.67	0.42	0.75	0.46	1.89	0.14
CP95PR1	2.25	0	0	0	0.02	0	0	0.94	0
CP95PR2	8.86	0	0	0.15	0.39	0	0.41	0.9	0
CP95PR3	20.34	0	0	1.39	2.5	0	5.36	8.92	0
CP95PR4	14.63	0	0	0.62	1.11	0	0.98	3.35	0
CP95PR5	17.71	0.44	0	1.48	1.8	0	1.4	4.79	0
CP95RC_	2.39	0	0	0	0	0	0	0	0
CP95SPY	32.06	0.52	0	2.75	0.91	1.32	0.18	2.42	0.59
CP95ZI_	2.77	0	0	0	0	0.03	0	0.03	0
ER-L	22.7	0.715[a]		0.5	1.22[a]	2.2	1.19[a]	1.58	0.32[a]
ER-M	180	4.30[a]		6	7.81[a]	27	4.77[a]	46.1	0.99[a]

due to chronic effects may be profound. Metals are frequently bioconcentrated in all tissues, particularly hepatic tissues (Eisler, 1971; Phillips, 1980). Most metals are significant toxins as ions, but others such as mercury and tin can be methylated and the organic forms are typically more toxic. Since metals are elements, they are highly persistent in the environment once introduced. Therefore, they are often trapped within a system and can become bioavailable from time to time in conjunction with changes in pH, oxidative processes, etc. (Luoma, 1983).

The concentrations of metal contaminants measured at core as well as supplemental stations are listed in Table 3-6. There were no core stations that had metal concentrations exceeding ER-M values, but sediments from one supplemental station (Shipyard Creek, CP95SPY) contained extremely high Cr concentrations as well as Ni concentrations that exceeded ER-M values. There were numerous ER-L exceedances (Table 3-6). Arsenic, Cr, and Ni were the most commonly elevated elements.

A summary of the ranges of concentrations for some of the analytes measured during the 1995 Year 2 Demonstration Project are listed in Table 3-7. The minimum and maximum values from the 1994 Year 1 Demonstration Project, as well as the ranges of concentrations reported from Louisianian and Virginian Provinces are also listed for comparison (Hyland et al., 1996; Macauley et al., 1994; Schimmel et al., 1994). There was a general tendency for higher concentrations of PAH analytes during 1994, although Total PAH concentrations were higher in 1995. PCB concentrations were higher in 1994, but pesticide concentrations were almost always higher in 1995. Metal concentrations were generally similar for both years. Organic contaminant concentrations from Louisianian Province sediments were generally lower than those measured in the Carolinian Province, although metal contaminants tended to be about the same or a little higher. PAH and metal contaminants measured in the Virginian Province were higher than those measured in both the Carolinian and Louisianian Provinces, but pesticide concentrations were highest in the Carolinian Province.

Classification of Stations Based on Chemical Contaminants

Although sediment guidelines have been established for individual contaminants, provisions for classifying stations with lower but enriched concentrations of multiple contaminants are less established. Habitats with contaminants that exceed ER-M values are generally regarded as being degraded to the point that biological impacts are expected. Elevations above ER-M values for a single contaminant were rare in the Carolinian Province, so few stations would be classified as degraded based on this criteria. However the biological impact of multiple ER-L exceedances may approach that of a single ER-M exceedance. Moreover, many sites had multiple contaminants that approached but did not quite exceed ER-L values, indicating that these sites are enriched by multiple contaminants, that may in combination affect the biota (Viarengo et al., 1987; Da Ros et al., 1995; Grundy et al., 1996; Arnold et al., 1996). Therefore, a quantitative approach developed during pilot year studies based on the summed proportional contributions of contaminants was applied to the 1995 data (Ringwood et al., 1995). The measured concentrations of each contaminant were divided by the respective ER-L or ER-M values to generate proportional concentrations (PC), and then

Table 3-6. The concentrations of metals measured at EMAP sites sampled in the Carolinian Province, summer 1995. Units are ug/g sediment dry weight. Values shaded in gray are ER-L exceedances; values shaded in black are ER-M exceedances. ER-L and ER-M values are listed at the end for reference.

Station	Al	Fe	Ag	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Hg	Sn
CP95101	46462	16870	0.04	7.05	0.074	50.63	7	175.3	11.2	21.39	43.23	0.04	1.26
CP95102	38325	15240	0.031	5.31	0.057	36.75	4.25	167.4	8.4	15.14	36.11	0.024	1.00
CP95103	96271	48950	0.163	7.67	0.45	83.11	27.92	1128.5	29.8	21.78	156.7	0.019	3.05
CP95104	16324	4658	0.015	0	0	12.61	1.61	126.7	2.5	6.99	16.38	0.015	0.41
CP95105	18438	4559	0.02	0.96	0.014	11	2.01	115.6	2.2	5.19	14.88	0	0.38
CP95106	29298	7785	0.028	1.55	0.035	23.14	2.61	155.2	4.9	9.55	25.26	0.01	0.57
CP95107	120210	60900	0.098	8.4	0.153	95.31	35.41	509.8	40.3	38.31	134.5	0.134	2.83
CP95108	17969	7670	0.017	0	0.036	16.8	1.48	381.5	3.8	8.49	26.22	0.01	0.42
CP95109	77430	32100	0.086	8.5	0.326	66.57	15.65	185.5	23.2	40.28	97.81	0.109	2.32
CP95110	17565	3112	0.011	0	0	10.17	1.3	66.3	1.7	6.66	11.74	0	0.93
CP95111	24451	8857	0.023	1.85	0.039	25.78	3.03	187.9	4.4	11.45	28.82	0.024	0.73
CP95112	572	419	0	0	0	0.79	0.86	0.0	0.5	0.9	5.83	0.014	0.02
CP95113	10034	3509	0.011	0.8	0	4.88	1.47	106.3	1.9	3.98	16.35	0	0.33
CP95114	51073	19110	0.044	6.39	0.16	51.38	6.35	208.9	13.4	20.29	70.13	0.05	1.32
CP95115	18588	5287	0	2.48	0	9.35	1.4	139.8	2.1	6.77	16.79	0.009	0.29
CP95116	84529	36220	0.074	10.39	0.334	82.66	13.78	345.4	24.5	30.15	119.7	0.078	2.22
CP95117	72404	38990	0.055	12.28	0.067	71.55	11.64	516.7	22.5	29.55	83.09	0.063	2.13
CP95118	15674	4208	0.013	1.52	0.015	19.27	1.27	117.7	1.5	6.3	13.92	0.009	0.33
CP95119	60793	28400	0.051	9.91	0.059	56.33	8.05	443.2	13.6	21.92	61.19	0.046	1.45
CP95120	72169	36510	0.117	7.3	0.56	61.68	14.73	201.6	16.9	29.91	85.4	0.097	2.91
CP95121	95277	46330	0.195	11.25	1.304	92.11	21.52	495.3	24.7	38.45	132.7	0.122	2.87
CP95122	97888	47850	0.18	11.33	1.12	98.07	22.24	526.2	24.2	39.41	133.9	0.119	3.33
CP95123	31304	9685	0.02	1.94	0.024	22.98	1.78	251.9	4.6	8.26	28.73	0.014	0.61
CP95124	84335	41300	0.112	9.77	0.387	83.01	15.81	572.0	25.3	33.21	106	0.079	2.37
CP95125	17060	6567	0	1.32	0	18.79	1.08	146.1	1.8	7.81	14.76	0.01	0.32
CP95126	18838	8100	0.011	1.71	0.014	29.31	0.94	229.6	2.3	8.1	19.03	0.01	0.47
CP95127	18435	4882	0.011	1.93	0	20.91	1.33	182.0	1.9	8.01	17.48	0.01	0.46
CP95128	29673	9316	0.018	1.72	0.067	37.08	2.77	235.8	3.7	9.44	28.19	0.01	0.59
CP95129	10333	6066	0	1.08	0.015	18.46	1.22	286.4	1.4	7.33	24.1	0	0.53
CP95130	8975	3014	0	0	0	6.16	0.97	149.9	2	7.36	15.37	0	0.26
CP95131	57745	26740	0.039	8.34	0.059	56.2	8.06	447.0	14.9	21.4	67.38	0.038	1.29
CP95132	18222	6389	0	1.44	0.014	19.25	1.12	198.5	2.4	7	27.11	0	0.27
CP95133	12042	4230	0	1.48	0	20.99	0.59	164.4	1.5	4.57	15.11	0	0.11
CP95134	8521	4886	0	0	0	15.25	0.84	236.6	1	5.48	17.35	0	0.47
CP95135	11770	2027	0	1.27	0	7.9	0.63	49.9	1.1	4.05	10.8	0	0.08
CP95136	77191	35930	0.102	11.86	0.185	72.75	13.21	601.9	21.4	30.85	87.81	0.058	2.11
CP95138	13860	11100	0	0	0.018	28.01	0.95	313.7	1.8	8.04	22.05	0.009	0.67
CP95139	79718	37830	0.256	11.12	0.408	75.54	21.95	952.5	23.5	36.62	122.2	0.106	2.33
CP95140	51890	27000	0.067	9.98	0.151	57.82	9.42	301.1	14.3	19.26	66.37	0.051	1.17
CP95141	46655	19670	0.039	8.04	0.055	47.48	6.38	199.6	15.2	18.44	48.51	0.037	1.22
CP95142	18606	7457	0.014	2.34	0.019	20.91	2.11	111.2	3.4	7.61	21.36	0.018	0.46
CP95143	57131	24080	0.039	7.83	0.037	58.37	7.3	245.2	12.7	19.48	60.95	0.033	1.55

(Table 3-6 continued)

Station	Al	Fe	Ag	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Hg	Sn
CP95145	33511	15130	0.036	6.44	0.045	45.36	3.76	151.2	6.2	13.24	36.5	0.023	0.98
CP95146	5395	5324	0	3.39	0.025	27.05	1.14	127.7	1.6	5	20.46	0	0.33
CP95147	33319	16340	0.02	4.41	0.029	44.85	4.2	180.0	8.5	9.97	36.23	0.014	0.71
CP95148	4181	3043	0	3.03	0	10.01	0.66	59.2	1	3.23	11.5	0	0.24
CP95149	85616	45300	0.043	15.15	0.053	71.13	22.97	979.8	24.4	21.68	79.28	0.066	1.98
CP95150	46954	22730	0.025	6.56	0.041	39.94	16.97	343.4	12.6	16.74	47.59	0.026	1.37
CP95151	27908	15710	0.083	7.58	0.1	43.9	10.7	309.0	8.7	15.78	51.02	0.062	1.19
CP95152	43483	22570	0.095	10.74	0.129	65.24	15.3	363.2	13.9	25.23	68.89	0.078	1.41
CP95153	22720	13440	0.013	3.11	0.029	30.2	1.37	247.1	3.3	10.3	24.1	0.011	0.54
CP95154	48555	24530	0.058	12.47	0.152	54.21	11.07	357.0	13.4	18.89	56.44	0.041	1.42
CP95155	13510	10530	0.03	8.16	0.095	28.7	2.38	273.1	4.7	5.69	21.66	0.018	0.77
CP95156	75104	39620	0.07	22.29	0.136	84.75	14.7	410.2	22	25.02	86.57	0.092	2.03
CP95157	5987	5585	0.019	1.2	0.055	23.36	0.6	193.4	1	5.13	16.57	0	0.52
CP95158	10147	9256	0.032	5.32	0.101	25.53	1.66	301.1	4.6	6.63	26.71	0.015	0.61
CP95159	8824	4004	0.014	2.05	0.168	13.3	0.52	126.1	1	4.83	13.08	0	0.36
CP95160	28369	14410	0.023	5.98	0.058	38.12	3.63	249.4	6.2	10.3	31.25	0.018	0.84
CP95161	15553	6726	0	2.93	0.1	13.31	1.25	184.8	2	6.35	19.03	0.011	0.38
CP95162	16799	8939	0	4.27	0.038	13.36	0.93	371.4	2.6	8.58	24.81	0.007	0.58
CP95163	17254	14700	0.023	4.43	0.161	52.33	1.65	401.3	3	8.87	28.57	0.015	0.90
CP95164	6369	3862	0.016	1.34	0.057	9.64	0.59	101.3	0.8	3.82	11.47	0	0.26
CP95165	11133	4206	0.016	2.47	0.047	9.26	1.15	103.9	1.5	6.01	12.45	0.01	0.13
CP95166	68587	31190	0.054	13.67	0.096	63.09	10.12	519.6	17	20.39	69.5	0.044	1.57
CP95167	18433	10150	0.021	4.19	0.041	20.5	2.52	128.6	4.4	6.53	23.74	0.015	0.56
CP95168	10455	6017	0.014	1.65	0.02	20.36	1.1	154.8	1.8	5.82	17.19	0.018	0.51
CP95169	30241	14600	0.032	7.15	0.054	36.02	3.57	283.5	6.5	7.89	33.16	0.023	0.97
CP95170	9454	5318	0.02	1.43	0.035	15.35	0.92	190.3	1.3	4.03	16.25	0.012	0.58
CP95171	56160	29970	0.225	11.11	0.246	68.54	23.75	663.1	16.8	30.52	109.1	0.138	2.06
CP95172	46295	28880	0.376	6.22	0.743	67.66	24.7	150.6	15.8	43.3	119.8	0.188	2.76
CP95173	28314	11780	0.023	3.27	0.053	30.84	5.86	150.8	4.9	10.31	29.22	0.028	0.84
CP95174	38818	22860	0.506	4.78	0.177	48.89	17.59	250.7	8.2	39.54	84.7	0.182	2.16
CP95175	9802	2488	0	0	0.018	8.49	0.97	60.6	1	4.32	9.25	0.012	0.37
CP95176	6587	1773	0.013	0	0.013	5.79	1.71	46.6	0.9	3.08	8.84	0.012	0.19
CP95177	5293	1830	0	0	0.028	6.72	1.71	41.8	0.9	2.29	9.23	0.012	0.11
CP95178	8189	3406	0.024	0.92	0.024	10.28	2.43	39.1	1.4	5.09	13.22	0.02	0.21
CP95179	11328	2925	0	0	0.025	9.19	1.44	81.4	1.3	5.03	11.1	0.012	0.20
CP95180	16807	8060	0.105	1.06	0.075	21.66	12.3	140.3	4.8	11.68	32.24	0.047	0.84
CP95181	50622	27640	0.348	4.11	0.364	71.92	33.07	337.0	16.5	45.62	104.8	0.141	2.61
CP95182	18147	5298	0.056	0	0.053	15.12	2.56	85.3	1.8	9	16.88	0.029	0.48
CP95183	18028	4849	0.021	1.33	0.053	13.76	1.29	111.2	1.7	7.41	13.69	0.008	0.43
CP95184	15723	7152	0.03	1.71	0.026	23.48	4.61	213.1	2	8.87	24.9	0.016	0.74
CP95185	17794	7053	0.039	1.77	0.032	19.84	5.19	129.8	2.3	8.5	23.33	0.024	0.64
CP95186	13603	3667	0.01	0	0.028	12.79	1.06	53.8	1.4	5.56	10.81	0.012	0.52
CP95187	22391	7645	0.037	1.93	0.242	21.24	2.03	111.6	2.9	9.45	17.16	0.024	0.56
CP95188	20848	8460	0.021	2.16	0.026	22.91	3.02	102.9	3.5	9.43	20.48	0.02	0.65

(Table 3-6 continued)

Station	Al	Fe	Ag	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Hg	Sn
CP95ASM	35235	9181	0.202	9.77	0.154	112.3	33.2	342.1	12.7	41.7	83.57	0.102	1.56
CP95CB_	34183	10260	0.012	0	0.052	26.41	3.19	214.1	6	10.32	30.73	0.02	0.85
CP95CF_	36156	22600	0.076	6.52	0.157	49.84	8.7	259.8	11	15.01	68.86	0.059	1.33
CP95DIE	84431	43110	0.298	19.73	0.267	119.6	33.5	352.4	27.1	51.18	151.3	0.131	2.70
CP95FOS	35298	16170	0.042	6.67	0.056	37.81	8.77	171.0	8.3	14	43.38	0.033	1.00
CP95KIA	50369	24790	0.033	10.47	0.048	58.21	7.52	358.3	11.7	18.35	52.15	0.026	1.07
CP95KOP	77643	39840	0.211	21.49	0.249	123.3	41.53	595.6	26.4	57.59	156.9	0.143	2.52
CP95LON	29592	11380	0.019	2.47	0.044	41.37	3.51	216.9	5.2	13.52	29.45	0.033	0.59
CP95MI_	4853	2341	0	1.77	0.013	7.85	0.69	51.5	0.8	2.47	11.6	0.008	0.28
CP95NMK	46884	23880	0.435	11.81	1.069	259.8	69.26	191.6	18.9	163.8	306.6	0.27	12.01
CP95NV1	29517	16590	1.196	5.57	0.292	80.79	40.54	198.9	22.8	107.3	129	0.026	3.73
CP95NV2	78595	41770	0.126	16.21	0.158	109.7	26.42	479.7	25.4	28.56	75.28	0.073	2.00
CP95PR1	11920	4575	0.023	0.96	0.09	9.81	1.65	127.7	2.1	7.21	18.73	0.018	0.32
CP95PR2	89995	43110	0.165	9.66	0.862	82.09	20.18	564.6	25.2	36.27	125.9	0.106	2.68
CP95PR3	98892	45380	0.272	8.84	1.657	83.3	26.24	432.6	26.2	41.86	152.6	0.131	3.11
CP95PR4	101824	49170	0.215	10.97	0.276	86.49	31.19	507.7	26.2	42.79	157	0.142	3.39
CP95PR5	96559	44840	0.289	10.06	0.992	76.61	36.42	403.2	23.9	47.43	154.7	0.15	3.30
CP95RC_	16945	6312	0.016	1.73	0.016	18.62	1.1	167.4	1.7	5.36	17.23	0.008	0.49
CP95SPY	24492	7037	0.177	7.18	0.477	20660	23.95	257.2	112	82.04	193.7	0.081	1.77
CP95ZI_	12327	5055	0.018	2.4	0.041	19.93	1.6	97.2	1.7	5.14	19.73	0.008	0.37

ER-L			1	8.2	1.2	81	34		20.9	46.7	150	0.15	
ER-M			3.7	70	9.6	370	270		51.6	218	410	0.71	

Table 3-7. Ranges of a subset of analytes measured in core stations for Carolinian, Louisianian, and Virginian Provinces. The numbers shown in parentheses for the Carolinian Province are maximum concentrations measured at the supplemental sites. The units for organic contaminants are ng/g, and for metal contaminants are ug/g.

Analyte	CA Province (1995)		CA Province (1994)		LA Province (1992)	VA Province (1991)
Napthalene	1.1 - 39.9	(207.3)	0.4 - 167	(174.8)	0 - 219	0 - 488
Acenapthylene	0.0 - 56.3	(83.4)	0 - 74.2	(133.9)	0 - 13	0 - 186
Acenapthene	0.0 - 53.2	(85.5)	0 - 33.6	(169)	0 - 43	0 - 2960
Fluorene	0.1 - 45.6	(94.7)	0.1 - 46.3	(376.5)	0 - 126	0 - 3180
Phenanthrene	0.2 - 114.6	(341)	0.3 - 263.1	(1138)	1 - 416	0 - 25500
Anthracene	0.0 - 142.4	(442.8)	0 - 136.4	(2478.3)	0 - 86	0 - 6510
Fluoranthene	0.1 - 701.6	(905.3)	0.1 - 802.1	(3857.4)	0 - 653	0 - 22900
Pyrene	0.3 - 3855.4	(829.5)	0.1 - 867.7	(3512)	1 - 1545	0 - 24600
Benzo (a) Anthracene	0.0 - 333.2	(656.8)	0 - 427	(1737.7)	0 - 278	0 - 10000
Chrysene	0.0 - 620.5	(846.6)	0.1 - 469.9	(2951)	0 - 295	0 - 9770
Benzo (a) Pyrene	0.0 - 685.9	(631.9)	0 - 431.3	(1434.5)	0 - 260	0 - 6040
Dibenzo (a,h) Anthracene	0.0 - 71.4	(93.2)	0 - 79.8	(201.8)	0 - 106	0 - 342
2-Methylnapthalene	0.1 - 18.4	(362.3)	0.2 - 56.1	(96.8)	0 - 327	0 - 459
Total PAHs	7.7 - 10708.9	(12307.9)	3.4 - 9179	(32188.9)	115 - 21119	0 - 141000
PCB	2.2 - 80.9	(216)	2.43 - 311.5	(534.1)	0 - 38	0 - 1040
Dieldrin	0 - 38.5	(4.7)	0 - 1.4	(3.3)	0 - 1.7	0 - 4.6
Endrin	0 - 36.9	(0.1)	0 - 0.3	(0)	0 - 0.3	0 - na
Chlordane	0 - 66.6	(27.5)	0 - 8.3	(33.6)	0 - 4.9	0 - 10.4
4,4' DDE	0 - 34.2	(18.8)	0 - 10.1	(14.1)	0 - 2.2	0 - 30.8
Total DDT	0 - 213.2	(44.2)	0 - 18.8	(42.8)	0 - 1.7	0 - 46
Ag	0 - 0.5	(1.2)	0 - 0.4	(0.4)	0 - 0.9	0 - 1.8
As	0 - 22.3	(21.5)	0 - 20.5	(25.4)	0 - 28.8	0.8 - 34.9
Cd	0 - 1.3	(1.7)	0 - 1.1	(0.9)	0 - 0.6	0 - 6.6
Cr	0.8 - 98.1	(20660)	4 - 97.0	(1911)	0 - 104.4	1.9 - 174
Cu	0.5 - 35.4	(69.3)	0 - 36.0	(76)	0 - 41.6	0.5 - 263
Ni	0.5 - 40.3	(112)	0.5 - 34.3	(25.9)	0 - 36.9	0 - 70.1
Pb	0.9 - 45.6	(163.8)	1.8 - 52.7	(166.2)	0 - 127.0	0 - 323
Zn	5.8 - 156.7	(306.6)	6.7 - 183.0	(274)	5 - 625.1	3.7 - 484
Hg	0 - 0.2	(0.3)	0 - 0.3	(0.2)	0 - 0.2	0 - 2.0

the proportions were summed over a contaminant class to yield the summed proportional concentrations (ΣPC). This exercise was conducted for only those analytes with ER-L and ER-M concentrations (Long and Morgan, 1990; Long et al., 1995), so those with only TEL or PEL concentrations (MacDonald, 1994) were not used (i.e., dieldrin, 4,4' DDD, 4,4' DDT, and lindane). The ΣPC based on ER-Ls (ΣPC-ERL) for PCBs, PAHs, pesticides, and metals at each station are listed in Table 3-8, and the ΣPC based on ER-Ms (ΣPC-ERM) are shown in Table 3-9. Contaminant data typically involves numerous analytes making it difficult to summarize the potential for stress. The ΣPC approach integrates over all contaminants by defining ER-L or ER-M equivalents. The general intent of this approach is to provide an estimate of the potential for interactions of multiple contaminants which may be sufficient to adversely affect biological integrity. Interaction effects may be antagonistic or synergistic as well as additive, but additivity is frequently assumed. Additive or synergistic interactions can result in toxicity at lower concentrations of multiple contaminants than would be expected based on single contaminant criteria. The combined effects of multiple pollutants may be as severe as those caused by high concentrations of a single contaminant, or may cause long-term chronic effects.

Approaches that integrate multiple contaminants as well as single contaminant criteria are essential for the valid classification of sites. The summed proportional method can be used with different classes of contaminants or summed over all contaminants, as shown in the last column of Tables 3-8 and 3-9. The use of an index that sums information over all contaminant classes could be a valuable means of ranking sites for comparative and regional assessments. When stations are classified based on the presence of single analyte criteria, the extremes, i.e. degraded and reference sites, may be identified. However, some sites may be clearly enriched, but may not quite meet the criteria for degraded, and there is no choice but to refer to them as reference. This may lead to erroneous conclusions regarding habitat status, or may impede our ability to identify sites that are in an early stage of degradation. These enriched sites may actually be more amenable to remediation actions that are more effective and less costly than those required when conditions advance to degraded status.

Therefore stations were classified as degraded when the ΣPC-ERM>1, enriched when the ΣPC-ERL>3 but ΣPC-ERM<1, and reference when the ΣPC-ERL<3 and ΣPC-ERM<1. The results are shown in Table 3-10. There were 42 core stations that were classified as reference (R), 14 were classified as enriched (E), and 30 were classified as degraded (D). For the supplemental stations, this yielded 5 reference, 1 enriched, and 14 degraded sites. This scheme would result in 34.5% of the area of the Carolinian Province characterized by degraded conditions, 56.8% as reference with no evidence of contamination, and 8.7% that show some evidence of anthropogenic enrichment.

Aluminum Normalization of Sediment Metals

Trace metals are naturally associated with the silt and clay fractions of detrital sediments, so finer grain sediments will inherently have higher concentrations of metals than sands. Normalization to aluminum is recognized as one of the most useful means of adjusting

Table 3-8. The Summed Proportional Concentrations (ΣPC) based on ER-L values (i.e., contaminant concentrations divided by ER-L values, and summed for each contaminant class). The ΣPCs for pesticides do not include dieldrin and endrin. The ΣPCs over all contaminants are listed in the last column.

Station	ΣPC Metals	ΣPC PAHs	ΣPC Pest	ΣPC PCB	TOTAL ΣPC-ERL
CP95101	3.34	0.41	0.66	0.15	**4.56**
CP95102	2.43	0.19	0.33	0.12	**3.08**
CP95103	6.38	4.85	20.93	1.42	**33.59**
CP95104	0.70	0.04	0.06	0.12	**0.92**
CP95105	0.66	0.06	0.00	0.12	**0.84**
CP95106	1.28	0.10	0.00	0.13	**1.51**
CP95107	8.01	1.09	1.57	0.28	**10.95**
CP95108	0.90	0.06	0.30	0.23	**1.50**
CP95109	6.03	4.34	136.98	1.49	**148.83**
CP95110	0.48	0.09	0.81	0.10	**1.48**
CP95111	1.50	0.61	0.65	0.15	**2.90**
CP95112	0.21	0.05	0.00	0.12	**0.37**
CP95113	0.50	0.05	0.00	0.14	**0.69**
CP95114	3.65	0.52	13.15	0.33	**17.67**
CP95115	0.88	0.15	0.00	0.10	**1.13**
CP95116	6.18	1.97	3.43	0.48	**12.06**
CP95117	5.52	0.85	0.87	0.19	**7.43**
CP95118	0.85	0.10	0.01	0.10	**1.06**
CP95119	4.08	0.59	0.31	0.17	**5.15**
CP95120	5.33	1.08	20.07	0.73	**27.22**
CP95121	8.13	1.80	7.37	0.78	**18.08**
CP95122	8.05	1.17	3.17	0.30	**12.69**
CP95123	1.29	0.08	0.00	0.12	**1.49**
CP95124	6.27	1.17	1.44	0.25	**9.13**
CP95125	0.84	0.05	0.00	0.10	**1.00**
CP95126	1.10	0.05	0.22	0.10	**1.46**
CP95127	0.99	0.04	0.00	0.11	**1.14**
CP95128	1.46	0.10	0.18	0.10	**1.84**
CP95129	0.79	0.08	0.12	0.11	**1.10**
CP95130	0.46	0.29	0.35	0.18	**1.28**
CP95131	3.91	0.44	0.29	0.10	**4.74**
CP95132	0.90	0.06	0.00	0.10	**1.07**
CP95133	0.73	0.08	0.00	0.11	**0.91**
CP95134	0.49	0.11	1.29	0.24	**2.13**
CP95135	0.48	0.11	0.00	0.11	**0.70**
CP95136	5.65	2.01	3.19	0.22	**11.07**
CP95138	0.85	0.11	115.04	3.21	**119.21**

(Table 3-8 continued)

Station	ΣPC Metals	ΣPC PAHs	ΣPC Pest	ΣPC PCB	TOTAL ΣPC-ERL
CP95139	6.96	1.65	3.77	0.42	**12.80**
CP95140	4.28	0.81	3.65	0.44	**9.18**
CP95141	3.53	0.28	0.81	0.17	**4.79**
CP95142	1.22	1.65	1.02	0.19	**4.09**
CP95143	3.61	0.51	1.84	0.28	**6.24**
CP95145	2.51	0.22	3.17	0.15	**6.05**
CP95146	1.12	0.08	0.12	0.13	**1.45**
CP95147	2.21	0.20	0.02	0.11	**2.55**
CP95148	0.71	0.10	0.00	0.10	**0.91**
CP95149	6.09	0.46	0.70	0.34	**7.58**
CP95150	3.30	3.29	0.78	0.26	**7.64**
CP95151	3.46	6.06	2.38	0.55	**12.44**
CP95152	4.95	25.21	4.77	0.79	**35.72**
CP95153	1.44	0.07	0.58	0.12	**2.22**
CP95154	4.40	1.50	1.90	0.48	**8.27**
CP95155	2.14	0.07	0.82	0.22	**3.26**
CP95156	7.16	0.53	5.73	0.34	**13.76**
CP95157	0.79	0.04	0.39	0.12	**1.33**
CP95158	1.77	0.06	0.45	0.18	**2.46**
CP95159	0.82	0.03	0.19	0.14	**1.18**
CP95160	2.22	0.11	0.80	0.16	**3.31**
CP95161	1.07	0.05	0.34	0.12	**1.58**
CP95162	1.26	0.07	0.47	0.13	**1.94**
CP95163	2.02	0.06	4.00	0.14	**6.21**
CP95164	0.56	0.03	51.17	0.20	**51.95**
CP95165	0.85	0.04	7.79	0.20	**8.88**
CP95166	4.88	0.37	229.32	0.91	**235.49**
CP95167	1.50	0.07	0.51	0.20	**2.28**
CP95168	0.96	0.06	1.69	0.30	**3.02**
CP95169	2.35	0.16	200.87	0.74	**204.12**
CP95170	0.78	0.06	0.02	0.14	**1.00**
CP95171	6.43	5.67	9.18	1.86	**23.15**
CP95172	7.05	5.32	18.53	3.56	**34.46**
CP95173	1.86	0.24	0.60	0.48	**3.18**
CP95174	5.37	5.31	5.10	0.93	**16.72**
CP95175	0.43	0.05	62.01	0.27	**62.76**
CP95176	0.39	0.05	0.15	0.15	**0.74**
CP95177	0.39	0.06	0.23	0.14	**0.82**
CP95178	0.75	0.18	7.04	0.21	**8.19**
CP95179	0.50	0.14	1.82	0.17	**2.63**

(Table 3-8 continued)

Station	ΣPC Metals	ΣPC PAHs	ΣPC Pest	ΣPC PCB	TOTAL ΣPC-ERL
CP95180	1.93	0.38	1.24	0.21	**3.76**
CP95181	6.42	1.03	4.07	0.32	**11.84**
CP95182	0.95	0.13	1.51	0.19	**2.78**
CP95183	0.82	0.09	0.60	0.16	**1.67**
CP95184	1.24	0.19	1.02	0.24	**2.69**
CP95185	1.29	0.21	0.57	0.15	**2.22**
CP95186	0.56	0.07	1.04	0.18	**1.86**
CP95187	1.41	0.12	0.36	0.16	**2.06**
CP95188	1.32	0.26	0.77	0.22	**2.56**
CP95ASM	6.62	4.92	4.17	0.93	**16.63**
CP95CB_	1.32	0.32	0.46	0.14	**2.24**
CP95CF_	3.57	2.12	2.34	0.53	**8.56**
CP95DIE	9.66	11.92	7.86	1.98	**31.42**
CP95FOS	2.83	0.50	0.88	0.25	**4.46**
CP95KIA	3.76	0.86	1.74	0.32	**6.68**
CP95KOP	10.28	28.71	11.77	1.35	**52.11**
CP95LON	1.93	0.22	48.37	0.31	**50.82**
CP95MI_	0.57	0.08	0.04	0.10	**0.79**
CP95NMK	16.27	31.38	72.65	9.52	**129.81**
CP95NV1	8.73	11.75	26.14	7.33	**53.95**
CP95NV2	7.18	24.31	8.88	3.18	**43.55**
CP95PR1	0.88	1.15	0.59	0.10	**2.73**
CP95PR2	7.20	0.97	0.87	0.39	**9.42**
CP95PR3	8.57	3.00	8.43	0.90	**20.89**
CP95PR4	7.93	2.00	3.36	0.64	**13.93**
CP95PR5	8.55	2.63	5.99	0.78	**17.95**
CP95RC_	0.87	0.07	0.00	0.11	**1.04**
CP95SPY	266.16	5.21	7.63	1.41	**280.42**
CP95ZI_	1.01	0.12	0.03	0.12	**1.29**

Table 3-9. The Summed Proportional Concentrations (ΣPC) based on ER-M values (i.e., contaminant concentrations divided by ER-M values, and summed for each contaminant class). The ΣPCs for pesticides do not include dieldrin and endrin. The ΣPCs over all contaminants are listed in the last column.

Station	ΣPC Metals	ΣPC PAHs	ΣPC Pest	ΣPC PCB	TOTAL ΣPC-ERM
CP95101	0.76	0.03	0.04	0.02	**0.84**
CP95102	0.56	0.02	0.02	0.02	**0.61**
CP95103	1.61	0.53	1.18	0.18	**3.51**
CP95104	0.19	0.00	0.00	0.02	**0.21**
CP95105	0.16	0.01	0.00	0.02	**0.18**
CP95106	0.32	0.01	0.00	0.02	**0.34**
CP95107	2.02	0.14	0.08	0.03	**2.28**
CP95108	0.25	0.01	0.03	0.03	**0.31**
CP95109	1.44	0.58	4.80	0.19	**7.01**
CP95110	0.13	0.01	0.04	0.01	**0.19**
CP95111	0.36	0.09	0.04	0.02	**0.50**
CP95112	0.05	0.00	0.00	0.01	**0.07**
CP95113	0.13	0.00	0.00	0.02	**0.15**
CP95114	0.88	0.06	0.93	0.04	**1.91**
CP95115	0.19	0.01	0.00	0.01	**0.22**
CP95116	1.49	0.25	0.20	0.06	**2.00**
CP95117	1.30	0.10	0.05	0.02	**1.47**
CP95118	0.19	0.01	0.00	0.01	**0.21**
CP95119	0.92	0.07	0.02	0.02	**1.03**
CP95120	1.23	0.13	1.43	0.09	**2.88**
CP95121	1.83	0.21	0.42	0.10	**2.56**
CP95122	1.82	0.15	0.15	0.04	**2.16**
CP95123	0.32	0.01	0.00	0.01	**0.34**
CP95124	1.51	0.15	0.07	0.03	**1.76**
CP95125	0.19	0.00	0.00	0.01	**0.21**
CP95126	0.25	0.00	0.01	0.01	**0.28**
CP95127	0.22	0.00	0.00	0.01	**0.24**
CP95128	0.34	0.01	0.01	0.01	**0.38**
CP95129	0.19	0.01	0.01	0.01	**0.22**
CP95130	0.13	0.02	0.01	0.02	**0.19**
CP95131	0.92	0.05	0.01	0.01	**1.00**
CP95132	0.22	0.01	0.00	0.01	**0.24**
CP95133	0.17	0.01	0.00	0.01	**0.19**
CP95134	0.13	0.01	0.09	0.03	**0.26**
CP95135	0.11	0.01	0.00	0.01	**0.13**
CP95136	1.31	0.26	0.15	0.03	**1.75**
CP95138	0.22	0.01	7.14	0.40	**7.78**

(Table 3-9 continued)

Station	ΣPC Metals	ΣPC PAHs	ΣPC Pest	ΣPC PCB	TOTAL ΣPC-ERM
CP95139	1.63	0.19	0.23	0.05	**2.10**
CP95140	0.97	0.09	0.21	0.06	**1.32**
CP95141	0.83	0.03	0.05	0.02	**0.93**
CP95142	0.28	0.19	0.06	0.02	**0.56**
CP95143	0.84	0.06	0.10	0.04	**1.04**
CP95145	0.55	0.02	0.24	0.02	**0.83**
CP95146	0.23	0.01	0.01	0.02	**0.26**
CP95147	0.53	0.01	0.00	0.01	**0.56**
CP95148	0.14	0.01	0.00	0.01	**0.15**
CP95149	1.37	0.04	0.04	0.04	**1.49**
CP95150	0.75	0.52	0.06	0.03	**1.36**
CP95151	0.75	0.82	0.18	0.07	**1.82**
CP95152	1.09	3.55	0.31	0.10	**5.05**
CP95153	0.32	0.01	0.04	0.01	**0.39**
CP95154	0.94	0.19	0.11	0.06	**1.30**
CP95155	0.42	0.01	0.06	0.03	**0.51**
CP95156	1.52	0.05	0.24	0.04	**1.86**
CP95157	0.18	0.00	0.03	0.01	**0.22**
CP95158	0.38	0.01	0.04	0.02	**0.44**
CP95159	0.16	0.00	0.01	0.02	**0.20**
CP95160	0.48	0.01	0.06	0.02	**0.58**
CP95161	0.22	0.00	0.02	0.01	**0.26**
CP95162	0.26	0.01	0.04	0.02	**0.32**
CP95163	0.42	0.01	0.33	0.02	**0.78**
CP95164	0.12	0.00	3.62	0.02	**3.76**
CP95165	0.17	0.00	0.61	0.02	**0.81**
CP95166	1.08	0.04	15.13	0.12	**16.36**
CP95167	0.33	0.01	0.04	0.03	**0.40**
CP95168	0.22	0.01	0.13	0.04	**0.39**
CP95169	0.50	0.02	12.93	0.09	**13.54**
CP95170	0.17	0.01	0.00	0.02	**0.20**
CP95171	1.44	0.69	0.65	0.23	**3.02**
CP95172	1.60	0.59	1.14	0.45	**3.79**
CP95173	0.42	0.03	0.03	0.06	**0.53**
CP95174	1.22	0.83	0.28	0.12	**2.45**
CP95175	0.11	0.00	4.39	0.03	**4.54**
CP95176	0.10	0.00	0.01	0.02	**0.13**
CP95177	0.09	0.00	0.01	0.02	**0.13**
CP95178	0.17	0.03	0.56	0.03	**0.78**
CP95179	0.13	0.02	0.14	0.02	**0.30**

(Table 3-9 continued)

Station	ΣPC Metals	ΣPC PAHs	ΣPC Pest	ΣPC PCB	TOTAL ΣPC-ERM
CP95180	0.45	0.04	0.09	0.03	**0.61**
CP95181	1.49	0.13	0.31	0.04	**1.96**
CP95182	0.23	0.01	0.12	0.02	**0.39**
CP95183	0.18	0.01	0.05	0.02	**0.26**
CP95184	0.28	0.02	0.08	0.03	**0.41**
CP95185	0.29	0.02	0.05	0.02	**0.37**
CP95186	0.14	0.01	0.09	0.02	**0.25**
CP95187	0.30	0.01	0.03	0.02	**0.36**
CP95188	0.30	0.02	0.06	0.03	**0.41**
CP95ASM	1.42	0.68	0.28	0.12	**2.50**
CP95CB_	0.36	0.02	0.03	0.02	**0.43**
CP95CF_	0.83	0.29	0.17	0.07	**1.35**
CP95DIE	2.15	1.65	0.53	0.25	**4.58**
CP95FOS	0.62	0.05	0.06	0.03	**0.77**
CP95KIA	0.82	0.11	0.12	0.04	**1.09**
CP95KOP	2.24	2.86	0.81	0.17	**6.08**
CP95LON	0.45	0.02	2.64	0.04	**3.15**
CP95MI_	0.12	0.01	0.00	0.01	**0.14**
CP95NMK	3.60	3.33	5.37	1.20	**13.50**
CP95NV1	2.09	1.30	1.55	0.92	**5.86**
CP95NV2	1.59	2.88	0.68	0.40	**5.55**
CP95PR1	0.21	0.19	0.02	0.01	**0.43**
CP95PR2	1.68	0.12	0.04	0.05	**1.89**
CP95PR3	1.95	0.38	0.43	0.11	**2.86**
CP95PR4	1.88	0.25	0.18	0.08	**2.38**
CP95PR5	1.94	0.34	0.35	0.10	**2.73**
CP95RC_	0.20	0.01	0.00	0.01	**0.21**
CP95SPY	59.26	0.54	0.56	0.18	**60.54**
CP95ZI_	0.22	0.01	0.00	0.02	**0.25**

Table 3-10. Classification of stations sampled in the Carolinian Province during Year 2 Demonstration Project, summer 1995 based on the following criteria: Degraded (**D**) if ΣPC-ERM > 1; Enriched (**E**) if ΣPC-ERL > 3, but ΣPC ER-M < 1; Reference (**R**) if ΣPC ER-L< 3 and ΣPC ER-M< 1. The number of analytes exceeding ERL/TEL and ERM/PEL values are also listed.

Station	ERL/TEL	ERM/PEL	ΣPC-ERL	ΣPC - ERM	Classification
CP95104	0	0	0.92	0.21	R
CP95105	0	0	0.84	0.18	R
CP95106	0	0	1.51	0.34	R
CP95108	1	0	1.50	0.31	R
CP95110	0	0	1.48	0.19	R
CP95111	0	0	2.90	0.50	R
CP95112	0	0	0.37	0.07	R
CP95113	0	0	0.69	0.15	R
CP95115	0	0	1.13	0.22	R
CP95118	0	0	1.06	0.21	R
CP95123	0	0	1.49	0.34	R
CP95125	0	0	1.00	0.21	R
CP95126	0	0	1.46	0.28	R
CP95127	0	0	1.14	0.24	R
CP95128	0	0	1.84	0.38	R
CP95129	0	0	1.10	0.22	R
CP95130	0	0	1.28	0.19	R
CP95132	0	0	1.07	0.24	R
CP95133	0	0	0.91	0.19	R
CP95134	0	0	2.13	0.26	R
CP95135	0	0	0.70	0.13	R
CP95146	0	0	1.45	0.26	R
CP95147	0	0	2.55	0.56	R
CP95148	0	0	0.91	0.15	R
CP95153	0	0	2.22	0.39	R
CP95157	0	0	1.33	0.22	R
CP95158	0	0	2.46	0.44	R
CP95159	0	0	1.18	0.20	R
CP95161	0	0	1.58	0.26	R
CP95162	0	0	1.94	0.32	R
CP95167	0	0	2.28	0.40	R
CP95170	0	0	1.00	0.20	R
CP95176	0	0	0.74	0.13	R
CP95177	0	0	0.82	0.13	R
CP95179	0	0	2.63	0.30	R
CP95182	0	0	2.78	0.39	R

(Table 3-10 continued)

Station	ER-L/TEL	ER-M/PEL	ΣPC-ERL	ΣPC - ERM	Classification
CP95183	0	0	1.67	0.26	R
CP95184	0	0	2.69	0.41	R
CP95185	0	0	2.22	0.37	R
CP95186	1	0	1.86	0.25	R
CP95187	0	0	2.06	0.36	R
CP95188	0	0	2.56	0.41	R
CP95CB_	0	0	2.24	0.43	R
CP95MI_	0	0	0.79	0.14	R
CP95PR1	0	0	2.73	0.43	R
CP95RC_	0	0	1.04	0.21	R
CP95ZI_	0	0	1.29	0.25	R
CP95101	0	0	4.56	0.84	E
CP95102	0	0	3.08	0.61	E
CP95131	1	0	4.74	1.00	E
CP95141	0	0	4.79	0.93	E
CP95142	0	0	4.09	0.56	E
CP95145	2	0	6.05	0.83	E
CP95155	0	0	3.26	0.51	E
CP95160	0	0	3.31	0.58	E
CP95163	1	1	6.21	0.78	E
CP95165	2	1	8.88	0.81	E
CP95168	2	0	3.02	0.39	E
CP95173	0	0	3.18	0.53	E
CP95178	1	1	8.19	0.78	E
CP95180	1	0	3.76	0.61	E
CP95FOS	0	0	4.46	0.77	E
CP95103	9	1	33.59	3.51	D
CP95107	5	0	10.95	2.28	D
CP95109	5	3	148.83	7.01	D
CP95114	2	1	17.67	1.91	D
CP95116	5	0	12.06	2.00	D
CP95117	2	0	7.43	1.47	D
CP95119	1	0	5.15	1.03	D
CP95120	5	2	27.22	2.88	D
CP95121	8	0	18.08	2.56	D
CP95122	4	0	12.69	2.16	D
CP95124	3	0	9.13	1.76	D
CP95136	3	0	11.07	1.75	D
CP95138	2	6	119.21	7.78	D
CP95139	5	0	12.80	2.10	D

(Table 3-10 continued)

Station	ER-L/TEL	ER-M/PEL	ΣPC-ERL	ΣPC - ERM	Classification
CP95140	4	0	9.18	1.32	D
CP95143	1	0	6.24	1.04	D
CP95149	2	0	7.58	1.49	D
CP95150	1	0	7.64	1.36	D
CP95151	1	0	12.44	1.82	D
CP95152	14	1	35.72	5.05	D
CP95154	1	0	8.27	1.30	D
CP95156	5	0	13.76	1.86	D
CP95164	3	4	51.95	3.76	D
CP95166	1	7	235.49	16.36	D
CP95169	0	7	204.12	13.54	D
CP95171	4	0	23.15	3.02	D
CP95172	9	0	34.46	3.79	D
CP95174	4	0	16.72	2.45	D
CP95175	3	4	62.76	4.54	D
CP95181	1	0	11.84	1.96	D
CP95ASM	4	0	16.63	2.50	D
CP95CF_	1	0	8.56	1.35	D
CP95DIE	17	0	31.42	4.58	D
CP95KIA	2	0	6.68	1.09	D
CP95KOP	21	0	52.11	6.08	D
CP95LON	4	1	50.82	3.15	D
CP95NMK	25	3	129.81	13.50	D
CP95NV1	17	0	53.95	5.86	D
CP95NV2	16	0	43.55	5.55	D
CP95PR2	3	0	9.42	1.89	D
CP95PR3	8	1	20.89	2.86	D
CP95PR4	6	0	13.93	2.38	D
CP95PR5	10	0	17.95	2.73	D
CP95SPY	6	2	280.42	60.54	D

for natural variability (Bruland et al., 1974; Goldberg et al., 1979; Windom et al., 1989). Once the stations were classified so that reference sites and degraded sites were identified, the sediment metal concentrations were examined using Al normalization procedures (Windom et al., 1989; Schropp et al., 1990). The regression parameters for metals measured in the 1995 Year 2 Demonstration Project are shown in Table 3-11, along with the results from the 1994 Year 1 Demonstration study. Similar results were observed for both years, and generally consistent with studies from the other provinces. Arsenic and cadmium concentrations were not related to Al concentrations ($p > 0.05$). Significant associations were observed with Ag, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn, and Zn. The data in Table 3-11 were based on expressing Al (and Fe) as percent, and the actual concentrations (ug metal / g dry sediment) were used for the other analytes. Regression analyses were also performed using log-log transformations, but r^2 increased slightly for Pb and Fe only; for all others a higher r^2 was achieved using % Al.

Table 3-11. The metal-aluminum regression parameters for sediment metal data analyzed by Al normalization procedures. The results with sediments collected in the Carolinian Province during 1995 and 1994 are presented. Aluminum and iron concentrations were expressed as percent, and other metal concentrations were expressed as ug metal / g dry sediment.

	Carolinian Province, 1995			Carolinian Province, 1994		
Metal	slope	intercept	r^2	slope	intercept	r^2
Ag	0.006	0.003	0.15	0.003	0.01	0.07
As	0.31	1.10	0.10	0.47	1.22	0.07
Cd	0.009	0.021	0.02	0.008	0.02	0.06
Cr	7.30	6.01	0.43	6.74	7.93	0.36
Cu	0.74	0.50	0.31	0.78	0.52	0.66
Hg	0.004	0.004	0.16	0.002	0.00	0.05
Mn	39.84	92.49	0.14	71.89	53.75	0.11
Ni	1.60	-0.15	0.65	1.58	0.10	0.82
Pb	2.47	2.74	0.69	2.44	2.50	0.88
Sn	0.159	0.191	0.39			
Zn	6.01	9.25	0.51	6.98	5.32	0.82
Fe	0.30	0.13	0.58	0.31	0.19	0.56

After the regression lines and prediction intervals are determined using the reference sites only, the remaining sites can be plotted, so that those that lie above the prediction intervals represent sites with significantly enriched metal concentrations. However, a numeric index of enrichment would be more valuable. The observed metal concentrations were divided by the expected metal concentrations (calculated from the regression parameters) to generate metal enrichment factors (MEFs) for each metal, and then summed or averaged

for each station Therefore, metal-enriched sites can be identified for each metal, and summed or averaged MEFs provide an integrated assessment of enrichment. The results of this exercise for 11 metal analytes are shown in Table 3-12, with the sites grouped according to their classification as reference, enriched, or degraded. As expected most of the reference sites have a summed MEF of approximately 11 and an average MEF around 1, whereas higher MEFs are observed with many of the enriched and degraded sites.

One problem with using ER-L and ER-M guidelines is that there is no way of correcting for variations in background concentrations associated with different sediment types. For example, it can be seen from Table 3-6 that Cu concentrations exceeded ER-L concentrations for only 1 core site (CP95107) and 3 supplemental sites (KOP, NMK, NV1) suggesting that Cu is not a serious problem. However Cu MEFs of > 3 were observed at 12 core sites and 10 supplemental sites, suggesting a higher incidence of anthropogenic enrichment. At CP95107 where Cu exceeded the ER-L guideline, the Al-normalized Cu MEF was 3.76. Although CP95103 had a similar Cu MEF of 3.65, and other sites (i.e., CP95139, -149, -150, -151, -152, -171, -172, -174, 181, ASM, DIE, NV2, PR3, PR4, PR5, SPY) were similar or even higher (some MEFs were > 10), none would be flagged as sites that may be experiencing significant Cu stress when ER-L guidelines are applied. For Pb, no core sites and 6 supplemental sites (DIE, KOP, NMK, NV1, PR5, SPY) exceeded ER-L values. However, the Pb MEFs for NMK and NV1 were greater than 10, but Pb MEFs for DIE and KOP were only 2.17 and 2.62 respectively, and a number of other sites had Pb MEFs $\geq$ 3 (i.e., CP95172, -174, -181, ASM). The occurrence of high As concentrations throughout Southeastern sediments has been documented, and 18 core stations and 10 supplemental stations exceeded ER-L values. Seven of these core sites had As MEFs < 3, while As MEFs > 3 were observed at 7 other core stations that did not exceed ER-L values. Conversely, many of the stations identified as having Cr concentrations that exceeded ER-L values frequently were not identified as metal enriched based on Al normalization. Seven core stations and 9 supplemental stations exceeded Cr ER-L concentrations, but all of the core stations had Cr MEFs close to 1 (ranged from 1 to 1.39), and only 3 of the supplemental stations had Cr MEFs > 3, suggesting that Cr contamination was not as prevalent as indicated by ER-L guidelines. These examples are indicative of the kinds of interpretive discrepancies that are apparent when Tables 3-6 and 3-12 are compared. With some metals, application of ER-L guidelines may result in an underestimation of metal contamination, while in others, metal contamination would be overestimated.

Metal enrichment is readily demonstrable, but the critical issue of what concentrations affect the biota is less easily determined. Muddier, siltier sediments would generally have higher background metal concentrations, so adjustment for this natural variable may be important for identifying levels of enrichment that are truly potentially damaging to the biological resources. Although different, Al normalization techniques are consistent with the theoretical basis of acid volatile sulfide (AVS) adjustments. Siltier sediments tend to have higher AVS concentrations, and bioavailability is believed to decrease as AVS increases (Di Toro, et al., 1992). However, given some of the logistical issues surrounding the proper handling of sediments for AVS analysis, etc., and the fact that Al concentrations, but not AVS concentrations are more frequently available, Al normalized data may be more readily

Table 3-12. The metal enrichment factors (MEF), measured concentrations divided by expected concentrations (calculated using Al normalized regresssions), of EMAP sites sampled in the Carolinian Province during summer 1995. The MEFs summed over 11 metal analytes as well the average MEF are listed at the end.

Station		MEF As	MEF Ag	MEF Cd	MEF Cu	MEF Cr	MEF Mn	MEF Ni	MEF Pb	MEF Zn	MEF Sn	MEF Hg	MEF SUM	MEF AVE
CP95104	R	0.00	1.09	0.00	0.94	0.70	0.80	1.01	1.03	0.86	0.91	1.53	**8.87**	**0.81**
CP95105	R	0.58	1.32	0.38	1.07	0.56	0.70	0.78	0.71	0.73	0.78	0.00	**7.62**	**0.69**
CP95106	R	0.78	1.27	0.75	0.97	0.84	0.74	1.08	0.96	0.94	0.87	0.68	**9.87**	**0.90**
CP95108	R	0.00	1.14	0.98	0.81	0.88	2.32	1.39	1.18	1.31	0.88	0.96	**11.85**	**1.08**
CP95110	R	0.00	0.75	0.00	0.72	0.54	0.41	0.64	0.94	0.59	1.98	0.00	**6.57**	**0.60**
CP95111	R	1.00	1.21	0.92	1.31	1.08	0.99	1.17	1.30	1.20	1.26	1.86	**13.30**	**1.21**
CP95112	R	0.00	0.00	0.00	1.57	0.12	0.00	0.00	0.31	0.61	0.10	3.66	**6.37**	**0.58**
CP95113	R	0.57	1.12	0.00	1.18	0.37	0.80	1.30	0.76	1.07	0.94	0.00	**8.11**	**0.74**
CP95115	R	1.49	0.00	0.00	0.74	0.48	0.84	0.74	0.92	0.82	0.60	0.84	**7.47**	**0.68**
CP95118	R	0.96	0.97	0.43	0.76	1.10	0.76	0.63	0.95	0.75	0.75	0.94	**9.01**	**0.82**
CP95123	R	0.94	0.85	0.50	0.63	0.80	1.16	0.94	0.79	1.02	0.89	0.90	**9.42**	**0.86**
CP95125	R	0.81	0.00	0.00	0.61	1.02	0.91	0.70	1.12	0.76	0.69	0.99	**7.61**	**0.69**
CP95126	R	1.02	0.71	0.37	0.49	1.48	1.37	0.80	1.09	0.93	0.96	0.93	**10.16**	**0.92**
CP95127	R	1.16	0.72	0.00	0.71	1.07	1.10	0.68	1.10	0.86	0.95	0.94	**9.29**	**0.84**
CP95128	R	0.86	0.81	1.43	1.02	1.34	1.12	0.80	0.94	1.04	0.89	0.67	**10.92**	**0.99**
CP95129	R	0.76	0.00	0.50	0.96	1.36	2.14	0.93	1.38	1.56	1.49	0.00	**11.08**	**1.01**
CP95130	R	0.00	0.00	0.00	0.83	0.49	1.17	1.55	1.48	1.05	0.78	0.00	**7.35**	**0.67**
CP95132	R	0.87	0.00	0.38	0.60	1.00	1.20	0.87	0.97	1.34	0.56	0.00	**7.78**	**0.71**
CP95133	R	1.01	0.00	0.00	0.42	1.42	1.17	0.84	0.80	0.92	0.29	0.00	**6.86**	**0.62**
CP95134	R	0.00	0.00	0.00	0.74	1.25	1.87	0.82	1.13	1.21	1.44	0.00	**8.45**	**0.77**
CP95135	R	0.87	0.00	0.00	0.46	0.54	0.36	0.63	0.72	0.66	0.21	0.00	**4.45**	**0.40**
CP95146	R	2.68	0.00	0.96	1.26	2.72	1.12	2.23	1.23	1.64	1.19	0.00	**15.03**	**1.37**
CP95147	R	2.08	0.81	0.58	1.41	1.48	0.80	1.64	0.91	1.24	0.99	0.86	**12.79**	**1.16**
CP95148	R	2.47	0.00	0.00	0.81	1.10	0.54	1.92	0.86	0.98	0.93	0.00	**9.60**	**0.87**
CP95153	R	1.73	0.73	0.71	0.63	1.34	1.35	0.94	1.23	1.05	0.98	0.90	**11.58**	**1.05**

(Table 3-12 continued)

Station		MEF As	MEF Ag	MEF Cd	MEF Cu	MEF Cr	MEF Mn	MEF Ni	MEF Pb	MEF Zn	MEF Sn	MEF Hg		MEF SUM	MEF AVE
CP95157	R	0.94	2.63	2.07	0.63	2.25	1.66	1.23	1.21	1.29	1.81	0.00		15.73	1.43
CP95158	R	3.77	3.24	3.35	1.32	1.90	2.27	3.11	1.26	1.74	1.73	2.01		25.70	2.34
CP95159	R	1.50	1.55	5.80	0.45	1.07	0.99	0.79	0.98	0.90	1.09	0.00		15.10	1.37
CP95161	R	1.86	0.00	2.88	0.75	0.77	1.20	0.85	0.96	1.02	0.87	1.15		12.32	1.12
CP95162	R	2.65	0.00	1.06	0.53	0.73	2.33	1.02	1.24	1.28	1.27	0.70		12.81	1.16
CP95167	R	2.52	1.38	1.10	1.35	1.05	0.77	1.57	0.89	1.17	1.16	1.41		14.38	1.31
CP95170	R	1.03	2.12	1.19	0.76	1.19	1.46	0.95	0.79	1.09	1.70	1.66		13.94	1.27
CP95176	R	0.00	1.71	0.48	1.72	0.53	0.39	0.99	0.70	0.67	0.64	1.96		9.81	0.89
CP95177	R	0.00	0.00	1.08	1.91	0.68	0.37	1.28	0.57	0.74	0.40	2.13		9.16	0.83
CP95179	R	0.00	0.00	0.80	1.07	0.64	0.59	0.78	0.91	0.69	0.54	1.51		7.54	0.69
CP95182	R	0.00	3.74	1.43	1.38	0.78	0.52	0.65	1.24	0.84	1.00	2.75		14.35	1.30
CP95183	R	0.81	1.41	1.44	0.70	0.72	0.68	0.62	1.03	0.68	0.90	0.76		9.74	0.89
CP95184	R	1.08	2.23	0.75	2.76	1.34	1.37	0.84	1.34	1.33	1.68	1.67		16.39	1.49
CP95185	R	1.08	2.64	0.87	2.84	1.04	0.79	0.85	1.19	1.17	1.35	2.31		16.14	1.47
CP95186	R	0.00	0.83	0.85	0.70	0.80	0.37	0.69	0.91	0.62	1.28	1.36		8.40	0.76
CP95187	R	1.08	2.09	5.97	0.94	0.95	0.61	0.84	1.14	0.76	1.02	1.98		17.38	1.58
CP95188	R	1.24	1.26	0.66	1.47	1.08	0.59	1.10	1.19	0.94	1.24	1.73		12.50	1.14
CP95CB	R	0.00	0.48	1.03	1.05	0.85	0.94	1.12	0.92	1.03	1.16	1.20		9.78	0.89
CP95MI_	R	1.42	0.00	0.51	0.80	0.82	0.46	1.27	0.63	0.95	1.04	1.46		9.36	0.85
CP95PR1	R	0.66	2.09	2.85	1.19	0.67	0.91	1.19	1.27	1.14	0.84	2.21		15.00	1.36
CP95RC	R	1.07	1.13	0.45	0.62	1.01	1.05	0.66	0.77	0.89	1.06	0.79		9.50	0.86
CP95ZI_	R	1.63	1.60	1.28	1.13	1.33	0.69	0.93	0.89	1.18	0.96	0.96		12.57	1.14
CP95101	E	2.80	1.21	1.21	1.77	1.27	0.63	1.53	1.50	1.16	1.36	1.88		16.32	1.48
CP95102	E	2.34	1.11	1.05	1.27	1.08	0.68	1.40	1.24	1.12	1.25	1.32		13.86	1.26
CP95131	E	2.91	0.97	0.83	1.68	1.17	1.39	1.64	1.26	1.53	1.16	1.48		16.02	1.46
CP95141	E	3.18	1.17	0.90	1.61	1.18	0.72	2.07	1.29	1.30	1.31	1.73		16.47	1.50
CP95142	E	1.40	0.92	0.51	1.12	1.07	0.67	1.20	1.04	1.05	0.94	1.68		11.59	1.05

(Table 3-12 continued)

Station		MEF As	MEF Ag	MEF Cd	MEF Cu	MEF Cr	MEF Mn	MEF Ni	MEF Pb	MEF Zn	MEF Sn	MEF Hg	MEF SUM	MEF AVE
CP95145	E	3.03	1.45	0.90	1.26	1.49	0.67	1.19	1.20	1.24	1.35	1.40	**15.18**	**1.38**
CP95155	E	5.40	2.49	2.88	1.58	1.81	1.87	2.33	0.94	1.25	1.90	2.05	**24.49**	**2.23**
CP95160	E	3.04	1.07	1.27	1.39	1.43	1.21	1.41	1.06	1.19	1.31	1.25	**15.62**	**1.42**
CP95163	E	2.72	1.60	4.45	0.92	2.81	2.49	1.15	1.27	1.46	1.93	1.47	**22.27**	**2.02**
CP95165	E	1.72	1.52	1.52	0.86	0.65	0.76	0.92	1.09	0.78	0.35	1.27	**11.45**	**1.04**
CP95168	E	1.16	1.39	0.66	0.86	1.49	1.15	1.18	1.09	1.11	1.43	2.37	**13.89**	**1.26**
CP95173	E	1.66	1.07	1.16	2.25	1.16	0.73	1.12	1.06	1.11	1.31	1.94	**14.58**	**1.33**
CP95178	E	0.68	2.78	0.84	2.19	0.86	0.31	1.20	1.07	0.93	0.65	2.97	**14.49**	**1.32**
CP95180	E	0.66	7.43	2.10	7.02	1.18	0.88	1.88	1.69	1.67	1.83	4.69	**31.04**	**2.82**
CP95FOS	E	3.06	1.62	1.09	2.81	1.19	0.73	1.51	1.22	1.42	1.33	1.93	**17.91**	**1.63**
CP95103	D	1.90	2.51	4.34	3.65	1.09	2.37	1.95	0.82	2.34	1.77	0.47	**23.21**	**2.11**
CP95107	D	1.76	1.22	1.23	3.76	1.02	0.89	2.11	1.18	1.65	1.35	2.71	**18.88**	**1.72**
CP95109	D	2.45	1.63	3.73	2.50	1.06	0.46	1.89	1.84	1.75	1.63	3.29	**22.24**	**2.02**
CP95114	D	2.40	1.22	2.46	1.48	1.19	0.71	1.67	1.32	1.76	1.32	2.17	**17.68**	**1.61**
CP95116	D	2.82	1.29	3.57	2.03	1.22	0.80	1.83	1.27	1.99	1.45	2.18	**20.46**	**1.86**
CP95117	D	3.71	1.11	0.81	1.98	1.22	1.36	1.96	1.43	1.57	1.59	2.02	**18.75**	**1.70**
CP95119	D	3.35	1.21	0.80	1.61	1.12	1.32	1.42	1.23	1.34	1.25	1.72	**16.37**	**1.49**
CP95120	D	2.21	2.36	6.75	2.51	1.05	0.53	1.48	1.45	1.62	2.18	3.12	**25.26**	**2.30**
CP95121	D	2.81	3.03	12.69	2.84	1.22	1.05	1.63	1.46	1.99	1.68	3.06	**33.47**	**3.04**
CP95122	D	2.77	2.73	10.67	2.86	1.27	1.09	1.56	1.46	1.97	1.91	2.91	**31.19**	**2.84**
CP95124	D	2.66	1.95	4.14	2.34	1.23	1.33	1.89	1.41	1.77	1.55	2.21	**22.48**	**2.04**
CP95136	D	3.43	1.93	2.12	2.12	1.17	1.50	1.75	1.41	1.58	1.49	1.76	**20.26**	**1.84**
CP95138	D	0.00	0.00	0.54	0.62	1.74	2.12	0.87	1.30	1.25	1.63	1.01	**11.09**	**1.01**
CP95139	D	3.15	4.71	4.56	3.42	1.18	2.32	1.86	1.63	2.14	1.60	3.12	**29.68**	**2.70**
CP95140	D	3.72	1.83	2.30	2.16	1.32	1.01	1.75	1.24	1.64	1.15	2.18	**20.29**	**1.84**
CP95143	D	2.75	0.98	0.53	1.54	1.22	0.77	1.41	1.15	1.40	1.41	1.30	**14.46**	**1.31**
CP95149	D	4.08	0.74	0.56	3.35	1.04	2.26	1.80	0.91	1.31	1.28	1.82	**19.13**	**1.74**

(Table 3-12 continued)

Station		MEF As	MEF Ag	MEF Cd	MEF Cu	MEF Cr	MEF Mn	MEF Ni	MEF Pb	MEF Zn	MEF Sn	MEF Hg		MEF SUM	MEF AVE
CP95150	D	2.59	0.75	0.67	4.26	0.99	1.23	1.71	1.17	1.27	1.46	1.21		17.29	1.57
CP95151	D	3.88	3.91	2.21	4.16	1.66	1.52	2.01	1.64	1.96	1.87	4.35		29.17	2.65
CP95152	D	4.42	3.05	2.20	4.10	1.73	1.37	2.04	1.87	1.95	1.60	3.86		28.18	2.56
CP95154	D	4.83	1.68	2.42	2.70	1.31	1.25	1.75	1.28	1.47	1.48	1.85		22.01	2.00
CP95156	D	6.57	1.36	1.59	2.42	1.39	1.05	1.85	1.17	1.59	1.47	2.85		23.31	2.12
CP95164	D	1.04	2.14	2.12	0.60	0.90	0.86	0.92	0.88	0.88	0.89	0.00		11.23	1.02
CP95166	D	4.28	1.14	1.20	1.81	1.12	1.42	1.57	1.03	1.38	1.23	1.48		17.66	1.61
CP95169	D	3.53	1.41	1.14	1.30	1.28	1.33	1.38	0.77	1.21	1.44	1.52		16.32	1.48
CP95171	D	3.95	5.73	3.55	5.08	1.46	2.10	1.90	1.83	2.54	1.90	5.52		35.54	3.23
CP95172	D	2.47	11.40	12.19	6.27	1.70	0.54	2.17	3.05	3.23	2.98	8.84		54.85	4.99
CP95174	D	2.09	17.94	3.24	5.20	1.42	1.01	1.35	3.20	2.60	2.67	9.89		50.62	4.60
CP95175	D	0.00	0.00	0.60	0.79	0.64	0.46	0.70	0.84	0.61	1.07	1.63		7.34	0.67
CP95181	D	1.55	9.73	5.63	7.76	1.67	1.15	2.07	2.99	2.64	2.62	6.15		43.98	4.00
CP95ASM	D	4.49	7.80	2.99	10.65	3.54	1.47	2.31	3.64	2.75	2.08	5.98		47.68	4.33
CP95CF_	D	2.96	2.87	3.00	2.73	1.54	1.10	1.95	1.28	2.22	1.74	3.39		24.78	2.25
CP95DIE	D	5.36	5.19	2.86	4.95	1.77	0.82	2.02	2.17	2.52	1.76	3.66		33.09	3.01
CP95KIA	D	3.97	0.93	0.75	1.77	1.36	1.22	1.48	1.21	1.32	1.08	1.14		16.22	1.47
CP95KOP	D	6.19	3.98	2.84	6.63	1.97	1.48	2.15	2.62	2.81	1.77	4.31		36.74	3.34
CP95LON	D	1.23	0.85	0.94	1.30	1.50	1.03	1.13	1.34	1.09	0.89	2.22		13.53	1.23
CP95NMK	D	4.66	13.04	17.40	17.39	6.46	0.69	2.56	11.42	8.19	12.83	12.57		107.21	9.75
CP95NV1	D	2.78	53.73	6.26	15.05	2.93	0.95	4.97	10.68	4.78	5.65	1.75		109.53	9.96
CP95NV2	D	4.63	2.35	1.79	4.17	1.73	1.18	2.04	1.29	1.33	1.39	2.17		24.07	2.19
CP95PR2	D	2.51	2.71	8.78	2.81	1.14	1.25	1.76	1.45	1.99	1.65	2.80		28.85	2.62
CP95PR3	D	2.15	4.08	15.66	3.35	1.06	0.89	1.67	1.54	2.22	1.76	3.17		37.55	3.41
CP95PR4	D	2.61	3.14	2.55	3.87	1.08	1.02	1.62	1.53	2.23	1.87	3.35		24.86	2.26
CP95PR5	D	2.48	4.44	9.55	4.75	1.00	0.84	1.56	1.78	2.30	1.91	3.71		34.34	3.12
CP95SPY	D	3.89	9.29	11.26	10.32	864.53	1.35	29.63	9.32	8.08	3.05	6.26		956.98	87.00

generated. Aluminum normalized MEFs may provide a more realistic estimate of significant metal enrichment than ER-L or ER-M guidelines. MEFs may function as a valuable index of metal bioavailability and levels that are more likely to cause toxic effects, particularly chronic effects.

The ultimate question is, are the biological resources compromised? A myriad of other factors such as pH and dissolved oxygen conditions also affect bioavailability, and organisms may activate compensatory mechanisms that ameliorate contaminant effects. Laboratory toxicity tests provide an important means of assessing the potential toxicity of the kinds of complex mixtures of chemicals that occur in estuaries. Organismal and community evaluations of the biota *in situ* provide an indication of the impacts on the biota when confronted with contaminant enrichment in conjunction with natural stressors. The relationships between toxicity assays and sediment contaminants will be discussed in the next chapter, and biotic condition indicators will be presented in Chapter 5.

CHAPTER 4. EXPOSURE INDICATORS: LABORATORY TOXICITY TESTS

INTRODUCTION

Sediment contaminant analyses can document the presence of contaminants, but the potential for adverse effects is not readily predictable. The bioavailability of pollutants to organisms is a dynamic component, that is the result of complex physical and chemical as well as biological interactions. Since sediments are the primary sink for contaminants, sediment bioassays are conducted to identify environmental conditions that could affect biotic integrity. Laboratory toxicity tests are used as indicators of potential impacts on the biota and as indirect indicators of contaminant bioavailability.

Acute and chronic bioassays were used to evaluate the toxicity of sediments collected from the Carolinian Province during 1995. All core stations and most of the supplemental stations were tested using three bioassay protocols: a 10-day static sediment bioassay using two amphipod species, *Ampelisca abdita* and *A. verrilli*; a 7-day static sediment bioassay using juvenile clams, *Mercenaria mercenaria*; and a Microtox® solid phase assay using the bacterium, *Vibrio fischeri* (formerly referred to as *Photobacterium phosphoreum*).

The 10-day sediment bioassay using *A. abdita* has been used in all previous EMAP Province studies, and was continued for the 1995 survey period to facilitate comparisons among regions, as well as comparisons between years within the Carolinian Province. However, this assay has proven to be relatively insensitive to sediment contaminants in both the Carolinian and Louisianian Province (Macauley et al., 1994; Hyland et al., 1996). Furthermore, *A. abdita* is not an abundant infaunal species in these regions during the summer months. For the 1994 Year 1 Demonstration Project, *Ampelisca verrilli* was tested with a subset of the core and supplemental samples collected in the Carolinian Province. This species is more common in this region than *A. abdita* and it is often found in very high abundances in shallow water habitats. Results obtained from the 1994 survey indicated that *A. verrilli* was more sensitive to sediment contaminants that *A. abdita*. Therefore, sediment testing using *A. verrilli* was expanded in 1995 to include all core stations and most supplemental stations.

The 7-day seed clam bioassay, developed during 1993 pilot studies, was modified and tested on a limited number of core and supplemental stations during 1994 in order to evaluate the relative sensitivity. Growth is used as the endpoint, so this is a sublethal assay designed to identify the potential for chronic effects. Results obtained during 1994 indicated that the seed clam assay was more sensitive than the acute toxicity tests used for either amphipod species (Ringwood et al., 1995; Hyland et al., 1996). Seed clams possess a number of valuable attributes. Newly metamorphosed bivalves exhibit very rapid growth, so effects on growth can be detected in a relatively short time frame. They are infaunal, crawling through the sediments and feeding at the surface-water interface. They are readily cultured (approximately 3 months from fertilization) so experiments can be conducted with a well

defined population, and a relatively small sediment sample volume (500 ml) is required for the assay. Therefore, potential sediment toxicity using this sublethal assay was expanded in 1995 so that its efficacy as an exposure indicator could be more rigorously evaluated.

The Microtox® solid-phase test, based on attenuation of light production by photoluminescent bacteria (Bulich, 1979; Qureshi et al., 1982), is another sublethal assay that was used in the Carolinian Province during 1994 as well as the 1993 pilot studies. The Microtox assay was also more successful at discriminating between reference sites and degraded sites than the amphipod toxicity assay (Ringwood et al., 1996; Hyland et al., 1996) . However, it has been shown that bacteria tend to adsorb onto sediment particles, particularly when silt-clay concentrations exceed 20%, so corrections for sediment type are necessary to avoid a high rate of false positives (Ringwood et al., 1997). Microtox has a number of logistical advantages, including the requirement for a small sediment sample size (a collection volume of < 100 ml is required, compared to > 2000 ml for the amphipod assays) and speed (assays are completed in a matter of hours). Therefore core and supplemental stations were evaluated using this assay during 1995, incorporating sediment characteristics data to interpret the results.

Two additional bioassays, a 96-hr feeding assay using *A. verrilli* and an oyster fertilization assay using *Crassostrea virginica* gametes, were evaluated on a subset of core and supplemental sites as part of the indicator development component of the EMAP program. The amphipod feeding assay should detect sublethal effects on feeding rates which may result from exposure to contaminants. After a 96 hour exposure to test sediments, laboratory-reared phytoplankton are added and amphipods are given the opportunity to feed for 1 hour. Gut chlorophyll a concentrations are used as an index of feeding rates. Reduced feeding rates may cause adverse effects on growth as well as other physiological processes, and may be attributed to impairment of feeding mechanics or reductions in assimilation processes. The oyster fertilization assay, adapted for bivalves using sea urchin fertilization protocols (Ringwood, 1992), was modified as a solid-phase test and evaluated. Previous studies have suggested that bivalve gametes could be used as readily as sea urchin gametes, and may not be hyper-sensitive to sample characteristics (an issue of concern for the sea urchin assay). Both assays provide sublethal endpoints that are potentially very sensitive to sediment contaminants, and can be performed in a relatively short time period at substantially lower costs than the 10-day acute amphipod tests.

METHODS

Processing of Sediment Samples

Sediments were collected using a 1/25-m^2 stainless steel Young-modified Van Veen grab sampler. Samples for toxicity tests were taken as subsamples from the sediment composite (composed of the top 2 cm of approximately 8 to 10 grabs), and stored in new polyethylene or polypropylene jars at 4°C in the dark until the tests were conducted by the

South Carolina Marine Resources Research Institute (SC-MRRI), or the Science Applications International Corporation - Environmental Testing Center (SAIC-ETC).

Just prior to conducting the amphipod bioassays using *A. verrilli*, sediment pore water was extracted for ammonia and H_2S tests by centrifuging a 50 ml sub-sample of the sediment. Both chemical parameters were measured using a Hach DR/700 colorimeter. The salicylate-cyanuarate method (Hach, 1994) was used to measure total ammonia-nitrogen (NH_3-N) and un-ionized ammonia (UAN) was calculated based on measures of pH, salinity, and temperature. Hydrogen sulfide was measured using the methylene blue method, which is accepted by the USEPA and is equivalent to the USEPA Method 376.2. Due to the necessity of holding some samples longer than anticipated, a subset of those samples were analyzed multiple times to determine how porewater ammonia and H_2S had changed over the holding time. All ammonia and hydrogen sulfide values reported for assays conducted by SAIC were based on the results obtained at the MRRI laboratory.

Amphipod 10-Day Acute Assays

Sediments from the core stations and supplemental sites (predominately degraded) were tested using both *Ampelisca abdita* and *A. verrilli* following the standard 10-day whole sediment amphipod bioassay (USEPA, 1994, and ASTM, 1993). The *A. abdita* assays were conducted by SAIC-ETC using amphipods collected from tidal flats in the Pettaquamscutt (Narrow) River, a small estuary flowing into Narragansett Bay, Rhode Island. The amphipods were collected by sieving surface sediments (up to 10 cm) through a 0.5 mm mesh screen and transporting them to the laboratory in buckets where they were again sieved to remove them from their tubes. The amphipods were then held in the laboratory under static conditions in uncontaminated sediment collected from the holding site. Fifty percent of the water in the holding containers was replaced daily when the amphipods were fed with cultures of the diatom, *Phaeodactylum tricornutum*.

The assays using *A. verrilli* were conducted by SC-MRRI using amphipods collected from a pristine location in the Folly River near Charleston, SC. All animals were collected by sieving the upper 8 to 10 cm of through a 1.0 mm mesh screen. The amphipods were then transported in buckets with approximately 10 L of seawater to the laboratory, where they were maintained in incubators at 20°C for 2-4 days prior to testing. During the holding period, the amphipods were fed *P. tricornutum* daily and the buckets were constantly aerated and filtered, except for a 5-hr period following each feeding, when they were only aerated.

In both the ETC and MRRI laboratories, all amphipod batches were evaluated for suitability for testing using the reference toxicant sodium dodecyl sulfate (SDS) in aqueous exposure tests. SDS was chosen as the reference toxicant because a considerable database of results using these species was already available for comparison at each of the laboratories. In order to match the existing data, *A. verrilli* tests were tested using a 24-hr exposure period and *A. abdita* were exposed for 96 hrs. Both tests followed the methods described by ASTM (1993), with the tests performed under static conditions in the dark. The trimmed Spearman-

Karber method of regression analysis was used to calculate the LC_{50} values for each batch of test animals (mean of two replicate test series). The tests were considered acceptable if they were within ±2 SD of the running mean based on the preceding 20 reference toxicant tests (SAIC only) or based on the running mean of all reference toxicant tests completed in 1995 at the MRRI laboratory (22 tests completed prior to initiation of the EMAP samples).

Test chambers used for the 10-day static sediment assays were quart-sized glass canning jars (SAIC), or 1000 ml Pyrex beakers (MRRI), with an inverted glass dish as a cover. All test sediments were prepared the day before a test was started by first homogenizing the sample, and then press-sieving it through a 2.0 mm mesh stainless-steel screen. Control samples were prepared in the same manner using either sediments obtained from the amphipod collection site (MRRI) or from the USACOE New England Division Central Long Island Sound reference station, which were used for the EMAP Virginian Province (1990-93) and other studies. Five replicate test containers were prepared for each sediment sample tested, with each jar containing 200 ml of sediment and 600-800 ml of filtered seawater. Test containers were randomly placed in a water bath maintained at 20°C and aerated for 24 hr prior to adding the amphipods.

At the start of each assay, amphipods were gently sieved from the holding containers and placed in small cups. Twenty amphipods were then randomly inoculated into a test container. Each container was examined after one hour to replace any animals that had not burrowed into the sediment. During the assay, all containers were constantly aerated using oil-free aerators, and illuminated to inhibit amphipod emergence from the sediment. Water bath temperatures were kept at 20°C (±1°C). Conditions in each container were monitored daily throughout the assay. Temperature was measured daily in either a sham container with sediments and seawater (ETC) or in the control jars (MRRI) . All jars were examined for the presence of amphipods that had emerged from the sediment; dead amphipods were removed and preserved for later measurement. On days 2 and 8, two random replicate containers of each sediment sample were measured for salinity, dissolved oxygen, pH, and total ammonia.

At the end of the assay, the test sediments were sieved through a 0.5 mm mesh screen and the number of animals alive, dead, or missing from each container was recorded. Replicates with missing *A. abdita* were preserved in formalin containing Rose Bengal stain. These were reexamined later and any amphipods still unaccounted for were considered to have died and decomposed in the sediment. Because of their larger size, *A. verrilli* which were not located after carefully sieving the sediment were assumed to be dead. All animals recovered at the end of the experiment were preserved in isopropyl alcohol and a subsample of each replicate was measured.

Test results of the ten-day sediment assay were considered valid if the mean survival in the control samples was > 85% and no replicate fell below 80%. Toxicity of the test sediments was assessed by statistically comparing the survival of the amphipods in the test samples versus control samples. Comparisons were made using an unpaired t-test (alpha = 0.05) assuming unequal variance (SAIC) on untransformed percentage data. A t-test on

untransformed percentage data was also used for comparison of samples at the MRRI laboratory. However, when the assumptions of the parametric test were violated, a Mann-Whitney U test was substituted for the t-test. Sediments were considered to be toxic if survival was statistically less in the test versus control sediment and < 80% of the mean control survival of the performance controls.

Microtox® Assays

Solid-phase tests were conducted according to standardized protocols with the Microtox® model 500 (Bulich, 1979; Ross et al., 1991; Microbics, 1992) using the large sample protocols. Test sediments were stirred and a 7 g sediment sample was mixed with 35 ml of a 2% NaCl diluent for 10 minutes. Subsamples of 1.5 ml were pipetted from this mixture (which effectively contains 0.3 g of the sediment sample) and used to prepare a 19.737% concentration and a 9.868% sediment concentration, which was then used to make a series of dilutions ranging from 0.01% to 10% sediment, and incubated with the bacteria (*Vibrio fischeri*, formerly referred to as *Photobacterium phosphoreum*) for 20 minutes. Therefore the test organisms come in direct contact with sediment associated contaminants in an aqueous suspension. A column filter was then used to separate the liquid phase containing the bacteria from the sediment, and their post-exposure light output was measured. The data from the analyzer was captured directly by the Microtox data system, and Gamma (% effect) was calculated. A log-linear regression model is used to calculate EC_{50} (the sediment concentration that reduces light production by 50%). Triplicate samples of the sediments were also dried (48 hr at 60°C) and weighed to determine % moisture. The percent water content of the sediments was used to correct the EC_{50} values, effectively transforming the results so that they were based on sediment dry weights.

Microtox results are strongly biased by the silt-clay content of sediments (Ringwood et al, 1996; Ringwood et al.,1997). Therefore, the following criteria were used to identify sites that cause Microtox toxicity: sites with silt-clays > 20% were classified as a "hit" if the EC_{50} was < 0.2; for sites with silt-clays <20% an EC_{50} of < 0.5 was used. For some sites, particularly sandy sites, an EC_{50} could not be calculated because increases in light production occurred relative to the water controls, or the inhibition of light never dropped low enough.

Seed Clam 7-Day Growth Assays

Juvenile clams (*Mercenaria mercenaria*) of approximately 1.0 mm in length (commonly referred to as seed clams) were exposed to sediments for 7 days and the effects on total dry weight were determined. Seed clams were obtained from Atlantic Clam Farms, Folly Beach, SC. On the day before initiation of an experiment, sediments were sieved through a 500 µm screen and approximately 50 mls were added to 4 replicate 250 ml beakers. Control sediments (Folly River sediments used for controls in the *Ampelisca verrilli* assays) were prepared in the same manner. Seawater was filtered through a 1 µm filter bag, adjusted to 25 ‰ with deionized water, and added to the replicate beakers (approximately 50 ml of sediment plus seawater for a total volume of 200 ml). The sediment suspension was allowed

to settle overnight and clams (30 - 50 per replicate) were added the next day. Clams were size-selected prior to use with 710 µm and 1000 µm sieves in series. Replicate subsets of clams were dried and weighed for initial weight estimates. All experiments were conducted at room temperature (23 - 25°C), with gentle aeration, and all replicates were fed 3 times during the course of the experiment (a phytoplankton mixture composed of equal volumes of *Isochrysis galbana* and *Chaetocerus gracilis*, cultured at MRRI and dialyzed against filtered seawater to remove excess nutrients and other components of the culture media).

All clam batches were evaluated for suitability and relative sensitivity using cadmium as the reference toxicant. Cadmium exposure experiments (water only, no sediments) were run at the same time as the sediment exposures, but were compared to their own water controls. Four Cd concentrations (25, 50, 100, 200 µg/L added as $CdCl_2$; 3 to 4 replicates of each) were used for each reference toxicant test. The effective Cd concentration that reduced growth by 50% (EC_{50}) relative to water controls was derived from regression analyses.

At the end of the 7 day exposure period, clams were sieved from the sediments (or water in the case of the reference toxicant tests), placed in clean seawater and allowed to depurate for approximately one hour. Clams were re-captured on a sieve, and rinsed briefly with distilled water to remove excess salt. Dead clams were removed before being processed for growth, although generally mortalities were less than 10%. The clams were dried overnight (60 - 70°C), counted, weighed on a micro-balance, and growth rates (µg/clam/day) were determined. The effects on growth rates were evaluated using a T-test or Mann-Whitney U test when variances were unequal (needed for only 8 site comparisons (CP95101, -107, -109, -113, -120, -171, -182, -186). Sediments were defined as toxic when the mean growth rate was statistically significantly different from the control sediment growth rate ($p < 0.05$), and <80% of the control sediment growth rate.

Amphipod Feeding-Inhibition Assays

These assays were performed on a subset of the sediment samples tested using the 10-day acute assay. The subgroup was comprised of both core stations and supplemental stations. By testing a combination of randomly selected sites and sites suspected to be degraded, we hoped to evaluate the sensitivity of this technique under conditions that would provide the best opportunity to see a range of effects.

The sediments and animals used in this assay were collected and held in the same manner as those of the 10-day bioassays. Test sediments were prepared one day before the beginning of the assay by homogenizing 500 ml of sediment to be tested, and inoculating three replicate 600 ml beakers with equal amounts of the sediment. Filtered seawater (375 ml) was then added to each container and the beakers were placed into an incubator at 20°C with aeration and allowed to settle for 24 hours. Ten *A. verrilli* were then added randomly to each beaker and maintained under constant illumination and aeration for 96 hours. During the exposure period, the beakers were inspected daily for dead animals and molts, which were immediately removed. At the end of the 96 hr exposure, each jar was inoculated with a

volume of concentrated *P. tricornutum* so that the concentration in the overlying water was raised to approximately 500,000 cells/ml. Preliminary experiments had confirmed that this concentration resulted in significant feeding over a one hour period in healthy animals. The algae added to all beakers of a particular test (i.e. the control and test sediments tested during a particular run) were taken from the same culture and the same volume was added to each jar.

After the one-hour feeding period, chlorophyll a content of the animals was determined as a pooled sample for each beaker using methods adapted from a technique described by Mackas and Bohrer (1976). The animals were first sieved from the sediment, counted, and carefully blotted dry. Each replicate batch of amphipods were then weighed, homogenized with a tissue grinder in 5 ml 90% acetone buffered with $MgCO_3$, and centrifuged at approximately 4700 rpm for five minutes. The supernatant was then decanted into a test tube and stored at -4°C in the dark until the animals from all beakers had been processed (<1.5 hrs). Replicate samples that had greater than 50% mortality were not tested due to the presence of insufficient numbers for adequate comparison with the control.

The concentration of chlorophyll a in the supernatant was quantified on a Turner Designs Model 10-AU Fluorometer using the method described by Yentsch and Menzel (1963) and expressed as mg chlorophyll a /mg. Chlorophyll a concentrations in animals from the test sediment were compared to those from control samples using a t-test to determine if chlorophyll a uptake in the amphipods was significantly reduced when exposed to test sediments. Those samples that had chlorophyll a uptake less than 80% of the controls were considered toxic.

Oyster Fertilization Assays

Sediments collected from various sites were sieved through a 500 µm screen and used to evaluate the potential of the bivalve fertilization assay as a laboratory toxicity assay. Although protocols for liquid-phase tests have been defined (Dinnel et al., 1987; Ringwood, 1992), one of the primary goals of this study was to determine if an acceptable solid-phase test could be developed. Therefore, the methods by which gametes were exposed to sediments varied during the course of the studies in order to optimize assay methods, including recovery of embryos and fertilization rates of controls. For some studies (Method A), small graduated beakers (20 ml) were used with 1 ml of sieved sediments and 15 ml of filtered seawater (FSW, 0.45 µm, 25 ‰). After the sediments were allowed to settle overnight, inert nylon screens (20 µm mesh) were placed into the exposure containers and the fertilization assays were conducted. Test tubes were used in some trials (Method B) in which 1 ml of sieved sediments and 10 ml of FSW were placed in disposable test tubes. After the sediments settled overnight, nylon mesh filters were placed into the exposure tubes, and the fertilization assay was conducted. We also tried conducting liquid-phase tests (Method C) in which 1 ml of sieved sediments and 10 ml of FSW were placed in disposable test tubes. The tubes were vortexed and allowed to settle for 24 hours. After 24 hours, the tubes were gently centrifuged, and the water was pipetted into test tubes for use in the fertilization assay.

Adult oysters, *Crassostrea virginica*, were taken from relatively pristine areas of Parrot Point Creek, Lighthouse Creek, and Clark Sound. Oysters were separated, scrubbed clean, and held at 23°C in oxygenated sea water until needed for the assays. The oysters were then carefully opened and gametes were striped from the gonads using a Pasteur pipette, taking care not to puncture the digestive gland. A wet mount of gametes from each oyster was prepared and examined for sex, gamete integrity, and parasitic infections. Eggs were filtered through a series of 105 µm and 20 µm screens to remove debris and immature eggs and concentrate mature ones. Acceptable gametes (large eggs with very little perivitellin space, and motile sperm) were resuspended in FSW, and kept separate, taking precautions to ensure that no accidental fertilization occurred. Sperm counts (number of sperm / ml) were conducted using a hemocytometer and a compound microscope, and egg concentrations were determined from 50 µl aliquots. Egg concentrations were adjusted to approximately 2000 eggs/ml, and sperm concentrations were adjusted to 4×10^5 sperm / ml. Preliminary tests indicated that a sperm:egg ratio of 100 was optimal for the assay.

For the fertilization assay, 2×10^5 sperm were added to each test container (typically 5 replicates were used for each treatment) and incubated for 1 hour. Eggs were then added (2000 eggs per test container) and incubated for an additional 2 hours, and samples were then fixed with Formalin. At least 200 embryos from each replicate were counted with a compound microscope, and scored as fertilized or unfertilized. Eggs were scored as fertilized if there was evidence that cleavage was proceeding, i.e. presence of a polar lobe, or 2 - 4 cell stages.

Metal exposure experiments (water only, no sediments) were also conducted with Cu, Cd, and Zn. For these experiments a range of metal concentrations were used and the assays were conducted as described. One or more metal exposure experiments were conducted in conjunction with the sediment assays to develop a database for reference toxicants that could be used to evaluate the suitability and sensitivity of the gametes for the assays. These experiments should also provide some data for comparing the relative sensitivity of bivalve and sea urchin gametes to metal contaminants.

RESULTS AND DISCUSSION

A summary of the various bioassay tests that were conducted at each site are listed in Table 4-1. The amphipod 10-day acute toxicity assays using *A. abdita* and *A. verrilli* were completed for all 86 core stations. Acute toxicity assays with *A. verrilli* were also conducted for 18 of 20 supplemental sites, and for 15 of the supplemental sites with *A. abdita*. Seed clam assays were conducted with sediments from all supplemental sites, and from all but one of the core stations (at CP95112, the sediments were very coarse and gravelly so insufficient amounts of sediments were obtained for the assay after sieving with a 500 µm screen). Microtox assays were conducted at all core and 18 of 20 supplemental sites. However, Microtox EC_{50}s could not be calculated for 5 core and 1 supplemental stations. A subgroup of random and non-random sites, comprised of 25 core stations and 15 supplemental stations,

Table 4.1. Summary of laboratory bioassays conducted at core and supplemental stations sampled during Year Two Demonstration Project in the Carolinian Province, summer 1995.

Station	State	*Ampelisca abdita*	*Ampelisca verrilli*	*Mercenaria mercenaria*	Microtox	*A. verrilli* Feeding Assay	Fertilization
CP95101	NC	X	X	X	X		
CP95102	NC	X	X	X	X		X
CP95103	NC	X	X	X	X	X	
CP95104	NC	X	X	X	X		
CP95105	NC	X	X	X	X		
CP95106	NC	X	X	X	X		
CP95107	NC	X	X	X	X	X	X
CP95108	NC	X	X	X	X	X	
CP95109	NC	X	X	X	X		
CP95110	NC	X	X	X	X		
CP95111	NC	X	X	X	X		
CP95112	NC	X	X		X		
CP95113	NC	X	X	X	X		
CP95114	NC	X	X	X	X		
CP95115	NC	X	X	X	*		
CP95116	NC	X	X	X	X		
CP95117	NC	X	X	X	X		
CP95118	NC	X	X	X	X		
CP95119	NC	X	X	X	X		
CP95120	NC	X	X	X	X	X	
CP95121	NC	X	X	X	X	X	
CP95122	NC	X	X	X	X	X	
CP95123	NC	X	X	X	X		
CP95124	NC	X	X	X	X		
CP95125	NC	X	X	X	X		
CP95126	NC	X	X	X	X		
CP95127	NC	X	X	X	X		
CP95128	NC	X	X	X	X		
CP95129	NC	X	X	X	X		
CP95130	NC	X	X	X	X		
CP95131	NC	X	X	X	X		X
CP95132	NC	X	X	X	*		
CP95133	NC	X	X	X	*		
CP95134	NC	X	X	X	X		
CP95135	NC	X	X	X	*		
CP95136	NC	X	X	X	X		
CP95138	NC	X	X	X	X		
CP95139	NC	X	X	X	X	X	X
CP95140	NC	X	X	X	X		X
CP95141	NC	X	X	X	X		X
CP95142	NC	X	X	X	X		
CP95143	NC	X	X	X	X		X
CP95145	NC	X	X	X	X		
CP95146	NC	X	X	X	X	X	
CP95147	NC	X	X	X	X	X	X
CP95148	NC	X	X	X	X		X

(Table 4-1 continued)

Station	State	*Ampelisca abdita*	*Ampelisca verrilli*	*Mercenaria mercenaria*	Microtox	*A. verrilli* Feeding Assay	Fertilization
CP95149	SC	X	X	X	X		
CP95150	SC	X	X	X	X		
CP95151	SC	X	X	X	X	X	X
CP95152	SC	X	X	X	X	X	X
CP95153	SC	X	X	X	X		
CP95154	SC	X	X	X	X	X	
CP95155	SC	X	X	X	X		X
CP95156	SC	X	X	X	X		X
CP95157	SC	X	X	X	X		
CP95158	SC	X	X	X	X		
CP95159	SC	X	X	X	*		
CP95160	SC	X	X	X	X	X	
CP95161	GA	X	X	X	X	X	
CP95162	GA	X	X	X	X		
CP95163	GA	X	X	X	X	X	
CP95164	GA	X	X	X	*		X
CP95165	GA	X	X	X	X	X	
CP95166	GA	X	X	X	X	X	
CP95167	GA	X	X	X	X	X	
CP95168	GA	X	X	X	X	X	
CP95169	GA	X	X	X	X	X	
CP95170	FL	X	X	X	X		
CP95171	FL	X	X	X	X	X	
CP95172	FL	X	X	X	X		
CP95173	FL	X	X	X	X		
CP95174	FL	X	X	X	X		X
CP95175	FL	X	X	X	X		X
CP95176	FL	X	X	X	X		X
CP95177	FL	X	X	X	X		X
CP95178	FL	X	X	X	X	X	
CP95179	FL	X	X	X	X	X	
CP95180	FL	X	X	X	X		
CP95181	FL	X	X	X	X		
CP95182	FL	X	X	X	X	X	X
CP95183	FL	X	X	X	X		
CP95184	FL	X	X	X	X		
CP95185	FL	X	X	X	X		X
CP95186	FL	X	X	X	X		
CP95187	FL	X	X	X	X		X
CP95188	FL	X	X	X	X	X	X
CP95ASM	SC	X	X	X	X	X	
CP95CB_	NC	X	X	X	X		
CP95CF_	NC	X	X	X	*		X
CP95DIE	SC	X	X	X	X	X	X
CP95FOS	SC		X	X	X	X	X
CP95KIA	SC		X	X	X	X	
CP95KOP	SC	X	X	X	X	X	X

(Table 4-1 continued)

Station	State	*Ampelisca abdita*	*Ampelisca verrilli*	*Mercenaria mercenaria*	Microtox	*A. verrilli* Feeding Assay	Fertilization
CP95LON	SC		X	X	X	X	
CP95MI_	NC	X	X	X	X	X	
CP95NM	SC	X	X	X	X	X	X
CP95NV1	SC	X	X	X	X	X	
CP95NV2	SC	X	X	X	X	X	
CP95PR1	NC			X			
CP95PR2	NC	X	X	X	X	X	
CP95PR3	NC	X	X	X	X	X	
CP95PR4	NC	X	X	X	X	X	
CP95PR5	NC			X			
CP95RC_	NC	X	X	X	X		X
CP95SPY	SC	X	X	X	X	X	
CP95ZI_	NC	X	X	X	X	X	X

X = Tested

* = Tested but light outputs too high for all dilutions to calculate EC_{50}

Blanks indicate No Tests conducted on that station

was tested using the *A. verrilli* feeding assay. Fertilization assays were completed for 22 core stations and 7 supplemental stations. The results of each type of assay are discussed in the following sections.

Amphipod 10-Day Acute Bioassays

Bioassays using *A. abdita* were completed for 101 sites in 12 test series and *A. verrilli* were used to test sediments from 104 sites in 13 test series (Table 4-1 and 4-2). Sediment storage time prior to initiation of these assays ranged from 5-33 days for the *A. abdita* tests, and from 4-48 days for the *A. verrilli* tests. Delays in initiating some of the tests within the desired 30-day holding period were due primarily to the collection of samples in North Carolina prior to initiation of the contract with the SC Marine Resources Division. This created a substantial backlog of samples that were processed as quickly as possible.

Ampelisca abdita Assays

Only one of the 86 core stations tested with *A. abdita* resulted in significant mortality relative to the performance controls based on the EMAP criteria of survival < 80% of the controls and $p < 0.05$ (Table 4-3). This represented less than 0.2% of the province area. In contrast, 30 of the stations were coded as "degraded" based on the sediment contaminant criteria described in Chapter 3. The station which caused significant mortality to *A. abdita* (CP95178) was located in North Carolina and was classified as enriched based on sediment contaminant levels. This station also had extremely high concentrations of total ammonia (120.0 mg/L as NH_3-N) and unionized ammonia (2.63 mg/L) which exceeded the No Observable Effect Concentration (NOEC) of 30 mg/L NH_3-N and 0.4 mg/L UAN for this species, respectively (USEPA, 1994). Therefore, it is likely that toxicity would have occurred even with no contaminants present.

Samples from 11 other core stations resulted in significantly lower amphipod survival compared to the performance controls for those tests, but only one of those samples (CP95133) also had a reduced percentage of control survival (82%) that approached the 80% criteria. Station CP95103, on the other hand, resulted in < 80% of control survival, but the difference was not statistically significant ($p > 0.05$). None of the supplemental stations tested with *A. abdita* during 1995 resulted in significant toxicity, even though 11 of these sites were considered degraded based on contaminant concentrations (Table 4-3). Mean amphipod survival in the sediments from one of these sites (CP95MI_) was statistically different than the controls; however, survival was still 90% of the control sample for this test series.

Performance control survival for this species ranged from 82 to 98% (Table 4-2). Due to the low survival in the control samples from one test series (SAIC-2, 82%), three samples which had relatively low survival in that test series were re-tested (CP95114, CP95121, CP95122). Results obtained from the second test on these samples were comparable to the first test , but control survival was substantially higher (95%).

Table 4.2. List of test parameters for the amphipod 10-day solid-phase toxicity tests conducted using *Ampelisca abdita* and *A. verrilli* during the Year Two Demonstration Project in the Carolinian Province, summer 1995.

Test Series	Start Date	Species	Survival % Control	Sediment Holding (Days) a	Amphipod Holding (Days) b	Amphipod Size (c)	Temp (°C)	SDS LC_{50} (mg/l) d
SAIC-1	8/14/95	*A. abdita*	91	26 to 27	4	1.0 to 1.4	19 to 21	8.1
SAIC-2	8/17/95	*A. abdita*	82	25 to 28	7	0.71 to 1.0	19 to 20	8.1
SAIC-3	8/21/95	*A. abdita*	92	27 to 28	6	1.0 to 1.4	20 to 20.5	6.97
SAIC-4	8/24/95	*A. abdita*	93	27 to 29	2 to 9 (f)	0.71 to 1.0	19.5 to 20	6.97/6.24
SAIC-5	8/27/95	*A. abdita*	92	24 to 29	5	0.71 to 1.0	20 to 24 (g)	6.24
SAIC-6	8/28/95	*A. abdita*	97	26 to 28	6	0.71 to 1.0	19.5 to 20.5	7.31
SAIC-7 (e)	8/31/95	*A. abdita*	95	21 to 28	2	0.71 to 1.0	20 to 20.5	7.31
SAIC-8	9/4/95	*A. abdita*	95	17 to 33	6	0.71 to 1.0	20 to 21	8.68
SAIC-9	9/7/95	*A. abdita*	93	16 to 30	2	0.71 to 1.0	20 to 21	7.02
SAIC-10	9/11/95	*A. abdita*	98	13 to 21	6	0.71 to 1.0	20 to 21	6.22
SAIC-11	10/2/95	*A. abdita*	96	5 to 27	5	0.71 to 1.0	19.5 to 20.5	7.99
SAIC-12	10/19/95	*A. abdita*	95	13 to 23	3	0.71 to 1.0	20.5 to 21.5	11.12

a The number of days test sediment was held in the laboratory.

b The number of days field-collected amphipods were held in the laboratory; 350-400 per holding jar.

c Numbers refer to the mesh size (mm) of the screens used to size the animals.

d The mean of two 96-hour water-only reference toxicant test LC_{50}'s (mg/L) using sodium dodecyl sulfate (SDS).

e Included retest of sediment samples from test SAIC-2. Retested samples exceeded the requirement for pretest holding by 11 to 12 days.

f Animals from two collections were randomly distributed into all test chambers.

g Temperature in table temporarily reached 24°C on Day 0, before animals were added.

Test Series	Start Date	Species	Survival % Control	Sediment Holding (Days) a	Amphipod Holding (Days) b	Amphipod Size (c)	Temp (°C)	SDS LC_{50} (mg/l) d
MRRI-1	8/7/95	*A. verrilli*	97	19-20	3	3 to 9	19.9 to 20.5	50.42
MRRI-2	8/14/95	*A. verrilli*	96	21-25	3	4 to 10	20.0 to 20.5	49.23
MRRI-3	8/21/95	*A. verrilli*	92	23-28	3	3 to 10	20.0 to 20.9	46.78
MRRI-4	9/1/95	*A. verrilli*	92	30-32	2	3 to 9	20.1 to 20.4	50.08
MRRI-5	9/8/95	*A. verrilli*	96	32-39	2	4 to 9	20.2 to 20.8	73.89 (e)
MRRI-6	9/11/95	*A. verrilli*	95	32-35	3	3 to 10	20.1 to 20.9	65.35
MRRI-7	9/18/95	*A. verrilli*	89	36-38	3	3 to 10	20.1 to 21.3	50.35
MRRI-8	9/25/95	*A. verrilli*	96	35-45	3	3 to 10	20.0 to 21.3	51.77
MRRI-9	10/2/95	*A. verrilli*	97	41-42	3	3 to 10	20.5 to 21.1	47.85
MRRI-10	10/9/95	*A. verrilli*	96	41-48	4	3 to 10	19.5 to 20.6	49.16
MRRI-11	10/16/95	*A. verrilli*	91	32-47	3	3 to 9	19.6 to 20.5	60.39
MRRI-12	10/23/95	*A. verrilli*	98	11-27	3	3 to 10	19.6 to 20.3	58.77
MRRI-13	10/30/95	*A. verrilli*	97	4-11	3	3 to 10	19.0 to 20.2	57.09

a The number of days test sediment was held in the laboratory.

b The number of days field-collected amphipods were held in the laboratory; 200-250 per holding container.

c Numbers refer to the size range of the animals in millimeters.

d The mean of two 24-hour water-only reference toxicant test LC_{50}'s (mg/L) using sodium dodecyl sulfate (SDS).

e SDS LC_{50} exceeded acceptable control limits.

Table 4-3. Summary of the survival data of *A. abdita* for 10-day solid-phase tests conducted during the evaluation of core and supplemental stations sampled during the Year Two Demonstration Project in the Carolinian Province, summer 1995. Statistical differences are relative to the sediment control.

Ampelisca abdita								
		Sediment	Mean			Elevated Contaminants		
Station	Test Series	Holding (Days)	Survival (%)	Std Dev	Survival % Control[1]	ER-L / TEL	ER-M / PEL	Site Classification[2]
CP95101	SAIC-7	22	95	5.0	100	0	0	E
CP95102	SAIC-7	22	94	4.2	99	0	0	E
CP95103	SAIC-7	23	73	35.5	77 †	9	1	D
CP95104	SAIC-9	27	94	6.5	101	0	0	R
CP95105	SAIC-9	27	97	4.5	104	0	0	R
CP95106	SAIC-8	24	98	2.7	103	0	0	R
CP95107	SAIC-8	25	97	4.5	102	5	0	D
CP95108	SAIC-9	30	90	5.0	97	1	0	R
CP95109	SAIC-8	23	93	5.7	98	5	3	D
CP95110	SAIC-8	23	96	4.2	101	0	0	R
CP95111	SAIC-9	26	98	2.7	105	0	0	R
CP95112	SAIC-8	22	87	11.0	92	0	0	R
CP95113	SAIC-8	22	91	2.2	96	0	0	R
CP95114	SAIC-2	27	82	15.2	99	2	1	D
CP95114	SAIC-7	41	94	4.2	99			
CP95115	SAIC-4	27	86	4.2	92 *	0	0	R
CP95116	SAIC-1	26	87	13.0	96	5	0	D
CP95117	SAIC-2	26	90	10.0	110	2	0	D
CP95118	SAIC-1	27	81	6.5	89 *	0	0	R
CP95119	SAIC-1	27	89	4.2	98	1	0	D
CP95120	SAIC-2	28	86	8.9	105	5	2	D
CP95121	SAIC-2	28	84	14.3	102	8	0	D
CP95121	SAIC-7	42	99	2.2	104			
CP95122	SAIC-2	28	83	7.6	101	4	0	D
CP95122	SAIC-7	42	95	0.0	100			
CP95123	SAIC-4	29	86	4.2	92 *	0	0	R
CP95124	SAIC-1	26	86	6.5	95	3	0	D
CP95125	SAIC-1	27	80	6.1	88 *	0	0	R
CP95126	SAIC-1	27	81	12.9	89	0	0	R
CP95127	SAIC-1	27	85	12.7	93	0	0	R
CP95128	SAIC-1	26	84	15.6	92	0	0	R
CP95129	SAIC-1	26	79	6.5	87 *	0	0	R
CP95130	SAIC-4	28	86	7.4	92	0	0	R
CP95131	SAIC-5	29	94	5.5	102	1	0	E
CP95132	SAIC-3	28	86	8.2	93	0	0	R
CP95133	SAIC-3	28	75	16.6	82 *	0	0	R
CP95134	SAIC-2	27	86	11.9	105	0	0	R
CP95135	SAIC-2	25	90	3.5	110	0	0	R
CP95136	SAIC-8	21	92	2.7	97	3	0	D
CP95138	SAIC-10	20	98	2.7	100	2	6	D
CP95139	SAIC-9	17	93	6.7	100	5	0	D
CP95140	SAIC-9	17	97	4.5	104	4	0	D

(Table 4-3 continued)

Ampelisca abdita								
Station	Test Series	Sediment Holding (Days)	Mean Survival (%)	Std Dev	Survival % Control[1]	Elevated Contaminants ER-L / TEL	ER-M / PEL	Site Classification[2]
CP95141	SAIC-6	26	95	3.5	98	0	0	E
CP95142	SAIC-5	26	86	4.2	93 *	0	0	E
CP95143	SAIC-6	26	94	4.2	97	1	0	D
CP95145	SAIC-5	27	94	2.2	102	2	0	E
CP95146	SAIC-9	16	92	5.7	99	0	0	R
CP95147	SAIC-9	16	95	3.5	102	0	0	R
CP95148	SAIC-9	14	95	3.5	102	0	0	R
CP95149	SAIC-8	17	97	4.5	102	2	0	D
CP95150	SAIC-8	17	89	8.9	94	1	0	D
CP95151	SAIC-8	33	94	4.2	99	1	0	D
CP95152	SAIC-8	33	91	5.5	96	14	1	D
CP95153	SAIC-8	32	94	8.9	99	0	0	R
CP95154	SAIC-8	31	93	7.6	98	1	0	D
CP95155	SAIC-6	28	92	5.7	95	0	0	E
CP95156	SAIC-6	27	97	2.7	100	5	0	D
CP95157	SAIC-9	22	93	3.5	100	0	0	R
CP95158	SAIC-9	23	98	2.7	105	0	0	R
CP95159	SAIC-10	14	97	4.5	99	0	0	R
CP95160	SAIC-10	13	95	5.0	97	0	0	E
CP95161	SAIC-10	12	95	3.5	97	0	0	R
CP95162	SAIC-10	13	89	4.2	91 *	0	0	R
CP95163	SAIC-10	13	92	4.5	94 *	1	1	E
CP95164	SAIC-10	20	98	4.5	100	3	4	D
CP95165	SAIC-11	24	95	3.5	99	2	1	E
CP95166	SAIC-11	25	94	2.2	98	1	7	D
CP95167	SAIC-11	27	95	5.0	99	0	0	R
CP95168	SAIC-11	26	96	4.2	100	2	0	E
CP95169	SAIC-11	25	94	4.2	98	0	7	D
CP95170	SAIC-7	27	93	5.7	98	0	0	R
CP95171	SAIC-7	28	94	2.2	99	4	0	D
CP95172	SAIC-8	19	93	5.7	98	9	0	D
CP95173	SAIC-7	24	98	2.7	103	0	0	E
CP95174	SAIC-7	24	95	3.5	100	4	0	D
CP95175	SAIC-7	22	89	4.2	94 *	3	4	D
CP95176	SAIC-5	27	95	11.2	103	0	0	R
CP95177	SAIC-5	27	95	6.1	103	0	0	R
CP95178	SAIC-4	28	50	7.9	54 †*	1	1	E
CP95179	SAIC-4	29	85	14.6	91	1	0	R
CP95180	SAIC-3	27	83	11.5	90	1	0	E
CP95181	SAIC-3	28	84	8.2	91	1	0	D
CP95182	SAIC-7	21	95	5.0	100	1	0	R
CP95183	SAIC-8	17	94	4.2	99	0	0	R
CP95184	SAIC-10	21	99	2.2	101	0	0	R
CP95185	SAIC-10	20	91	4.2	93 *	0	0	R
CP95186	SAIC-9	16	94	6.5	101	1	0	R
CP95187	SAIC-9	15	97	2.7	104	0	0	R
CP95188	SAIC-9	13	96	5.5	103	0	0	R

(Table 4-3 continued)

Ampelisca abdita								
Station	Test Series	Sediment Holding (Days)	Mean Survival (%)	Std Dev	Survival % Control[1]	Elevated Contaminants ER-L / TEL	ER-M / PEL	Site Classification[2]
CP95ASM	SAIC-12	13	93	4.5	98	4	0	D
CP95CB_	SAIC-8	24	97	2.7	102	0	0	R
CP95CF_	SAIC-9	16	91	7.4	98	1	0	D
CP95DIE	SAIC-11	6	95	7.1	99	17	0	D
CP95KOP	SAIC-12	23	98	2.7	103	21	0	D
CP95MI_	SAIC-5	24	83	6.7	90 *	0	0	R
CP95NMK	SAIC-11	5	94	5.5	98	25	3	D
CP95NV1	SAIC-12	15	97	4.5	102	17	0	D
CP95NV2	SAIC-12	15	95	5.0	100	16	0	D
CP95PR2	SAIC-11	18	97	2.7	101	3	0	D
CP95PR3	SAIC-11	18	98	4.3	102	8	1	D
CP95PR4	SAIC-11	18	95	5.0	99	6	0	D
CP95RC_	SAIC-5	26	95	6.1	103	0	0	R
CP95SPY	SAIC-11	5	95	5.0	99	6	2	D
CP95ZI_	SAIC-9	16	95	6.1	102	0	0	R
LIS950814	SAIC-1		91					
LIS950817	SAIC-2		82					
LIS950821	SAIC-3		92					
LIS950824	SAIC-4		93					
LIS950827	SAIC-5		92					
LIS950828	SAIC-6		97					
LIS950831	SAIC-7		95					
LIS950904	SAIC-8		95					
LIS950907	SAIC-9		93					
LIS950911	SAIC-10		98					
LIS951002	SAIC-11		96					
LIS951019	SAIC-12		95					

1 * = Sample results were statistically less than the performance control.
† =Sample results were less than 80% of control survival.
Both significance conditions have to be satisfied for a site to be identified as toxic.

2 Classifications are based on criteria described in Chapter 3.

Reference toxicant tests completed for this species resulted in 96-hr LC50 values that were within the upper and lower control, with the exception of one test which had an LC50 of 11.2 mg/L (Table 4-2). At the 0.05 probability level, one in 20 tests is expected to fall outside of the control limits by chance alone, regardless of how well the laboratory performs (USEPA, 1988, 1993). Since all other test conditions were within acceptable parameters, this test was not repeated.

Ampelisca verrilli Assays

The assays conducted using *A. verrilli* showed slightly greater sensitivity than the *A. abdita* assays, but use of this species still resulted in only three core stations being coded as toxic (Table 4-4). These sites represented approximately 10% of the province area. All three sites (CP95103, CP95108, CP95178) were located in North Carolina, but only CP95103 and CP95178 (approx. 4% of the province area) were considered to be degraded based on sediment chemistry. As noted for *A. abdita*, the very high ammonia concentrations noted at CP95178 are likely to have accounted for most of the *A. verrilli* mortality based on an estimated NOEC of 45 mg/L and an LC50 of 88 mg/L NH_3-N obtained for this species in 10-day spiked sediment tests recently completed by the SCMRRI (unpublished).

Samples from three other core stations (CP95145, CP95149, CP95152) resulted in significantly lower amphipod survival compared to the performance controls, with survival in those samples ranging from 84-91% of the controls. These stations were classified as enriched or degraded based on sediment chemistry. One other site (CP95183) resulted in only 78% of control survival, but the difference was not statistically significant ($p > 0.05$). This station was not degraded based on sediment contaminant levels.

None of the sediments collected from the supplemental sites were toxic to *A. verrilli*. However, one of these samples (CP95NMK) was just above the toxicity criteria (81% of control survival, $p < 0.05$). This site had 25 contaminants that exceeded ER-L / TEL values and 3 contaminants that exceeded ER-M / PEL concentrations. Another site (CP95NV1) resulted in significantly lower amphipod survival than the controls, but the percent of control survival in this sample was 86%.

All control sediment samples conducted with *A. verrilli* resulted in > 89% of control survival , and only one of the 24-hr reference toxicant tests exceeded acceptable control limits (Table 4-2). After consultation with the Province Manager, it was agreed that this test would not be repeated due to the backlog of existing samples. Furthermore, all other test conditions for this test series were within normal parameters.

In general, the two amphipod species showed comparable results with respect to percent survival in the various test sediments (Figures 4-1 to 4-3). Both species were the least sensitive to sediments with elevated contaminant levels compared to the other bioassay protocols. Although *A. verrilli* showed a higher percentage of mortality in the assays

Table 4-4. Summary of the survival data of *A. verrilli* for 10-day solid-phase tests conducted during the evaluation of core and supplemental stations sampled during the Year Two Demonstration Project in the Carolinian Province, summer 1995. Statistical differences are relative to the sediment control.

Ampelisca verrilli								
Station	Test Series	Sediment Holding (Days)	Mean Survival (%)	Std Dev	Survival % Control[1]	Elevated Contaminants ER-L / TEL	ER-M / PEL	Site Classification[2]
CP95101	MRRI-6	33	98	2.7	103	0	0	E
CP95102	MRRI-6	33	93	7.6	98	0	0	E
CP95103	MRRI-6	34	60	11.2	63 †*	9	1	D
CP95104	MRRI-7	38	91	4.2	103	0	0	R
CP95105	MRRI-8	45	93	8.4	97	0	0	R
CP95106	MRRI-7	38	94	4.2	107	0	0	R
CP95107	MRRI-6	32	89	5.5	94	5	0	D
CP95108	MRRI-6	34	57	14.8	60 †*	1	0	R
CP95109	MRRI-7	37	82	7.6	93	5	3	D
CP95110	MRRI-7	37	95	6.1	108	0	0	R
CP95111	MRRI-7	37	97	2.7	110	0	0	R
CP95112	MRRI-7	36	83	7.6	94	0	0	R
CP95113	MRRI-7	36	88	5.7	100	0	0	R
CP95114	MRRI-2	24	96	4.2	100	2	1	D
CP95115	MRRI-3	27	97	2.7	105	0	0	R
CP95116	MRRI-1	19	98	2.7	101	5	0	D
CP95117	MRRI-2	23	96	6.5	100	2	0	D
CP95118	MRRI-1	20	94	6.5	97	0	0	R
CP95119	MRRI-1	20	95	5.0	98	1	0	D
CP95120	MRRI-2	25	90	5.0	94	5	2	D
CP95121	MRRI-2	25	99	2.2	103	8	0	D
CP95122	MRRI-2	25	93	5.6	97	4	0	D
CP95123	MRRI-3	26	96	5.5	104	0	0	R
CP95124	MRRI-1	19	93	5.7	96	3	0	D
CP95125	MRRI-1	20	93	8.4	96	0	0	R
CP95126	MRRI-1	20	94	4.2	97	0	0	R
CP95127	MRRI-1	20	98	2.7	101	0	0	R
CP95128	MRRI-1	20	93	7.6	96	0	0	R
CP95129	MRRI-1	19	92	7.6	95	0	0	R
CP95130	MRRI-3	25	90	7.1	98	0	0	R
CP95131	MRRI-3	23	95	8.7	103	1	0	E
CP95132	MRRI-3	28	98	2.7	107	0	0	R
CP95133	MRRI-3	28	92	4.5	100	0	0	R
CP95134	MRRI-2	24	98	2.7	102	0	0	R
CP95135	MRRI-2	22	93	6.7	97	0	0	R
CP95136	MRRI-8	42	92	10.4	96	3	0	D
CP95138	MRRI-10	48	97	2.7	101	2	6	D
CP95139	MRRI-9	42	95	5.0	98	5	0	D
CP95140	MRRI-9	42	89	6.5	92	4	0	D
CP95141	MRRI-4	30	89	8.9	97	0	0	E
CP95142	MRRI-4	31	91	4.2	99	0	0	E
CP95143	MRRI-4	30	88	10.4	96	1	0	D

(Table 4-4 continued)

Ampelisca verrilli								
Station	Test Series	Sediment Holding (Days)	Mean Survival (%)	Std Dev	Survival % Control[1]	Elevated Contaminants ER-L / TEL	ER-M / PEL	Site Classification[2]
CP95145	MRRI-4	32	84	6.5	91 *	2	0	E
CP95146	MRRI-10	48	96	2.2	100	0	0	R
CP95147	MRRI-10	48	97	2.7	101	0	0	R
CP95148	MRRI-10	46	97	4.5	101	0	0	R
CP95149	MRRI-8	38	81	10.8	84 *	2	0	D
CP95150	MRRI-8	38	95	5.0	99	1	0	D
CP95151	MRRI-4	30	82	15.2	89	1	0	D
CP95152	MRRI-5	37	85	5.4	89 *	14	1	D
CP95153	MRRI-5	36	91	2.2	95	0	0	R
CP95154	MRRI-5	35	97	2.7	101	1	0	D
CP95155	MRRI-4	32	89	11.4	97	0	0	E
CP95156	MRRI-4	31	89	6.5	97	5	0	D
CP95157	MRRI-8	40	88	13.1	92	0	0	R
CP95158	MRRI-8	41	94	4.2	98	0	0	R
CP95159	MRRI-10	42	98	4.5	102	0	0	R
CP95160	MRRI-10	41	96	4.2	100	0	0	E
CP95161	MRRI-11	47	95	6.1	104	0	0	R
CP95162	MRRI-10	41	92	4.5	96	0	0	R
CP95163	MRRI-10	41	91	5.5	95	1	1	E
CP95164	MRRI-9	41	95	3.5	98	3	4	D
CP95165	MRRI-11	38	86	5.5	94	2	1	E
CP95166	MRRI-11	39	92	2.7	101	1	7	D
CP95167	MRRI-11	41	95	5.0	104	0	0	R
CP95168	MRRI-11	40	97	4.5	106	2	0	E
CP95169	MRRI-11	39	93	5.7	102	0	7	D
CP95170	MRRI-5	35	94	6.5	98	0	0	R
CP95171	MRRI-5	36	90	7.1	94	4	0	D
CP95172	MRRI-8	40	91	7.4	95	9	0	D
CP95173	MRRI-5	32	93	5.7	97	0	0	E
CP95174	MRRI-6	35	93	5.7	98	4	0	D
CP95175	MRRI-6	33	93	4.5	98	3	4	D
CP95176	MRRI-5	39	95	3.5	99	0	0	R
CP95177	MRRI-5	39	95	5.0	99	0	0	R
CP95178	MRRI-3	25	54	26.8	59 †*	1	1	E
CP95179	MRRI-3	26	91	4.2	99	1	0	R
CP95180	MRRI-3	27	94	4.2	102	1	0	E
CP95181	MRRI-2	21	95	3.5	99	1	0	D
CP95182	MRRI-6	32	92	4.5	97	1	0	R
CP95183	MRRI-8	38	75	39.2	78 †	0	0	R
CP95184	MRRI-8	35	90	6.1	94	0	0	R
CP95185	MRRI-9	41	94	2.2	97	0	0	R
CP95186	MRRI-9	41	96	2.2	99	1	0	R
CP95187	MRRI-10	47	90	0.2	94	0	0	R
CP95188	MRRI-10	45	96	2.2	100	0	0	R

(Table 4-4 continued)

Ampelisca verrilli									
Station	Test Series	Sediment Holding (Days)	Mean Survival (%)	Std Dev	Survival % Control[1]		Elevated Contaminants ER-L / TEL	ER-M / PEL	Site Classification[2]
CP95ASM	MRRI-12	17	91	6.5	93		4	0	D
CP95CB_	MRRI-7	38	91	6.7	105		0	0	R
CP95CF_	MRRI-9	41	90	5.6	93		1	0	D
CP95DIE	MRRI-12	27	96	6.5	98		17	0	D
CP95FOS	MRRI-12	13	96	4.2	98		0	0	E
CP95KIA	MRRI-12	11	91	6.5	93		2	0	D
CP95KOP	MRRI-12	27	88	9.1	90		21	0	D
CP95LON	MRRI-13	11	96	6.5	99		4	1	D
CP95LTH	MRRI-13	5	97	6.7	100				
CP95MI_	MRRI-5	36	79	36.1	82		0	0	R
CP95NMK	MRRI-12	26	79	9.6	81	*	25	3	D
CP95NV1	MRRI-12	19	84	9.6	86	*	17	0	D
CP95NV2	MRRI-12	19	99	2.2	101		16	0	D
CP95PR2	MRRI-11	32	95	5.0	104		3	0	D
CP95PR3	MRRI-11	32	96	2.2	105		8	1	D
CP95PR4	MRRI-11	32	94	5.5	103		6	0	D
CP95RC_	MRRI-4	31	87	11.5	95		0	0	R
CP95SPY	MRRI-12	26	96	4.2	98		6	2	D
CP95ZI_	MRRI-9	41	95	5.0	98		0	0	R
FOL950807	MRRI-1	3	97	4.5					
FOL950814	MRRI-2	3	92	2.7					
FOL950821	MRRI-3	3	96	4.2					
FOL950901	MRRI-4	2	95	6.1					
FOL950908	MRRI-5	2	89	5.7					
FOL950911	MRRI-6	3	96	4.2					
FOL950918	MRRI-7	3	97	4.5					
FOL950925	MRRI-8	3	96	2.2					
FOL951002	MRRI-9	3	91	2.2					
FOL951009	MRRI-10	4	98	2.7					
FOL951016	MRRI-11	3	97	4.5					
FOL951023	MRRI-12	3	96	4.2					
FOL951030	MRRI-13	3	92	7.6					

1 * = Sample results were statistically less than the performance control.
† =Sample results were less than 80% of control survival.
Both significance conditions have to be satisfied for a site to be identified as toxic.

2 Classifications are based on criteria described in Chapter 3.

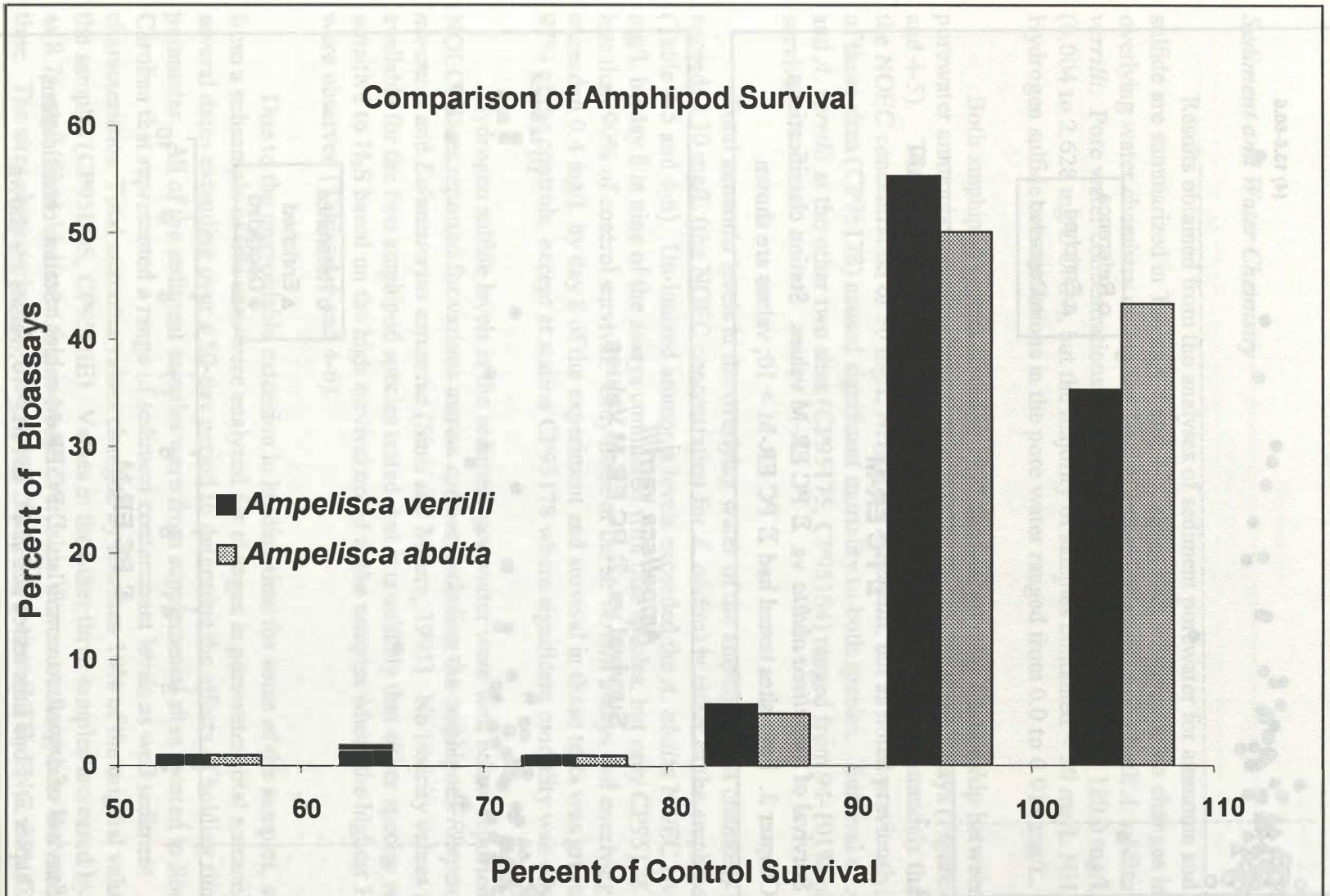

Figure 4-1. Comparison of *Ampelisca abdita* and *A. verrilli* survival in 10-day whole sediment bioassays tested in 1995.

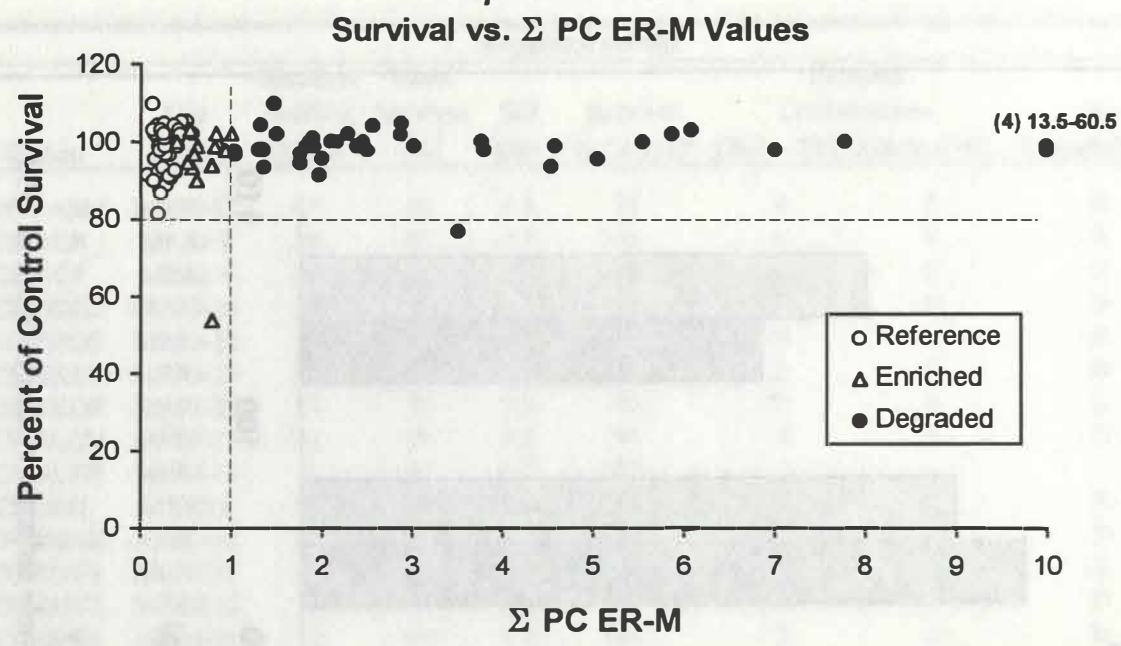

Figure 4-2. Survival of *Ampelisca abdita* vs. Σ PC ER-M values. Station classifications described in Chapter 3. Four sites tested had Σ PC ER-M > 10; values are shown.

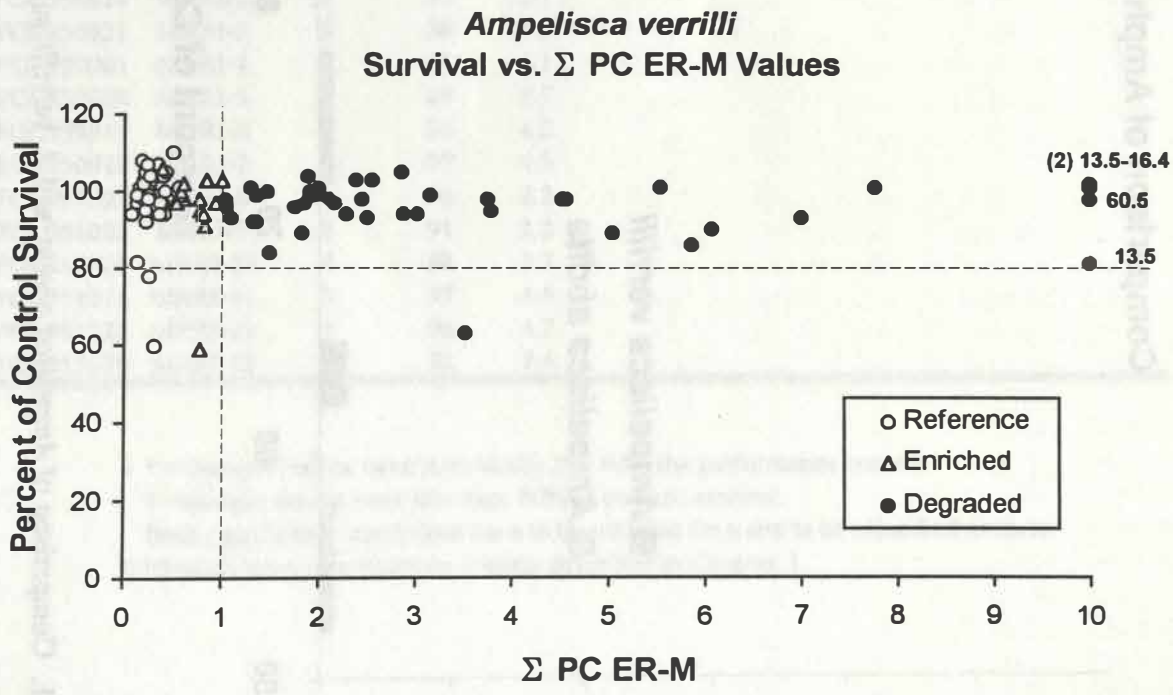

Figure 4-3. Survival of *Ampelisca verrilli* vs. Σ PC ER-M values. Station classifications described in Chapter 3. Four sites tested had Σ PC ER-M > 10; values are shown.

conducted during 1994 when compared with *A. abdita*, this pattern was not observed in the 1995 study, even at stations with several contaminants that exceeded ER-M levels.

Sediment and Water Chemistry

Results obtained from the analyses of sediment porewater for ammonia and hydrogen sulfide are summarized in Tables 4-5 and 4-6, along with information on changes in the overlying water chemistry during the 10-day amphipod assays using both *A. abdita* and *A. verrilli*. Pore water concentrations of total ammonia ranged from 1.5 - 120.0 mg/L NH_3-N (0.004 to 2.628 mg/L UAN), but the majority of samples contained < 20 mg/L NH_3-N. Hydrogen sulfide concentrations in the pore water ranged from 0.0 to 0.018 mg/L.

Both amphipod species tested in 1995 showed no clear relationship between porewater ammonia concentrations and survival in the 10-day static assays (Figures 4-4 and 4-5). Three of the stations had porewater concentations of total ammonia that exceeded the NOEC concentration of 30 mg/L NH_3-N for *A. abdita*, but as noted previously, only one of these sites (CP95178) caused significant mortality to both species. Survival of *A. abdita* and *A. verrilli* at the other two sites (CP95175, CP95184) ranged from 94-101% of control survival.

Total ammonia levels in the overlying water of the amphipod test chambers never exceeded 30 mg/L (the NOEC concentration for *A. abdita*) in either of the amphipod assays (Table 4-5 and 4-6). Un-ionized ammonia levels exceeded the *A. abdita* NOEC level of 0.4 mg/L by day 8 in nine of the assays conducted with that species, but only CP95178 resulted in less than 90% of control survival. Only three of the *A. verrilli* assays had overlying water that exceeded 0.4 mg/L by day 8 of the experiment and survival in those tests was greater than 97% of the controls, except at station CP95178 where significant mortality was observed.

Hydrogen sulfide levels in the sediment porewater were well below reported LC_{50} and NOEC values reported for various marine species, including the amphipods *Rhepoxynius abronius* and *Eohaustorius estuarius* (Sims and Moore, 1995). No toxicity values are available for the two amphipod species tested, but it is unlikely that either species was sensitive to H_2S based on the high survival noted in the samples where the highest H_2S values were observed (Tables 4-5 and 4-6).

Due to the unavoidable extension in holding time for some of the samples, sediments from a subsample of five sites were analyzed for changes in porewater total ammonia on several dates extending over a 50-day period to determine the effects of holding time on this parameter. All of the sediment samples were from supplemental sites located in South Carolina that represented a range of sediment contaminant levels as well sediment characteristics. Total ammonia values changed by less than 10% of the original value in two of the samples (CP95FOS, CP95DIE). Values in the other three samples increased by as much as 8.75 mg/L (2 to 11 eleven fold increase over initial concentrations) over the entire holding time. The sites characterized by the greatest change over time (LTH, LNG, SPY) were from

Table 4-5. Summary of *Ampelisca abdita* survival, total ammonia (NH_3-N) and un-ionized ammonia (UAN), and sulfide (S^{2-}) and hydrogen sulfide (H_2S) measured in porewater and overlying water of EMAP Carolinian samples. Overlying water data are means from two replicate test chambers.

Ampelisca abdita										
			Porewater				Overlying Water			
							Day 2	Day 2	Day 8	Day 8
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)
CP95101	SAIC-7	100	0.39	0.015	9.00	0.040	1.83	0.074	1.38	0.051
CP95102	SAIC-7	99	0.30	0.010	4.75	0.027	0.60	0.020	1.32	0.049
CP95103	SAIC-7	77			3.75	0.042	0.76	0.006	1.42	0.000
CP95104	SAIC-9	101	0.13	0.002	10.25	0.143	0.47	0.016	2.37	0.117
CP95105	SAIC-9	104	0.19	0.002	17.75	0.389	3.00	0.096	3.01	0.180
CP95106	SAIC-8	103	0.26	0.003	9.25	0.203	1.66	0.054	2.84	0.202
CP95107	SAIC-8	102	0.28	0.005	3.25	0.045	0.40	0.010	0.87	0.019
CP95108	SAIC-9	97	0.29	0.003	17.00	0.372	0.41	0.010	7.88	0.424
CP95109	SAIC-8	98	0.21	0.007	4.75	0.027	1.23	0.024	1.23	0.016
CP95110	SAIC-8	101	0.29	0.003	10.25	0.224	2.48	0.093	5.23	0.329
CP95111	SAIC-9	105	0.73	0.018	5.75	0.051	0.44	0.013	0.90	0.038
CP95112	SAIC-8	92					0.27	0.008	0.30	0.012
CP95113	SAIC-8	96	0.00	0.000			0.48	0.017	0.06	0.002
CP95114	SAIC-2	99	0.70	0.005	5.40	0.185				
CP95114R	SAIC-7	99					0.91	0.028	0.85	0.026
CP95115	SAIC-4	92	0.10	0.001	4.80	0.239	1.34	0.057	1.05	0.039
CP95116	SAIC-1	96	0.25	0.003	5.00	0.109	0.65	0.021	0.11	0.003
CP95117	SAIC-2	110	0.18	0.001	4.10	0.131	1.11	0.030	0.00	0.000
CP95118	SAIC-1	89	0.18	0.002	6.30	0.138	1.00	0.035	0.04	0.001
CP95119	SAIC-1	98	0.14	0.002	3.90	0.068	0.82	0.027	0.10	0.004
CP95120	SAIC-2	105	1.56	0.009	4.70	0.201	1.71	0.032	0.08	0.002
CP95121	SAIC-2	102	0.19	0.001	5.50	0.188				
CP95121R	SAIC-7	104					5.59	0.204	1.51	0.048
CP95122	SAIC-2	101	0.41	0.002						
CP95122R	SAIC-7	100					1.69	0.052	1.57	0.056
CP95123	SAIC-4	92					1.53	0.066	1.63	0.078
CP95124	SAIC-1	95	0.25	0.002	6.10	0.209	1.73	0.061	0.11	0.004
CP95125	SAIC-1	88	0.19	0.002	6.00	0.131	1.68	0.062	1.08	0.041
CP95126	SAIC-1	89	0.37	0.003	4.90	0.168	1.56	0.063	0.76	0.033
CP95127	SAIC-1	93	0.12	0.001	4.10	0.112	1.13	0.039	0.73	0.026
CP95128	SAIC-1	92	0.21	0.002	4.70	0.161	1.33	0.043	0.25	0.010
CP95129	SAIC-1	87	0.21	0.001	7.90	0.338	2.55	0.100	4.61	0.262

(Table 4-5 continued)

Ampelisca abdita										
			Porewater				Overlying Water			
							Day 2	Day 2	Day 8	Day 8
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)
CP95130	SAIC-4	92	0.11	0.001	3.30	0.113	0.56	0.022	0.12	0.004
CP95131	SAIC-5	102	0.08	0.001	3.10	0.106	0.63	0.019	0.14	0.010
CP95132	SAIC-3	93	0.00	0.000	9.60	0.308	1.35	0.043	1.37	0.066
CP95133	SAIC-3	82	0.00	0.000	4.80	0.150	0.12	0.004	0.06	0.002
CP95134	SAIC-2	105	0.20	0.002	7.60	0.260	1.22	0.030	0.98	0.050
CP95135	SAIC-2	110					0.18	0.006	0.26	0.014
CP95136	SAIC-8	97	0.24	0.003	3.75	0.082	0.26	0.009	0.00	0.000
CP95138	SAIC-10	100	0.55	0.004	20.50	0.702	2.25	0.115	4.04	0.282
CP95139	SAIC-9	100	0.14	0.003	10.75	0.095	0.04	0.001	0.00	0.000
CP95140	SAIC-9	104	0.09	0.001	12.75	0.223	0.00	0.000	0.00	0.000
CP95141	SAIC-6	98	0.12	0.003	13.50	0.104	0.86	0.028	0.10	0.003
CP95142	SAIC-5	93	0.11	0.003	8.20	0.063	1.53	0.062	0.79	0.061
CP95143	SAIC-6	97	0.09	0.002	3.20	0.025	0.57	0.018	0.08	0.002
CP95145	SAIC-5	102	0.08	0.002	3.60	0.028	0.38	0.014	0.10	0.005
CP95146	SAIC-9	99	0.09	0.002	8.00	0.102	0.04	0.001	0.09	0.004
CP95147	SAIC-9	102	0.00	0.000	3.50	0.035	0.00	0.000	0.00	0.000
CP95148	SAIC-9	102			13.00	0.390	0.02	0.001	2.50	0.190
CP95149	SAIC-8	102	0.18	0.007	2.50	0.011	0.36	0.009	0.48	0.011
CP95150	SAIC-8	94	0.21	0.001	1.50	0.080	0.05	0.001	0.24	0.006
CP95151	SAIC-8	99	0.14	0.002	6.60	0.086	0.61	0.022	0.01	0.000
CP95152	SAIC-8	96	0.17	0.003	7.60	0.079	0.87	0.016	0.15	0.007
CP95153	SAIC-8	99	0.18	0.003	9.30	0.118	0.62	0.024	1.76	0.109
CP95154	SAIC-8	98	0.13	0.001	6.50	0.130	1.09	0.040	0.01	0.001
CP95155	SAIC-6	95					0.34	0.011	0.12	0.003
CP95156	SAIC-6	100	0.12	0.009	3.50	0.004	0.85	0.014	1.04	0.011
CP95157	SAIC-9	100	0.35	0.008	4.50	0.040	6.21	0.211	0.00	0.000
CP95158	SAIC-9	105	0.13	0.001	8.25	0.169	6.59	0.259	0.50	0.024
CP95159	SAIC-10	99					0.27	0.014	0.03	0.002
CP95160	SAIC-10	97	0.25	0.003	9.50	0.190	1.37	0.061	0.93	0.060
CP95161	SAIC-10	97	0.00	0.000	6.50	0.106	0.41	0.019	0.06	0.003
CP95162	SAIC-10	91	0.00	0.000	2.00	0.035	0.33	0.014	0.01	0.000
CP95163	SAIC-10	94	0.10	0.001	11.75	0.240	1.18	0.054	0.48	0.027
CP95164	SAIC-10	100	0.00	0.000	7.00	0.114	0.26	0.013	0.33	0.017
CP95165	SAIC-11	99	0.00	0.000	12.50	0.174	0.96	0.040	0.31	0.015
CP95166	SAIC-11	98	0.10	0.001	9.25	0.151	2.08	0.103	1.74	0.077
CP95167	SAIC-11	99	0.00	0.000	6.75	0.094	0.62	0.020	0.48	0.022

(Table 4-5 continued)

Ampelisca abdita										
			Porewater				Overlying Water			
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	Day 2 NH_3-N (mg/l)	Day 2 UAN (mg/l)	Day 8 NH_3-N (mg/l)	Day 8 UAN (mg/l)
CP95168	SAIC-11	100	0.00	0.000	8.75	0.114	0.61	0.019	0.03	0.001
CP95169	SAIC-11	98	0.11	0.001	3.25	0.102	0.69	0.022	0.44	0.018
CP95170	SAIC-7	98	0.09	0.002	12.00	0.153	1.03	0.036	4.75	0.177
CP95171	SAIC-7	99	0.11	0.003	12.00	0.079	4.75	0.219	1.98	0.110
CP95172	SAIC-8	98	0.27	0.010	24.50	0.109	7.36	0.270	12.24	0.629
CP95173	SAIC-7	103	0.12	0.002	11.00	0.143	1.32	0.052	0.81	0.060
CP95174	SAIC-7	100	0.16	0.003	9.25	0.129	1.81	0.062	1.71	0.072
CP95175	SAIC-7	94	0.41	0.007	31.50	0.410	1.75	0.080	1.27	0.098
CP95176	SAIC-5	103	0.13	0.001	24.50	0.672	3.47	0.157	4.60	0.333
CP95177	SAIC-5	103	0.19	0.003	25.50	0.446	3.68	0.150	6.74	0.545
CP95178	SAIC-4	54	0.97	0.011	120.00	2.628	16.82	0.694	28.01	1.252
CP95179	SAIC-4	91	0.21	0.002	16.75	0.459	6.69	0.348	9.85	0.523
CP95180	SAIC-3	90	0.25	0.002	28.00	0.768	5.51	0.249	5.39	0.523
CP95181	SAIC-3	91	0.12	0.001	8.90	0.474	2.10	0.071	0.22	0.024
CP95182	SAIC-7	100	0.59	0.010	29.00	0.404	3.69	0.121	0.38	0.056
CP95183	SAIC-8	99	0.20	0.004	22.75	0.220	2.17	0.075	4.27	0.459
CP95184	SAIC-10	101	0.14	0.002	36.00	0.788	5.32	0.229	10.01	0.778
CP95185	SAIC-10	93	0.18	0.001	18.25	0.585	2.28	0.119	2.39	0.318
CP95186	SAIC-9	101	0.09	0.001	14.50	0.297	3.77	0.139	2.30	0.296
CP95187	SAIC-9	104	0.09	0.001	15.25	0.489	1.56	0.059	0.02	0.001
CP95188	SAIC-9	103	0.00	0.000	11.00	0.225	3.50	0.131	0.26	0.018
CP95ASM	SAIC-12	98	0	0.000	10.50	0.230	1.84	0.078	0.05	0.003
CP95CB_	SAIC-8	102	0.61	0.010	9.50	0.132	1.72	0.055	3.40	0.121
CP95CF_	SAIC-9	98	0	0.000	6.75	0.047	0.06	0.002	0.00	0.000
CP95DIE	SAIC-11	99	0.00	0.000	6.25	0.087	1.69	0.058	1.09	0.048
CP95KOP	SAIC-12	103	0.11	0.003	14.25	0.100	4.02	0.143	0.04	0.002
CP95MI_	SAIC-5	90	0.29	0.003	22.00	0.421	3.72	0.150	8.09	0.473
CP95NMK	SAIC-11	98	0.13	0.007	19.50	0.055	2.44	0.123	2.20	0.160
CP95NV1	SAIC-12	102	0.09	0.002	7.00	0.078	1.01	0.037	0.09	0.004
CP95NV2	SAIC-12	100	0.00	0.000	9.75	0.136	2.29	0.098	0.00	0.000
CP95PR2	SAIC-11	101	0.00	0.000	8.25	0.092	1.24	0.032	0.11	0.004
CP95PR3	SAIC-11	102	0.00	0.000	10.75	0.076	3.26	0.105	0.09	0.005
CP95PR4	SAIC-11	99	0.00	0.000	7.50	0.083	1.08	0.027	0.16	0.005
CP95RC_	SAIC-5	103	0.19	0.005	29.00	0.223	5.36	0.183	10.54	0.348
CP95SPY	SAIC-11	99	0.12	0.002	4.50	0.063	0.73	0.027	0.11	0.006
CP95ZI_	SAIC-9	102	0.13	0.001	17.00	0.325	0.06	0.002	2.02	0.164

(Table 4-5 continued)

Ampelisca abdita										
			Porewater				Overlying Water			
							Day 2	Day 2	Day 8	Day 8
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)
LIS950814	SAIC-1									
LIS950817	SAIC-2									
LIS950821	SAIC-3						1.01	0.028	0.02	0.001
LIS950824	SAIC-4									
LIS950827	SAIC-5						0.95	0.030		
LIS950828	SAIC-6									
LIS950831	SAIC-7						0.53	0.021		
LIS950904	SAIC-8									
LIS950907	SAIC-9									
LIS950911	SAIC-10									
LIS951002	SAIC-11						1.20	0.032	0.23	0.013
LIS951019	SAIC-12						1.09	0.037	0.02	0.001

Table 4-6. Summary of *Ampelisca verrilli* survival, total ammonia (NH_3-N) and un-ionized ammonia (UAN), and sulfide (S^{2-}) and hydrogen sulfide (H_2S) measured in porewater and overlying water of EMAP Carolinian samples. Overlying water data are means from two replicate test chambers.

Ampelisca verrilli										
			Porewater				Overlying Water			
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	Day 2 NH_3-N (mg/l)	Day 2 UAN (mg/l)	Day 8 NH_3-N (mg/l)	Day 8 UAN (mg/l)
CP95101	MRRI-6	103	0.39	0.015	9.00	0.040	2.40	0.055	2.40	0.048
CP95102	MRRI-6	98	0.30	0.010	4.75	0.027	0.95	0.030	1.94	0.039
CP95103	MRRI-6	63			3.75	0.042	2.20	0.016	3.64	0.001
CP95104	MRRI-7	103	0.13	0.002	10.25	0.143	2.60	0.052	3.65	0.091
CP95105	MRRI-8	97	0.19	0.002	17.75	0.389	2.20	0.062	3.10	0.097
CP95106	MRRI-7	107	0.26	0.003	9.25	0.203	2.40	0.060	3.00	0.094
CP95107	MRRI-6	94	0.28	0.005	3.25	0.045	0.80	0.021	1.06	0.019
CP95108	MRRI-6	60	0.29	0.003	17.00	0.372	5.45	0.192	4.89	0.138
CP95109	MRRI-7	93	0.21	0.007	4.75	0.027	2.30	0.023	1.30	0.007
CP95110	MRRI-7	108	0.29	0.003	10.25	0.224	3.00	0.075	4.50	0.141
CP95111	MRRI-7	110	0.73	0.018	5.75	0.051	1.90	0.031	1.90	0.048
CP95112	MRRI-7	94					0.70	0.018	0.20	0.006
CP95113	MRRI-7	100	0.00	0.000			1.10	0.026	1.00	0.031
CP95114	MRRI-2	100	0.70	0.005	5.40	0.185	1.15	0.026	0.00	0.000
CP95115	MRRI-3	105	0.1	0.001	4.80	0.239	1.30	0.039	0.30	0.007
CP95116	MRRI-1	101	0.25	0.003	5.00	0.109	1.25	0.028	0.00	0.000
CP95117	MRRI-2	100	0.18	0.001	4.10	0.131	0.95	0.027	0.00	0.000
CP95118	MRRI-1	97	0.18	0.002	6.30	0.138	0.95	0.030	0.00	0.000
CP95119	MRRI-1	98	0.14	0.002	3.90	0.068	0.70	0.019	0.05	0.000
CP95120	MRRI-2	94	1.56	0.009	4.70	0.201	1.40	0.025	0.10	0.002
CP95121	MRRI-2	103	0.19	0.001	5.50	0.188	1.50	0.042	0.00	0.000
CP95122	MRRI-2	99	0.41	0.002	6.40	0.341	1.35	0.027	0.00	0.000
CP95123	MRRI-3	104					1.10	0.033	0.10	0.003
CP95124	MRRI-1	96	0.25	0.002	6.10	0.209	1.65	0.033	0.00	0.000
CP95125	MRRI-1	96	0.19	0.002	6.00	0.131	1.15	0.033	0.30	0.009
CP95126	MRRI-1	97	0.37	0.003	4.90	0.168	0.90	0.023	0.25	0.008
CP95127	MRRI-1	101	0.12	0.001	4.10	0.112	0.70	0.022	0.05	0.002
CP95128	MRRI-1	96	0.21	0.002	4.70	0.161	1.15	0.026	0.05	0.002
CP95129	MRRI-1	95	0.21	0.001	7.90	0.338	2.45	0.041	3.35	0.147
CP95130	MRRI-3	98	0.11	0.001	3.30	0.113	0.80	0.022	0.00	0.000
CP95131	MRRI-3	103	0.08	0.001	3.10	0.106	1.40	0.031	0.15	0.004
CP95132	MRRI-3	107	0.00	0.000	9.60	0.308	1.80	0.043	1.90	0.057

(Table 4-6 continued)

Ampelisca verrilli										
			Porewater				Overlying Water			
							Day 2	Day 2	Day 8	Day 8
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)
CP95133	MRRI-3	100	0.00	0.000	4.80	0.150	1.00	0.030	0.70	0.015
CP95134	MRRI-2	102	0.20	0.002	7.60	0.260	1.00	0.023	1.40	0.044
CP95135	MRRI-2	97					0.00	0.000	0.05	0.002
CP95136	MRRI-8	96	0.24	0.003	3.75	0.082	0.45	0.009	0.00	0.000
CP95138	MRRI-10	101	0.55	0.004	20.50	0.702	2.50	0.075	4.25	0.166
CP95139	MRRI-9	98	0.14	0.003	10.75	0.095	2.55	0.139	0.15	0.011
CP95140	MRRI-9	92	0.09	0.001	12.75	0.223	0.90	0.036	0.00	0.000
CP95141	MRRI-4	97	0.12	0.003	13.50	0.104	1.60	0.040	1.15	0.034
CP95142	MRRI-4	99	0.11	0.003	8.20	0.063	1.05	0.026	1.20	0.070
CP95143	MRRI-4	96	0.09	0.002	3.20	0.025	0.40	0.010	0.10	0.005
CP95145	MRRI-4	91	0.08	0.002	3.60	0.028	0.30	0.009	0.20	0.005
CP95146	MRRI-10	100	0.09	0.002	8.00	0.102	0.40	0.010	0.10	0.004
CP95147	MRRI-10	101	0.00	0.000	3.50	0.035	0.35	0.008	0.00	0.000
CP95148	MRRI-10	101			13.00	0.390	1.45	0.039	2.05	0.096
CP95149	MRRI-8	84	0.18	0.007	2.50	0.011	0.40	0.007	0.75	0.015
CP95150	MRRI-8	99	0.21	0.001	1.50	0.080	0.55	0.014	0.30	0.006
CP95151	MRRI-4	89	0.14	0.002	6.60	0.086	1.00	0.025	0.10	0.003
CP95152	MRRI-5	89	0.17	0.003	7.60	0.079	1.10	0.033	0.15	0.006
CP95153	MRRI-5	95	0.18	0.003	9.30	0.118	1.65	0.044	2.25	0.096
CP95154	MRRI-5	101	0.13	0.001	6.50	0.130	1.05	0.033	0.80	0.032
CP95155	MRRI-4	97					0.05	0.001	0.20	0.006
CP95156	MRRI-4	97	0.12	0.009	3.50	0.004	0.85	0.021	1.35	0.012
CP95157	MRRI-8	93	0.35	0.008	4.50	0.040	0.45	0.010	0.10	0.003
CP95158	MRRI-8	98	0.13	0.001	8.25	0.169	1.35	0.038	1.00	0.031
CP95159	MRRI-10	102					0.25	0.007	0.20	0.007
CP95160	MRRI-10	100	0.25	0.003	9.50	0.190	1.70	0.037	1.00	0.039
CP95161	MRRI-11	104	0.00	0.000	6.50	0.106	1.00	0.027	0.25	0.008
CP95162	MRRI-10	96	0.00	0.000	2.00	0.035	0.15	0.003	0.00	0.000
CP95163	MRRI-10	95	0.10	0.001	11.75	0.240	1.40	0.042	0.85	0.028
CP95164	MRRI-9	98	0.00	0.000	7.00	0.114	0.15	0.009	0.05	0.000
CP95165	MRRI-11	94	0.00	0.000	12.50	0.174	0.60	0.014	0.00	0.000
CP95166	MRRI-11	101	0.10	0.001	9.25	0.151	2.35	0.064	2.15	0.067
CP95167	MRRI-11	104	0.00	0.000	6.75	0.094	1.10	0.034	0.45	0.013
CP95168	MRRI-11	106	0.00	0.000	8.75	0.114	1.10	0.034	0.00	0.000
CP95169	MRRI-11	102	0.11	0.001	3.25	0.102	0.55	0.017	0.00	0.000
CP95170	MRRI-5	98	0.09	0.002	12.00	0.153	1.75	0.052	1.30	0.039

(Table 4-6 continued)

Ampelisca verrilli										
			Porewater				Overlying Water			
							Day 2	Day 2	Day 8	Day 8
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)
CP95171	MRRI-5	94	0.11	0.003	12.00	0.079	6.25	0.216	4.75	0.232
CP95172	MRRI-8	95	0.27	0.010	24.50	0.109	8.45	0.271	9.25	0.296
CP95173	MRRI-5	97	0.12	0.002	11.00	0.143	2.15	0.064	2.35	0.135
CP95174	MRRI-6	98	0.16	0.003	9.25	0.129	1.65	0.050	0.73	0.021
CP95175	MRRI-6	98	0.41	0.007	31.50	0.410	3.40	0.117	3.53	0.165
CP95176	MRRI-5	99	0.13	0.001	24.50	0.672	4.10	0.123	4.95	0.241
CP95177	MRRI-5	99	0.19	0.003	25.50	0.446	3.65	0.114	5.40	0.263
CP95178	MRRI-3	59	0.97	0.011	120.00	2.628	15.25	0.390	25.70	0.422
CP95179	MRRI-3	99	0.21	0.002	16.75	0.459	6.45	0.137	10.30	0.309
CP95180	MRRI-3	102	0.25	0.002	28.00	0.768	4.90	0.174	4.90	0.239
CP95181	MRRI-2	99	0.12	0.001	8.90	0.474	1.60	0.036	0.30	0.027
CP95182	MRRI-6	97	0.59	0.010	29.00	0.404	3.30	0.085	3.23	0.225
CP95183	MRRI-8	78	0.20	0.004	22.75	0.220	2.75	0.069	4.60	0.195
CP95184	MRRI-8	94	0.14	0.002	36.00	0.788	4.80	0.150	7.80	0.372
CP95185	MRRI-9	97	0.18	0.001	18.25	0.585	2.75	0.160	3.30	0.501
CP95186	MRRI-9	99	0.09	0.001	14.50	0.297	2.15	0.100	3.45	0.541
CP95187	MRRI-10	94	0.09	0.001	15.25	0.489	1.80	0.049	0.75	0.024
CP95188	MRRI-10	100	0.00	0.000	11.00	0.225	1.65	0.049	0.80	0.037
CP95ASM	MRRI-12	93	0.00	0.000	10.50	0.230	1.30	0.033	0.15	0.007
CP95CB_	MRRI-7	105	0.61	0.010	9.50	0.132	2.60	0.043	4.30	0.138
CP95CF_	MRRI-9	91	0.00	0.000	6.75	0.047	0.60	0.026	0.00	0.000
CP95DIE	MRRI-12	98	0	0.000	6.25	0.087	1.65	0.033	1.30	0.041
CP95FOS	MRRI-12	98	0.10	0.002	10.75	0.119	2.10	0.047	1.00	0.049
CP95KIA	MRRI-12	93	0.16	0.003	5.00	0.048	0.85	0.020	0.75	0.048
CP95KOP	MRRI-12	90	0.11	0.003	14.25	0.100	3.05	0.055	1.20	0.052
CP95LNG	MRRI-13	99	0.16	0.004	1.00	0.007	0.75	0.017	0.00	0.000
CP95LTH	MRRI-13	100	0.12	0.002	0.50	0.008	0.50	0.013	0.60	0.031
CP95MI_	MRRI-5	82	0.29	0.003	22.00	0.421	4.30	0.132	7.00	0.299
CP95NMK	MRRI-12	81	0.13	0.007	19.50	0.055	4.10	0.082	3.10	0.151
CP95NV1	MRRI-12	86	0.09	0.002	7.00	0.078	0.65	0.016	0.15	0.004
CP95NV2	MRRI-12	101	0.00	0.000	9.75	0.136	2.20	0.054	0.25	0.010
CP95PR2	MRRI-11	104	0.00	0.000	8.25	0.092	2.55	0.080	0.00	0.000
CP95PR3	MRRI-11	105	0.00	0.000	10.75	0.076	2.55	0.071	0.00	0.000
CP95PR4	MRRI-11	103	0.00	0.000	7.50	0.083	2.25	0.045	0.00	0.000
CP95RC_	MRRI-4	95	0.19	0.005	29.00	0.223	5.25	0.144	9.45	0.227
CP95SPY	MRRI-12	98	0.12	0.002	4.50	0.063	0.95	0.019	0.10	0.004
CP95ZI_	MRRI-9	98	0.13	0.001	17.00	0.325	2.15	0.113	3.45	0.307

(Table 4-6 continued)

Ampelisca verrilli										
			Porewater				Overlying Water			
							Day 2	Day 2	Day 8	Day 8
Station	Test Series	Survival % Control	S^{2-} (mg/l)	H_2S (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)	NH_3-N (mg/l)	UAN (mg/l)
FOL950807	MRRI-1				2.30	0.029	0.60	0.017	1.10	0.044
FOL950814	MRRI-2		1.87	0.005	1.90	0.012	0.10	0.003	0.90	0.033
FOL950821	MRRI-3		0.00	0.000	4.50	0.108	1.40	0.042	2.25	0.067
FOL950901	MRRI-4		0.00	0.000	2.50	0.050	0.45	0.013	1.65	0.054
FOL950908	MRRI-5		0.13	0.000	1.90	0.038	0.60	0.019	1.70	0.083
FOL950911	MRRI-6		0.11	0.000	2.50	0.040	0.00	0.000	0.63	0.020
FOL950918	MRRI-7		0.00	0.000			1.30	0.025	1.55	0.092
FOL950925	MRRI-8		0.12	0.000	4.50	0.113	0.65	0.020	1.15	0.054
FOL951002	MRRI-9		0.00	0.000	4.00	0.080	0.70	0.042	1.05	0.093
FOL951009	MRRI-10		0.08	0.000	4.25	0.085	0.60	0.014	1.50	0.070
FOL951016	MRRI-11		0.00	0.000	3.00	0.048	0.65	0.016	0.00	0.000
FOL951023	MRRI-12		0.00	0.000	4.50	0.057	0.90	0.018	0.80	0.028
FOL951030	MRRI-13		0.17	0.000	3.20	0.032	0.60	0.014	1.00	0.075

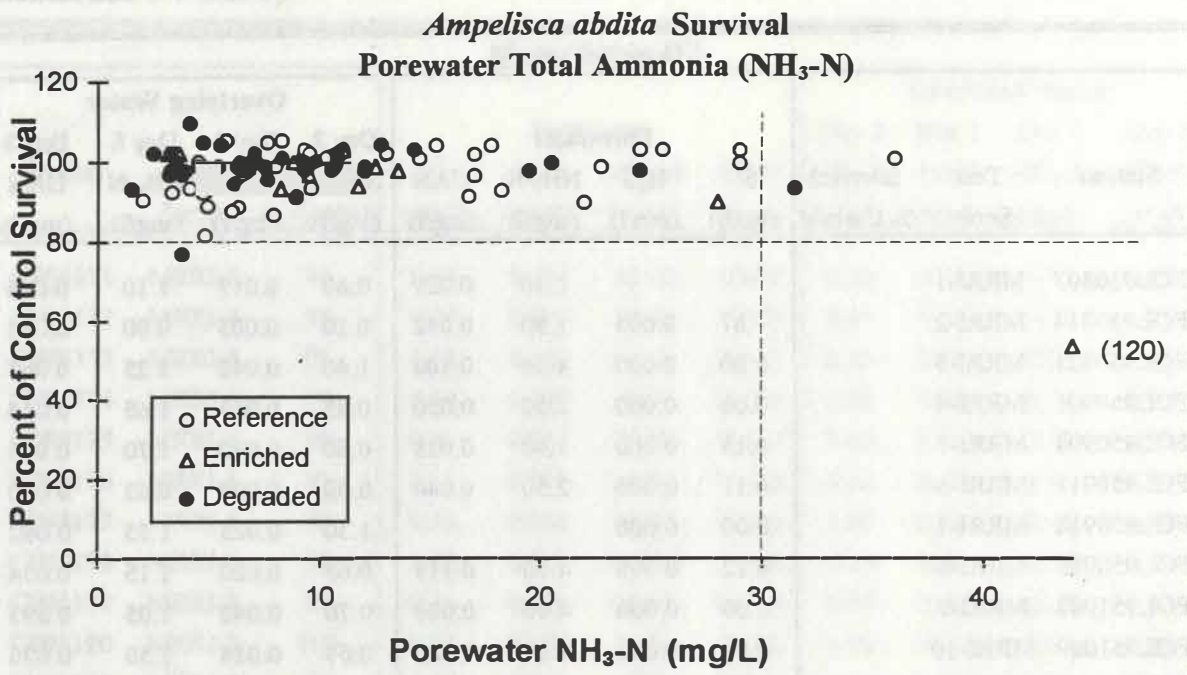

Figure 4-4. Survival of *Ampelisca abdita* vs. total ammonia (NH_3-N) concentrations of sediment porewaters. The vertical dotted line indicates NOEC for *A. abdita*. CP95178 had a much higher ammonia concentration (120 mg/L) than the other sites.

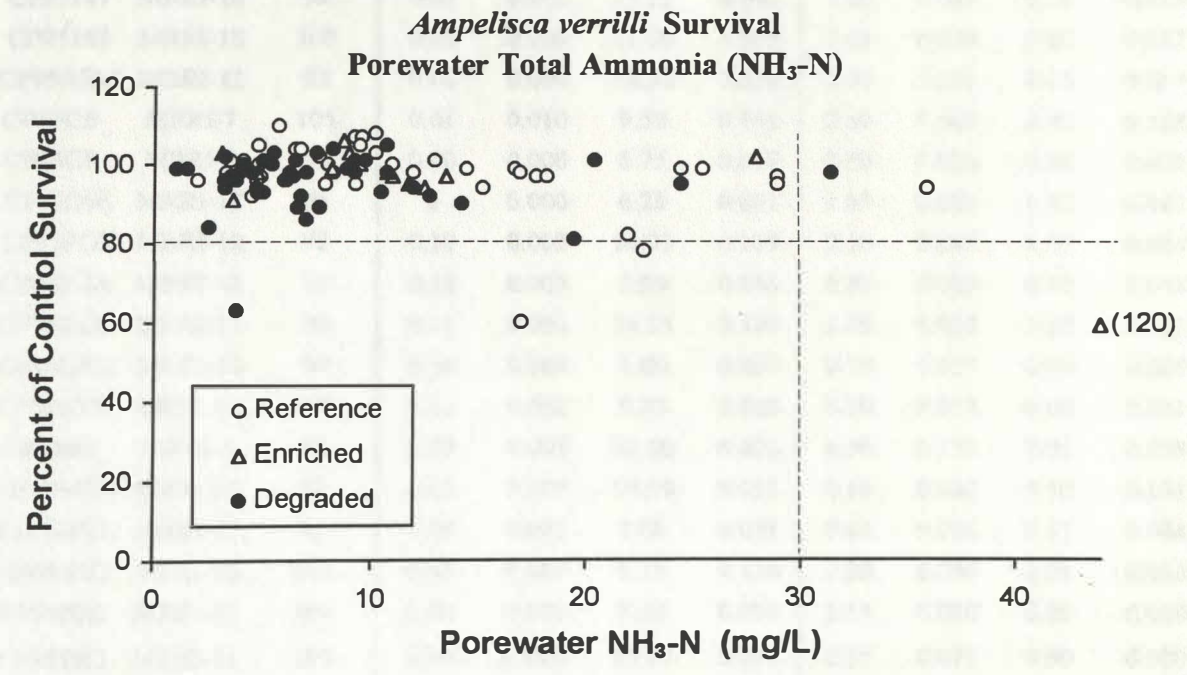

Figure 4-5. Survival of *Ampelisca verrilli* vs. total ammonia (NH_3-N) concentrations of sediment porewaters. The vertical dotted line indicates NOEC for *A. abdita*. CP95178 had a much higher ammonia concentration (120 mg/L) than the other sites.

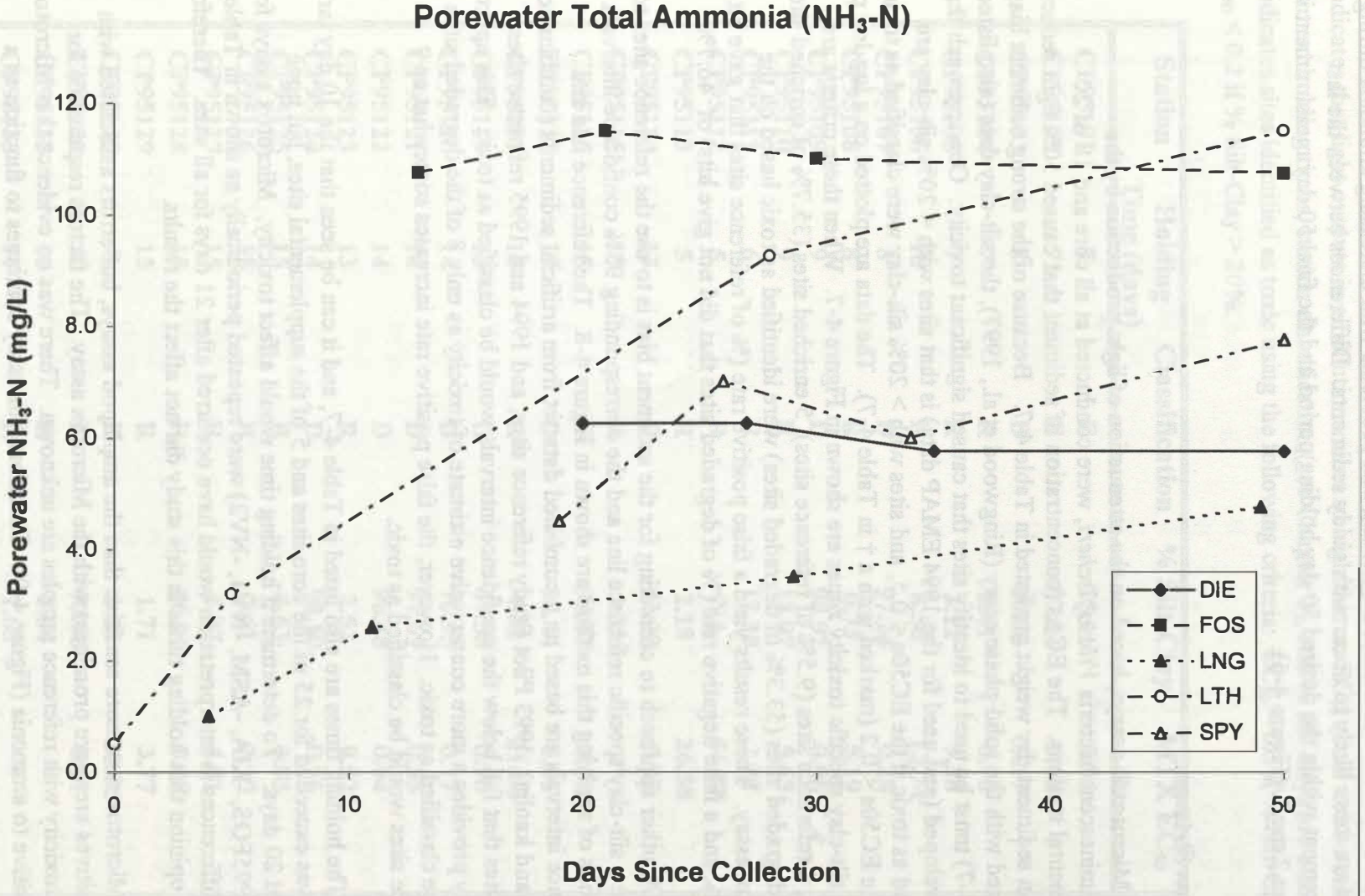

Figure 4-6. Changes in porewater total ammonia (NH_3-N) over time in 5 sediment samples collected during EMAP sampling, summer 1995.

sediments with < 25% silt-clay, suggesting that problems with increasing ammonia during storage are more likely to occur with sandy sediments. Differences between the last measurement within the desired 30 day holding period and the final 50 day measurement were less than 2 mg/L (Figure 4-6).

Microtox® Assays

Microtox® assays, based on the attenuation of light production by the photoluminescent bacteria *Vibrio fischeri*, were conducted at all core and 18 of 20 supplemental stations. The EC_{50}s (concentration of sediment that caused 50% light reduction) based on sediment dry weight are listed in Table 4-7. Because of the strong sediment bias associated with the solid-phase assay (Ringwood et al., 1997), the silt-clay data (also listed in Table 4-7) must be used to identify sites that caused significant toxicity. One approach that was developed (and used for the 1994 EMAP data) is that sites with < 20% silt-clay are classified as toxic if the EC50s < 0.5, and sites with > 20% silt-clay were classified as toxic when the EC50s < 0.2 (marked with a † in Table 4-7). The data are plotted on a log-log plot and the silt-clay specific toxicity zones are shown in Figure 4-7. When these criteria are applied, 4 reference sites (9.5% of reference sites), 5 enriched sites (35.7% of enriched sites), and 16 degraded sites (53.3% of degraded sites) were identified as toxic based on the Microtox assay. These results yield a false positive rate (% of reference sites that gave hits) of 9.5%, and a false negative rate (% of degraded sites that did not give hits) of 46.7%.

Another approach to correcting for the sediment bias is to use the reference sites to generate a silt-clay specific reference line and the corresponding 95% confidence intervals. The results of applying this method are shown in Figure 4-8. The reference line and confidence intervals are based on a combined data set from artificial sediments (combinations of sand and kaolin), 1993 Pilot Study reference sites, and 1994 and 1995 reference sites. Those sites that fall below the confidence intervals would be classified as toxic. This approach generally provides a more conservative estimate of toxicity as only 8 of the degraded sites would be classified as toxic. However, the false positive rate increases somewhat as 9 reference sites would be classified as toxic.

The holding times are also listed in Table 4-7, and it can be seen that the 10 day target period was exceeded for 25 of the core sites and 5 of the supplemental sites, but none exceeded 20 days. To determine if holding time would affect toxicity, Microtox assays for 5 sites (CP95FOS, -KIA, -ASM, -NV1, -NV2) were repeated periodically as shown in Table 4-8. No differences in interpretation would have occurred after 21 days for all sites. Therefore it is our opinion that holding times in this study did not affect the results.

Microtox was more sensitive than the amphipod assays, but errors associated with false positives are more prominent with the Microtox assay. The factors responsible for causing toxicity with reference samples are unknown. There was no evidence that Microtox was sensitive to ammonia (Figure 4-9). Therefore this assay continues to function as a

Table 4-7. Results of the Microtox analyses of sediments collected during EMAP sampling in the Carolinian Province, summer 1995. The EC_{50} values are based on sediment dry weight. * Indicates that light outputs in all dilutions were so high that an EC_{50} could not be calculated. Sediment holding times, station classification (see Chapter 3), and % silt-clays are also listed. † indicates sites identified as toxic using the following criteria: $EC_{50} < 0.5$ if % Silt-Clay < 20%; $EC_{50} < 0.2$ if % Silt-Clay > 20%.

Station	Holding Time (days)	Classification	% Silt-Clay	MTX EC_{50}	
CP95101	7	E	75.11	0.36	
CP95102	7	E	37.34	0.18	†
CP95103	8	D	99.63	0.17	†
CP95104	7	R	2.41	0.70	
CP95105	7	R	2.12	9.38	
CP95106	10	R	8.56	13.74	
CP95107	8	D	97.24	0.28	
CP95108	8	R	0.73	5.19	
CP95109	9	D	98.92	0.06	†
CP95110	9	R	13.07	5.63	
CP95111	6	R	12.38	2.22	
CP95112	5	R	NA	56.87	
CP95113	5	R	2.18	26.38	
CP95114	13	D	43.29	0.97	
CP95115	10	R	2.33	*	
CP95116	15	D	94.77	0.50	
CP95117	13	D	98.44	0.36	
CP95118	15	R	4.32	21.68	
CP95119	15	D	67.50	0.90	
CP95120	14	D	76.95	0.77	
CP95121	14	D	97.69	0.55	
CP95122	14	D	96.48	0.64	
CP95123	13	R	2.52	9.52	
CP95124	14	D	98.10	0.56	
CP95125	15	R	3.63	3.83	
CP95126	15	R	7.61	2.19	
CP95127	15	R	5.37	4.81	
CP95128	15	R	16.21	0.80	
CP95129	15	R	1.71	3.77	
CP95130	8	R	1.83	38.36	
CP95131	8	E	70.66	0.51	
CP95132	11	R	1.04	*	
CP95133	11	R	1.68	*	
CP95134	14	R	0.78	12.32	

(Table 4-7 continued)

Station	Holding Time (days)	Classification	% Silt-Clay	MTX EC_{50}	
CP95135	12	R	2.24	*	
CP95136	4	D	88.62	0.64	
CP95138	17	D	3.19	23.23	
CP95139	18	D	96.18	0.17	†
CP95140	18	D	78.90	0.60	
CP95141	8	E	62.91	0.32	
CP95142	9	E	18.31	1.38	
CP95143	8	D	89.87	0.16	†
CP95145	9	E	49.96	0.12	†
CP95146	17	R	2.14	4.29	
CP95147	17	R	33.22	0.45	
CP95148	15	R	5.14	2.42	
CP95149	3	D	46.40	0.04	†
CP95150	3	D	15.39	0.88	
CP95151	8	D	19.04	0.17	†
CP95152	8	D	33.73	0.08	†
CP95153	8	R	4.29	5.08	
CP95154	7	D	45.88	0.17	†
CP95155	9	E	2.38	10.71	
CP95156	1	D	77.38	0.02	†
CP95157	1	R	2.42	16.30	
CP95158	1	R	6.19	0.89	
CP95159	3	R	1.40	*	
CP95160	2	E	1.40	0.36	†
CP95161	1	R	2.81	4.99	
CP95162	2	R	1.23	19.97	
CP95163	2	E	5.18	1.25	
CP95164	2	D	1.46	*	
CP95165	3	E	3.41	5.31	
CP95166	4	D	64.21	0.23	
CP95167	3	R	8.72	0.49	†
CP95168	2	E	5.90	0.93	
CP95169	4	D	25.35	0.60	
CP95170	7	R	2.59	10.50	
CP95171	8	D	89.92	0.09	†
CP95172	2	D	96.33	3.21	
CP95173	7	E	25.33	0.32	
CP95174	7	D	46.07	0.20	
CP95175	5	D	6.38	0.65	

(Table 4-7 continued)

Station	Holding Time (days)	Classification	% Silt-Clay	MTX EC_{50}	
CP95176	9	R	3.47	1.11	
CP95177	9	R	3.72	1.50	
CP95178	8	E	9.42	0.31	†
CP95179	9	R	19.11	0.23	†
CP95180	7	E	23.10	0.26	
CP95181	8	D	69.29	0.11	†
CP95182	6	R	8.85	0.58	
CP95183	4	R	6.17	0.85	
CP95184	4	R	12.26	0.47	†
CP95185	3	R	17.29	0.26	†
CP95186	3	R	4.75	1.02	
CP95187	2	R	16.27	0.52	
CP95188	6	R	20.70	0.21	
CP95ASM	5	D	33.50	0.22	
CP95CB_	10	R	23.52	25.86	
CP95CF_	17	D	37.62	*	
CP95DIE	1	D	94.59	0.13	†
CP95FOS	1	E	28.89	0.14	†
CP95KIA	7	D	37.18	0.19	†
CP95KOP	1	D	92.68	0.18	†
CP95LON	6	D	20.10	1.17	
CP95MI_	8	R	2.17	3.97	
CP95NMK	1	D	46.67	0.23	
CP95NV1	1	D	19.45	0.24	†
CP95NV2	1	D	93.26	0.05	†
CP95PR2	20	D	98.32	0.58	
CP95PR3	20	D	99.29	0.24	
CP95PR4	20	D	99.43	0.54	
CP95RC_	9	R	2.86	9.41	
CP95SPY	1	D	14.26	0.74	
CP95ZI_	17	R	6.90	0.60	

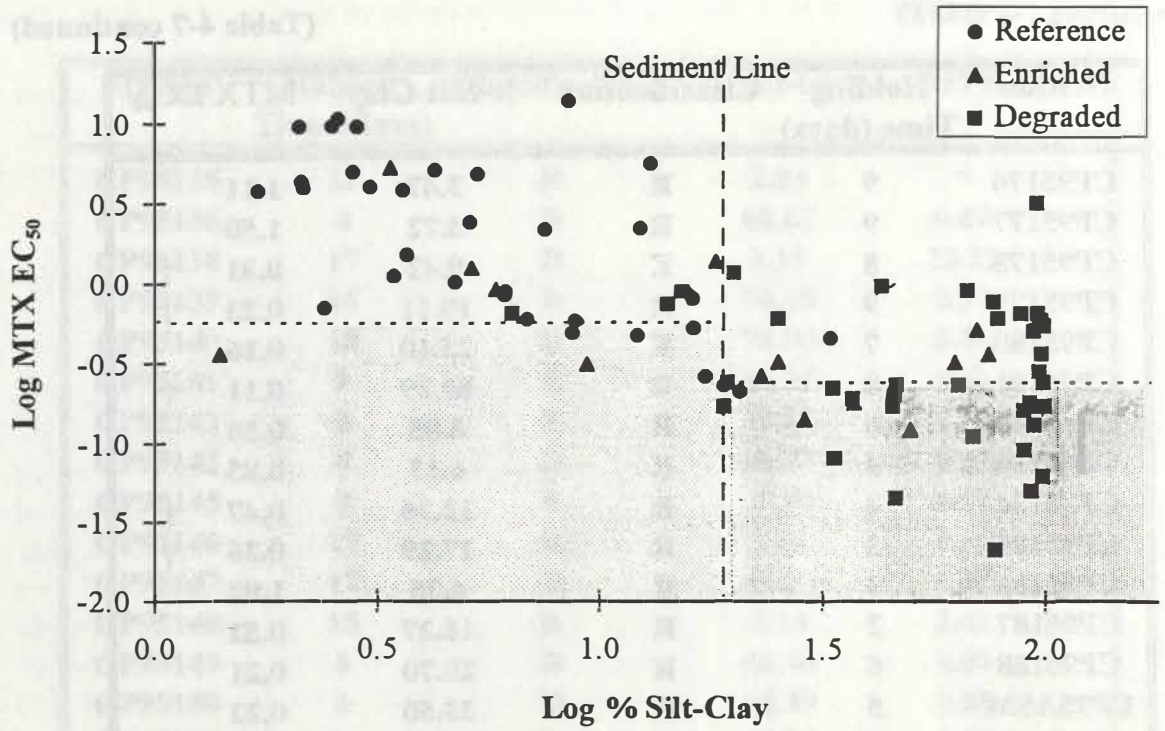

Figure 4-7. Log-log plot of Microtox EC_{50}s vs % Silt-Clay. Shaded area to the left of the sediment line represents sites with < 20% Silt-Clay that would be classified as toxic, and shaded area to the right would contain sites with ≥ 20% Silt-Clay that would be classified as toxic.

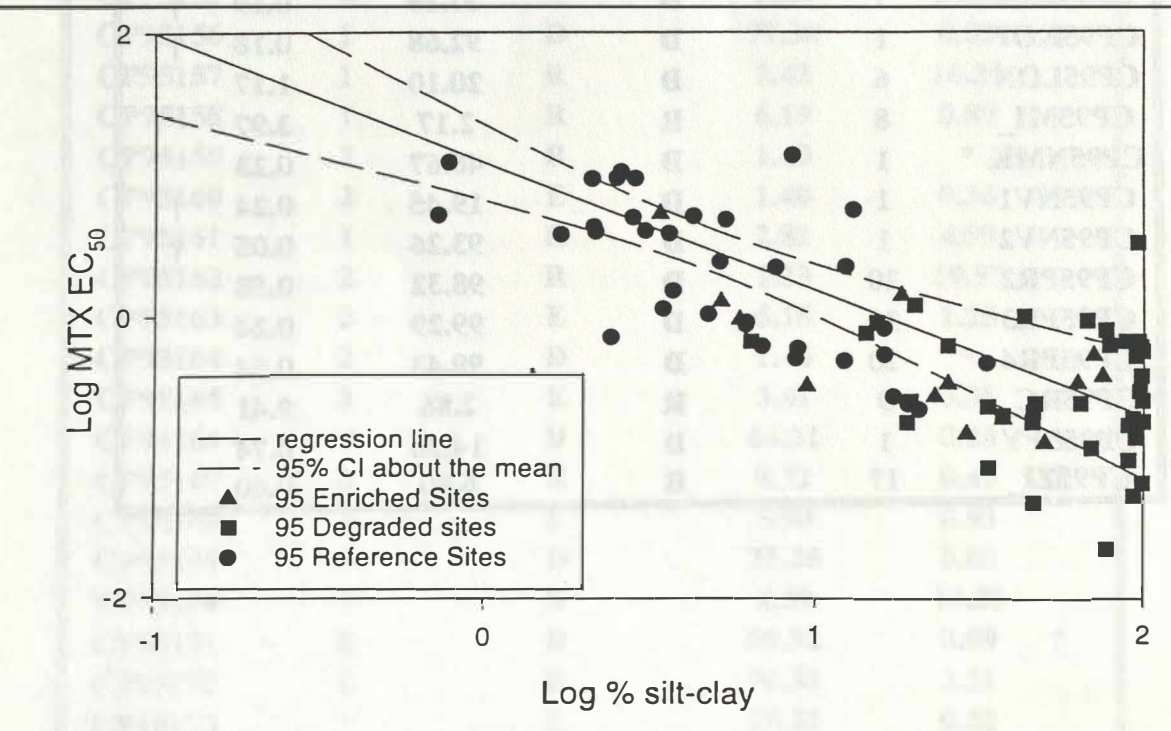

Figure 4-8. Log-log plot of Microtox EC_{50}s vs % Silt-Clay. Reference line and confidence intervals based on reference sites from 1993, 1994, 1995 and artificial sediments are shown.

Table 4-8. The effects of holding time (shown in italics in parenthesis for each repeat analysis) on Microtox EC_{50}s.

Station	Initial	Repeat 1	Repeat 2	Repeat 3	Repeat 4
FOS	**0.14** *(1 day)*	**0.17** *(23 days)*	**0.19** *(42 days)*	**0.22** *(63 days)*	**0.35** *(84 days)*
KIA	**0.19** *(7 days)*	**0.13** *(21 days)*	**0.25** *(40 days)*	**0.34** *(61 days)*	**0.34** *(82 days)*
ASM	**0.22** *(5 days)*	**0.32** *(19 days)*	**0.37** *(40 days)*	**0.53** *(60 days)*	**0.68** *(83 days)*
NV1	**0.24** *(1 day)*	**0.31** *(21 days)*	**0.47** *(42 days)*	**0.44** *(62 days)*	**0.45** *(85 days)*
NV2	**0.05** *(1 day)*	**0.06** *(21 days)*	**0.08** *(42 days)*	**0.12** *(62 days)*	**0.16** *(85 days)*

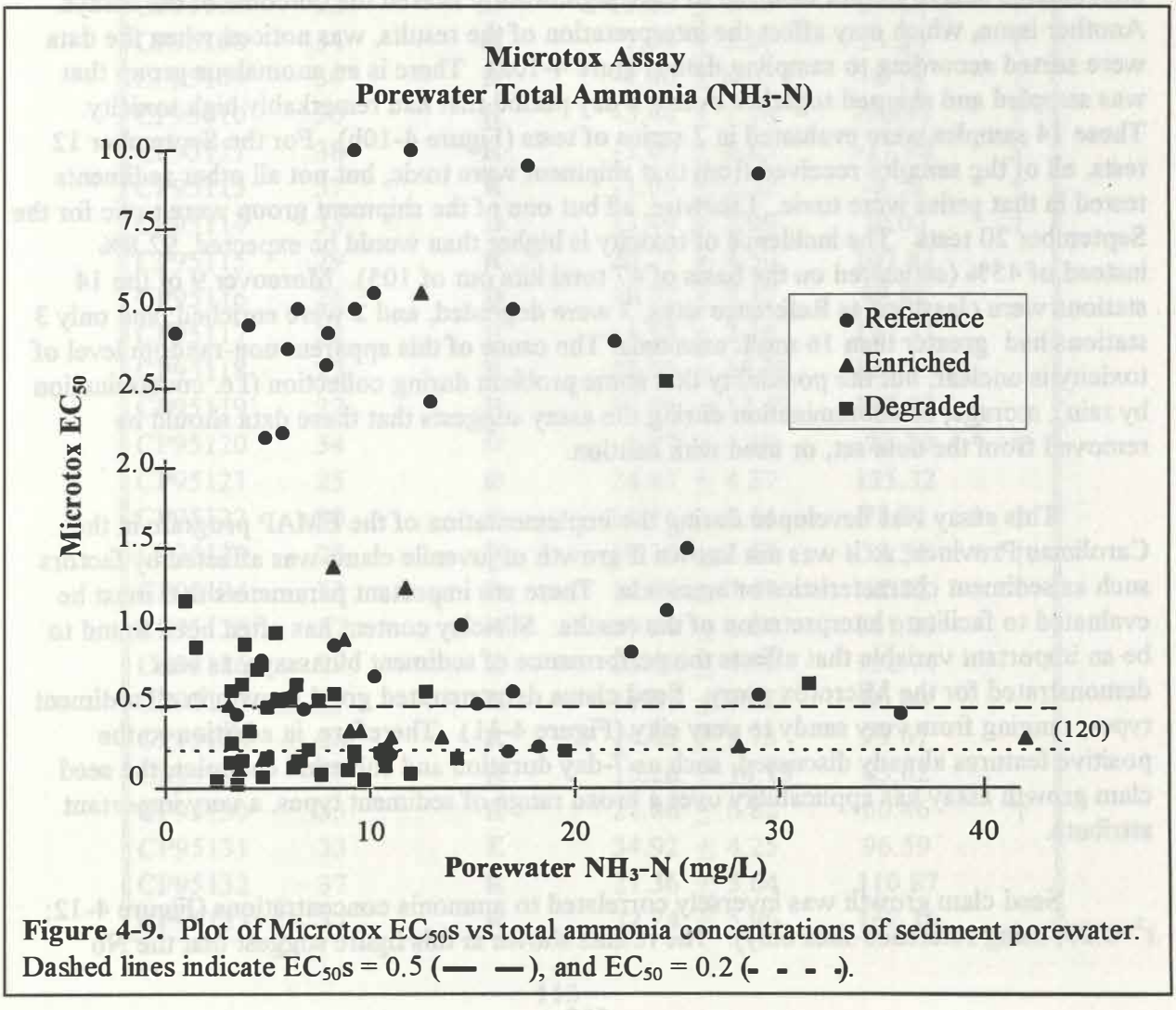

Figure 4-9. Plot of Microtox EC_{50}s vs total ammonia concentrations of sediment porewater. Dashed lines indicate EC_{50}s = 0.5 (— —), and EC_{50} = 0.2 (- - - -).

sensitive indicator that can be conducted quickly at a moderate cost. However, limitations associated with sediment biases indicate that the results must be interpreted carefully, and the Microtox assay should be used in conjunction with some other bioassay(s).

Seed Clam Growth Assays

Seed clam assays were conducted with sediments from 85 core stations and all 20 supplemental stations. This is a sublethal assay based on growth as an indicator of potential sediment toxicity, and so may represent the potential for chronic as well as acute effects. The growth rates and resulting indicators of toxicity (statistical difference from sediment controls and < 80% of control growth) are listed in Table 4-9. There were 47 stations characterized as toxic, composed of 20 degraded stations, 23 reference stations, and 4 enriched stations.

The sediment holding times are also listed in Table 4-9. Although many of the samples exceeded the 30 day holding time, none of the core sites were held for more than 40 days before being tested, and only 3 supplemental sites were held longer than 40 days. These unavoidable delays are not believed to have significantly altered the outcome of the assays. Another issue, which may affect the interpretation of the results, was noticed when the data were sorted according to sampling date (Figure 4-10a). There is an anomalous group that was sampled and shipped together over a 2 day period that had remarkably high toxicity. These 14 samples were evaluated in 2 series of tests (Figure 4-10b). For the September 12 tests, all of the samples received from that shipment were toxic, but not all other sediments tested in that series were toxic. Likewise, all but one of the shipment group were toxic for the September 20 tests. The incidence of toxicity is higher than would be expected, 92.8% instead of 45% (estimated on the basis of 47 total hits out of 105). Moreover 9 of the 14 stations were classified as Reference sites, 3 were degraded, and 2 were enriched; and only 3 stations had greater than 16 mg/L ammonia. The cause of this apparent non-random level of toxicity is unclear, but the possibility that some problem during collection (i.e. contamination by rain), storage, or contamination during the assay suggests that these data should be removed from the data set, or used with caution.

This assay was developed during the implementation of the EMAP program in the Carolinian Province, so it was not known if growth of juvenile clams was affected by factors such as sediment characteristics or ammonia. These are important parameters that must be evaluated to facilitate interpretation of the results. Silt-clay content has often been found to be an important variable that affects the performance of sediment bioassays, as was demonstrated for the Microtox assay. Seed clams demonstrated good growth in all sediment types, ranging from very sandy to very silty (Figure 4-11). Therefore, in addition to the positive features already discussed, such as 7-day duration and sublethal endpoint, the seed clam growth assay has applicability over a broad range of sediment types, a very important attribute.

Seed clam growth was inversely correlated to ammonia concentrations (Figure 4-12; r^2=0.35, using reference sites only). The results shown in this figure suggest that the No

Table 4-9. Results of the seed clam growth assay with sediments collected during EMAP sampling in the Carolinian Province, summer 1995. Data are presented as mean growth rates (total dry weight) ± standard deviation (4 replicates, each replicate was a composite of 30 - 50 clams). Sediment holding times, and station classification (see Chapter 3) are also listed.
* Indicates growth rates that were significantly different from control sediments (t-test, $p \leq 0.05$)
† indicates sites that were biologically significant (growth rates were < 80% of control sediments

Station	Sediment Holding (days)	Classification	Growth Rate ug/clam/day	% Control		
CP95101	33	E	23.35 ± 3.84	66.64	*	†
CP95102	33	E	21.96 ± 9.75	62.69		†
CP95103	34	D	-9.95 ± 2.89	-28.39	*	†
CP95104	39	R	2.84 ± 1.74	17.05	*	†
CP95105	39	R	-4.23 ± 2.77	-25.39	*	†
CP95106	39	R	-5.47 ± 1.49	-32.84	*	†
CP95107	32	D	13.03 ± 8.70	37.18	*	†
CP95108	34	R	7.44 ± 3.07	21.24	*	†
CP95109	30	D	-1.46 ± 0.95	-8.78	*	†
CP95110	30	R	-5.48 ± 2.18	-32.91	*	†
CP95111	38	R	-3.00 ± 0.85	-17.98	*	†
CP95113	37	R	-1.09 ± 2.32	-6.52	*	†
CP95114	33	D	13.49 ± 2.09	70.02	*	†
CP95115	29	R	20.77 ± 4.50	107.81		
CP95116	26	D	18.02 ± 7.37	98.02		
CP95117	32	D	24.53 ± 2.16	127.33		
CP95118	27	R	28.56 ± 15.19	155.35		
CP95119	27	D	27.06 ± 12.40	147.22		
CP95120	34	D	-5.07 ± 4.19	-26.29	*	†
CP95121	25	D	24.87 ± 4.27	135.32		
CP95122	30	D	15.16 ± 3.44	78.71	*	†
CP95123	28	R	10.12 ± 1.68	52.54	*	†
CP95124	33	D	11.55 ± 7.49	62.82		†
CP95125	27	R	29.64 ± 1.84	161.25		
CP95126	27	R	28.08 ± 4.99	152.74		
CP95127	27	R	15.81 ± 5.32	86.00		
CP95128	26	R	14.63 ± 9.73	79.61		
CP95129	26	R	15.26 ± 14.13	83.02		
CP95130	35	R	21.86 ± 6.82	60.46		†
CP95131	33	E	34.92 ± 4.25	96.59		
CP95132	37	R	21.36 ± 5.64	110.87		
CP95133	37	R	32.24 ± 5.96	167.36		

(Table 4-9 continued)

Station	Sediment Holding (days)	Classification	Growth Rate ug/clam/day	% Control	
CP95134	33	R	16.13 ± 3.17	83.71	
CP95135	31	R	25.69 ± 3.44	133.34	
CP95136	36	D	15.68 ± 2.95	94.08	
CP95138	36	D	25.95 ± 6.31	80.55	
CP95139	37	D	36.69 ± 10.03	113.91	
CP95140	37	D	31.58 ± 6.66	98.05	
CP95141	29	E	41.07 ± 6.10	113.59	
CP95142	30	E	32.39 ± 2.28	89.58	
CP95143	29	D	35.63 ± 6.36	98.56	
CP95145	31	E	36.02 ± 9.63	99.63	
CP95146	36	R	10.21 ± 1.77	31.69	* †
CP95147	36	R	26.27 ± 3.64	81.55	
CP95148	34	R	37.88 ± 6.35	117.61	
CP95149	33	D	3.79 ± 1.01	22.74	* †
CP95150	33	D	4.58 ± 0.80	27.50	* †
CP95151	29	D	39.69 ± 1.56	109.78	
CP95152	29	D	34.71 ± 4.68	96.00	
CP95153	28	R	50.84 ± 6.75	145.12	
CP95154	27	D	44.60 ± 15.95	127.32	
CP95155	31	E	61.34 ± 8.27	169.65	
CP95156	30	D	-0.61 ± 2.23	-1.69	* †
CP95157	30	R	15.00 ± 1.70	90.02	
CP95158	31	R	21.59 ± 0.88	129.58	
CP95159	38	R	29.47 ± 10.56	109.22	
CP95160	37	E	36.30 ± 6.23	134.55	
CP95161	36	R	31.55 ± 15.81	116.94	
CP95162	37	R	37.53 ± 4.66	139.10	
CP95163	37	E	37.79 ± 11.25	140.07	
CP95164	36	D	26.37 ± 5.54	81.87	
CP95165	28	E	35.47 ± 3.20	131.48	
CP95166	29	D	37.28 ± 6.68	138.19	
CP95167	31	R	34.17 ± 13.17	126.65	
CP95168	30	E	26.54 ± 6.03	98.36	
CP95169	29	D	31.33 ± 7.42	116.12	
CP95170	38	R	48.49 ± 10.89	138.42	
CP95171	39	D	12.47 ± 7.12	35.59	* †
CP95172	34	D	1.29 ± 0.97	7.72	* †
CP95173	35	E	41.35 ± 8.90	118.02	
CP95174	35	D	61.62 ± 5.84	175.90	

(Table 4-9 continued)

Station	Sediment Holding (days)	Classification	Growth Rate ug/clam/day	% Control		
CP95175	33	D	26.25 ± 8.57	74.91		†
CP95176	31	R	31.72 ± 6.84	87.72		
CP95177	31	R	22.97 ± 6.65	63.52		†
CP95178	35	E	0.14 ± 8.45	0.38	*	†
CP95179	27	R	-1.64 ± 9.35	-8.51	*	†
CP95180	29	E	3.03 ± 3.35	15.71	*	†
CP95181	30	D	19.91 ± 3.04	103.33		
CP95182	32	R	22.34 ± 7.80	63.78		†
CP95183	40	R	23.22 ± 14.68	72.08		†
CP95184	37	R	-0.55 ± 2.86	-1.72	*	†
CP95185	36	R	18.24 ± 4.15	56.62	*	†
CP95186	36	R	20.64 ± 0.88	64.07	*	†
CP95187	35	R	36.48 ± 2.90	113.25		
CP95188	33	R	30.05 ± 10.15	93.28		
CP95ASM	11	D	20.66 ± 3.92	101.97		
CP95CB_	47	R	24.07 ± 3.18	74.72	*	†
CP95CF_	28	D	-4.39 ± 3.00	-26.33	*	†
CP95DIE	21	D	17.20 ± 2.37	84.86	*	
CP95FOS	7	E	21.62 ± 3.56	106.71		
CP95KIA	5	D	22.56 ± 2.09	111.35		
CP95KOP	21	D	13.18 ± 3.46	65.02	*	†
CP95LON	8	D	42.44 ± 3.77	101.20		
CP95MI_	40	R	14.67 ± 8.07	41.88	*	†
CP95NMK	30	D	31.62 ± 9.76	75.41		†
CP95NV1	13	D	18.18 ± 1.12	89.71		
CP95NV2	13	D	19.70 ± 3.49	97.20		
CP95PR1	43	R	22.49 ± 2.10	53.63	*	†
CP95PR2	33	D	12.66 ± 1.39	62.48	*	†
CP95PR3	33	D	12.50 ± 2.59	61.67	*	†
CP95PR4	33	D	11.88 ± 1.36	58.63	*	†
CP95PR5	43	D	28.17 ± 4.85	67.19	*	†
CP95RC_	30	R	-4.85 ± 2.48	-13.43	*	†
CP95SPY	30	D	21.99 ± 4.45	108.51		
CP95ZI_	36	R	22.53 ± 6.94	69.93		†

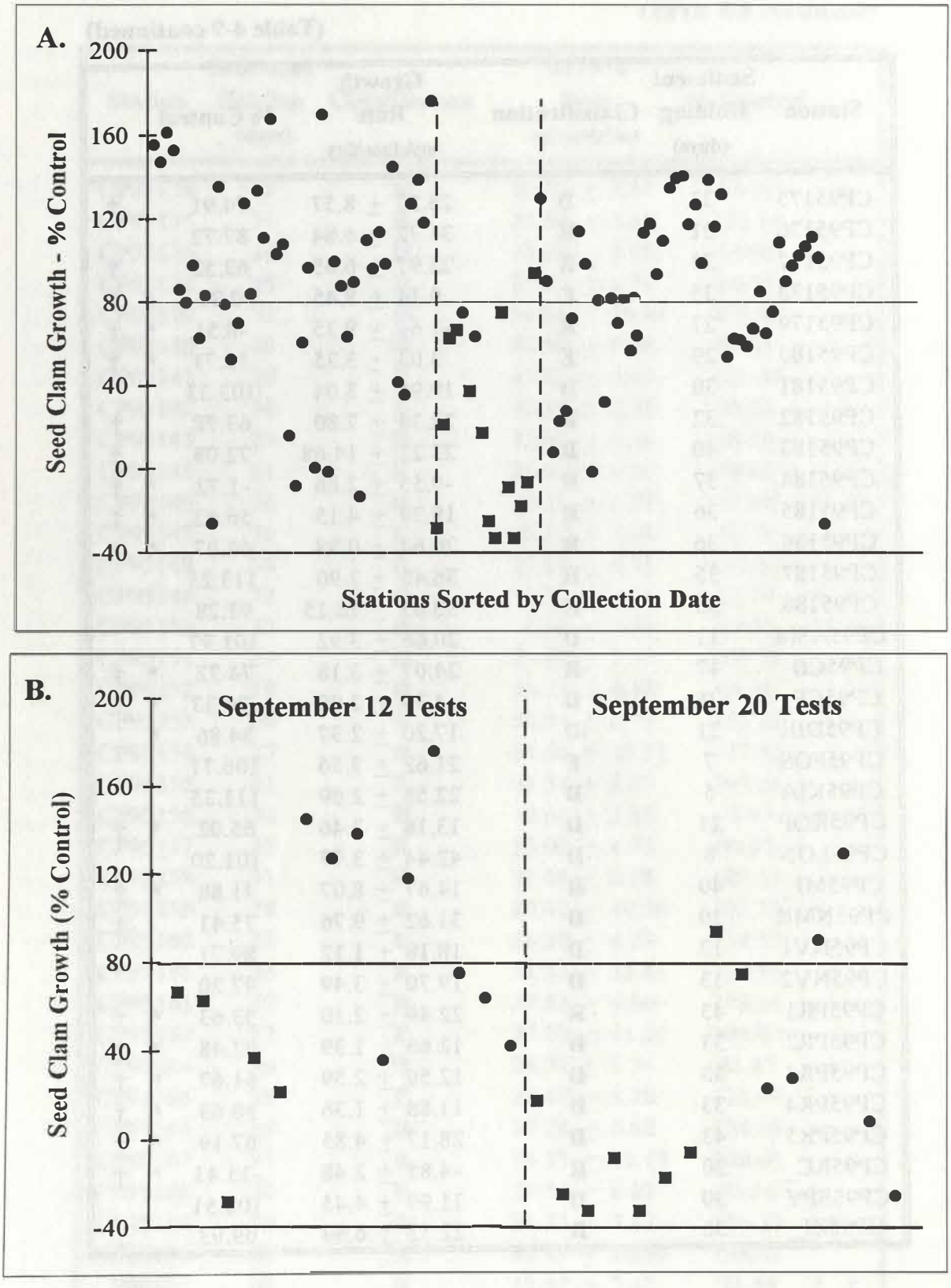

Figure 4-10. Diagrams showing positions of a set of samples (indicated by ■) that demonstrated unusually high toxicity. **(A)** Seed clam results sorted by sampling date. **(B)** Results of all assays conducted at the same as the anomalous set.

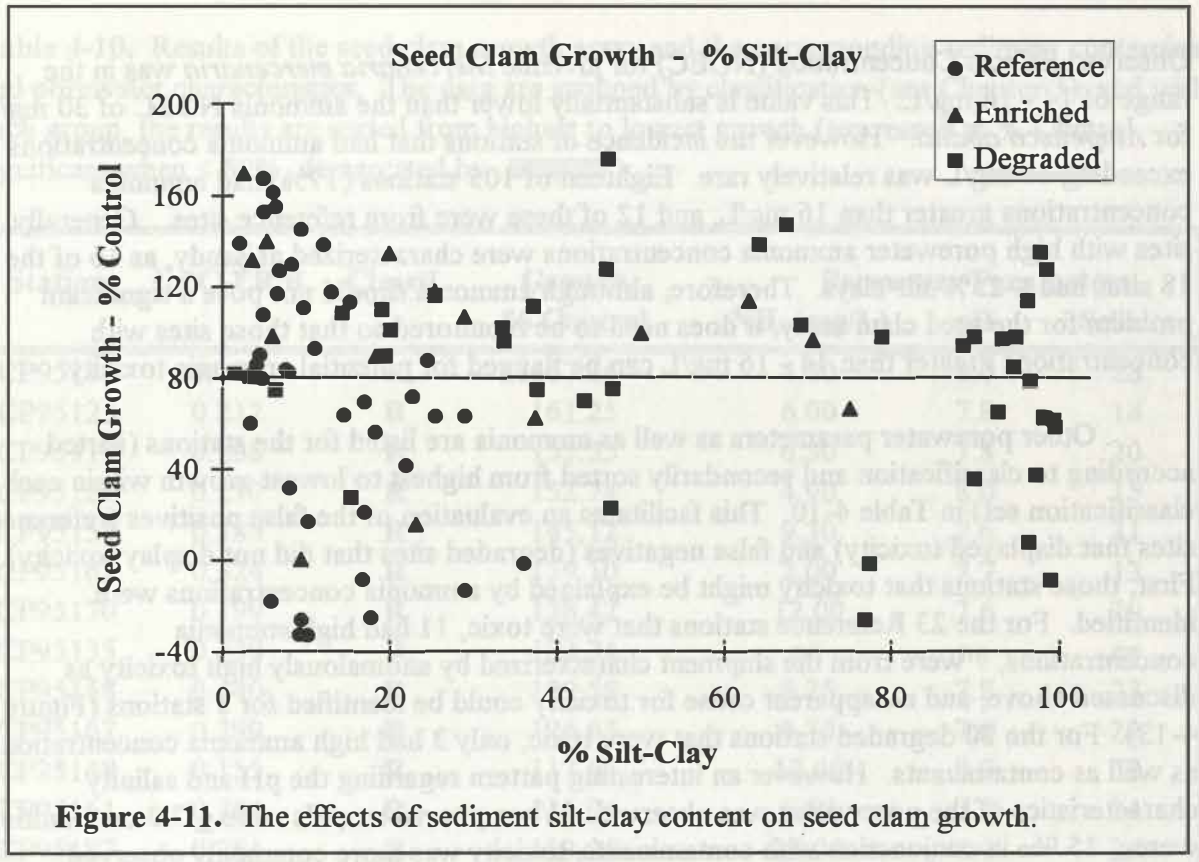

Figure 4-11. The effects of sediment silt-clay content on seed clam growth.

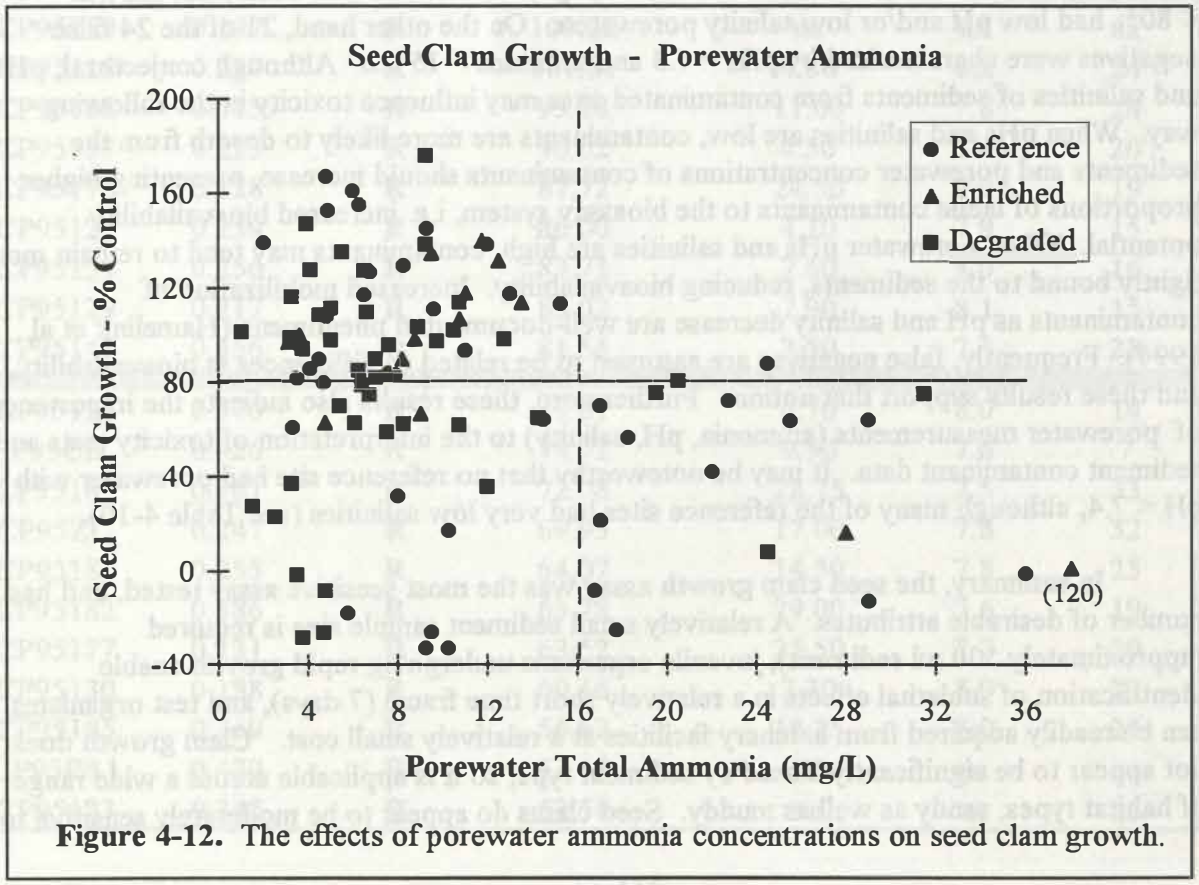

Figure 4-12. The effects of porewater ammonia concentrations on seed clam growth.

Observed Effects Concentration (NOEC) for juvenile *Mercenaria mercenaria* was in the range of 14 - 16 mg/L. This value is substantially lower than the ammonia NOEC of 30 mg/L for *Ampelisca abdita*. However the incidence of stations that had ammonia concentrations exceeding 16 mg/L was relatively rare. Eighteen of 105 stations (17%) had ammonia concentrations greater than 16 mg/L, and 12 of these were from reference sites. Generally, sites with high porewater ammonia concentrations were characterized as sandy, as 16 of the 18 sites had < 25% silt-clays. Therefore, although ammonia should not pose a significant problem for the seed clam assay, it does need to be monitored so that those sites with concentrations greater than 14 - 16 mg/L can be flagged for potential ammonia toxicity.

Other porewater parameters as well as ammonia are listed for the stations (sorted according to classification and secondarily sorted from highest to lowest growth within each classification set) in Table 4-10. This facilitates an evaluation of the false positives (reference sites that displayed toxicity) and false negatives (degraded sites that did not display toxicity). First, those stations that toxicity might be explained by ammonia concentrations were identified. For the 23 Reference stations that were toxic, 11 had high ammonia concentrations, 7 were from the shipment characterized by anomalously high toxicity as discussed above, and no apparent cause for toxicity could be identified for 5 stations (Figure 4-13). For the 20 degraded stations that were toxic, only 3 had high ammonia concentrations as well as contaminants. However an interesting pattern regarding the pH and salinity characteristics of the porewaters was observed. When porewater pHs were $\leq$ 7.3 or salinities were $\leq$ 15 ‰ in conjunction with contaminants, toxicity was more commonly observed. Excluding those with high ammonia levels, all degraded stations with seed clam growth < 80% had low pH and/or low salinity porewaters. On the other hand, 21 of the 24 false negatives were characterized by pHs > 7.3 and salinities > 15 ‰. Although conjectural, pHs and salinities of sediments from contaminated sites may influence toxicity in the following way. When pHs and salinities are low, contaminants are more likely to desorb from the sediments and porewater concentrations of contaminants should increase, presenting higher proportions of labile contaminants to the bioassay system, i.e. increased bioavailability potential. When porewater pHs and salinities are high, contaminants may tend to remain more tightly bound to the sediments, reducing bioavailability. Increased mobilization of contaminants as pH and salinity decrease are well-documented phenomena (Hamelink et al., 1994). Frequently, false negatives are assumed to be related to differences in bioavailability, and these results support that notion. Furthermore, these results also indicate the importance of porewater measurements (ammonia, pH, salinity) to the interpretation of toxicity tests and sediment contaminant data. It may be noteworthy that no reference site had porewater with pH < 7.4, although many of the reference sites had very low salinities (see Table 4-10).

In summary, the seed clam growth assay was the most sensitive assay tested, and has a number of desirable attributes. A relatively small sediment sample size is required (approximately 500 ml sediment), juvenile organisms undergoing rapid growth enable identification of sublethal effects in a relatively short time frame (7 days), and test organisms can be readily acquired from hatchery facilities at a relatively small cost. Clam growth does not appear to be significantly biased by sediment type, so it is applicable across a wide range of habitat types, sandy as well as muddy. Seed clams do appear to be moderately sensitive to

Table 4-10. Results of the seed clam growth assay and the corresponding sediment contaminant and porewater characteristics. The data are grouped by classification (see Chapter 3), and within each group, the results are sorted from highest to lowest growth (expressed as % Control, significant when < 80%, demarcated by ▨).

Station	ΣPC-ERM	Classif.	Growth	Porewater Parameters		
			% Control	NH_4 (mg/L)	pH	Salinity
CP95133	0.186	R	167.36	4.80	8.0	28
CP95125	0.212	R	161.25	6.00	7.8	18
CP95118	0.208	R	155.35	6.30	7.8	20
CP95126	0.277	R	152.74	4.90	8.0	15
CP95153	0.389	R	145.12	9.30	7.6	31
CP95162	0.324	R	139.10	2.00	7.7	13
CP95170	0.199	R	138.42	12.00	7.6	29
CP95135	0.130	R	133.34	na	na	na
CP95158	0.440	R	129.58	8.25	7.8	23
CP95167	0.399	R	126.65	6.75	7.6	22
CP95148	0.155	R	117.61	13.00	8.0	32
CP95161	0.264	R	116.94	6.50	7.7	24
CP95187	0.361	R	113.25	15.25	8.0	26
CP95132	0.241	R	110.87	9.60	8.0	23
CP95159	0.197	R	109.22	na	na	na
CP95115	0.217	R	107.81	4.80	8.2	24
CP95188	0.415	R	93.28	11.00	7.8	24
CP95157	0.223	R	90.02	4.50	7.4	20
CP95176	0.128	R	87.72	24.50	7.9	19
CP95127	0.239	R	86.00	4.10	7.9	15
CP95134	0.256	R	83.71	7.60	8.0	16
CP95129	0.217	R	83.02	7.90	8.1	15
CP95147	0.556	R	81.55	3.50	7.5	28
CP95128	0.376	R	79.61	4.70	8.0	14
CP95CB_	0.426	R	74.72	9.50	7.6	7
CP95183	0.261	R	72.08	22.75	7.5	33
CP95ZI_	0.247	R	69.93	17.00	7.8	32
CP95186	0.255	R	64.07	14.50	7.8	25
CP95182	0.386	R	63.78	29.00	7.6	19
CP95177	0.131	R	63.52	25.50	7.7	20
CP95130	0.188	R	60.46	3.30	8.0	22
CP95185	0.369	R	56.62	18.25	8.0	25
CP95PR1	0.429	R	53.63	na	na	na
CP95123	0.345	R	52.54	na	na	na

(Table 4-10 continued)

Station	ΣPC-ERM	Classif.	Growth	Porewater Parameters		
			% Control	NH_4 (mg/L)	pH	Salinity
CP95MI_	0.138	R	41.88	22.00	7.8	32
CP95146	0.262	R	31.69	8.00	7.6	30
CP95108	0.311	R	21.24	17.00	7.8	3
CP95104	0.207	R	17.05	10.25	7.6	1
CP95184	0.406	R	-1.72	36.00	7.8	21
CP95113	0.149	R	-6.52	na	7.4	25
CP95179	0.302	R	-8.51	16.75	7.9	17
CP95RC_	0.215	R	-13.43	29.00	7.4	35
CP95111	0.502	R	-17.98	5.75	7.4	6
CP95105	0.183	R	-25.39	17.75	7.8	4
CP95106	0.344	R	-32.84	9.25	7.8	5
CP95110	0.186	R	-32.91	10.25	7.8	6
CP95155	0.509	E	169.65	na	na	na
CP95163	0.776	E	140.07	11.75	7.8	26
CP95160	0.577	E	134.55	9.50	7.8	28
CP95165	0.812	E	131.48	12.50	7.6	21
CP95173	0.532	E	118.02	11.00	7.6	24
CP95141	0.929	E	113.59	13.50	7.4	34
CP95FOS	0.765	E	106.71	10.75	7.5	18
CP95145	0.825	E	99.63	3.60	7.4	32
CP95168	0.387	E	98.36	8.75	7.6	27
CP95131	0.999	E	96.59	3.10	8.0	20
CP95142	0.559	E	89.58	8.20	7.4	35
CP95101	0.844	E	66.64	9.00	7.1	5
CP95102	0.611	E	62.69	4.75	7.2	6
CP95180	0.608	E	15.71	28.00	7.9	18
CP95178	0.784	E	0.38	120.00	7.8	18
CP95174	2.450	D	175.90	9.25	7.6	22
CP95119	1.031	D	147.22	3.90	7.7	21
CP95166	16.365	D	138.19	9.25	7.7	25
CP95121	2.556	D	135.32	5.50	8.0	13
CP95117	1.470	D	127.33	4.10	8.0	24
CP95154	1.301	D	127.32	6.50	7.8	30
CP95169	13.539	D	116.12	3.25	8.0	29
CP95139	2.099	D	113.91	10.75	7.4	19
CP95KIA	1.092	D	111.35	5.00	7.5	33

(Table 4-10 continued)

Station	ΣPC-ERM	Classif.	Growth	Porewater Parameters		
			% Control	NH_4 (mg/L)	pH	Salinity
CP95151	1.824	D	109.78	6.60	7.6	24
CP95SPY	60.539	D	108.51	4.50	7.6	20
CP95181	1.963	D	103.33	8.90	8.2	19
CP95ASM	2.499	D	101.97	10.50	7.8	20
CP95LON	3.152	D	101.20	1.00	7.3	9
CP95143	1.039	D	98.56	3.20	7.4	34
CP95140	1.323	D	98.05	12.75	7.7	19
CP95116	1.997	D	98.02	5.00	7.8	12
CP95NV2	5.550	D	97.20	9.75	7.6	20
CP95152	5.052	D	96.00	7.60	7.5	24
CP95136	1.754	D	94.08	3.75	7.8	21
CP95NV1	5.864	D	89.71	7.00	7.5	16
CP95DIE	4.578	D	84.86	6.25	7.6	20
CP95164	3.762	D	81.87	7.00	7.7	23
CP95138	7.776	D	80.55	20.50	8.0	19
CP95122	2.160	D	78.71	6.40	8.2	14
CP95NMK	13.501	D	75.41	19.50	6.9	16
CP95175	4.536	D	74.91	31.50	7.6	27
CP95114	1.907	D	70.02	5.40	8.0	10
CP95PR5	2.730	D	67.19	na	na	na
CP95KOP	6.079	D	65.02	14.25	7.3	18
CP95124	1.759	D	62.82	6.10	8.0	15
CP95PR2	1.890	D	62.48	8.25	7.5	14
CP95PR3	2.865	D	61.67	10.75	7.3	13
CP95PR4	2.385	D	58.63	7.50	7.5	13
CP95107	2.282	D	37.18	3.25	7.6	2
CP95171	3.018	D	35.59	12.00	7.3	24
CP95150	1.362	D	27.50	1.50	8.2	3
CP95149	1.493	D	22.74	2.50	7.1	8
CP95172	3.792	D	7.72	24.50	7.1	4
CP95156	1.859	D	-1.69	3.50	6.5	13
CP95109	7.008	D	-8.78	4.75	7.2	4
CP95120	2.878	D	-26.29	4.70	8.1	5
CP95CF_	1.353	D	-26.33	6.75	7.3	20
CP95103	3.511	D	-28.39	3.75	7.5	1

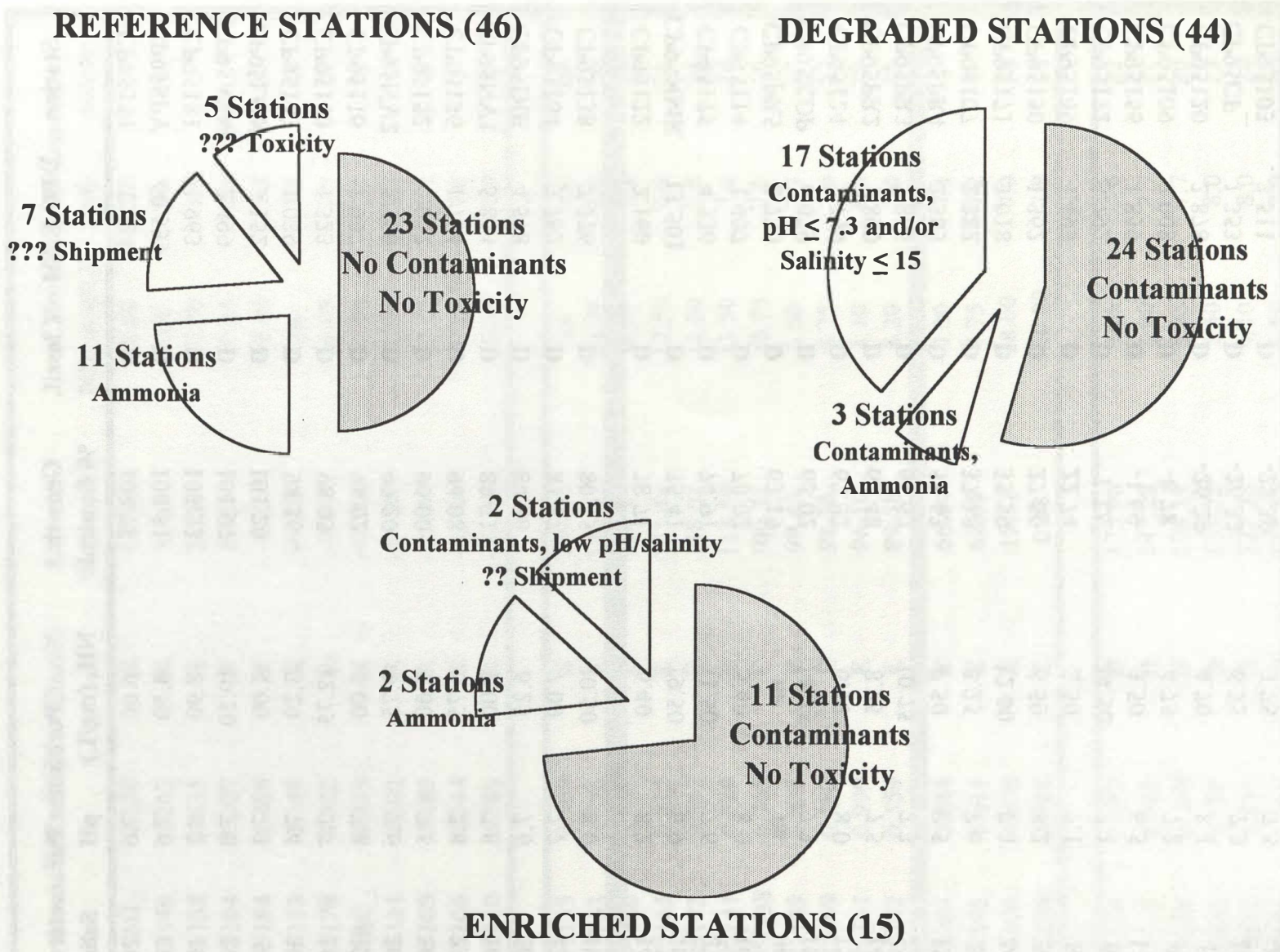

Figure 4-13. Seed clam growth assays for the 3 station classifications. Shaded sections indicate sites with no toxicity; clear sections represent portion of stations that were toxic and their potential causes.

ammonia, which is primarily a problem with sandy sediments, such that sediments that cause toxicity and have ammonia concentrations > 14 - 16 mg/L should be flagged to identify that ammonia may be the causative agent. Integration of other porewater parameters such as pH and salinity may provide valuable information regarding the outcome of the tests, particularly false negatives.

Ampelisca verrilli Feeding-Inhibition Assays

A new candidate indicator that was evaluated during Year 2 Demonstration Project was the *A. verrilli* feeding-inhibition assay. Forty sediment samples, representing both degraded and non-degraded sites, were tested. All assays were completed in eight test series consisting of 2 - 11 test sediments and a sediment control sample obtained from the site where the amphipods were collected. This sublethal assay was designed to evaluate the effects of contaminant exposures on feeding rates.

Mean chlorophyll-a concentrations in the amphipods exposed to 19 of the test samples were less than 80% of the chlorophyll-a concentration in the control samples, but only three of these (CP95103, CP95139, CP95NV2) were also significantly lower (Table 4-11). Among the samples that showed reduced feeding, 9 were chemically degraded, 4 were enriched, and 6 were reference sites. Station CP95178 (the station with very high ammonia concentrations) was so toxic that there was insufficient survival to calculate a feeding endpoint. Excluding this station, 16 of the 29 samples that were chemically degraded or enriched resulted in chlorophyll-a uptake of > 80% of the control (false negative).

The three sediment samples that caused the greatest decrease in feeding rates as indicated by chlorophyll-a concentrations ($p<0.05$ and <80% of control) were classified as degraded based on elevated contaminant levels, and one sample (CP95103) resulted in significant mortality for this species in the 10-day acute toxicity assay (Table 4-4). Stations CP95139 and CP95NV2, while not toxic in the acute assays, were considered toxic based on the Microtox assay but not toxic for the seed clam assay. In the majority of tests where feeding was reduced but there was no statistical difference, we noted that sample variances among the replicates were very high relative to the means. Further analysis of this subset of data indicated that the average power to detect differences (beta) was only 0.4 which substantially reduced our ability to distinguish statistical differences among the test versus control samples. Modifications that could reduce the variances include: increasing the number of replicates per treatment, increasing the number of animals per beaker, and better standardization of the extraction procedure by switching to an electric grinder. Despite the variance problem, this assay showed evidence of being more sensitive than the ten-day acute assay, and shows promise as a method for further development.

Table 4-11. Results of *Ampelisca verrilli* feeding bioassays on selected core and supplemental stations sampled during the Year Two Demonstration Project in the Carolinian Province, summer 1995. The assimilation of chlorophyll is expressed as µg chl-a/mg tissue wet weight and as percent control.

Station	Classif.	Test Date	Survival % Control	Mean chl-a (µg/mg)	Std. Dev.	Chl-a (% control)	p value
FOL950818		950818	86.7	33.3	8.3		
CP95120	D	950818	92.6	43.2	13.1	129.8	0.33
CP95121	D	950818	92.6	49.5	9.5	148.7	0.09
CP95122	D	950818	105.6	37.5	11.9	112.7	0.66
FOL950825		950825		45.9	1.9		
CP95179	R	950825	96.6	39.1	3.4	85.1	0.04
CP95178	E	950825	0.0	----	----	----	----
FOL950921		950921		32.3	8.7		
CP95MI	R	950921	90.0	49.1	8.9	151.9	0.08
CP95152	D	950921	121.7	40.2	14.5	124.4	0.47
CP95154	D	950921	117.4	49.7	21.8	153.8	0.27
CP95171	D	950921	104.3	63.7	16.3	197.1	0.04
FOL951006		951006		41.1	14.2		
CP95108	R	951006	96.6	38.6	4.5	93.9	0.79
CP95103	D	951006	89.7	12.4	9.0	30.1	0.04
CP95107	D	951006	100.0	18.9	17.5	46.1	0.16
CP95151	D	951006	82.8	32.5	11.1	79.1	0.16
FOL951013		951013		20.8	8.5		
CP95146	R	951013	103.6	9.2	3.6	44.4	0.10
CP95147	R	951013	103.6	10.4	4.8	50.0	0.14
CP95161	R	951013	82.1	11.2	10.5	54.1	0.29
CP95167	R	951013	107.1	15.8	13.5	76.1	0.62
CP95182	R	951013	96.4	12.7	5.2	61.0	0.23
CP95188	R	951013	92.9	9.2	5.2	44.4	0.12
CP95160	E	951013	96.4	18.9	7.1	90.9	0.78
CP95163	E	951013	100.0	16.0	7.9	76.8	0.51
CP95139	D	951013	100.0	4.0	0.6	19.4	0.03
CP95166	D	951013	103.6	15.2	8.3	73.3	0.47
CP95169	D	951013	80.4	15.9	5.5	76.6	0.45
FOL951020		951020		39.3	19.3		
CP95165	E	951020	108.3	29.1	0.9	73.9	0.41
CP95168	E	951020	104.2	27.4	3.4	69.7	0.35
CP95DIE	D	951020	112.5	43.9	14.1	111.7	0.76
CP95KOP	D	951020	100.0	50.9	2.8	129.3	0.37
CP95NMK	D	951020	113.0	39.7	6.6	101.0	0.98
CP95PR2	D	951020	96.6	33.7	5.2	85.6	0.65
CP95PR3	D	951020	116.7	13.2	4.3	33.5	0.08
CP95PR4	D	951020	116.7	27.9	9.6	71.0	0.41
CP95SPY	D	951020	112.5	36.2	4.0	92.0	0.80
FOL951027		951027		27.1	1.1		
CP95FOS	E	951027	100.0	20.9	4.2	77.2	0.07
CP95ASM	D	951027	89.7	27.8	8.2	102.6	0.89
CP95KIA	D	951027	96.6	30.8	12.3	113.7	0.63
CP95NV1	D	951027	116.7	22.5	2.2	82.8	0.03
CP95NV2	D	951027	93.1	16.5	4.3	60.7	0.01
FOL951103		951103		24.4	2.0		
CP95ZI	R	951103	116.7	21.0	3.5	85.9	0.21
CP95LNG	D	951103	80.0	23.5	3.7	96.1	0.72

Oyster Fertilization Assay

Another candidate indicator that was evaluated during 1995 was the oyster fertilization assay. Adapted from the sea urchin fertilization assay, this is a short-term assay in which the fertilization success of the gametes is determined after the sperm are pre-incubated with test waters or sediments. Four modes of exposure were used: water only exposures, direct sediment exposures in small beakers (Method A), direct sediment exposures in tubes (Method B), seawater extracts of sediments (Method C). Numerous experiments using the fertilization test were conducted, most of which are listed in Table 4-12. However, tests with control fertilization rates less than 50% should be ruled invalid, so most of these experiments would not be regarded as valid tests.

Although the fertilization assay has been used as a liquid-phase test, we had explored the possibility of using a whole sediment assay over the last couple of years, conducting a few tests using a basic approach of placing a nylon screen on top of settled sediments to facilitate the retrieval of the embryos. We had also conducted some experiments to determine the optimum sperm to egg ratio, found to be 100:1 for *Crassostrea virginica*. This ratio was the same as that found for another bivalve species, and substantially lower than the ratio typically required for effective fertilization in sea urchin species (Ringwood, 1992). The results of the primary test of these techniques associated with the present studies (conducted 6/13/95 using Method A) was successful, suggesting that the assay could be conducted using this method. Fertilization in the sediment controls was as successful as the water controls, and 2 of the 3 degraded sediments caused significant decreases in fertilization (Figure 4-14). The metal exposure studies (water tests) conducted during the month of June were also successful. We therefore believed that we had established the definitive protocols and were ready to proceed with the tests using EMAP sediments.

However, all tests conducted during July and most of August were not successful. Since the sperm:egg ratio can be a critical detail that affects the success of the test, this issue was re-evaluated (7/26/95, 7/27/95, 8/23/95). Although fertilization rates in some of these experiments were low, sperm to egg ratios greater than 100 did not result in increases in fertilization rates. Therefore, low gamete viability rather than the sperm:egg ratio was believed to be the primary problem. Gamete viability was highest during months that represent peak spawning periods (major spawning in spring, and typically another, less significant fall spawning). The effects of gamete viability on the success of the assay using sea urchin gametes has been documented (Ringwood, 1992), and similar problems were encountered with bivalve gametes in these studies.

The experiments conducted on 8/23/95 indicated that fertilization may be more successful in tubes rather than beakers, and that even control sediments could reduce fertilization rates, suggesting that inherent sediment effects may preclude the use of whole sediment fertilization tests. Therefore we switched to using Method B, and also tested seawater extracts of sediments (Method C). A simple sediment extraction approach was tested in which 1 g of test sediments was incubated with 10 ml seawater for 24 hr, and the

Table 4-12. Summary of oyster fertilization assays conducted as part EMAP studies in the Carolinian Province, summer 1995. Four methods of exposure were used: water only; direct sediment exposures in 20 ml beakers (A); direct sediment exposures in 12 ml test tubes (B); seawater extracts of sediments (C).

Date	Method of Exposure	Description	Control Fertilization (%) Water	Sediment
6/13/95	Sediments (A)	5 Field Sites	98.2	94.8
6/19/95	Water	Metal Exposures, tubes Cd (125-2000 ppb), Cu (31.25-500 ppb);	90.9	
6/27/95	Water	Metal Exposures, tubes Cu (20-200 ppb)	90.3	
7/10/95	Sediments (A)	Metal-spiked Sediment Exposures Cu (20-200 ppb), Zn (50-2000 ppb)		0
7/18/95	Water	Metal Exposures, tubes Zn (125-2000 ppb), Cu (12.5-200 ppb)	< 10	
7/20/95	Water	Metal Exposures, tubes Zn (50-2000 ppb), Cu (12.5-200 ppb)	< 10	
7/25/95	Water	Metal Exposures, tubes Zn (50-2000 ppb), Cu (12.5-200 ppb)	10	
7/26/95	Water	Re-evaluated sperm/egg (S:E) ratio, tubes S:E Ratios: 4 treatments (48:1 to 2375:1)	35.4	
7/27/95	Water	Re-evaluated sperm/egg (S:E) ratio, tubes S:E Ratios: 5 treatments (50:1 to 250:1)	45	
7/28/95	Water	Metal Exposures, tubes Cu (12.5-200 ppb)	< 10	
8/10/95	Water	Metal Exposures, tubes Zn (50-2000 ppb), Cu (12.5-200 ppb)	94.2	
8/16/95	Water Sediments (A)	Metal Exposures, tubes Cu (6.25-50 ppb), Zn (500-2000 ppb) EMAP Sites (10)	96.1	14
8/23/95	Water Water or Sediments (A)	S:E Ratios, Compared tubes vs beakers Compared water vs sediments (beakers) (no toxins in any treatments)	87 (tubes) 54 (beakers)	38 (beakers)
8/24/95	Water Sediments (B)	Metal Exposures, water, tubes Cu (5-80 ppb), Zn (500-1500 ppb) EMAP Sites (12)	0	0

(Table 4-12 continued)

Date	Method of Exposure	Description	Control Fertilization (%) Water	Sediment
8/30/95	Water	Metal Exposures, water, tubes Zn (500-1500 ppb), Cu (5-80 ppb)	Oysters not ripe, no gametes	
9/6/95	Water	Metal Exposures, water, tubes Cu (5-80 ppb), Zn (500-1500 ppb)	96.9	
	Sediments (B)	EMAP Sites (10)		48.1
9/13/95	Water	Metal Exposures, water, tubes Cu (5-80 ppb), Zn (500-1500 ppb)	42	
	Sediments (B)	EMAP Sites (5)		13
	Sediments (C)	EMAP Sites (5)		29.2
10/5/95	Water	Metal Exposures, water, tubes Cu (5-80 ppb), Zn (500-1500 ppb)	29.5	
	Sediments (C)	EMAP Sites (10)		74.2
10/11/95	Water	Metal Exposures, water, tubes Cu (5-80 ppb), Zn (500-1500 ppb)	< 10	
	Sediments (C)	EMAP Sites (13)		< 10

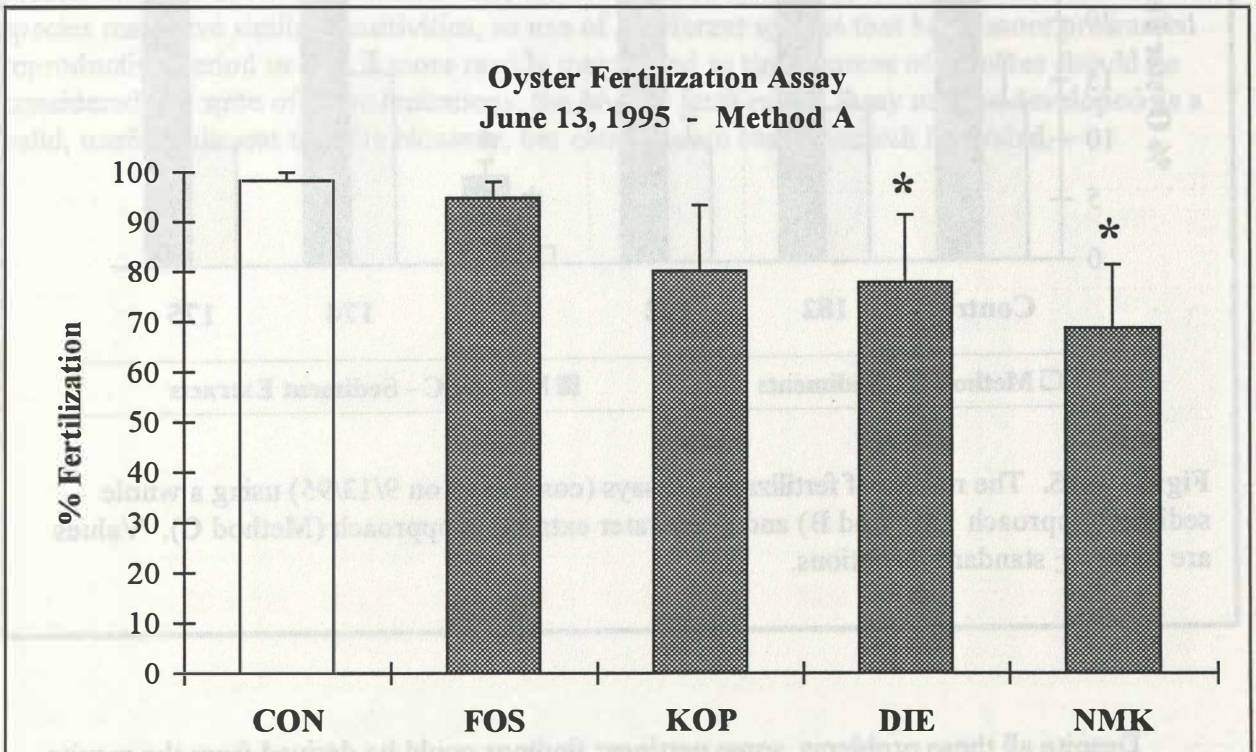

Figure 4-14. Oyster fertilization assays conducted on June 13, 1995 using Method A. CON indicates water only exposures, and FOS was used as the control sediments. KOP, DIE, and NMK were degraded sites. Values are mean fertilization rates + standard deviations (n=5).

supernatants (i.e., seawater extracts) were then used to evaluate fertilization success. Methods B and C were compared on a subset of samples and the results are shown in Figure 4-15. Generally fertilization was higher in sediment-free preparations (Method C), but the interpretation of the results would have been the same, i.e., significant toxicity was observed with sediments or seawater extracts of sediments for one degraded site. Using a non-solvent extraction method like the one used here may provide a good media for detecting the effects of labile contaminant components that may be mobilized from sediments. Note, however, that the actual fertilization rates are shown in Figure 4-15, and that the maximal fertilization rates were < 40%. Experiments with acceptable rates are needed before any conclusive statements about the relative merits of the two methods can be made.

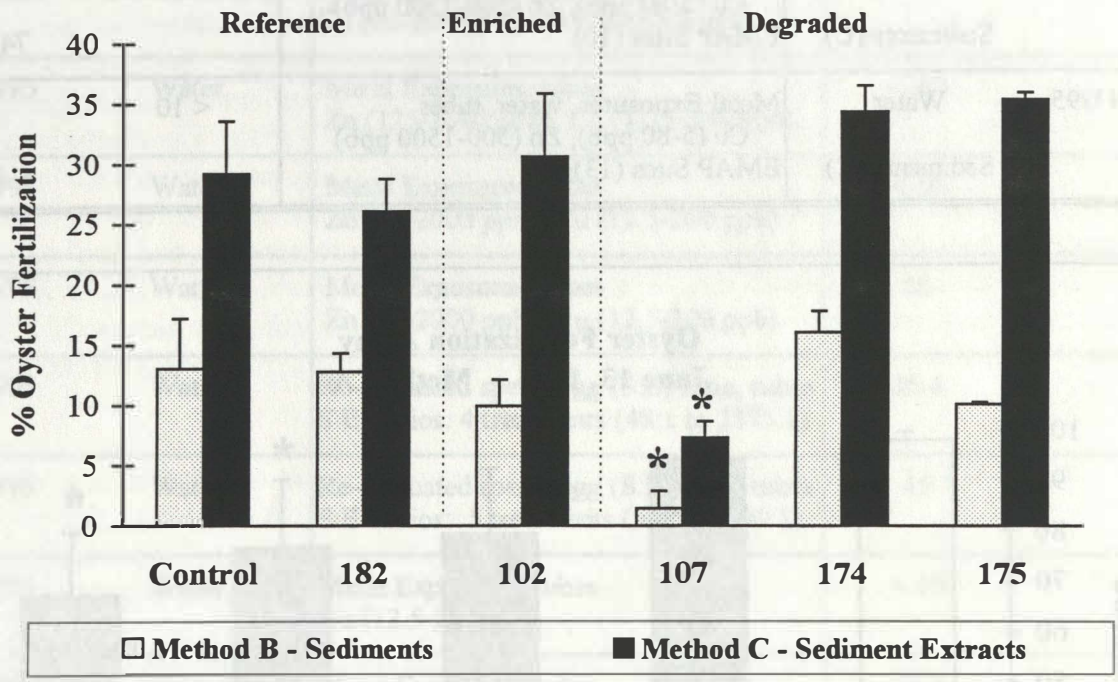

Figure 4-15. The results of fertilization assays (conducted on 9/13/95) using a whole sediment approach (Method B) and a seawater extraction approach (Method C). Values are means ± standard deviations.

Despite all these problems, some pertinent findings could be derived from the results. There were 5 tests in which metal exposures (water only) were valid (i.e., control fertilization ≥ 50%). The results of Cu and Zn exposures are shown in Figure 4-16. Four of the five Cu experiments yielded similar results, indicating that *C. virginica* gametes were similarly

sensitive to another bivalve species (*Isognomon californicum*, NOEC Cu = 20 ug/L). The Cu NOEC for sea urchin gametes is approximately 5.0 ug/L (Dinnel et al., 1989; Ringwood, 1992), indicating that bivalve gametes are slightly less sensitive than sea urchin gametes. One of the concerns regarding the sea urchin test is that it is hyper-sensitive. Bivalve embryos may function as a more suitable test species that is sufficiently sensitive to contaminant stress without being overly sensitive.

Six series of experments were conducted with EMAP sediments (8/16, 8/24, 9/6, 9/13, 10/5, 10/11). The only valid set (i.e. control fertilization > 50%) was conducted on 10/5, although the 9/6 tests were almost acceptable (control fertilization was 48.1%). The results of these two series of experiments using EMAP sediments (expressed as % of Controls) are shown in Figures 4-17 and 4-18. The results do indicate that significant toxicity was more frequently observed with sediments from degraded sites. When all of the results shown in Figures 4-15, -17, and -18 are considered, toxicity was observed at only 1 out of 14 reference sites, no enriched sites, and 4 out of 10 degraded sites.

The problems with the oyster fertilization assay preclude any definitive statements regarding its utility as a sediment bioassay. Gamete viability problems that occurred during non-peak spawning periods indicate that careful manipulation and conditioning of broodstock are important optimization components. There was evidence that seawater extracts could yield results similar to whole sediment assays, and overall fertilization rates tended to be greater with the seawater extracts. The metal exposure studies indicated that different bivalve species may have similar sensitivities, so use of a different species that has a more protracted reproductive period or that is more readily maintained as ripe sources of gametes should be considered. In spite of these limitations, the bivalve fertilization assay may be developed as a valid, useful sediment toxicity bioassay, but clearly more basic research is needed.

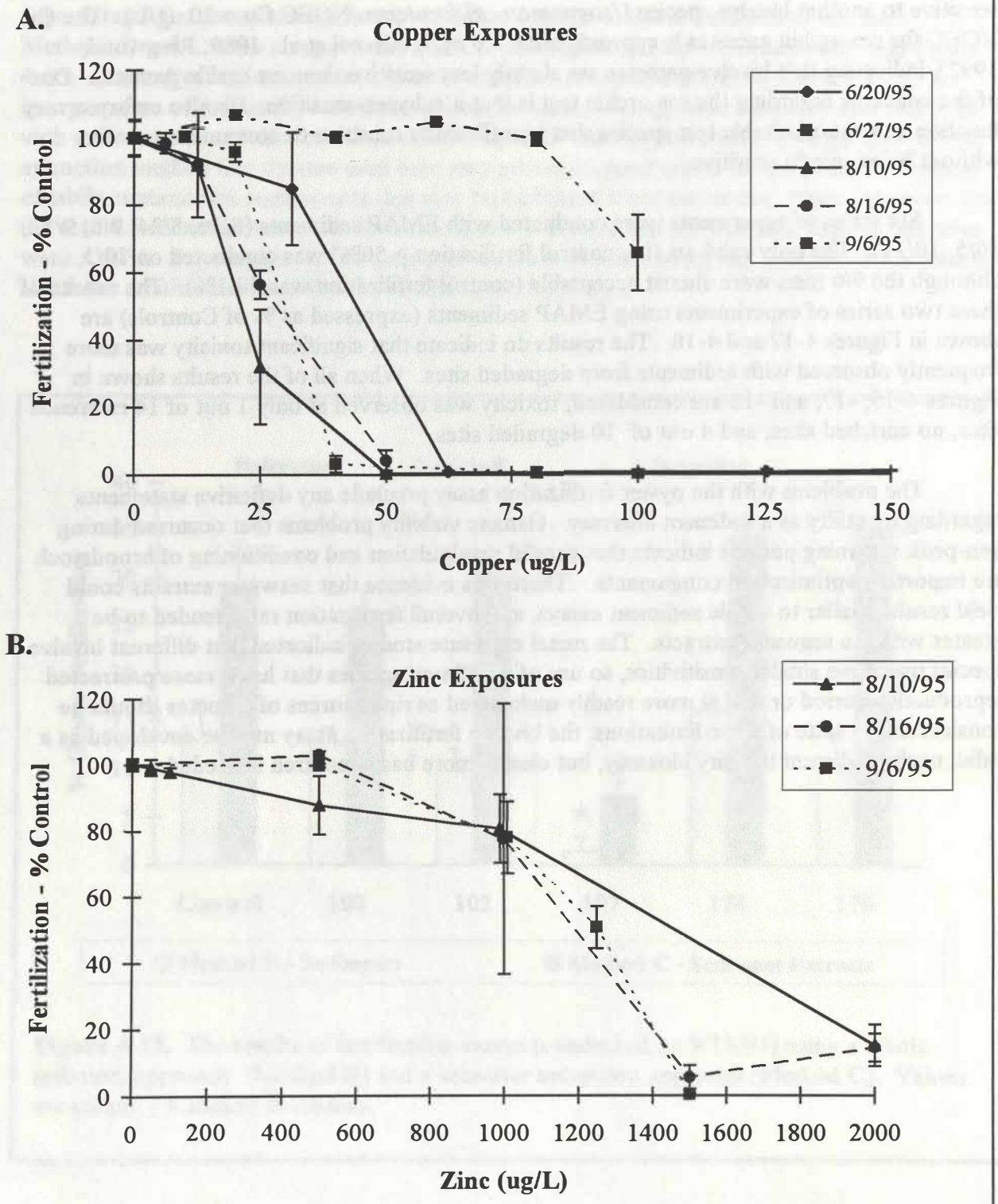

Figure 4-16. The effects of copper **(A)** and zinc **(B)** exposures on fertilization rates in *Crassostrea virginica*. All experiments were water only exposures. Values are means ± standard deviations

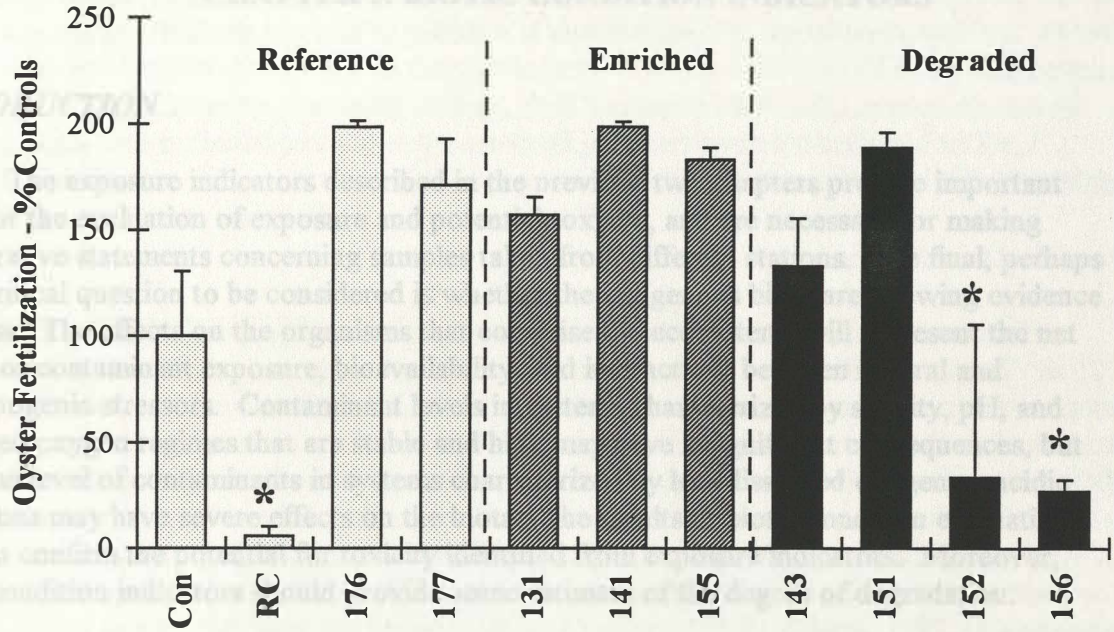

Figure 4-17. Fertilization assays conducted with EMAP sediments on 9/6/95. Method B was used, and results are expressed as % of Controls (means ± standard deviations).

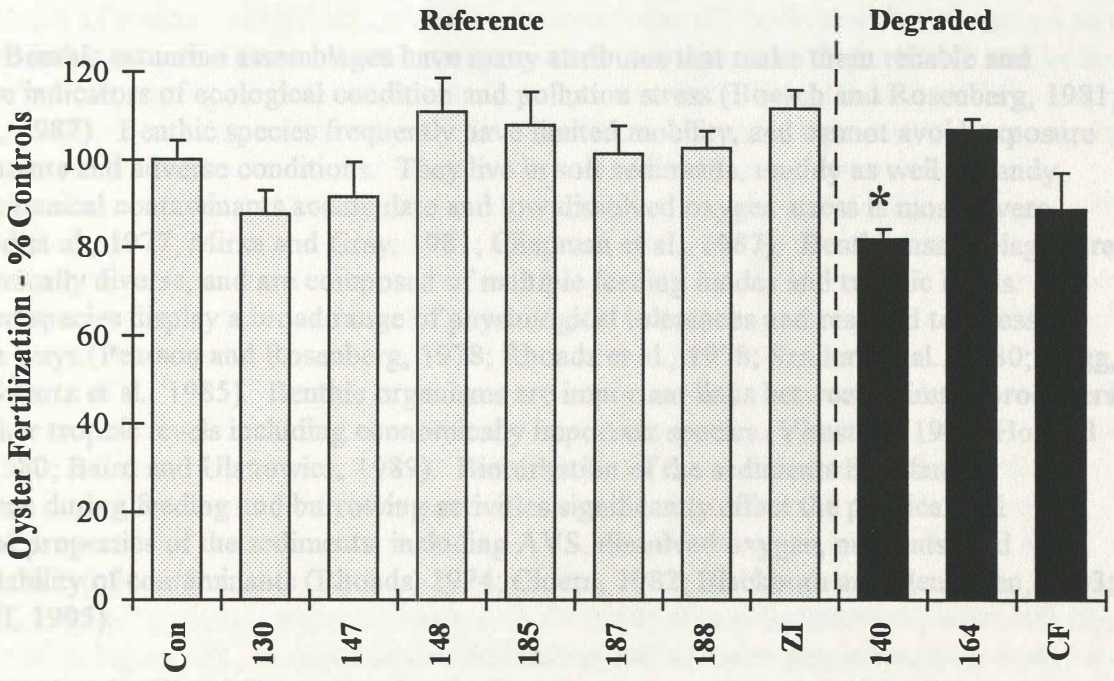

Figure 4-18. Fertilization assays conducted with EMAP sediments on 10/5/95. Method C was used, and results are expressed as % of Controls (means ± standard deviations).

CHAPTER 5. BIOTIC CONDITION INDICATORS

INTRODUCTION

The exposure indicators described in the previous two chapters provide important tools for the evaluation of exposure and potential toxicity, and are necessary for making comparative statements concerning samples taken from different stations. The final, perhaps most critical question to be considered is whether the indigenous biota are showing evidence of stress. The effects on the organisms that comprise the ecosystems will represent the net results of contaminant exposure, bioavailability, and interactions between natural and anthropogenic stressors. Contaminant levels in systems characterized by salinity, pH, and dissolved oxygen regimes that are stable and high may have insignificant consequences, but the same level of contaminants in systems characterized by low dissolved oxygen or acidic conditions may have severe effects on the biota. The results of biotic condition evaluations serve to confirm the potential for toxicity identified from exposure indicators. Moreover, biotic condition indicators should provide some estimate of the degree of degradation.

Indicators of biotic condition should reflect the response of the organisms to environmental perturbation. These indicators include measurements of the kinds and abundances of the biota present, as well as their health and condition. Environmental perturbations may affect the biota in a variety of ways, ranging from no effects to severe acute effects and an extremely depauperate community, characterized by severe reductions in numbers of species and/or abundances.

Benthic estuarine assemblages have many attributes that make them reliable and sensitive indicators of ecological condition and pollution stress (Boesch and Rosenberg, 1981; Bilyard, 1987). Benthic species frequently have limited mobility, and cannot avoid exposure to pollutants and adverse conditions. They live in soft sediments, muddy as well as sandy, where chemical contaminants accumulate and low dissolved oxygen stress is most severe (Holland et al., 1977; Mirza and Gray, 1981; Chapman et al., 1987). Benthic assemblages are taxonomically diverse, and are composed of multiple feeding modes and trophic levels. Different species display a broad range of physiological tolerances and respond to stress in variable ways (Pearson and Rosenberg, 1978; Rhoads et al., 1978; Sanders et al., 1980; Rygg, 1986; Swartz et al., 1985). Benthic organisms are important links between primary producers and higher trophic levels including economically important species (Virnstein, 1977; Holland et al., 1980; Baird and Ulanowicz, 1989). Bioturbation of the sediments by infaunal organisms during feeding and burrowing activities significantly affect the physical and chemical properties of the sediments, including AVS, dissolved oxygen, nutrients, and bioavailability of contaminants (Rhoads, 1974; Cloern, 1982; Blackburn and Henriksen, 1983; Matisoff, 1995).

During the Year 2 Demonstration Project, data were collected on four different types of biotic condition indicators: benthic assemblages, fish and shellfish assemblages, incidence of pathologies, and bioaccumulation of contaminants. This chapter contains the results of the

benthic and trawl studies for South Carolina and Georgia stations. The analyses of tissues for data on the bioaccumulation of contaminants in a subset of fish and shellfish has not yet been completed.

METHODS

Benthic Assemblages

Bottom samples for the benthic species community indicators were obtained using a 1/25 m^2 Young-modified Van Veen grab sampler. The sediment and other material in the sample were sieved on a 0.5-mm screen while in the field, and the sieving process was conducted so that water was introduced from the bottom of the sieve to avoid damaging soft-bodied organisms. Material collected on the screen was preserved in 10% buffered formalin-rose bengal solution and stored in Nalgene polypropylene containers. Four grabs were collected and processed in the field. All four replicates were sorted in the laboratory, and Replicates 1 and 2 were identified to the lowest taxonomic level; the other 2 sorted replicates were archived.

Fish and Shellfish Assemblages

Fish and shellfish were collected using standard EMAP 16 ft high-rise trawl nets (nets were not outfitted with liners or tickler chains). Two 10-minute trawls were conducted at each station. The contents of the net were sorted and identified, and measured to the nearest millimeter. When a species was present in very high numbers, a subsample of at least 30 individuals was measured. The following species were identified as target species, i.e., priority species that required special processing when they were encountered in the trawls:

Scientific Name	Common Name
Callinectes sapidus	Blue crab
Penaeus aztecus	Brown shrimp
Penaeus setiferus	White shrimp
Micropogonias undulatus	Atlantic croaker
Leiostomus xanthurus	Spot
Stellifer lanceolatus	Star drum
Bagre marinus	Gafftopsail catfish
Trinectes maculatus	Hogchoker

Individuals with pathologies, and samples of target species coded as reference pathologies were fixed and processed as described below. Samples of 3 target species (*P. setiferus, M. undulatus, C. sapidus*) were frozen for bioaccumulation analyses.

Incidence of Pathologies

Fish and crustaceans caught in the trawls were examined for evidence of gross external pathologies (lumps, tumors, abscesses for fish; shell disease in blue crabs; cotton disease in shrimp). Fish with potential pathologies were fixed in Dietrichs and transferred to Dr. J. Fournie, Gulf Breeze, EPA. Crabs and shrimp were fixed in 10% formalin, and transferred to Dr. E. Noga, NC State University.

RESULTS AND DISCUSSION

Benthic Assemblages

Benthic species composition and abundance have been used to measure the status and trends of estuaries for several decades (Sanders, 1956; Rosenberg, 1976; Boesch, 1973; Pearson and Rosenberg, 1978; Boesch and Rosenberg, 1981; Holland et al., 1987), and many attempts have been made to identify characteristics of benthic assemblages that represent environmental quality and have broad applicability (Sanders, 1968; Grizzle, 1984; Warwick, 1986). Previously proposed measures include: (1) biodiversity and species richness, (2) species composition, (3) changes in the relative abundance and productivity of functional groups, (4) changes in the relative abundance and productivity of "key" species, (5) changes in biomass, and (6) changes in the relative size of biota. In other EMAP provinces, multiple benthic attributes have been used in multivariate techniques to develop a benthic index, and this approach is also being used in the Carolinian Province. A major limitation to the development of national and regional scale environmental quality indicators based upon estuarine benthic communities is that natural variations in environmental conditions can have major effects on abundance and distributional patterns (Carriker, 1967; Rhoads, 1974). Salinity, sediment characteristics, and latitudinal gradients are particularly important environmental factors known to have major effects on benthic species composition and abundance (Carriker, 1967; Gosner, 1971; Boesch, 1977; Holland et al., 1987). Development of a benthic index (including approaches to minimize the effects of natural variables) represents work that is being conducted at the province-wide level by the CPO. The results of benthic studies with samples from SC and GA sites are limited to simple summaries of diversity and abundance.

The numbers of species for the SC and GA sites are listed in Table 5-1, and plotted in Figure 5-1 by station classification (Reference, Enriched, Degraded) based on contaminant data as described in Chapter 3. The mean numbers of species over the 8 reference sites, 6 enriched sites, and 16 degraded sites were 24, 27.5, and 14.2 respectively. Twelve of the sixteen degraded stations had < 20 total species in the 2 grab replicates, as did 3 of the 6 enriched sites and 4 of the 8 reference sites. The abundance data are also listed in Table 5-1 and plotted in Figure 5-2. In general, the trends observed with the abundance data were similar to those noted for the numbers of species. Most stations characterized by low diversity also had low abundances. The mean abundances for the reference, enriched, and

Table 5-1. Summary of benthic communities sampled during Year 2 Demonstration Project in the Carolinian Province, summer 1995.

Site	Class	# Species			Abundance			Most Common Species
		Rep 1	Rep 2	TOTAL	Rep 1	Rep 2	TOTAL	
153	R	29	34	42	186	328	514	*Streblospio benedicti*
157	R	9	9	18	21	21	42	*Aricidea wassi*
158	R	35	16	40	362	46	408	*Streblospio benedicti*
159	R	6	11	17	12	40	52	*Aricidea wassi*
161	R	21	11	26	202	484	686	*Oligochaeta unid.*
162	R	4	3	5	12	10	22	*Oligochaeta unid.*
167	R	14	11	19	131	133	264	*Scoloplos rubra*
LTH	R	13	22	25	40	283	323	*Monticellina dorsobranchialis*
155	E	11	18	25	62	114	176	*Nematoda unid.*
160	E	42	28	56	209	98	307	*Scoloplos rubra*
163	E	47	28	57	504	392	896	*Streblospio benedicti*
165	E	5	3	8	10	5	15	*Oligochaeta unid.*
168	E	5	7	10	7	13	20	*Oligochaeta unid.*
FOS	E	5	8	9	109	73	182	*Streblospio benedicti*
149	D	6	1	6	13	1	14	*Oligochaeta unid.*
150	D	5	5	7	19	20	39	*Oligochaeta unid.*
151	D	33	15	36	138	33	171	*Neanthes succinea*
152	D	17	8	20	48	9	57	*Streblospio benedicti*
154	D	19	18	28	57	56	113	*Streblospio benedicti*
156	D	3	2	3	14	13	27	*Oligochaeta unid.*
164	D	7	11	13	8	17	25	*Aricidea wassi*
166	D	7	7	11	51	36	87	*Paraprionospio pinnata*
169	D	10	48	54	16	279	295	*Sphenia antillensis*
ASM	D	7	4	9	17	22	39	*Streblospio benedicti*
DIE	D	4	1	4	7	2	9	*Streblospio benedicti*
KOP	D	2	2	3	12	8	20	*Paraprionospio pinnata*
NMK	D	2	2	3	44	10	54	*Streblospio benedicti*
NV1	D	8	8	10	34	12	46	*Heteromastus filiformis*
NV2	D	3	6	7	7	15	22	*Paraprionospio pinnata*
SPY	D	13	7	13	232	201	433	*Heteromastus filiformis*

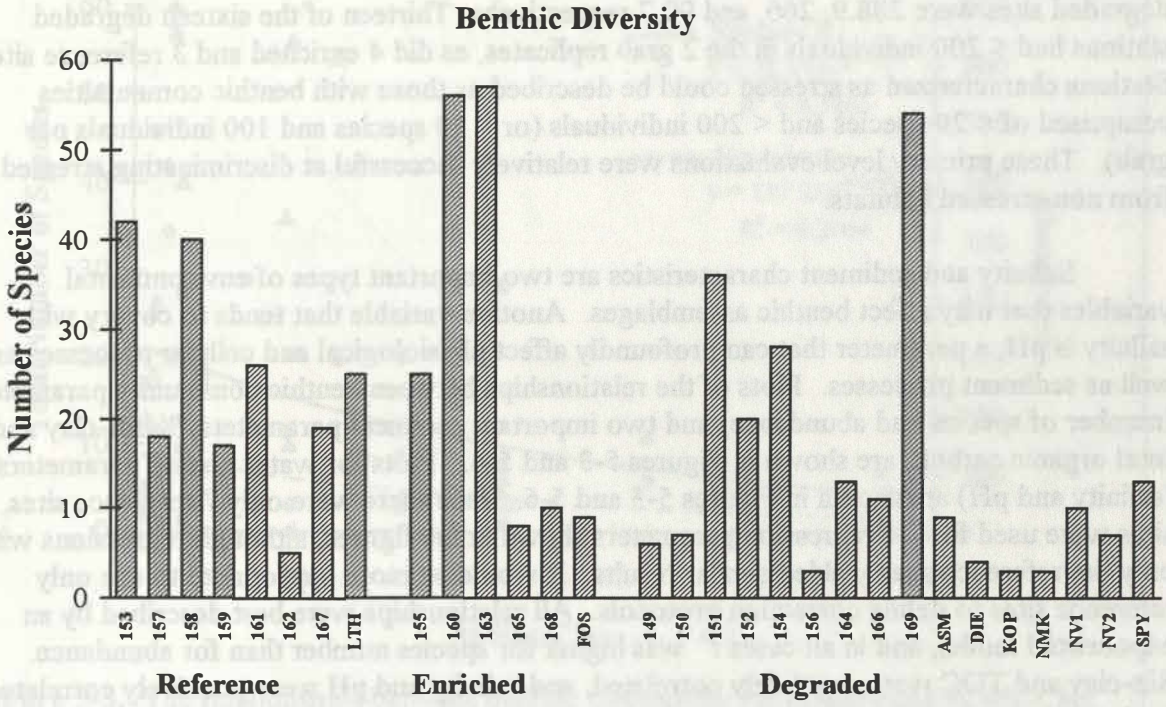

Figure 5-1. Total number of species found in 2 grab samples taken at SC and GA stations during Year 2 Demonstration Project in the Carolinian Province, summer 1995.

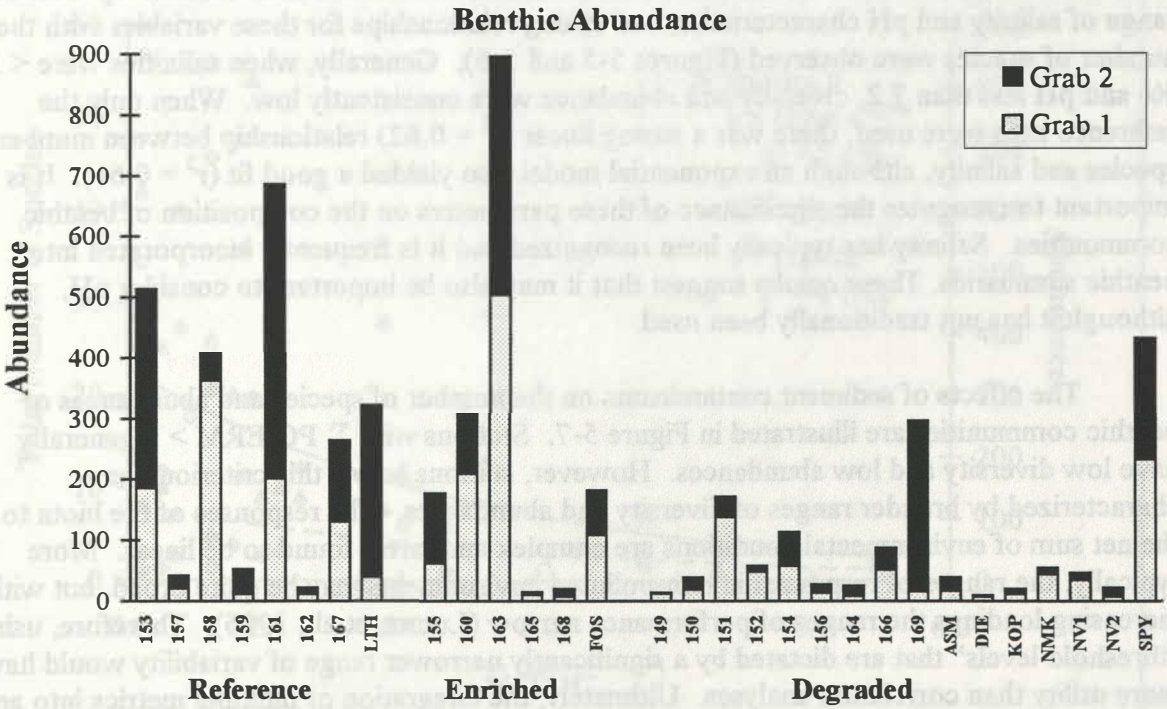

Figure 5-2. Number of individuals found in 2 replicate grab samples taken at SC and GA stations during Year 2 Demonstration Project in the Carolinian Province, summer 1995.

degraded sites were 288.9, 266, and 90.7 respectively. Thirteen of the sixteen degraded stations had < 200 individuals in the 2 grab replicates, as did 4 enriched and 3 reference sites. Stations characterized as stressed could be described as those with benthic communities comprised of < 20 species and < 200 individuals (or < 10 species and 100 individuals per grab). These primary level evaluations were relatively successful at discriminating stressed from non-stressed habitats.

Salinity and sediment characteristics are two important types of environmental variables that may affect benthic assemblages. Another variable that tends to covary with salinity is pH, a parameter that can profoundly affect physiological and cellular processes as well as sediment processes. Plots of the relationships between benthic community parameters (number of species and abundance) and two important sediment parameters, % silt-clay and % total organic carbon, are shown in Figures 5-3 and 5-4. Plots for water quality parameters (salinity and pH) are shown in Figures 5-5 and 5-6. Since there were only 7 reference sites, all sites were used for the regression parameters shown in the figures, although regressions with only the reference sites yielded similar results. It would be more appropriate to use only reference sites to define correction protocols. All relationships were best described by an exponential model, and in all cases r^2 was higher for species number than for abundance. Silt-clay and TOC were negatively correlated, and salinity and pH were positively correlated. In these plots, the reference sites are plotted using open symbols, and solid symbols are used for the enriched and degraded sites. For the sediment parameters (Figures 5-3 and 5-4), the reference sites (characterized by low % silt-clay and low TOC) tended to cluster together. It may be difficult to correct for these parameters because contaminant loads also tend to covary with % silt-clay and TOC. On the other hand, reference sites were characterized by a broader range of salinity and pH characteristics, and strong relationships for these variables with the number of species were observed (Figures 5-5 and 5-6). Generally, when salinities were < 14 ‰ and pH less than 7.2, diversity and abundance were consistently low. When only the reference sites were used, there was a strong linear ($r^2 = 0.62$) relationship between number of species and salinity, although an exponential model also yielded a good fit ($r^2 = 0.61$). It is important to recognize the significance of these parameters on the composition of benthic communities. Salinity has typically been recognized and it is frequently incorporated into benthic summaries. These results suggest that it may also be important to consider pH, although it has not traditionally been used.

The effects of sediment contaminants on the number of species and abundances of benthic communities are illustrated in Figure 5-7. Stations with Σ PC-ERM > 1 generally have low diversity and low abundances. However, stations below this criterion were characterized by broader ranges of diversity and abundances. The responses of the biota to the net sum of environmental conditions are complex and rarely found to be linear. More typically, the ranges of responses in non-polluted environments may be quite broad, but with increasing loadings the ranges of performance narrow (Luoma et al., 1996). Therefore, using "threshold levels" that are dictated by a significantly narrower range of variability would have more utility than correlation analyses. Ultimately, the integration of multiple metrics into an overall benthic index (currently under development by the CPO) should provide better measures of benthic community responses to habitat conditions.

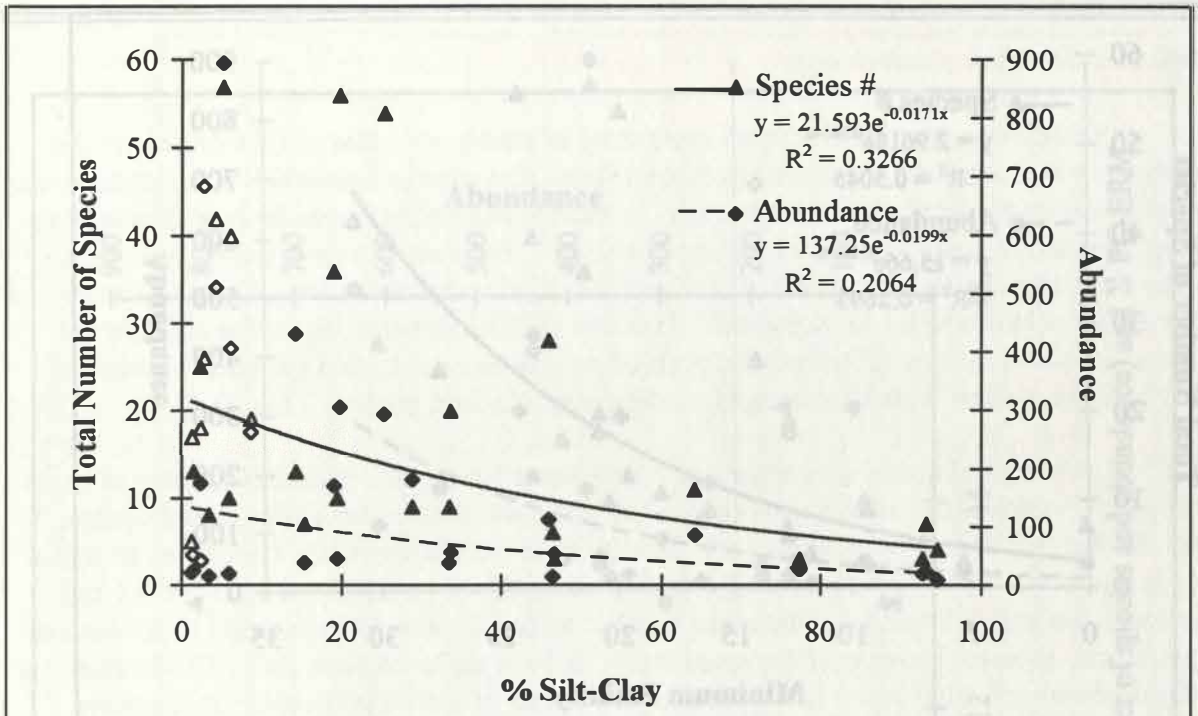

Figure 5-3. The relationships between benthic community parameters and % Silt-Clay. Reference sites are plotted with open symbols, and degraded and enriched sites are plotted with solid symbols.

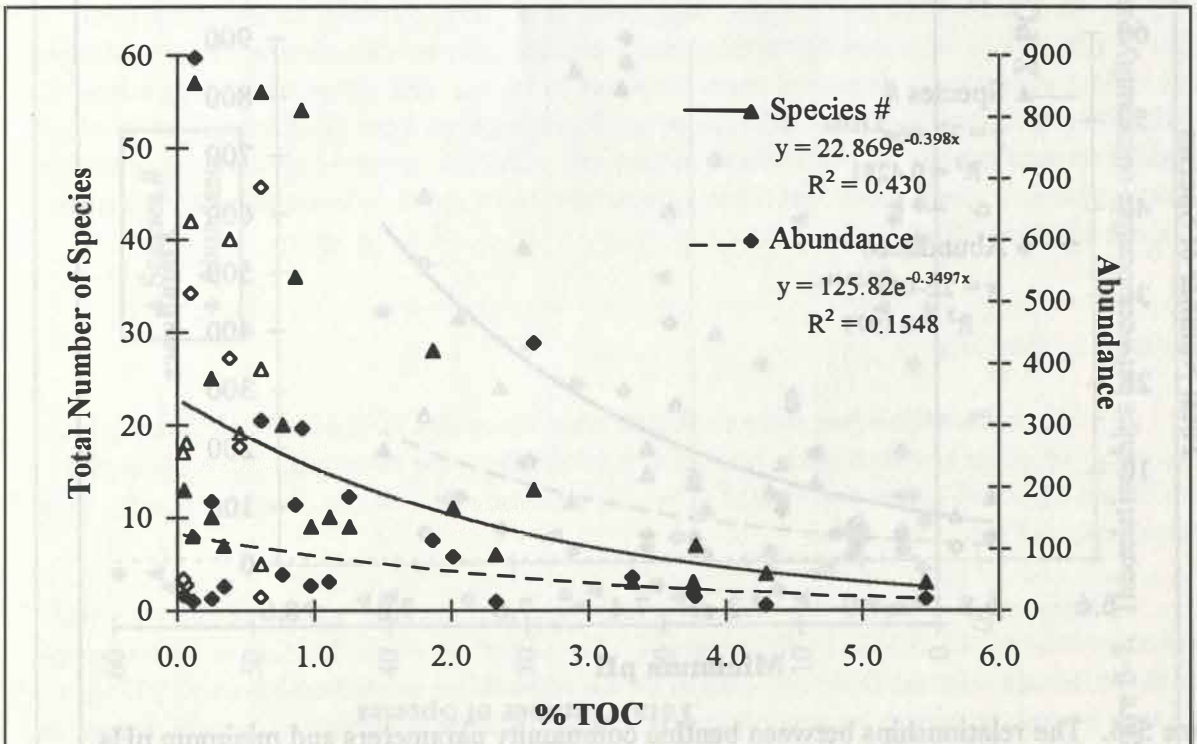

Figure 5-4. The relationships between benthic community parameters and % total organic carbon (TOC). Reference sites are plotted with open symbols, and degraded and enriched sites are plotted with solid symbols.

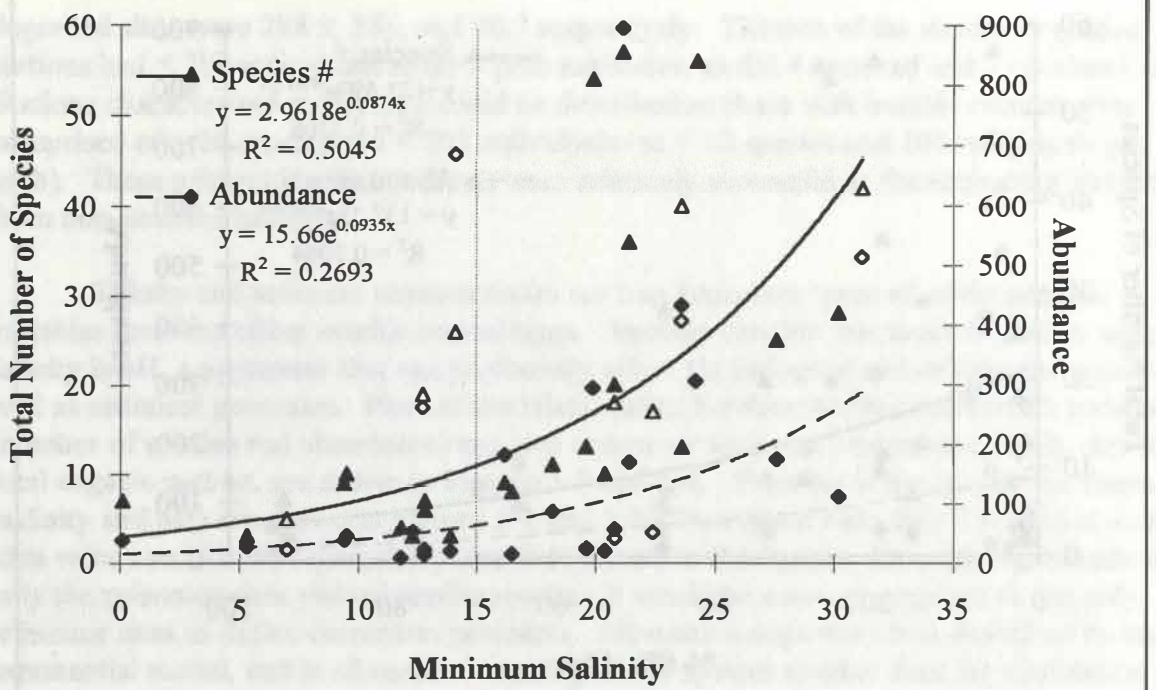

Figure 5-5. The relationships between benthic community parameters and minimum salinities. Reference sites are plotted with open symbols, and degraded and enriched sites are plotted with solid symbols.

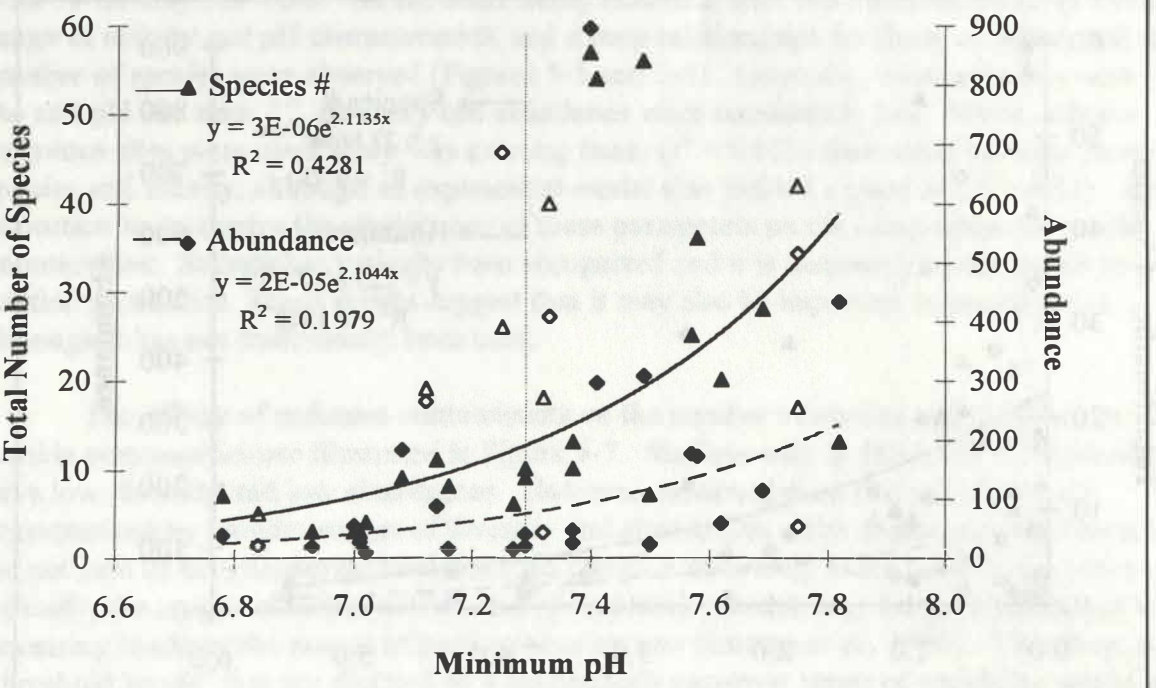

Figure 5-6. The relationships between benthic community parameters and minimum pHs. Reference sites are plotted with open symbols, and degraded and enriched sites are plotted with solid symbols.

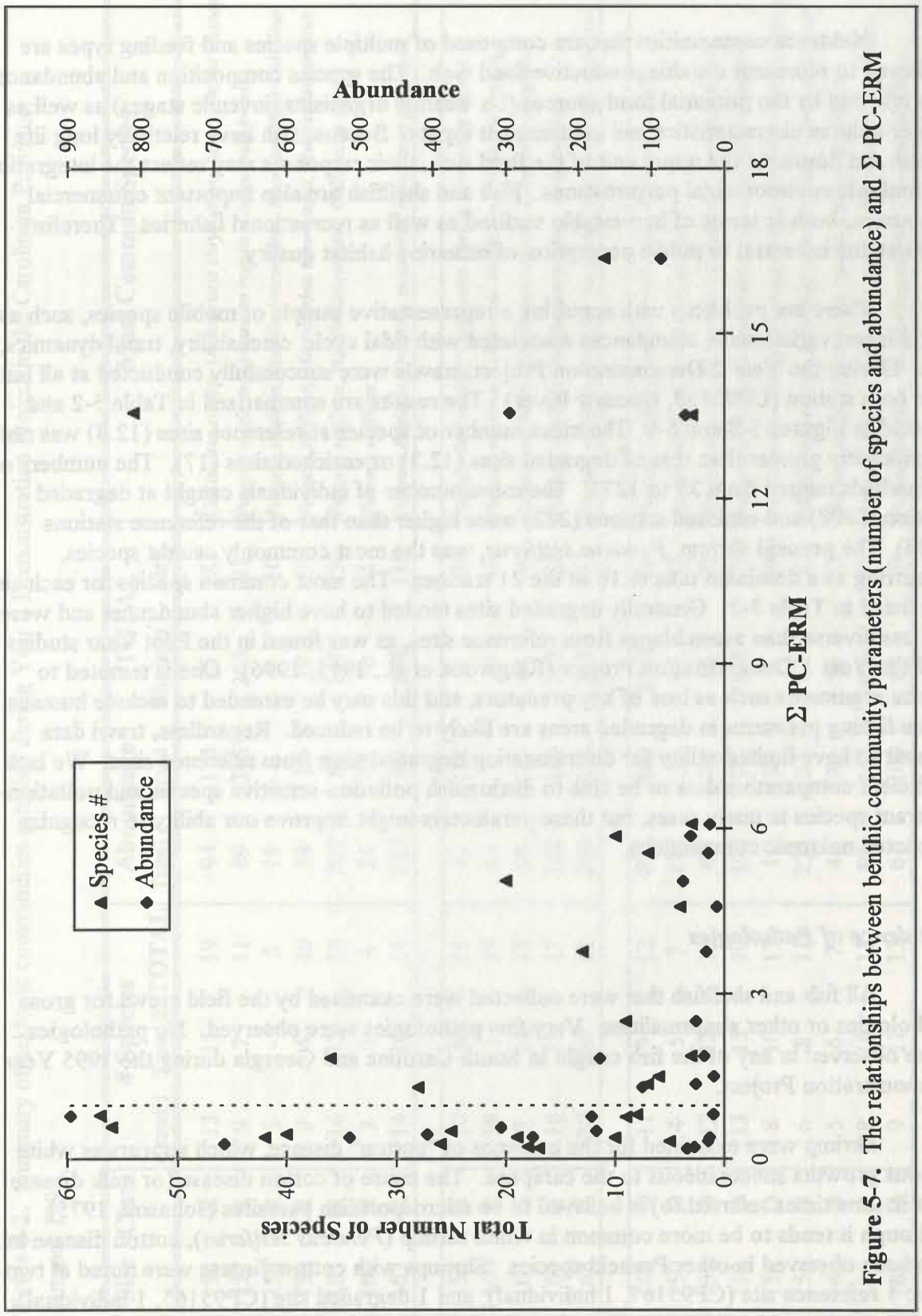

Figure 5-7. The relationships between benthic community parameters (number of species and abundance) and Σ PC-ERM

Fish and Shellfish Assemblages

Nektonic communities that are composed of multiple species and feeding types are believed to represent a stable productive food web. The species composition and abundances are affected by the potential food sources (i.e. benthic organisms, juvenile stages) as well as water column characteristics and contaminant inputs. Because fish have relatively long life spans and dominate the upper end of the food web, their responses may reflect the integration of multiple environmental perturbations. Fish and shellfish are also important commercial resources, both in terms of harvestable seafood as well as recreational fisheries. Therefore their status is central to public perception of estuarine habitat quality.

There are problems with acquiring a representative sample of mobile species, such as patchiness, variations in abundances associated with tidal cycle, catchability, trawl dynamics, etc. During the Year 2 Demonstration Project, trawls were successfully conducted at all but one core station (CP95158, Coosaw River). The results are summarized in Table 5-2 and plotted in Figures 5-8 and 5-9. The mean number of species at reference sites (12.8) was not significantly greater than that of degraded sites (12.3) or enriched sites (17). The numbers of individuals ranged from 39 to 1273. The mean number of individuals caught at degraded stations (308) and enriched stations (212) were higher than that of the reference stations (206). The penaeid shrimp, *Penaeus setiferus*, was the most commonly caught species, occurring as a dominant taxa at 16 of the 21 stations. The most common species for each site are listed in Table 5-2. Generally degraded sites tended to have higher abundances and were no less diverse than assemblages from reference sites, as was found in the Pilot Year studies and the Year 1 Demonstration Project (Ringwood et al., 1995, 1996). One is tempted to evoke arguments such as loss of key predators, and this may be extended to include humans, since fishing pressures in degraded areas are likely to be reduced. Regardless, trawl data appear to have limited utility for discriminating degraded sites from reference sites. We lack sufficient comparative data to be able to distinguish pollution-sensitive species and pollution-tolerant species in many cases, but these parameters might improve our ability to recognize impacted nektonic communities.

Incidence of Pathologies

All fish and shellfish that were collected were examined by the field crews for gross pathologies or other abnormalities. Very few pathologies were observed. No pathologies were observed in any of the fish caught in South Carolina and Georgia during the 1995 Year 2 Demonstration Project.

Shrimp were examined for the presence of "cotton" disease, which appears as white fibrous growths subcutaneous to the carapace. The cause of cotton disease (or milk disease as it is sometimes referred to) is believed to be microsporidian parasites (Johnson, 1975). Although it tends to be more common in white shrimp (*Penaeus setiferus*), cotton disease has also been observed in other Penaeid species. Shrimps with cotton disease were noted at two sites: 1 reference site (CP95167, 1 individual), and 1 degraded site (CP95165, 1 individual).

Table 5-2. Summary of nektonic communities sampled during Year 2 Demonstration Project in the Carolinian Province, summer 1995.

Site	Class	# Species			Abundance		TOTAL		Most Common Species
		Trawl 1	Trawl 2	TOTAL	Trawl 1	Trawl 2	Shrimp	Fish	
153	R	13	15	19	94	114	25	183	*Callinectes similis, Orthopristis chrysoptera, Monocanthus hispidus*
157	R	9	7	11	89	215	263	41	*Penaeus setiferus, Cynoscion regalis, Loliguncula brevis*
158	R	5	-	5	19	-	9	10	*Penaeus setiferus, Stellifer lanceolatus, Micropogonius undulatus*
159	R	9	4	10	29	10	19	20	*Penaeus setiferus, Menticirrhus americanus, Stellifer lanceolatus*
161	R	16	12	19	203	88	141	150	*Penaeus setiferus, Stellifer lanceolatus, Callinectes similis*
162	R	3	2	4	26	48	70	4	*Penaeus setiferus*
167	R	14	10	14	227	96	204	119	*Penaeus setiferus, Trinectes maculatus, Symphurus plagiusa*
155	E	10	8	13	42	102	8	136	*Stellifer lanceolatus, Callinectes similis, Cynoscion regalis*
160	E	19	1	19	65	1	18	48	*Penaeus setiferus, Leiostomus xanthurus, Cynoscion regalis*
163	E	7	14	15	49	76	61	64	*Penaeus setiferus, Stellifer lanceolatus, Symphurus plagiusa*
165	E	16	13	17	102	169	113	158	*Penaeus setiferus, Stellifer lanceolatus, Ariopsis felis*
168	E	20	10	21	250	204	242	212	*Penaeus setiferus, Trinectes maculatus, Micropogonius undulatus*
149	D	11	5	12	872	401	1230	43	*Penaeus setiferus, Trinectes maculatus, Cynoscion regalis*
150	D	4	5	7	123	39	95	67	*Penaeus setiferus, Leiostomus xanthurus*
151	D	12	12	16	81	73	64	90	*Penaeus aztecus, Micropogonius undulatus, Penaeus setiferus*
152	D	13	15	19	104	76	108	72	*Penaeus setiferus, Penaeus aztecus, Micropogonius undulatus*
154	D	8	10	15	11	33	5	39	*Leiostomus xanthurus, Micropogonius undulatus, Trinectes maculatus*
156	D	6	8	11	231	37	41	227	*Stellifer lanceolatus, Micropogonius undulatus, Penaeus setiferus*
164	D	5	6	7	45	33	56	22	*Penaeus setiferus, Cynoscion regalis, Loliguncula brevis*
166	D	8	10	11	97	353	406	44	*Penaeus setiferus, Callinectes sapidus, Micropogonius undulatus*
169	D	9	11	13	61	100	62	99	*Penaeus setiferus, Stellifer lanceolatus, Trinectes maculatus*

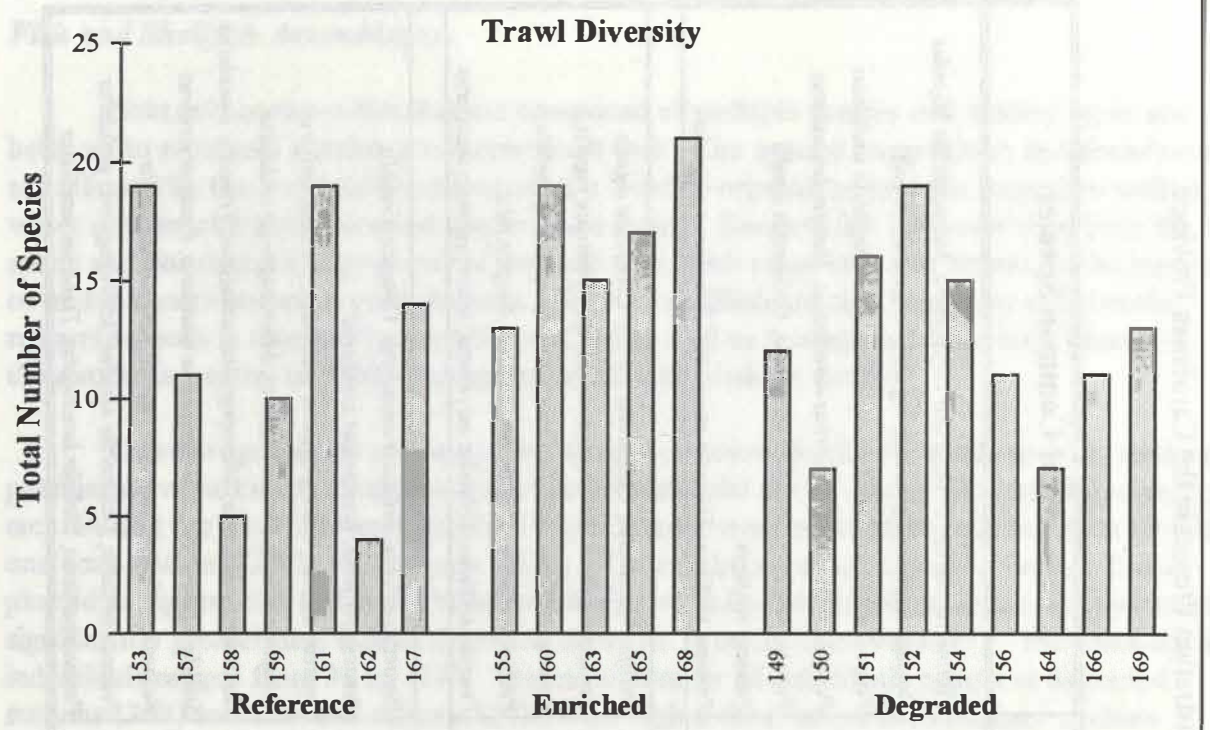

Figure 5-8. Total number of species caught in 2 trawls conducted at SC and GA stations during Year 2 Demonstration Project in the Carolinian Province, summer 1995.

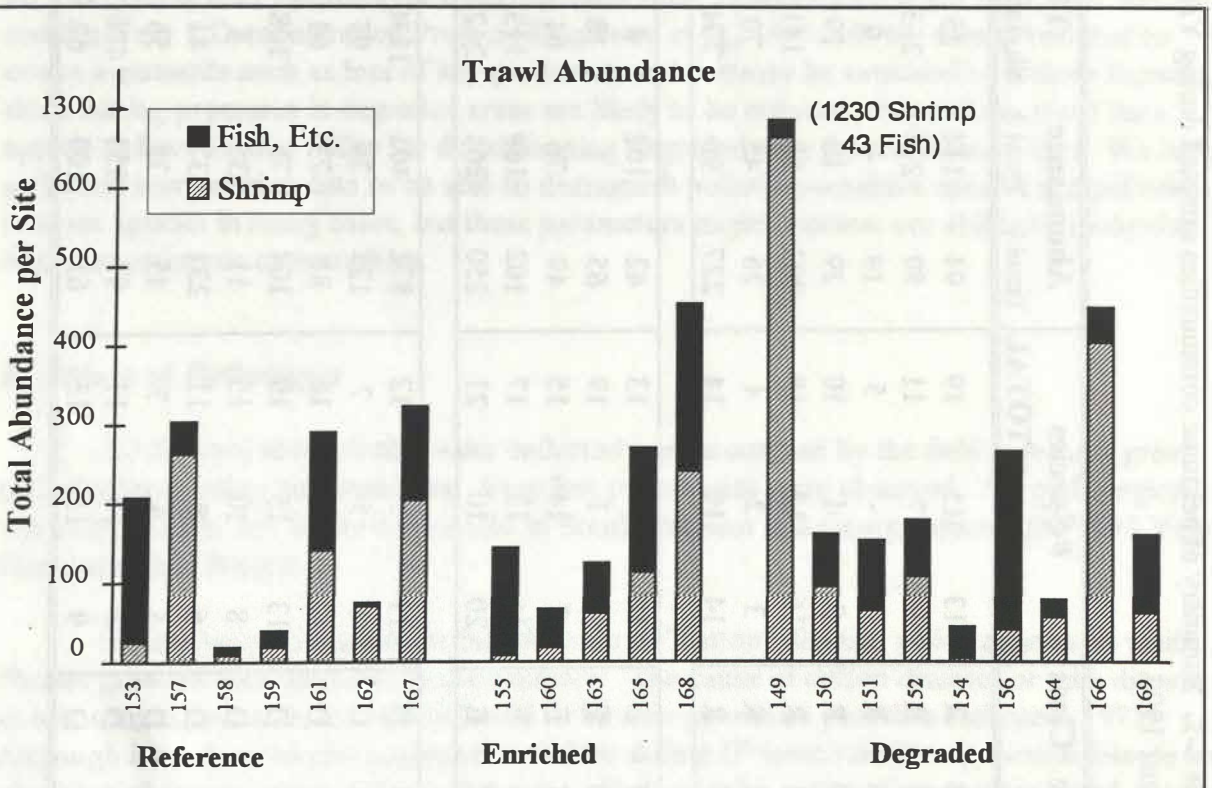

Figure 5-9. Number of individual fish and shrimp caught in 2 trawls conducted at SC and GA stations during Year 2 Demonstration Project in the Carolinian Province, summer 1995.

In blue crabs (*Callinectes sapidus*), shell disease is sometimes observed, which can range from rust-like spots on the carapace and appendages to large ulcers and loss of portions of their bodies. The etiology is uncertain, but a number of pathogens (chitinoclastic bacteria belonging to *Vibrio* and *Pseudomonas* genera, and fungi) have been reported from lesions (Johnson, 1983). Increased incidences of shell disease have been reported from polluted environments (Young and Pearce, 1975), and there is some evidence that immunological function is compromised (indicated by decreased anti-bacterial activity of blood) in crabs from impacted areas (Noga et al., 1990). Only 1 crab (from a degraded site, CP95165) was found with shell disease from SC and GA trawls.

Although the incidence of pathologies is relatively rare, the presence of diseased organisms is regarded as a powerful indicator of stress. There is a growing body of evidence that pollutant-associated diseases are increasing in fish and shellfish populations (Sinderman, 1993). EMAP programs in other provinces (Virginian and Louisianian) have focused primarily on fish disorders, but the occurrence of shrimp and crab diseases should also be included.

CONCLUSIONS

Monitoring programs strive to identify sites with evidence of stress, so that areal or trend estimates can be generated. Exposure and condition indicators should provide an accurate image of habitat condition. Since it is likely that any indicator will sometimes yield false-positives or false-negatives, it is important to incorporate a variety of indicators that represent various levels of organization to provide the most reliable evaluations. It has been stated that exposure and condition indicators should cross-validate the findings. A summary of this type of approach can be seen in Table 5-3. Sites with significant adverse findings for the various indicators are marked with an X as folows: sites with significantly elevated contaminants (both enriched and degraded) as described in Table 3-10; sites characterized as dissolved oxygen stressed as listed in Table 3-3; significant toxicity for the various laboratory toxicity assays (amphipod, seed clam, and Microtox) as described in Chapter 4; adverse effects on the benthos (< 20 species and/or < 200 individuals) as described in this chapter. Therefore, definitive classification of a site would require that there is evidence of degraded conditions in 3 of the 4 major indicator classes (contaminant loadings, dissolved oxygen, toxicity tests, and benthic communities). Using this approach, 1 reference site (167), 1 enriched site (FOS) and 12 degraded sites have evidence of significant ecological stress.

Integration of these indicators as well as others (such as pH and salinity) should provide a powerful representation of habitat condition. Estuaries are complex multidimensional resources that require a multidisciplinary approach to identify areas under stress. We must continue to develop tools, such as *in situ* methods and molecular biomarkers that will enable us to recognize habitats in early, possibly reversible, stages of degradation as well as those that would require more costly efforts to remediate.

Table 5-3. Summary of the results of various exposure and condition indicators for SC and GA sites sampled during Year 2 Demonstration Project, summer 1995. x[1] indicates that only one toxicity criterion was satisified, i.e. either statistical significance or < 80% of controls, but not both. Shaded cells signify that the indicator was not evaluated for that site.

Station	Class	Contam	DO	*A. abdita*	*A. verrilli*	Microtox	Seed Clam	Benthos	
								Diversity	Abundance
CP95153	R		X						
CP95157	R							X	X
CP95158	R								
CP95159	R							X	X
CP95161	R								
CP95162	R							X	X
CP95167	R		X			X		X	
CP95155	E	X							X
CP95160	E	X				X			
CP95163	E	X							
CP95165	E	X						X	X
CP95168	E	X						X	X
CP95FOS	E	X	X			X	X	X	X
CP95149	D	X			x[1]	X	X	X	X
CP95150	D	X						X	X
CP95151	D	X				X			X
CP95152	D	X			x[1]	X			X
CP95154	D	X				X			X
CP95156	D	X				X	X	X	X
CP95164	D	X						X	X
CP95166	D	X	X					X	X
CP95169	D	X							
CP95ASM	D	X						X	X
CP95DIE	D	X	X			X	x[1]	X	X
CP95KIA	D	X				X			
CP95KOP	D	X	X			X	X	X	X
CP95LON	D	X							
CP95NMK	D	X	X		x[1]		x[1]	X	X
CP95NV1	D	X			x[1]	X		X	X
CP95NV2	D	X	X			X		X	X
CP95SPY	D	X	X					X	

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APPENDIX A

Table A-1. Corrected chlordane concentrations and the resulting effects on ER-L and ER-M exceedances. The new ΣPCs and classification of sites when these values were used to generate ΣPCs are also shown.

Station	Chlordane	ERL/TEL	ERM/PEL	ΣPC-ERL	ΣPC-ERM	Classification
CP95104	0	0	0	0.92	0.21	R
CP95105	0	0	0	0.84	0.18	R
CP95106	0	0	0	1.51	0.34	R
CP95108	0.15	1	0	1.50	0.31	R
CP95110	0.03	0	0	1.48	0.19	R
CP95111	0.06	0	0	2.88	0.50	R
CP95112	0	0	0	0.37	0.07	R
CP95113	0	0	0	0.69	0.15	R
CP95115	0	0	0	1.13	0.22	R
CP95118	0	0	0	1.06	0.21	R
CP95123	0	0	0	1.49	0.34	R
CP95125	0	0	0	1.00	0.21	R
CP95126	0	0	0	1.46	0.28	R
CP95127	0	0	0	1.14	0.24	R
CP95128	0	0	0	1.84	0.38	R
CP95129	0	0	0	1.10	0.22	R
CP95130	0	0	0	1.28	0.19	R
CP95132	0	0	0	1.07	0.24	R
CP95133	0	0	0	0.91	0.19	R
CP95134	0.4	0	0	2.13	0.26	R
CP95135	0	0	0	0.70	0.13	R
CP95146	0	0	0	1.43	0.26	R
CP95147	0	0	0	2.55	0.56	R
CP95148	0	0	0	0.91	0.15	R
CP95153	0.17	0	0	2.08	0.38	R
CP95157	0.16	0	0	1.33	0.22	R
CP95158	0.14	0	0	2.34	0.43	R
CP95159	0.08	0	0	1.18	0.20	R
CP95161	0.08	0	0	1.54	0.26	R
CP95162	0.13	0	0	1.80	0.31	R
CP95163	0.08	0	1	2.49	0.47	R
CP95165	0.04	1	1	2.20	0.26	R
CP95167	0.2	0	0	2.26	0.40	R
CP95168	0.08	1	0	1.86	0.29	R
CP95170	0.01	0	0	1.00	0.20	R
CP95176	0	0	0	0.68	0.12	R

(Table A-1 continued)

Station	Chlordane	ERL/TEL	ERM/PEL	ΣPC-ERL	ΣPC-ERM	Classification
CP95177	0	0	0	0.70	0.12	R
CP95178	0.27	0	1	2.31	0.29	R
CP95179	0.58	1	0	2.27	0.27	R
CP95182	0.5	1	0	2.38	0.35	R
CP95183	0.21	0	0	1.49	0.25	R
CP95184	0.14	0	0	2.13	0.36	R
CP95185	0.2	0	0	2.10	0.36	R
CP95186	0.27	0	0	1.36	0.21	R
CP95187	0.05	0	0	1.84	0.34	R
CP95188	0.18	0	0	2.22	0.39	R
CP95CB_	0.09	0	0	2.24	0.43	R
CP95MI_	0.02	0	0	0.79	0.14	R
CP95PR1	0	0	0	2.73	0.43	R
CP95RC_	0	0	0	1.04	0.21	R
CP95ZI_	0	0	0	1.29	0.25	R
CP95101	0.14	0	0	4.56	0.84	E
CP95102	0.08	0	0	3.08	0.61	E
CP95131	0	1	0	4.74	1.00	E
CP95141	0.06	0	0	4.59	0.91	E
CP95142	0.13	0	0	3.97	0.55	E
CP95145	0.04	1	0	3.59	0.62	E
CP95155	0.23	0	0	3.16	0.50	E
CP95160	0.3	0	0	3.25	0.57	E
CP95164	0.06	3	3	17.03	0.85	E
CP95173	0.06	0	0	3.18	0.53	E
CP95175	0.08	3	3	20.10	0.98	E
CP95180	0.29	0	0	3.34	0.57	E
CP95FOS	0.07	0	0	4.16	0.74	E
CP95103	1.71	9	1	27.51	3.00	D
CP95107	0.27	5	0	10.95	2.28	D
CP95109	1.03	5	3	148.83	7.01	D
CP95114	0.31	3	1	9.57	1.23	D
CP95116	0.29	5	0	11.74	1.97	D
CP95117	0.15	2	0	7.43	1.47	D
CP95119	0	1	0	5.15	1.03	D
CP95120	1.18	5	1	15.86	1.93	D
CP95121	0.65	8	0	17.66	2.52	D
CP95122	0	4	0	12.69	2.16	D
CP95124	0	3	0	9.13	1.76	D
CP95136	0.02	3	0	11.07	1.75	D

(Table A-1 continued)

Station	Chlordane	ERL/TEL	ERM/PEL	ΣPC-ERL	ΣPC-ERM	Classification
CP95138	0.52	3	5	65.53	3.30	**D**
CP95139	0.53	5	0	12.80	2.10	**D**
CP95140	0.37	3	0	8.54	1.27	**D**
CP95143	0.12	1	0	5.96	1.02	**D**
CP95149	0.11	2	0	7.58	1.49	**D**
CP95150	0.18	1	0	7.36	1.34	**D**
CP95151	0.78	1	0	12.14	1.80	**D**
CP95152	1.06	14	1	35.04	5.00	**D**
CP95154	0.25	1	0	8.11	1.29	**D**
CP95156	0.13	5	0	13.70	1.85	**D**
CP95166	0.33	1	6	102.93	5.32	**D**
CP95169	0.48	0	6	95.74	4.51	**D**
CP95171	1.3	4	0	19.31	2.70	**D**
CP95172	3.12	9	0	32.20	3.60	**D**
CP95174	0.22	3	0	15.92	2.38	**D**
CP95181	1.27	1	0	11.04	1.90	**D**
CP95ASM	0.84	4	0	15.93	2.44	**D**
CP95CF_	0.56	1	0	8.02	1.31	**D**
CP95DIE	1.38	17	0	29.96	4.46	**D**
CP95KIA	0.14	1	0	5.90	1.03	**D**
CP95KOP	1.64	21	0	47.83	5.72	**D**
CP95LNG	4.14	4	1	47.30	2.86	**D**
CP95NMK	18.45	25	3	111.79	12.00	**D**
CP95NV1	3.32	17	0	50.35	5.56	**D**
CP95NV2	3.22	16	0	42.65	5.48	**D**
CP95PR2	0.16	3	0	9.44	1.89	**D**
CP95PR3	0.53	8	1	19.17	2.72	**D**
CP95PR4	0.15	5	0	12.99	2.31	**D**
CP95PR5	0.86	10	0	16.71	2.63	**D**
CP95SPY	1.59	6	2	278.10	60.35	**D**