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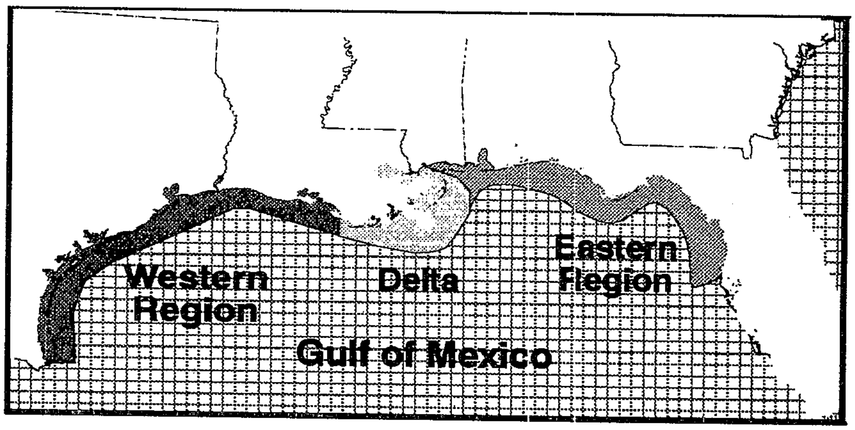
Statistical Summary

EMAP-Estuaries Louisianian Province-1992



Environmental Monitoring and Assessment Program

EPA/620/R-94/002
January 1994

STATISTICAL SUMMARY: EMAP-ESTUARIES LOUISIANIAN PROVINCE - 1992

by

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DISCLAIMER

This report represents data from a single year of field operations of the Environmental Monitoring and Assessment Program (EMAP). Because the probability-based scientific design used by the EMAP necessitates multiple years of sampling, there may be significant levels of uncertainty associated with some of these data. This uncertainty will decrease as the full power of the approach is realized by the collection of data over several years. Similarly, temporal changes and trends cannot be reported, as these require multiple years of observation. Please note that this report contains data from research studies in only one biogeographic region (Louisianian Province) collected in a short index period (July-August) during a single year (1992). Appropriate precautions should be exercised when using this information for policy, regulatory or legislative purposes.

PREFACE

This document is the second annual statistical summary for the Louisianian Province of the Estuaries component of the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program for estuaries (EMAP-E).

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ACKNOWLEDGEMENTS

A large geographically extensive monitoring program such as EMAP in the Louisianian Province requires the interaction, coordination and cooperation of literally hundreds of individuals working together to complete the 1992 Demonstration. Space does not permit the individual citation of all who participated in the 1992 effort. We would like to take this opportunity to thank everyone who has participated in the success of the Louisianian Province and specifically acknowledge the following:

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STATISTICAL SUMMARY
EMAP-E LOUISIANIAN PROVINCE - 1991

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EXECUTIVE OVERVIEW

STATUS OF THE CONDITION OF LOUISIANIAN PROVINCE ESTUARIES - 1992

This statistical summary of the ecological condition of the estuarine resources is based on the results of the 1992 Louisianian Province Demonstration Project. The population of estuarine resources within the Louisianian Province consists of all estuarine areas located along the coastline of the Gulf of Mexico between and including, the Rio Grande, TX and Anclote Anchorage, FL.

Estuarine areas are defined as the saline, tidal ecosystems characterized by harbors, sounds, bays, and embayments bounded by barrier islands (seaward boundary) or surrounded by land with a restricted confluence with the Gulf of Mexico including portions of tidal rivers having a detectable tide (> 2.5 cm). These resources have been classified into three estuarine types:

- Large estuaries (surface area > 250 km^2, aspect (length/mean width) < 18)
- Large tidal rivers (surface area > 250 km^2, aspect > 18)
- Small estuaries and tidal rivers (2 km^2 < surface area < 250 km^2)

The Environmental Monitoring and Assessment Program (EMAP) is a national program initiated by EPA and integrating the efforts of several federal agencies to evaluate the status and trends of the ecological resources of the United States. EMAP-Estuaries (EMAP-E) is a part of EMAP organized to evaluate the status and trends of the estuarine resources of the United States. The Louisianian Province represents a single biogeographic area of the country corresponding to the Gulf of Mexico. The Louisianian Province Demonstration Project was conducted during the summer of 1992 (July-August) using a probability-based sampling design to evaluate the condition of the estuarine resources in this geographic region. This probabilistic sampling design makes it possible to estimate the proportion or amount of the total area in the Louisianian Province (25,725 km^2) having defined environmental conditions based on sampling only a portion of the province.

One hundred and sixty-nine sites between Anclote Anchorage, FL and the Rio Grande, TX were sampled during the eight-week sampling period (Fig. 1). Ten sites were not sampled, due to inadequate water depth for sampling (i.e., < 1 m). Thus, based on the 1992 sampling design, 6.6% of the total estuarine area in the Louisianian Province cannot be sampled with the present sampling plan. The bulk of this "unsampleable" area occurs in the shoreline areas of large estuaries where the average depth is < 1 m. (locations in Apalachee Bay, FL; Laguna Madre, TX; and Mobile Bay, AL account for 96% of this unsampleable area) We will evaluate methods for obtaining data from these shallow locations in 1993. Of the remaining sites, 100 locations represent probability-based sampling for the province and are used for the class and province estimates produced in this report. Fifty-nine sites were collected to provide estimates of variance, local enhancements of

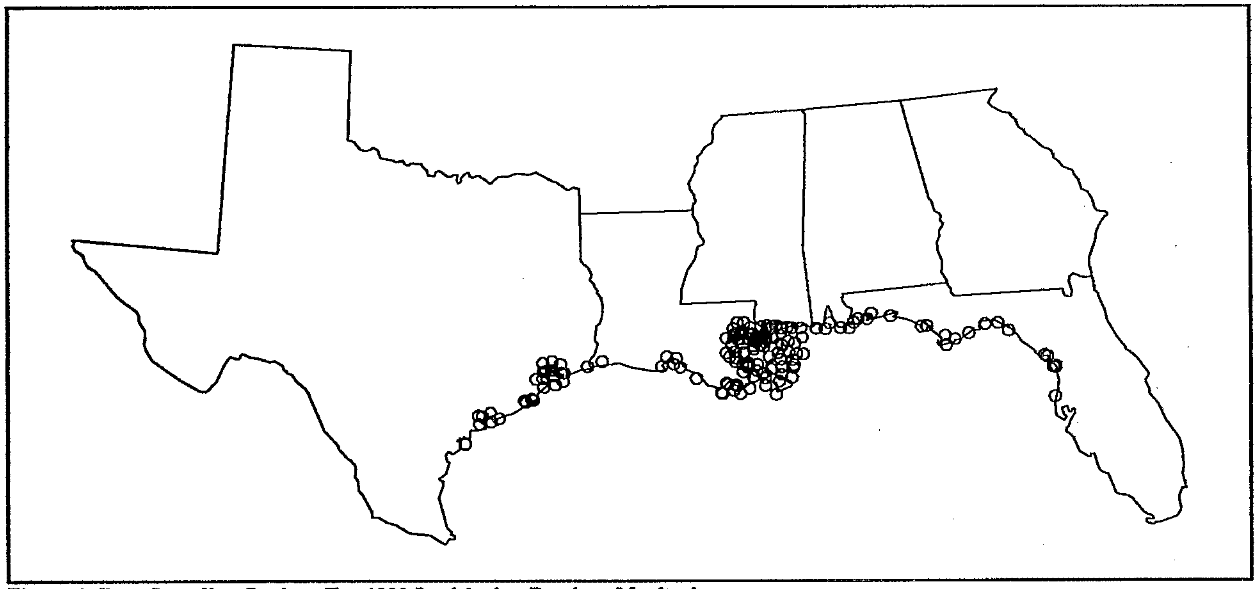

Figure 1. Base Sampling Stations For 1992 Louisianian Province Monitoring.

spatial scale for Lake Pontchartrain, and long-term trend estimation.

A series of indicators that are representative of the overall condition of estuarine resources was measured at each site. These indicators were designed to address three major attributes of concern: 1) estuarine biotic integrity, 2) societal values related to public use of estuarine resources, and 3) pollutant exposure or the environmental conditions under which biota live.

BIOTIC INTEGRITY

The condition of biological resources in the Louisianian Province was assessed using two indicators: one that measured the condition of estuarine benthos (bottom dwelling organisms) and one that measured the condition of fish communities. The benthic and fish indicators use measures of species composition, abundance, and health to evaluate the condition of the benthic and fish assemblages. Both use indices determined from the combined 1991-1992 data to represent a combination of ecological measurements for each assemblage that best discriminate between good and poor environmental conditions. These indices represent EMAP-E's attempt to reduce dozens of indicators into a simple, interpretive value that has a high level of discriminatory power between good and poor environmental conditions. The indices were developed separately for fish and benthos using information from regional reference sites and sites with known pollution exposure. The indices have been partially validated, but additional years of information will be required for complete validation; therefore, assessments based on these indices should be considered preliminary.

Benthic organisms were used as an indicator because previous studies suggested that they are sensitive to pollution exposure (Pearson and Rosenberg 1978, Boesch and Rosenberg 1981). They also integrate responses to exposure over relatively long periods of time. One reason for their sensitivity to pollutant exposure is that benthic organisms live in and on the sediments, a medium that accumulates environmental contaminants over time (Schubel and Carter 1984, Nixon et al. 1986). Their relative immobility also prevents benthic organisms from avoiding pollution exposure and environmental disturbance. A preliminary benthic index for the Louisianian Province was developed in 1991 (Engle et. al. 1993).

Preliminary estimates based on the 1992 Louisianian Province Demonstration indicate that 27±10% of the estuarine area in the province had benthic resources characterized by lower than expected benthic diversity and low numbers of indicator species. Of the 25,725 km^2 comprising the estuaries of the Louisianian Province, about 7000 km^2 were ecologically degraded. For the benthic index, degraded conditions were defined as an index value < 4.0.

Although EMAP-E's primary objective is to describe status and trends at the province level, estimates can also be generated for subpopulations. The EMAP sampling design defined three classes of estuarine resources: large estuaries, large tidal rivers, and small estuarine resources. These classes were defined because estuaries of different sizes may show markedly different responses to anthropogenic impacts.

The incidence of degraded benthic resources was dissimilar among the three classes of estuaries sampled during 1992. Proportionately, large tidal rivers were the most degraded with most of the resource having degraded resources (90±22% of the area of the tidal portion of the Mississippi River) (Fig. 2). Thirty-three percent (±24%) of small estuarine resources were degraded on an areal basis and large estuaries had only 24±11% of their area represented by degraded benthos (Fig. 2). However, while the proportion of area degraded in the large tidal river and small estuarine resources classes was high, the total area of degraded benthic resources in large estuaries was about 4400 km^2 as compared to 2500 km^2 for small estuaries and 120 km^2 for large tidal rivers.

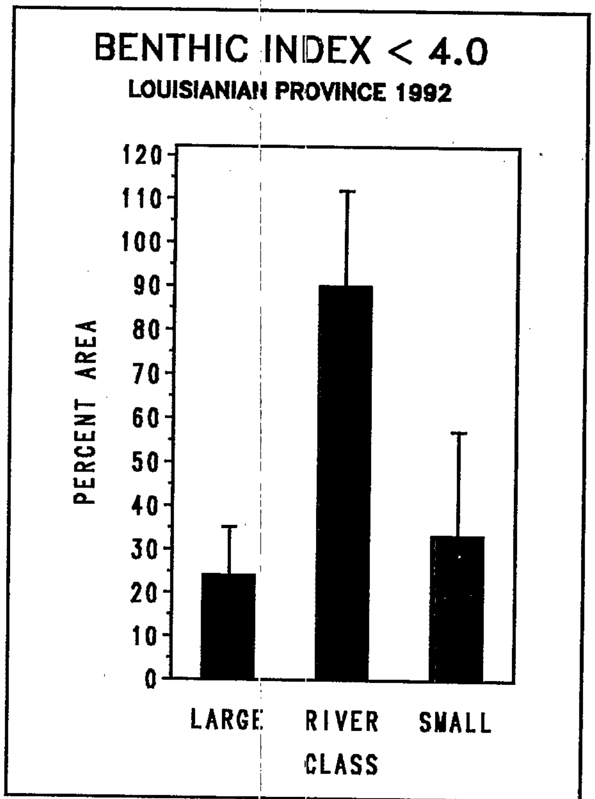

Figure 2. Percent of area having benthic index value < 4.0 for large estuaries (large), small estuaries (small), and large tidal rivers (river).

HUMAN USE

Although the major objective of EMAP-E is to describe the status of estuarine resources using indicators of ecological condition, certain characteristics of estuaries, valued by society, may not be reflected by these indicators. We have included three indicators of perceptual condition in our assessment: incidence of marine debris, clarity of water, and contaminant levels in edible fish flesh. Data were collected during the 1992 Louisianian Province Demonstration to estimate the areal extent of estuaries having trash and turbid waters. Measurements were taken to estimate the proportion of fish and shellfish populations for selected ecological, recreational, and commercial species having unacceptable levels of contaminants.

Observations concerning marine debris are important because debris has multiple deleterious effects on estuarine biota (entanglement and ingestion), can economically affect tourist areas (loss of tourists, beach clean-up costs), and contributes to the public perception of the general environmental condition of estuaries (Ross et al. 1991). It is estimated that marine debris was present at 6±5% of the estuarine area in the Louisianian Province. This accumulates to over 1500 km^2 of estuarine bottom having identifiable marine debris in the Louisianian Province. No trash was identified as medical or hospital waste.

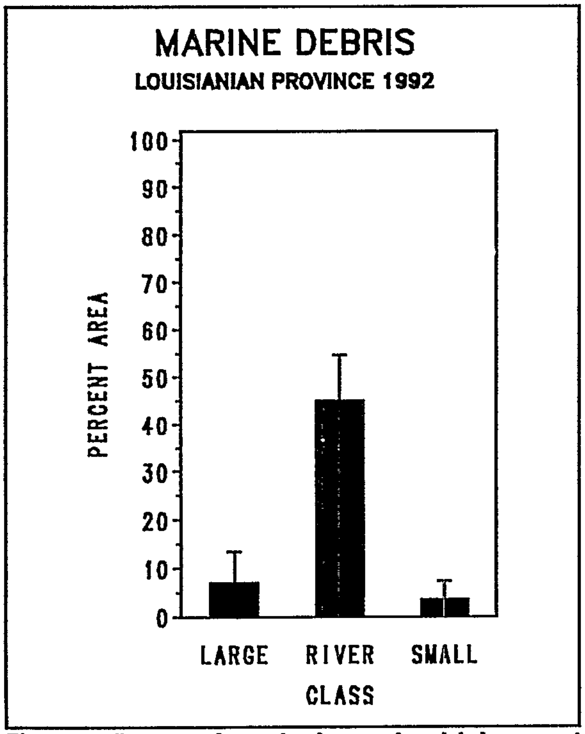

Figure 3. Percent of area having marine debris present for large estuaries (large), small estuaries (small), and large tidal rivers (river).

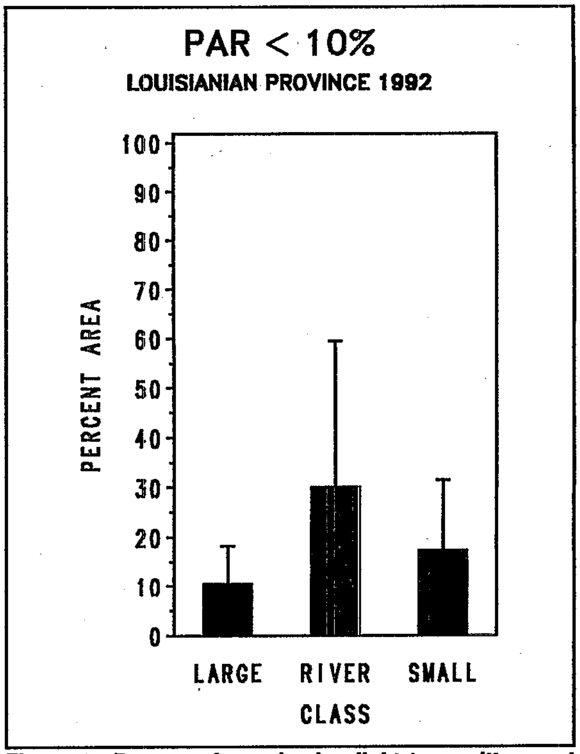

Figure 4. Percent of area having light transmittance at one meter depth at <10% of incident light for large estuaries (large), small estuaries (small), and large tidal rivers (river).

Proportion of area having marine debris was higher in the large tidal rivers 45±27%, while 7±7% of the area of large estuaries, and 4±7% of the area in small estuaries had trash (Fig. 3).

Clear waters are valued by society and contribute to the maintenance of healthy and productive ecosystems. Water clarity was estimated using light transmission data as a comparison of incident light at the surface and reduced light at a depth of one meter. Water visibility of 10% at one meter was used to represent poor visibility (i.e., visibility of < 1 ft). Approximately 12±7% of the province had waters with visibility of < 10%. Clarity was much poorer in large tidal rivers (30±29% with < 10% transmittance) than either small estuaries (17±14%) or large tidal estuaries (10±8%)(Fig. 4).

Contaminant levels in edible fish tissue are perceived by the public as a negative quality for estuarine waters even if the concentrations are below levels that could have harmful effects.

EMAP-E has compiled contaminant levels of pesticides, heavy metals, and polychlorinated biphenyls (PCBs) in edible fish and shellfish tissues for three species groups: Atlantic croaker (*Micropogonias undulatus*), commercial shrimps (*Penaeus aztecus* and *Penaeus setiferus*), and marine catfish (*Arius felis*, *Bagre marinus*, and *Ictalurus furcatus*). The analysis done for tissue contaminants differ from those previously discussed in that the results refer to populations of organisms rather than areal extent in estuaries.

In general, contaminant concentrations in fish and shellfish were low with the exception of some heavy metals (arsenic, chromium, mercury, and zinc) (Tables 1-3). Concentrations of pesticides and PCBs measured in brown and white shrimp tissue did not exceed existing FDA or international criteria (USFDA 1982, 1984; Nauen 1983). However, selenium concentrations exceeded the international criterion in 4% of sampled shrimp populations (Table 1).

Atlantic croaker is a recreationally and commercially important fish in the Louisianian Province. Concentrations of all chlorinated pesticides and PCBs were below FDA criteria. Cadmium concentrations exceeding 0.5 ppm (International criteria) were found in 4% of the croaker population (Table 2).

Marine catfish represent a minor recreational fishery in the Louisianian Province. Because their feeding habits bring them in direct contact with sediments, catfish were analyzed to examine the concentration of contaminants in their flesh. This category included sea cats (hardheads), gafftopsail catfish, and blue

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-4.5	5000	0%
DDE	0-0.5	5000	0%
DDT	0-14.0	5000	0%
Aldrin	0-0.7	300	0%
Chlordane	0-0.0	300	0%
Dieldrin	0-0.0	300	0%
Endosulfan	0-0.0	NA[2]	0%
Endrin	0-0.0	300	0%
Heptachlor	0-4.2	300	0%
Heptachlor Epoxide	0-0.4	300	0%
Hexachlorobenzene	0-0.0	200	0%
Lindane	0-0.0	200	0%
Mirex	0-16.0	100	0%
Toxaphene	0-0.0	5000	0%
Trans-Nonachlor	0-0.0	NA	U[3]
PCBs (ng/g wwt)			
21 Congeners	0-16.0	500	0%
Total PCBs	0-27.4	2000	0%
Heavy Metals (µg/g wwt)			
Aluminum	0-5.1	NA	U
Arsenic	0-1.4	2	0%
Cadmium	0-0.4	0.5	0%
Chromium	0-0.4	1	0%
Copper	0-2.4	15	0%
Lead	0-0.2	0.5	0%
Mercury	0-0.2	1	0%
Nickel	0-0.4	NA	U
Selenium	0-1.1	1	4%
Silver	0-0.5	NA	U
Tin	0-1.0	NA	U
Zinc	1-11.5	60	0%

[1] Criteria were selected from FDA established limits for pesticides and PCBs (USFDA 1982, 1984) except hexachlorobenzene and lindane which are based on Swedish limits (Nauen 1983); no FDA limits exist for metals other than mercury; metals criteria reflect means of international limits (Nauen 1983)
[2]NA = Not available
[3]U = Unknown because no criterion level available

Table 1. Overview of the contaminant levels observed in edible flesh of brown shrimp and white shrimp (N=523).

Contaminant	Observed range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-6.1	5000	0%
DDE	0-9.3	5000	0%
DDT	0-36.6	5000	0%
Aldrin	0-8.6	300	0%
Chlordane	0-3.5	300	0%
Dieldrin	0-3.5	300	0%
Endosulfan	0-2.0	NA	U
Endrin	0-1.1	300	0%
Heptachlor	0-3.0	300	0%
Heptachlor Epoxide	0-2.9	300	0%
Hexachlorobenzene	0-2.9	200	0%
Lindane	01.3	200	0%
Mirex	0-42.1	100	0%
Toxaphene	0-0	5000	0%
Trans-Nonachlor	0-5.6	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-30.3	500	0%
Total PCBs	0-98.9	2000	0%
Heavy Metals (µg/g wwt)			
Aluminum	0-4.1	NA	U
Arsenic	0-0.9	2	0%
Cadmium	0-0.7	0.5	4%
Chromium	0-0.5	1	0%
Copper	0-1.3	15	0%
Lead	0-0.2	0.5	0%
Mercury	0-0.4	1	0%
Nickel	0-0.8	NA	U%
Selenium	0-0.6	1	0%
Silver	0-0.5	NA	U%
Tin	0-0.9	NA	U%
Zinc	1-5.8	60	0%

[1]Criteria were selected from FDA established limits for pesticides and PCBs (USFDA 1982, 1984) except hexachlorobenzene and lindane which are based on Swedish limits (Nauen 1983); no FDA limits exist for metals other than mercury; metals criteria reflect means of international limits (Nauen 1983)

Table 2. Overview of the contaminant levels observed in edible flesh of Atlantic croaker (N=571). NA= Not available; U= Unknown, no criterion level is available.

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-13.0	5000	0%
DDE	0-20.9	5000	0%
DDT	0-37.8	5000	0%
Aldrin	0-16.7	300	0%
Chlordane	0-79.9	300	0%
Dieldrin	0-5.0	300	0%
Endosulfan	0-2.8	NA	U
Endrin	0-12.5	300	0%
Heptachlor	0-49.2	300	0%
Heptachlor Epoxide	0-2.3	300	0%
Hexachlorobenzene	0-2.5	200	0%
Lindane	0-15.4	200	0%
Mirex	0-72.6	100	0%
Toxaphene	0-0	5000	0%
Trans-Nonachlor	0-3.2	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-44.8	500	0%
Total PCBs	0-79.9	2000	0%
Heavy Metals (µg/g wwt)			
Aluminum	0-16.7	NA	U
Arsenic	0-10.3	2	15%
Cadmium	0-0.5	0.5	1%
Chromium	0-0.7	1	0%
Copper	0-2.0	15	0%
Lead	0-0.3	0.5	0%
Mercury	0-1.2	1	1%
Nickel	0-2.2	NA	U
Selenium	0-1.3	1	2%
Silver	0-0.5	NA	U
Tin	0-2.6	NA	U
Zinc	1-18.2	60	0%

[1] Criteria were selected from FDA established limits for pesticides and PCBs (USFDA 1982, 1984) except hexachlorobenzene and lindane which are based on Swedish limits (Nauen 1983); no FDA limits exist for metals other than mercury; metals criteria reflect means of international limits (Nauen 1983)

Table 3. Overview of the contaminant levels observed in edible flesh of catfish (N=633). NA= Not available; U= Unknown as no criterion level is available.

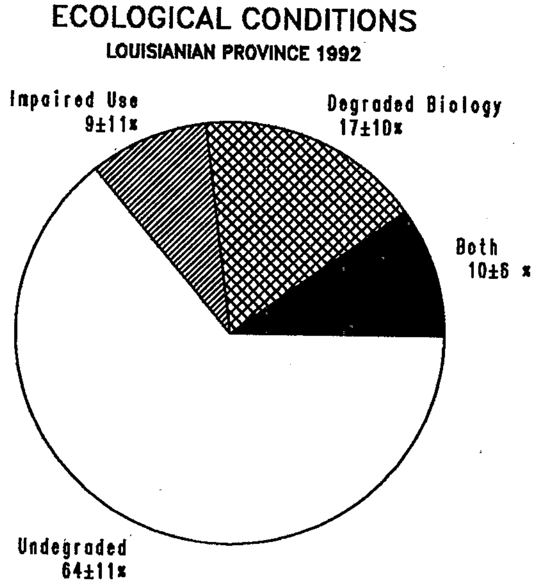

Figure 5. Summary of environmental conditions in Louisianian Province in 1992.

catfish. As was seen with croaker, catfish flesh contained concentrations of chlorinated pesticides and PCBs well within established criteria. Catfish contained elevated levels of arsenic (15% of samples exceeding 2 ppm). Selenium concentrations exceeded 1 ppm in 2% of the catfish populations. Mercury and cadmium exceeded 1 ppm and 0.5 ppm, respectively, in 1% of the catfish populations (Table 3).

Overall, the number of contaminants seen in fish and shellfish exceeding the FDA action limits was low. However, a few contaminants (selected heavy metals) occurred in high enough concentrations to exceed international guidelines in small portions of the populations examined. These contaminants were arsenic, selenium, mercury, and cadmium. Because of the paucity of information concerning U.S. standards for heavy metals other than mercury in fish, the criteria levels used for metals in Table 1 through 3 (i.e., World Health Organization guidelines) may not be acceptable. However, the contaminant data are available to be compared to any criteria and can be used to track potential trends in contaminant concentrations in flesh for the croaker, catfish, and shrimp populations in the Louisianian Province.

INTEGRATION OF ESTUARINE CONDITIONS

A single index value has been developed to summarize the overall condition of the estuaries in the Louisianian Province by combining the benthic index, marine debris, water clarity and tissue contaminants, weighted equally. This single value includes an index of societal values (aesthetics) and estuarine biotic integrity based on benthic assemblages (Fig. 5). Indicators relating to biotic integrity and aesthetics were used to estimate overall environmental conditions in the estuaries. Thirty-six percent of the estuarine area in the Louisianian Province showed evidence of degraded biological resources or was impaired with respect to its ability to support activities valued by society (Fig. 5). Of the 25,725 km^2 of estuarine surface area in the Louisianian Province, 9,650 km^2 were potentially degraded based on the 1992 sampling.

The locations of degraded biological resources were sometimes different from those having aesthetic problems. Both sets of conditions were found in 10% of the estuarine area, whereas degraded biological conditions alone were found in 17% of the province, and poor aesthetics were found in 9% (Fig. 5).

POLLUTANT EXPOSURE

While EMAP-E's major objective is to describe the status of estuaries using indicators of ecological condition, we have taken numerous measurements of the magnitude and extent of pollutant exposure in order to ascertain some preliminary links between observed estuarine degradation and observed pollutant exposure. Many of these pollutant measures are described in detail in Section 2; however, a few exposure indicators are discussed below: dissolved oxygen concentrations, sediment toxicity, and sediment contaminants.

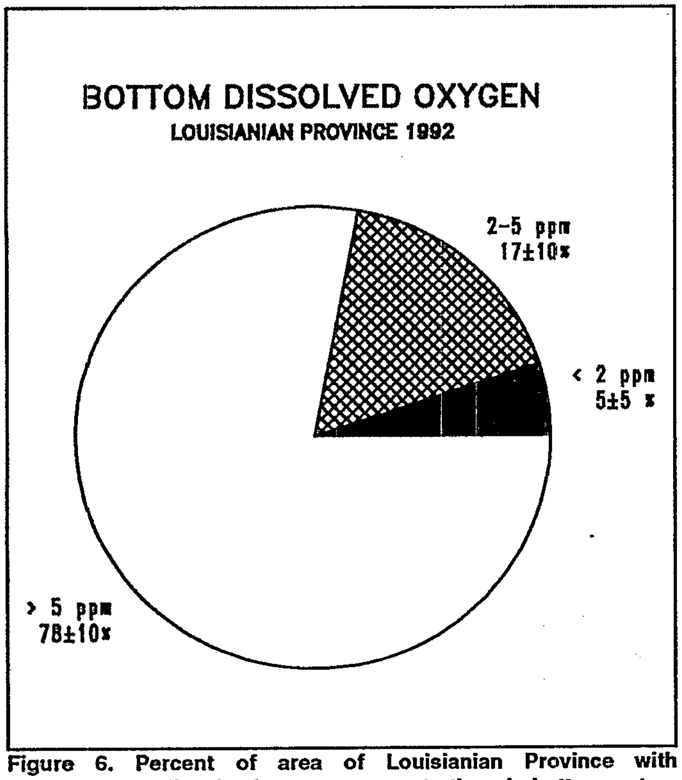

Figure 6. Percent of area of Louisianian Province with instantaneous dissolved oxygen concentrations in bottom waters < 2ppm, 2-5 ppm, and > 5ppm.

Dissolved oxygen is a fundamental requirement for all estuarine organisms. A threshold concentration of 4 to 5 ppm is used by many states to set water quality standards. Bottom waters in 22%±10% of the Louisianian Province had point measurements of dissolved oxygen concentrations that failed to meet the 5 ppm criterion (Fig. 6). A concentration of approximately 2 ppm is often used as a threshold for oxygen concentrations thought to be extremely stressful to most estuarine organisms. Results from the 1992 Louisianian Province Demonstration indicate that point measurements of bottom dissolved oxygen concentrations below this threshold were found in 5±5% of the province (Fig. 6).

Two types of dissolved oxygen measurements were taken in 1992: point measurements and continuous measurements. Continuous measurements were used to supplement point measures as some estuaries appear to undergo severe dissolved oxygen stress during nighttime hours. Point measurements taken during daylight hours could erroneously characterize a site as having acceptable dissolved oxygen concentrations when that site receives severe dissolved oxygen stress for several hours every night. In general, the continuous dissolved oxygen concentration measurements mimic the point measurements (Figs. 7-9).

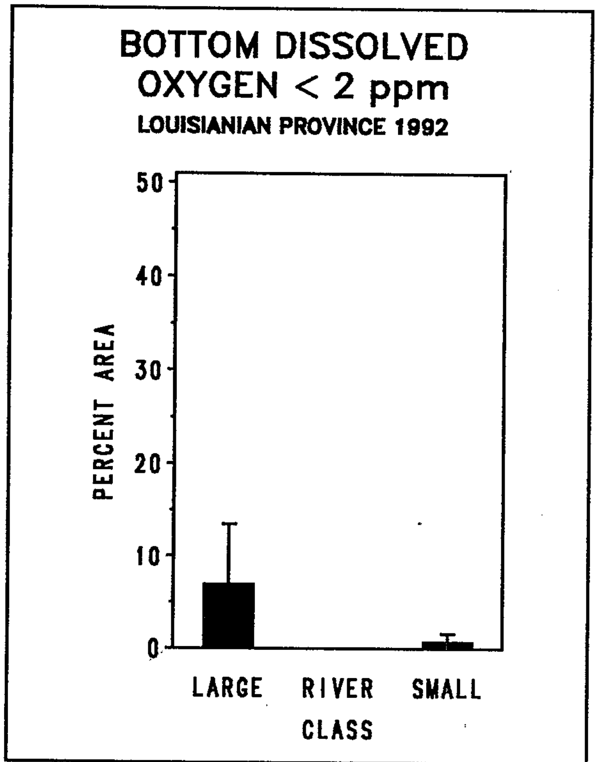

Figure 7. Percent of area having instantaneous dissolved oxygen concentrations in bottom waters of < 2 ppm for large estuaries (large), small estuaries (small), and large tidal rivers (river).

Sediment bioassays are the most direct measure available for estimating the potential for contaminant-induced effects in biological communities. These tests provide information that is independent of chemical characterizations and ecological surveys (Chapman 1988). Direct measures of sediment contaminant concentrations do not show which concentrations may adversely affect biological resources because many chemicals are bound tightly to sediment particles or are chemically-complexed (USEPA 1989, Long and Morgan 1990). Sediment toxicity tests avoid this problem by indicating when contaminant concentrations have the potential to impact biological resources. Laboratory bioassays were conducted to determine if the sediments in the Louisianian Province were toxic to representative estuarine organisms. Based upon the results of these tests, 10±6% of the Louisianian Province contained sediments that were toxic to estuarine organisms. Because *Ampelisca abdita,* the test organism used in the bioassays is not common to the Louisianian Province, additional testing was conducted using a common mysid. The results of this mysid testing generally agree with those found using *Ampelisca* with 5±4% of the province showing toxicity. The proportion of area containing toxic sediments was very different among the three estuarine classes (Fig. 10) with the highest proportion occurring in the large tidal river class (30±22%) and significantly smaller proportion in large estuaries (12±8%).

Measurements of concentrations of contaminants in sediments were used to estimate the areal extent of sediment having pollutant concentrations that are above

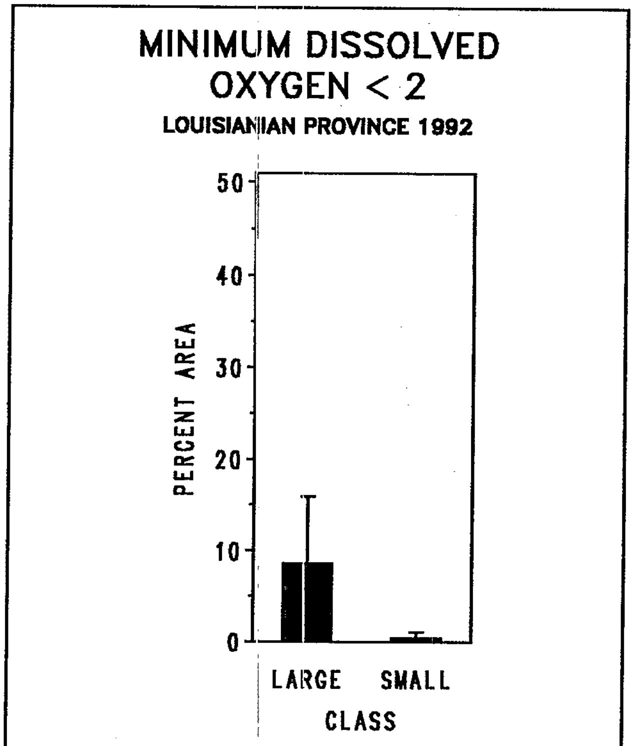

Figure 8. Percent of area having minimum dissolved oxygen concentrations in bottom waters of <2 ppm for large estuaries (large), small estuaries (small), and large tidal rivers (river).

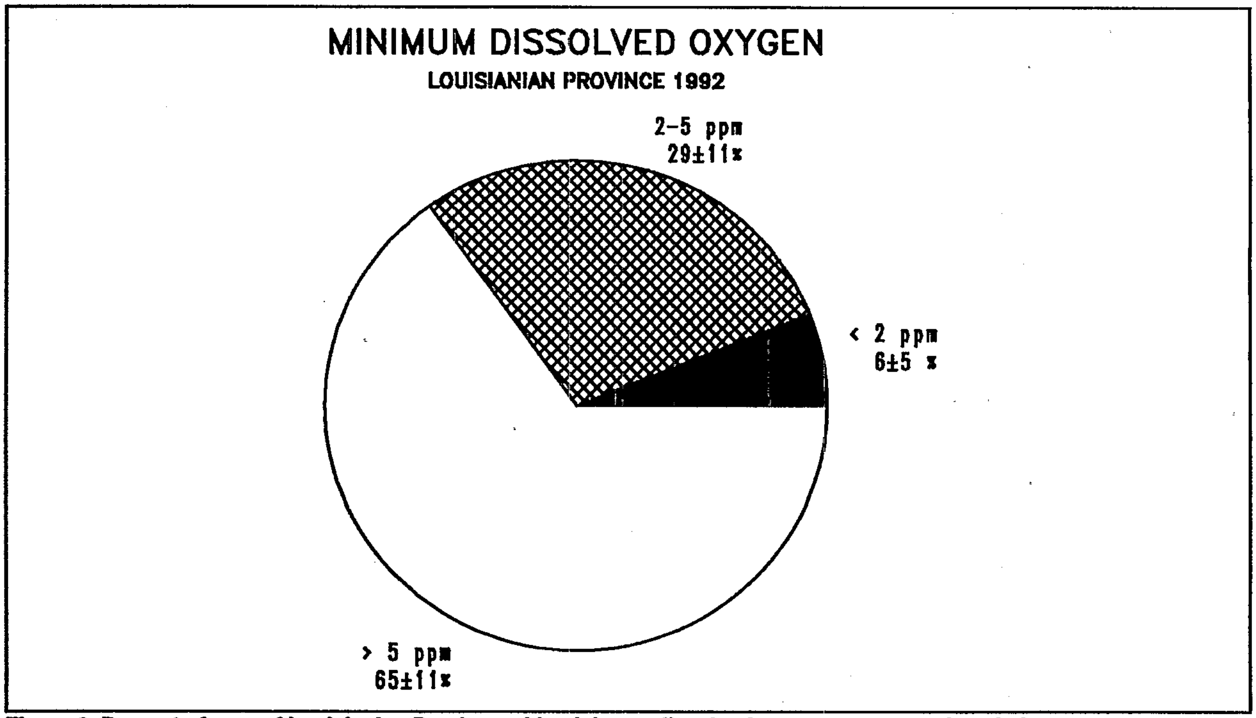

Figure 9. Percent of area of Louisianian Province with minimum dissolved oxygen concentrations in bottom waters < 2ppm, 2-5 ppm, and > 5 ppm based on 24 hours of data.

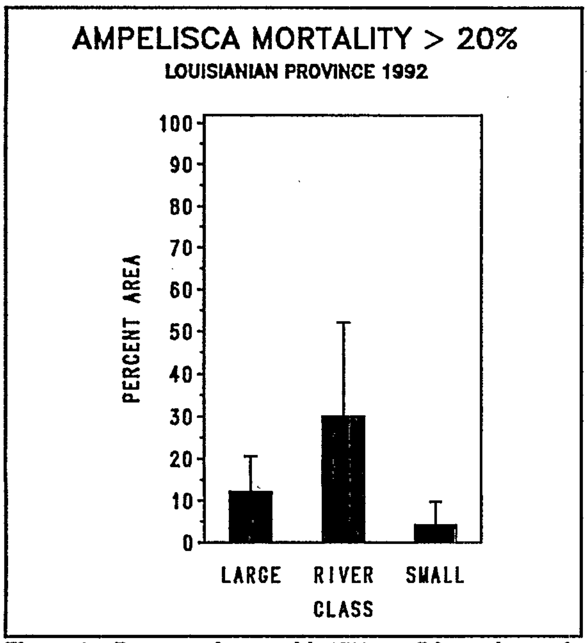

Figure 10. Percent of area with 95% confidence intervals having sediment toxicity for large estuaries (large), small estuaries (small), and large tidal rivers (river).

hypothesized levels that could cause biotic effects and that could be attributed to human activities. For this summary, sediment contaminants will be discussed as five major groups: heavy metals, alkanes and isoprenoids, polynuclear aromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenyls (PCBs) and as a single group of contaminated substances. For all contaminants, the criteria used to assess potential for degradation were the Long and Morgan (1990) median values (ER-M) associated with biological effects. All values above these median criteria were assessed as being representative of sediment degradation. In addition, the 10% Long and Morgan values (ER-L) were used to assess locations where some contamination occurred but at levels that could result in ecological problems some of the time. These criteria levels are not available for all toxic substances. The criteria used for contaminants are shown in Table 4.

Chemical Analyte	Criterion for Potential Degradation 10% Effects	Criterion for Degradation 50% Effects
Trace Elements (ppm)		
Antimony	2	25
Arsenic	33	85
Cadmium	5	9
Chromium	80	145
Copper	70	390
Lead	35	110
Mercury	0.15	1.3
Nickel	30	50
Silver	1	2.2
Tin	NA	NA
Zinc	120	270
Polychlorinated Biphenyls (ppb)		
Total PCBs	50	400
DDT and Metabolites (ppb)		
DDT	1	7
DDD	2	20
DDE	2	15
Total DDT	3	350
Other Pesticides (ppb)		
Lindane	NA	NA
Chlordane	0.5	6
Heptachlor	NA	NA
Dieldrin	0.02	8
Aldrin	NA	NA
Endrin	0.02	45
Mirex	NA	NA
Polynuclear Aromatic Hydrocarbons (ppb)		
Acenaphthene	150	650
Anthracene	85	960
Benzo(a)anthracene	230	1600
Benzo(a)pyrene	400	2500
Benzo(e)pyrene	NA	NA
Biphenyl	NA	NA
Chrysene	400	2800
Dibenz(a,h)anthracene	60	260
2,6-dimethylnaphthylene	NA	NA
Fluoranthene	600	3600
Fluorene	35	640
1-methylnaphthalene	NA	NA
2-methylnaphthalene	65	670
1-methylphenanthrene	NA	NA
Naphthalene	340	2100
Perylene	NA	NA
Phenanthrene	225	1380
Pyrene	350	2200
2,3,5-trimethylnaphthalene	NA	NA
Total PAH	4000	35000

Table 4. Criteria values used to characterize degraded sediments (from Long and Morgan 1990). NA= Not available.

Natural sources of metals and chemical and physical processes in estuaries may concentrate metals in fine-grained sediments or in depositional areas of estuaries. In addition to the criteria-based assessments described above, analyses were conducted to distinguish areas with elevated concentrations of metals as a result of anthropogenic enrichment by adjusting for aluminum sediment concentrations. Based upon these two approaches, 17±9% of the Louisianian Province has sediments with elevated concentrations of one or more heavy metals based on the criteria values and 20±9% of the area has heavy metal concentrations that were higher than would be expected based on aluminum background concentrations (Fig. 11). These elevated metals were primarily copper, arsenic, lead, mercury, and zinc. Enriched metal concentrations varied widely among classes with the greatest enrichment (21±23% of sediments) occurring in the small estuaries,

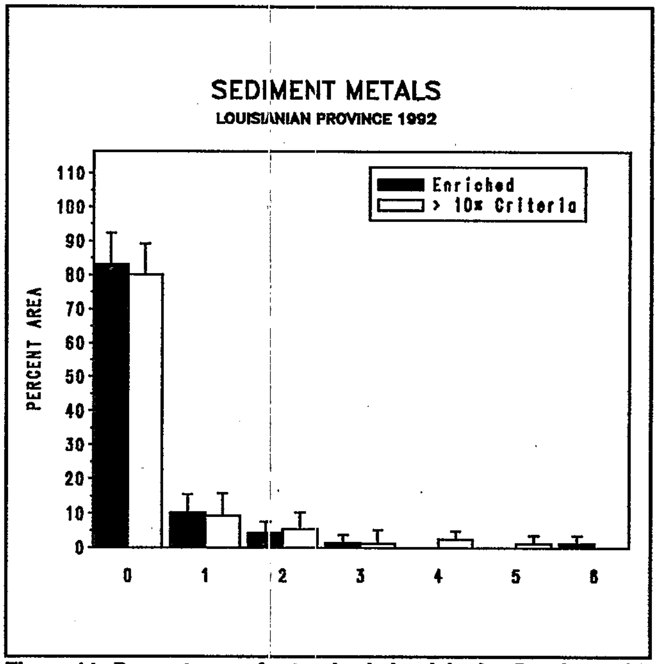

Figure 11. Percent area of estuaries in Louisianian Province with one or more sediment heavy metal concentrations > 10% Long-Morgan sediment criteria or greater than expected based on aluminum concentrations (bars represent 95% confidence intervals).

16±10% of the sediments being enriched in large estuaries, and only 5±22% of sediments in large tidal river systems.

Alkanes and isoprenoids are hydrocarbons associated with the petrochemical industry (drilling, transport, refinement). While 27 individual alkanes were examined, total alkanes were used to provide an overall assessment of sediment contamination due to alkanes. A criteria value of >7000 ppb total alkanes was used to characterize a degraded estuarine condition. An intermediate criterion of 5000-7000 ppb total alkanes was used as indicative of potential contamination. Eleven percent of the sediments in the Louisianian Province had elevated levels of alkanes. Elevated levels of alkanes were observed in 60±29% of the sediments of the large tidal rivers class and the proportion of area displaying elevated alkane concentrations in large and small estuaries were similar, 7±7% and 13±13%, respectively (Fig. 12).

Polynuclear aromatic hydrocarbons represent a common component of the contaminants released by point source industrial effluents. A total of 44 individual PAHs was examined but criteria levels were available for only 12 of these compounds (Long and Morgan 1990).

However, a criterion is available for total PAHs based on the Long and Morgan (1990) estimate for sediment concentrations resulting in biological effects 50% of the time -- >35,000 ppb. Due to the magnitude of this concentration, we also examined the concentration range that produced ecological effects >10% of the time -- >4000 ppb total PAHs. No total PAH concentrations in the observed Louisianian Province sediments exceeded 35,000 ppb. Only 4±4% of the province is characterized by the intermediate total PAH concentration of > 4000 ppb. No elevated PAH values were observed in large estuaries or large tidal rivers. The intermediate level of PAHs was found primarily in large estuarine systems comprising 5±6% and 30±32% of the total sediments in large tidal rivers (Fig. 13).

Polychlorinated biphenyls (PCBs) represent very toxic compounds in the environment. Twenty-five individual PCB congeners were examined in the 1992 Louisianian Province Demonstration. Long and Morgan (1990) provide a criterion of >400 ppb total PCBs as the concentration likely to result in ecological effects. They provide a secondary concentration of >50 ppb at which some effects might be expected. Total PCB concentrations in observed Louisianian Province sediments did not exceed 400 ppb. None of the Louisianian Province sediments were characterized by total PCB concentrations > 40 ppb.

Pesticides are introduced into the estuarine environment through three pathways: direct emission as a result of point source discharge

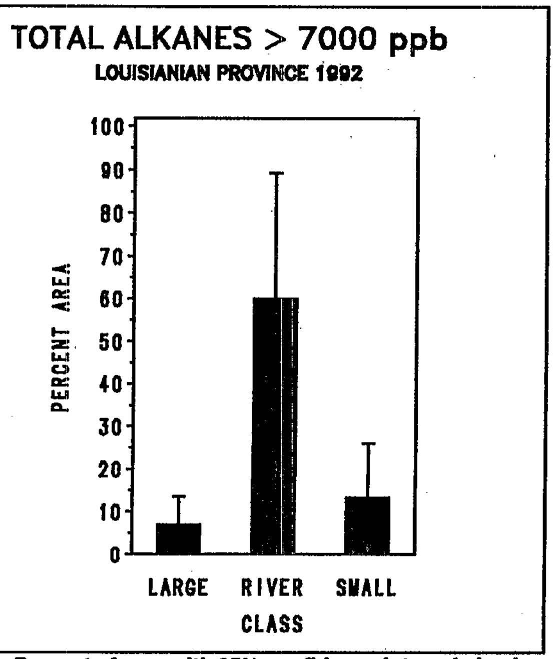

Figure 12. Percent of area with 95% confidence intervals having total PAH concentrations in sediment > 7000 ppb for large estuaries (large), small estuaries (small), and large tidal rivers (river).

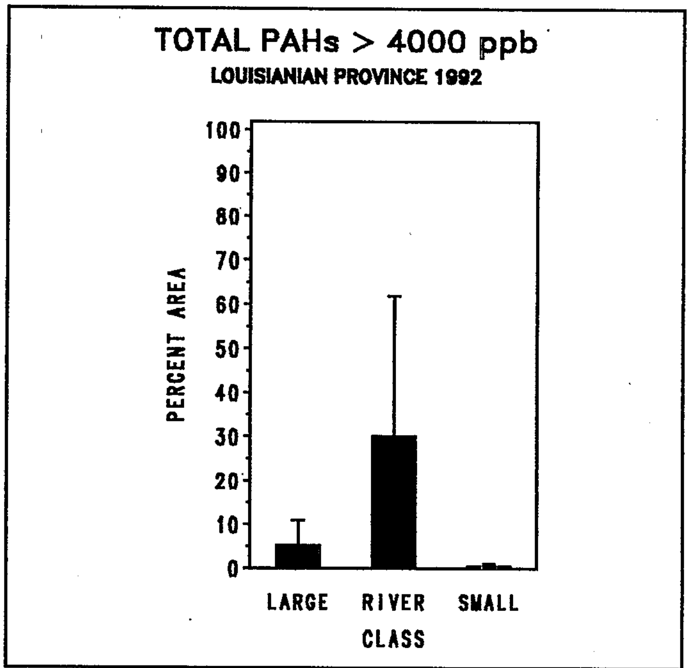

Figure 13. Percent of area and 95% confidence intervals having total PAH concentrations in sediment > 4000 ppb for large estuaries (large), small estuaries (small), and large tidal rivers (river).

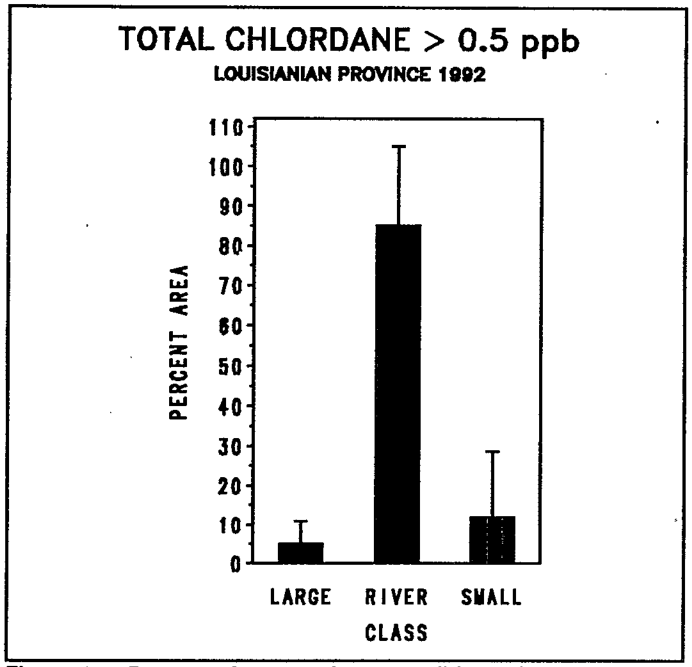

Figure 14. Percent of area and 95% confidence intervals having chlordane concentrations in sediments > 0.5 ppb for large estuaries (large), large tidal rivers (river), and small estuaries (small).

(generally through manufacture or disposal), non-point emission through agricultural or horticultural application, and atmospheric through deposition of volatilized materials. In the 1992 Louisianian Province Demonstration, 25 pesticides and derivatives were examined. For this summary, total pesticides, total DDT, and total chlordane are reported. Generally accepted sediment quality criteria are not yet available and even reasonable criteria are only available for 9 of the 25 pesticides examined. Long and Morgan (1990) report the following critical concentrations for DDT, DDD, DDE, chlordane, dieldrin, and endrin: 7 ppb, 20 ppb, 15 ppb, 6 ppb, 8 ppb, and 45 ppb, respectively.

The DDT criteria value of 7 ppb was not exceeded for the sediments in the Louisianian Province. However, 17±9% of the sediments showed total DDT (including DDE and DDD) concentrations exceeding 1 ppm.

Total chlordane showed concentrations > 0.5 ppb in 8±6% of the sediments of the Louisianian Province with some individual sediment samples exceeding 4 ppb. Elevated chlordane concentrations were observed in all three estuarine classes (Fig. 14) with 85±20% of the sediments in large tidal rivers showing elevated concentrations; 12±17% in small estuaries and 5±6% in large estuaries.

Tributyltin was measured at sediment concentrations > 1 ppb in 42±11% and > 5 ppb in 3±3% of the sediments of the Louisianian Province. Using 5 ppb as a clear indicator of degraded conditions, most of the high-TBT sediments were found in large tidal rivers (20±4% of sediments) and to a lesser extent in large (3±2%) and small (2±1%) estuarine sediments (Figure 15).

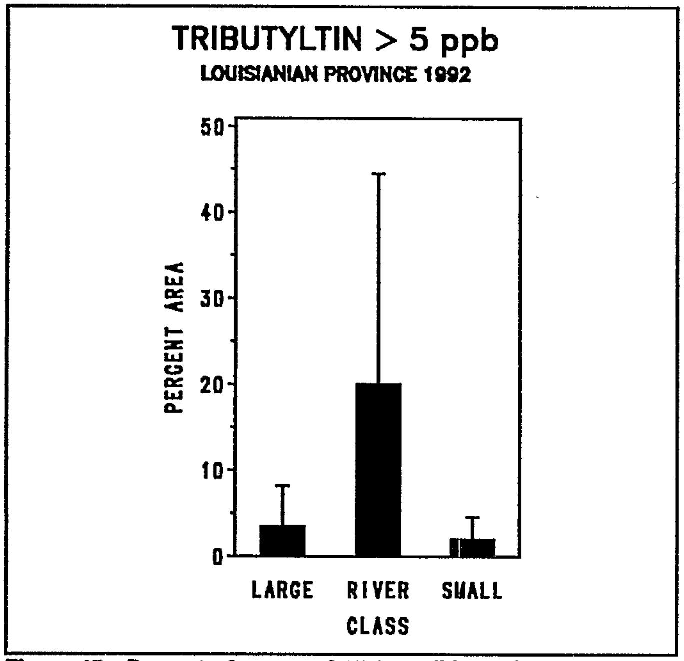

Figure 15. Percent of area and 95% confidence intervals having sediments with tributyltin > 5 ppb for large estuaries, large tidal rivers, and small estuaries.

Ninety-five percent confidence intervals (95% CI) were calculated for all parameters described in this summary. Table 5 provides the 95% confidence intervals for the major indicators for the proportion of the province and the three estuarine classes.

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	**100**	**58**	**32**	**43**
Estuarine Condition	36(11)	33(12)	100(17)	42(25)
(% of Province showing degraded biological resources or impaired use)				
BIOTIC CONDITION				
Benthic Index	27(10)	24(11)	90(22)	33(24)
Abundance < 10	15(9)	9(7)	20(21)	30(26)
# Species < 2	10(9)	3(5)	25(22)	25(26)
# Species ≤ 5	21(10)	16(9)	70(26)	33(26)
Fish				
Abundance < 2	13(8)	14(9)	60(29)	12(16)
Abundance ≤ 5	20(9)	22(11)	90(26)	13(16)
# Species < 1	4(4)	5(6)	15(20)	< 1(1)
# Species < 2	11(8)	12(8)	40(29)	9(15)
Fish Pathology[1]	< 27(11)	< 27(12)	< 29(30)	28(26)
Fish Contaminants[1]				
Shrimp				
All > FDA Limits	0(0)	0(0)	0(0)	0(0)
Croaker				
All > FDA Limits	0(0)	0(0)	0(0)	0(0)
Marine Catfish				
Hg > FDA Limits	1(1)	1(1)	0(0)	0(0)
Others > FDA Limits	0(0)	0(0)	0(0)	0(0)
Bottom DO[2] < 2 ppm	5(5)	7(7)	0(0)	1(1)
Bottom DO[2] ≤ 5 ppm	22(10)	24(11)	10(19)	13(20)
Minimum DO < 2 ppm	6(5)	9(7)		< 1(1)
Sediment Toxicity	10(6)	12(8)	30(22)	4(6)

[1] Percentage based on sample size rather than estuarine area
[2] Instantaneous dissolved oxygen measurements

Table 5. Estimate of the proportion of the Louisianian Province and estuarine classes experiencing the levels of the listed parameters with associated 95% confidence intervals in parentheses (N = number of sampling sites).

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	**100**	**58**	**10**	**32**
ABIOTIC CONDITION				
Marine Debris	6(5)	7(7)	45(27)	4(4)
Water Clarity				
PAR < 10%	12(7)	10(8)	30(29)	17(14)
PAR < 25%	45(10)	29(12)	80(28)	84(16)
Silt-Clay Content				
< 20%	18(8)	21(10)	0(0)	11(10)
> 80%	29(10)	33(12)	45(27)	21(19)
Alkanes				
Total > 7000 ppb	9(6)	7(7)	60(29)	13(13)
PAHs				
Total > 4000 ppb	4(4)	5(6)	30(32)	< 1(1)
PCBs				
Total > 200 ppb	0(0)	0(0)	0(0)	0(0)
Pesticides				
Chlordane > .5 ppb	8(6)	5(6)	85(20)	12(17)
Dieldrin > .02 ppb	34(11)	31(12)	100(0)	39(27)
Endrin > .02 ppb	4(4)	5(6)	45(30)	1(2)
DDT > 1 ppb	< 1(1)	0(0)	10(22)	< 1(1)
DDE > 2 ppb	2(3)	2(3)	0(0)	1(2)
DDD > 2 ppb	< 1(1)	0(0)	15(25)	< 1(1)
Metals				
Ag > 1 ppm	0(0)	0(0)	0(0)	0(0)
As > 33 ppm	0(0)	0(0)	0(0)	0(0)
Cd > 5 ppm	0(0)	0(0)	0(0)	0(0)
Cr > 80 ppm	4(4)	5(6)	0(0)	0(0)
Cu > 70 ppm	0(0)	0(0)	0(0)	0(0)
Hg > .15 ppm	1(2)	2(3)	0(0)	< 1(1)
Ni > 30 ppm	10(7)	12(8)	0(0)	6(9)
Pb > 35 ppm	2(3)	3(5)	0(0)	< 1(1)
Sb > 2 ppm	1(2)	2(3)	0(0)	0(0)
Sn > 3 ppm	20(7)	10(8)	0(0)	12(17)
Zn > 120 ppm	10(7)	12(8)	0(0)	7(10)
Tributyltin				
TBT > 1 ppb	42(11)	34(12)	65(29)	61(24)
TBT > 5 ppb	3(3)	3(5)	20(24)	2(3)

Table 5 *(cont.)* Percent of area and 95% confidence intervals having sediments with tributyltin > 5 ppb for large estuaries, large tidal rivers, and small estuaries.

SECTION 1

INTRODUCTION

The Environmental Monitoring and Assessment Program (EMAP) is a national program initiated by EPA's Office of Research and Development (ORD)(USEPA, 1992). EMAP is an integrated federal program; ORD is coordinating the planning and implementation of EMAP with other federal agencies including the Agricultural Research Service (ARS), Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (FWS), Forest Service (FS), U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). These other agencies and offices participate in the collection and analysis of EMAP data and will use it to guide their policy decisions, as appropriate.

EMAP-Estuaries (EMAP-E) represents one portion of EMAP's efforts in near coastal environments and is jointly conducted by EPA/ORD and NOAA. These efforts are designed to provide a quantitative assessment of the regional extent of coastal environmental problems by measuring status and change in selected ecological condition indicators. In 1992, EMAP-E continued a demonstration project in the estuaries of the Louisianian Province (i.e., all estuarine areas located along the coastline of the Gulf of Mexico between the Rio Grande River, TX and Anclote Anchorage, FL). This Statistical Summary reports on the 1992 sampling effort.

1.1 OBJECTIVES OF THE 1992 LOUISIANIAN PROVINCE ESTUARINE SAMPLING

The specifics of the planning activities of the Louisianian Province Demonstration are documented in Summers et al. (1991). This continuing demonstration was held in the Louisianian Province to show the utility of regional monitoring programs for assessing the condition of estuarine resources. Sampling was conducted from July through August spanning 169 sites utilizing 30 field personnel and three program/logistical coordinators.

The objectives of the 1992 Louisianian Province Continuing Demonstration were to:

1) assess the condition of estuarine resources in the Louisianian Province using a probability-based sampling design; and,

2) develop and refine analytical procedures for using regional-scale monitoring data to assess the ecological status of estuaries and apply these procedures to establish the baseline conditions in the Louisianian Province.

1.2 ENVIRONMENTAL VALUES AND ASSESSMENT QUESTIONS

The environmental value depicted by the EMAP-E in the Louisianian Province, as well as other provinces, is estuarine condition. The subvalues comprising condition are ecological integrity and societal values.

Ecological integrity is comprised of ecosystem quality (estuarine trophic state and acreage of unique habitats) and biotic integrity (benthic index and fish index). The primary assessment questions relating to ecological integrity addressed by the demonstration in the Louisianian Province are:

- What proportion of the bottom waters of the estuaries in the Louisianian Province experience hypoxia (i.e., dissolved oxygen concentrations < 2 ppm greater than 20% of the time)?

- What proportion of the estuarine sediments of the Louisianian Province has benthic community structure indicative of polluted environments?

- What proportion of the estuarine waters of the Louisianian Province is eutrophic?

- What is the total acreage of submerged aquatic vegetation in the Louisianian Province?

- What proportion of fish populations in the Louisianian Province has characteristics similar to those indicative of polluted environments?

Societal values are characterized by consumptive uses (i.e., quantity and quality of fishery stocks) and non-consumptive uses (i.e., aesthetics and water contact). The primary assessment questions related to societal values are:

- What proportion of target fish in the Louisianian Province has contaminant concentrations in edible tissues greater than FDA action limits?

- What proportion of target species in the Louisianian Province has external gross pathologies in excess of 0.5%?

- What proportion of estuarine sediments in the Louisianian Province contains anthropogenic marine debris?

- What proportion of estuarine waters in the Louisianian Province has insufficient water clarity to permit < 10% of incident sunlight to reach a depth of 30 cm?

- What proportion of estuarine waters in the Louisianian Province has unacceptable levels of pathogenic microbial agents?

In addition, several assessment questions relate to the relationships among the response indicators measured to address the above assessment questions and stressor conditions in the estuaries of the Louisianian Province. These questions are:

- Are observed areas of eutrophic condition in the Louisianian Province associated with stressor conditions?

- Are observed areas of poor biotic community conditions in the Louisianian Province associated with stressor conditions?

- Are observed areas of poor societal value conditions in the Louisianian Province associated with stressor conditions?

Many of these assessment questions are addressed in this statistical summary; however, some of the associational questions are not addressed in this summary but are addressed in the Louisianian Province Demonstration Report (Summers et al. 1993a).

1.3 PURPOSE AND ORGANIZATION OF THIS REPORT

The purpose of this report is to provide estimates of the ecological condition of the estuarine resources of the Louisianian Province during 1992. This report is meant to be a summarization of all the data collected in the 1992 Demonstration. As a result, different topics are dealt with using varying levels of detail based on their importance to the estimation of ecological condition of the estuarine resources of the Louisianian Province.

The Statistical Summaries that will be produced by EMAP-E are meant to provide large quantities of information without extensive interpretation of these data. Interpretive reports are anticipated every 4 to 5 years or in specialized documents such as the Demonstration Report for the Louisianian Province (Summers et al. 1993a). As a result, the Statistical Summaries will not provide information concerning sampling methodologies, field logistics, the development of indicators, and design modifications. Additional or expanded sections on methods, logistics, designs, and indicators were included in the 1991 EMAP-E Statistical Summary (Summers et. al. 1993b). Also, to demonstrate the flexibility of the EMAP-E sampling design in the Louisianian Province, additional data presentations (i.e., across states and EPA regions) are provided, which may not be presented in other future EMAP-E Statistical Summaries.

Section 2 provides information about the results of the 1992 Demonstration with details of the regional ecological "report card" for the estuaries of the Gulf of Mexico.

Section 3 summarizes the conclusions that can be drawn from the 1992 Demonstration in the Louisianian Province as they relate to the stated objectives.

Section 4 lists the literature cited in this report.

Appendix A provides a series of subpopulation estimates created from the base monitoring data to represent the conditions in the estuarine resources in the five Gulf states and in the portions of EPA Regions IV and VI located in the Louisianian Province.

SECTION 2

STATISTICAL SUMMARY

The following discussion is organized by indicator type into biotic and abiotic condition indicators and habitat indicators. In each instance, an indicator will be described minimally with text, the cumulative distribution function (CDF) for that indicator will delineate the frequency of occurrence of observations within the province, and pie charts and bar graphs will delineate the proportions of the province or estuarine class showing particular magnitudes.

2.1 BIOTIC INDICATORS

Biotic condition indicators are characteristics of the environment that provide quantitative evidence of the status of ecological resources and biological integrity of a sample site from which they are drawn (Messer 1990). Ecosystems with a high degree of biotic integrity (i.e., healthy ecosystems) are composed of balanced populations of indigenous benthic and water column organisms with species compositions, diversity, and functional organization comparable to natural habitats (Karr and Dudley 1981). Response measures include measurements of the kinds and abundances of biota present and human use parameters that describe human perceptions of the condition of estuarine systems. Biotic condition indicators included in the 1992 Louisianian Province Demonstration included both measured and derived indicators: number of benthic species, abundance of total benthos, benthic community composition, benthic abundance by taxonomic group, a benthic index of condition based on bioindicators, number of fish species, abundance of finfish, fish community composition, target species abundances, fish lengths, a fish index of condition, and contaminants in fish and shellfish (i.e., pesticides, PCBs, and heavy metals).

2.1.1 NUMBER OF BENTHIC SPECIES

Total number of benthic species has been used to characterize the environment of estuarine habitats. Three replicate benthic grabs at each sampling location in the Louisianian Province resulted in a distribution of total number of benthic species mean ranging from 0 to nearly 90 species (Fig. 2-1). There are no significant differences among the replicates suggesting that, at least for region-wide characterizations of species distribution, a single replicate is acceptable. Selecting 2 and 5 species as critical values for "diverse" benthic communities based on comparisons of impacted and reference sites of similar salinity (Summers et al 1993b) results in 10±9% of the sediments in the province having near mono-specific stands of benthos, while 21±10% of the sediments have communities comprised of 5 or fewer species (Fig. 2-2). These areas with reduced numbers of benthic species are primarily located in the large tidal river and small estuaries classes (Fig. 2-3).

As a more meaningful comparison than simple total species numbers, the proportion of expected benthic species was estimated for the 1992 monitoring samples. This comparison

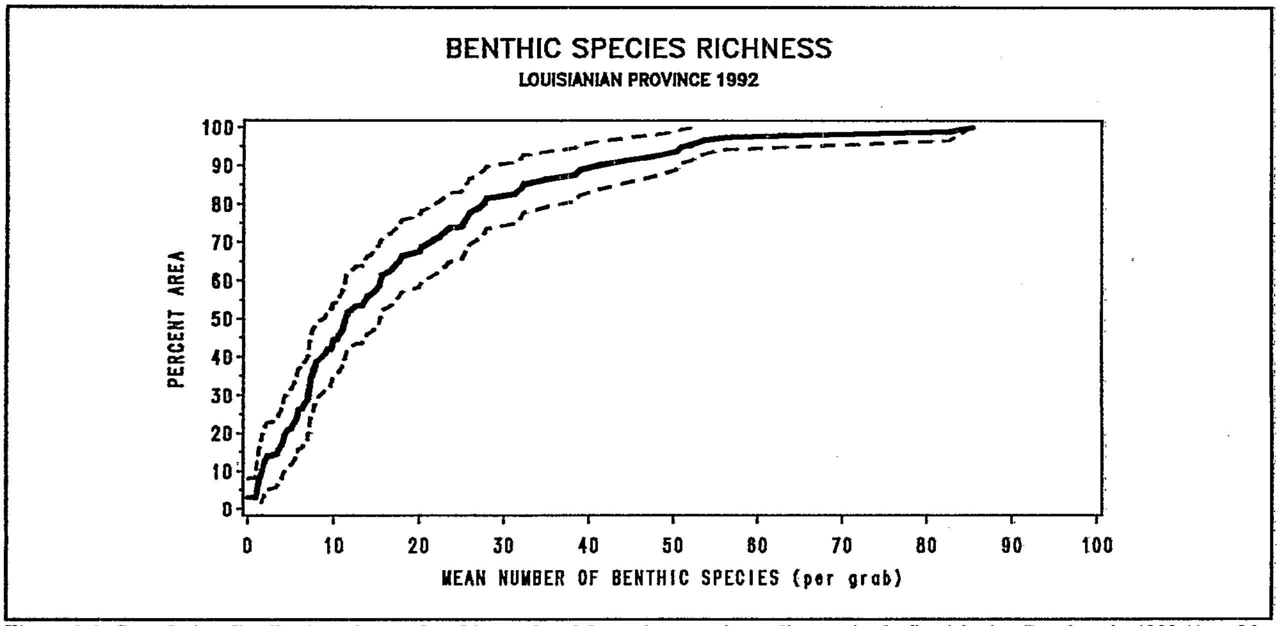

Figure 2-1. Cumulative distribution of mean benthic species richness in estuarine sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

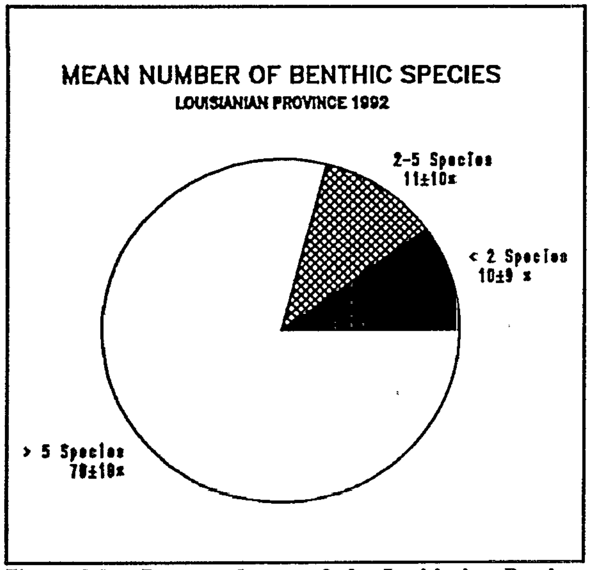

Figure 2-2. Percent of area of the Louisianian Province estuarine sediment associated with mean number of benthic species categories in 1992.

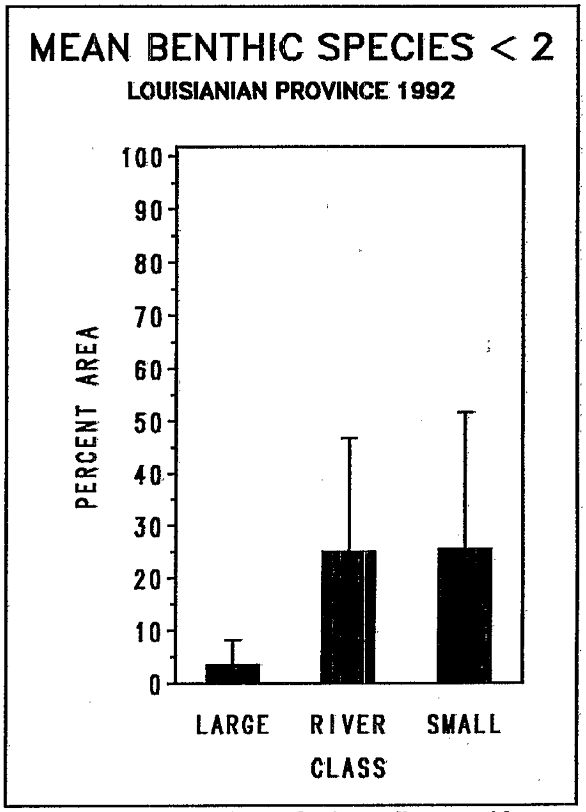

Figure 2-3. Percent of area having sediments with mean benthic species < 2 for large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

was based on the 1991-1992 regression of salinity and mean number of benthic species per grab (Engle et al. 1993). This proportion of expected number of species, normalized for salinity differences, ranged from 0.0 to 2.1 (Fig. 2-4). About 29±10% of the sediments of the Gulf of Mexico estuaries had < 33% of the expected number of species based on salinity zone; 32±10% had between 33 to 66% of expected species; and, 39±10% had > 66% of the number species expected based on salinity zone (Fig. 2-5). These areas of reduced expected numbers of benthic species are primarily located in the large tidal river and small estuary/small tidal river classes (Fig. 2-6). Benthic diversity associated with the three grabs varies widely over the province (Fig. 2-7) with 14±9% of the province having a benthic Shannon-Weiner diversity index of < 0.2 and 26±10% less than 0.4 (Fig. 2-8).

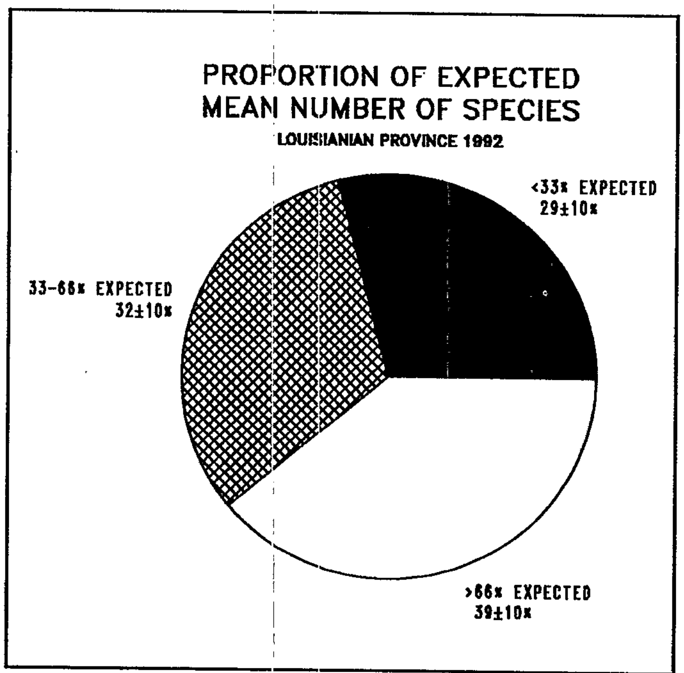

Figure 2-5. Percent area of the Louisianian Province estuarine sediments associated with proportion of expected benthic species categories in 1992.

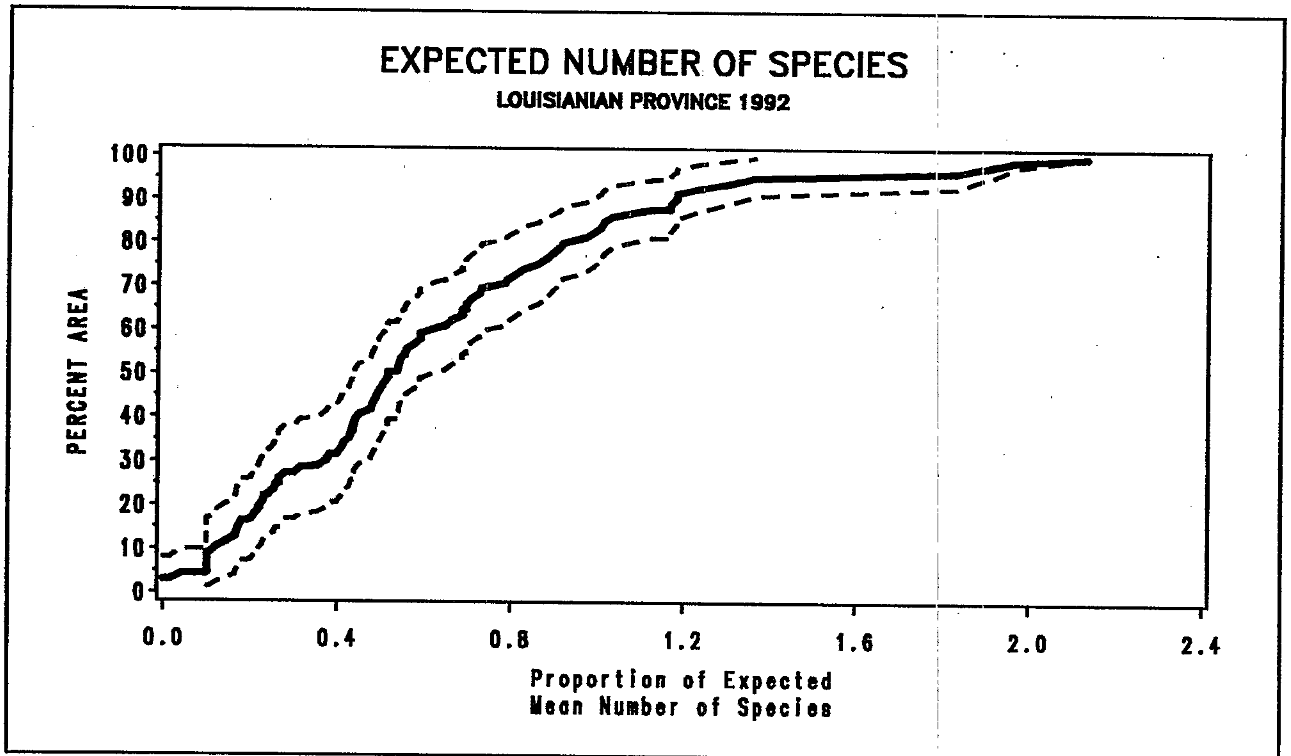

Figure 2-4. Cumulative distribution of proportion of expected number of benthic species observed in the estuarine sediments of the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

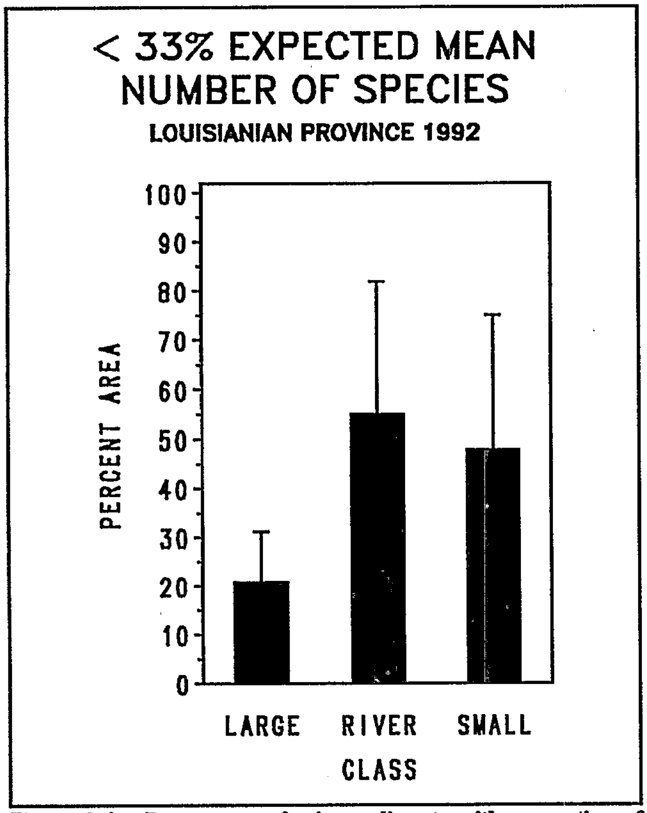

Figure 2-6. Percent area having sediments with proportion of expected benthic species < 33% in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

2.1.2 TOTAL BENTHIC ABUNDANCE

Benthic abundance is another indicator of the condition of biotic estuarine resources. Abundant benthic organisms particularly in communities characterized by multiple species and feeding types suggest a productive estuarine environment. Mean benthic abundance (Fig. 2-9) shows a range in benthic abundance in the Louisianian Province of 0 to about 1400 organisms per grab or over 30,000 organisms/m^2. Using 10 organism/grab (about 200/m^2) and 25/grab (about 500/m^2) as indicators of poor or marginal condition, respectively, 15±9% of Louisianian Province sediments have poor benthic abundance and an additional 13±11% have marginal abundance (Fig. 2-10). These areas of low abundance are primarily associated with small estuaries and large tidal rivers (30±26% and 20±21%, respectively,) (Fig. 2-11).

2.1.3 BENTHIC ABUNDANCE BY TAXONOMIC GROUP

The cumulative distribution functions can be used to describe the breakdown of the total benthic abundance described above into major taxonomic groups (Figs. 2-12, 2-13, 2-14, 2-15). Over 30% of the sediments sampled in the 1991 Louisianian Province Demonstration did not have amphipods as part of the community (Fig. 2-12) while 24% did have gastropods (Fig. 2-13). Tubificids are absent from 70% of sediments while polychaetes were found in 85-90% of the sediments sampled (Figs. 2-14 and 2-15).

2.1.4 BENTHIC INDEX

The construction of the 1991 benthic index was described in Summers et al. (1993b) and Engle et al. (1993). Initial validation of the 1991 benthic index model using 1992 data revealed some difficulties. About 20% of the stations sampled in 1992 were misclassified based on the 1991 benthic index model and the contaminant and hypoxia criteria used in 1991. The discriminant model that was developed in 1991 used the proportion of expected species diversity adjusted by numbers of indicator species to differentiate between a priori selected reference and affected sites according to the relationship:

91 Benthic Index =

(2.3841) * Proportion of Expected Diversity +
(-1.6728) * Percent Tubificid Abundance +
(0.6683) * Percent Bivalve Abundance

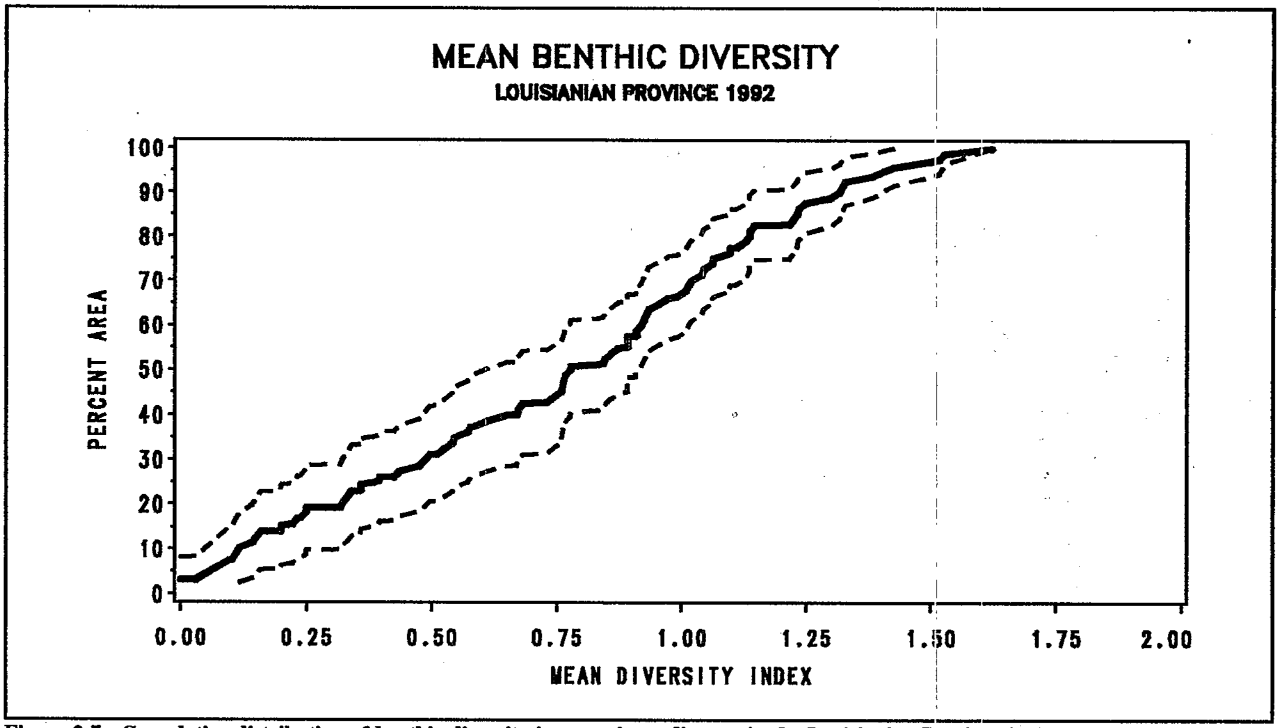

Figure 2-7. Cumulative distribution of benthic diversity in estuarine sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

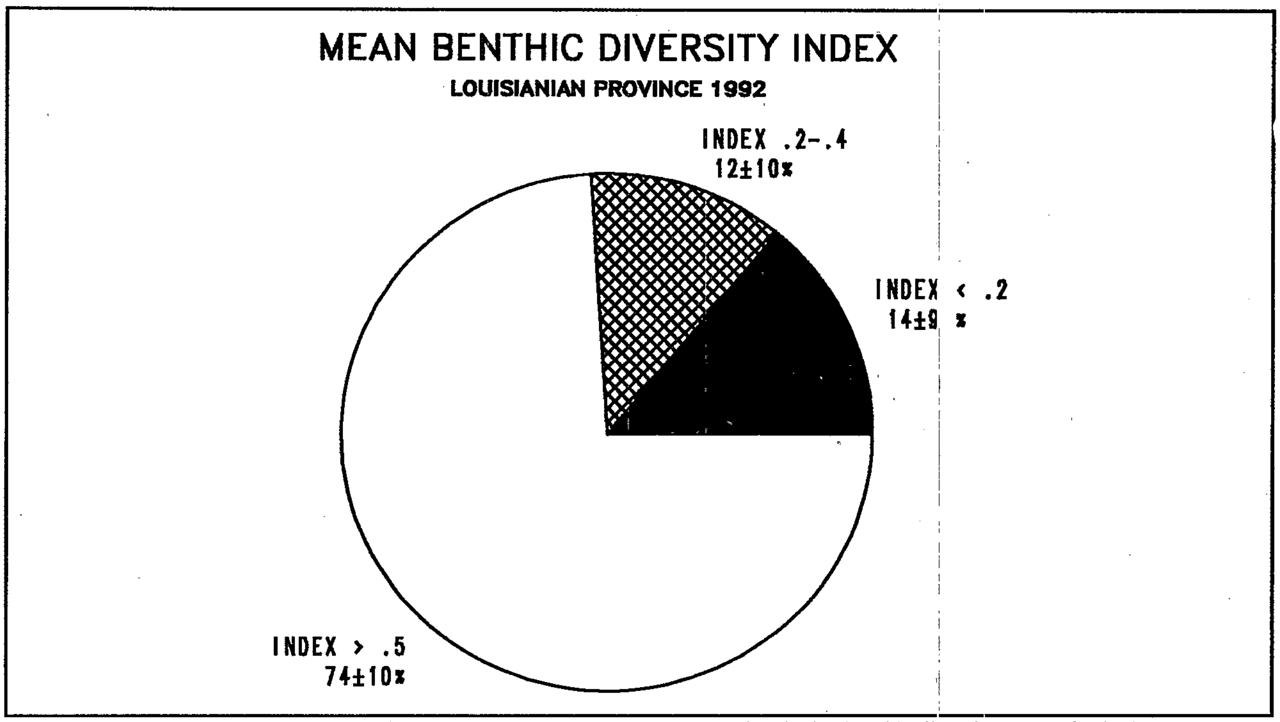

Figure 2-8. Percent area of the Louisianian Province estuarine sediments associated with benthic diversity categories in 1992.

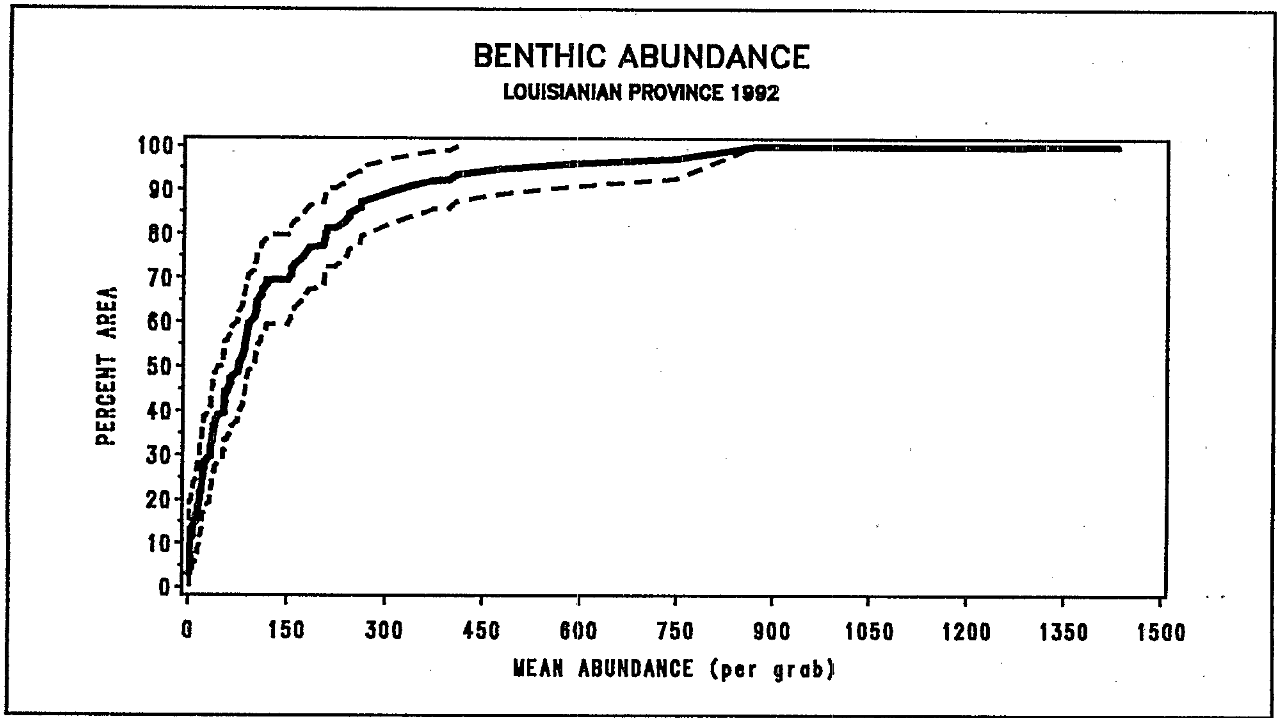

Figure 2-9. Cumulative distribution of mean abundance per grab in estuarine sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

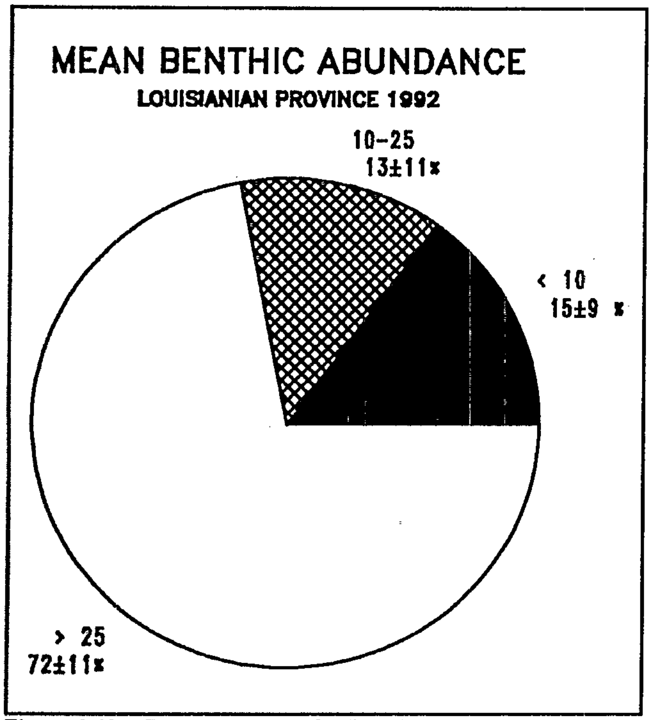

Figure 2-10. Percent area of the Louisianian Province estuarine sediments associated with benthic abundance categories in 1992.

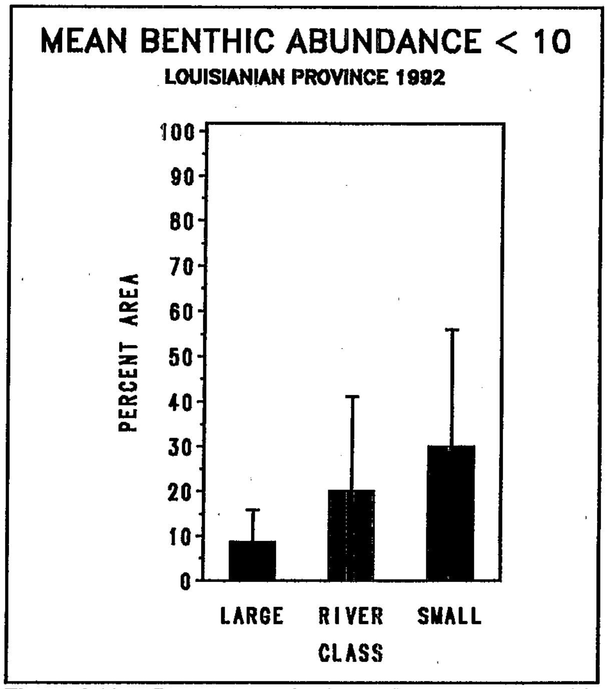

Figure 2-11. Percent area having sediments with benthic abundance < 10 organisms per grab in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

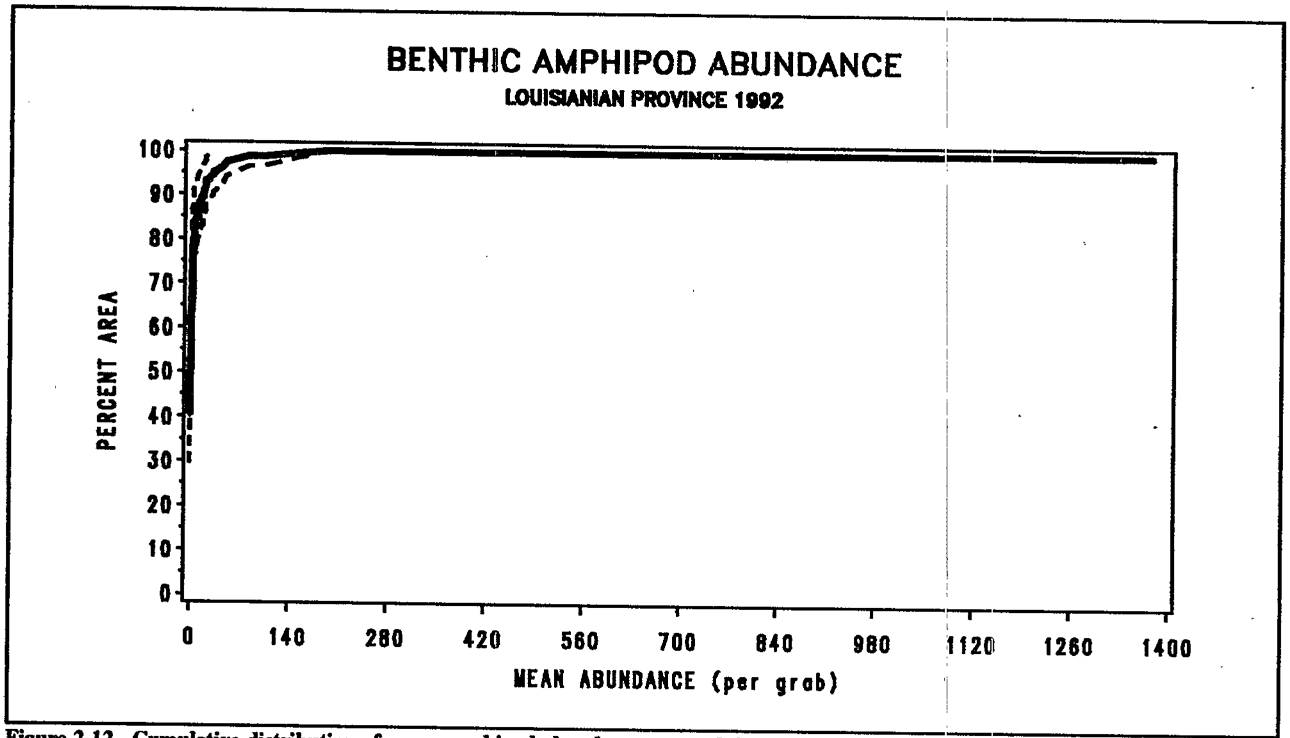

Figure 2-12. Cumulative distribution of mean amphipod abundance per grab in estuarine sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

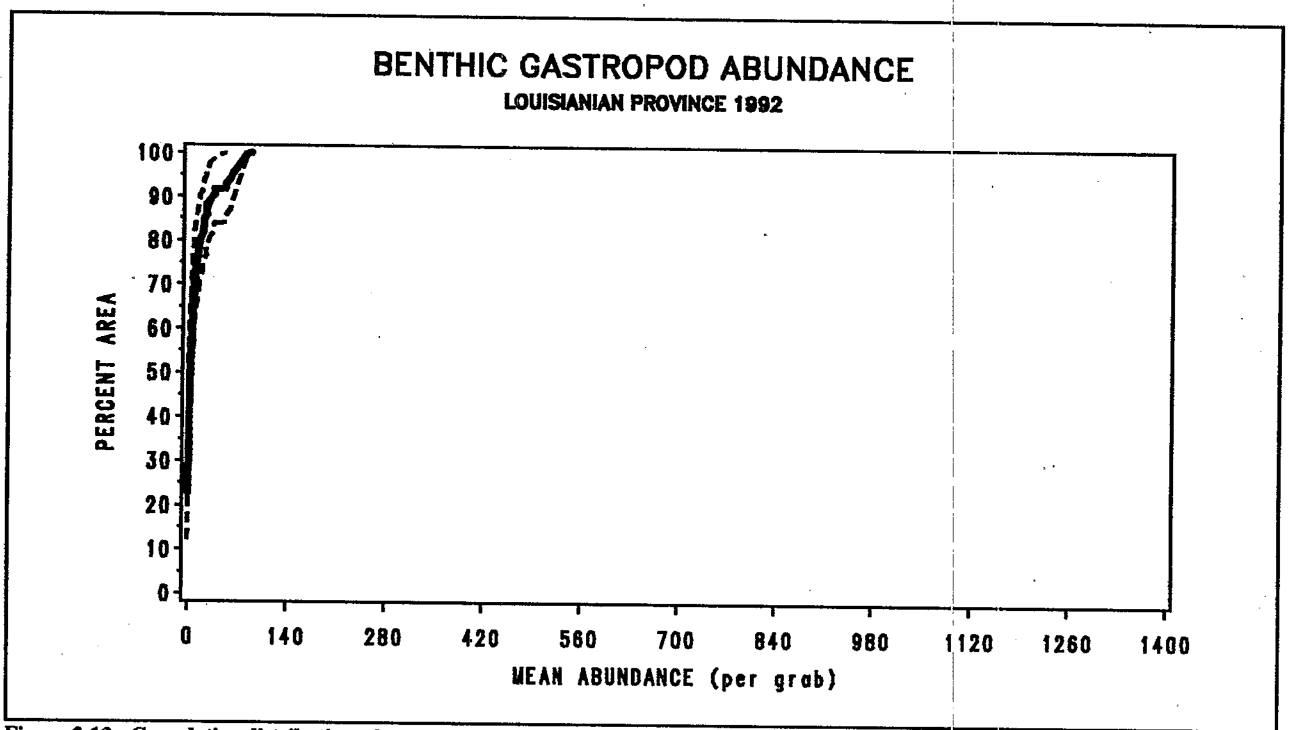

Figure 2-13. Cumulative distribution of mean gastropod abundance per grab in estuarine sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

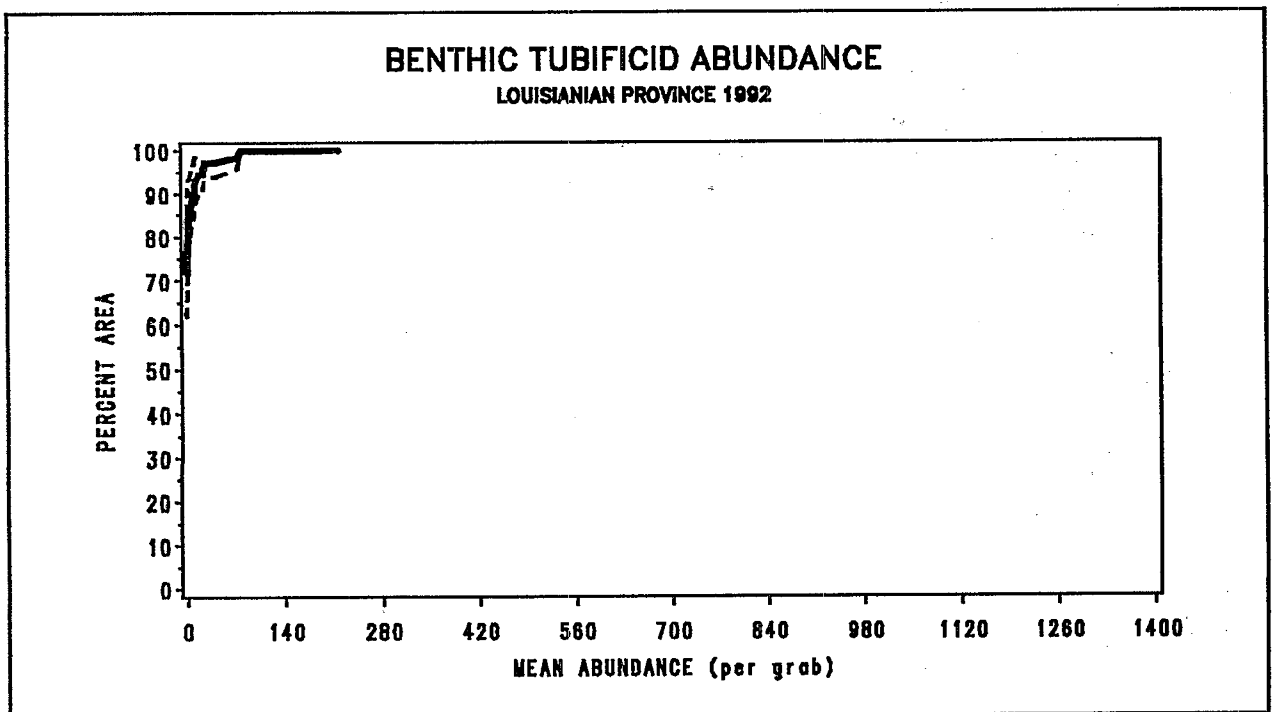

Figure 2-14. Cumulative distribution of mean tubificid oligochaete abundance per grab in estuarine sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

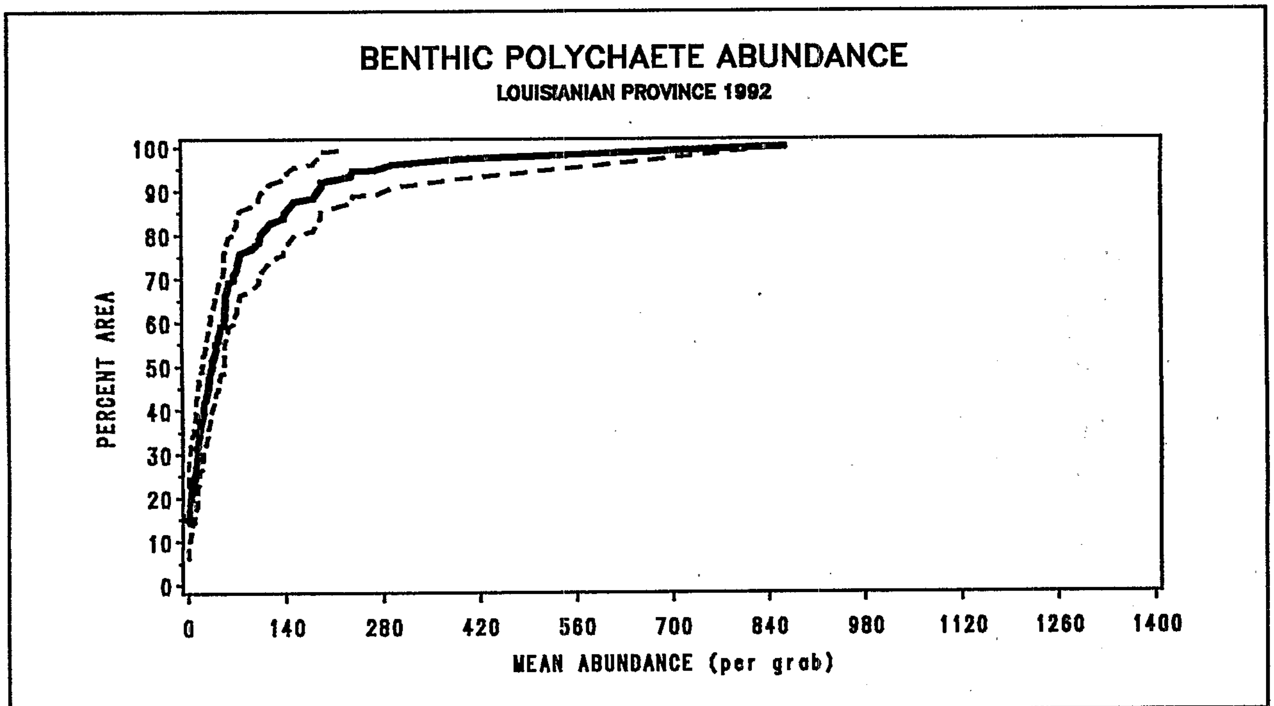

Figure 2-15. Cumulative distribution of mean polychaete abundance per grab in estuarine sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

The normalized benthic index scores for the Louisianian Province in 1991 ranged from 0 to 10.8 with the break point between stressed ("degraded") and reference ("undegraded") occurring at 4.1.

Use of the 1991 model on the 1992 data, showed several stations that were significantly more "degraded" than the 1991 test data set resulting in negative index values ranging to -11.5 (Fig. 2-16). As a result, we revised the benthic index based on the combined 1991-1992 benthic data. The 1991-1992 benthic index represents a refined version of the earlier model and encompasses a broader range of community conditions particularly for stressed environments. The 1991-1992 index ranged from -2.5 to 10.5 (Fig. 2-17) and is characterized by mean benthic diversity adjusted by indicator species presence and abundance:

91-92 Benthic Index = (2.028) * Species Diversity +
(0.763) * Percent Gastropod Abundance +
(0.561) * Percent Amphipod Abundance +
(-0.742) * Tubificid Abundance +
(-0.666) * Capitellid Abundance

This adjusted model accounts for 82% of the variability in the test data set with less than a 5% misclassification rate. A comparison of the 1991 and the 1991-1992 models showed no significant differences between the two models beyond the adjusted model better describing the range of the benthic data (i.e., sites with poor benthic conditions are predicted to be poor regardless of index). The combined 1991-1992 benthic data set better depicts the range of conditions observed in Gulf of Mexico estuarine environments over the two year span, particularly those in the Mississippi River. As a result, the adjusted 1991-1992 index described above is used to describe the condition of Louisianian Province benthic communities.

About 27±10% of the sediments in the Louisianian Province contained stressed or degraded benthic communities (Fig. 2-18) with the highest proportion of the communities occurring in large tidal rivers (90±22%) and small estuaries (33±24%) (Fig. 2-19). These figures do not suggest that these stressed communities are solely the result of anthropogenic influences. Some of the poor

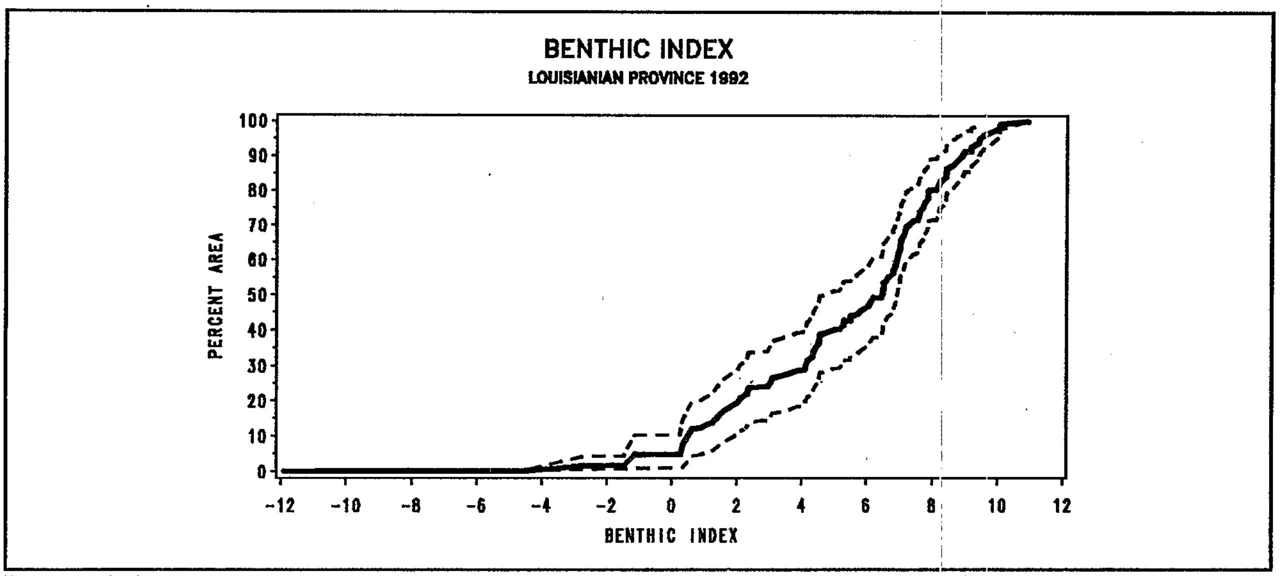

Figure 2-16. Cumulative distribution of 1991 benthic index applied to 1992 benthic data in the Louisianian Province (-) and its associated 95% confidence interval (--).

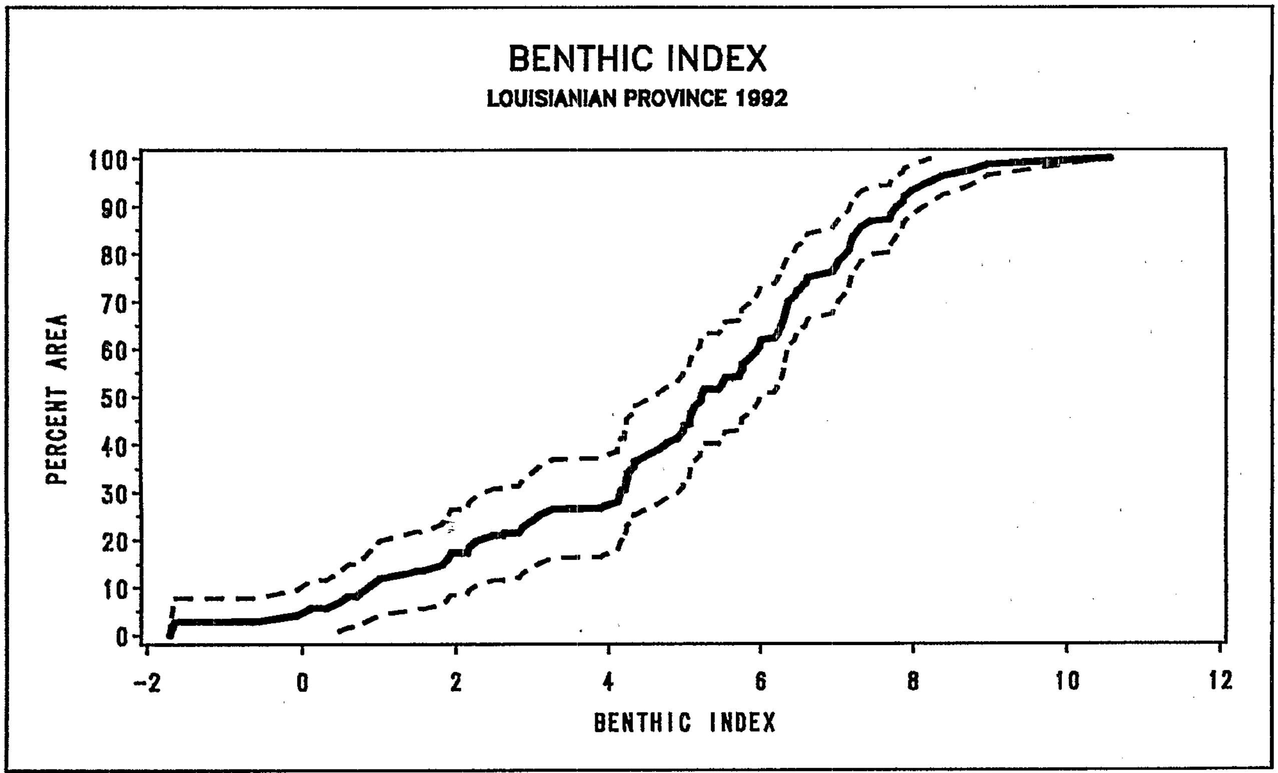

Figure 2-17. Cumulative distribution of revised 1991-1992 benthic index applied to the estuarine sediments of the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

benthic communities described could be the result of natural conditions (e.g., naturally induced hypoxia). However, 56% of the difference observed between stressed and unstressed benthic communities were associated with elevated concentrations of sediment contaminants or sediment toxicity while only 5% of the differences were attributable to low dissolved oxygen concentrations. The associations for the remaining 39% of the differences were either unknown or related to habitat variations (e.g. sediment enrichment).

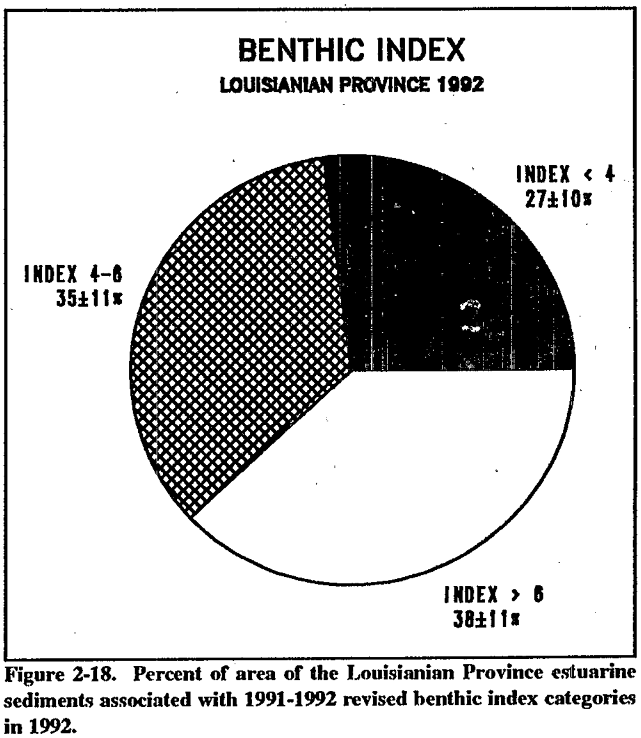

Figure 2-18. Percent of area of the Louisianian Province estuarine sediments associated with 1991-1992 revised benthic index categories in 1992.

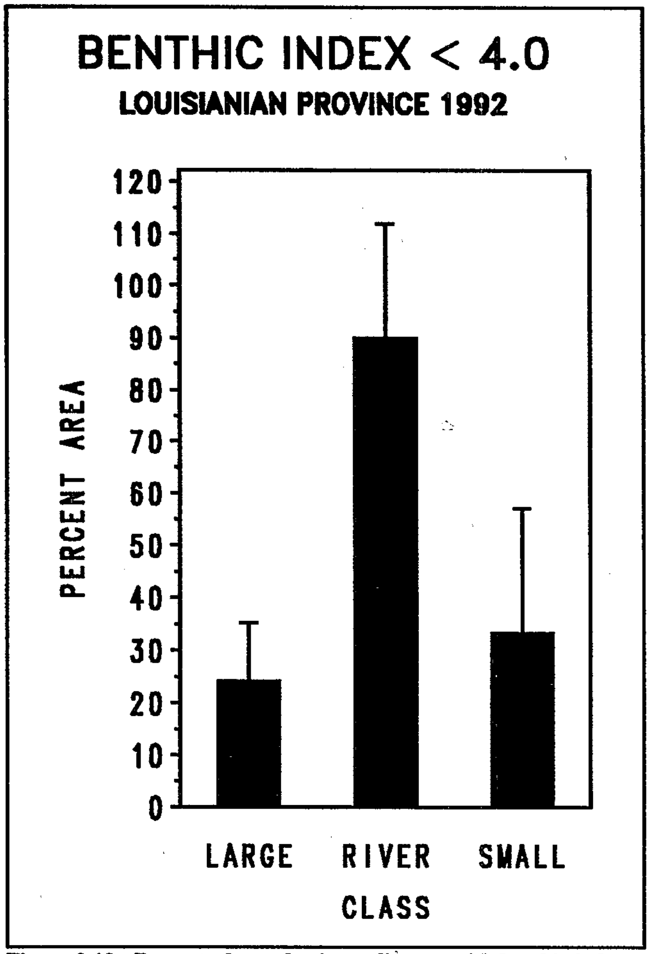

Figure 2-19. Percent of area having sediments with benthic index < 4.0 in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

2.1.5 NUMBER OF FISH SPECIES

Total number of fish species has been used to characterize the environmental condition of estuarine habitats. Dual 10-min trawls, taken at each sampling location in the Louisianian Province, resulted in a distribution of total number of nekton species per trawl ranging from 0 to 15 species (Fig. 2-20) with a total of 88 species collected throughout the province. Selecting 0 and < 2 species as comparative values for fish communities with low species abundance results in 4±4% of the province having no fish taken in multiple trawls, while 11±8% of the province had nekton communities comprised of < 2 species per trawl (Fig. 2-21). Areas having minimal < 2 nekton species are primarily located in the large tidal river class (Fig. 2-22).

2.1.6 TOTAL FINFISH ABUNDANCE

Finfish abundance is another indicator of the condition of biotic estuarine resources. Abundant nektonic organisms particularly in communities characterized by multiple species and feeding types suggest a productive estuarine food web. Finfish abundance in the trawls taken ranged from 0 to over 250 organisms per trawl (Fig. 2-23). Using 2 organisms/trawl and 5/trawl as values representing low and marginal numbers of fish abundance respectively, 13±8% of Louisianian Province waters have low finfish abundances and an additional 7±9% have marginal abundance (Fig. 2-24). These areas of low abundance are primarily associated with large tidal rivers where 60±29% of waters in the class have finfish abundances < 2 (Fig. 2-25).

2.1.7 EXTERNAL GROSS PATHOLOGY

The frequency and type of external gross pathology associated with nekton taken in the fish trawls is an indicator of the overall condition of fish collected in trawls. All fish that were collected during the 1992 Louisianian Province Demonstration were examined by the field crews for external gross pathologies, such as tumors and lesions. Over 20,000 fish were examined for gross pathologies and a total of 271 external pathologies were noted. Fourteen±10% of the area of the Louisianian Province produced trawls with > 2 pathologies/trawl (Fig. 2-26). Overall in the

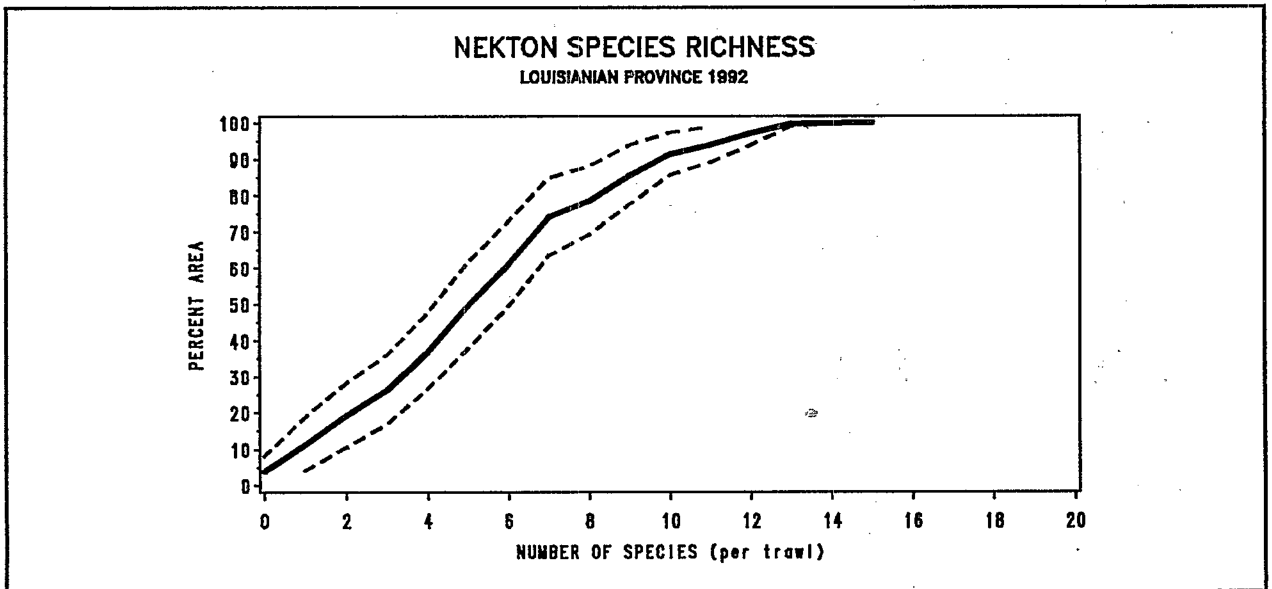

Figure 2-20. Cumulative distribution of number of fish species per trawl in the Louisianian Province estuaries in 1992 (-) and its associated 95% confidence interval (--).

province, 1% of the fish examined had visible pathological disorders (Fig. 2-27). The prevalence of abnormalities for demersal and commercially harvested fish (0.4% and 1.1%, respectively) was about the same as the background level observed for all fish (1.0%). However, upper trophic level fish (e.g.,

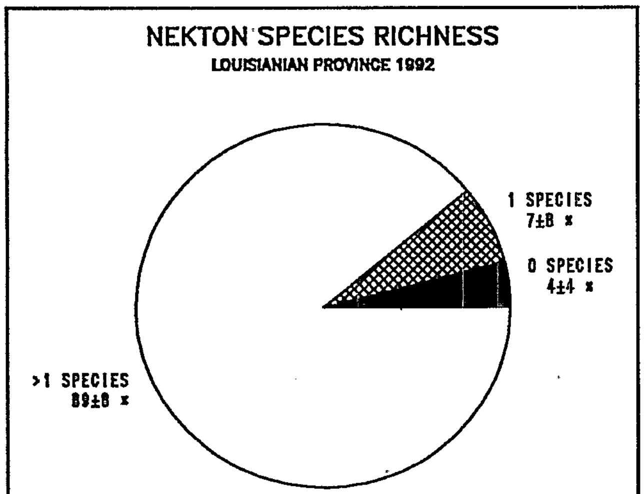

Figure 2-21. Percent of area of the Louisianian Province estuaries associated with the number of fish species per trawl categories in 1992.

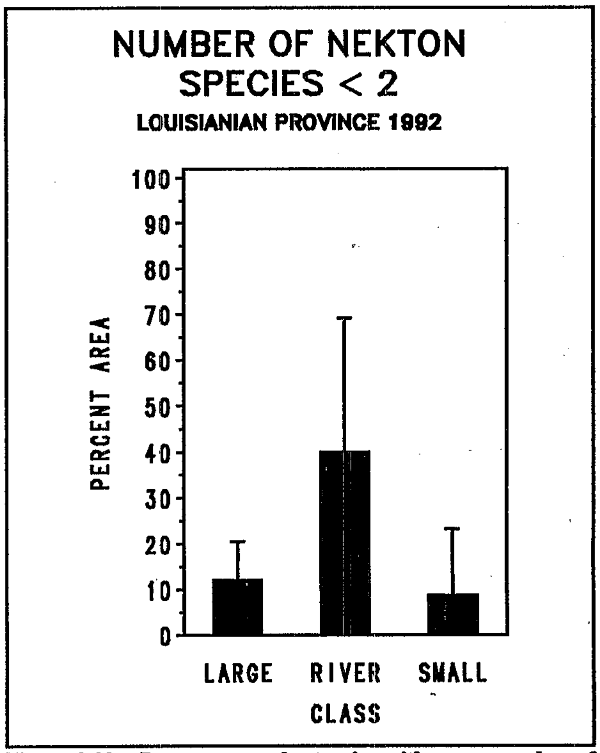

Figure 2-22. Percent area of estuaries with mean number of species per trawl < 2 species in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

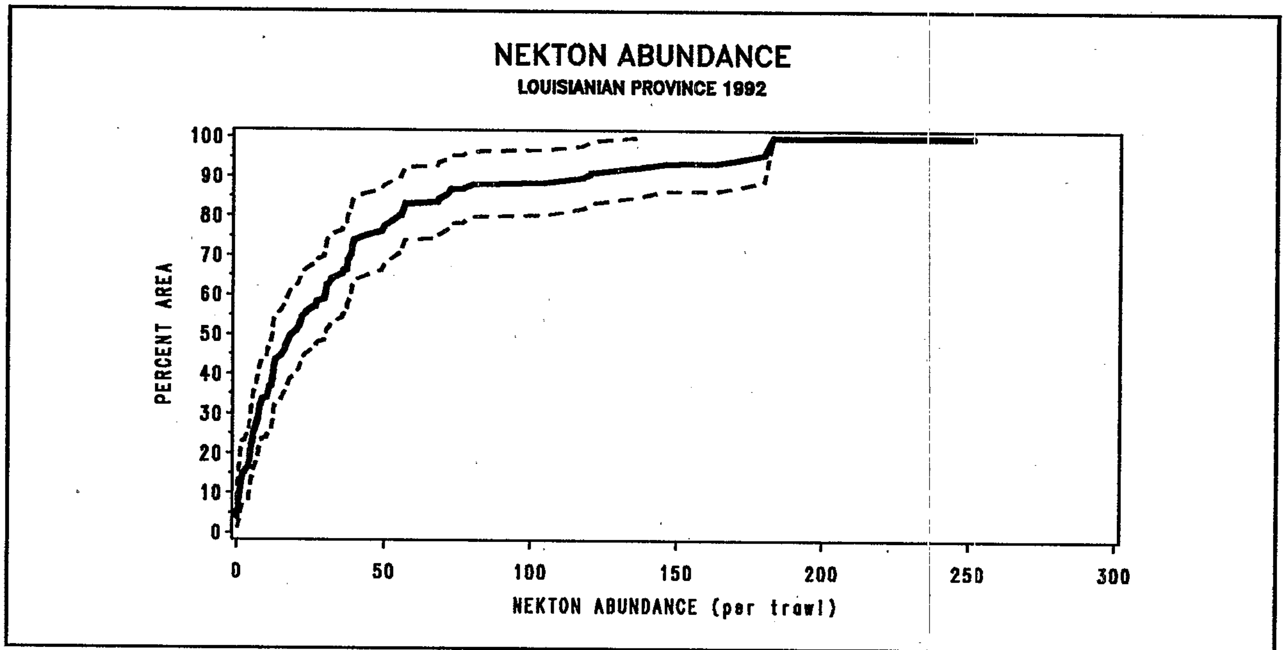

Figure 2-23. Cumulative distribution of mean fish abundance per trawl in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

piscivores) and pelagic species demonstrated a significantly higher incidence of pathology (2.7% and 4.2%, respectively) (Fig. 2-27). Examples of upper trophic level fish are seatrouts, permits, and spadefish. Pelagic species included menhaden and bumper. The

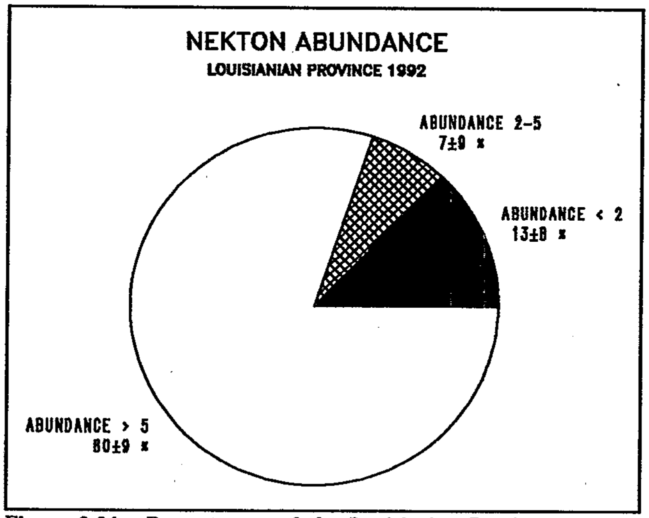

Figure 2-24. Percent area of the Louisianian Province estuaries associated with the mean fish abundance species categories in 1992.

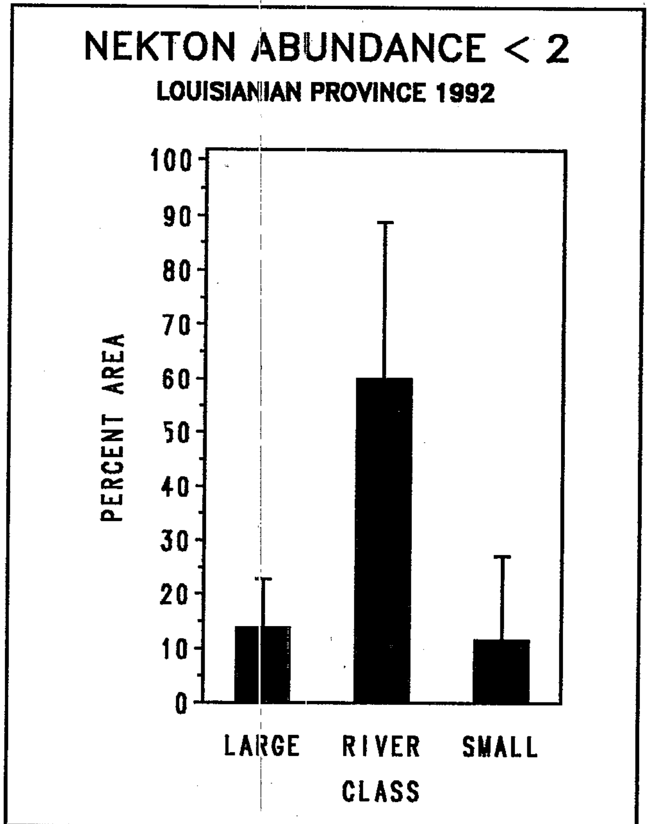

Figure 2-25. Percent area of estuaries with mean fish abundance per trawl < 2 species in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

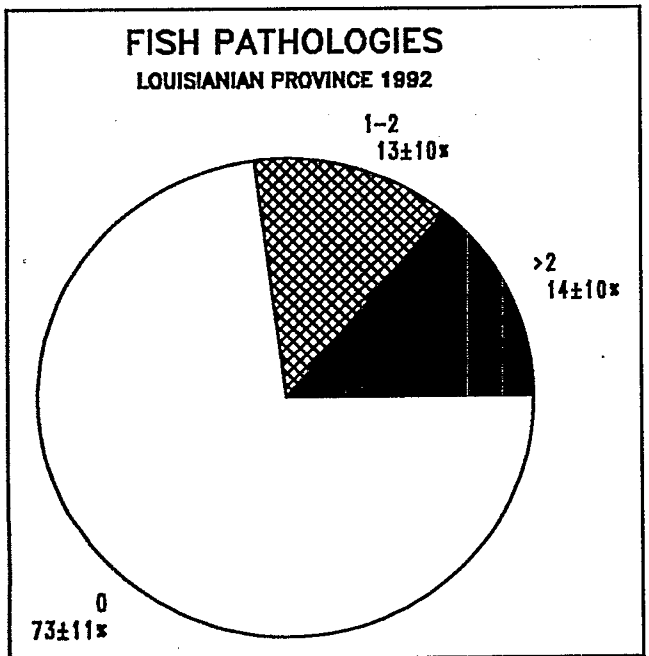

Figure 2-26. Percent of fish examined from the Louisianian Province estuaries associated with the number of external pathologies per trawl categories in 1992.

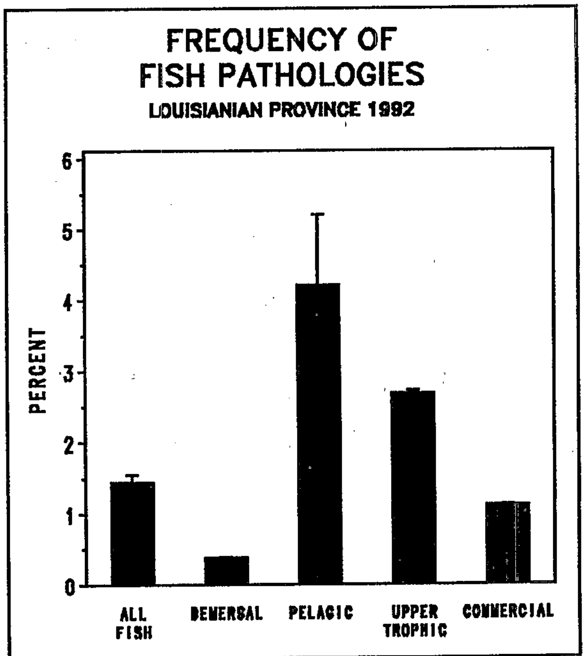

Figure 2-27. Percent of fish examined from the Louisianian Province with external pathologies by fish class (bars represent 95% confidence intervals).

majority of pelagic pathologies were noted at a single site. Removal of this site reduced the incidence of pelagic pathologies to 1.4%. Sand seatrout, threadfin shad, Gulf menhaden, Atlantic bumper and blue catfish had visible pathology rates that were clearly higher than the observed background. Although statistically significant from the background rate, the higher incidence of pathologies in permit, harvestfish, Spanish mackerel, and yellowfin menhaden are not supportable due to the small number of individuals of these species examined (< 100 fish).

2.1.8 MACROPHAGE AGGREGATES

Pigment-bearing macrophages are a prominent feature of fish spleen, kidney, and liver (Agius 1980) and, in advanced telosts, they form discrete aggregations called macrophage aggregates (MAs) (Wolke et al. 1985). Suggested functions for these aggregates include the centralizations of foreign materials and cellular debris for destruction, detoxification, and/or reuse (Ferguson 1976; Ellis et al. 1976). It has been demonstrated that MAs' occurrence may vary depending on the size, nutritional state, or health of a particular fish (Agius 1979, 1980; Agius and Roberts 1981; Wolke et al. 1985) with the number and size of MAs increasing with age, starvation, and/or disease. Recent studies suggest that MAs may be sensitive histological indicators of fish health and environmental quality (Summers et al. 1993b, Blazer et al. 1993). By comparing the MA number and percent area occupied by MAs, the general distribution of health condition of fish in the Louisianian Province can be described (Fig. 2-28).

About 10±0.1% of the fish sampled in the Louisianian Province contained macrophage aggregate concentrations > 40/mm^2 (Fig. 2-29).

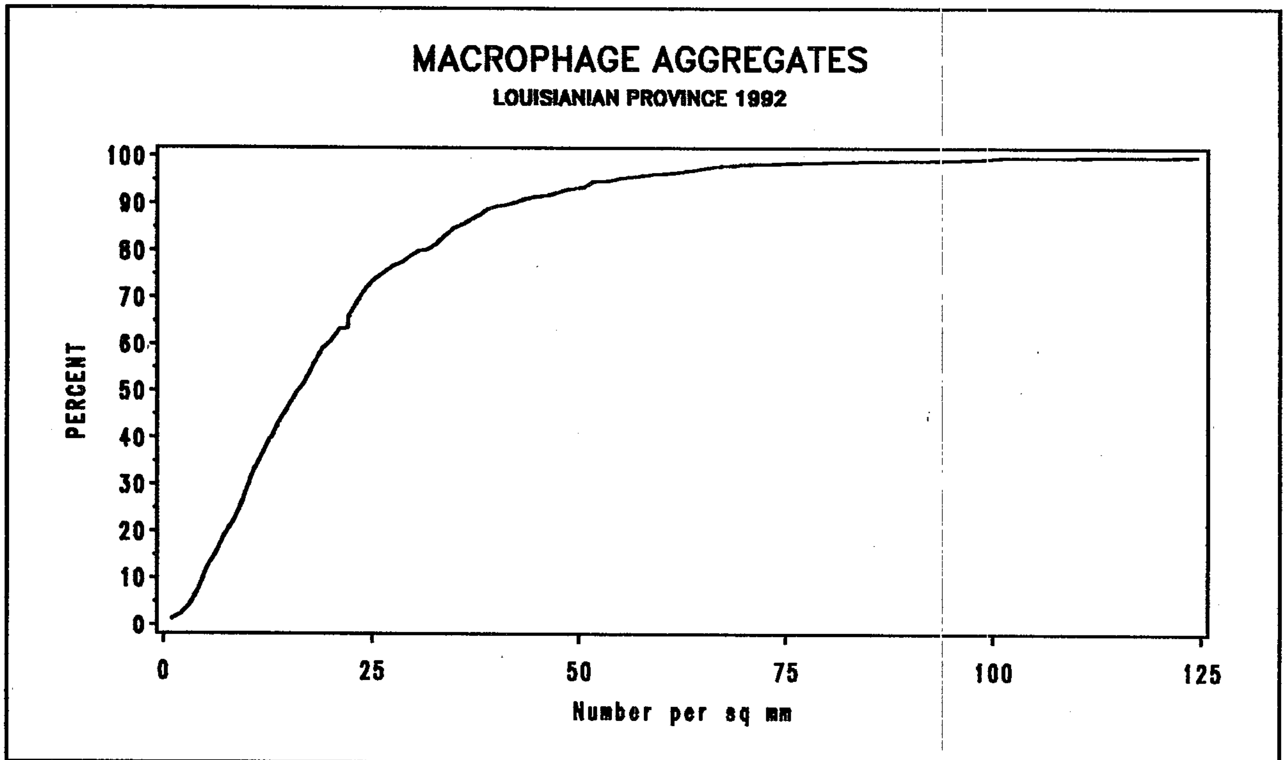

Figure 2-28. Cumulative distribution of number of macrophage aggregates per mm^2 in fish examined from the Louisianian Province in 1992 (associated 95% confidence interval too narrow to portray).

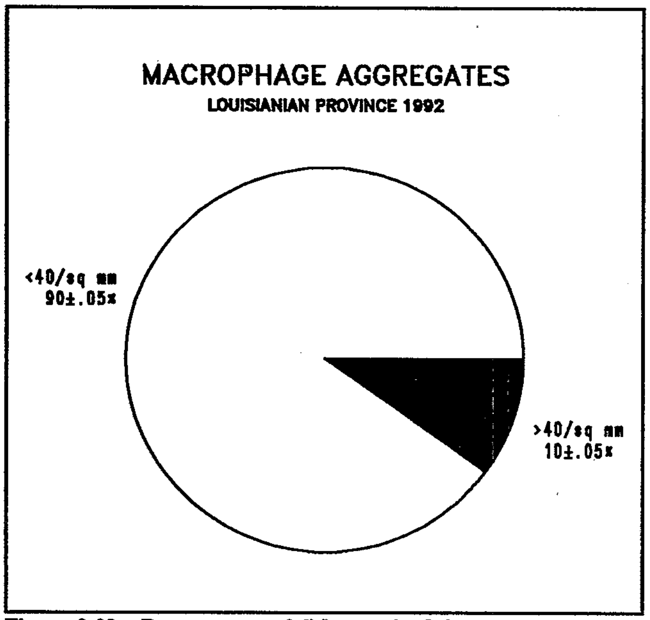

Figure 2-29. Percent area of fish examined from the Louisianian Province estuaries with number of macrophage aggregates per mm^2 in 1992.

The distribution of percent area occupied by macrophage aggregates is similar to number of aggregates with the proportion of the fish populations showing > 5% of spleen area covered by aggregates being 12±0.1% (Fig. 2-30). These figures do not suggest that these stressed communities are solely the result of anthropogenic influences. Some of the high level of macrophage aggregates described could be the result of natural conditions (e.g., naturally induced hypoxia, low food supply). However, 54% of the differences observed between locations with fish with high or low levels of macrophage aggregates were associated with sediment contaminants or sediment toxicity while only 4% of the differences were attributable to low dissolved oxygen concentrations. The associations for the remaining 42% of the differences were either unknown or related to habitat variations.

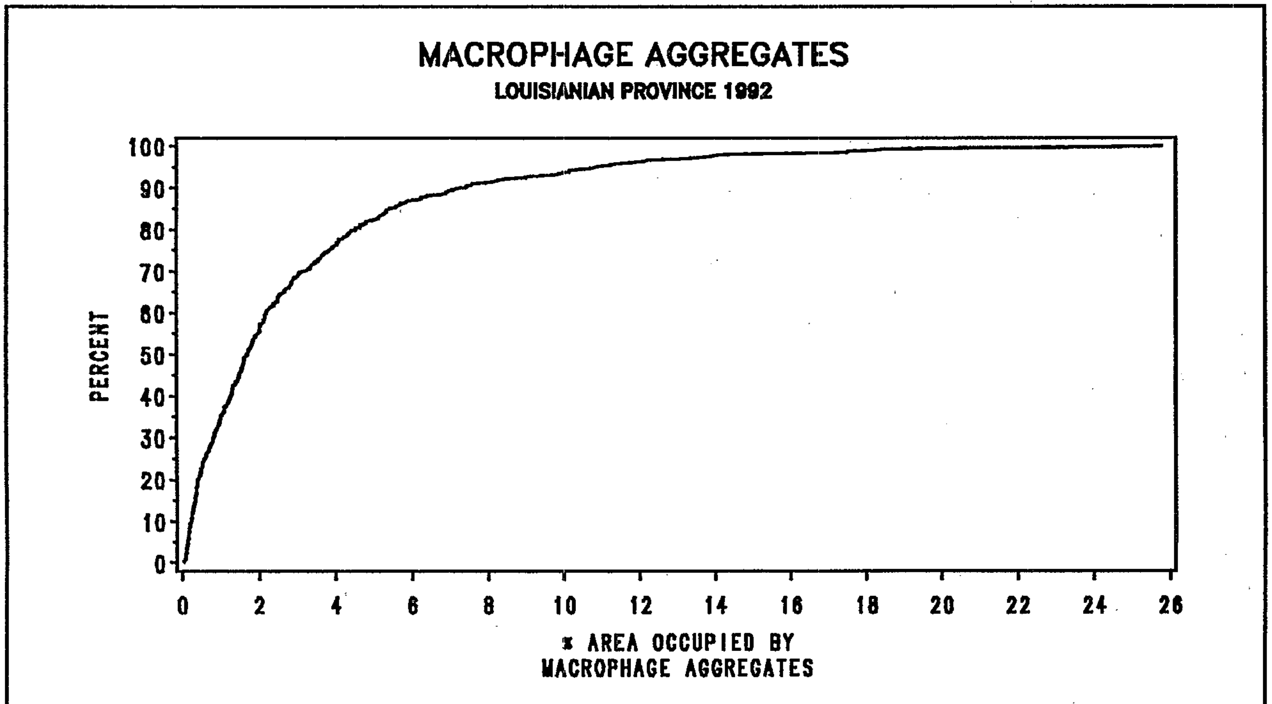

Figure 2-30. Cumulative distribution of percent area of spleen occupied by macrophage aggregates per mm^2 in fish examined from the Louisianian Province in 1992 (associated 95% confidence interval to narrow to portray).

2.1.9 MARINE DEBRIS

The presence of marine debris is one of the obvious indicators of estuarine "degradation" from a human use perspective. The presence of trash in the water and along the bottom reduces the value of the water body as a recreational resource and may have ecological effects as well. During the 1992 Louisianian Province Demonstration the presence of marine debris was noted in bottom sediments and the water column and the type of the trash was determined (e.g., plastic, anthropogenic wood, metal, glass, etc.). In 1992, over 6±5% of the surface area of the Louisianian Province contained at least one item of marine debris. The estuarine class with the largest proportion of sediment having marine debris was large tidal rivers with 45±27% coverage. Large estuaries and small estuaries had 7±7% and 4±4% of their sediments containing marine debris, respectively (Fig. 2-31).

2.1.10 WATER CLARITY

Another "social" or human use criterion for good condition of an estuary is water clarity and the lack of noxious odors. The presence of odors was noted at each sampling site during the Demonstration; however, no sites were classified as having any unusual odor. Water clarity was measured using a comparison of surface ambient light, photosynthetically active radiation (PAR), and the amount of light reaching any depth (measurements were taken every meter to the bottom). For the sake of relative comparison, the proportion of incident light reaching 1 meter was used as the standard for all sites (i.e., all sites were at least 1 m in depth). The proportion of light transmittance at 1 meter ranged from near 0% to about 56% (Fig. 2-32). Using 10% transmittance (i.e., 10% of surface light) as a measure of "turbid" clarity (i.e., cannot see your hand in front of your face),

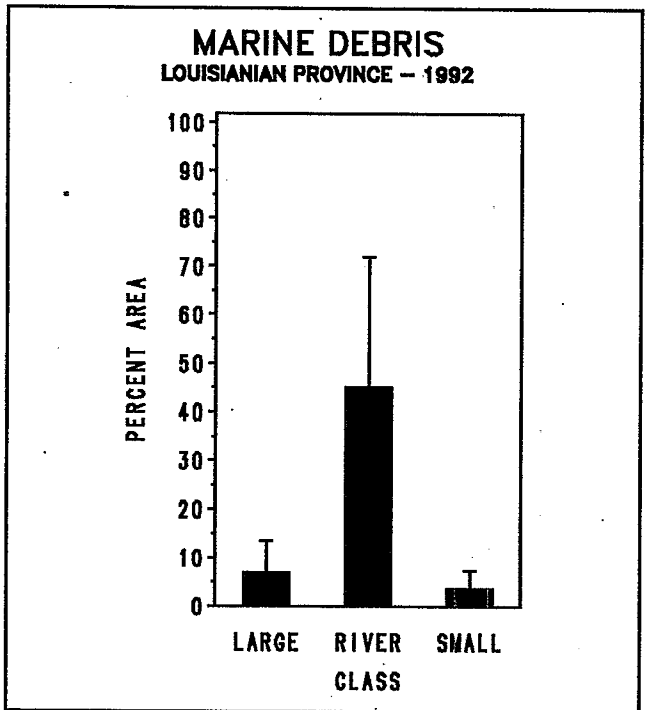

Figure 2-31. Percent area of estuaries with presence of marine debris in sediments in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

12±7% of the Louisianian Province experienced turbid water clarity (Fig. 2-33). Alternatively, using 25% transmittance as a measure of moderate clarity (cannot see your toes in waist deep water), resulted in 45±10% of the Louisianian Province had water clarity that could not pass this visual test. The poorest water clarity occurred in large tidal rivers and small estuaries with 30±29% and 17±14%, respectively. (Fig. 2-34).

2.1.11 FISH TISSUE CONTAMINANTS

Three sets of target species were examined for the concentrations of selected contaminants in edible flesh. These were: shrimp (brown and white), Atlantic croaker, and catfish (hardhead, gafftopsail, and blue catfish). The edible portions of the shrimps were defined as the tail meat with the shell removed, as the fillet with

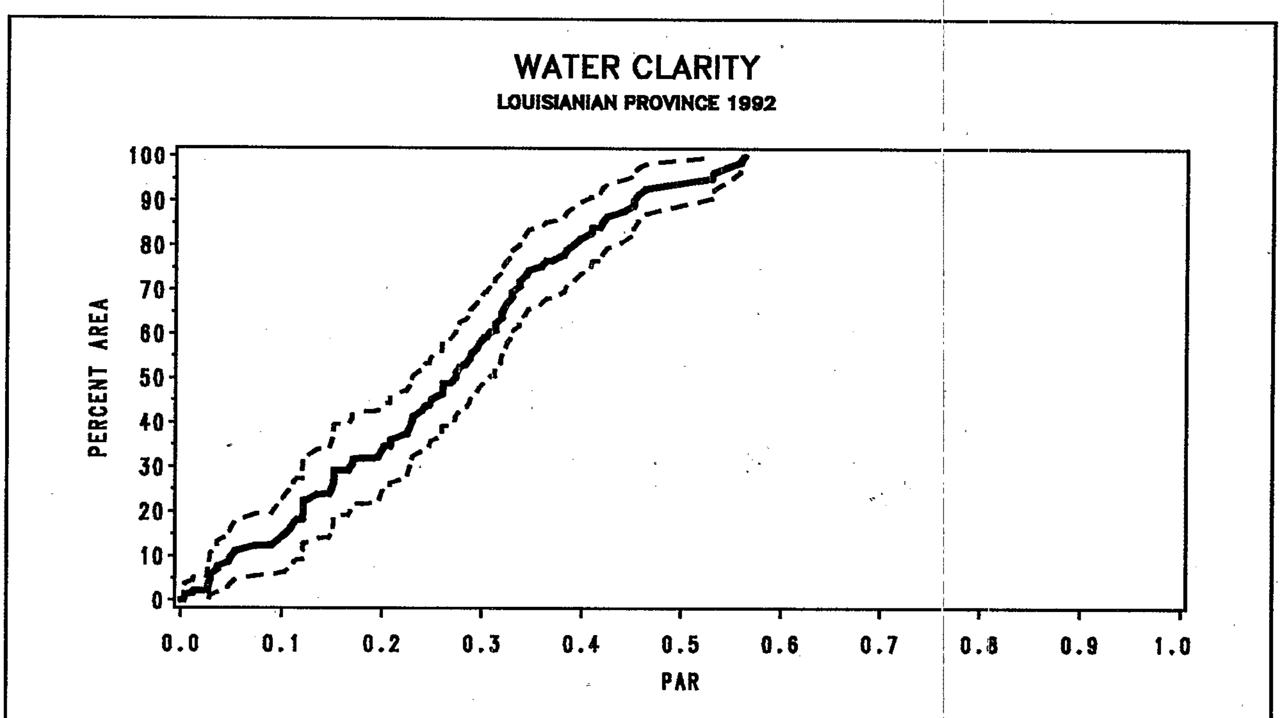

Figure 2-32. Cumulative distribution of water clarity as measured as percent of surface light reaching a depth of 1 m in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

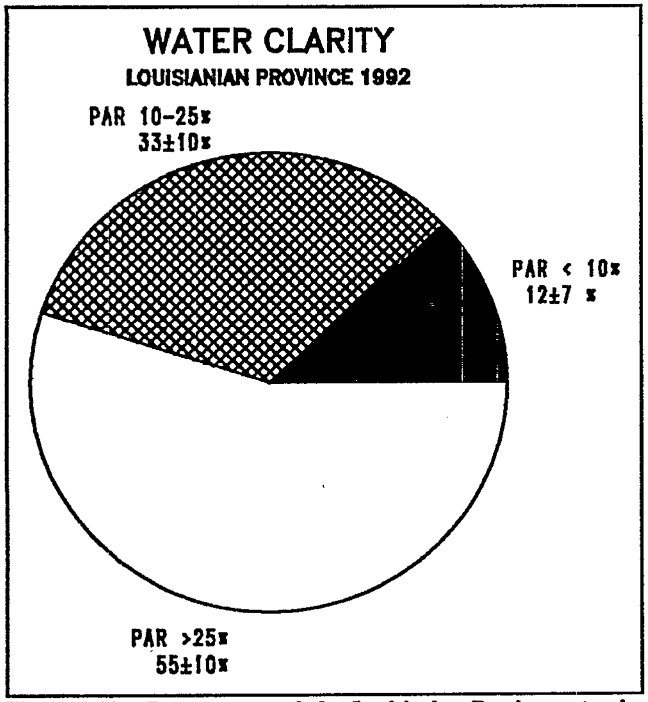

Figure 2-33. Percent area of the Louisianian Province estuaries associated with PAR categories in 1992.

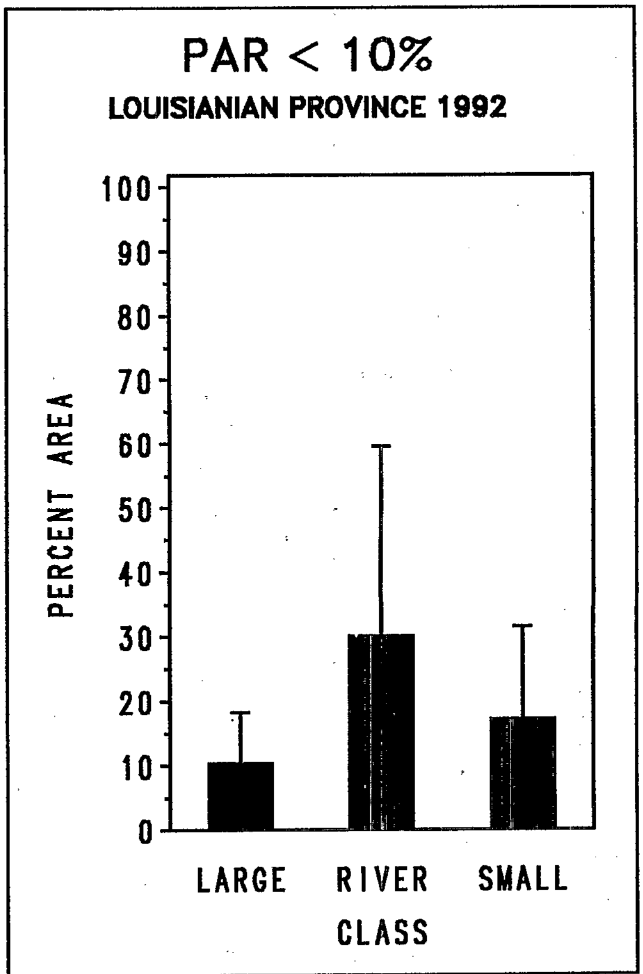

Figure 2-34. Percent area of estuaries with PAR < 10% at a depth of 1 m in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

skin for Atlantic croaker, and as the fillet without skin for the catfish. All samples represented a composite of 4 to 10 individuals collected from a single site. Initially, criteria levels for pesticides, PCBs, and mercury were taken from USFDA standards (USFDA 1982, 1984) with the exception of hexachlorobenzene, lindane, endosulfan, and trans-nonachlor for which U.S. standards were not available. Swedish standards were substituted for hexachlorobenzene and lindane (Nauen 1983). Other than mercury, no USFDA standards were available for metals; therefore, metals criteria reflect the means of international limits (Nauen 1983).

This comparison of fish population contaminant distributions to FDA action limits represents a slight misuse of these criteria. The EMAP-Estuaries data for the Louisianian Province do not represent only market-size fish (i.e., most fish were less than market size) or those fish transported across state lines for sale. However, the FDA action limits do provide a convenient point of comparison to track potential trends in tissue residue levels in juvenile fish.

No pesticide, PCB, or heavy metal concentrations exceeded the specified criteria for shrimp (Table 2-1). The highest concentration of an organic contaminant found was 27 ppb total PCBs (compared to the standard of 2000). Mirex and DDT were the pesticides found in highest concentrations in

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-4.5	5000	0%
DDE	0-0.5	5000	0%
DDT	0-14.0	5000	0%
Aldrin	0-0.7	300	0%
Chlordane	0-0.0	300	0%
Dieldrin	0-0.0	300	0%
Endosulfan	0-0.0	NA[2]	U[3]
Endrin	0-0.0	300	0%
Heptachlor	0-4.2	300	0%
Heptachlor Epoxide	0-0.4	300	0%
Hexachlorobenzene	0-0.0	200	0%
Lindane	0-0.0	200	0%
Mirex	0-16.0	100	0%
Toxaphene	0-0.0	5000	0%
Trans-Nonachlor	0-0.0	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-16.0	500	0%
Total PCBs	0-27.4	2000	0%
Heavy Metals (μg/g wwt)			
Aluminum	0-5.1	NA	U
Arsenic	0-1.4	2	0%
Cadmium	0-0.4	0.5	0%
Chromium	0-0.4	1	0%
Copper	0-2.4	15	0%
Lead	0-0.2	0.5	0%
Mercury	0-0.2	1	0%
Nickel	0-0.4	NA	U
Selenium	0-1.1	1	4%
Silver	0-0.5	NA	U
Tin	0-1.0	NA	U
Zinc	1-11.5	60	0%

---

[1] Criteria were selected from FDA established limits for pesticides and PCBs (USFDA 1982, 1984) except hexachlorobenzene and lindane which are based on Swedish limits (Nauen 1983); no FDA limits exist for metals other than mercury; metals criteria reflect means of international limits (Nauen 1983)
[2]NA = Not available
[3]U = Unknown because no criterion level available

Table 2-1. Overview of the contaminant levels observed in edible flesh of brown shrimp and white shrimp (N=523).

Contaminant	Observed range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-6.1	5000	0%
DDE	0-9.3	5000	0%
DDT	0-36.6	5000	0%
Aldrin	0-8.6	300	0%
Chlordane	0-3.5	300	0%
Dieldrin	0-3.5	300	0%
Endosulfan	0-2.0	NA	U
Endrin	0-1.1	300	0%
Heptachlor	0-3.0	300	0%
Heptachlor Epoxide	0-2.9	300	0%
Hexachlorobenzene	0-2.9	200	0%
Lindane	01.3	200	0%
Mirex	0-42.1	100	0%
Toxaphene	0-0	5000	0%
Trans-Nonachlor	0-5.6	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-30.3	500	0%
Total PCBs	0-98.9	2000	0%
Heavy Metals (μg/g wwt)			
Aluminum	0-4.1	NA	U
Arsenic	0-0.9	2	0%
Cadmium	0-0.7	0.5	4%
Chromium	0-0.5	1	0%
Copper	0-1.3	15	0%
Lead	0-0.2	0.5	0%
Mercury	0-0.4	1	0%
Nickel	0-0.8	NA	U
Selenium	0-0.6	1	0%
Silver	0-0.5	NA	U
Tin	0-0.9	NA	U
Zinc	1-5.8	60	0%

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[1]Criteria were selected from FDA established limits for pesticides and PCBs (USFDA 1982, 1984) except hexachlorobenzene and lindane which are based on Swedish limits (Nauen 1983); no FDA limits exist for metals other than mercury; metals criteria reflect means of international limits (Nauen 1983)

Table 2-2. Overview of the contaminant levels observed in edible flesh of Atlantic croaker (N=571). NA= Not available; U= Unknown, no criterion level is available.

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-13.0	5000	0%
DDE	0-20.9	5000	0%
DDT	0-37.8	5000	0%
Aldrin	0-16.7	300	0%
Chlordane	0-79.9	300	0%
Dieldrin	0-5.0	300	0%
Endosulfan	0-2.8	NA	U
Endrin	0-12.5	300	0%
Heptachlor	0-49.2	300	0%
Heptachlor Epoxide	0-2.3	300	0%
Hexachlorobenzene	0-2.5	200	0%
Lindane	0-15.4	200	0%
Mirex	0-72.6	100	0%
Toxaphene	0-0	5000	0%
Trans-Nonachlor	0-3.2	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-44.8	500	0%
Total PCBs	0-79.9	2000	0%
Heavy Metals (µg/g wwt)			
Aluminum	0-16.7	NA	U
Arsenic	0-10.3	2	15%
Cadmium	0-0.5	0.5	1%
Chromium	0-0.7	1	0%
Copper	0-2.0	15	0%
Lead	0-0.3	0.5	0%
Mercury	0-1.2	1	1%
Nickel	0-2.2	NA	U
Selenium	0-1.3	1	2%
Silver	0-0.5	NA	U
Tin	0-2.6	NA	U
Zinc	1-18.2	60	0%

---

[1] Criteria were selected from FDA established limits for pesticides and PCBs (USFDA 1982, 1984) except hexachlorobenzene and lindane which are based on Swedish limits (Nauen 1983); no FDA limits exist for metals other than mercury; metals criteria reflect means of international limits (Nauen 1983)

Table 2-3. Overview of the contaminant levels observed in edible flesh of catfish (N=633). NA= Not available; U= Unknown as no criterion level is available.

shrimp tailmeat at 14 to 16 ppb. This represents < 1% of the FDA limit for DDT and 16% of the limit for Mirex.

No pesticide or PCB concentrations exceeded the specified FDA action limits for Atlantic croaker (Table 2-2). As with shrimp, total PCBs, DDT and mirex represented the highest fillet organic residues found in Atlantic croaker at 99, 37, and 42 ppb, respectively. These concentrations represent 1 to 42% of the action limits for these contaminants. Cadmium exceeded the international standards of 0.5 ppm in 4% of the croakers examined.

No pesticide or PCB concentrations exceeding the specified FDA action limits were found in marine catfish (Table 2-3). Several heavy metals exceeded the international standards with 15% of marine catfish in excess of 2 ppm arsenic, 2% in excess of 1 ppm selenium, 1% in excess of 1 ppm mercury, and 1% in excess of 0.5 ppm cadmium.

2.1.12 INTEGRATION OF ESTUARINE CONDITIONS

A single value has been developed to summarize the overall condition of the estuaries in the Louisianian Province by combining the benthic index, marine debris, water clarity and tissue contaminants, weighted equally. This single value includes an index of societal values (aesthetics) and estuarine biotic integrity based on benthic assemblages and fish health condition (Fig. 2-35). Indicators relating to biotic integrity and aesthetics were used to estimate overall environmental conditions in the estuaries. Thirty-six percent (±11%) of the estuarine area in the Louisianian Province showed evidence of degraded biological resources or was impaired with respect to its ability to support activities valued by society (Fig. 2-35). Of the 25,725 km^2 of estuarine surface area in the Louisianian Province,

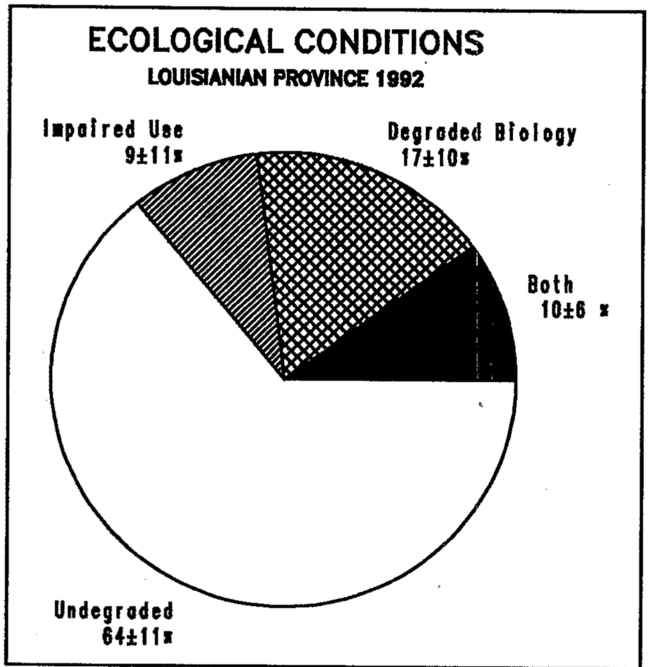

Figure 2-35. Percent area of the Louisianian Province estuaries in 1992 associated with degraded biology and degraded use.

9,261±2,830 km^2 were potentially degraded.

The location of degraded biological resources were sometimes different from those having aesthetic problems. Both sets of conditions were found in 10±6% of the estuarine area, whereas degraded biological conditions alone were found in 17±10% of the province and degraded human use alone was found in 9±11% of the Louisianian Province.

2.2 EXPOSURE INDICATORS

Exposure indicators have historically been the mainstay of environmental monitoring programs. Indicators of pollutant exposure measured during the 1992 Louisianian Province Demonstration were dissolved oxygen concentration (instantaneous and continuous), sediment toxicity (*Ampelisca* and *Mysidopsis*), sediment contaminants (27 alkanes, 43 PAHs, 25 pesticides, 20 PCB congeners, 4 butyltins, and 15 heavy metals).

2.2.1 DISSOLVED OXYGEN (INSTANTANEOUS)

As stated earlier, dissolved oxygen (DO) concentration is important because it is a fundamental requirement of populations of benthos, fish, shellfish, and other aquatic biota. DO was measured in two ways during the 1992 Louisianian Province Demonstration: instantaneous point measures at 1-m depth intervals during sampling and deployed continuous recordings of dissolved oxygen for a 24-hour period at a depth of 0.5m above the bottom.

The cumulative distribution functions of instantaneous dissolved oxygen concentrations at depth intervals showed, as would be expected, an increased tendency toward lower concentrations with depth (Figures 2-36 through 2-40). Minimum DO concentrations derived from province-wide instantaneous estimates decreased from 3.4 ppm at the surface to 2.9 ppm at 1 m, 1.5 ppm at 2 m, 0.6 ppm at 3 m, and 0.0 at the bottom. The minima show this steady decline with depth reflecting the stratified nature of some estuaries. However, the median values change very little (ranging from 6.4 at the surface to 5.4 at the bottom) suggesting that most estuaries in the Louisianian Province are well mixed. Surface dissolved oxygen concentrations were rarely observed to be below 5 ppm during the daylight sampling (Fig. 2-41) while bottom DO concentrations were below 5 ppm for 22±10% of the province and below 2 ppm for 5±5% of the province (Fig. 2-42). Bottom dissolved oxygen concentrations < 5 ppm were seen in all three estuarine classes with large estuaries displaying the greatest extent at 24±11% of the class resources, with small estuaries at 13±20%, and large tidal rivers at 10±19% (Fig. 2-43).

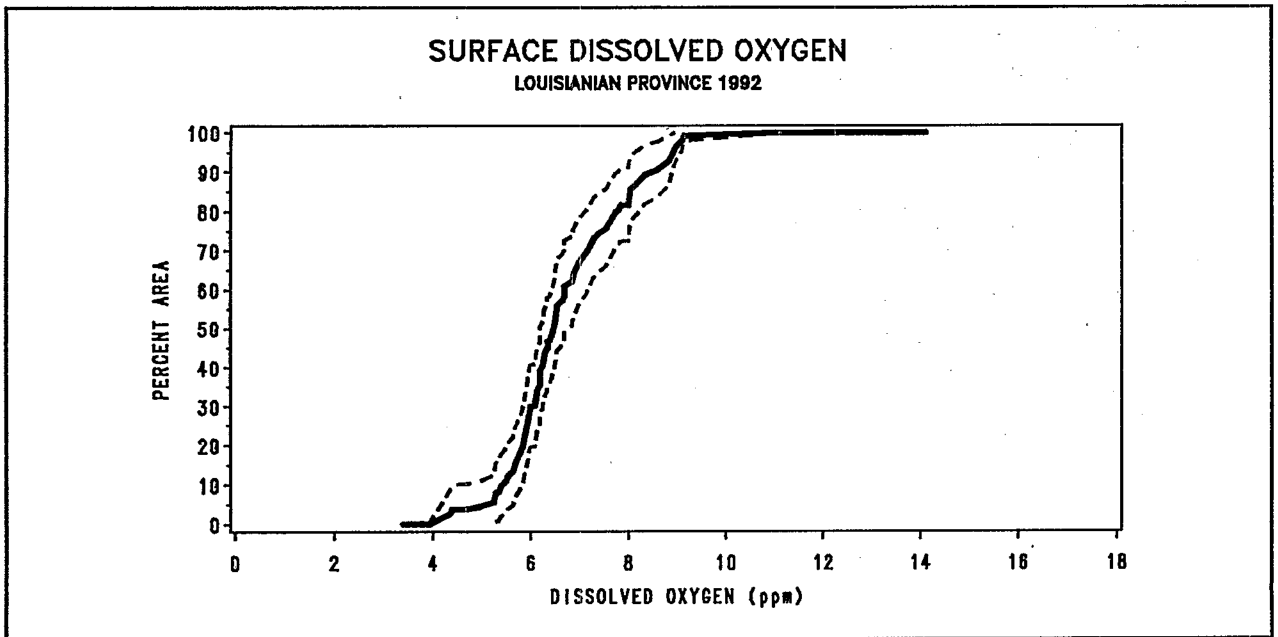

Figure 2-36. Cumulative distribution of surface dissolved oxygen concentration in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

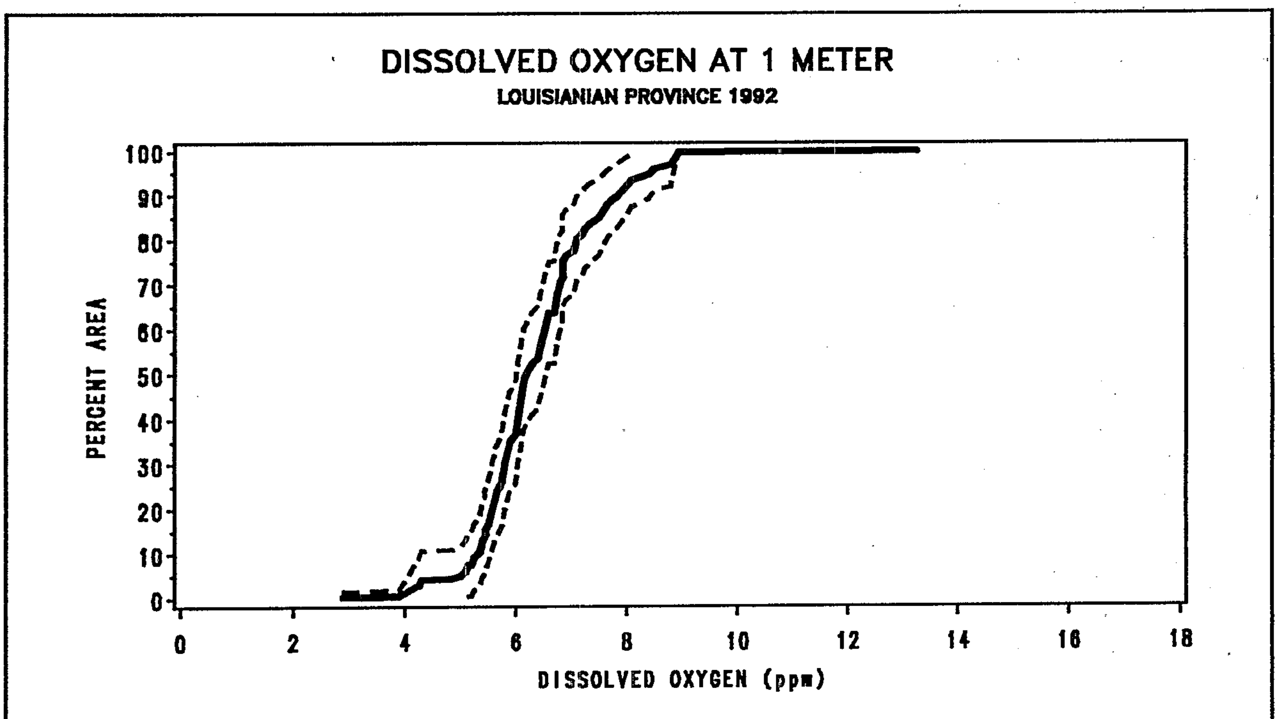

Figure 2-37. Cumulative distribution of dissolved oxygen concentration at a depth of 1 m in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

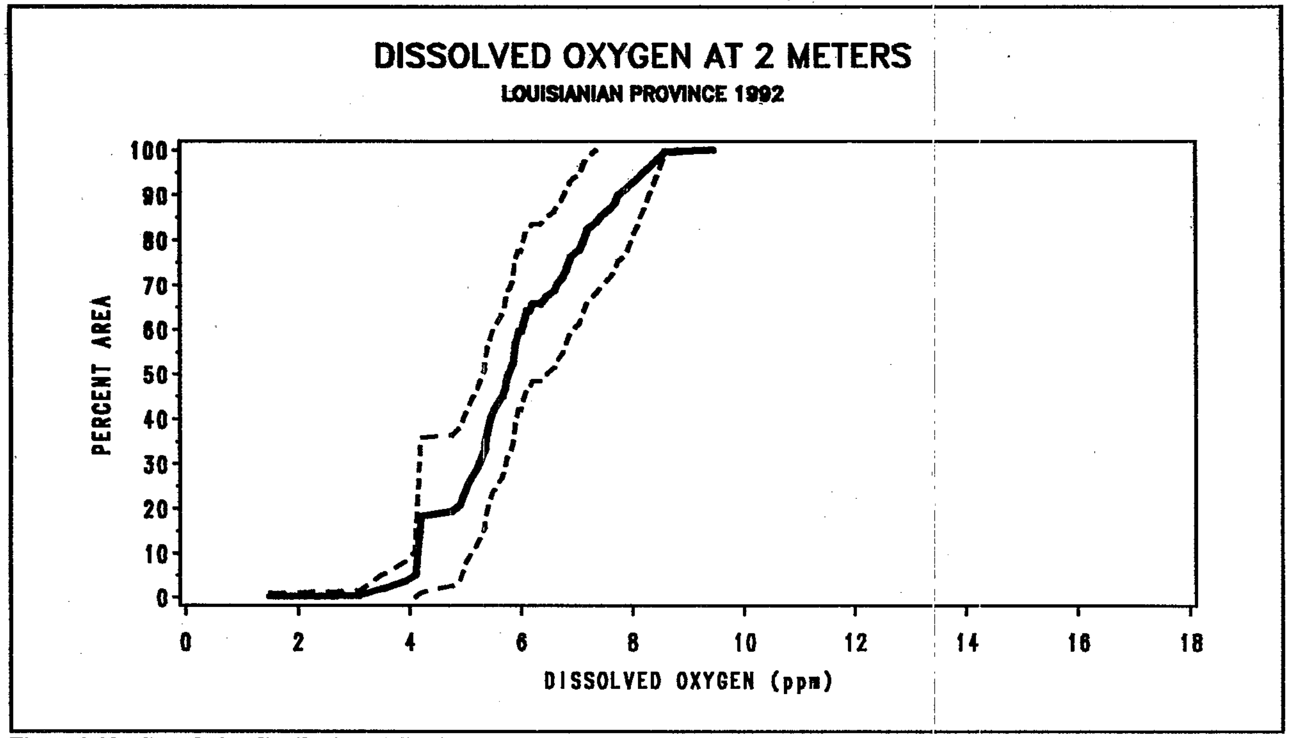

Figure 2-38. Cumulative distribution of dissolved oxygen concentration at a depth of 2 m in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

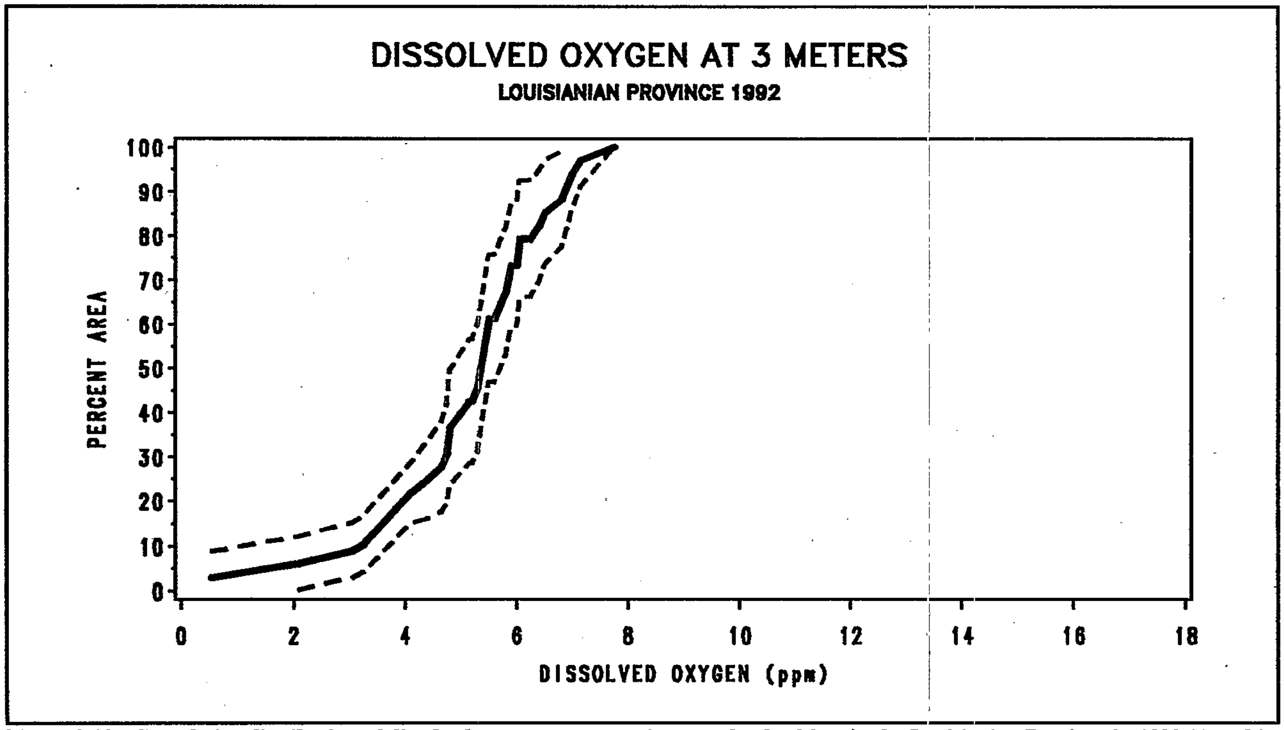

Figure 2-39. Cumulative distribution of dissolved oxygen concentration at a depth of 3 m in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

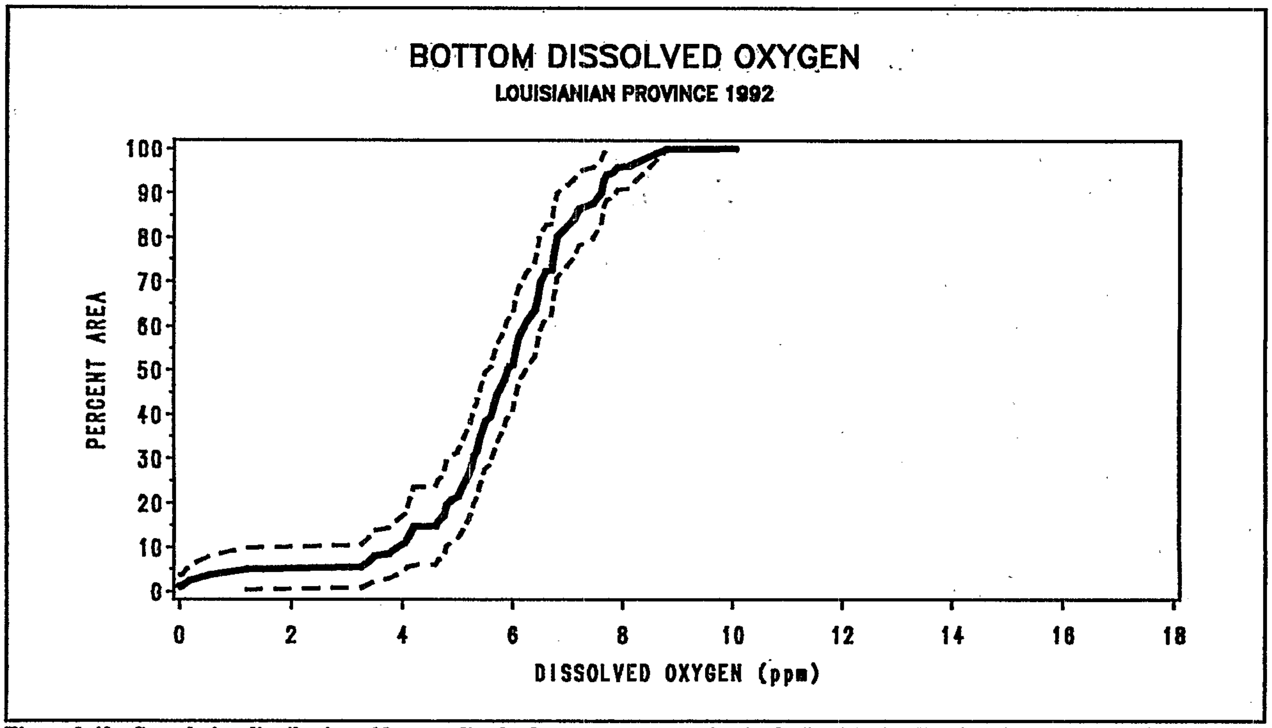

Figure 2-40. Cumulative distribution of bottom dissolved oxygen concentration in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

However, the proportion of class resources that experienced DO concentrations < 2 ppm were almost exclusively within the large estuary class where 7±7% were characterized by these conditions. Small estuaries and large tidal rivers had virtually no incidence of DO concentrations below 2 ppm during daylight sampling (Fig. 2-44).

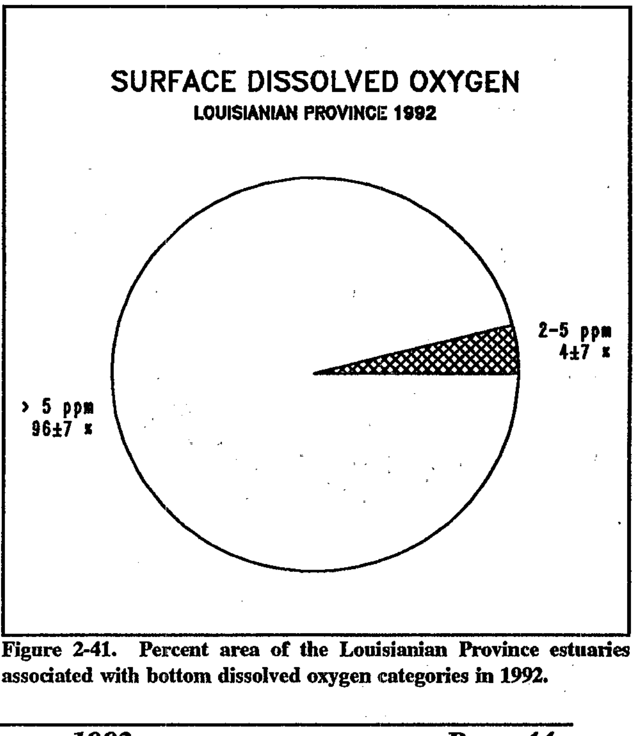

Figure 2-41. Percent area of the Louisianian Province estuaries associated with bottom dissolved oxygen categories in 1992.

2.2.2 DISSOLVED OXYGEN - (CONTINUOUS)

Unlike the instantaneous measures, the continuous dissolved oxygen concentration measurements provide a complete picture of the DO conditions within an estuary by including periods of high water column and sediment respiration (i.e., night). The continuous measures were collected because earlier studies (Summers and Engle 1993)

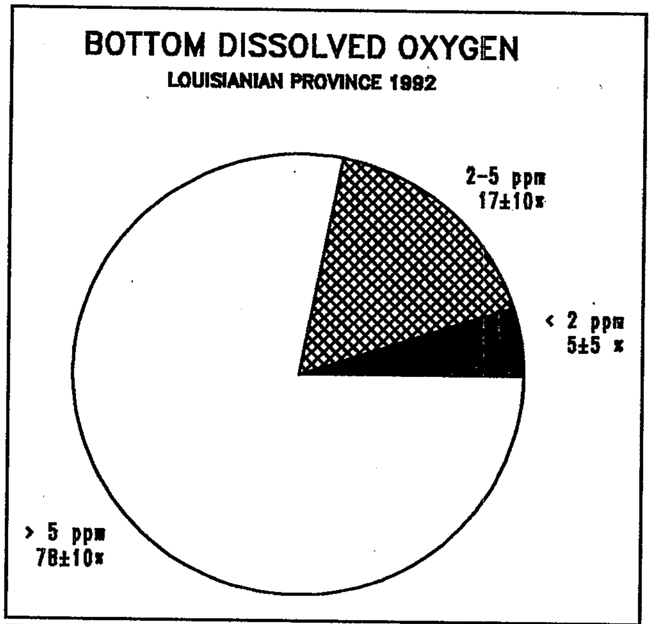

Figure 2-42. Percent area of the Louisianian Province estuaries associated with bottom dissolved oxygen categories in 1992.

showed that a combination of daily minimum DO concentration and the incidence of DO concentrations < 2 ppm for > 20% of the deployed period could be used to successfully characterize an estuary as "good" or "hypoxic" with regard to index period DO conditions. Minimum DO concentrations resulting from continuous recordings showed that 6±5% of the province experienced DO conditions below 2 ppm (Fig. 2-45) while 35±11% of the province had minimal dissolved oxygen concentrations < 5 ppm (Fig. 2-46). Based on the above estimation technique, this represents only a 1% increase in the estuarine bottom area experiencing low DO conditions based on instantaneous measurements during daylight hours. Thus in 1992, only an additional 1% of province estuaries experience cyclic DO conditions so that high concentrations are observed during the day and concentrations < 2 ppm are observed at night. Similarly, an additional 13% of estuaries in the Louisianian Province experience DO conditions < 5 ppm at

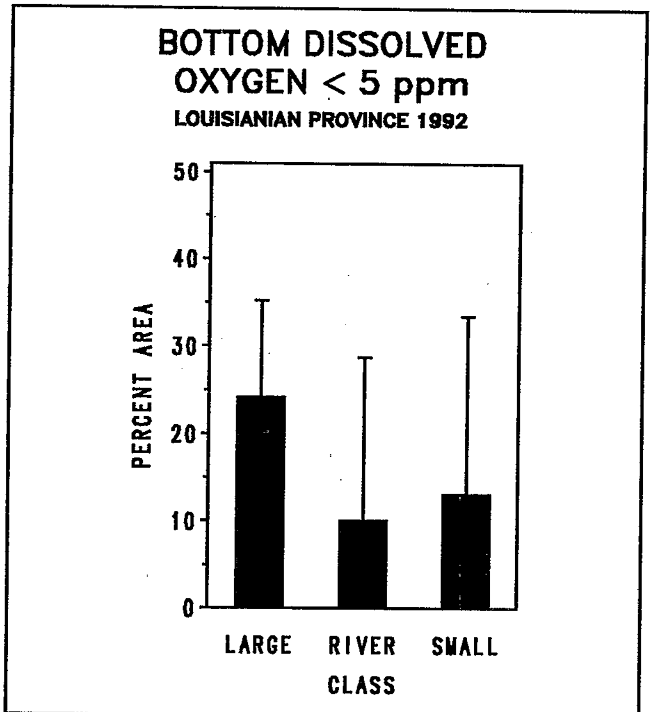

Figure 2-43. Percent area of estuaries with bottom dissolved oxygen < 5 ppm in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

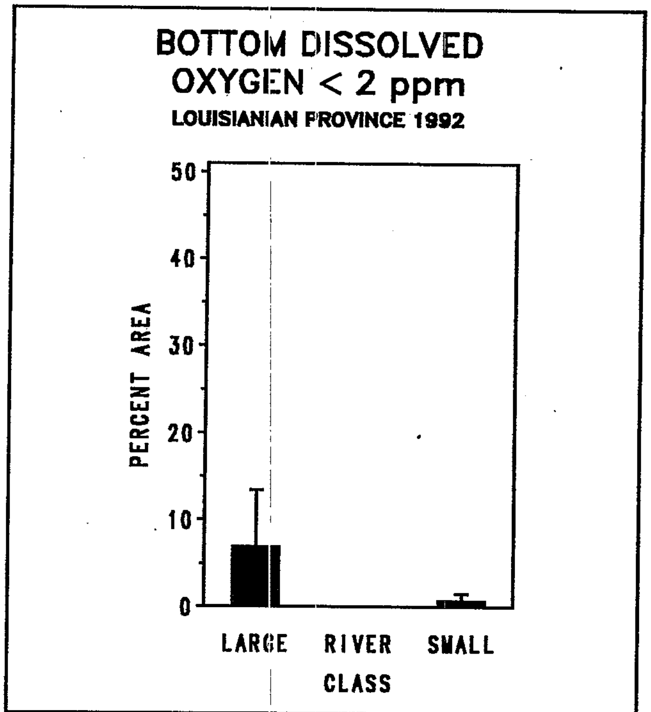

Figure 2-44. Percent area of estuaries with bottom dissolved oxygen < 2 ppm in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

night. In 1992, where lower DO conditions were predominate in large estuaries during daylight hours, continuous measurements also showed that large estuaries experience DO conditions below 2 ppm more frequently than other estuaries (Fig. 2-47). Thus, unlike the conditions observed in 1991, DO conditions in 1992 rarely portrayed extreme cyclic patterns showing DO conditions < 2 ppm only at night. Systems experiencing low bottom DO conditions continuously (day and night) include about 5% of the large estuarine surface area within the province (e.g., Mobile Bay, parts of Chandeleur Sound).

All estuaries exhibit DO cycling to some degree. However, the cyclic nature described here suggests wide amplitude changes in concentrations from day to night in many small estuaries although few estuaries cycle lower than 2 ppm. Examination of the duration of low DO conditions in the Louisianian Province showed that 5±5% of the province exhibited DO concentrations below 2 ppm for greater than 5 hours during the day (20% of time). These measurements were primarily seen in the large estuarine class (Fig. 2-48).

2.2.3 SEDIMENT TOXICITY - *AMPELISCA ABDITA*

Sediment toxicity tests were performed on the composited surface sediments collected from each sampling site. Tests included a standard 10-day acute test (Swartz et al. 1985; ASTM 1990) using the tube-dwelling amphipod, *Ampelisca abdita*. About 10±6% of the sediments collected in the Louisianian Province were toxic to the amphipods (Fig. 2-49). In these sediments, mortality rates were >20% higher than those observed in the controls . The estuarine sampling class with the largest proportion of toxic sediment was the large tidal river class (30±22%) while small estuaries (4±6%) and large estuaries (12±8%) showed toxicity to a lesser extent (Fig. 2-50). However, on a province-wide scale, most of the toxic sediments occur in large estuaries (2,240 km^2) with small estuaries contributing 300 km^2 of toxic sediments and the large tidal rivers showing toxicity in only 41 km^2.

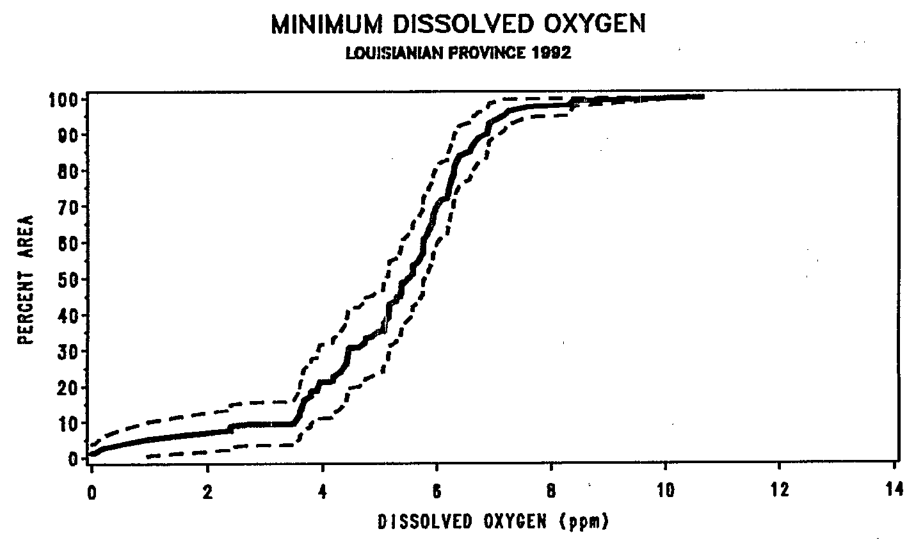

Figure 2-45. Cumulative distribution of minimum bottom dissolved oxygen concentration in the Louisianian Province in 1992 based on 24 hours of measurements (_) and its associated 95% confidence interval (--).

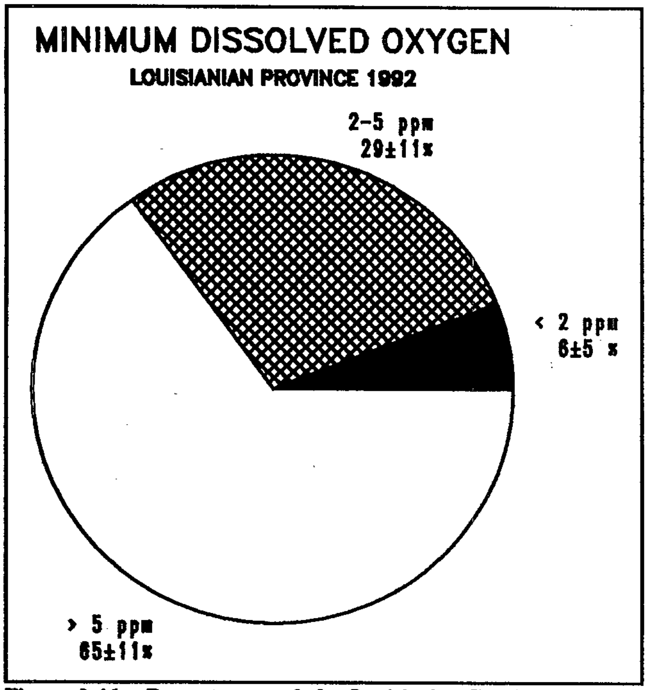

Figure 2-46. Percent area of the Louisianian Province estuaries associated with minimum bottom dissolved oxygen categories in 1992.

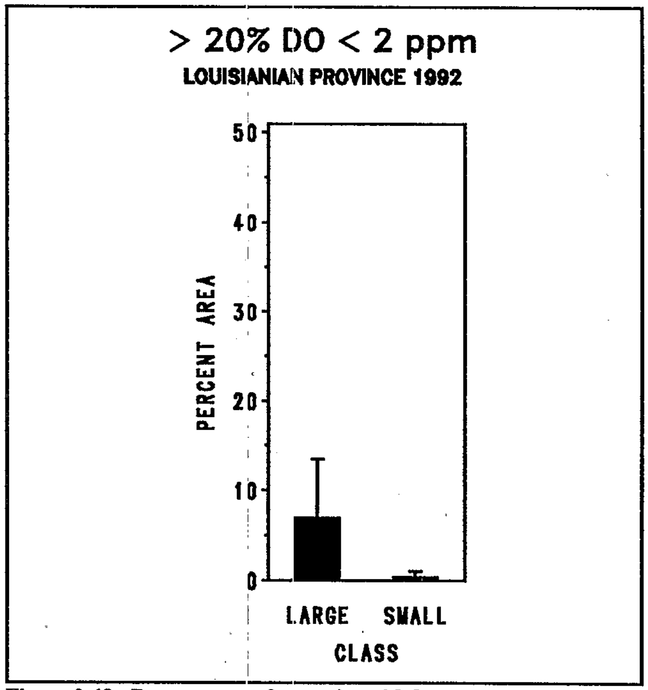

Figure 2-48. Percent area of estuaries with bottom dissolved oxygen < 2 ppm for greater than 20% of the observations in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

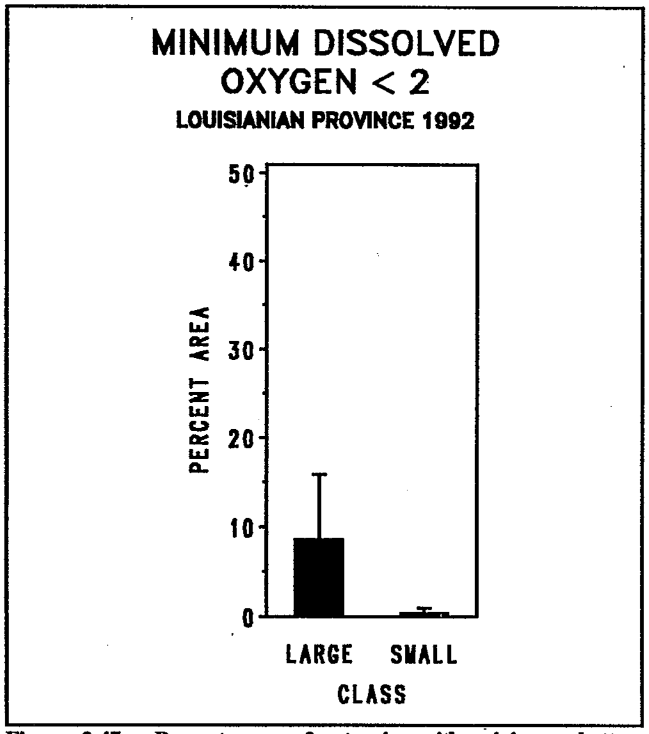

Figure 2-47. Percent area of estuaries with minimum bottom dissolved oxygen < 2 ppm in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

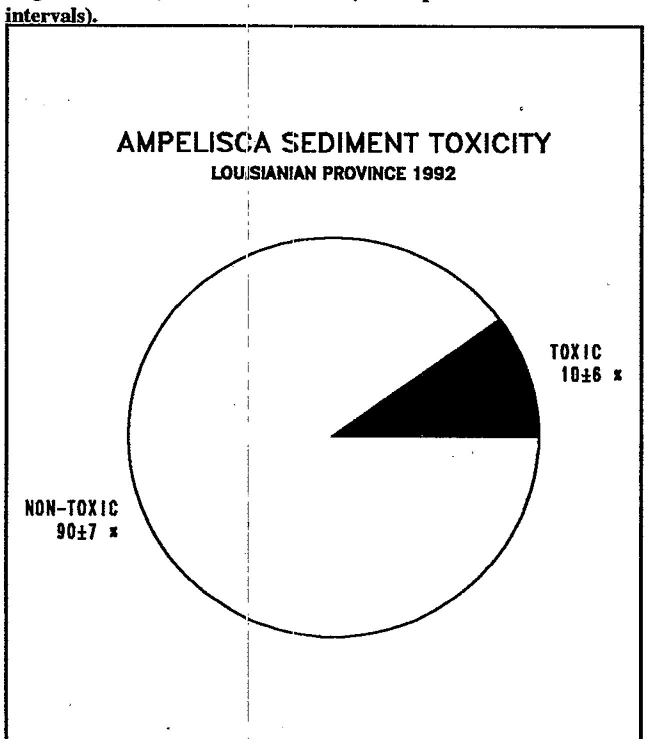

Figure 2-49. Percent area of the Louisianian Province estuaries associated with Ampelisca sediment toxicity categories in 1992.

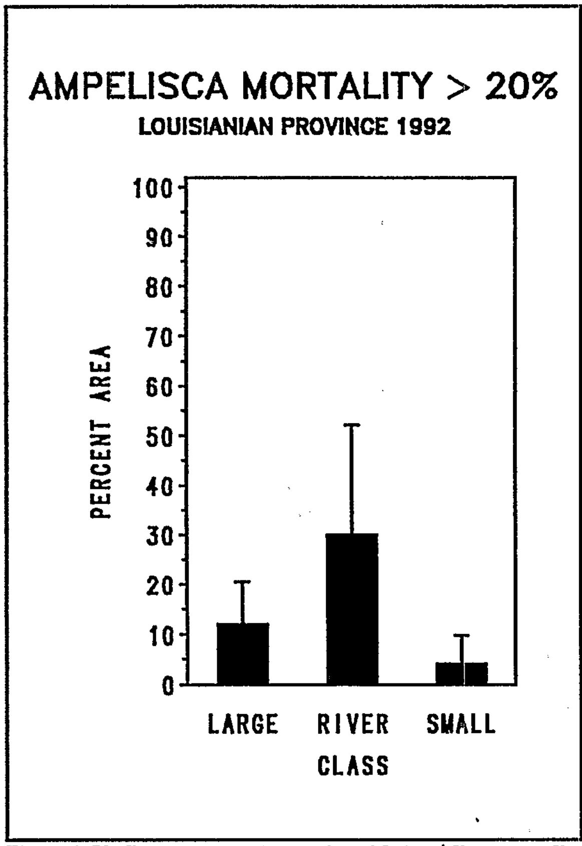

Figure 2-50. Percent area of estuaries with Ampelisca mortality > 20% in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

2.2.4 SEDIMENT TOXICITY - *MYSIDOPSIS BAHIA*

Because *Ampelisca abdita* is relatively uncommon in the estuaries of the Louisianian Province and had to be purchased and transported from California, a second organism, *Mysidopsis bahia*, was tested to see whether it provided the same results on a province-wide scale as the amphipod. Mysids are readily culturable but do not clearly associate themselves with sediments. Mysid contact with the sediments is frequent but not continuous whereas the tube-dwelling amphipod is generally contact with the tested sediments. About 5±4% of the sediments in the Louisianian Province was toxic to mysids resulting in mortalities >20% higher than those observed in control tests (Fig. 2-51). This figure compares favorably with the 10% observed for *Ampelisca* toxicity. The major differences between amphipod and mysid testing are shown in Figures 2-50 and 2-52 where the percentage of area in the large tidal river class varies widely; 30±22% for Ampelisca and 65±27% for mysids. However, the observed toxicities in the large and small estuaries are similar.

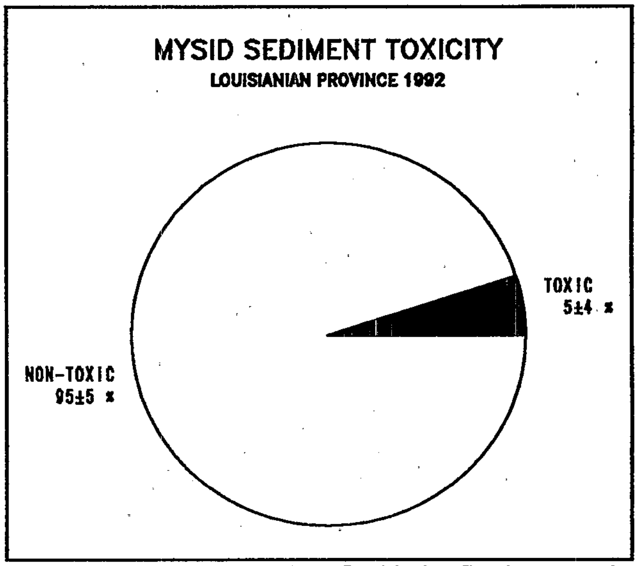

Figure 2-51. Percent area of the Louisianian Province estuaries associated with Mysidopsis sediment toxicity categories in 1992.

2.2.5 SEDIMENT CONTAMINANTS - ALKANES AND ISOPRENOIDS

Alkanes and isoprenoids are contaminants associated primarily with the petroleum industry. Sediments collected throughout the Louisianian Province were analyzed for 27 individual alkanes and total alkanes. The distribution of observed concentrations for total alkanes in Louisianian Province sediments is shown in Figure 2-53 depicting concentrations ranging from 84 to 20,805 ppb. About 9±6%

of the sediments in the province are characterized by alkane concentrations in excess of 7000 ppb (Fig. 2-54). Alkanes at concentrations > 7000 ppb were most often observed in the large tidal river class (60±29%) but these concentrations were seen in 7±7% of

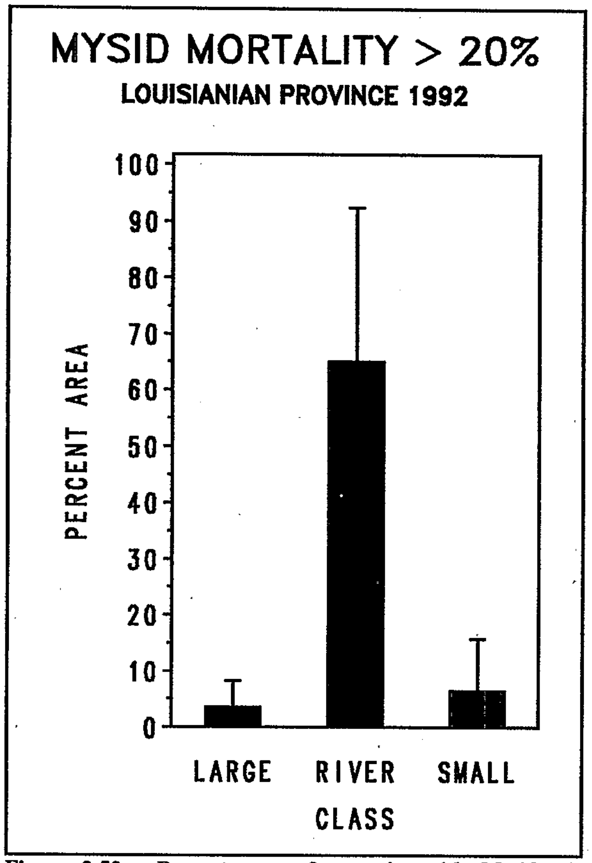

Figure 2-52. Percent area of estuaries with Mysidopsis mortality > 20% in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

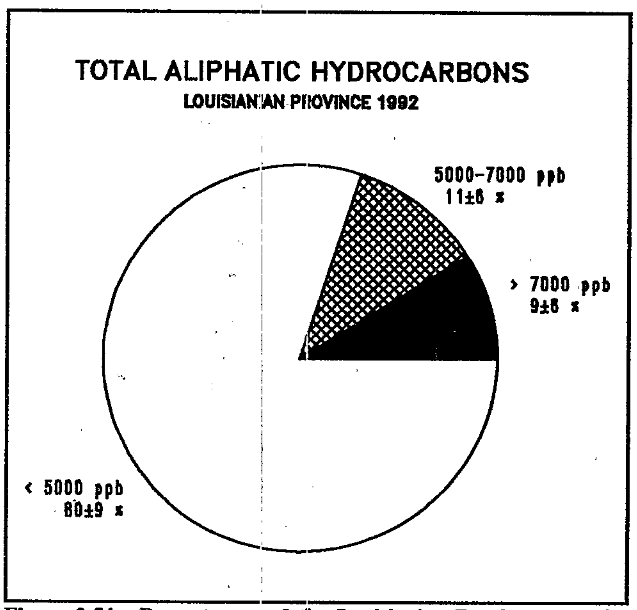

Figure 2-54. Percent area of the Louisianian Province estuaries associated with sediment alkane concentration categories in 1992.

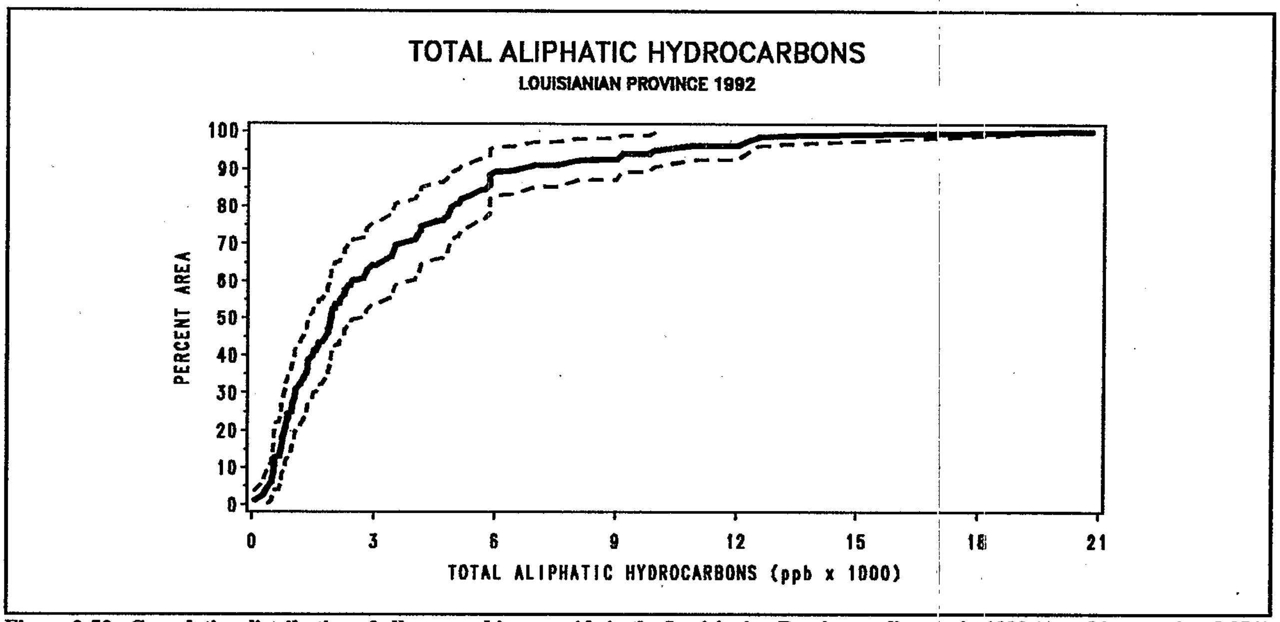

Figure 2-53. Cumulative distribution of alkanes and isoprenoids in the Louisianian Province sediments in 1992 (-) and its associated 95% confidence interval (--).

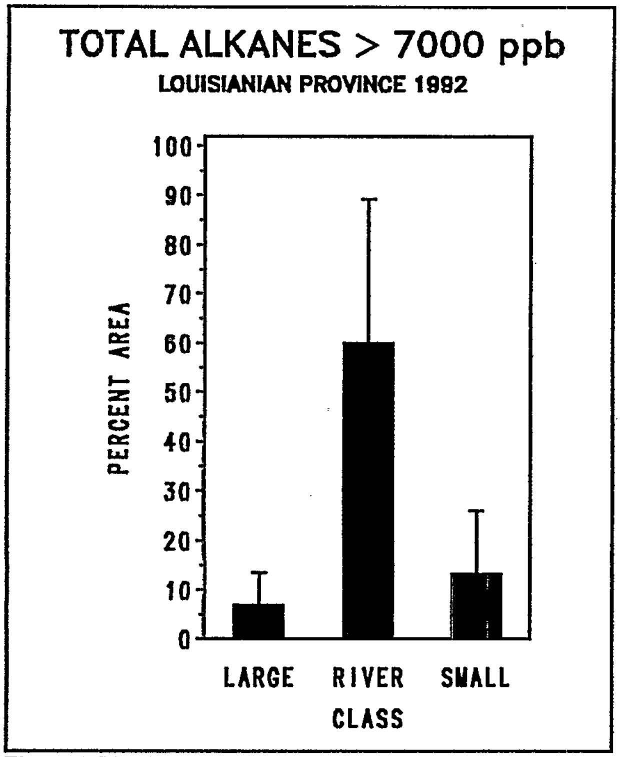

Figure 2-55. Percent area of estuaries with sediment alkane concentrations > 7000 ppb in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

the large estuarine sediments and 13±13% of small estuarine sediments (Fig. 2-55). The ranges of concentrations and the percentage province-wide areas in excess of 1000 ppb for the 27 individual alkanes analyzed are shown in Table 2-4.

Alkane	Range (ppb)	Percent Area > 1000 ppb
C10	0 - 1018	1%
C11	0 - 525	0%
C12	1 - 1043	1%
C13	0 - 1256	4%
C14	4 - 951	0%
C15	6 - 1976	3%
C16	5 - 2383	4%
C17	6 - 2708	7%
Pristane	2 - 774	0%
C18	2 - 1404	2%
Phytane	2 - 1970	4%
C19	3 - 1179	1%
C20	1 - 999	0%
C21	1 - 757	0%
C22	1 - 497	0%
C23	2 - 488	0%
C24	1 - 228	0%
C25	3 - 919	0%
C26	1 - 310	0%
C27	2 - 1581	1%
C28	1 - 380	<0%
C29	3 - 2453	4%
C30	0 - 379	0%
C31	1 - 1841	4%
C32	0 - 410	0%
C33	0 - 907	<1%
C34	0 - 111	0%
TOTAL	84 - 20805	9%

Table 2-4. Alkane concentration ranges measured in the 1992 Demonstration and the percentage of province sediments exceeding 1000 ppb for individual alkanes and 7000 ppb for total alkanes.

2.2.6 SEDIMENT CONTAMINANTS - POLYNUCLEAR AROMATIC HYDROCARBONS

Forty-three individual polynuclear aromatic hydrocarbons (PAHs) were analyzed from the collected Louisianian Province sediments. The distribution of the total of these 43 PAHs is shown in Fig. 2-56 ranging from 115 ppb to about 21000 ppb. None of the sampled sediments exceeded the median Long and Morgan (1990) criteria of 35,000 ppb although 4±4% of the sediments did exceed their lower criterion (4000 ppb) for ecological effects (Fig. 2-57). None of the PAH concentrations exceeding 4000 ppb were found in small estuaries. These conditions comprised over 30±32% of the sediments in the large tidal river class and 5±6% in the large estuary class (Fig. 2-58). The ranges of individual PAHs, the criteria used, and the extent to which observations exceeded these criteria are shown in Table 2-5.

EPA is currently in the process of establishing Sediment Quality Criteria (SQC). Draft SQC are presently available for three of the PAH analytes EMAP-Estuaries is measuring and one

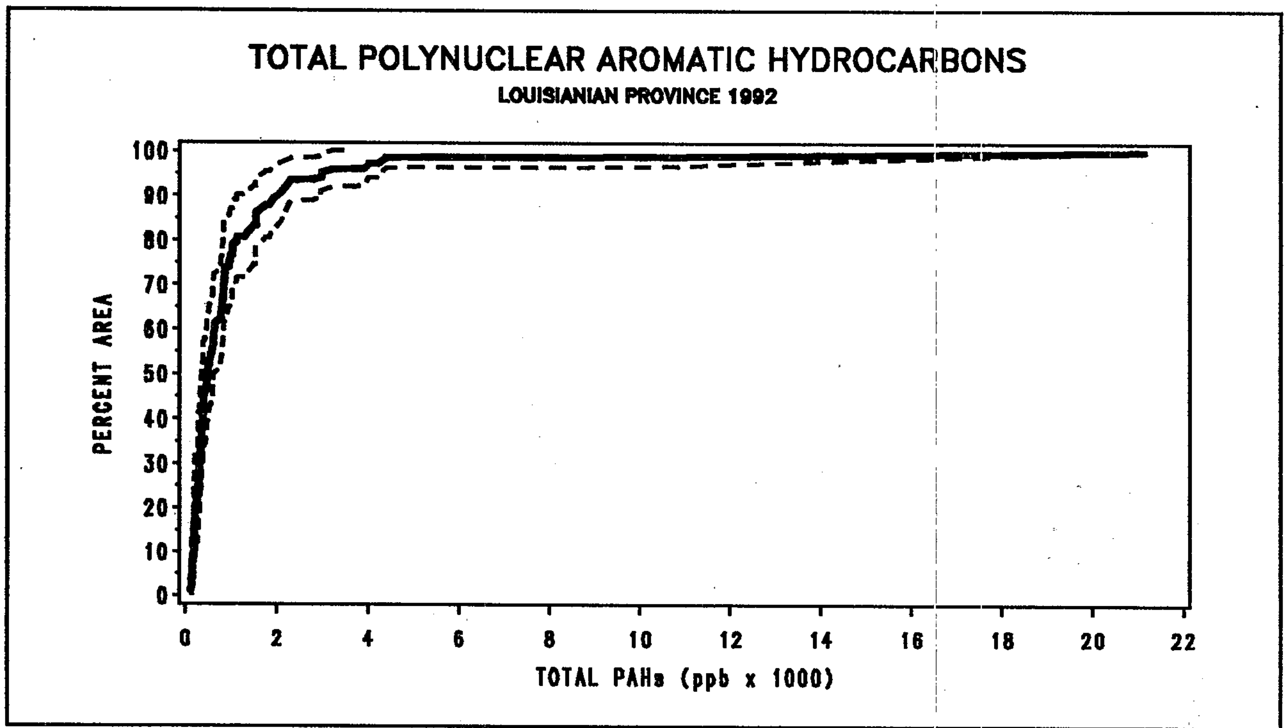

Figure 2.56. Cumulative distribution of PAH concentrations in the Louisianian Province sediments in 1992 (-) and its associated 95% confidence interval (--).

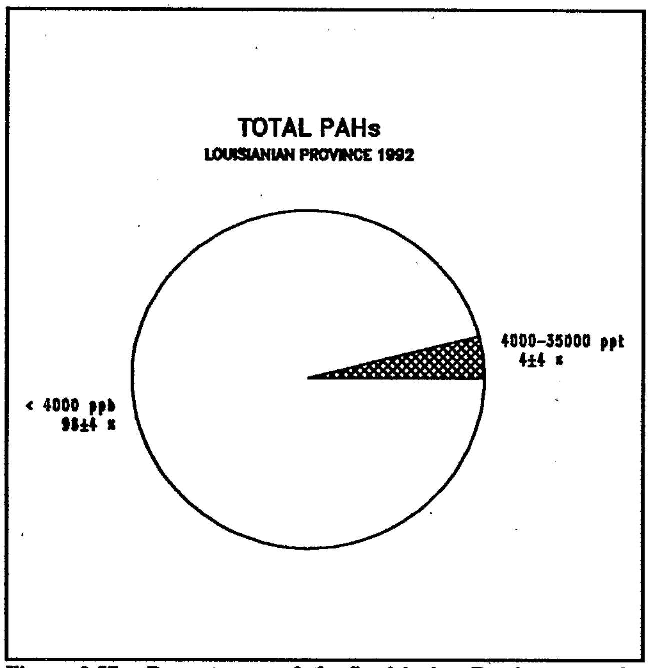

Figure 2-57. Percent area of the Louisianian Province estuaries associated with sediment PAH concentration categories in 1992.

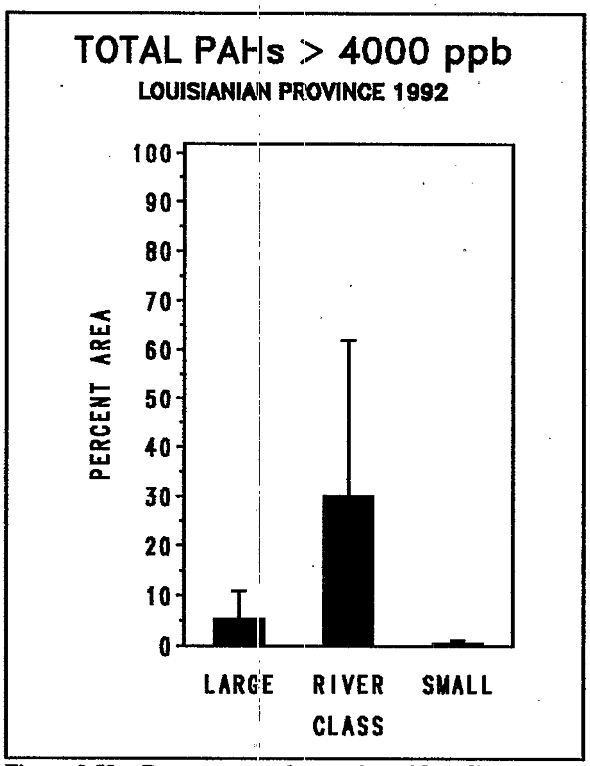

Figure 2-58. Percent area of estuaries with sediment PAH concentrations > 4000 ppb in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

PAH	Range (ppb)	Criteria	Percent Exceeded (10%)	(50%)
Acenaphthene(L)	0 - 43	150/650	0%	0%
Acenaphthylene(L)	0 - 13	NA	U	U
Anthracene(H)	0 - 86	85/960	< 1%	0%
Benzo(a)anthracene(H)	0 - 278	230/1600	< 1%	0%
Benzo(a)pyrene(H)	0 - 317	400/2500	0%	0%
Benzo(b)fluoranthene(H)	0 - 335	NA	U	U
Benzo(e)pyrene(H)	0 - 260	400/2500	0%	0%
Benzo(g,h,i)perylene(H)	0 - 281	NA	U	U
Benzo(k)fluoranthene(H)	0 - 339	NA	U	U
Biphenyl(L)	0 - 102	NA	U	U
Chrysene(H)	0 - 295	400/2800	0%	0%
C1-chrysene(H)	0 - 907	400/2800	< 1%	0%
C2-chrysene(H)	0 - 851	400/2800	< 1%	0%
C3-chrysene(H)	0 - 161	400/2800	0%	0%
C4-chrysene(H)	0 -1263	400/2800	< 1%	0%
Dibenzo(a,h)anthracene(H)	0 - 106	60/260	< 1%	0%
Dibenzothio(H)	0 - 75	NA	U	U
C1-dibenzothio(H)	0 - 382	NA	U	U
C2-dibenzothio(H)	0 - 812	NA	U	U
C3-dibenzothio(H)	0 - 813	NA	U	U
Fluoranthene(H)	0 - 653	600/3600	< 1%	0%
C1-fluoranthpyrene(L)	1 - 351	NA	U	U
Fluorene(L)	0 - 126	35/640	6%	0%
C1-fluorene(L)	0 - 373	35/640	16%	0%
C2-fluorene(L)	0 - 250	35/640	42%	0%
C3-fluorene(L)	0 -1435	35/640	54%	1%
Naphthalene(L)	0 - 219	340/2100	0%	0%
C1-naphthalene(L)	0 - 581	340/2100	1%	0%
C2-naphthalene(L)	0 -1509	340/2100	3%	0%
C3-naphthalene(L)	0 -3401	340/2100	5%	1%
C4-naphthalene(L)	0 -3298	340/2100	3%	1%
Perylene(H)	0 - 517	NA	U	U
Phenanthrene(H)	1 - 416	225/1380	1%	0%
C1-phenanthrene(H)	3 -1427	225/1380	2%	0%
C2-phenanthrene(H)	4 -2148	225/1380	3%	0%
C3-phenanthrene(H)	0 -1572	225/1380	3%	0%
C4-phenanthrene(H)	3 - 702	225/1380	1%	0%
Pyrene(H)	1 -1545	350/2200	< 1%	0%
(i)1,2,3-c,d-pyrene(H)	0 - 291	NA	U	U
1-methylnaphthalene(L)	0 - 303	NA	U	U
2-methylnaphthalene(L)	0 - 327	NA	U	U
2,3,5 Trimethylnapthalene(L)	0 - 773	NA	U	U
2,6 Dimethylnapthalene(L)	0 - 590	NA	U	U
1-methylphenanthrene(H)	0 - 306	NA	U	U
High Molecular Wt. PAHs	46-7170	NA	1%	0
Low Molecular Wt. PAHs	9-13949	NA	1%	0
Total PAHs	115-21119	4000/35000	4%	0

Table 2.5 Ranges of PAH concentrations found in the 1992 Louisianian Province Demonstration, criteria used for comparison from Long and Morgan (1990) [x/y where x=concentration where biological effects occurred 10% of the time and y=median concentration for effects to occur], and the percent of sediments exceeding these criteria. (NA = None Available; U = Unknown)

pesticide: acenaphthalene, phenanthrene, fluoranthene, and dieldrin (US EPA 1993b-e). SQC are expressed as µg analyte/g organic carbon; therefore, concentrations must first be normalized for the organic carbon content of the sediment. Only those sediments with organic carbon concentrations > 0.2% can be examined using this approach. Separate SQC values have been tentatively established for freshwater and saltwater sediments.

SQC values for the four analytes measured are listed in Table 2-6, along with the upper and lower bounds. It is important to note that these values are still in draft form and are subject to change as the documents proceed through the peer review process.

The distributions of three of these four analytes in the Louisianian Province in 1992 normalized for organic carbon of the sediments are shown in Figures 2-59 through 2-61. The percent areas exceeding SQC in freshwater and saltwater habitats in the estuaries of the Louisianian province in 1992 shows that 0% of the estuarine sediments exceeded these criteria for acenapthene, phenanthrene, and fluoranthene.

Analyte		SQC F/S	Upper SQC	Lower SQC
Acenaphthene				
	F	130	280	62
	S	230	500	110
Phenanthrene				
	F	180	390	85
	S	240	510	110
Fluoranthene				
	F	510	1100	240
	S	650	1400	300
Dieldrin				
	F	11	24	5.2
	S	20	44	9.5

Table 2.6 U.S. EPA draft Sediment Quality Criteria (SQC) for analytes measured. Freshwater (F), Saltwater (S), and upper and lower confidence intervals are included. All values are µg/g organic carbon.

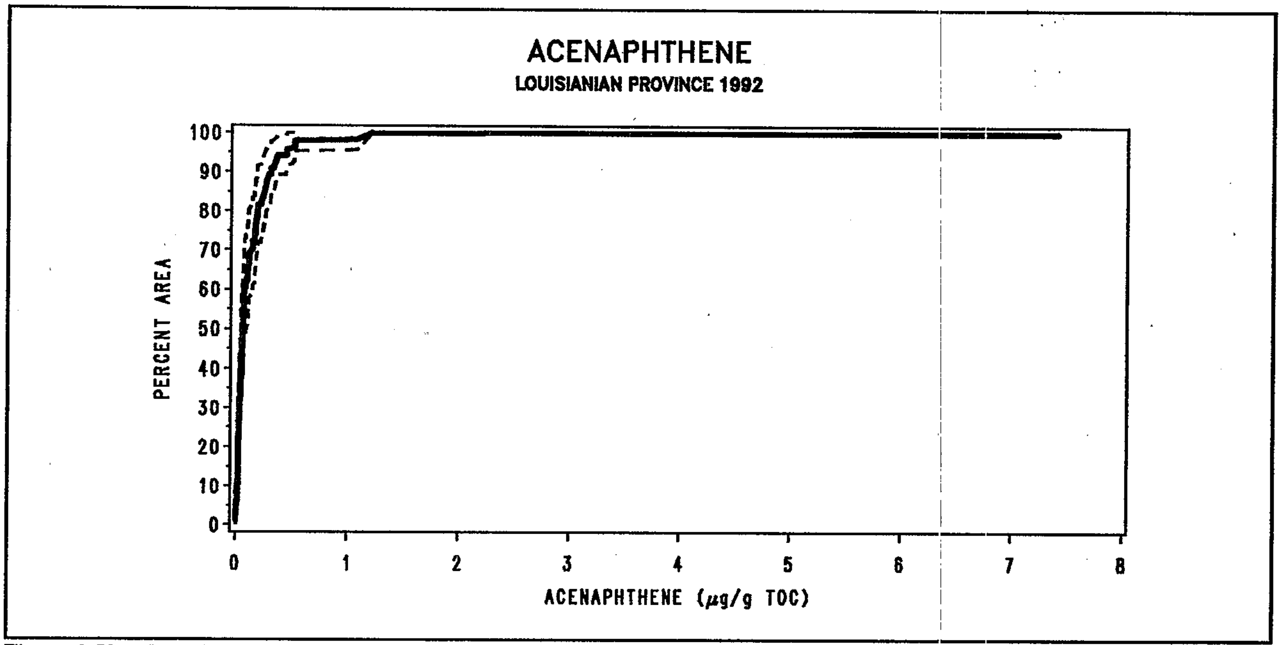

Figure 2-59. Cumulative distribution of acenaphthalene concentrations normalized for organic carbon content of sediments in the Louisianian Province sediments in 1992 (-) and its associated 95% confidence interval (--).

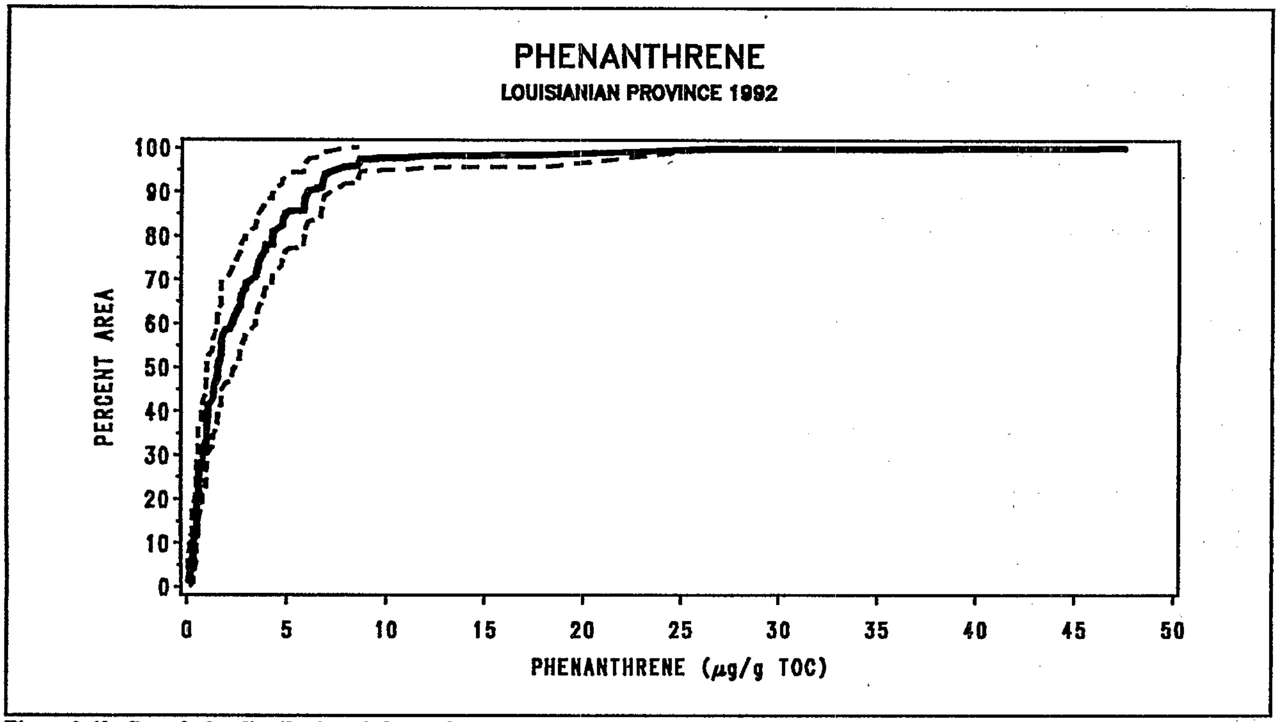

Figure 2-60. Cumulative distribution of phenanthrene concentrations normalized for organic carbon content of sediments in the Louisianian Province sediments in 1992 (-) and its associated 95% confidence interval (--).

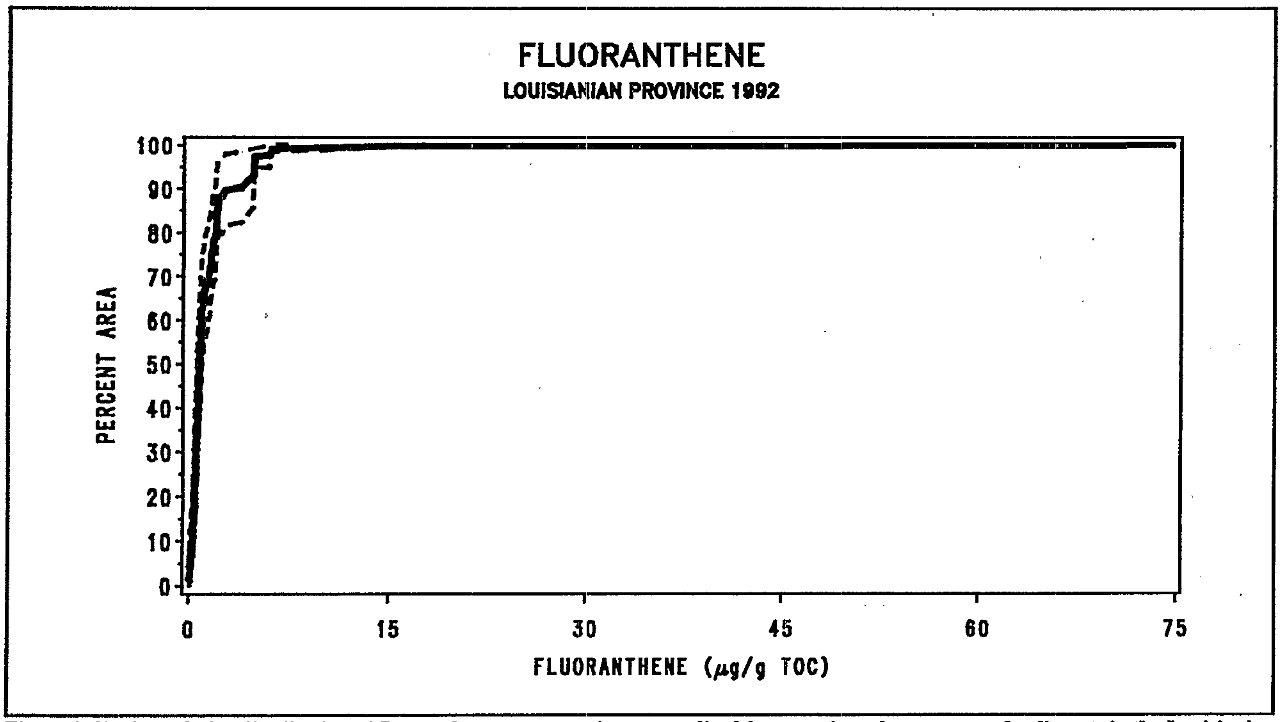

Figure 2-61. Cumulative distribution of fluoranthene concentrations normalized for organic carbon content of sediments in the Louisianian Province sediments in 1992 (-) and its associated 95% confidence interval (--).

Petroleum and combustion-type PAH sources contain very different PAH compound distributions. Because of this, the distributions of PAHs in a sample can provide information on the relative importance of petroleum versus combustion PAH sources (Lake et al. 1979). Petroleum products contain relatively large amounts of lower molecular weight compounds relative to combustion sources which are dominated by higher molecular weight compounds.

The cumulative distribution function of the relative percent of high molecular weight compounds (see Table 2-5 for a listing of high and low molecular weights) shown in Figure 2-62 shows the relatively even distribution of high and low weight PAHs. This indicates that neither combustion processes or petroleum products are dominant sources of these compounds but rather both contribute to the observed PAHs in the Louisianian Province estuarine sediments. No differences were noted among the three estuarine classes with regard to dominant sources of PAHs. However, a slight dominance of low molecular weight PAHs was observed east of the Mississippi River while high molecular weight PAHs slightly dominated in western Gulf of Mexico estuaries. (Figures 2-63 and 2-64).

2.2.7 SEDIMENT CONTAMINANTS - POLYCHLORINATED BIPHENYLS

Twenty polychlorinated biphenyl (PCB) congeners were analyzed from the Louisianian Province sediments. Concentrations of total PCBs (sum of the twenty congeners) ranged from 0 to 38 ppb (Fig. 2-65). Given that the criterion for low-level ecological effects is 400 ppb for total PCBs and 25 ppb for individual congeners (Long and Morgan 1990), no PCB concentrations exceeded these criteria (Table 2-7).

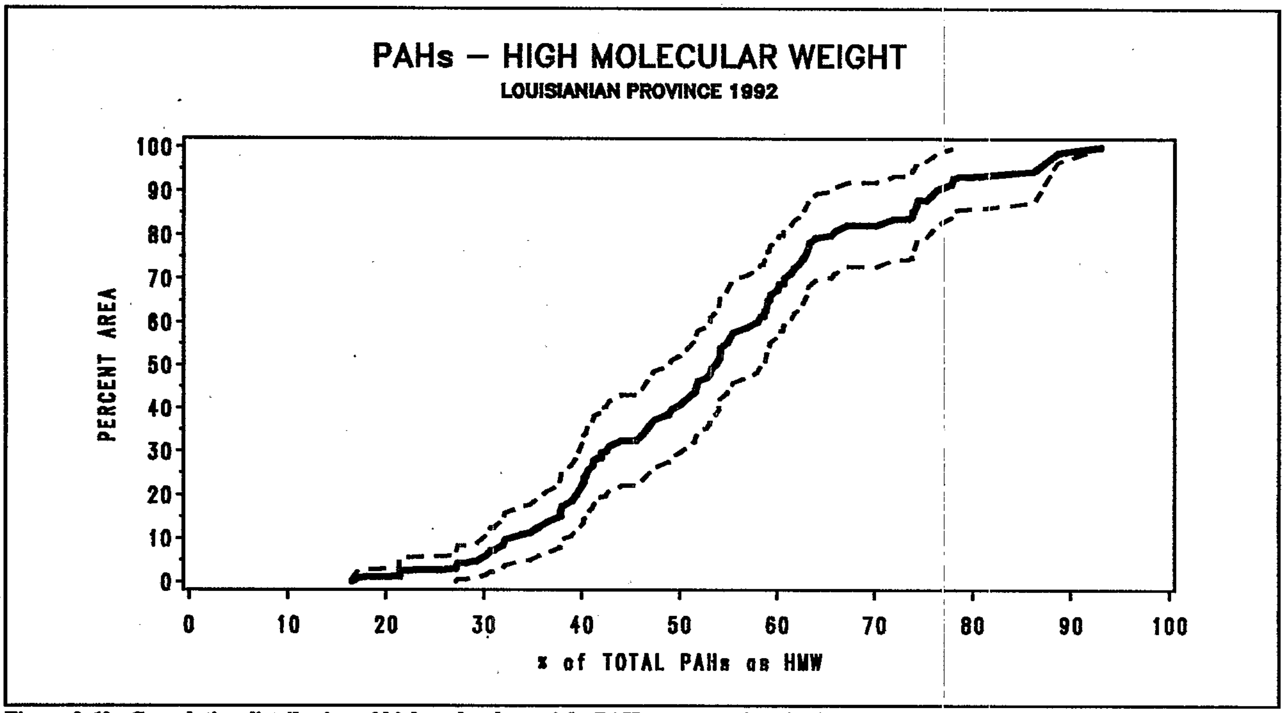

Figure 2-62. Cumulative distribution of high molecular weight PAH concentrations in the Louisianian Province sediments in 1992 (-) and its associated 95% confidence interval (--).

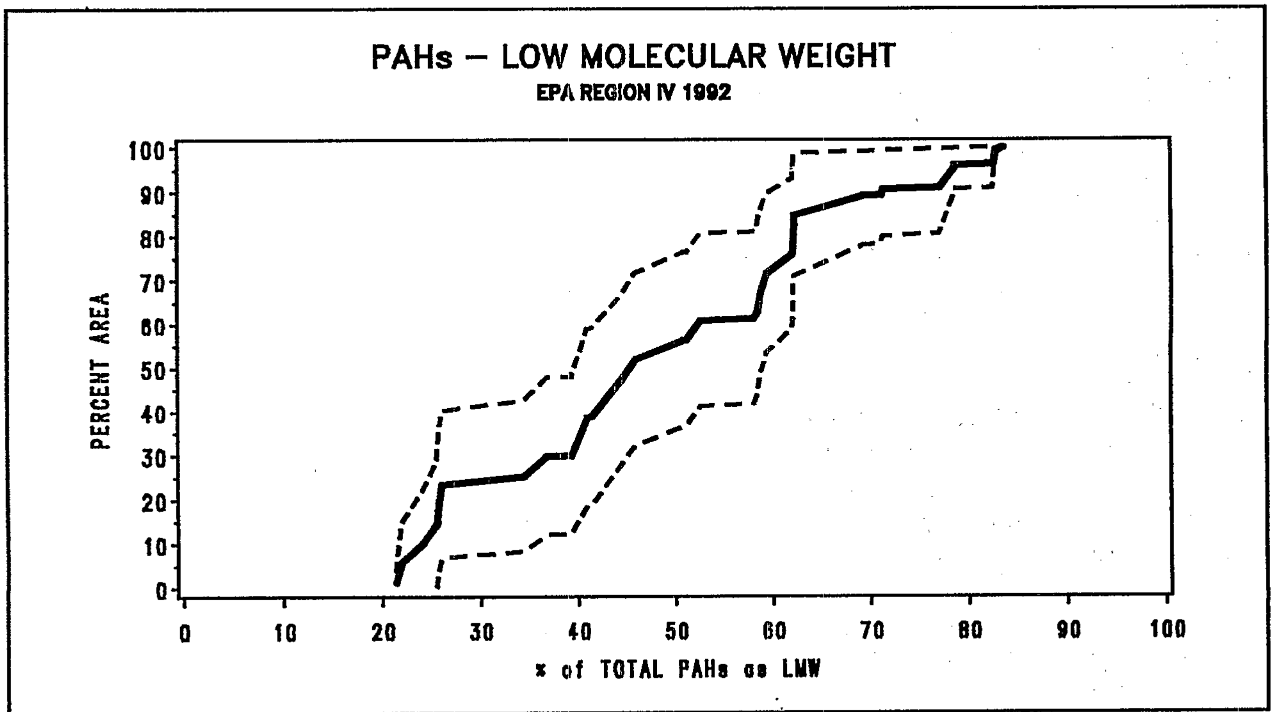

Figure 2-63. Cumulative distribution of low molecular weight PAH concentrations in the Louisianian Province sediments in 1992 east of the Mississippi River (-) and its associated 95% confidence interval (--).

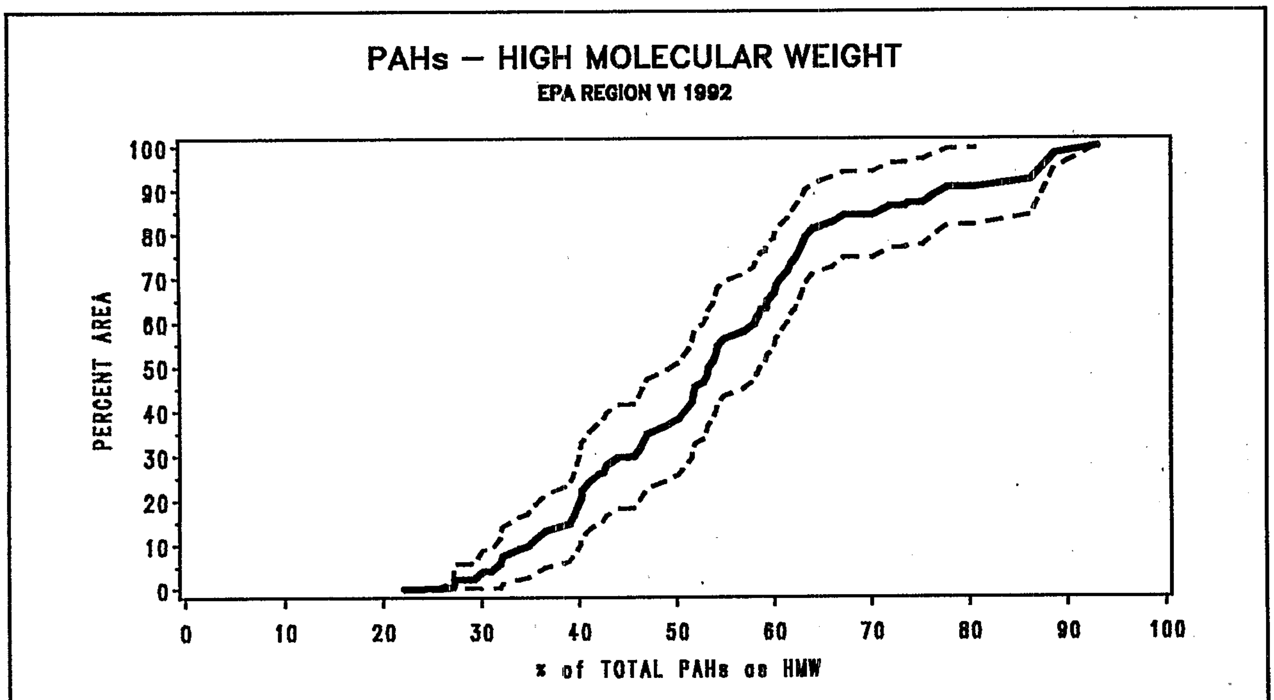

Figure 2-64. Cumulative distribution of the proportion of high molecular weight PAHs in the Louisianian Province sediments in 1992 west of the Mississippi River delta (-) and its associated 95% confidence interval (--).

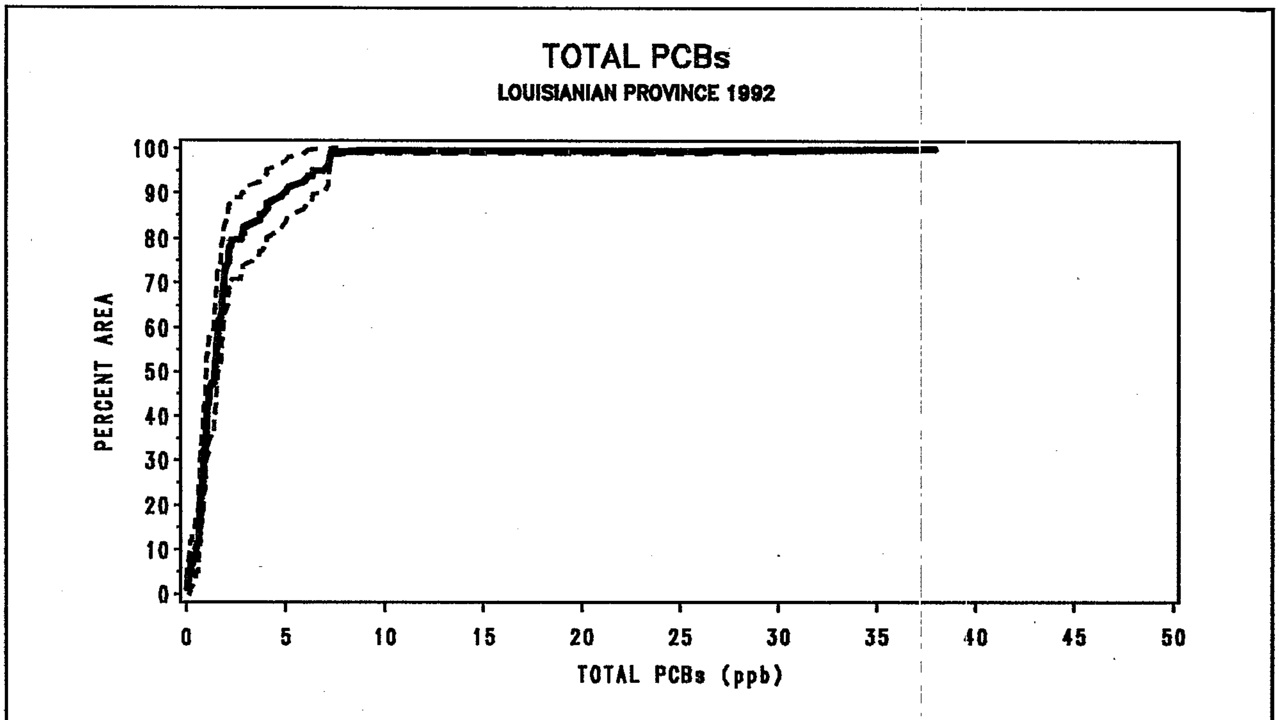

Figure 2-65. Cumulative distribution of total PCB concentrations in the Louisianian Province sediments in 1992 (-) and its associated 95% confidence interval (--).

PCB # (Chlorination)	Range (ppb)
8 (CL2)	0 - 0.8
18 (CL3)	0 - 1.2
28 (CL3)	0 - 2.0
44 (CL4)	0 - 2.5
52 (CL4)	0 - 10.5
66 (CL4)	0 - 1.4
101 (CL5)	0 - 2.9
105 (CL5)	0 - 0.7
110/77 (CL5/4)	0 - 5.1
118/108/149 (CL 5/5/6)	0 - 1.6
126 (CL5)	0 - 1.4
128 (CL6)	0 - 0.4
138 (CL6)	0 - 3.5
153 (CL6)	0 - 3.0
170 (CL7)	0 - 0
180 (CL7)	0 - 1.8
187/182/159 (CL 7/7/6)	0 - 0.7
195 (CL8)	0 - 0.2
206 (CL9)	0 - 0.2
209 (CL10)	0 - 2.0
TOTAL PCBs	0 - 38

Table 2.7 Ranges of polychlorinated biphenyl concentrations determined from Louisianian Province sediments.

2.2.8 SEDIMENT CONTAMINANTS - PESTICIDES

Pesticides constitute a major portion of nonpoint source runoff from agricultural fields, suburban lawns, and golf courses. Twenty-three chlorinated insecticides, including DDT and its derivatives, and one fungicide were analyzed from Louisianian Province sediments. No pesticides have accepted sediment criteria; therefore, we used the few criteria available from Long and Morgan (1990) for DDT and its derivatives, chlordane, endrin, and dieldrin. The ranges of observed concentrations of all pesticides examined are shown in Table 2-8.

Total DDT concentrations (2,4'DDT and 4,4'DDT) above the criterion (7 ppb) were not found in the sediments of the Louisianian Province (Fig. 2-66). However, < 1±1% of sediments contained DDT at concentrations > 1 ppb. These concentrations were found primarily in the large tidal river class

Pesticide	Range (ppb)	Criteria Exceeded	Percent (10%)	Percent (50%)
2,4'DDD	0 - 1.29	2.0/20	0%	0%
4,4'DDD	0 - 2.25	2.0/20	<1%	0%
2,4'DDE	0 - 1.80	2.0/15	<1%	0%
4,4'DDE	0 - 2.18	2.0/15	<1%	0%
2,4'DDT	0 - 0.15	1.0/7	0%	0%
4,4'DDT	0 - 1.44	1.0/7	<1%	0%
Aldrin	0 - 0.98	NA	U	U
Alpha-BHC	0 - 1.67	NA	U	U
beta-BHC	0 - 1.52	NA	U	U
delta-BHC	0 - 0.61	NA	U	U
alpha-Chlordane	0 - 3.21	.5/6	1%	0%
gamma-Chlordane	0 - 4.94	.5/6	5%	0%
Dieldrin	0 - 1.17	.02/8	34%	0%
Endosulfan	0.- 0	NA	0%	0%
Endrin	0 - 0.30	.02/45	4%	0%
Hexachlorobenzene	0 - 4.90	NA	U	U
Heptachlor	0 - 0.25	NA	U	U
Heptachlor Epoxide	0 - 1.87	NA	U	U
Mirex	0 - 0.08	NA	U	U
cis-Nonachlor	0 - 0.91	NA	U	U
trans-Nonachlor	0 - 2.61	NA	U	U
Oxychlordane	0 - 0.21	NA	U	U
Toxaphene	0 - 0	NA	0%	0%
Total BHCs	0 - 4.13	NA	U	U

Table 2.8 Ranges of pesticide concentrations found in the 1992 Louisianian Province Demonstration, criteria used for comparison from Long and Morgan (1990) [x/y where x=concentration where biological effects occurred 10% of the time and y=median concentration for effects to occur], and the percent of sediments exceeding these criteria. (NA = None Available; U = Unknown)

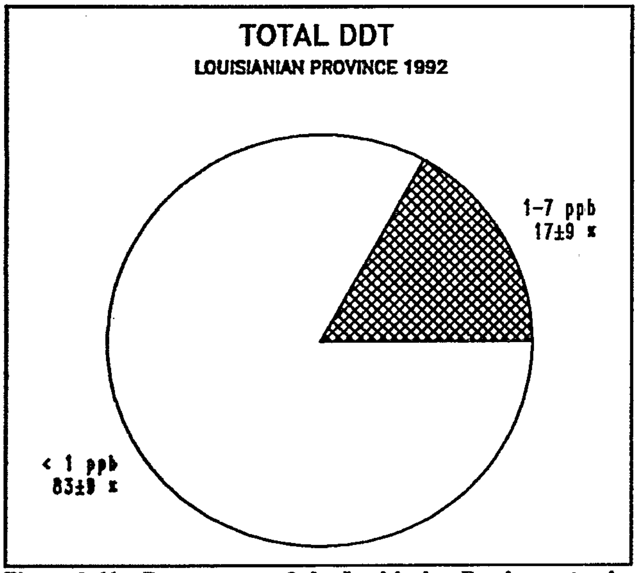

Figure 2-66. Percent area of the Louisianian Province estuaries associated with sediment DDT concentration categories in 1992.

(10±22%) and to a lesser extent in small estuaries (< 1±1%).

Total chlordane concentrations exceeded the criterion of 6 ppb in < 1% of the sediments in the Louisianian Province but did exceed 0.5 ppb (10% effects criterion) in 8±6% of estuarine sediments. These concentrations were found primarily in the large tidal river class (85±20%) and to a somewhat lesser extent in small estuaries (12±17%) and large estuaries (5±6%) (Fig. 2-67).

Endrin concentration did not exceed its median criterion (45 ppb) in any of the sediments examined from the Louisianian Province; however, 4±4% of sediment contained endrin at > 0.02 ppb.

Dieldrin concentration did not exceed its median criterion of 8 ppb in any sediments collected from the Louisianian Province:

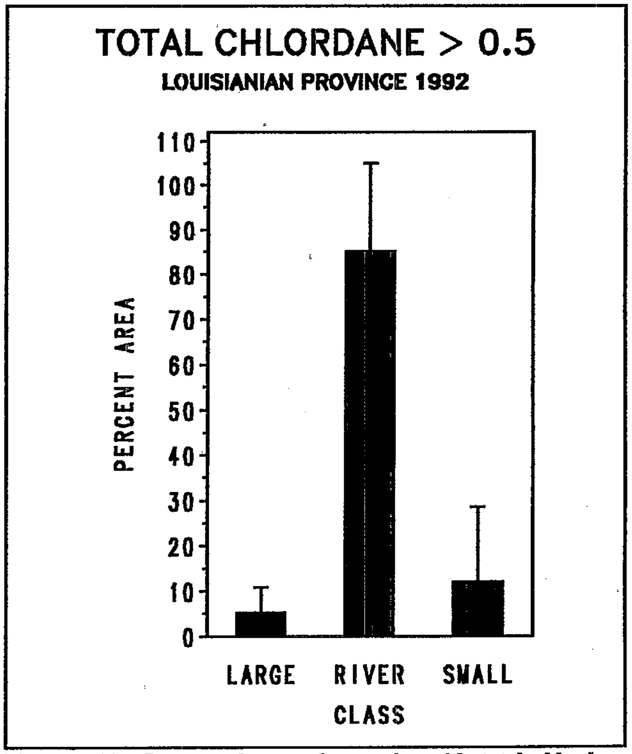

Figure 2-67. Percent of area of estuaries with total chlordane concentrations > 0.5 ppb in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

however, 34±11% of sediments had dieldrin concentrations > 0.02 ppb, the 10% effects-level listed by Long & Morgan (1990).

2.2.9 SEDIMENT CONTAMINANTS - HEAVY METALS

Fifteen heavy metals were analyzed for the sediments collected in the 1992 Louisianian Province Demonstration. These metals were examined from two perspectives: (1) Criteria-based and (2) Anthropogenic enrichment. Criteria-based analyses were conducted similarly to those for other contaminants where a criterion of degradation was selected for each metal and distributional analysis showed the proportion of the sediments exceeding that criterion value. Anthropogenic enrichment was determined using a reduced data set and regressing log-transformed metal concentrations against log-transformed aluminum concentrations. The data set reduction required the removal of clearly elevated concentrations (i.e., metal concentrations > 10% Long and Morgan Values). Once the regression is completed, the complete data set is compared to the upper 95% confidence interval of the regression. All sites with concentrations exceeding the upper 95% confidence interval are anthropogenically enriched with regard to metals.

2.2.10. CRITERIA COMPARISONS

Table 2.9 shows the ranges of heavy metals concentrations found during the 1992 Louisianian Province Demonstration and their criteria values for comparison. Only nickel, zinc, tin, and to a lesser extent lead, mercury, antimony, and chromium exceed the selected criteria values (Fig. 2-68). Using the lower criteria (i.e., concentrations resulting in effects 10% of the time), 20±7% of sediments in the Louisianian Province have metal concentrations in excess of these values (Fig. 2-69) whereas only 3±1% of the sediments exceed the higher criteria. Over 5% of the sediments have two or more metals exceeding the lower criteria values.

These high metal concentrations are found primarily in large estuary classes (21±8%, Fig. 2-70) and small estuaries (18±8%, Fig. 2-71). Only 5±5% of the sediments in large tidal rivers (Fig. 2-72) showed metal concentrations in excess of criteria levels.

Metal	Range (ppm)	Criteria (ppm)	Percent Exceeded (10%)	(50%)
Aluminum	76 - 97388	NA	U	U
Antimony	0 - 3.2	2/25	1%	0%
Arsenic	0 - 28.8	33/85	0%	0%
Cadmium	0 - 0.6	5/9	0%	0%
Chromium	0 - 104.4	80/145	4%	0%
Copper	0 - 41.6	70/390	0%	0%
Iron	0 - 71177	NA	U	U
Lead	0 - 127.0	35/110	3%	1%
Manganese	0 - 1260	NA	U	U
Mercury	0 - 0.2	.15/1	1%	0%
Nickel	0 - 36.9	30/50	10%	0%
Selenium	0 - 1.2	NA	U	U
Silver	0 - 0.9	1/2	0%	0%
Tin	0 - 6.3	1/3	68%	10%
Zinc	5 - 625.1	120/270	11%	1%

Table 2.9 Ranges of heavy metal concentrations found in the 1992 Louisianian Province Demonstration, criteria used for comparison from Long and Morgan (1990) [x/y where x=concentration where biological effects occurred 10% of the time and y=median concentration for effects to occur], and the percent of sediments exceeding these criteria. NA = None Available; U= Unknown)

2.2.10.1 ANTHROPOGENIC ENRICHMENT

Aluminum concentrations vary over three orders of magnitude (76 to 97000 ppm) in the Louisianian Province. As aluminum content in sediments is primarily derived from the natural crust of the earth, this wide variation generally

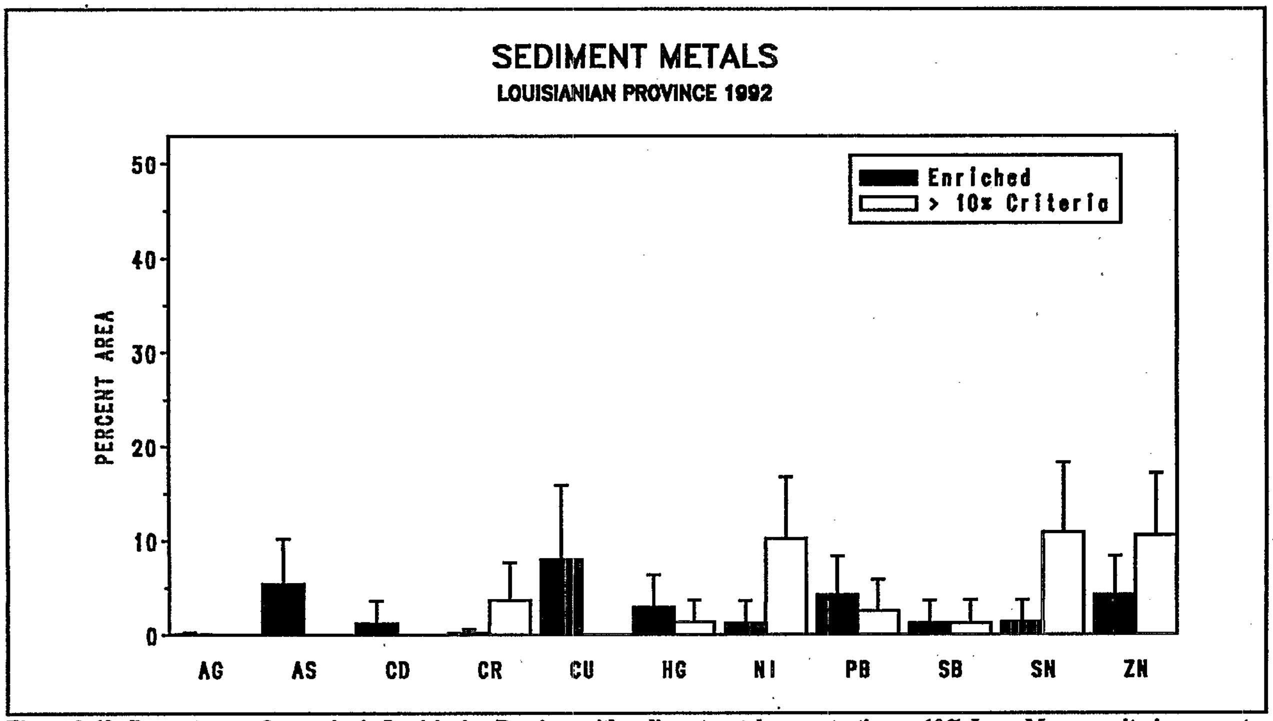

Figure 2-68. Percent area of estuaries in Louisianian Province with sediment metal concentrations > 10% Long-Morgan criteria or greater than expected based on aluminum concentrations (bars represent 95% confidence intervals).

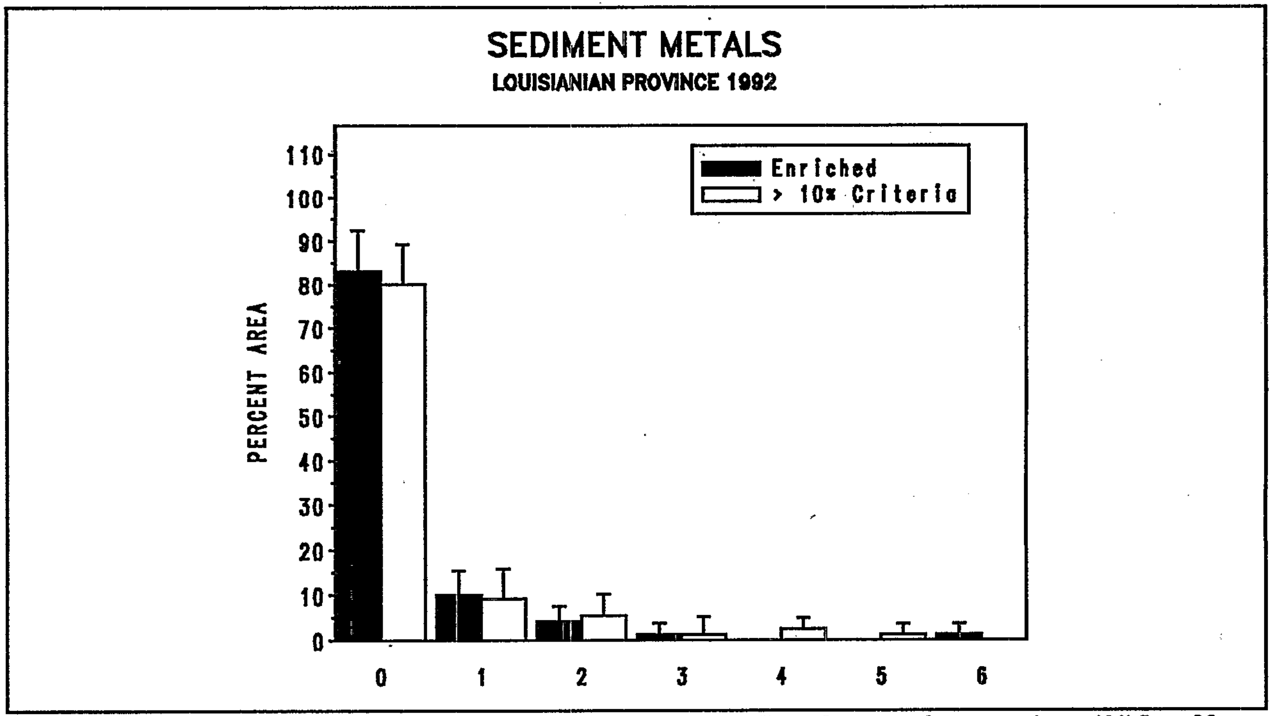

Figure 2-69. Percent area of estuaries in Louisianian Province with one or more sediment heavy metal concentrations > 10% Long-Morgan sediment criteria or greater than expected based on aluminum concentrations (bars represent 95% confidence intervals).

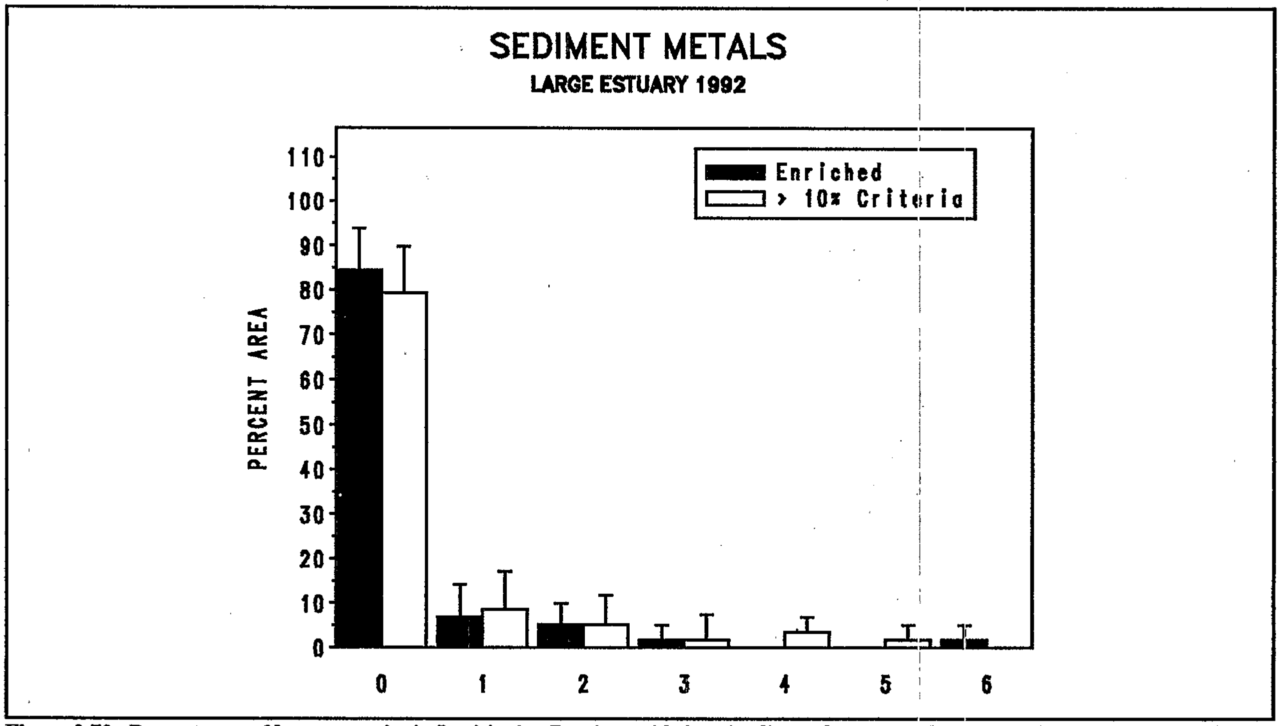

Figure 2-70. Percent area of large estuaries in Louisianian Province with 0 to 6 sediment heavy metal concentrations > 10% Long-Morgan sediment criteria or greater than expected based on aluminum concentrations (bars represent 95% confidence interval).

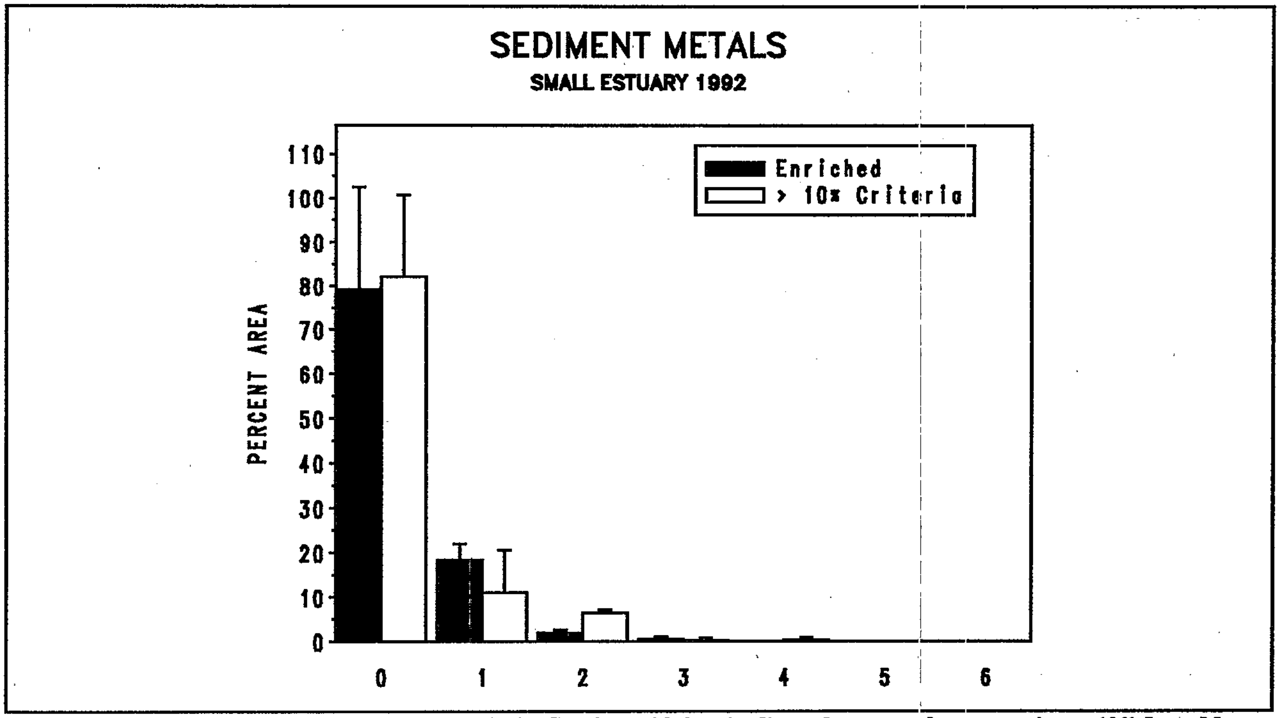

Figure 2-71. Percent area of small estuaries in Louisianian Province with 0 to 6 sediment heavy metal concentrations > 10% Long-Morgan sediment criteria or greater than expected based on aluminum concentrations (bars represent 95% confidence interval).

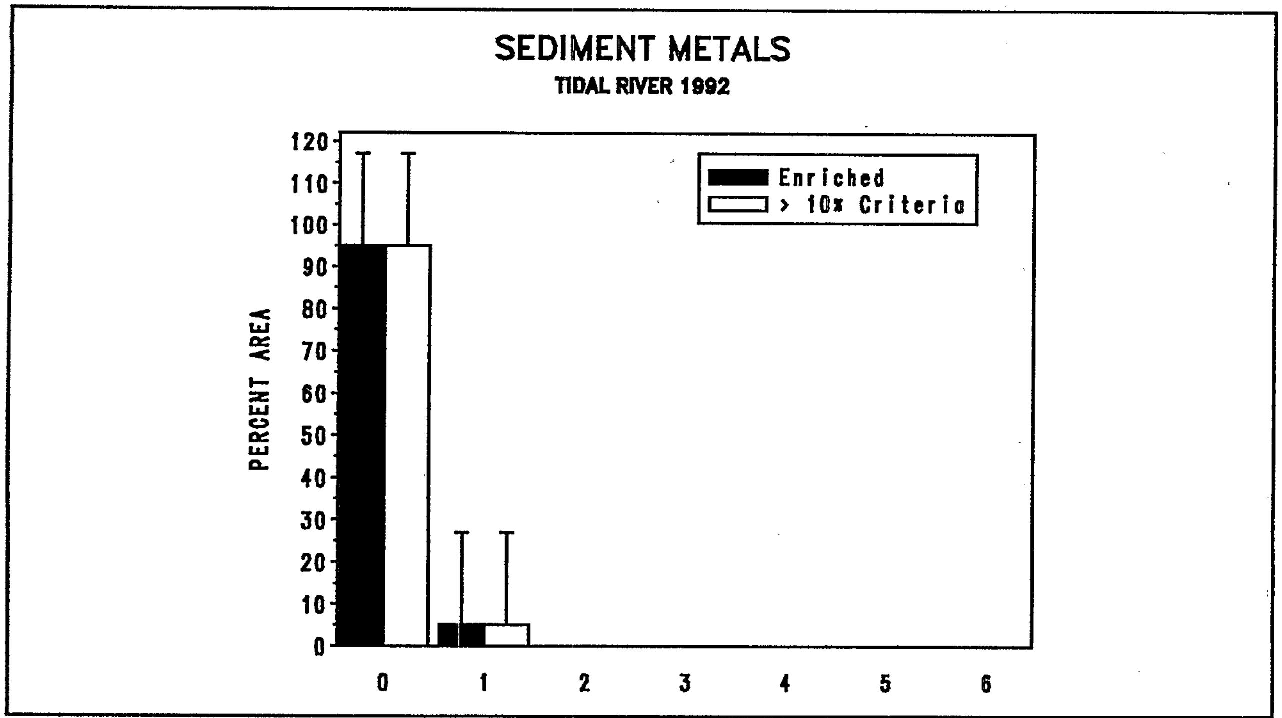

Figure 2-72. Percent area of large tidal rivers in Louisianian Province with 0 to 6 sediment metal concentrations > 10% Long-Morgan sediment criteria or greater than expected based on aluminum concentrations (bars represent 95% confidence interval).

is accompanied by wide variations in the portion of other metals observed that is attributable to the earth's crust. Therefore, the observed metal concentrations should be adjusted for a reference metal (i.e., aluminum). This approach has been used numerous times in estuarine environments (Klinkhammer and Bender 1981, Trefry et al. 1985, Windom et al. 1989, Schropp et al. 1990). Simple log-log regressions were completed using aluminum and each of the other observed metals. All regressions were significant (< 0.05); thus, aluminum was used as the adjustment reference metal.

Sampling sites that were within the 1991 and 1992 Louisianian Province Demonstration data sets that were determined to be representative of natural, unenriched areas were selected to develop the regressions. The results of these regressions are shown in Table 2-10. The slopes and intercepts of these regressions were similar in 1991 and 1992. The metal-specific regression slope and its associated 95% confidence intervals were then compared to the complete data set and all locations falling above the 95% confidence interval represent sites that are anthropogenically enriched. The results of these regression analyses for all metals revealed some enrichment of all metals except silver although the technique would be expected to show 1-2% enrichment as an artifact of the technique. Even with this slight bias, enrichment of Louisianian Province sediments is evident for arsenic, mercury, copper, lead and zinc (3 to 6% sediments), (Fig. 2-68).

By comparison, the two methods yielded very similar results with 80±8% of the sediments meeting the criteria levels and 84±8% of the sediments being "unenriched" (Figure 2-69). While the overall picture is the same, inspection of Fig. 2-68 shows some marked differences. While zinc, tin, and nickel levels exceed criteria values for 10 to 12% of

Table 2-10. Relationship between sediment metal concentration and aluminum, using only those sites with levels below criteria values. The significance level for all models was < .001. Model: ln(metal) = intercept + slope*ln(Al)

		1991			1992		
Metal	criteria value	r^2	slope	intercept	r^2	slope	intercept
Ag	1	.51	.439	-2.650	.56	.489	-2.873 *
As	33	.61	.574	1.015	.67	.630	0.874
Cd	5	.38	.457	-2.601	.46	.599	-2.704
Cr	80	.84	.611	2.904	.77	.660	2.707
Cu	70	.80	.790	1.140	.79	.781	1.139
Hg	.15	.50	.435	-3.447	.39	.401	-3.833
Ni	30	.90	.814	1.512	.87	.791	1.531
Pb	35	.90	.695	1.747	.93	.665	1.623
Sb	2	.38	.290	-0.904	.24	.371	-1.203 *
Sn	3	.79	.608	-0.582	.63	.753	-0.902 *
Zn	120	.85	.923	2.625	.80	.777	2.859

r^2 = the correlation coefficient for the linear model on the transformed data.

* = slope and intercept represent combined 91 and 92 data as individual year estimates were significantly different

sediments, aluminum-adjusted concentrations show much reduced enrichment (2 to 5%). Conversely, arsenic, cadmium, and copper never exceed their criterion but based on regressions with aluminum are enriched in 1 to 7% of Louisianian Province sediments.

2.2.11 SEDIMENT CONTAMINANTS - BUTYLTINS

Tributyltin (TBT), a compound found in anti-fouling paints until recently, was an effective and widespread means of protecting recreational and commercial craft from fouling organisms in seawater. TBT is considered highly toxic and is a serious environmental concern (Kelly et al. 1990). TBT has been shown to affect shell generation in oysters (Weis and Perlmutter 1987, Weis 1988) and alter the reproductive dynamics of whelks (Weis and Perlmutter 1987). Although TBT is not believed to be a persistent chemical, having a half-life of 7 to 12 days, its continual release through leaching remains a continuing environmental problem. Determination of tributyltin was made for all sediments collected in the 1991 Louisianian Province Demonstration with concentrations expressed as ng (Sn)/g dwt. Only 29±10% of the sediments analyzed showed no traces (0 ppb) of TBT. Seventy-one percent (±10%) of the sediments had concentrations of TBT > 0, with 3±3% having concentrations > 5 ppb (Fig. 2-73). According to Laughlin et al. (1984), long-term tests of tributyltin compounds on fish and invertebrates suggest that the maximum acceptable concentration for TBT would be < 1 ppb. Using 5 ppb as a clear indicator of degraded conditions, most of the high-TBT sediments are found in large tidal rivers (20±24% of sediments) and to a lesser extent

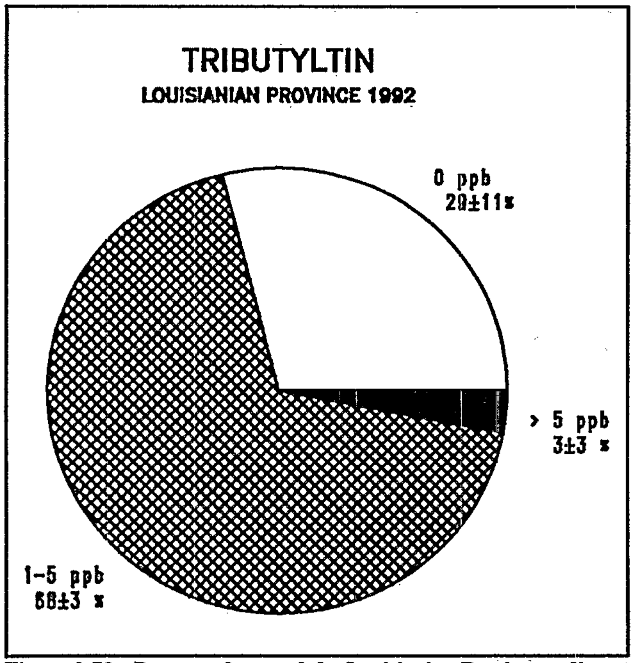

Figure 2-73. Percent of area of the Louisianian Province sediment associated with tributyltin concentration categories in 1992.

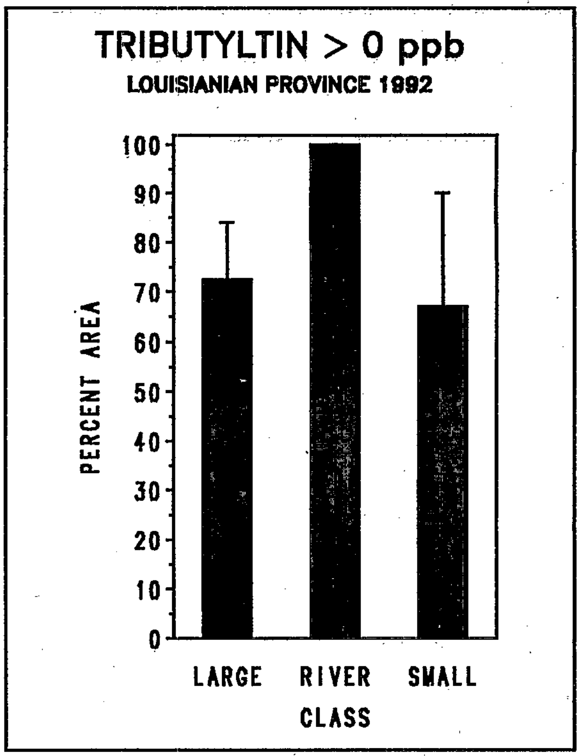

Figure 2-75. Percent of area having sediments with tributyltin > 0 ppb for large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

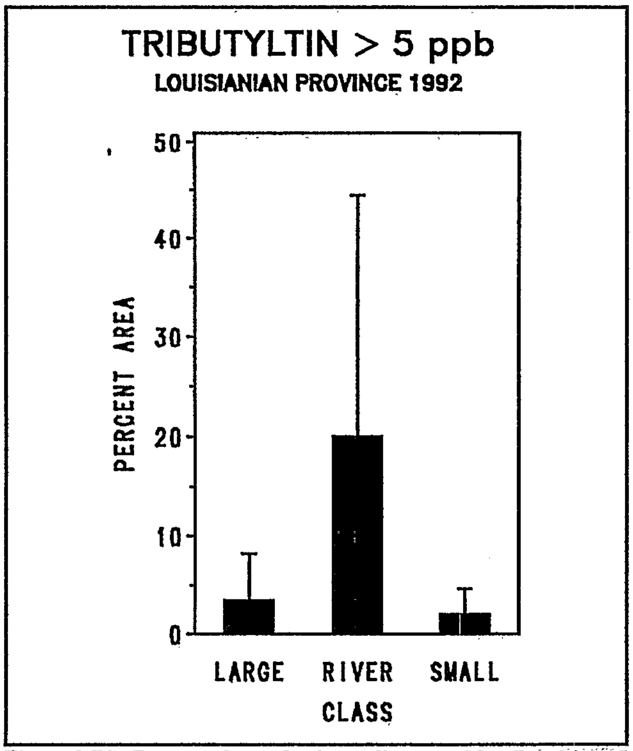

Figure 2-74. Percent of area having sediments with tributyltin > 5 ppb for large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

in small and large estuarine sediments (2±3% and 3±5%, respectively) (Fig. 2-74). Using 1 ppb TBT as an indicator of potential ecological effects results in all sampling classes being represented with 100% of the sediments in large tidal rivers, 67% of sediments in small estuaries, and 74% of sediments in large estuaries having measurable TBT (Fig. 2-75).

2.3 HABITAT INDICATORS

Habitat indicators describe the natural physical and chemical conditions of the locations sampled in the 1992 Louisianian Province Demonstration. These parameters are discussed below.

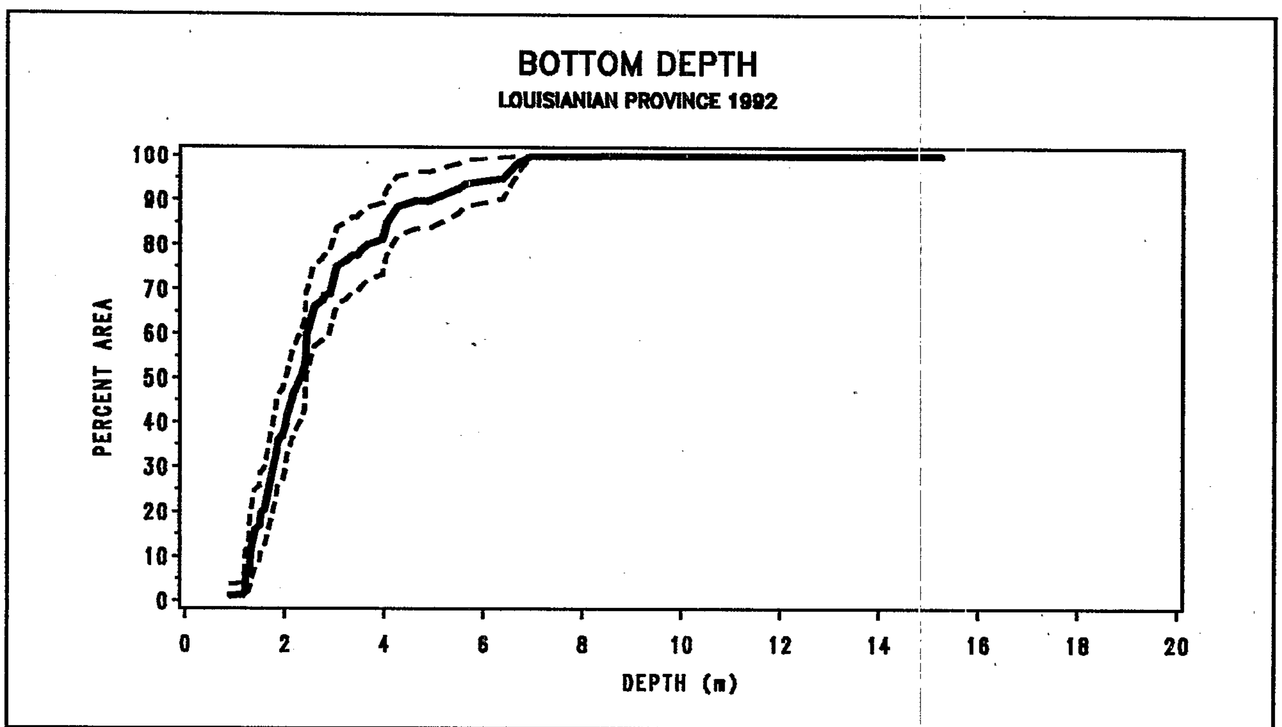

Figure 2-76. Cumulative distribution of water depth in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

2.3.1 WATER DEPTH

The Louisianian Province is comprised primarily of large and small shallow estuaries with water depths rarely exceeding 3 to 4 m except in dredged channels or the Mississippi River. The distribution of water depth observed in the Louisianian Province in 1992 is shown in Fig. 2-76. The proportions of the estuarine classes that have water depths of less than three meters are shown in Fig. 2-77 with large and small estuaries showing significant expanses of shallow water (57±13% of large estuaries and 99±1% of small estuaries).

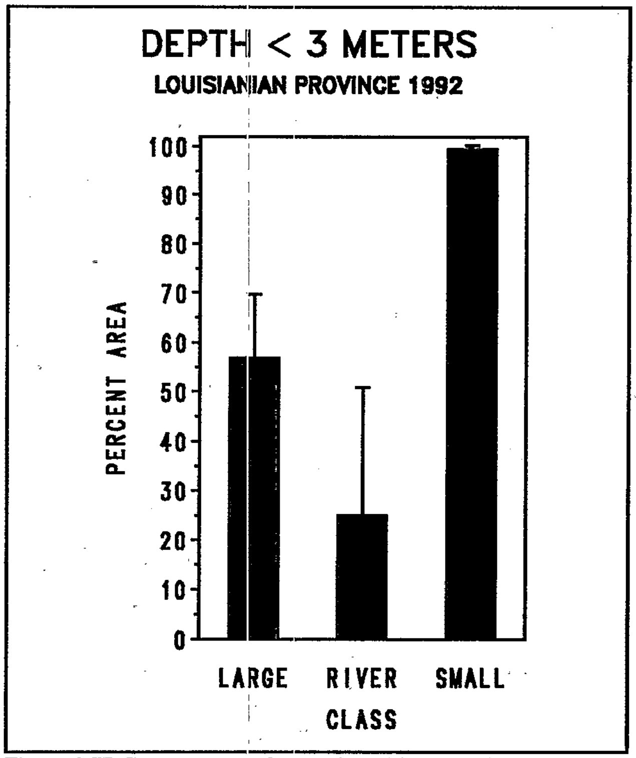

Figure 2-77. Percent area of estuaries with water depth < 3 m in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

2.3.2 WATER TEMPERATURE

Water temperature remained relatively constant, regardless of location, over the six-week sampling period of the Louisianian Province Demonstration. The total range of bottom water temperature observed in July and August spanned only eight degrees Celsius (Fig. 2-78)

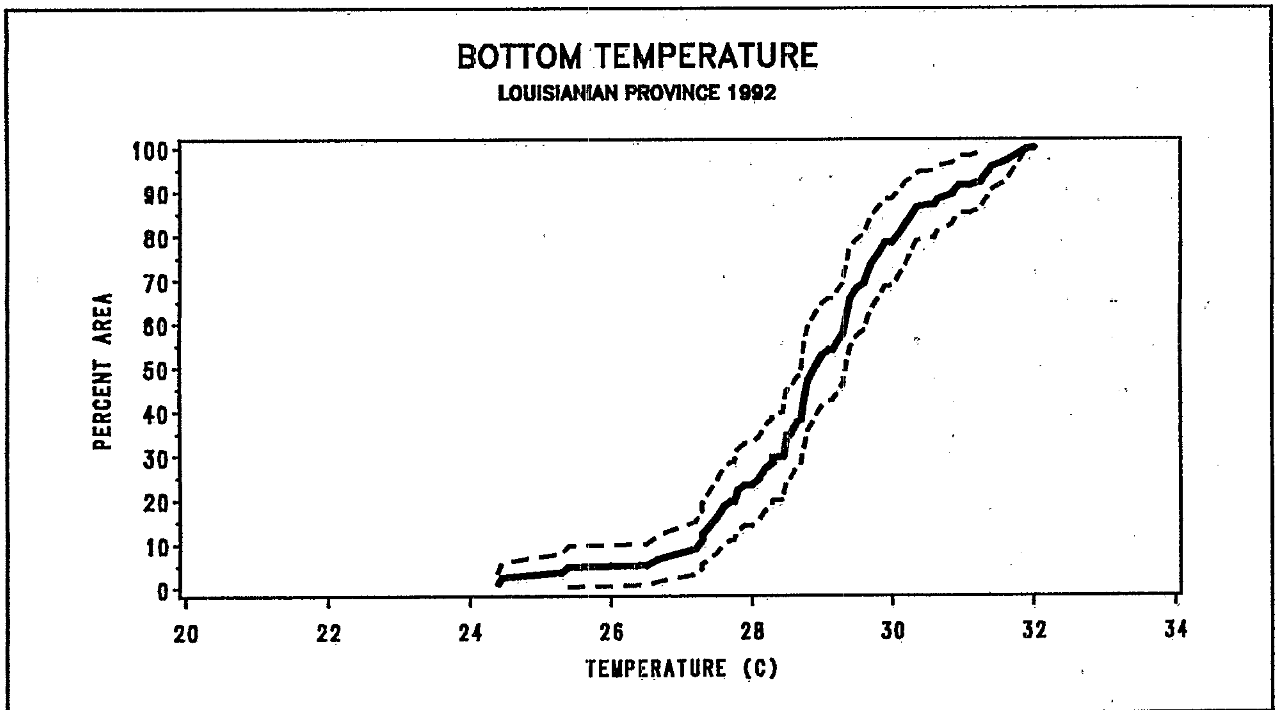

Figure 2-78. Cumulative distribution of water temperature in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

from 24°C to 32°C. Estuarine biota and habitats in the Louisianian Province are exposed to water temperature above 24°C continuously throughout the index sampling period (July and August).

2.3.3 SALINITY

Salinity varied widely among sampling locations. Popular opinion would suggest that salinities in Gulf of Mexico estuaries in late summer would be predominately polyhaline (i.e., > 18 ppt). However, 1992 was a very wet year, particularly in early spring. As a result, the Louisianian Province was characterized by a wide variety of salinity conditions. Salinity ranged from 0 to 38 ppt throughout the province (Fig. 2-79). Continuous salinity measurements did not show any changes in the observed salinity range or distribution. Oligohaline waters (0 to 5 ppt) comprised 18±9% of the province estuarine waters, mesohaline waters (5 to 18 ppt) contributed 28±11%, while polyhaline waters made up the majority of the resource at 54±11% (Fig. 2-80). As expected, the large estuarine waters were primarily polyhaline in 1992 (Fig. 2-81). Large tidal rivers are predominantly (89±23%) oligohaline, while large and small estuaries are about 14 to 25% oligohaline (Fig. 2-82). Almost all of the oligohaline observations that comprise these numbers come from locations within Louisiana. The large tidal river class is equivalent to the Mississippi River. Vermilion and East Cote Blanche Bays (large estuaries in Louisiana) were virtually fresh during sampling due to increased drainage through the Atchafalaya River system, the old drainage for the Mississippi River. The remainder of large estuarine systems are largely polyhaline while small estuarine systems are predominantly mesohaline (49±22%) (Fig. 2-83).

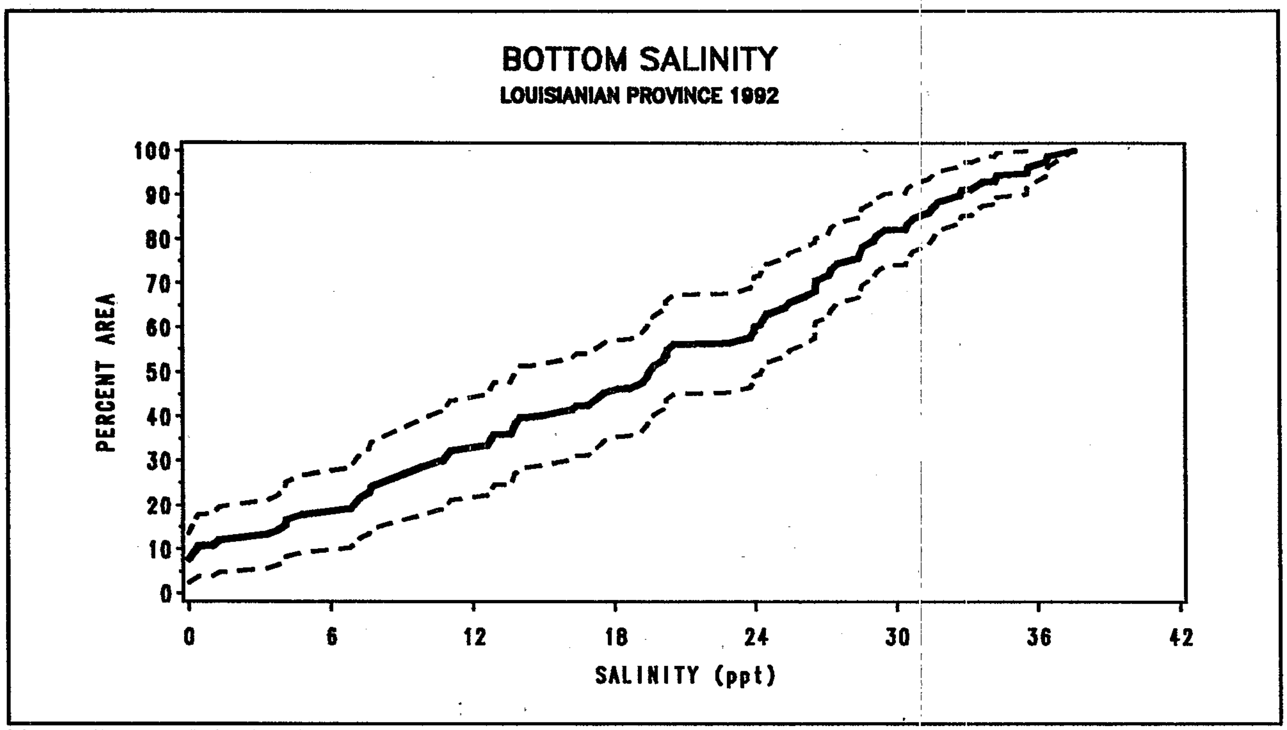

Figure 2-79. Cumulative distribution of bottom salinity in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

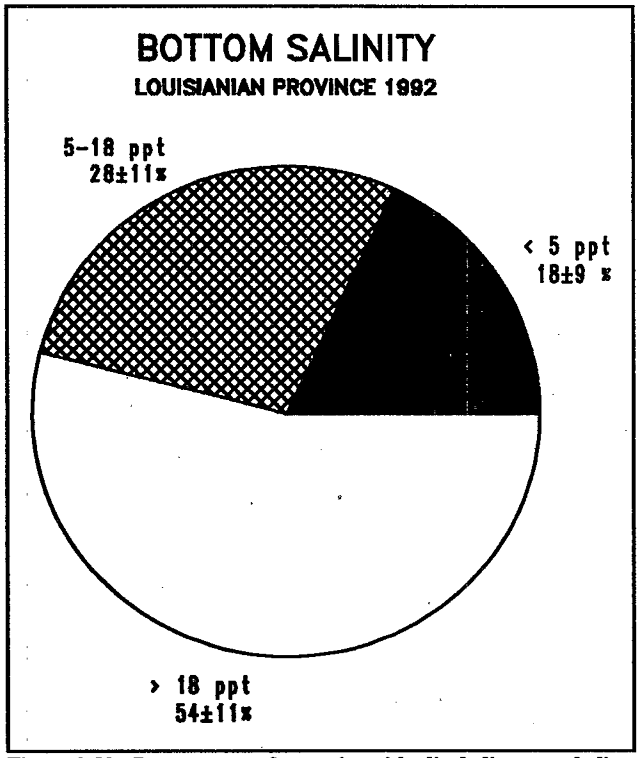

Figure 2-80. Percent area of estuaries with oligohaline, mesohaline, and polyhaline bottom waters in the Louisianian Province in 1992.

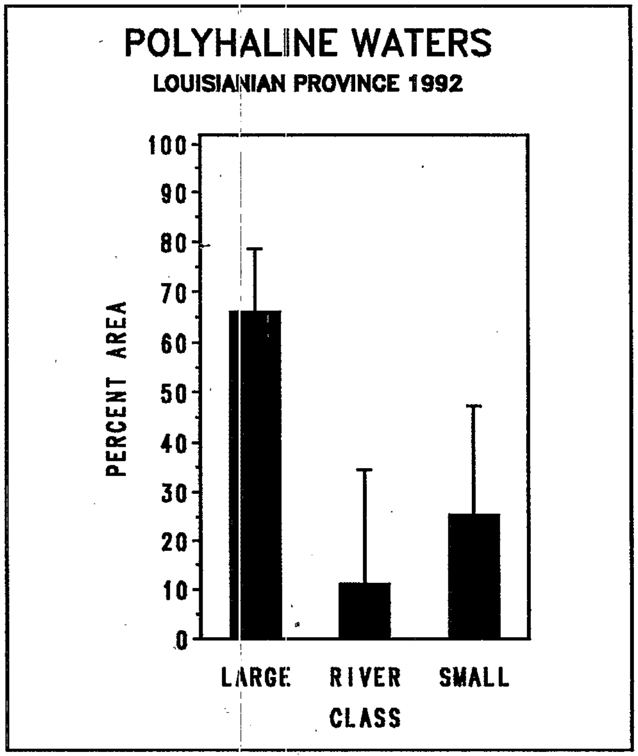

Figure 2-81. Percent area of estuaries with polyhaline salinities in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

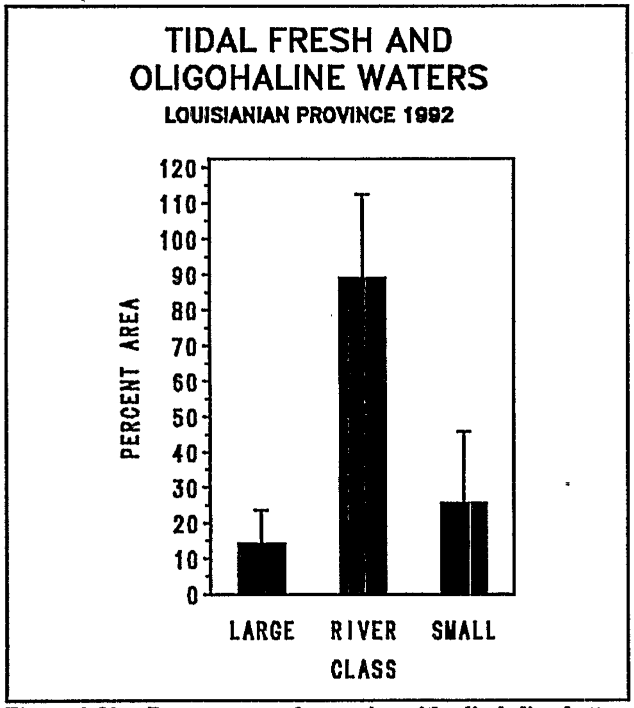

Figure 2-82. Percent area of estuaries with oligohaline bottom waters in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

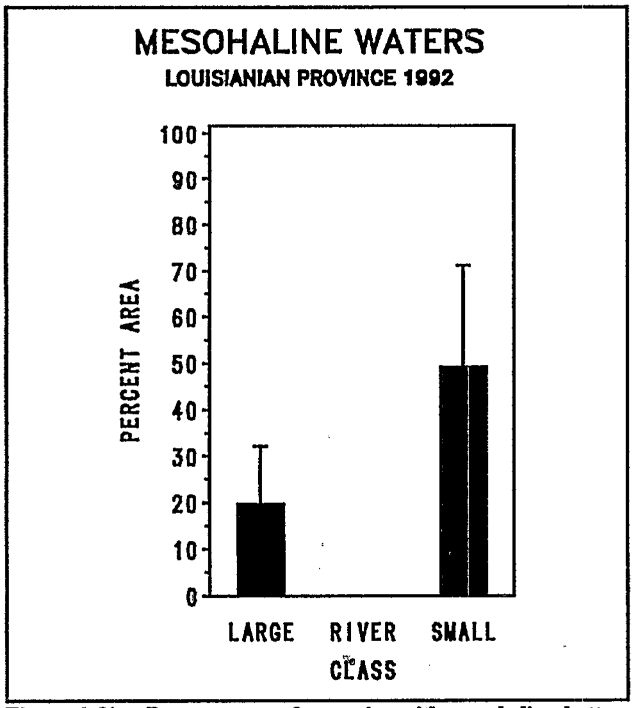

Figure 2-83. Percent area of estuaries with mesohaline bottom waters in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

2.3.4 pH

Estuaries are primarily neutral bodies of water with changes in pH often quickly modified by the ions associated with salinity. However, as stated above, about one-third of the estuarine waters of the Louisianian Province were tidal fresh to brackish in 1992. Bottom pHs ranged from 6.1 to 9.4 (Fig. 2-84) during the sampling period in 1992 with all of the pH values < 7 occurring in large estuaries (Fig. 2-85).

2.3.5 STRATIFICATION

Previous studies have shown that the probability of finding low dissolved oxygen concentrations is greater in areas where there is density stratification of the water column. This occurs because stratification reduces exchange between bottom and oxygen-rich surface waters. Results from the 1992 Louisianian Province Demonstration show that stratification salinity differences range from -5 to 22 ppt often over only 2 to 3 m of water column (Fig. 2-86). Normally, density stratification or delta sigma-T is calculated using both salinity and temperature differences. However, because water temperature is relatively constant from surface to bottom throughout the province, stratification has been approximated based solely on salinity differences. Significant stratification (i.e., salinity differences of > 6 ppt) occurs in only about 4±4% of the estuarine waters in the province (Fig. 2-86) and is primarily seen in large estuaries and the lower portions of large tidal rivers.

2.3.6 PERCENT SILT-CLAY CONTENT

The composition of bottom sediments in terms of grain size or percentage of silts and clays can be an important determinant of the types of estuarine organisms utilizing the bottom. The

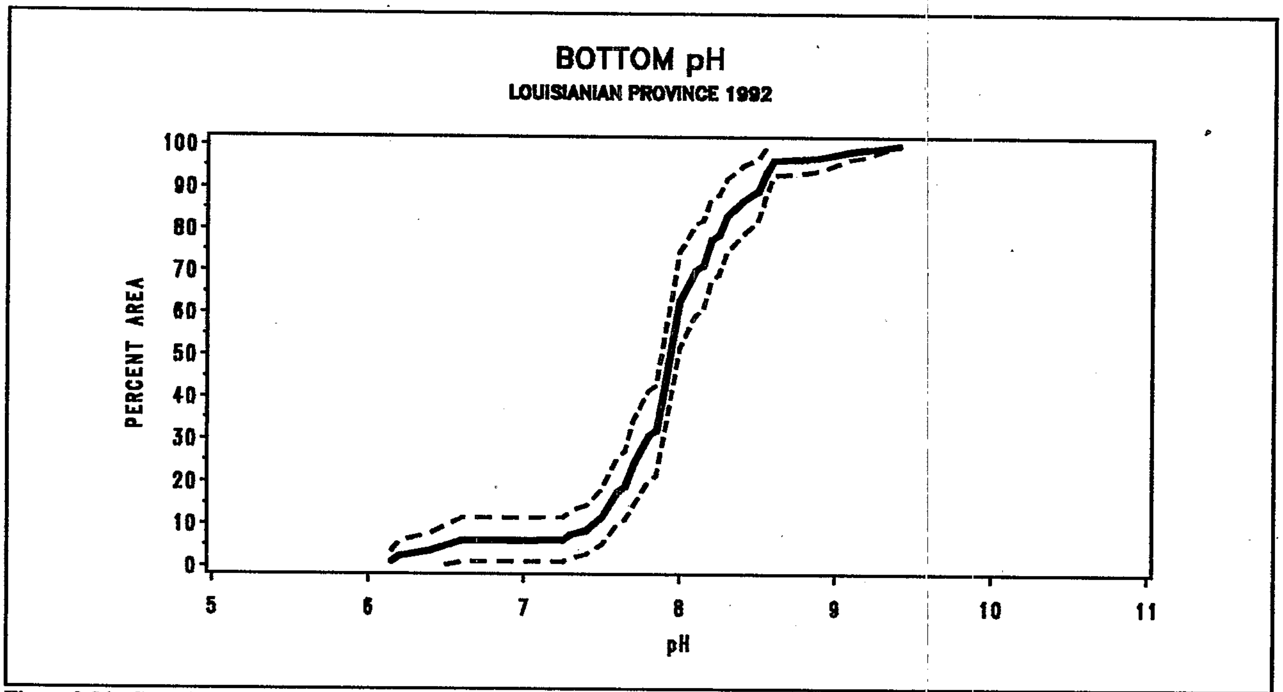

Figure 2-84. Cumulative distribution of bottom pH in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

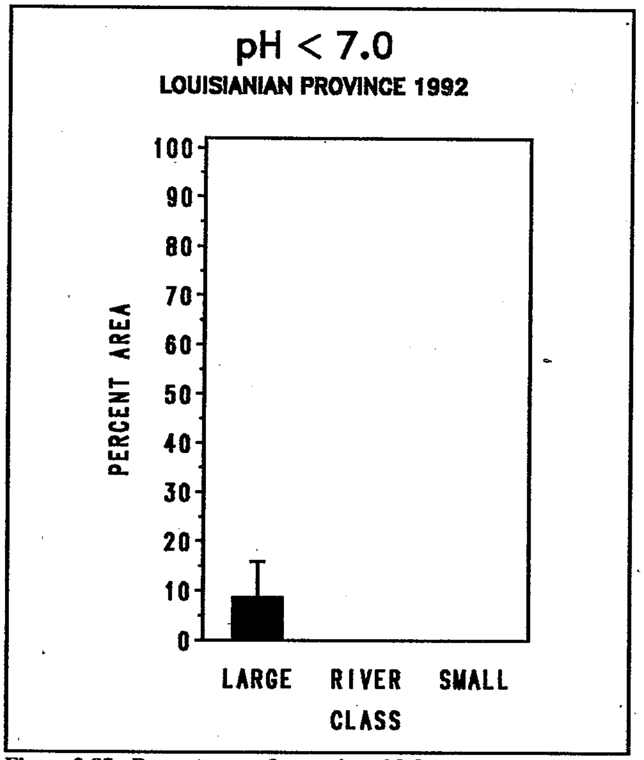

Figure 2-85. Percent area of estuaries with bottom waters with pH < 7 in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

Louisianian Province is comprised of 29±10% mud (> 80% silts and clays), 53±10% intermediate muddy-sand (20-80% silts and clays), and 18±8% sand (< 20% silts and clays) (Fig. 2-87). This distribution also holds for the three sampling classes with the exception of large tidal rivers which have no sand and 45±27% mud (Figs. 2-88 through 2-90).

2.3.7 PERCENT TOTAL ORGANIC CARBON

Another important physico-chemical characteristic of estuarine sediments is the proportion of organic carbon in the sediments. High levels (> 2%) of total organic carbon (TOC) suggest possible enrichment, whether naturally through detrital accumulation or anthropogenically through point source discharges. Based on the results of the 1992 Louisianian Province Demonstration, sediments in the province range from nearly pure sand (no organic carbon) to highly enriched

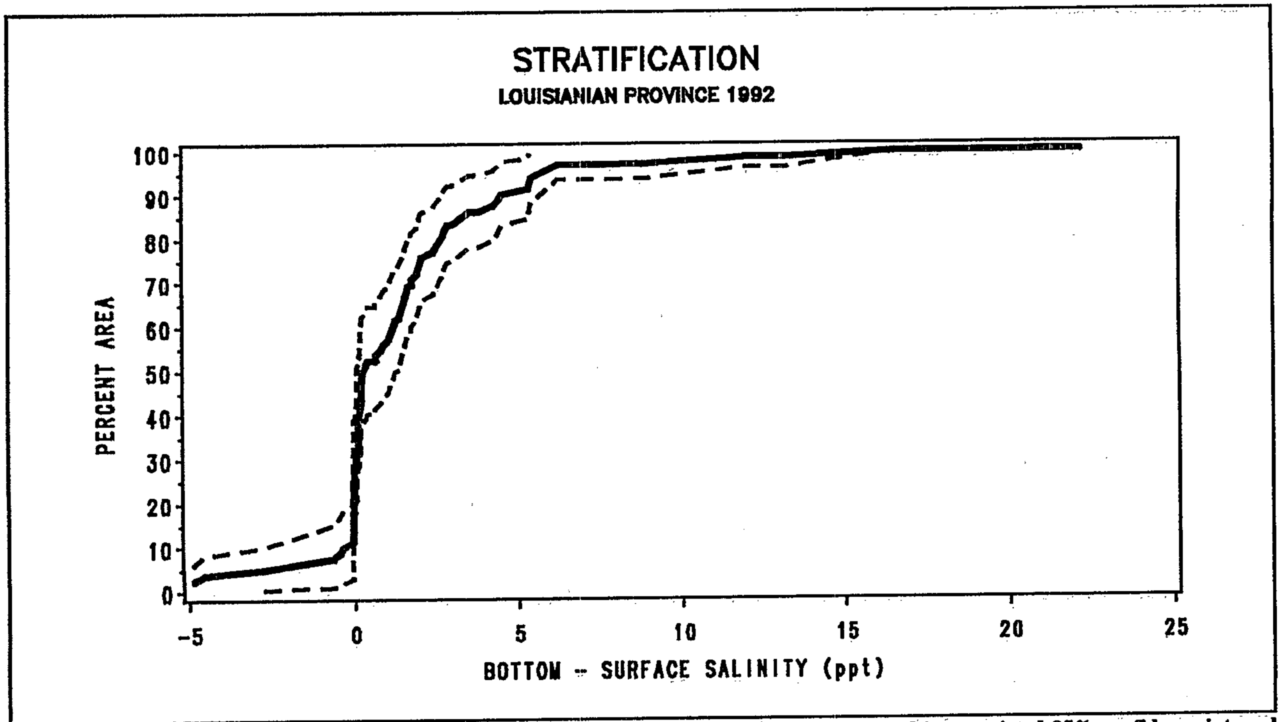

Figure 2-86. Cumulative distribution of stratification in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

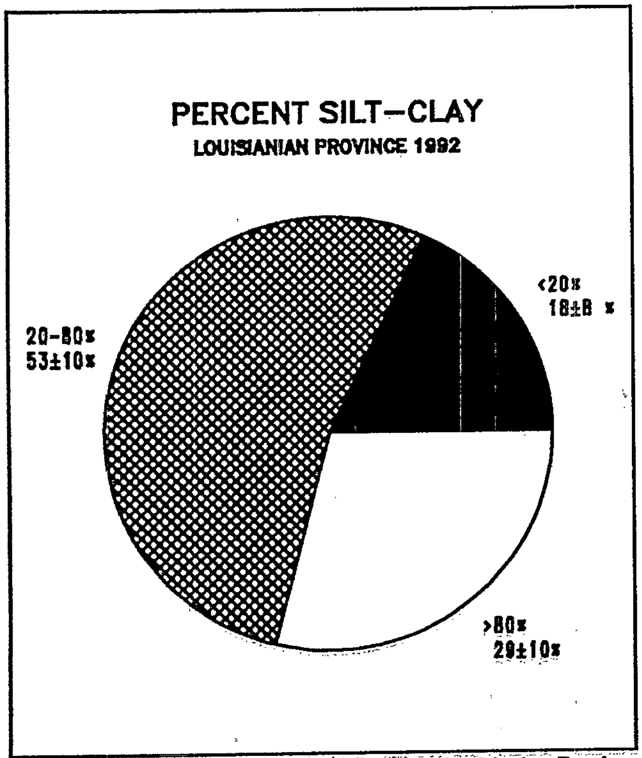

Figure 2-87. Percent area of estuaries in the Louisianian Province associated with percent silt-clay categories in 1992.

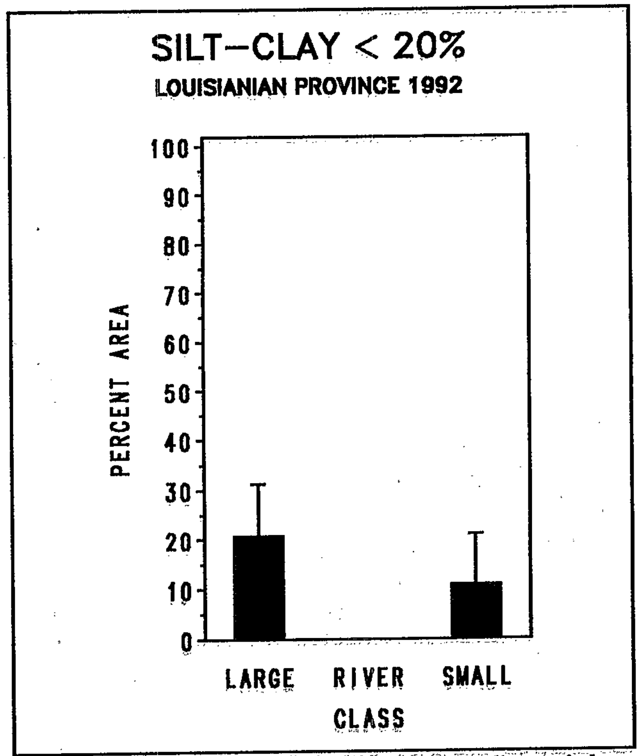

Figure 2-88. Percent area of estuaries with sandy sediments in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

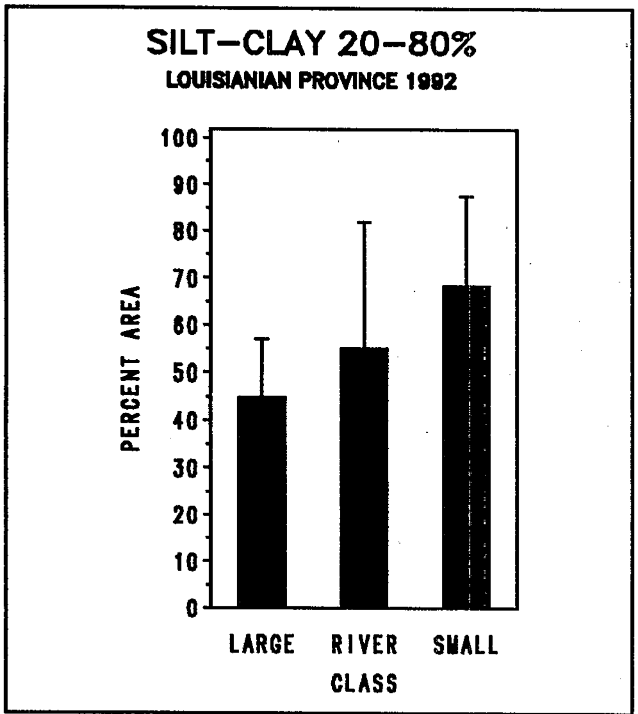

Figure 2-89. Percent area of estuaries with mixed sediments in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

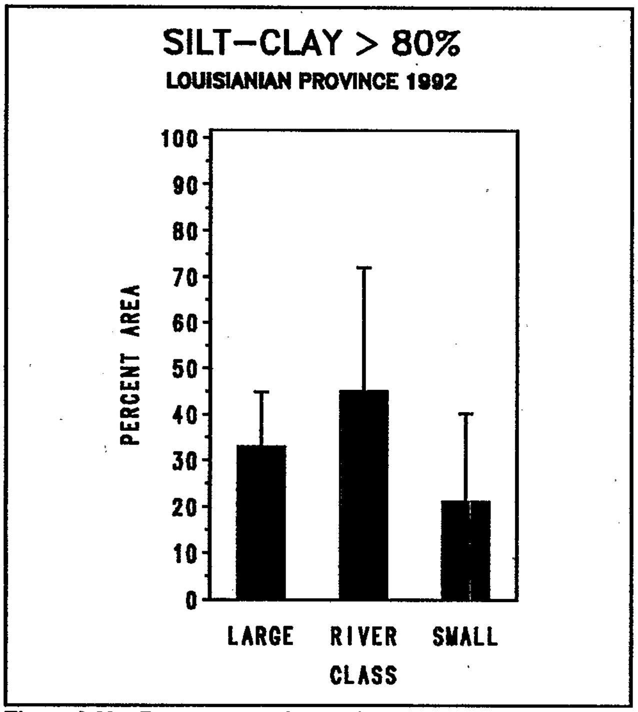

Figure 2-90. Percent area of estuaries with muddy sediments in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

sediments approaching 8% TOC (Fig. 2-91). Low to normal organic carbon content (0-1%) was found in 53%±12% of province sediments, 28%±8% of the province was slightly enriched, while 19%±8% was enriched to the extent of producing a sediment that was > 2% TOC (Fig. 2-91). No organically enriched sediments were found in the large tidal rivers of the province (Fig. 2-92). About 17 to 19% of the sediments from large and small estuarine systems have organic carbon content > 2%.

2.3.8 ACID VOLATILE SULFIDES

Acid volatile sulfides (AVS) measure the amorphous or moderately crystalline monosulfides in sediments that are important in controlling the bioavailability of metals under anoxic conditions (DiToro et al. 1991). AVS in the Louisianian Province ranged from 0 to 20 micromoles AVS/ g dwt sediment (Fig. 2-93).

2.4 CONFIDENCE INTERVALS FOR PROVINCE AND CLASS-LEVEL ESTIMATES

Ninety-five percent confidence intervals (95% CI) were calculated for all parameters described in this section. The methods for these calculations were described in Summers, et al (1993b). Table 2-11 provides these intervals for the major indicators for the proportion of the province and the three estuarine classes.

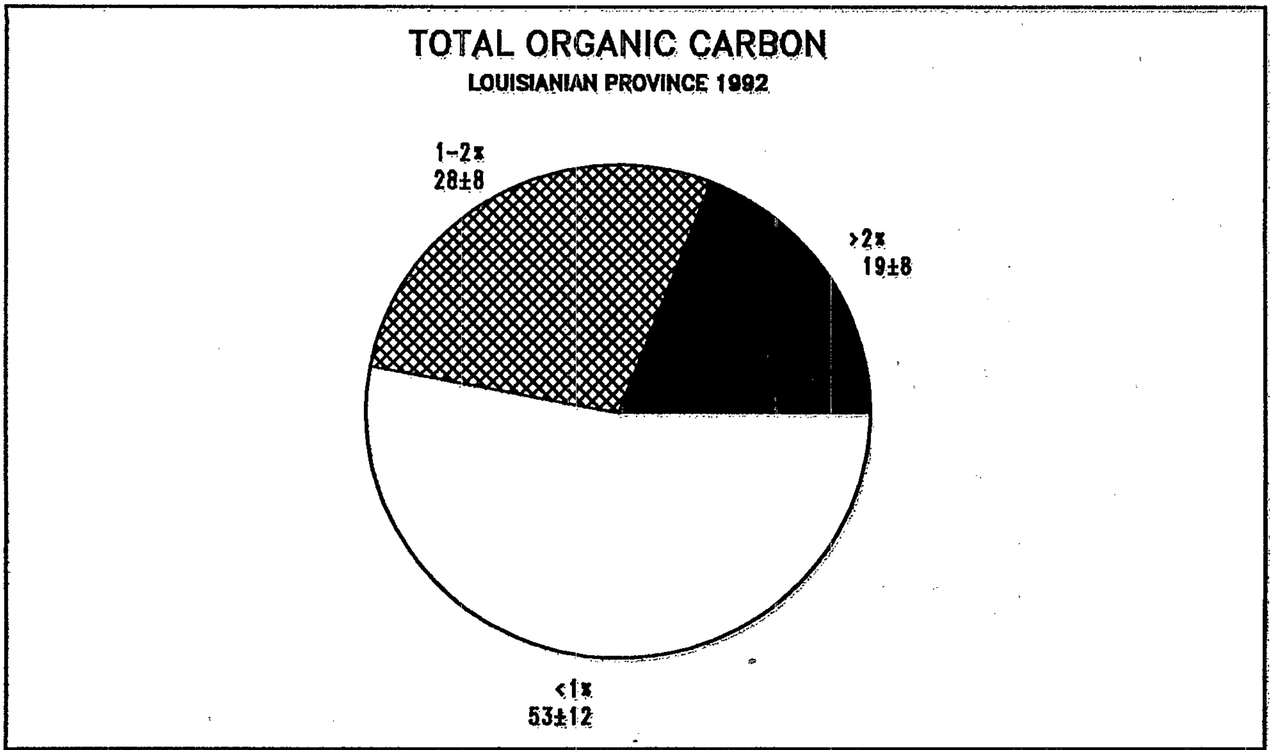

Figure 2-91. Cumulative distribution of percent organic carbon in sediments in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

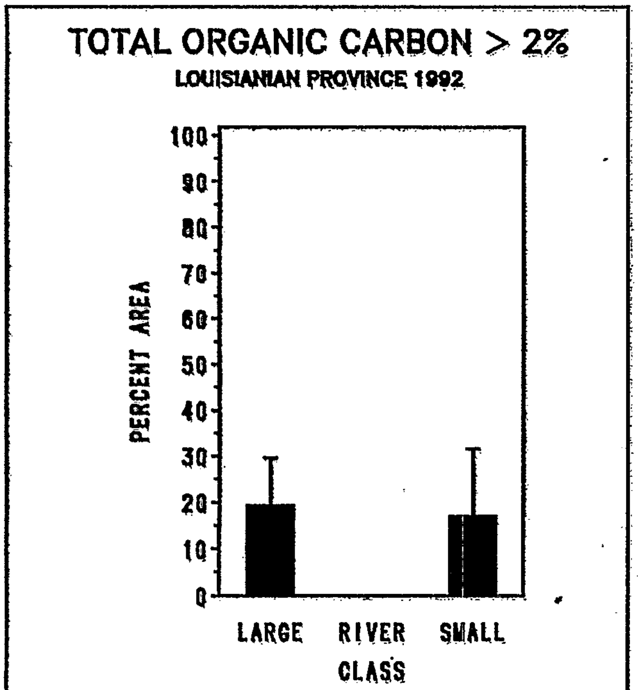

Figure 2-92. Percent area of estuaries with TOC > 2% in large estuaries, large tidal rivers, and small estuaries (bars represent 95% confidence intervals).

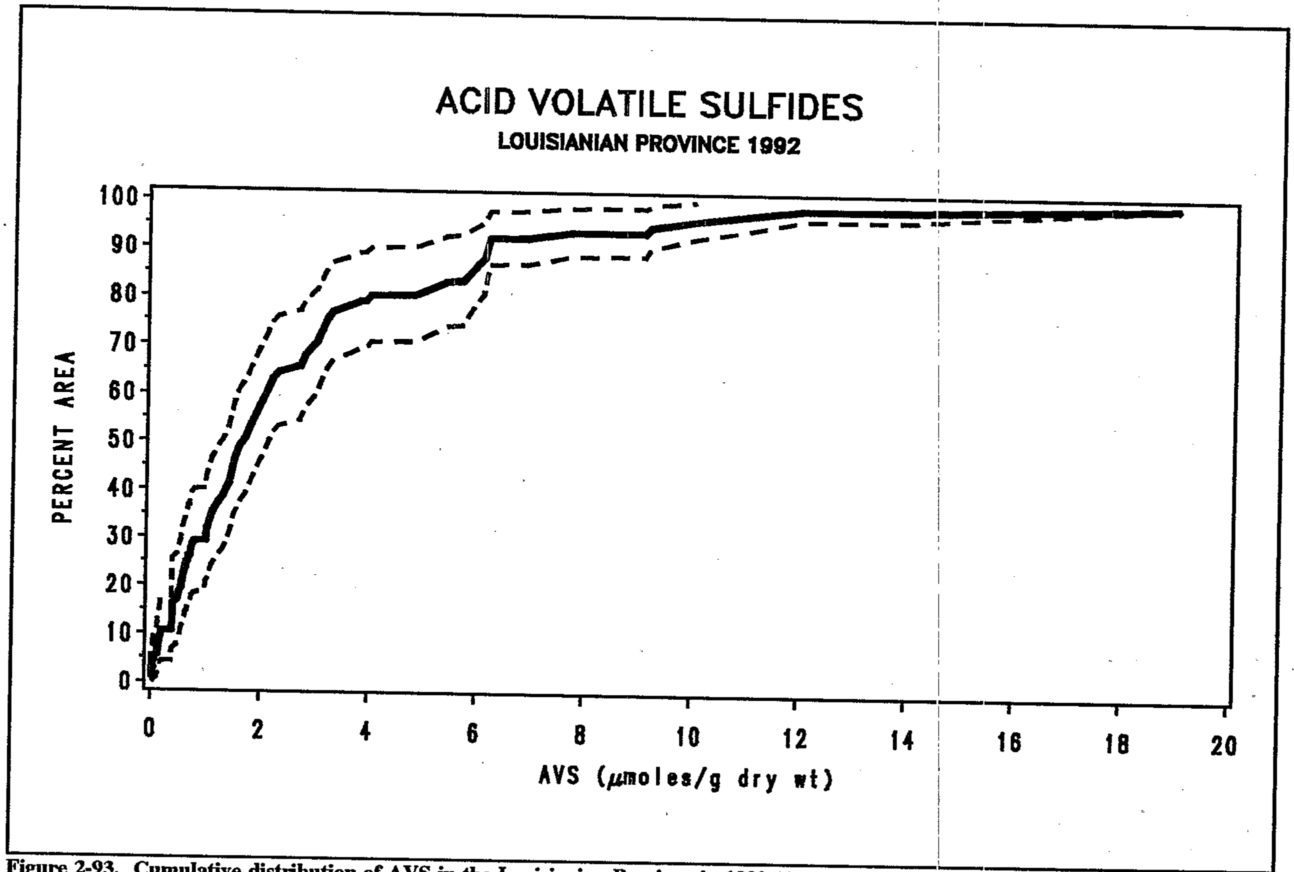

Figure 2-93. Cumulative distribution of AVS in the Louisianian Province in 1992 (-) and its associated 95% confidence interval (--).

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	100	58	10	32
Estuarine Condition	36(11)	33(12)	100(17)	42(25)
(% of Province showing degraded biological resources or impaired use.)				
BIOTIC CONDITION				
Benthic Index	27(10)	24(11)	90(22)	33(24)
Abundance < 10	15(9)	9(7)	20(21)	30(26)
# Species < 2	10(9)	3(5)	25(22)	25(26)
# Species ≤ 5	21(10)	16(9)	70(26)	33(26)
Fish				
Abundance < 2	13(8)	14(9)	60(29)	12(16)
Abundance ≤ 5	20(9)	22(11)	90(26)	13(16)
# Species < 1	4(4)	5(6)	15(20)	< 1(1)
# Species < 2	11(8)	12(8)	40(29)	9(15)
Fish Pathology[1]	1(0)	1(0)	1(0)	1(0)
Fish Contaminants[1]				
Shrimp				
All > FDA Limits	0(0)	0(0)	0(0)	0(0)
Croaker				
All > FDA Limits	0(0)	0(0)	0(0)	0(0)
Marine Catfish				
Hg > FDA Limits	1(1)	1(1)	0(0)	0(0)
Others > FDA Limits	0(0)	0(0)	0(0)	0(0)
Bottom DO[2] < 2 ppm	5(5)	7(7)	0(0)	1(1)
Bottom DO[2] ≤ 5 ppm	22(10)	24(11)	10(19)	13(20)
Minimum DO < 2 ppm	6(5)	9(7)		< 1(1)
Sediment Toxicity	10(6)	12(8)	30(22)	4(6)

[1] Percentage based on sample size rather than estuarine area

[2] Instantaneous dissolved oxygen measurements

Table 2-11. Estimates of the proportion of the Louisianian Province and estuarine classes experiencing the levels of the listed parameters and their associated 95% confidence interval in parentheses (N = number of sampling sites).

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	**100**	**58**	**10**	**32**
ABIOTIC CONDITION				
Marine Debris	6(5)	7(7)	45(27)	4(4)
Water Clarity				
PAR < 10%	12(7)	10(8)	30(29)	17(14)
PAR < 25%	45(10)	29(12)	80(28)	84(16)
Silt-Clay Content				
< 20%	18(8)	21(10)	0(0)	11(10)
> 80%	29(10)	33(12)	45(27)	21(19)
Alkanes				
Total > 7000 ppb	9(6)	7(7)	60(29)	13(13)
PAHs				
Total > 4000 ppb	4(4)	5(6)	30(32)	< 1(1)
PCBs				
Total > 200 ppb	0(0)	0(0)	0(0)	0(0)
Pesticides				
Chlordane > .5 ppb	8(6)	5(6)	85(20)	12(17)
Dieldrin > .02 ppb	34(11)	31(12)	100(0)	39(27)
Endrin > .02 ppb	4(4)	5(6)	45(30)	1(2)
DDT > 1 ppb	< 1(1)	0(0)	10(22)	< 1(1)
DDE > 2 ppb	2(3)	2(3)	0(0)	1(2)
DDD > 2 ppb	< 1(1)	0(0)	15(25)	< 1(1)
Metals				
Ag > 1 ppm	0(0)	0(0)	0(0)	0(0)
As > 33 ppm	0(0)	0(0)	0(0)	0(0)
Cd > 5 ppm	0(0)	0(0)	0(0)	0(0)
Cr > 80 ppm	4(4)	5(6)	0(0)	0(0)
Cu > 70 ppm	0(0)	0(0)	0(0)	0(0)
Hg > .15 ppm	1(2)	2(3)	0(0)	< 1(1)
Ni > 30 ppm	10(7)	12(8)	0(0)	6(9)
Pb > 35 ppm	3(3)	3(5)	0(0)	< 1(1)
Sb > 2 ppm	1(2)	2(3)	0(0)	0(0)
Sn > 3 ppm	10(7)	10(8)	0(0)	12(17)
Zn > 120 ppm	11(7)	12(8)	0(0)	7(10)
Tributyltin				
TBT > 0 ppb	71(10)	72(12)	100(0)	67(23)
TBT > 5 ppb	3(3)	3(5)	20(24)	2(3)

Table 2-11 Estimates of the proportion of the Louisianian Province and estuarine classes experiencing the levels of the listed parameters and their associated 95% confidence interval in parentheses (N = number of sampling sites).

SECTION 3

SUMMARY OF CONCLUSIONS

The Demonstration Project in the Louisianian Province in 1992 produced thousands of pieces of information about the estuarine resources of the Gulf of Mexico and their present condition. The following summarizes key information concerning the conduct of the demonstration and highlights the findings.

3.1 OVERVIEW OF PROVINCE CHARACTERISTICS

- The Louisianian Province is comprised of 25,725 km^2 of estuarine resources spanning from Anclote Anchorage, FL to the Rio Grande, TX.

- Estuarine resources are defined as those water bodies located between sources of freshwater and the Gulf of Mexico bounded on the seaward region by barrier islands and on the landward side by head of tide. For example, this would include as estuarine resources the lower Mississippi River from the delta to roughly New Orleans, LA and Apalachee Bay, FL which is bordered on the seaward margin by submerged barrier islands.

- All estuarine resources in the Louisianian province were divided among three estuarine classes: large estuaries, large tidal rivers, and small estuaries/tidal rivers. Their delineation was based primarily on size.

- Large estuaries include Laguna Madre, Baffin Bay, Corpus Christi Bay, San Antonio Bay, Matagorda Bay, Galveston Bay, Calcasieu Lake, Vermilion Bay, Cote Blanche Bays, Atchafalaya Bay, Terrebone/Timbalier Bays, Caillou Bay, Barataria Bay, Chandeleur Sound, Breton Sound, Lake Borgne, Lake Pontchartrain, Lake Maurepas, Lake Salvador, Mississippi Sound, Mobile Bay, Bon Secour Bay, Pensacola Bay, Choctawhatchee Bay, St. Andrews Bay, St. George Sound and Apalachee Bay.

- Large tidal river class is comprised solely of the Mississippi River.

- Small estuary/tidal river class incorporates 165 estuarine systems between 2 to 260 km^2 of which 43 were selected for sampling in 1992.

- The total area of estuarine resources in the Louisianian Province can be subdivided among these three estuarine classes: large estuaries comprise km^2 (72%), large tidal rivers constitute 138 km^2 (<1%), and small estuaries make up km^2 (28%). Thus, province-wide conclusions, based on areal weighting, will be dominated by information from the large estuaries.

- 169 stations were selected for sampling using multiple indicators of estuarine condition (e.g., benthic abundance, fish community composition, sediment chemistry, sediment toxicity).

- 10 selected sites could not be sampled due to insufficient depth (< 1 m). In terms of areal extent, these sites represent 7% of the estuarine resources in the province. The majority of these unsampleable sites occurred in the shallow zones of large estuaries.

3.2 CONCLUSIONS OF THE 1992 SAMPLING

- Nearly 36±11% of the Louisianian Province estuarine resources were determined to be degraded in terms of biotic integrity or human use indicators. Seventeen percent of the province experienced only low levels of biotic integrity, 9±11% experienced either marine debris or poor water clarity, and 10±6% experienced both forms of degradation.

- About 6±5% of the bottom sediments in Louisianian Province estuaries were littered with marine debris.

- 12±7% of the estuarine waters in the province had poor water clarity with 99% of these areas occurring west of the Mississippi River Delta.

- Estuarine sediments in the Louisianian Province generally contained concentrations of organic contaminants that were below criteria values expected to result in significant ecological effects. Some contaminants were above these criteria for 3 to 9% of the sediments.

- Louisianian Province sediments were shown to be enriched with several heavy metals. 16±8% of Louisianian Province sediments were enriched with at least one metal. Three to six percent of sediments were enriched with mercury, copper, arsenic, lead, and zinc.

- Metal enrichment was observed in large estuarine resources.

- Approximately 10±6% of the sediments in the Louisianian Province (2050 km^2) proved to be toxic to tested estuarine organisms. Nearly 30±22% of the Mississippi River sediments were toxic while 12±8% of sediments and 4±6% of small estuary sediments were toxic.

- Tributyltin was measurable in 71±11% of Louisianian Province sediments; however only 3±3% of sediments had concentrations ≥ 5 ppb.

- The edible portions of shrimp, Atlantic croaker, and catfish contained contaminant concentrations below FDA limits for PCBs, pesticides, and mercury. Shrimp, croakers and catfish contained levels of arsenic, cadmium, mercury and selenium in their edible tissues that was higher than international standards. One to four percent of croaker and marine catfish contained cadmium levels above 0.5 ppm, 15% of marine catfish contained arsenic concentrations above 2 ppm, and 1% of marine catfish exceeded 1 ppm mercury. Concentrations of selenium greater than 1 ppm were observed in 4% of shrimp and 2% of marine catfish.

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APPENDIX A

SUBPOPULATION ESTIMATION BASED ON EMAP SAMPLING

One of the major advantages of the probability-based sampling design used by all elements of the Environmental Monitoring and Assessment Program (EMAP) is the ability to use the data to address questions and/or objectives other than those specified by the program. Essentially, the only negative aspect associated with these additional analyses is an increase in the uncertainty associated with the estimates due to a decrease in the sample size (i.e., not all the data is used). This process is called "subpopulation estimation". For EMAP-E, for example, the process might involve using a specific portion of the collected data to examine a question concerning a subset of the ecological community (i.e., only surface measures), a subset of estuarine resources (e.g., those in a particular state or EPA Region), or a subset for an individual estuary (e.g., Galveston Bay, Mississippi Sound).

In this appendix, all of the major ecological indicators described in Chapter 2 are evaluated in terms of state specific resources. The statistical methods used to perform this level of evaluation are the same as those described in Appendix A but are adapted to the estuarine resources of each estuarine class within the boundaries of each of the five Gulf states.

A.1 BIOTIC CONDITION INDICATORS

Biotic condition indicators are characteristics of the environment that provide quantitative evidence of the status of ecological resources and biological integrity at a sampling site. Biotic condition measures examined here include measurements of the kinds and abundances of biota present and human use parameters that describe human perceptions of the condition of estuarine systems. No state-level estimates have been made for fish pathologies or tissue contaminant levels. Subpopulation estimation for these indicators based on spatial reduction is not possible without using complex statistical methods to fit spatial response surfaces to estimate these indicators where fish were not collected in adequate numbers.

The following presentation does not represent all the analyses completed at the state-level for each indicator. For example, a set of five individual state CDFs and pie charts exists for each indicator but only one CDF and pie chart for a selected state will be shown in this appendix. However, the proportion of estuarine resources in each state associated with the criterion for subnominal condition is shown in the bar charts.

The uncertainty associated with the state estimates is directly proportional to the total number of sites within the state boundaries. This uncertainty ranges, in general, from a low of about 5 to 7% for Louisiana (N=52) to a high for Mississippi of approximately 20 to 30% (N=9). The 95% confidence intervals are shown for each CDF shown in Appendix A and in tabular form for all states at the end of the appendix.

Although the sample size for Alabama estuarine waters is small (N=3), the corresponding variance estimates are also small (see Table A-1). The reduced variance and 95% confidence interval are due to the extreme similarity of the collected data from the three sites and the heavy weighting associated with a single site. Therefore, estimates for Mississippi showed uncertainties of 20 to 30% while estimates for Alabama show uncertainties of only 3 to 4%.

A.1.1 BENTHIC INDEX

The construction of the benthic index is described in Summers et al. (1993b) and Engle et al. (1993). The cumulative distribution function for the benthic index in Mississippi and Texas are shown in Figures A-1 and A-2. About 27±26% of the estuarine sediments in Mississippi contained benthic communities similar to those observed at known environmentally degraded sites (Fig. A-3). The highest proportion of degraded benthic communities within the Gulf states in 1992 were found in Louisiana and Texas (Fig. A-4).

A.1.2 NUMBER OF FISH SPECIES

Total number of fish species has been used to characterize the environmental condition of estuarine habitats. A single 10-min trawl, taken at each sampling in the Louisianian

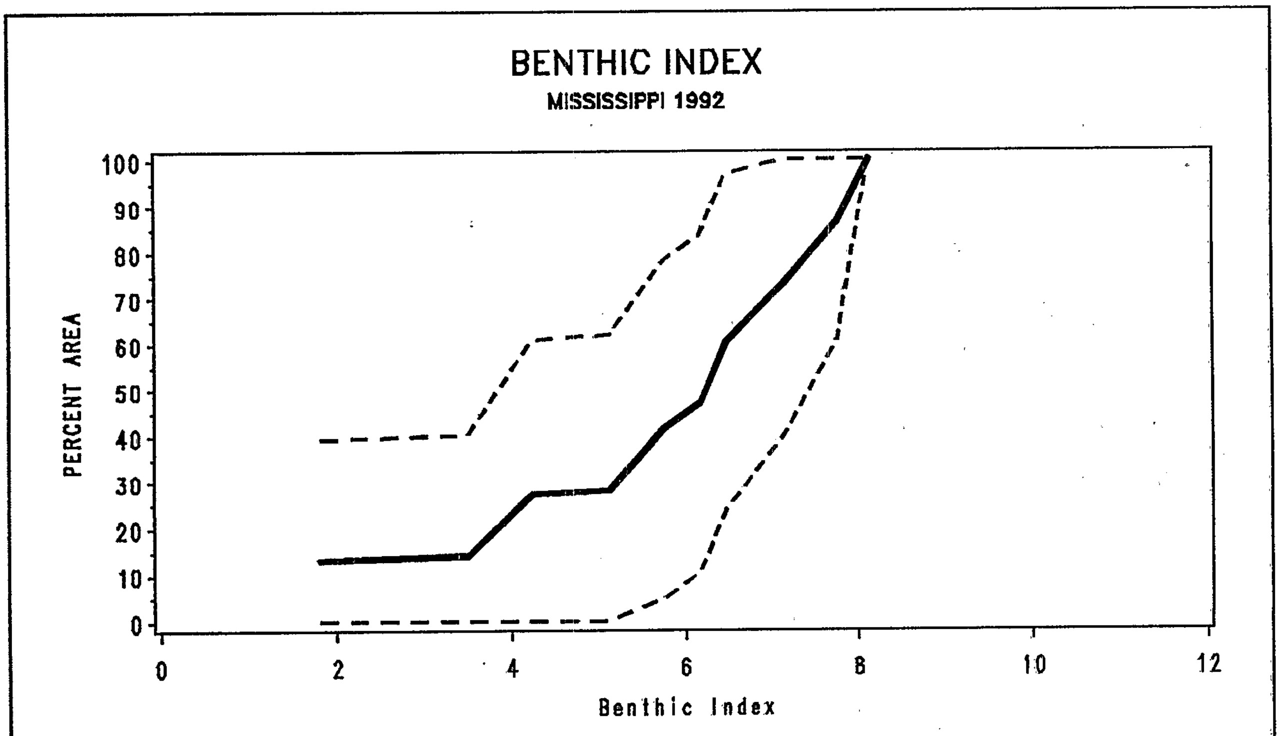

Figure A-1. Distribution of benthic index values in the estuarine resources of Mississippi (-) with 95% confidence intervals (--).

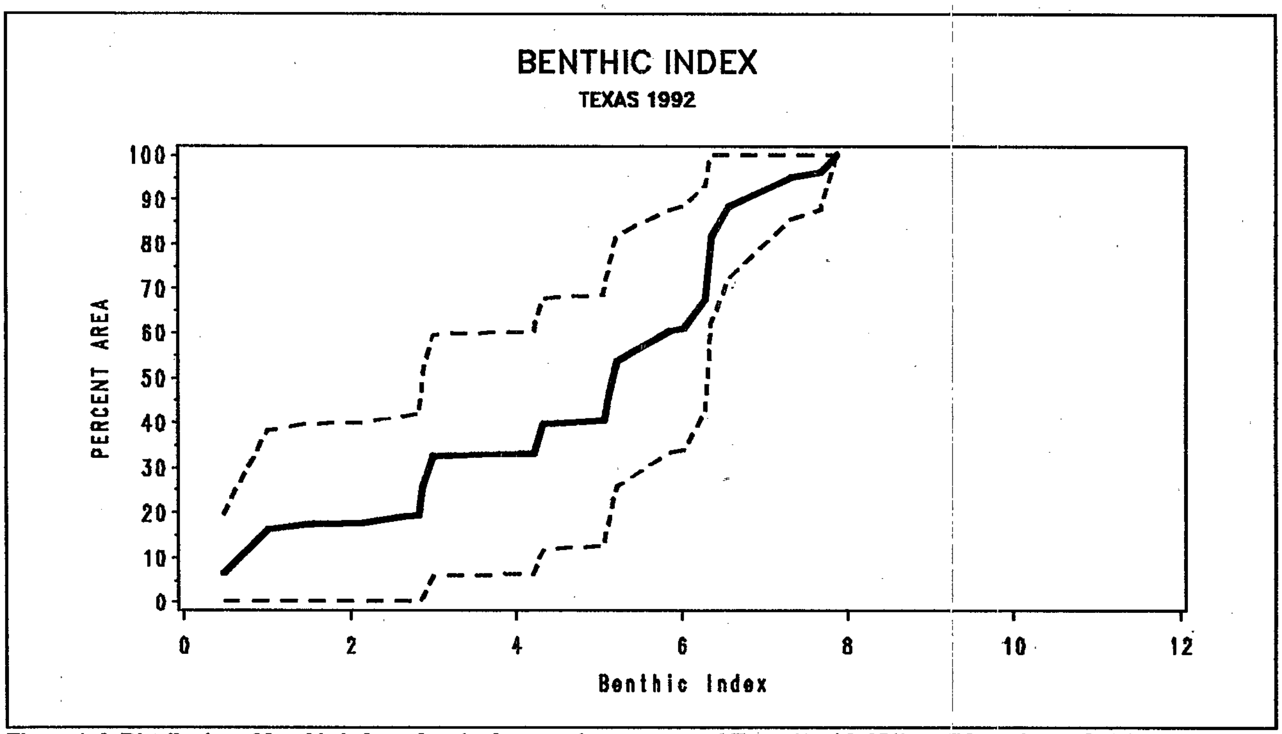

Figure A-2. Distribution of benthic index values in the estuarine resources of Texas (-) with 95% confidence intervals (--).

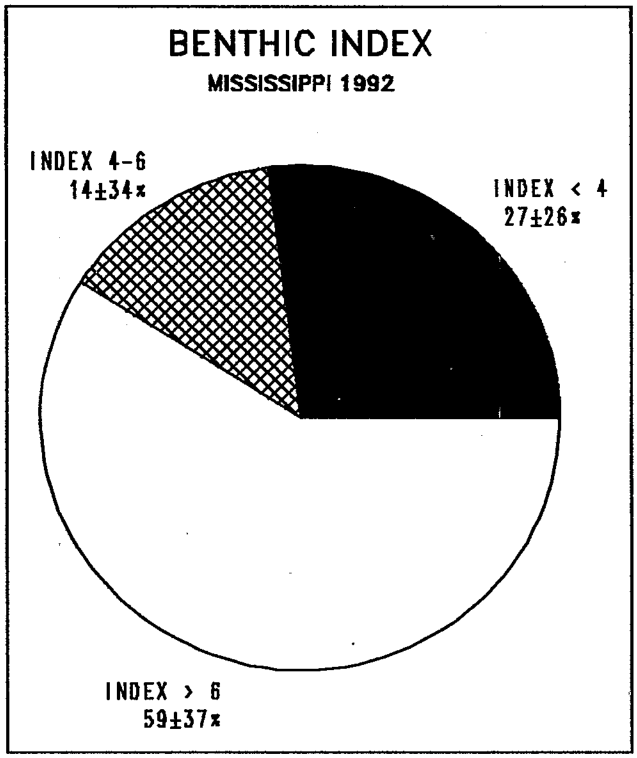

Figure A-3. Proportion of Mississippi estuarine resources with benthic index values in selected categories.

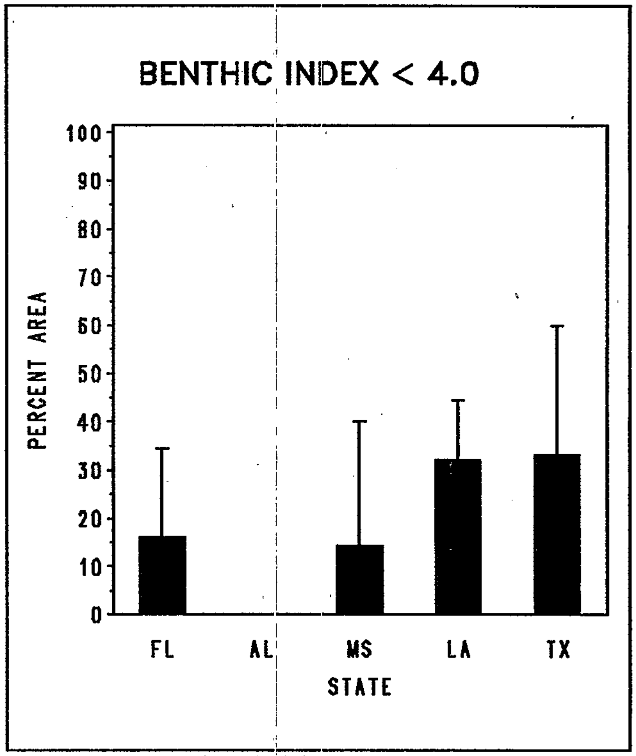

Figure A-4. Proportion of Gulf states' estuarine resources with benthic index values < 4.0 (bars represent 95% confidence intervals).

Province, resulted in a distribution of total number of species for sites in Louisiana and Texas shown in Figures A-5 and A-6. About 18±11% of the estuarine waters in Louisiana produced one or fewer species in a single 10-min trawl (Fig. A-7). Thirteen (±26) to 18±10% of the estuarine waters in Louisiana and Mississippi were characterized by these small numbers of species (Fig. A-8).

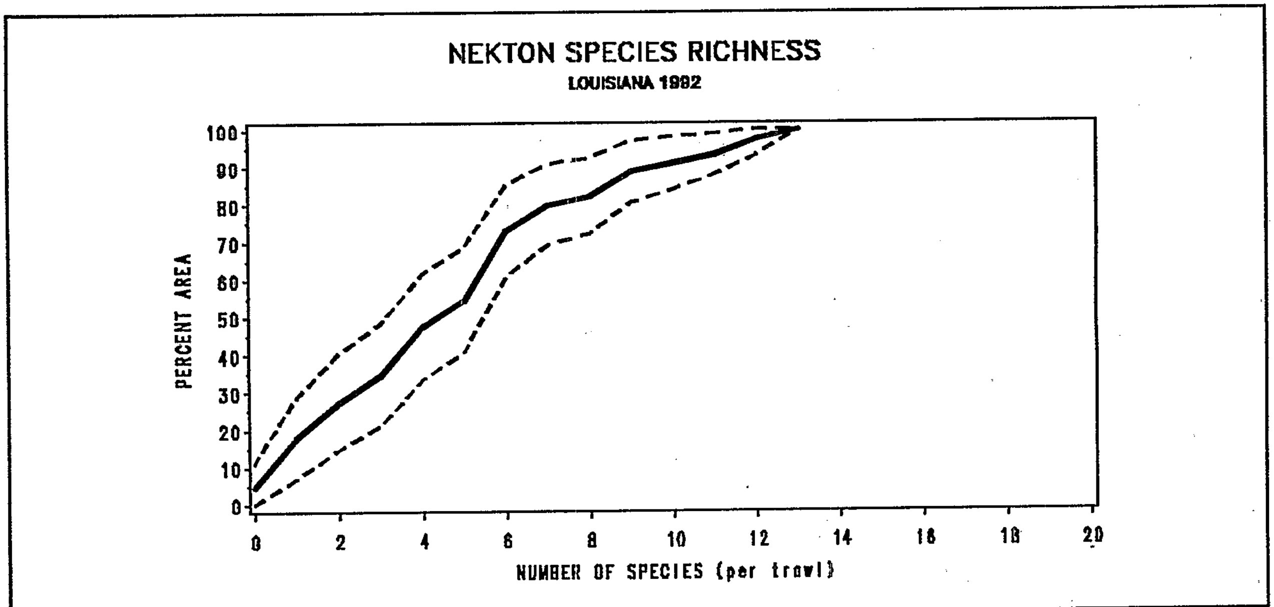

Figure A-5. Distribution of number of fish species per trawl in the estuarine resources of Louisianan (-) with 95% confidence intervals (--).

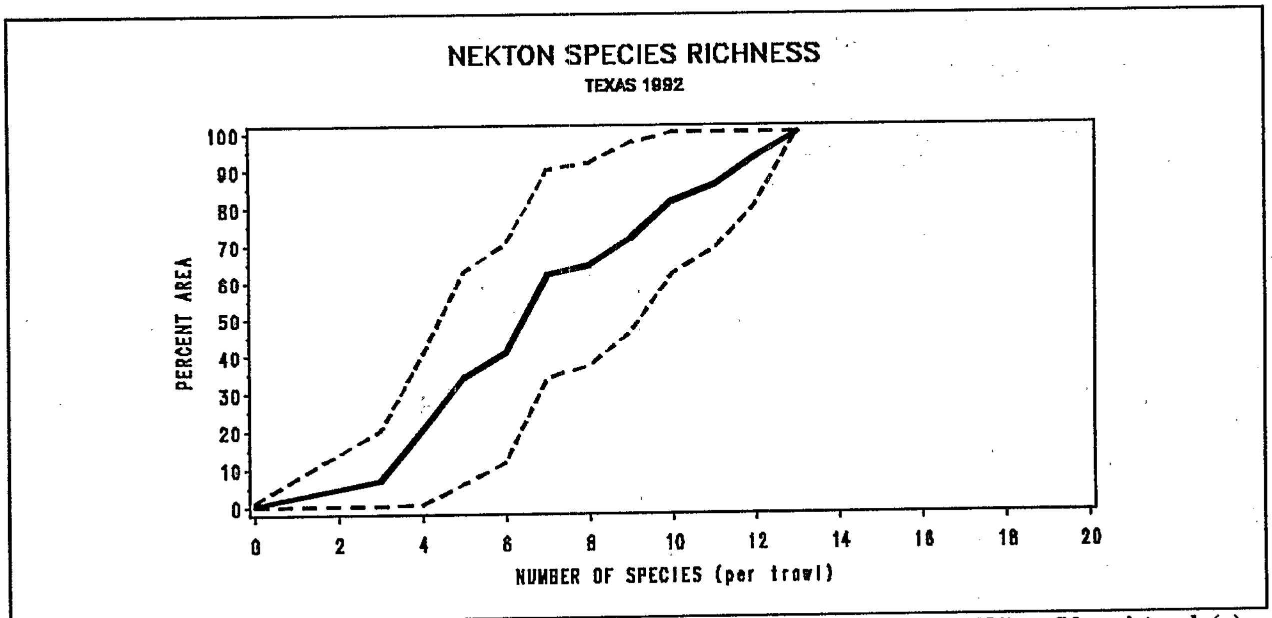

Figure A-6. Distribution of number of fish species per trawl in the estuarine resources of Texas (-) with 95% confidence intervals (--).

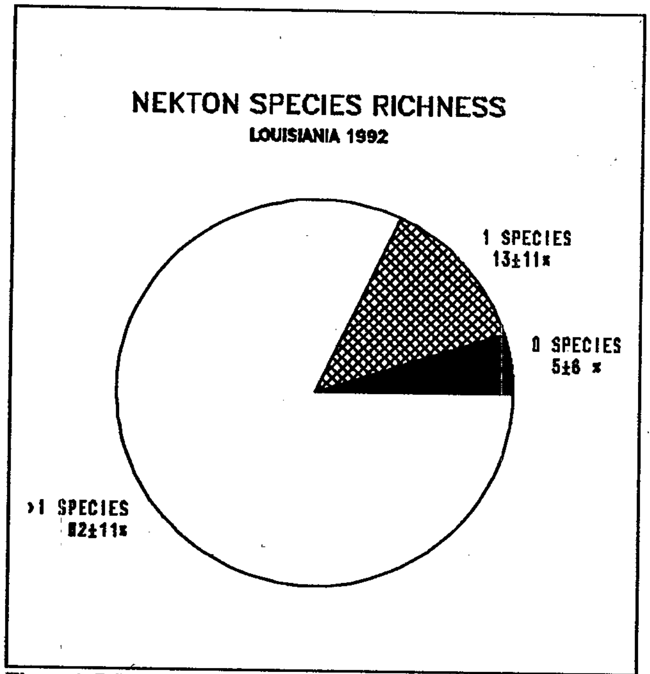

Figure A-7. Proportion of Louisiana estuarine resources with number of fish species per trawl in selected categories.

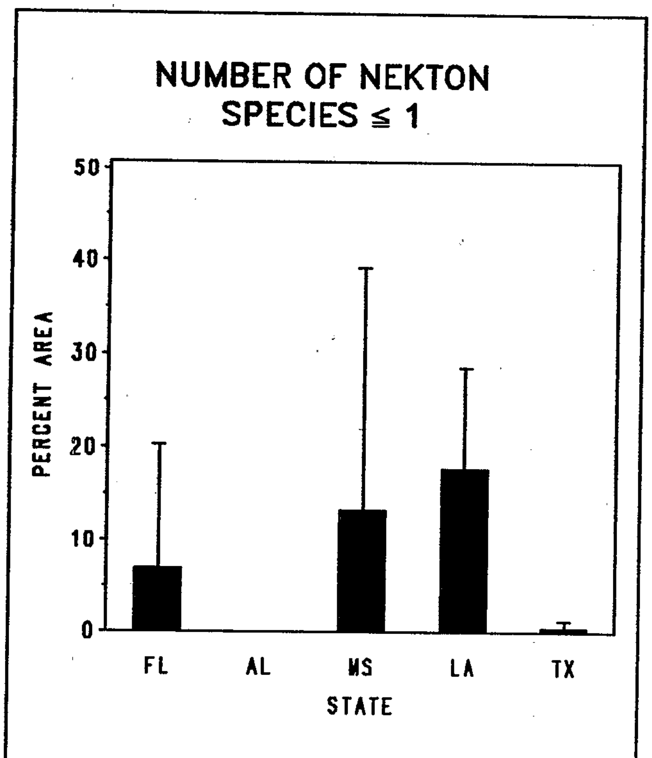

Figure A-8. Proportion of Gulf states' estuarine resources with number of fish species per trawl ≤ 1 (bars represent 95% confidence intervals).

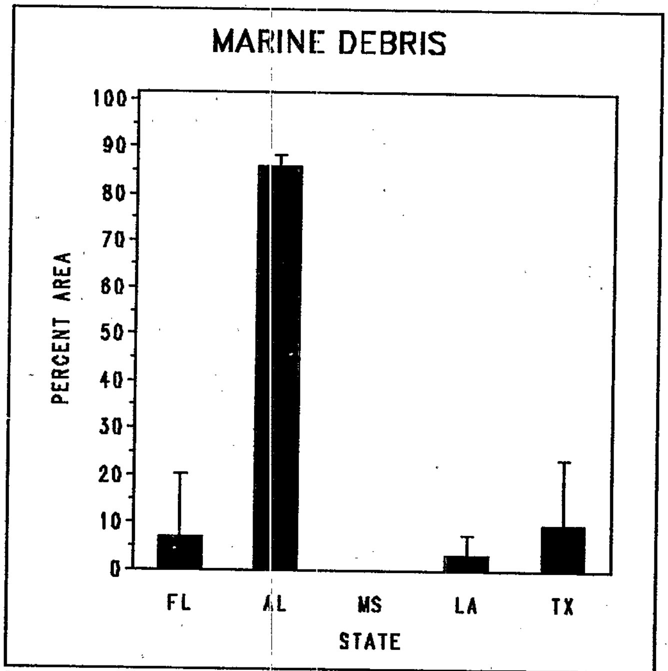

Figure A-9. Proportion of Gulf states' estuarine resources with marine debris present in bottom sediments (bars represent 95% confidence intervals).

A.1.3 MARINE DEBRIS

The presence of marine debris is one of the obvious indicators of estuarine "degradation" from a human use perspective. Over 85% of the estuarine sediments in Alabama contained marine debris with about 7% of Florida and 10% in Texas estuarine sediments containing marine debris (Fig. A-9).

A.1.4 WATER CLARITY

Another social or human use criterion for good estuarine condition is water clarity. Water clarity was measured using a comparison of surface ambient light and the amount of light reaching 1 meter in depth. The cumulative distribution function for water clarity in Louisiana is shown in Fig. A-10 where proportional light reaching 1 meter ranged

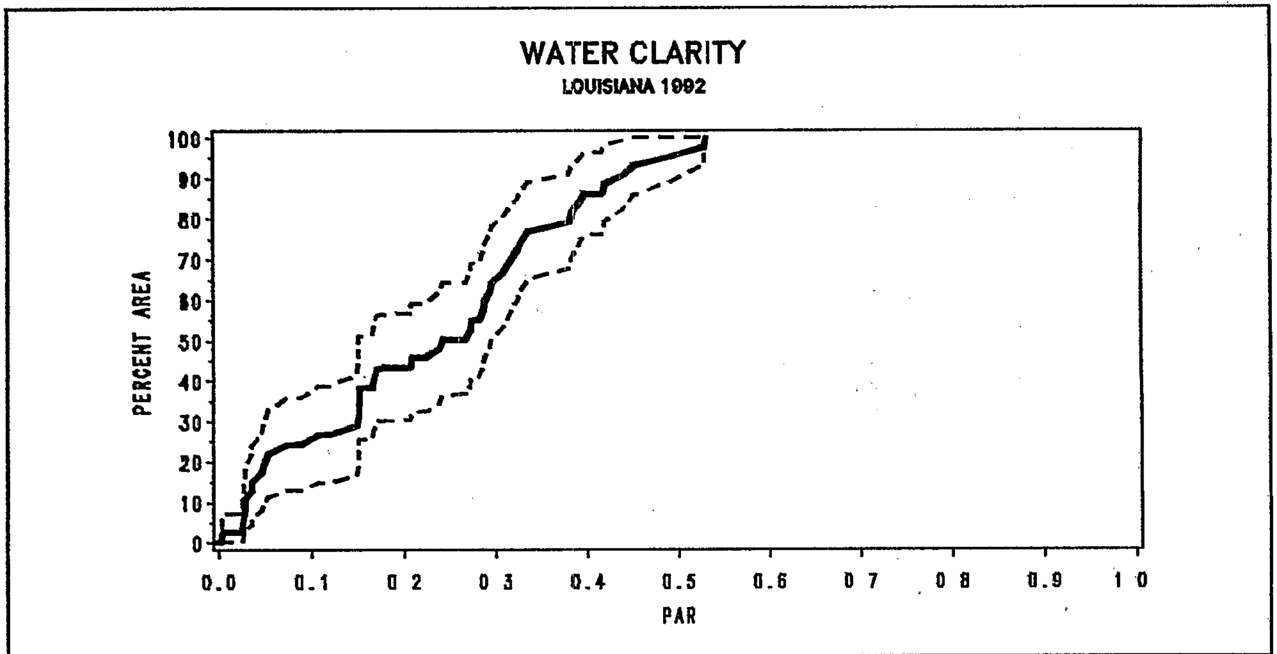

Figure A-10. Distribution of water clarity as % surface light reaching a depth of 1 meter (PAR) in the estuarine resources of Louisiana(-) with 95% confidence intervals (--).

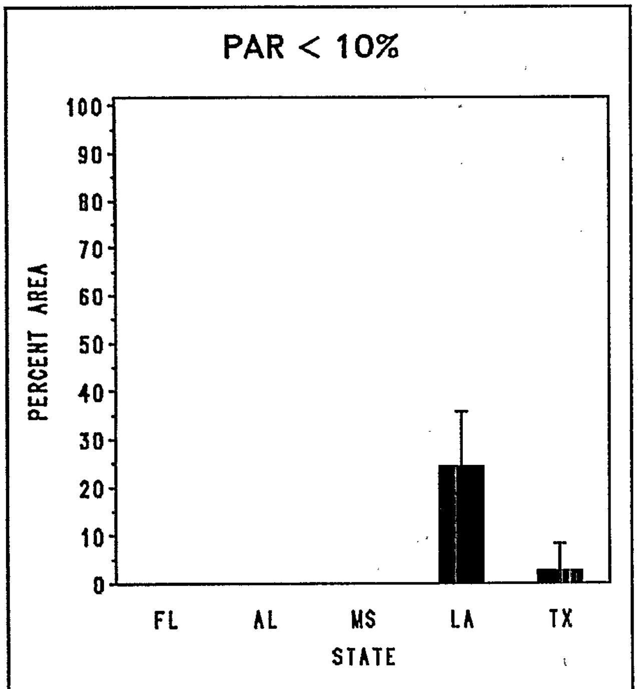

Figure A-11. Proportion of Gulf states' estuarine resources with percent surface light reaching a depth of one meter < 10% (bars represent 95% confidence intervals).

from 0-50%. A value of 10% transmittance reaching a depth of one meter was used as a measure of turbid conditions. Most of the water of lower transmissivity in Gulf estuaries is located in Louisiana (24±12%) and Texas (3±6%) (Fig. A-11).

A.1.5 INTEGRATION OF ESTUARINE CONDITIONS

A single index value has been developed to summarize the overall condition of the estuaries in the Louisianian Province by combining the benthic index, marine debris and water clarity, weighted equally. This single value can also be used to summarize the overall condition of estuaries in each of the Gulf states. Figure A-12 shows that 23±20% of the estuarine resources in the portion of Florida in the Louisianian Province were degraded with regard to biotic communities or human uses. Similar summarizations are shown in Figures A-13 through A-16 for Alabama, Mississippi, Louisiana and Texas and ranged from 14±26% degraded estuarine area in Mississippi to 86±3% in Alabama.

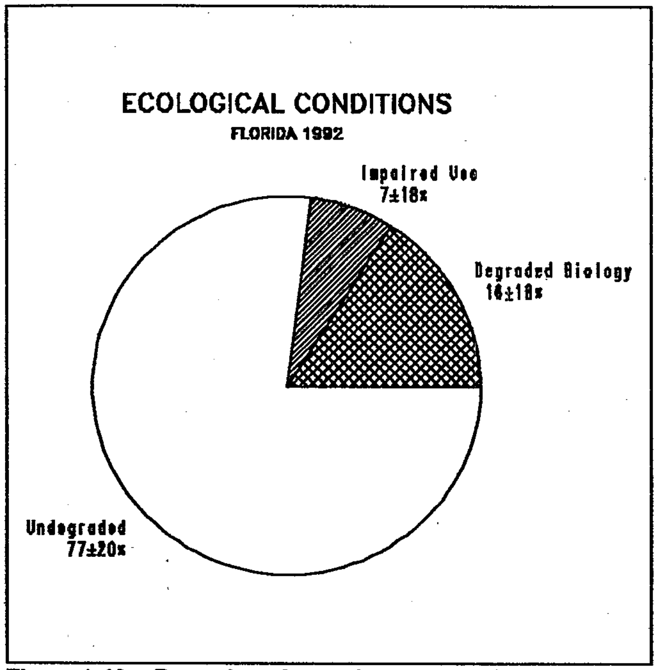

Figure A-12. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Florida.

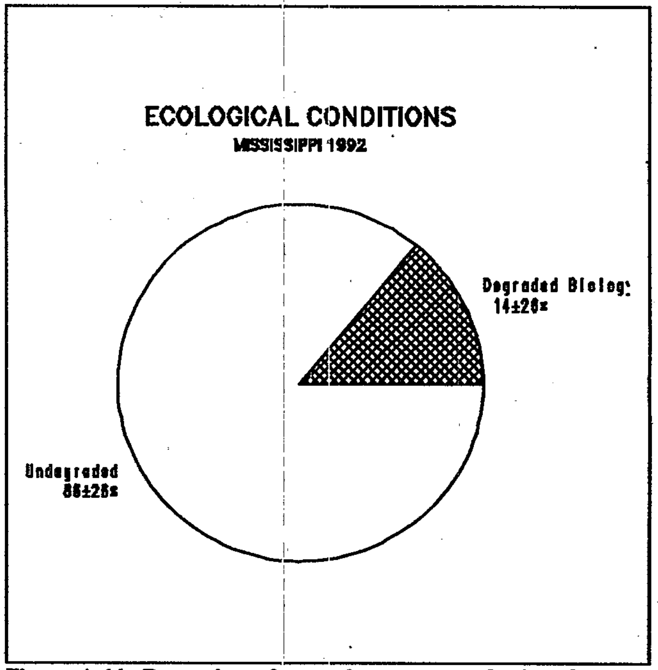

Figure A-14. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Mississippi.

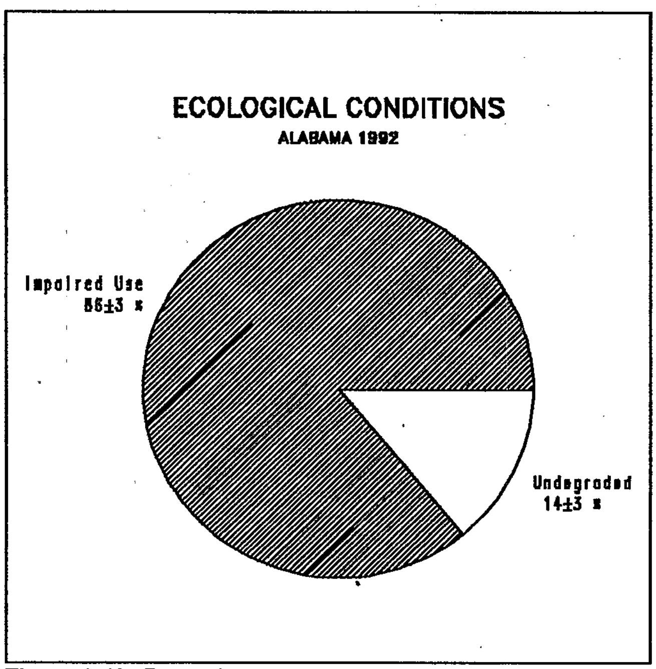

Figure A-13. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Alabama.

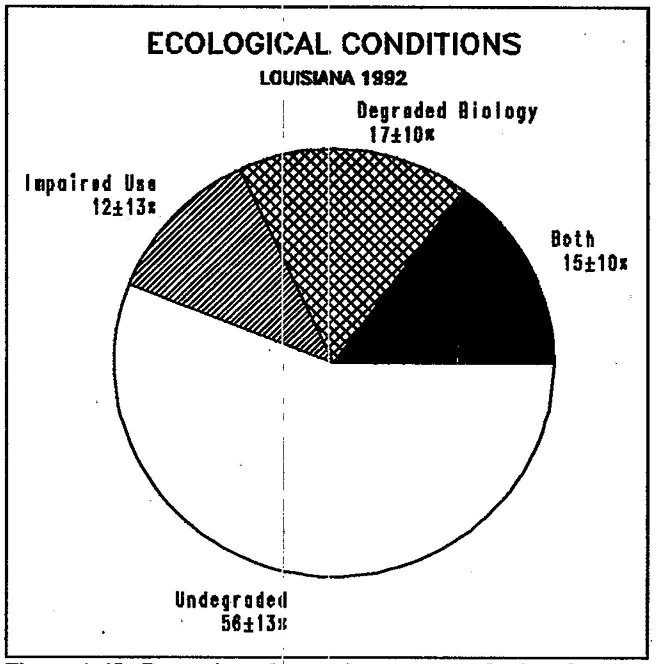

Figure A-15. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Louisiana.

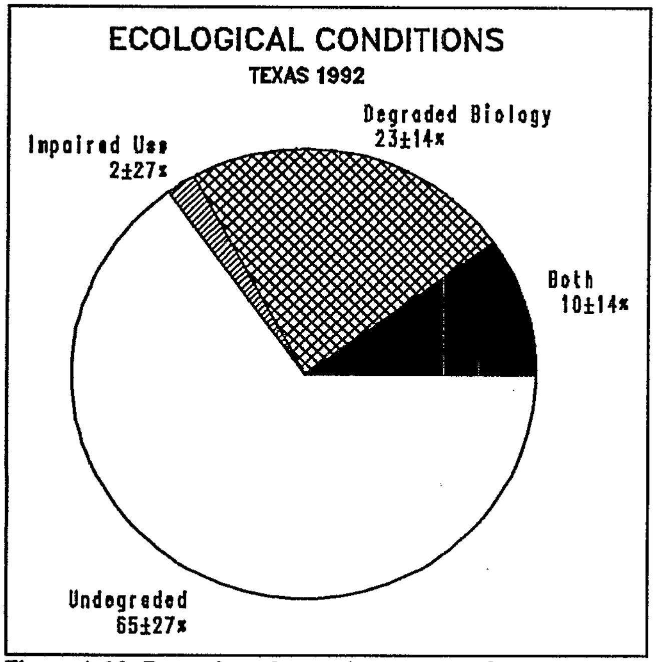

Figure A-16. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Texas.

A.2 ABIOTIC CONDITION INDICATORS

Abiotic condition indicators have historically been the mainstay of state environmental monitoring programs. The results for Gulf states are shown for dissolved oxygen, sediment toxicity, and sediment contaminants.

A.2.1 DISSOLVED OXYGEN (INSTANTANEOUS)

Dissolved oxygen (DO) concentration is a fundamental requirement of populations of benthos, fish, shellfish, and other aquatic biota. DO was measured in two ways: instantaneous point measures at 1-m depth intervals during the sampling and deployed continuous recordings of dissolved oxygen for a 24-hour period.

The cumulative distribution function of bottom dissolved oxygen in Florida estuaries is shown in Figure A-17. All Gulf states experienced

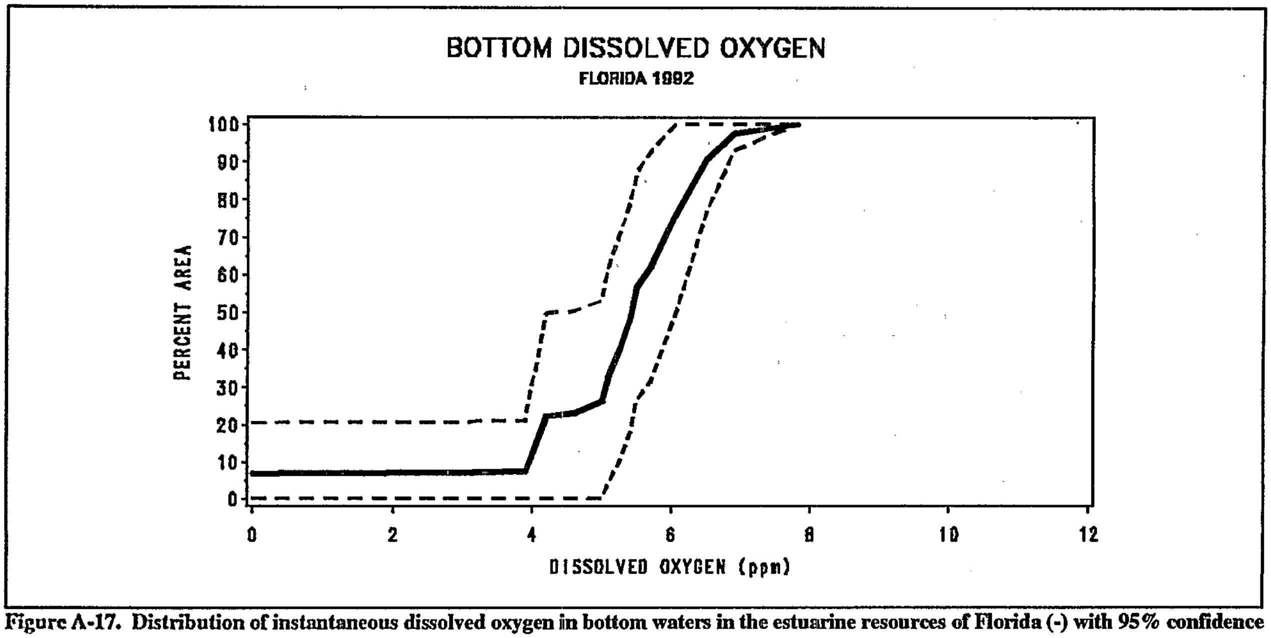

Figure A-17. Distribution of instantaneous dissolved oxygen in bottom waters in the estuarine resources of Florida (-) with 95% confidence intervals (--).

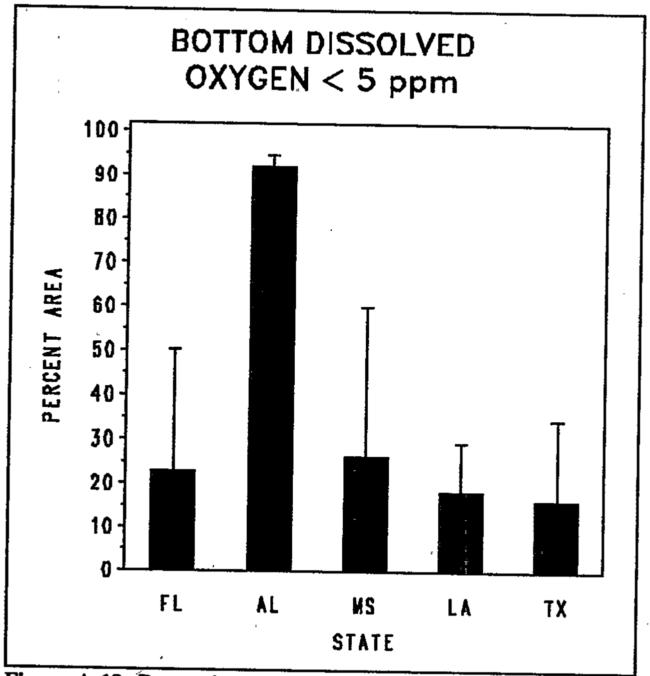

Figure A-18. Proportion of Gulf states' estuarine resources with instantaneous dissolved oxygen concentration < 5 ppm in bottom waters (bars represent 95% confidence intervals).

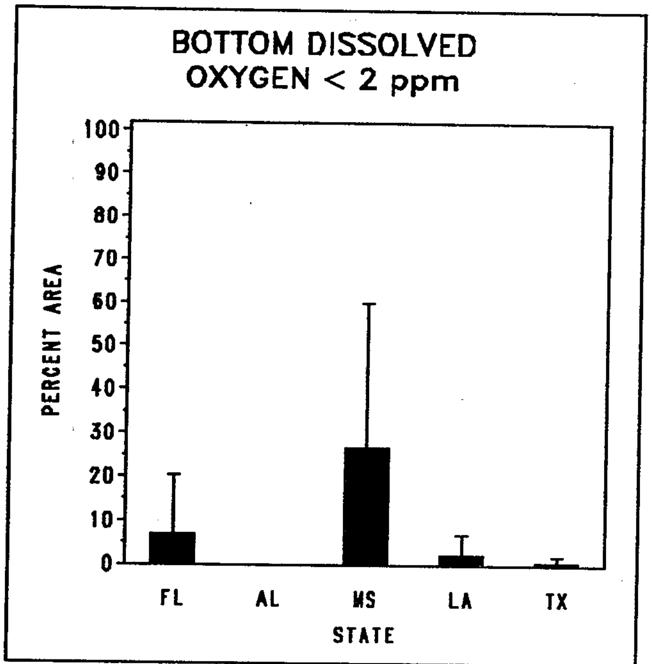

Figure A-19. Proportion of Gulf states' estuarine resources with instantaneous dissolved oxygen concentration < 5 ppm in bottom waters (bars represent 95% confidence intervals).

DO conditions < 5 ppm but Alabama, Mississippi and Florida predominated with almost 23 to 92(±3 to 34)% of their resources below this figure (Fig. A-18). All dissolved concentrations < 2 ppm were primarily observed in Mississippi and Florida (Fig. A-19).

A.2.2 DISSOLVED OXYGEN (CONTINUOUS)

Unlike the instantaneous measures, the continuous dissolved oxygen concentration measurements provide a complete picture of the DO conditions at a site by including day and night conditions as well as all tidal conditions. Continuous bottom DO concentrations in Louisiana ranged from 0 to 12 ppm (Fig. A-20). Minimum dissolved oxygen concentrations below 2 ppm were most often observed in Mississippi (Fig. A-21).

A.2.3 SEDIMENT TOXICITY - *AMPELISCA ABDITA*

Sediment toxicity tests were performed on the composited surface sediments collected from each sampling site. Tests included a 10-day acute test using the tube-dwelling amphipod, *Ampelisca abdita*. The continuous distribution function for sediment toxicity testing results are shown for Florida in Figure A-22. Most of the sediments proving significantly toxic to Ampelisca (control-corrected mortality > 20%) were located in Florida (20±20%) and Texas (13±17%) estuarine waters (Fig. A-23).

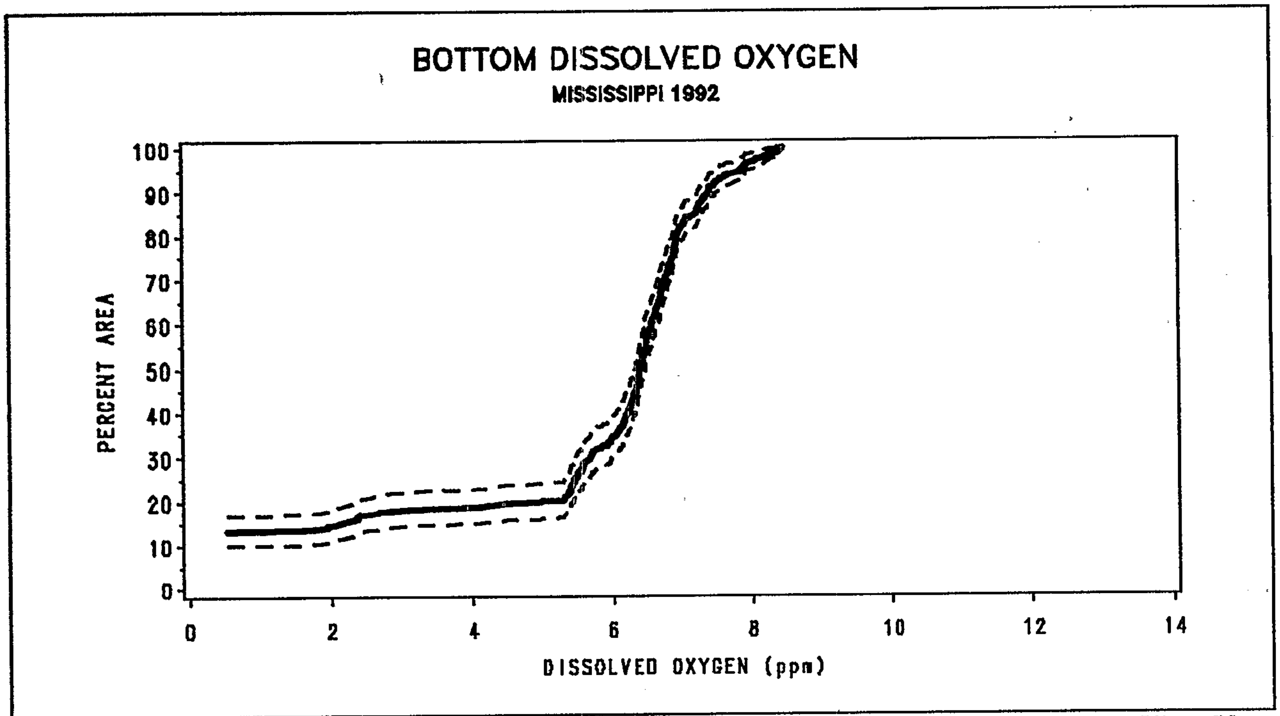

Figure A-20. Cumulative distribution of continuous dissolved oxygen in the estuarine resources of Louisiana (-) with 95% confidence intervals (--).

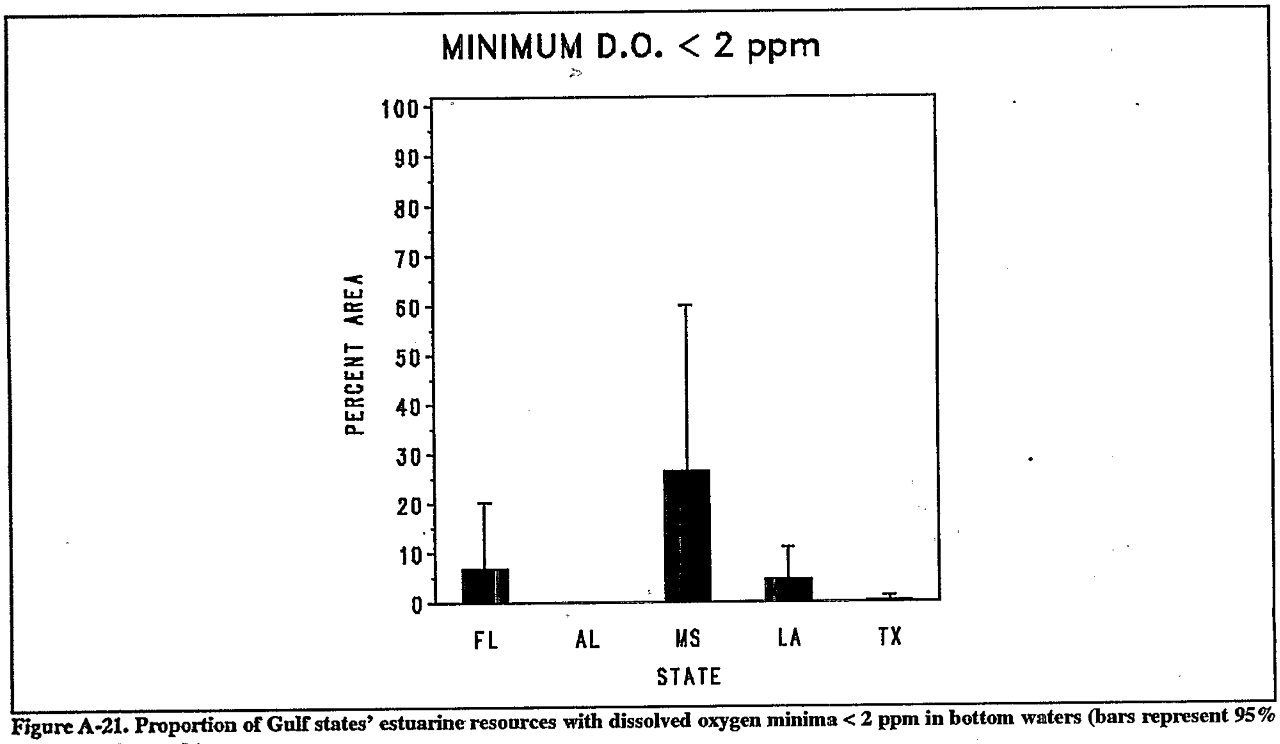

Figure A-21. Proportion of Gulf states' estuarine resources with dissolved oxygen minima < 2 ppm in bottom waters (bars represent 95% confidence intervals).

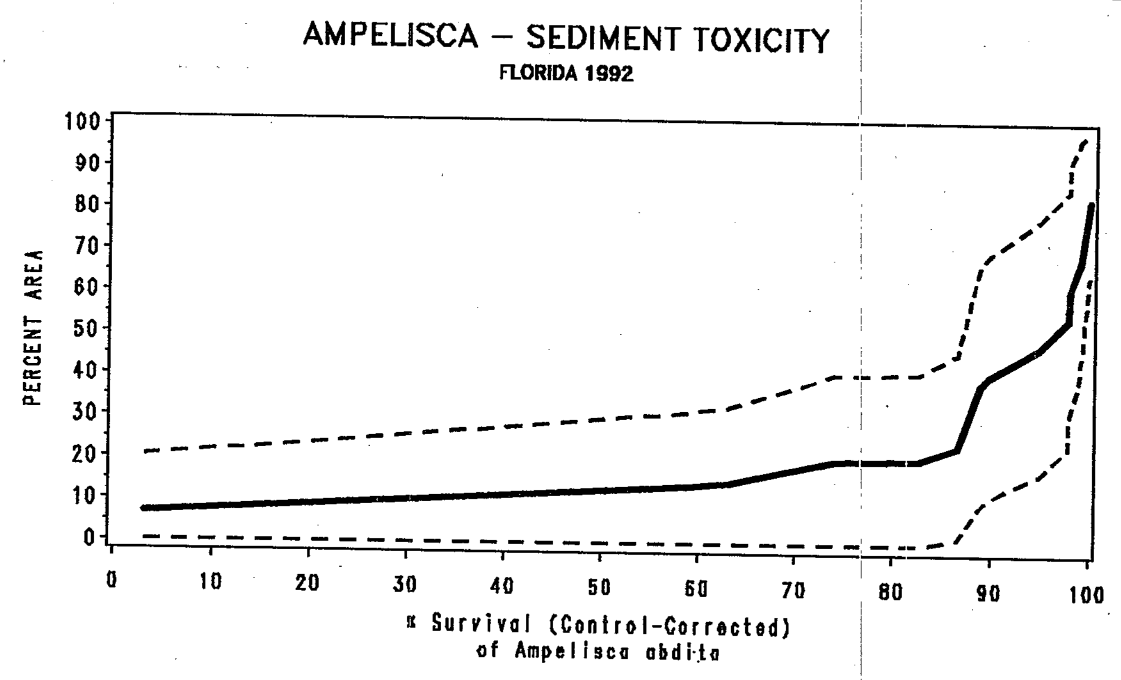

Figure A-22. Distribution of toxicity of estuarine sediments in Florida to amphipods (-) with 95% confidence intervals (--).

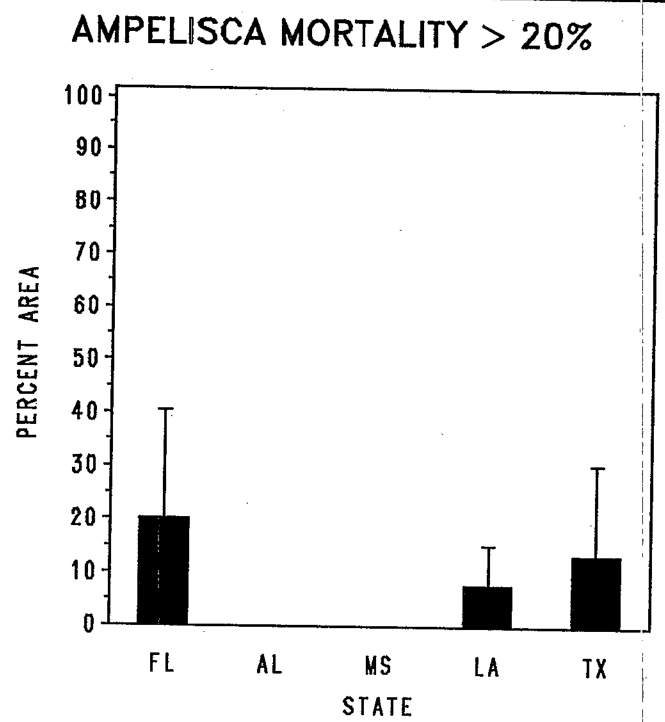

Figure A-23. Proportion of Gulf states' estuarine sediments with toxicity to amphipods resulting in < 80% survival (bars represent 95% confidence intervals).

A.2.4 ALKANES AND ISOPRENOIDS

Alkanes and isoprenoids are contaminants associated primarily with the petroleum industry and uses of its products. The continuous distribution function for total alkanes and isoprenoids for Florida ranges from 0 to 21,000 ppb (Fig. A-24). Total alkane concentrations exceeding 7000 ppb in sediments were located only in Florida (16±18%), Louisiana (11±8%) and Texas (7±13%) (Fig. A-25).

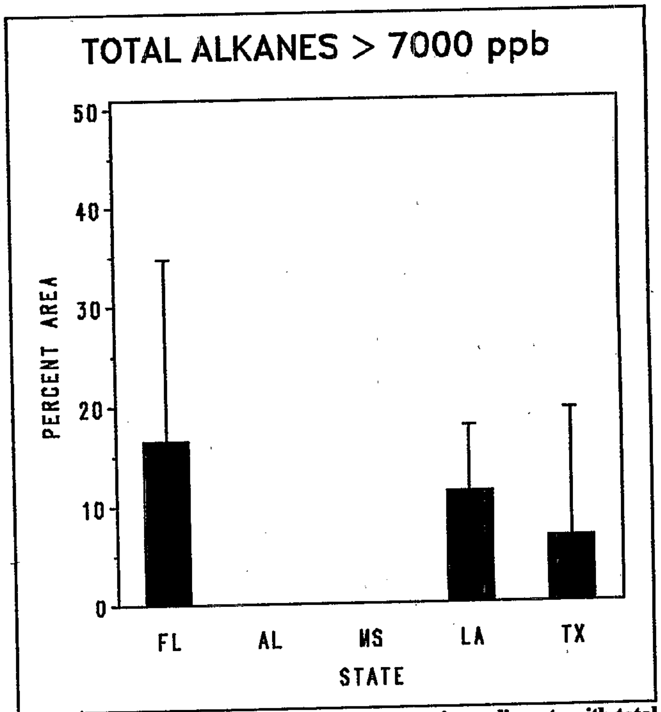

Figure A-25. Proportion of Gulf states' estuarine sediments with total alkanes concentrations > 7000 ppb (bars represent 95% confidence intervals).

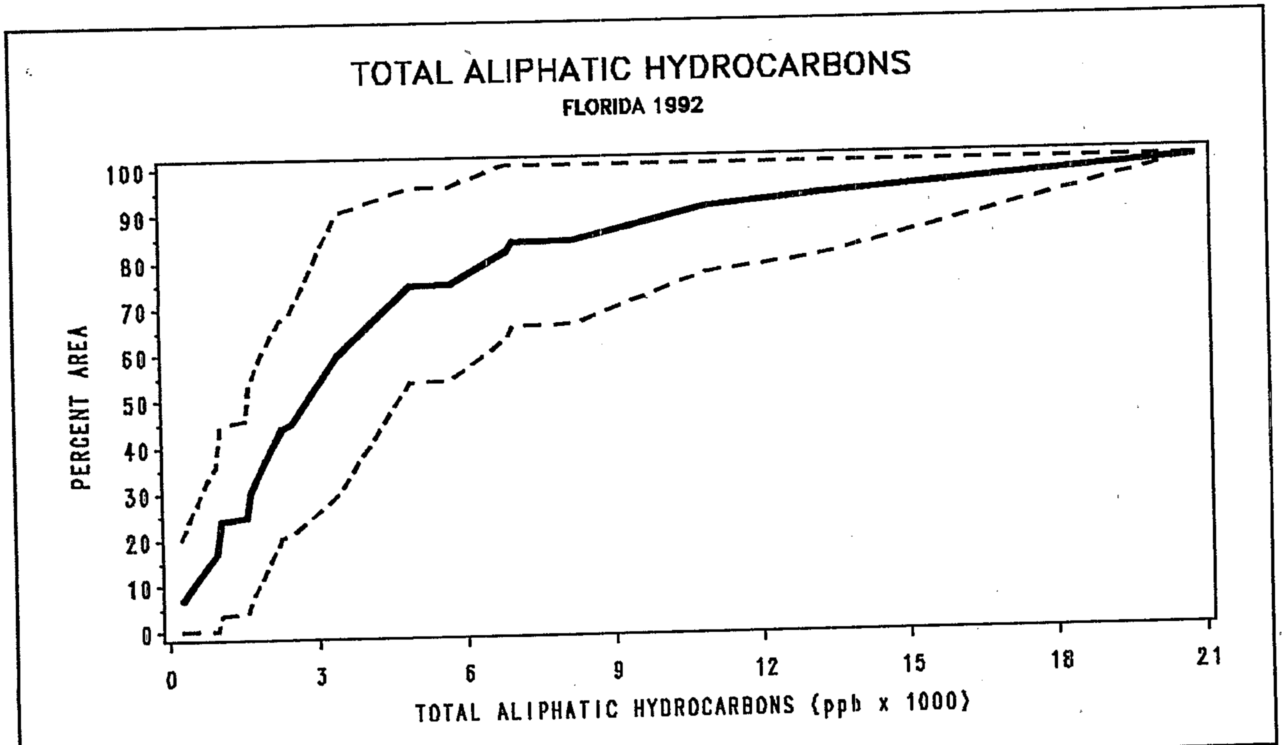

Figure A-24. Distribution of total aliphatic hydrocarbons in estuarine sediments of Florida (-) with 95% confidence intervals (--).

A.2.5 POLYNUCLEAR AROMATIC HYDROCARBONS

Forty three individual polynuclear aromatic hydrocarbons (PAHs) were analyzed from collected Louisianian Province sediments. The distribution of total C3-fluorene is shown in Fig. A-26 and ranges from 0.1 to 267 ppb/g dwt in Louisiana. Total PAH concentrations exceeding 4000 ppb (the concentration resulting in ecological effects 10% of the time) were found in sediments of small estuaries in Florida (14±18%), Louisiana (< 1±0%) and Texas (7±13%) (Fig. A-27).

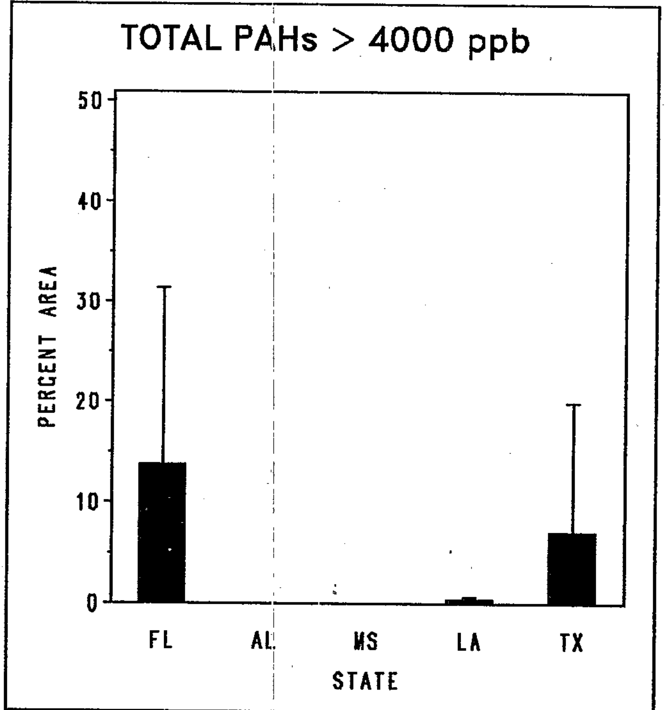

Figure A-27. Proportion of Gulf states' estuarine sediments with total PAH > 4000 ppb (based on 43 PAHs) (bars represent 95% confidence intervals).

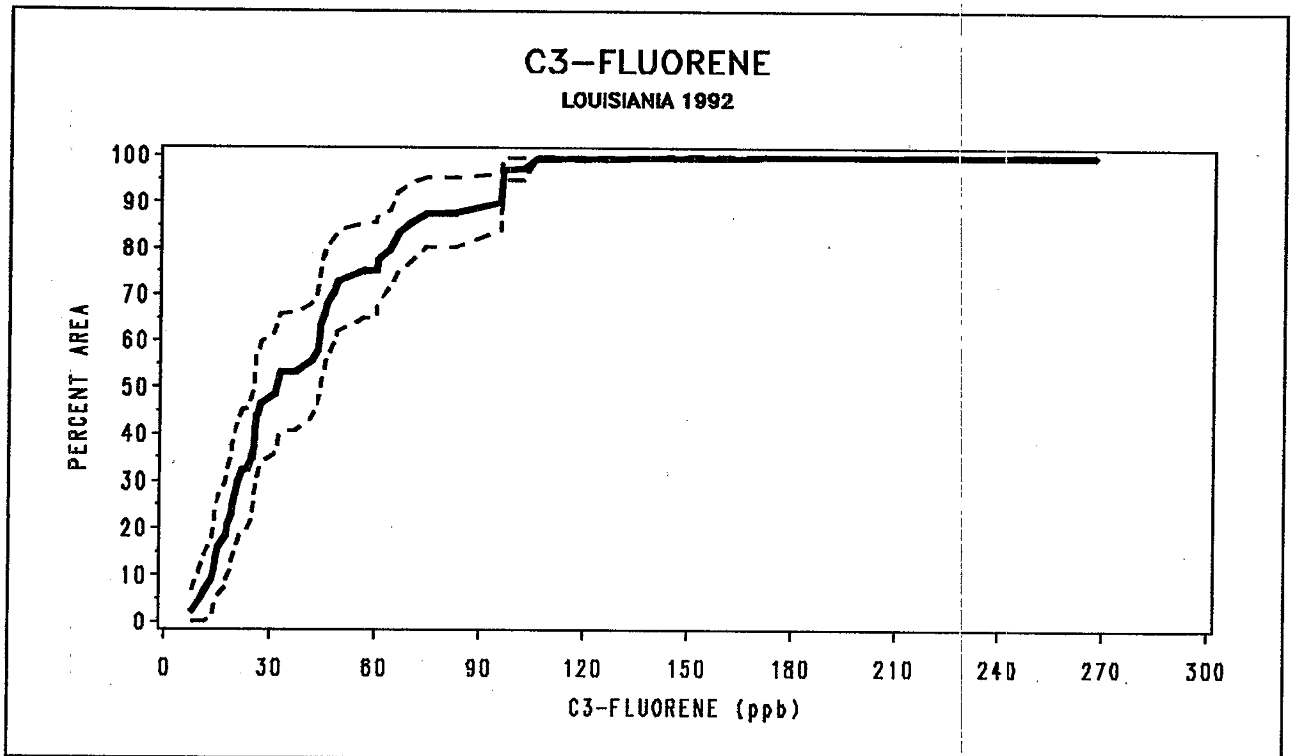

Figure A-26. Distribution of c3-fluorene in estuarine sediments of Louisiana (-) with 95% confidence intervals (--).

A.2.6 POLYCHLORINATED BIPHENYLS

Twenty polychlorinated biphenyl (PCB) congeners were analyzed from the Louisianian Province sediments. Concentrations of total PCBs in Florida ranged from 2 to 14 ppb (Fig. A-28). Given that the criterion for low-level ecological effects are 400 ppb for total PCBs, no PCB concentrations exceeded these criteria in any of the Gulf states.

A.2.7 TRIBUTYLTIN

Tributyltin (TBT), a compound found in antifouling paints until recently, was an effective and widespread means of protecting recreational and commercial craft from fouling organisms. The continuous distribution function of TBT in Texas in shown in Fig. A-29 ranging from 0 to 9 ppb. Most of the high levels of TBT (> 5 ppb) were seen in Florida estuaries (15±10%) while some sediments in Texas (8±13%) and Louisiana (7±8%) contained high levels of TBT (Fig. A-30). Using 1 ppb TBT as an indicator of the presence of TBT results in a more even distribution of TBT among the estuarine sediments of all of the Gulf states (Fig. A-31).

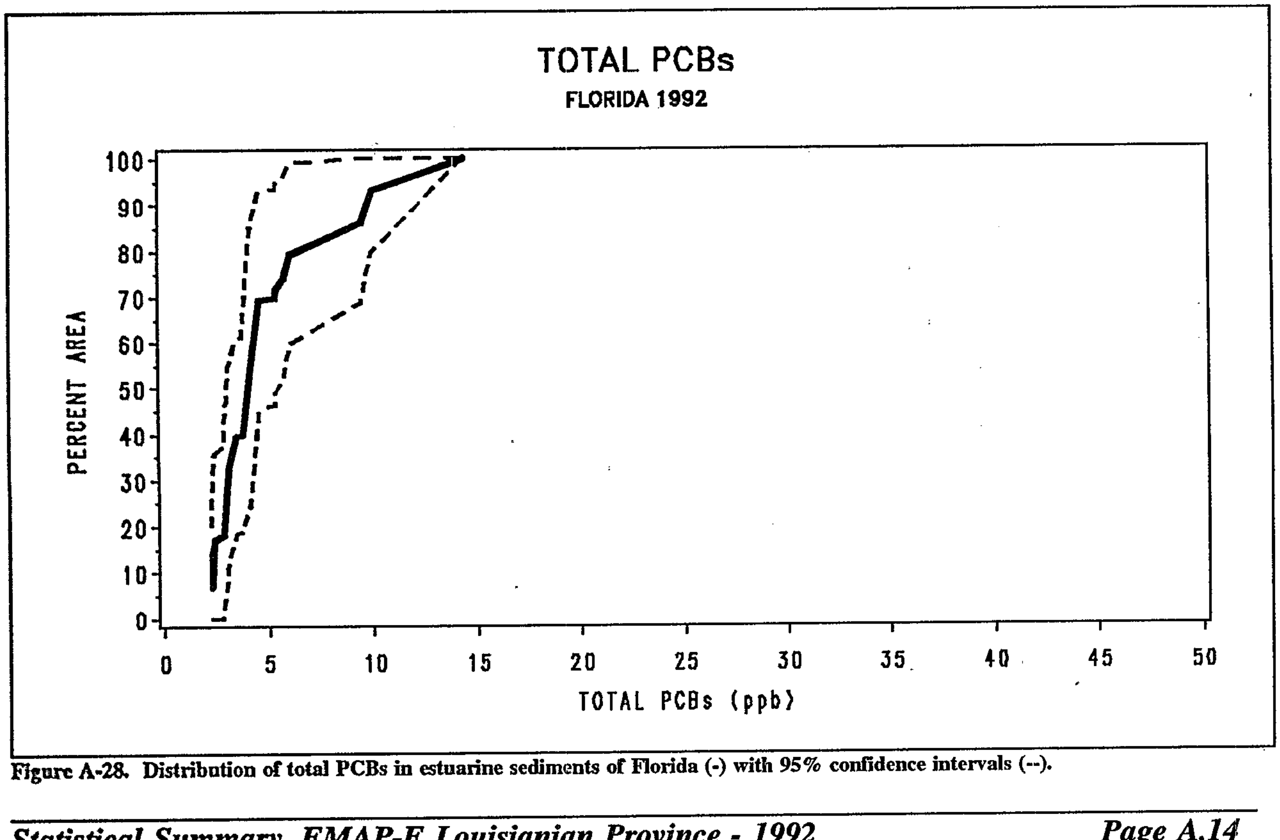

Figure A-28. Distribution of total PCBs in estuarine sediments of Florida (-) with 95% confidence intervals (--).

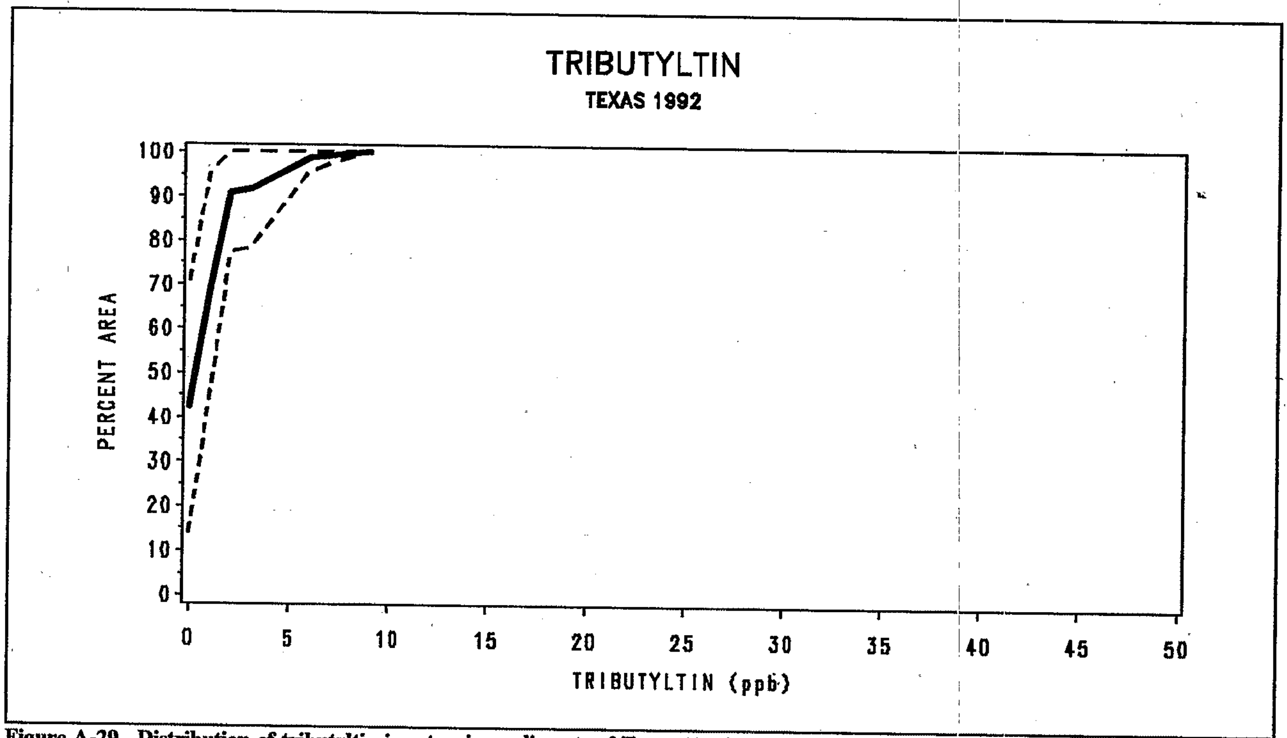

Figure A-29. Distribution of tributyltin in estuarine sediments of Texas (-) with 95% confidence intervals (--).

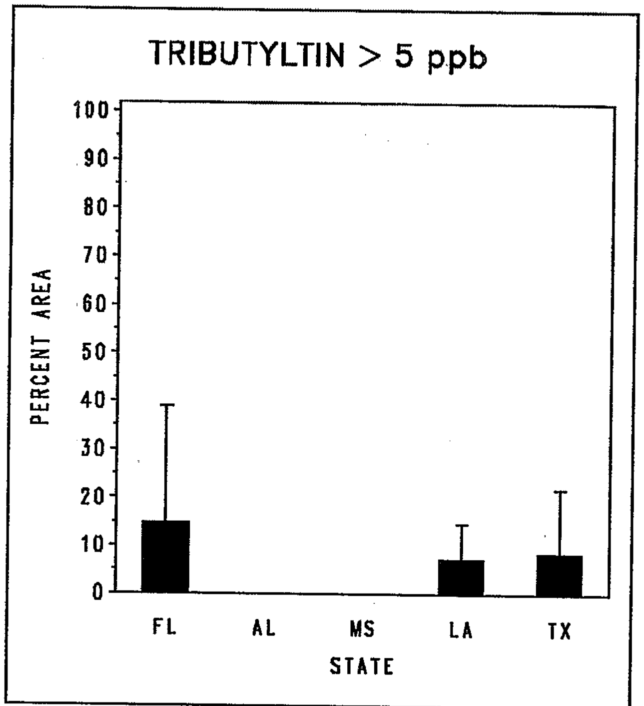

Figure A-30. Proportion of Gulf states' estuarine sediments with TBT > 5 ppb (bars represent 95% confidence intervals).

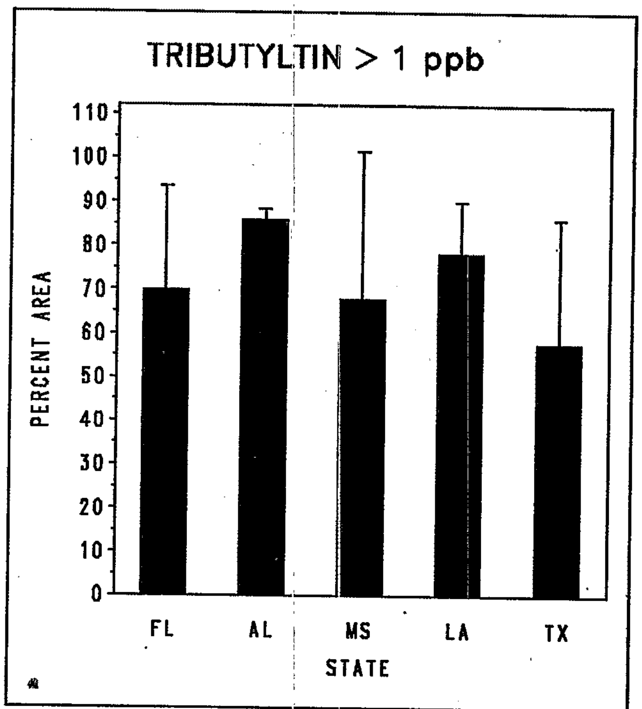

Figure A-31. Proportion of Gulf states estuarine sediments with TBT > 1 ppb (bars represent 95% confidence intervals).

A.2.8 PESTICIDES

Pesticides constitute a major portion of nonpoint source runoff from agricultural fields, suburban lawns, and golf courses. Twenty-four pesticides, including DDT and its derivatives, were analyzed from Louisianian Province sediments. The cumulative distribution function for dieldrin in Texas is shown in Figure A-32. None of the pesticides exceeded the 50% Long and Morgan criteria; however, several pesticides exceeded the 10% criteria. Dieldrin was found exceeding 0.02 ppb in 6 to 43% the estuarine sediments of Gulf States (Fig. A-33).

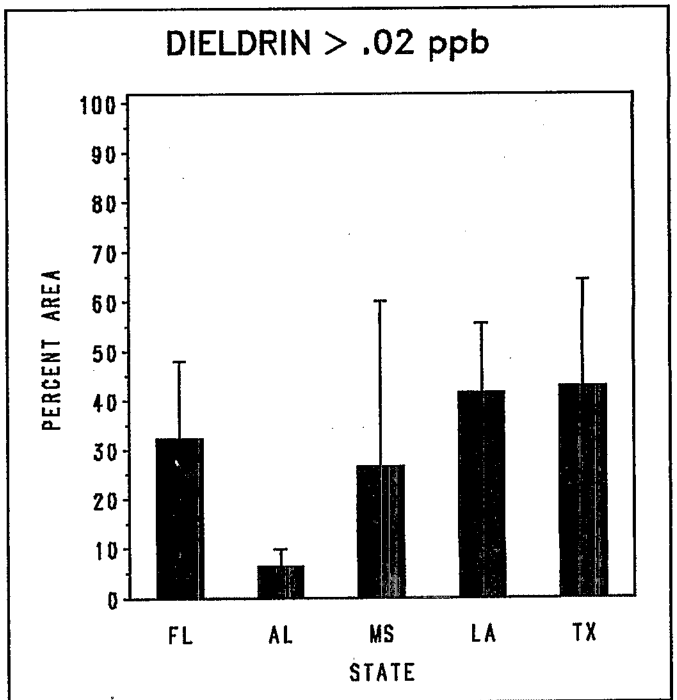

Figure A-33. Proportion of Gulf states' estuarine sediments with dieldrin > 0.02 ppb (bars represent 95% confidence intervals).

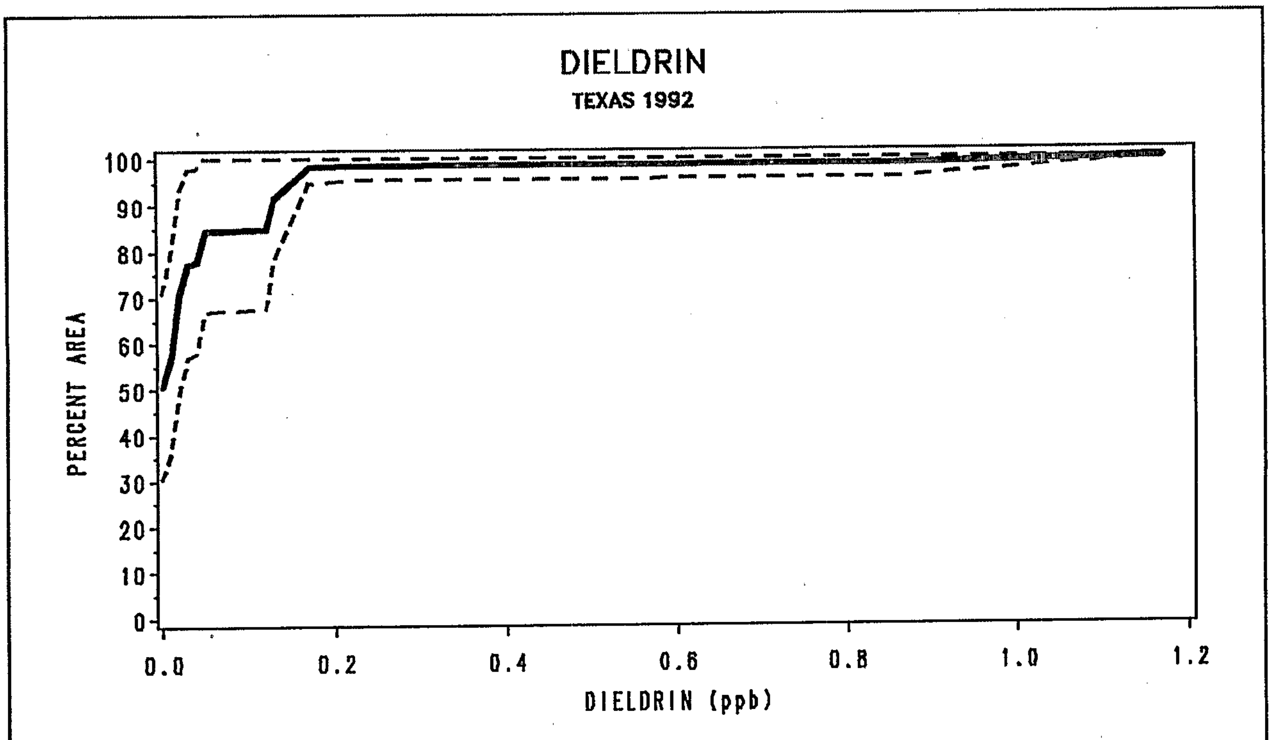

Figure A-32. Distribution of dieldrin in estuarine sediments of Texas (-) with 95% confidence intervals (--).

A.2.9 HEAVY METALS

Fifteen heavy metals were analyzed for the sediments collected in 1992. Examining the metal concentrations based on Long and Morgan criteria, several heavy metals exceeded the 10% criteria. The cumulative distribution function of mercury in Texas sediments is shown in Figure A-34. The proportion of estuarine sediments in each of the Gulf states that exceeded 0.15 ppm mercury (10% criterion) is shown in Figure A-35. The percentage of estuarine area in each state that exceeded the 10% Long and Morgan criteria for each analyzed metal are shown in Figures A-36 to A-40.

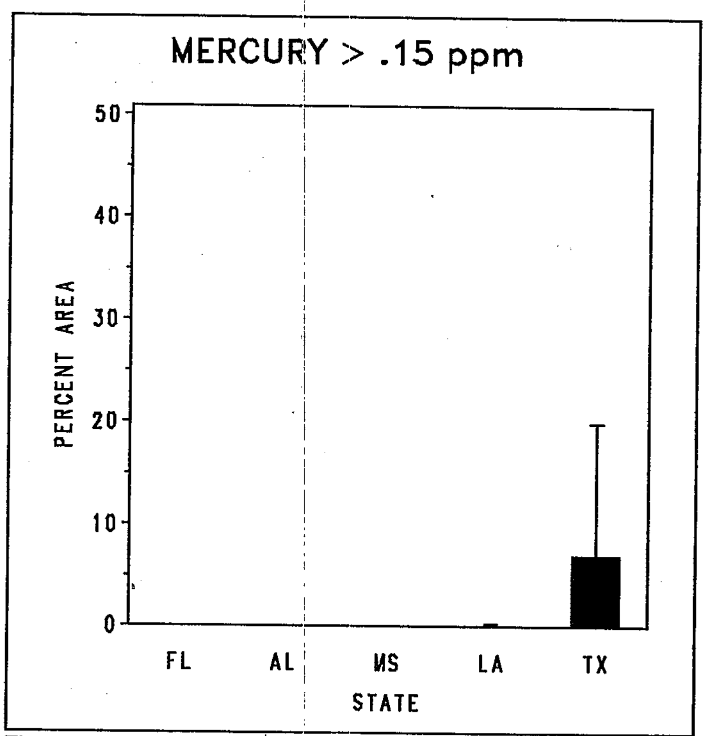

Figure A-35. Proportion of Gulf states' estuarine sediments with mercury > 0.15 ppb (bars represent 95% confidence intervals).

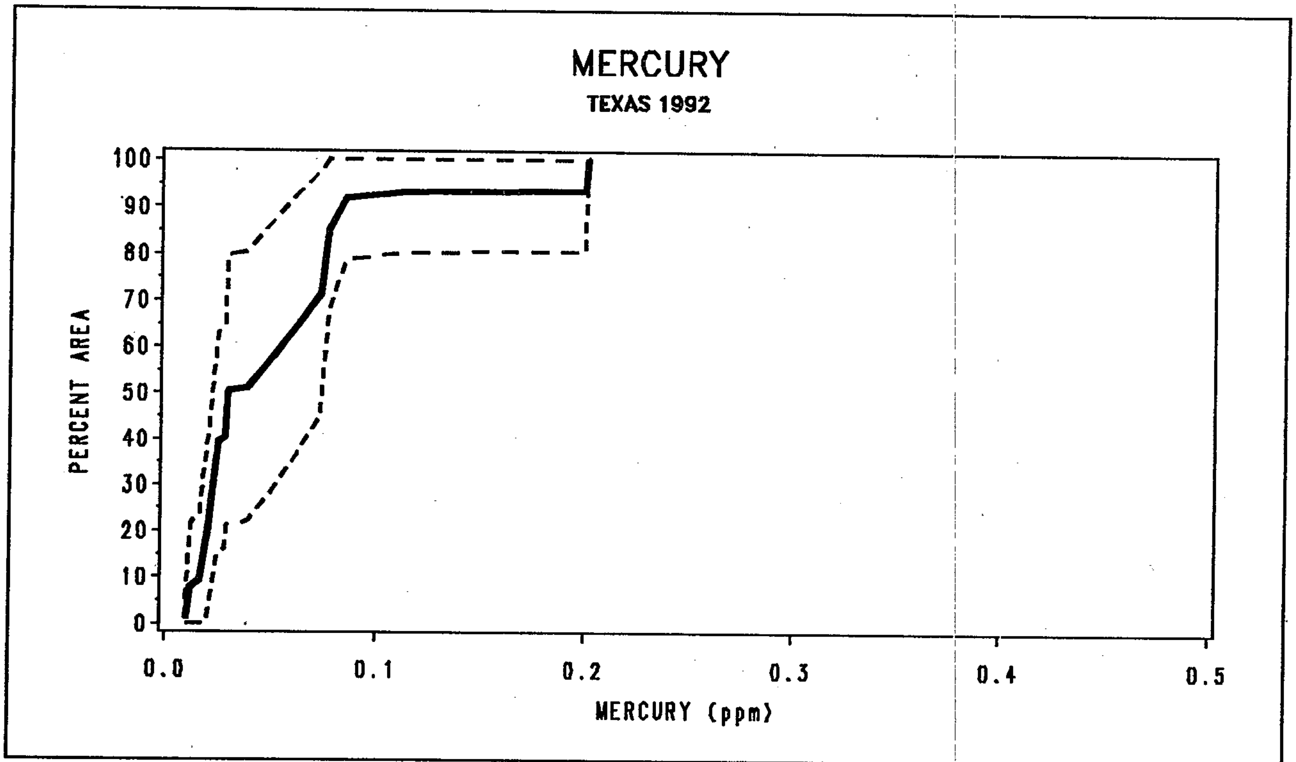

Figure A-34. Distribution of mercury in estuarine sediments of Texas (-) with 95% confidence intervals (--).

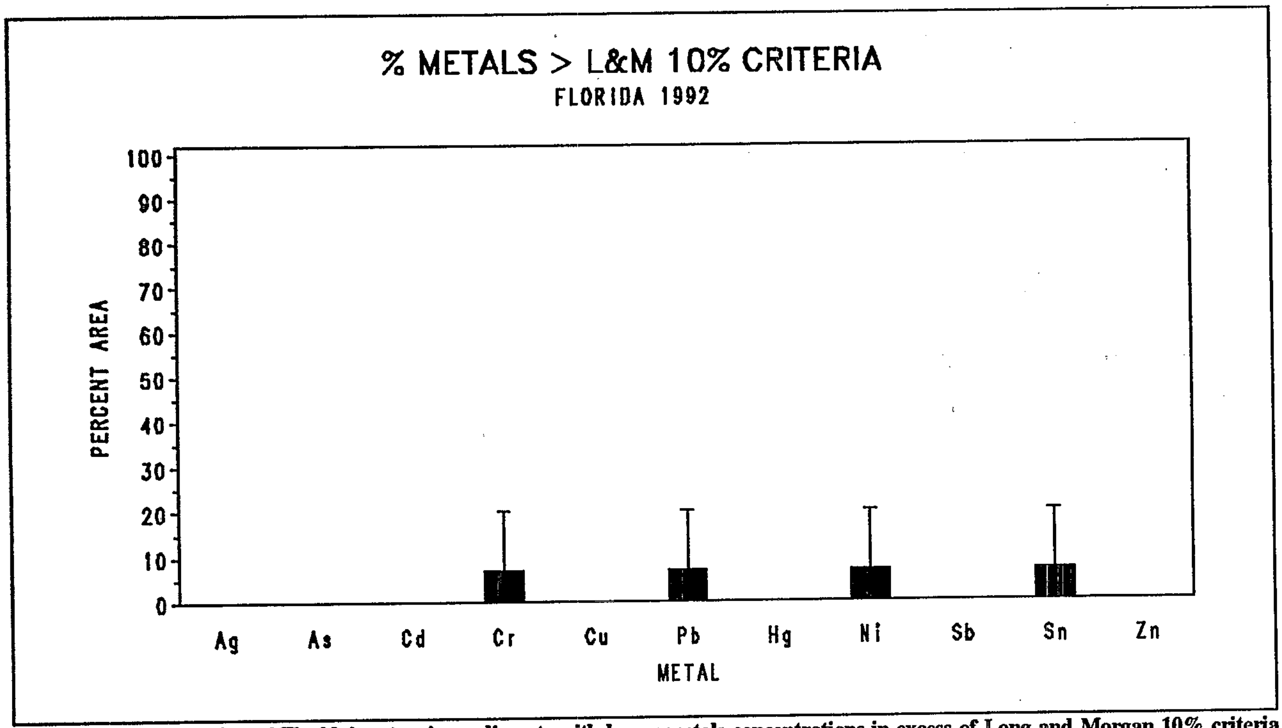

Figure A-36. Proportion of Florida's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria (bars represent 95% confidence intervals).

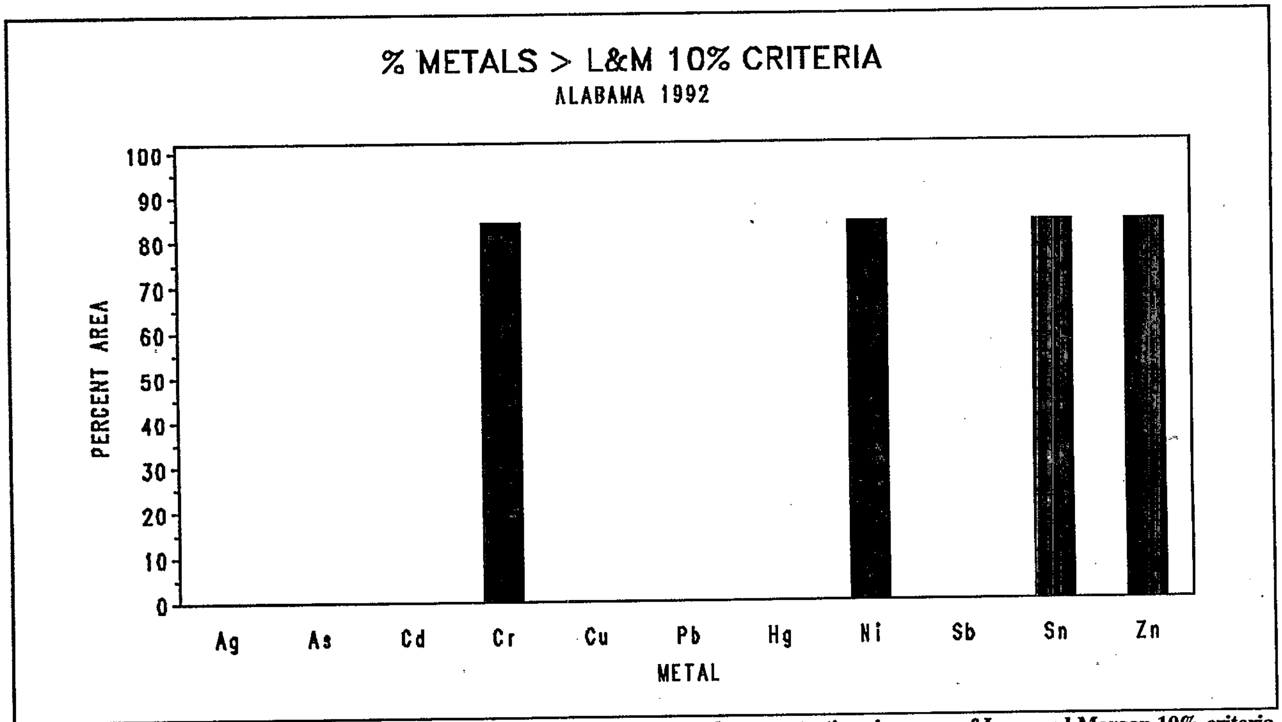

Figure A-37. Proportion of Alabama's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria. There is no error associated with these estimates because the estimates are heavily weighted by a single station.

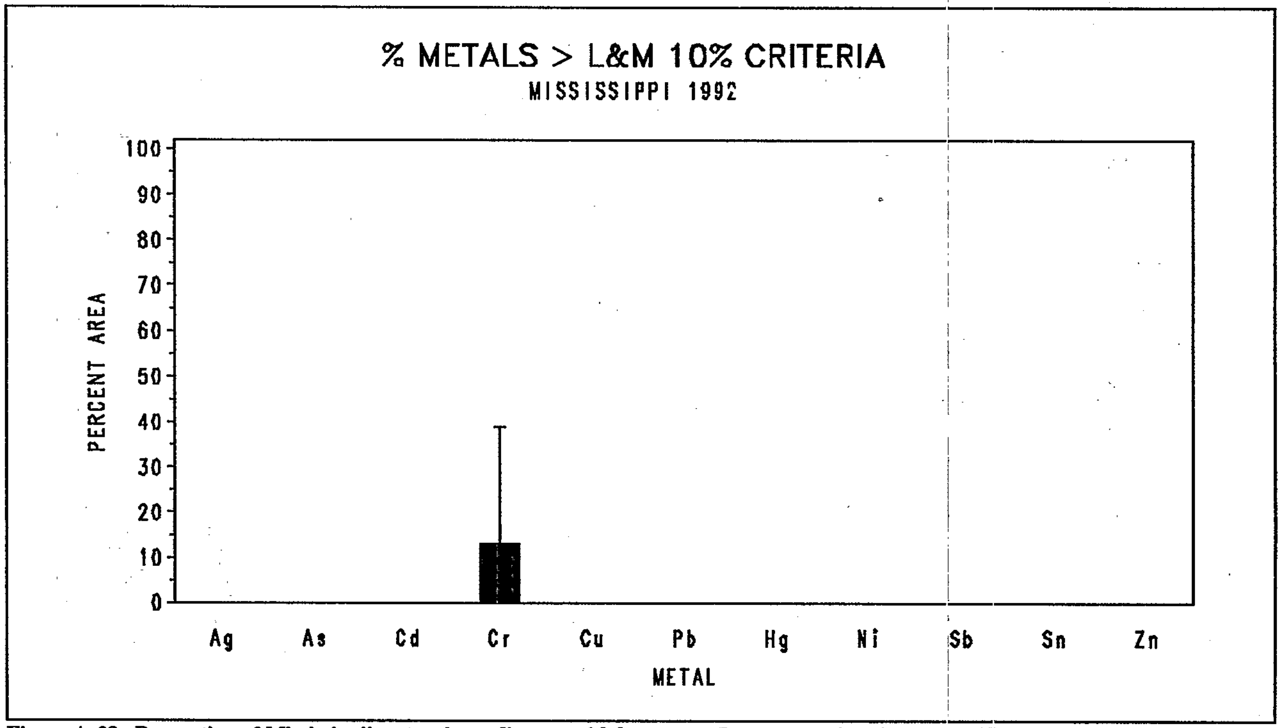

Figure A-38. Proportion of Mississippi's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria (bars represent 95% confidence intervals).

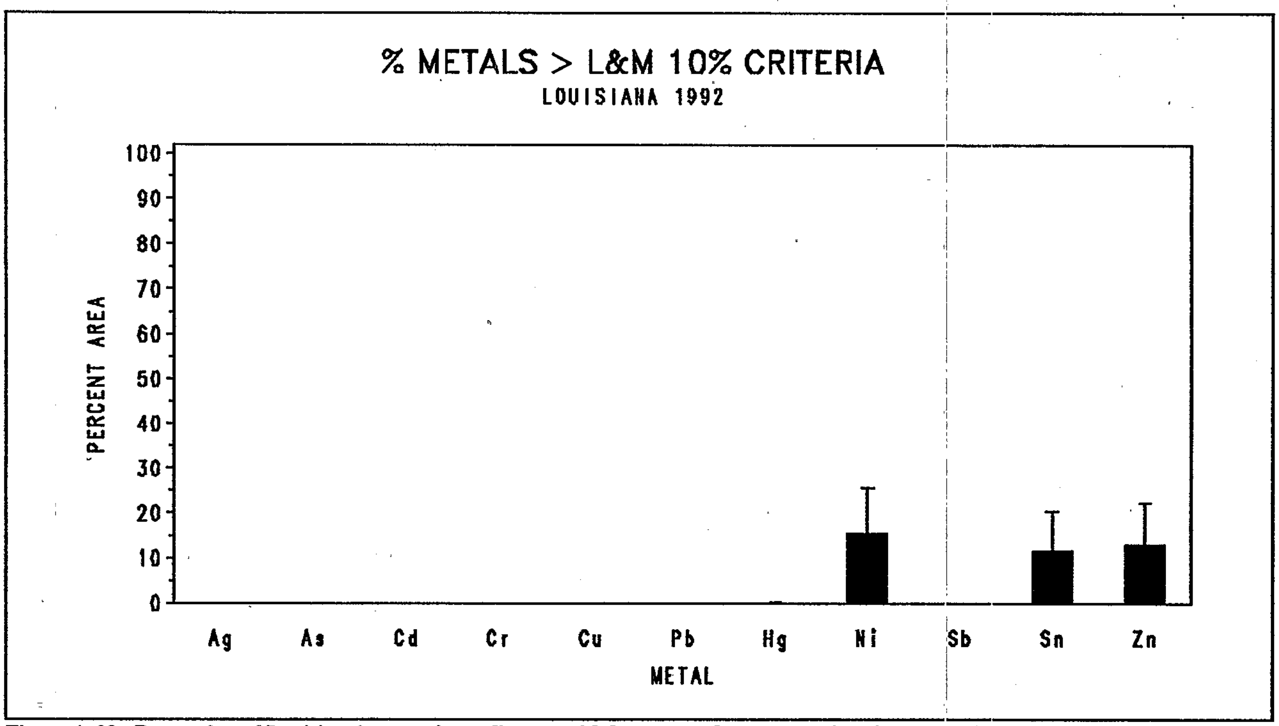

Figure A-39. Proportion of Louisiana's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria (bars represent 95% confidence intervals).

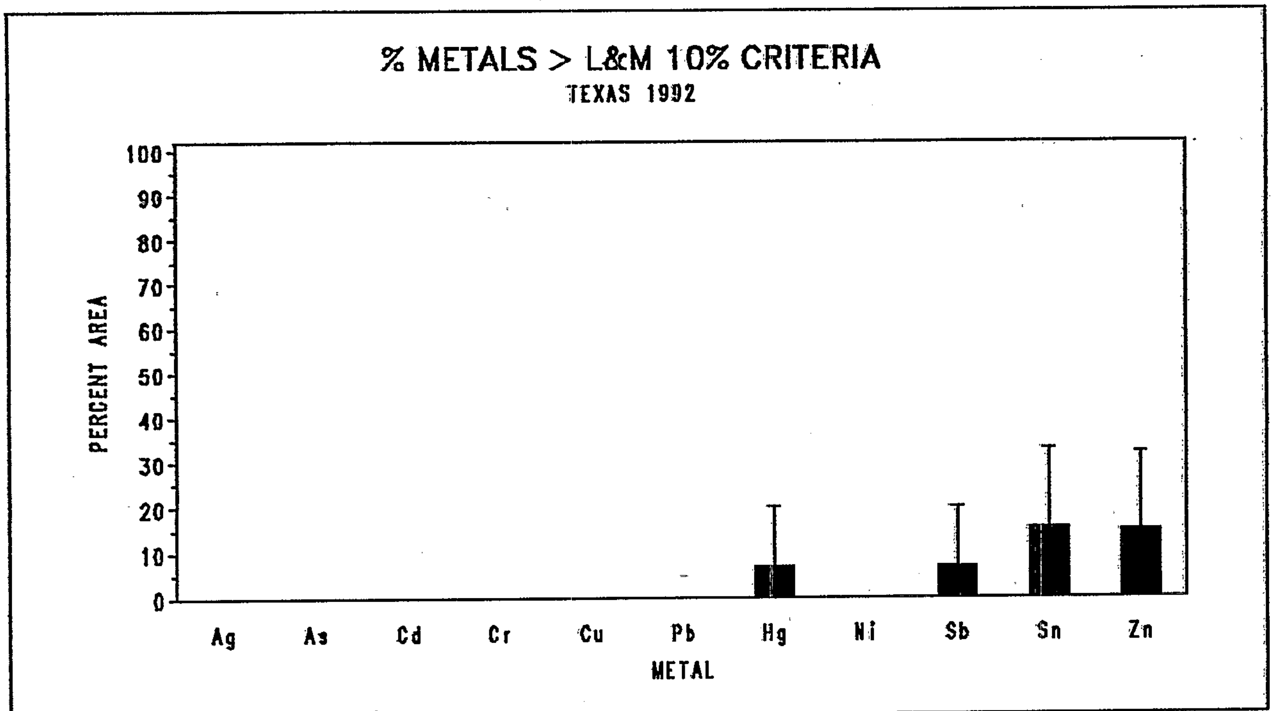

Figure A-40. Proportion of Texas' estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria (bars represent 95% confidence intervals).

A.3 CONFIDENCE INTERVALS FOR STATE-LEVEL ESTIMATES

Ninety-five percent confidence intervals (95%CI) were calculated for all parameters described in this section. The methods for these calculations were described in Summers et al (1993b). Table A-1 provides these intervals for the major indicators for the proportion of the five Gulf States assessed as degraded for each parameter.

Parameter	Florida	Alabama	Mississippi	Louisiana	Texas
N	16	3	9	52	20
Estuarine Condition	23(20)	86(3)	14(26)	44(13)	35(27)
Biotic Condition					
Benthic Index	16(18)	0(0)	14(26)	32(13)	33(27)
Abundance < 10	14(18)	6(4)	0(0)	7(7)	31(18)
# Species < 2	7(13)	0(0)	0(0)	3(4)	24(13)
# Species < 5	16(18)	6(4)	0(0)	12(9)	46(23)
Fish					
Abundance < 5	22(22)	0(0)	13(26)	25(12)	14(17)
Abundance < 10	35(24)	0(0)	40(37)	37(14)	27(21)
# Species < 1	7(14)	0(0)	0(0)	5(6)	< 1(1)
# Species < 2	0(0)	0(0)	13(26)	18(10)	< 1(1)
Fish Pathology	< 1(0)	84(0)	27(33)	23(11)	49(30)
Fish Contaminants[1]					
Shrimp					
All > FDA Limits	0(0)	0(0)	0(0)	0(0)	0(0)
Croaker					
All > FDA Limits	0(0)	0(0)	0(0)	0(0)	0(0)
Marine Catfish					
Hg > FDA Limits	0(0)	0(0)	0(0)	1(1)	0(0)
Others > FDA Limits	0(0)	0(0)	0(0)	0(0)	0(0)
Bottom DO[2] < 2 ppm	7(14)	0(0)	26(34)	2(5)	< 1(1)
Bottom DO[2] < 5 ppm	23(27)	92(3)	26(34)	18(11)	16(18)
Minimum DO < 2 ppm	7(14)	0(0)	26(34)	5(6)	< 1(1)
Sediment Toxicity	20(20)	0(0)	0(0)	8(7)	13(17)

1 Percentage based on sample size rather than estuarine area
2 Instantaneous dissolved oxygen measurements

Table A-1. Estimates of the proportion of the individual Gulf states experiencing the listed parameters and their associated 95% confidence intervals in parentheses (N = number of sampling sites).

Parameter	Florida	Alabama	Mississippi	Louisiana	Texas
N	16	3	9	52	20
Abiotic Condition					
Marine Debris[3]	7	86	0	3	10
Water Clarity					
PAR < 10%	0(0)	0(0)	0(0)	24(12)	3(6)
PAR < 25%	39(21)	8(3)	34(33)	50(14)	40(13)
Silt-Clay Content					
< 20%	45(24)	8(3)	26(34)	7(7)	17(19)
> 80%	9(14)	84(0)	26(33)	39(14)	27(21)
Alkanes					
Total > 7000 ppb	16(18)	0(0)	0(0)	11(8)	7(13)
PAHs					
Total > 4000 ppb	14(18)	0(0)	0(0)	< 1(0)	7(13)
PCBs					
Total > 200 ppb	0(0)	0(0)	0(0)	0(0)	0(0)
Pesticides					
Chlordane > .5 ppb	0(0)	0(0)	0(0)	15(10)	2(3)
Dieldrin > .02 ppb	32(16)	6(4)	26(33)	42(14)	43(22)
Endrin > .02 PPB	0(0)	0(0)	0(0)	5(6)	8(13)
DDT > 1 ppb	0(0)	0(0)	0(0)	< 1(0)	1(2)
DDE > 2 ppb	0(0)	84(0)	0(0)	0(0)	1(1)
DDD > 2 ppb	0(0)	0(0)	0(0)	< 1(1)	1(3)
Metals					
Ag > 1 ppm	0(0)	0(0)	0(0)	0(0)	0(0)
As > 33 ppm	0(0)	0(0)	0(0)	0(0)	0(0)
Cd > 5 ppm	0(0)	0(0)	0(0)	0(0)	0(0)
Cr > 80 ppm	7(13)	84(0)	13(26)	0(0)	0(0)
Cu > 70 ppm	0(0)	0(0)	0(0)	0(0)	0(0)
Hg > .15 ppm	0(0)	0(0)	0(0)	< 1(0)	7(13)
Ni > 30 ppm	7(13)	84(0)	0(0)	16(10)	0(0)
Pb > 35 ppm	7(13)	0(0)	0(0)	0(0)	7(13)
Sb > 2 ppm	0(0)	0(0)	0(0)	0(0)	7(13)
Sn > 3 ppm	7(13)	84(0)	0(0)	9(7)	16(18)
Zn > 120 ppm	0(0)	84(0)	0(0)	13(9)	15(18)
Tributyltin					
TBT > 1 ppb	39(21)	84(0)	13(26)	53(14)	31(26)
TBT > 5 ppb	15(10)	0(0)	0(0)	7(8)	8(13)

3 Estimate based on presence-absence so 95% confidence intervals are not calculated.

Table A-1.(*cont.*) **Estimates of the proportion of the individual Gulf states experiencing the listed parameters and their associated 95% confidence intervals in parentheses (N = number of sampling sites).**

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