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January 1993

Statistical Summary

EMAP- Estuaries Louisianian Province-1991

Environmental Monitoring and Assessment Program

ERRATA

STATISTICAL SUMMARY: EMAP-ESTUARIES LOUISIANIAN PROVINCE-1991 EPA/620/R-93/007 JANUARY 1993

Appendix C of this report should be disregarded. The Appendix was developed as a screening exercise to assist in identifying possible concerns associated with seafood from the estuaries of the Gulf of Mexico. However, this was premature as data are still being gathered and analyzed under the EMAP Louisianian Province demonstration project. These data, with procedural modifications, are expected to provide a more useful and accurate contribution to improving this risk-screening process.

In its present form, the data set contains several errors, including:

- inappropriately assessing non-carcinogenic effects using methods designed for assessing carcinogenic risks (e.g., the use of incremental risks);
- using unconfirmed cancer potency factors (CPFs) to estimate the risks associated with carcinogenic contaminants; and
- expressing hazards to humans on the basis of fish-population contaminant levels which do not necessarily reflect realistic scenarios for an exposed human population.

In view of these errors, health risks should be addressed in the context of more definitive published EPA guidance.

EPA/620/R-93/007
January 1993

STATISTICAL SUMMARY: EMAP-ESTUARIES LOUISIANIAN PROVINCE - 1991

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 (1991). Appropriate precautions should be exercised when using this information for policy, regulatory or legislative purposes.

PREFACE

This document is the first 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).

The appropriate citation for this report is:

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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 1991 Demonstration. Space does not permit the individual citation of all who participated in the 1991 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

This statistical summary of the ecological condition of the estuarine resources is based on the results of the 1991 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 Gulf of Mexico and the 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 agenices 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 area. The Louisianian Province Demonstration Project was conducted during the summer of 1991 (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 eighty three sites between Anclote Anchorage, FL and the Rio Grande, TX were sampled during the seven-week sampling period (Fig. 1). An additional 19 sites were scheduled, but not sampled, due to inadequate water depth for sampling (i.e., < 1 m). Thus, based on the 1991 sampling design, 7.4% 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 Laguna Madre, TX where the average depth is < 1 m. About 60% of the unsampleable area occurs in this water body. We will evaluate methods in 1992 for obtaining data from Laguna Madre in 1993.

A series of indicators that are

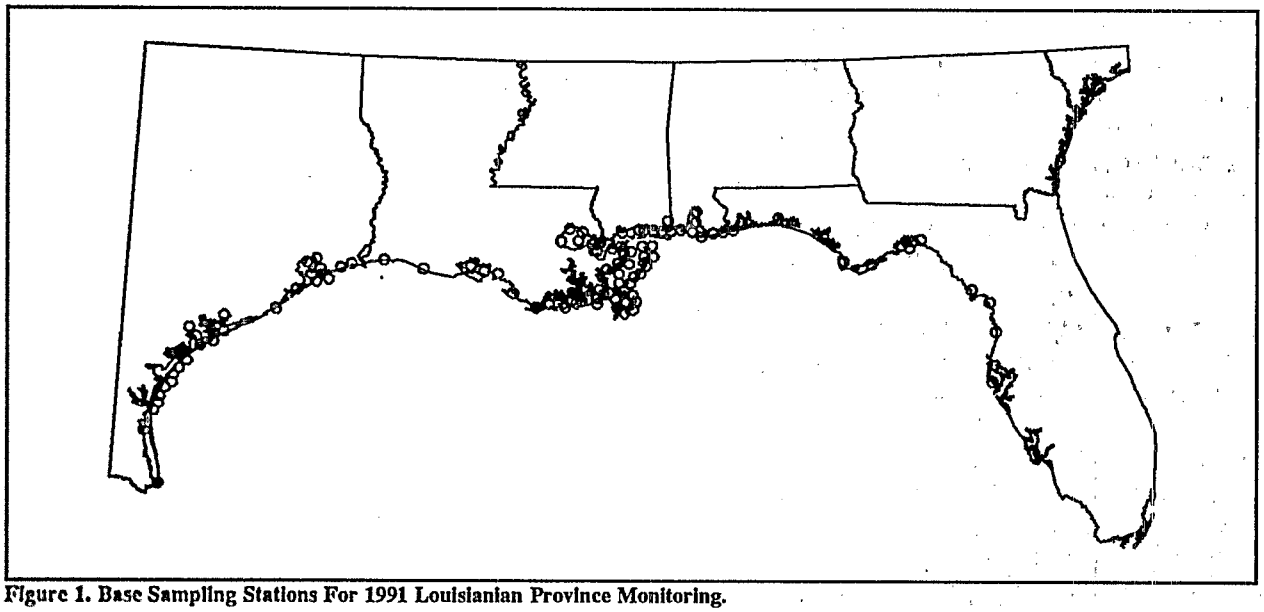

Figure 1. Base Sampling Stations For 1991 Louisianian Province Monitoring.

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) aesthetics representing societal values related to public use of estuarine resources, and 3) pollutant exposure or the 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 and abundance to evaluate the condition of the benthic and fish assemblages. Both use indices determined from the 1991 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, using the 1991 data but several additional years of information will be required for complete validation; therefore, assessments based on these indices should be considered preliminary. In fact, due to the use of single trawls to characterize fish communities, the fish index is not incorporated into the assessment of the proportion of degraded estuarine area in the Louisianian Province.

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.

Preliminary estimates based on the 1991 Louisianian Province Demonstration indicate that 30% of the estuarine area in the province had degraded benthic resources. Of the 25,725 km^2 comprising the estuaries of the Louisianian Province, over 8000 km^2 were ecologically degraded. For the benthic index, degraded conditions were defined in as an index value < 4.1.

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 1991. Proportionately, large tidal rivers were the most degraded with most of the resource (80% of the area of the tidal portion of the Mississippi River) having degraded resources (Fig. 2). Forty-one percent of small estuarine resources were degraded on an areal basis and large estuaries had only 27% of their area represented by

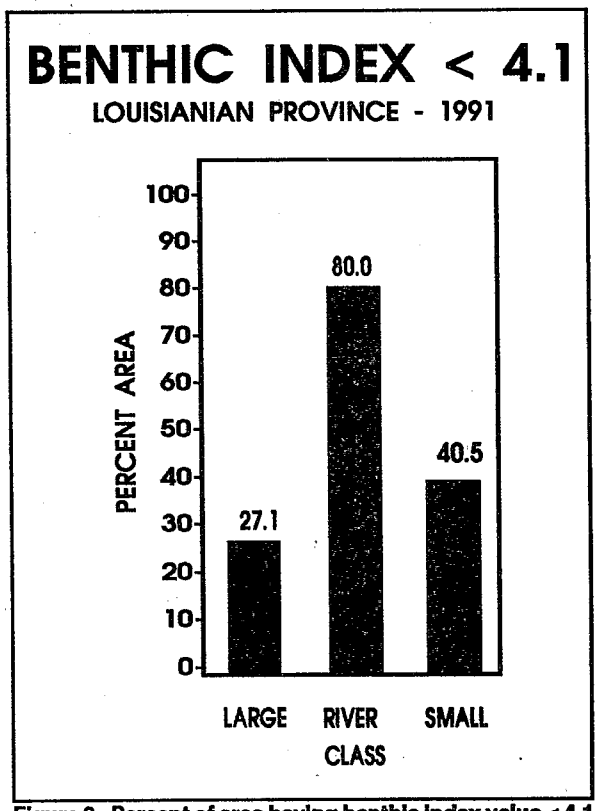

Figure 2. Percent of area having benthic index value < 4.1 for large estuaries (large), small estuaries (small), and large tidal rivers (river).

degraded benthos (Fig. 2). However, while the proportional area degraded was high in the large tidal river and small estuarine resources classes, the actual total area of degraded benthic resources in large estuaries was 5000 km^2 as compared to 2800 km^2 for small estuaries and 110 km^2 for large tidal rivers.

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 1991 Louisianian Province Demonstration to estimate the areal extent of estuaries having trash and turbid waters. Measurements were taken to estimate the proportion of fish populations of ecological, recreational, and commercial fish 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 17% of the estuarine area in the Louisianian Province with 3% represented by plastics and 14% by cans, glass, paper, and wood. This accumulates to 3600 km^2 of estuarine bottom having identifiable marine debris in the Louisianian Province. No trash could be specifically identified as medical or hospital waste. Proportion of area having marine debris was higher in the large tidal river and small estuary classes (30% and 25%, respectively) and 12% of the area of large 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. It was determined that water visibility of 10% at one meter would be used to represent poor visibility (i.e.,

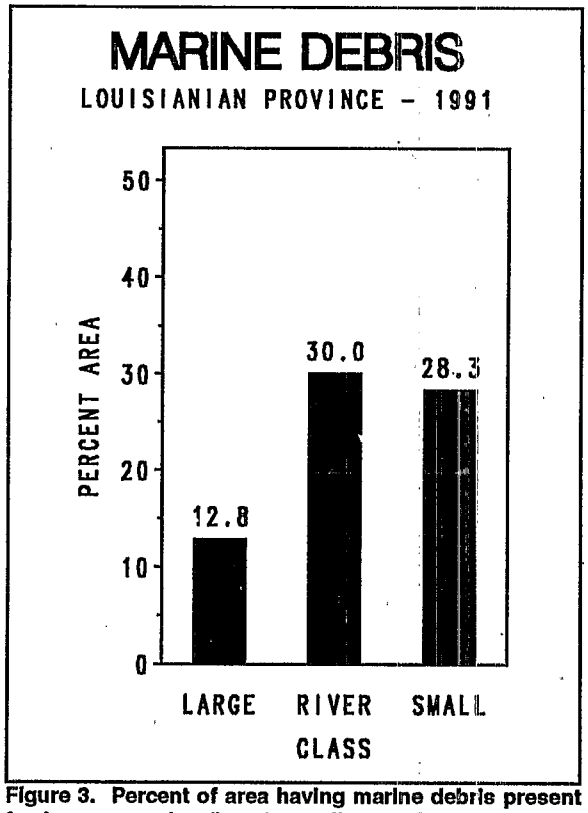

Figure 3. Percent of area having marine debris present for large estuaries (large), small estuaries (small), and large tidal rivers (river).

visibility of < 1 ft). Approximately 27% of the province had waters with visibility of < 10%. Clarity was much poorer in small estuaries (41% with < 10% transmittance) than either large estuaries (21%) or large tidal rivers (0%)(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 polycyclic chlorinated biphenyls (PCBs) in edible fish tissues for three species groups: Atlantic croaker (*Micropogonias undulatus*), commercial shrimps (*Penaeus aztecus* and

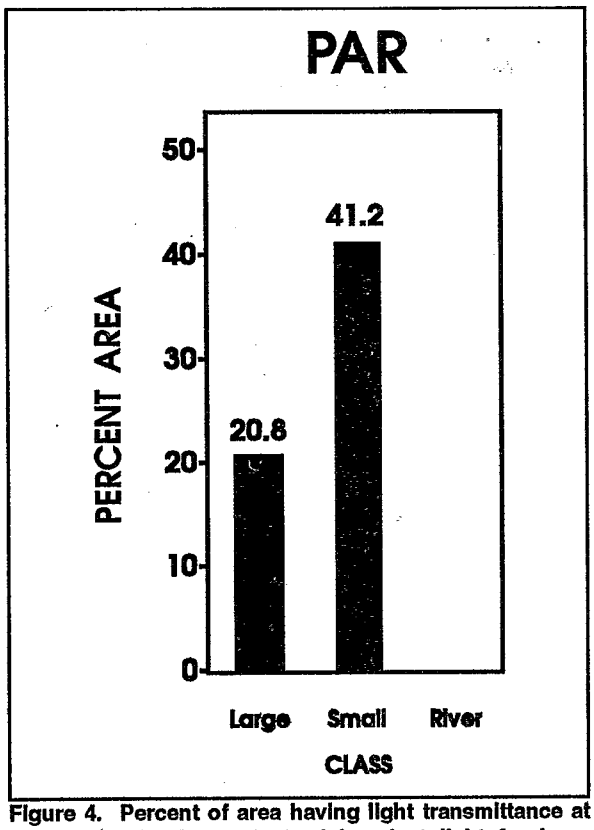

Figure 4. Percent of area having light transmittance at one meter depth at <10% of incedent light for large estuaries (large), small estuaries (small), and large tidal rivers (river).

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, 2, and 3). Concentrations of pesticides and PCBs measured in brown and white shrimp tissue did not exceed existing FDA and international criteria (USFDA 1982, 1984; Nauen 1983). However, certain heavy metals were characterized by concentrations exceeding criteria in small portions of the sampled populations of shrimp (Table 1). Arsenic and chromium exceeded criteria levels in 4% of the population sampled.

Atlantic croaker is a recreationally and commercially important fish in the Louisianian Province. Concentrations of all chlorinated pesticides and PCBs were below FDA criteria. Arsenic concentrations exceeding 2.0 ppm were found in 3% of the croaker population.

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 catfish. As was seen with croaker, catfish flesh contained concentrations of chlorinated pesticides and PCBs well within established criteria. As seen with shrimp and croaker, catfish contained elevated levels of arsenic (8% of samples exceeding 2 ppm). Zinc concentrations exceeded 60 ppm in 2% of the catfish populations. Mercury exceeded 1 ppm in 1% of the catfish populations.

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 FDA action limits in small portions of the populations examined. These contaminants were arsenic, zinc, mercury, and chromium. 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

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-4.9	5000	0%
DDE	0-1.7	5000	0%
DDT	0-74.0	5000	0%
Aldrin	0-1.6	300	0%
Chlordane	0-1.9	300	0%
Dieldrin	0-1.6	300	0%
Endosulfan	0-0.0	NA[2]	0%
Endrin	0-12.8	300	0%
Heptachlor	0-0.0	300	0%
Heptachlor Epoxide	0-3.9	300	0%
Hexachlorobenzene	0-2.5	200	0%
Lindane	0-0.0	200	0%
Mirex	0-43.5	100	0%
Toxaphene	0-0.0	500	0%
Trans-Nonachlor	0-1.3	NA	U[3]
PCBs (ng/g wwt)			
21 Congeners	0-16.1	500	0%
Total PCBs	0-30.3	2000	0%
Heavy Metals (ng/g wwt)			
Aluminum	0-78.5	NA	U
Arsenic	0-3.9	2	4%
Cadmium	0-0.3	0.5	0%
Chromium	0-6.1	1	4%
Copper	0-9.6	15	0%
Lead	0-0.3	0.5	0%
Mercury	0-0.3	1	0%
Nickel	0-9.0	NA	U
Selenium	0-0.3	1	0%
Silver	0-0.3	NA	U
Tin	0-1.1	NA	U
Zinc	1-18.8	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 mean 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=370).

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. 5a). Indicators relating to biotic integrity and aesthetics were used to estimate overall environmental conditions in the estuaries. Forty two 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. 5a). Of the 25,725 km^2 of estuarine surface area in the Louisianian Province, 10,805 km^2 were potentially degraded.

The locations of degraded biological resources were sometimes different from those having aesthetic problems. Both sets of conditions were found in 20% of the estuarine area, whereas degraded biological conditions alone were found in 10% of the province, and poor aesthetics were found in 12% (Fig. 5a).

Contaminant	Observed range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-16.0	5000	0%
DDE	0-3.5	5000	0%
DDT	0-24.2	5000	0%
Aldrin	0-3.2	300	0%
Chlordane	0-8.2	300	0%
Dieldrin	0-26.2	300	0%
Endosulfan	0-1.7	NA	U
Endrin	0-22.5	300	0%
Heptachlor	0-5.7	300	0%
Heptachlor Epoxide	0-16.7	300	0%
Hexachlorobenzene	0-77.4	200	0%
Lindane	0-0.0	200	0%
Mirex	0-88.5	100	0%
Toxaphene	0-1800	500	0%
Trans-Nonachlor	0-1.3	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-40.6	500	0%
Total PCBs	0-62.5	2000	0%
Heavy Metals (ng/g wwt)			
Aluminum	0-6.9	NA	U
Arsenic	0-2.1	2	3%
Cadmium	0-0.1	0.5	0%
Chromium	0-0.3	1	0%
Copper	0-5.3	15	0%
Lead	0-0.3	0.5	0%
Mercury	0-0.4	1	0%
Nickel	0-0.3	NA	U%
Selenium	0-0.3	1	0%
Silver	0-1.8	NA	U%
Tin	0-0.7	NA	U%
Zinc	1-11.8	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 mean of international limits (Nauen 1983)

Table 2. Overview of the contaminant levels observed in edible flesh of Atlantic croaker (N=580). NA= Not available; U= Unknown, no criterion level is available.

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-207.4	5000	0%
DDE	0-12.2	5000	0%
DDT	0-39.4	5000	0%
Aldrin	0-2.7	300	0%
Chlordane	0-6.1	300	0%
Dieldrin	0-24.4	300	0%
Endosulfan	0-1.8	NA	U
Endrin	0-10.1	300	0%
Heptachlor	0-5.7	300	0%
Heptachlor Epoxide	0-5.7	300	0%
Hexachlorobenzene	0-4.0	200	0%
Lindane	0-4.1	200	0%
Mirex	0-30.7	100	0%
Toxaphene	0-1400	5000	0%
Trans-Nonachlor	0-4.3	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-19.5	500	0%
Total PCBs	0-67.9	2000	0%
Heavy Metals (ng/g wwt)			
Aluminum	0-105.1	NA	U
Arsenic	0-10.1	2	8%
Cadmium	0-0.4	0.5	0%
Chromium	0-0.8	1	0%
Copper	0-10.3	15	0%
Lead	0-0.4	0.5	0%
Mercury	0-1.2	1	1%
Nickel	0-0.7	NA	U
Selenium	0-0.4	1	0%
Silver	0-0.3	NA	U
Tin	0-1.2	NA	U
Zinc	1-234.0	60	2%

[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 mean of international limits (Nauen 1983)

Table 3. Overview of the contaminant levels observed in edible flesh of catfish (N=1130). NA= Not available; U= Unknown as no criterion level is available.

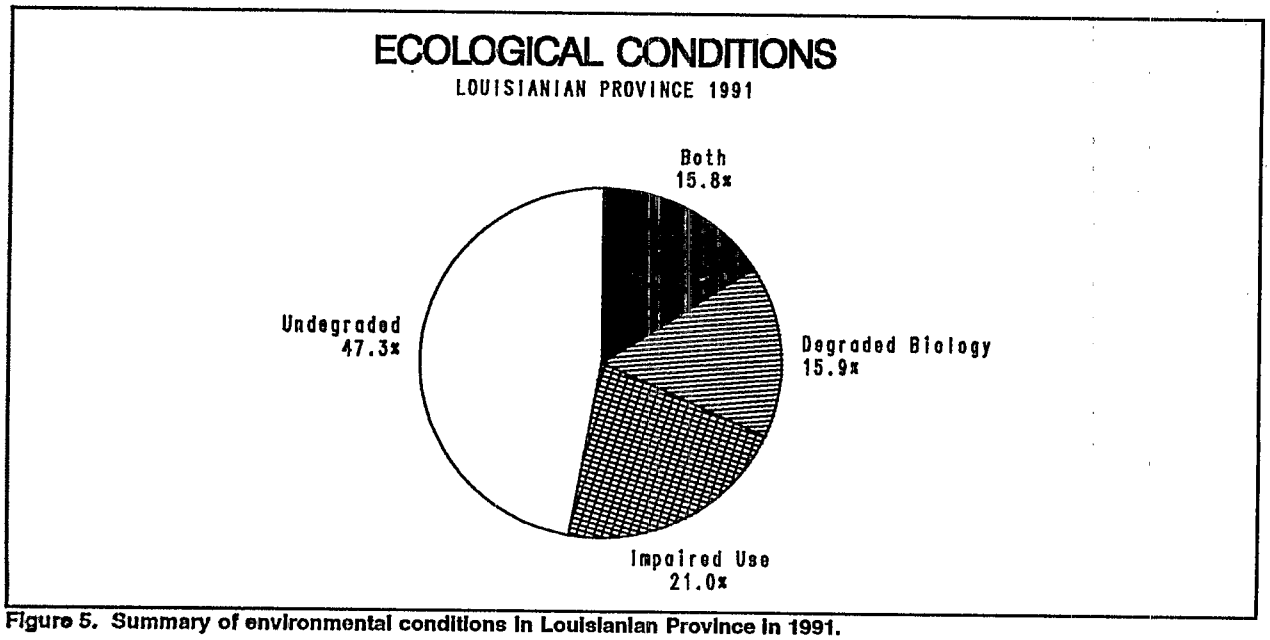

Figure 5. Summary of environmental conditions in Louisianian Province in 1991.

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.

Dissolved oxygen is a fundamental requirement for all estuarine organisms. A threshold concentration of 4-5 ppm is used by many states to set water quality standards. Bottom waters in 15% of the Louisianian Province had point measurements of dissolved oxygen concentrations that failed to meet the 5ppm 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 1991 Louisianian Province Demonstration indicate that point measurements of bottom dissolved oxygen concentrations below this threshold were found in 6% of the province (Fig. 6).

Two types of dissolved oxygen measurements were taken in 1991: 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. As a result, point measurements during daylight hours could erroneously characterize a site that receives severe dissolved oxygen stress for several hours every night as a site with acceptable dissolved oxygen concentrations because high levels were found during the day. In general, the continuous dissolved oxygen concentration measurements mimic the point

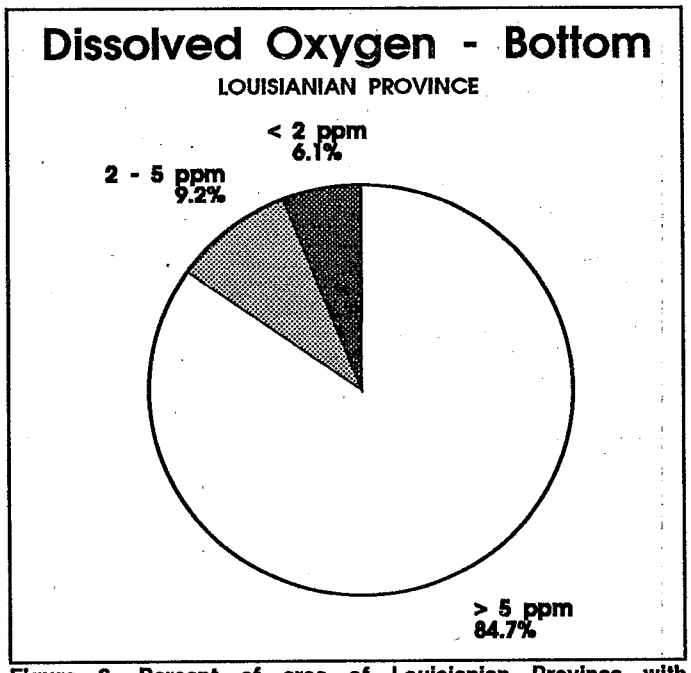

Figure 6. Percent of area of Louisianian Province with instantaneous dissolved oxygen concentrations in bottom waters < 2ppm, 2-5 ppm, and > 5ppm.

measurements in large estuaries and large tidal rivers but continuous measurements show a significant increase in the area experiencing dissolved oxygen concentrations less than 2 ppm in small estuarine systems from < 1% based on point measurements (Fig. 7) to over 15% based on continuous measurements (Fig. 8). This doubles the total proportion of the province experiencing stressful dissolved oxygen concentrations (< 2 ppm) from 6% to 12% and increases the proposition experiencing < 5 ppm from 15% to 37% of the Louisianian Province (Fig. 9). Thus, continuous measurements are necessary to characterize correctly the exposure of low dissolved oxygen.

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, 7% 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 the Louisianian Province, additional testing was completed using a common mysid. The results of this mysid testing generally agree with those found using *Ampelisca* with 7% of the province showing toxicity. The proportion of area containing toxic sediments was very different among the three classes (Fig. 10) with the highest proportion occurring in the large tidal river class (67%) and significantly smaller proportions in the small estuaries (14%) and large estuaries (6%).

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

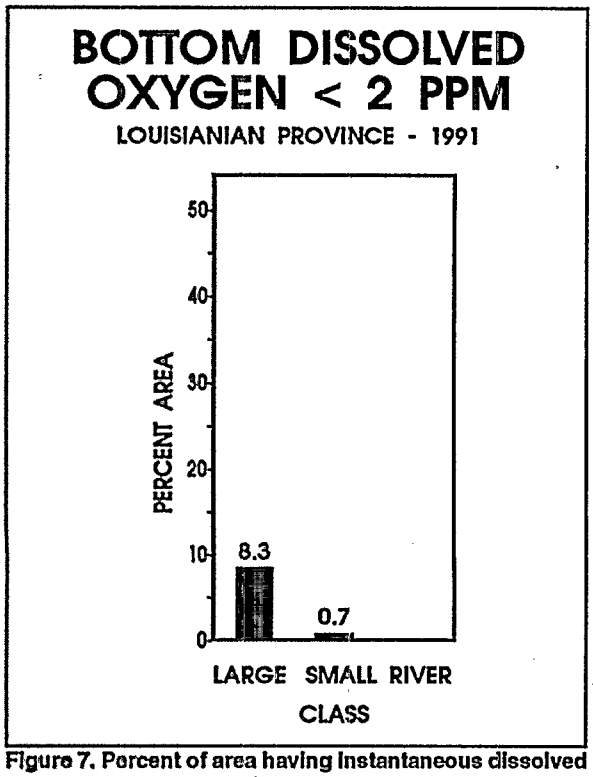

Figure 7. Percent of area having instantaneous dissolved oxygen concentrations in bottom waters of < 2 ppm for large estuaries (large), small estuaries (small), and large tidal rivers (river).

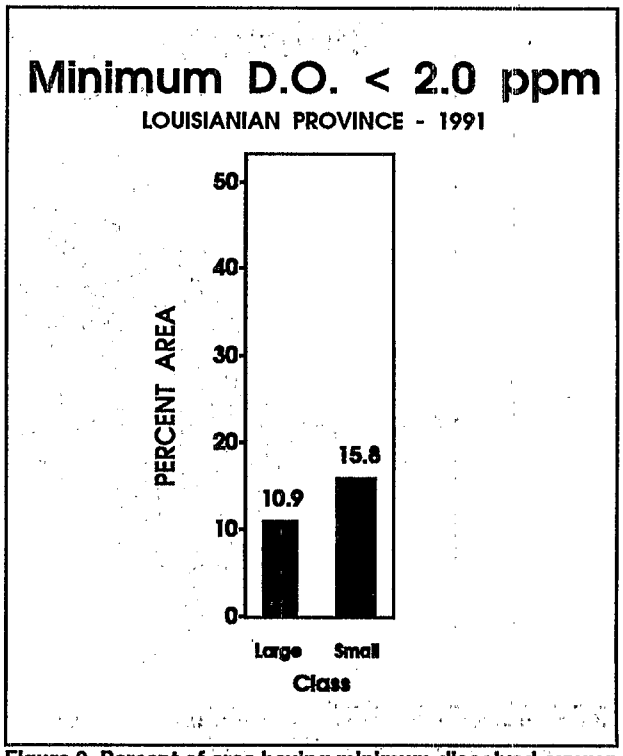

Figure 8. Percent of area having minimum dissolved oxygen concentrations in bottom waters of <2 ppm for large estuaries (large), small estuaries (small), and large tidal rivers (river).

aromatic hydrocarbons (PAHs), pesticides, and polycyclic chlorinated 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 criterion levels are not available for all toxic substances. The criteria used for contaminants are shown in Table 4.

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, 32% of the Louisianian Province has sediments with elevated concentrations of one or more heavy metals based on the criteria values and 33% of the area has heavy metal concentrations that were higher than would be expected based on aluminum background concentrations. These elevated metals were primarily mercury,

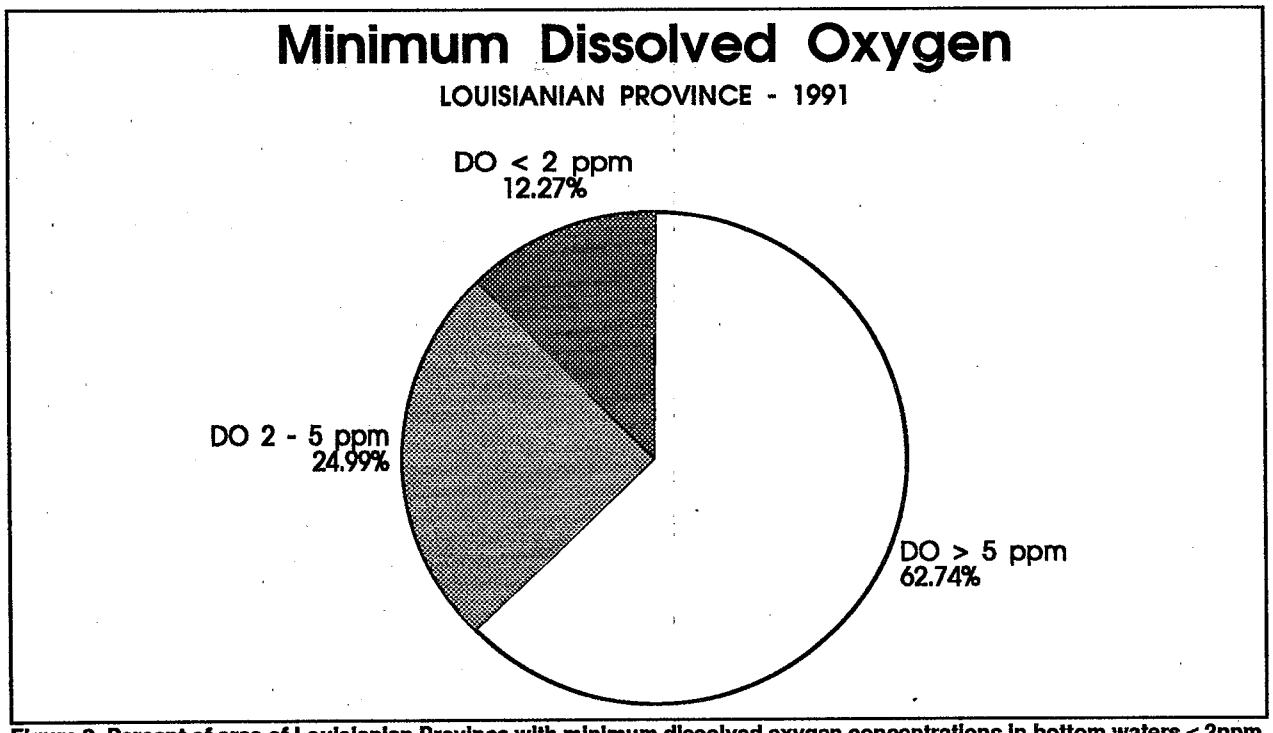

Figure 9. Percent of area of Louisianian Province with minimum dissolved oxygen concentrations in bottom waters < 2ppm, 2-5 ppm, and > 5 ppm based on 24 hours of data.

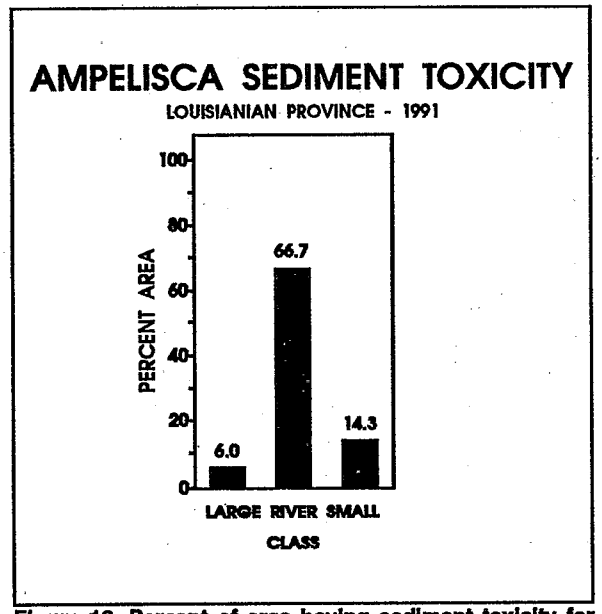

Figure 10. Percent of area having sediment toxicity for large estuaries (large), small estuaries (small), and large tidal rivers (river).

nickel, chromium, zinc, and to a smaller extent, tin and lead. Enriched metal concentrations varied widely among classes with the greatest enrichment (80% of sediments) occurring in the large tidal rivers, 40% of the sediments being enriched in large estuaries, and only 9% of sediments in small estuarine systems (Fig. 11).

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 on 5000-7000 ppb total alkanes was used as indicative of potential contamination. Eleven percent of

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.

the sediments in the Louisianian Province had elevated levels of alkanes. No elevated levels of alkanes were observed in the large tidal rivers class and the proportion of area displaying elevated alkane concentrations in large and small estuaries was about the same, 10% and 12%, 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 were 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

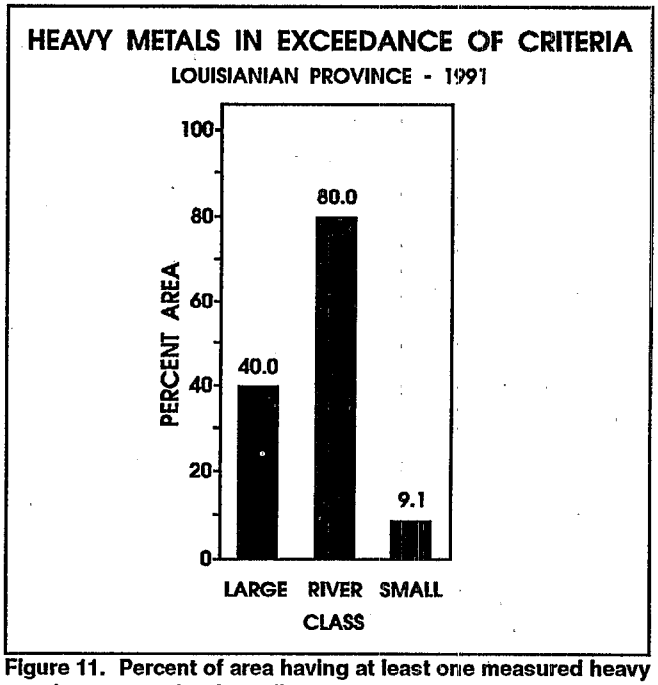

Figure 11. Percent of area having at least one measured heavy metal concentration in sediments exceeding its criterion value for large estuaries (large), large tidal rivers (river), and small estuaries (small).

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 3% 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. All of the intermediate level of PAHs was found in small estuarine systems comprising 10% of the total sediments in small estuaries (Fig. 13).

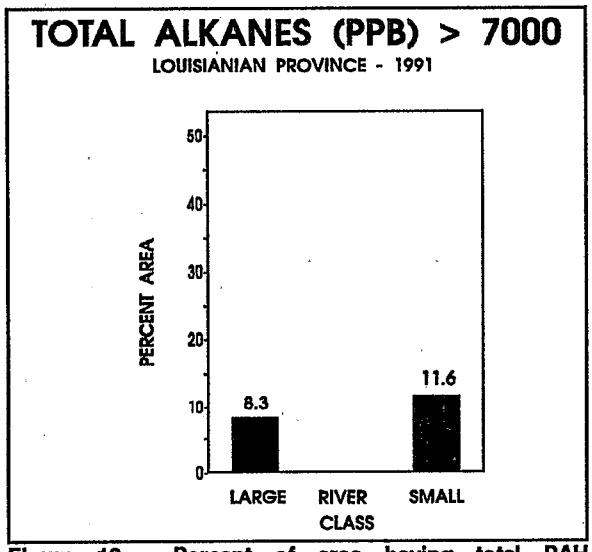

Figure 12. Percent of area having total PAH concentrations in sediment > 7000 ppb for large estuaries (large), small estuaries (small), and large tidal rivers (river).

Polycyclic chlorinated biphenyls (PCBs) represent a very toxic compound in the environment. Twenty-five individual PCB congeners were examined in the 1991 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. However, <1% of the Louisianian Province sediments were characterized by total PCB concentrations > 50 ppb. No elevated PCB concentrations were observed in either large estuaries or large tidal rivers. All elevated total PCB values were seen in small estuarine systems where 0.6% of the sediment exceeded the immediate PCB concentration.

Pesticides are introduced into the estuarine environment through three pathways: direct emission as a result of point source discharge (generally through manufacture or disposal), non-point emission through agricultural or horticultural application, and atmospheric through deposition of volatilized materials. In the 1991 Louisianian Province Demonstration, 25 pesticides and derivatives were examined.

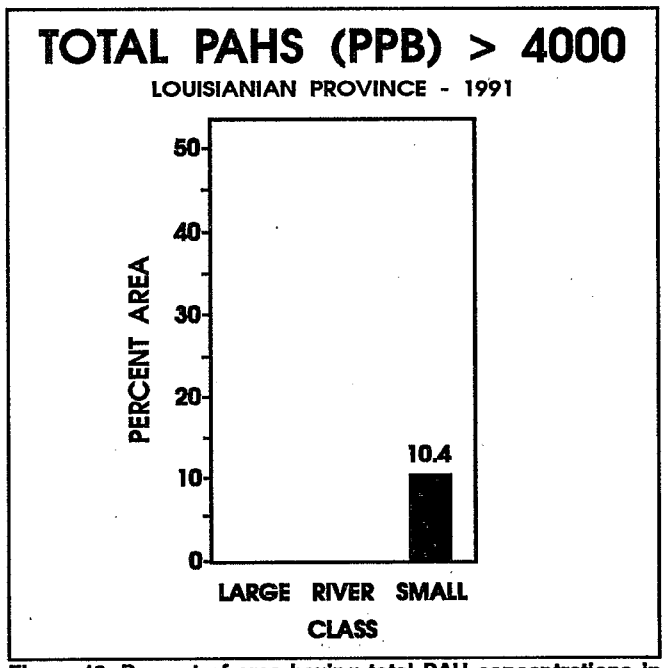

Figure 13. Percent of area having total PAH concentrations in sediment > 4000 ppb for large estuaries (large), small estuaries (small), and large tidal rivers (river).

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, 0.5 ppb, 0.02 ppb, and 0.02 ppb, respectively.

The DDT criteria value of 7 ppb was exceeded for < 1% of the sediments in the Louisianian Province. No sediments in large estuaries and < 1% of sediments in small estuaries exceeded this value but 10% of the sediments in the large tidal rivers showed elevated levels of DDT.

Total chlordane showed concentrations > 0.5 ppb in 2% of the sediments of the Louisianian Province with some individual sediment samples exceeding 5 ppb. Elevated chlordane concentrations were observed in all three estuarine classes (Fig. 14) with 50% of the sediments in large tidal rivers showing elevated concentrations; 2% in small estuaries and < 1% in large estuaries.

Total pesticides were evaluated by examining each individual pesticide and computing the number of sediment samples in which at least one criterion was exceeded. Based on this approach, 24% of Louisianian Province sediments exceeded at least one of these pesticide concentrations. There was wide variation among the three estuarine classes with 27% of large estuaries, 89% of large tidal rivers, and 16% of small estuaries being characterized by high pesticide concentrations. This exceedance was primarily related to high concentrations of DDT, dieldrin, and chlordane.

Tributyltin was measured at sediment concentrations > 1 ppb in 13% and 75 ppb in 4% 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 small estuaries (9% of sediments) and to a lesser extent in large estuarine sediments (2%) (Figure 15).

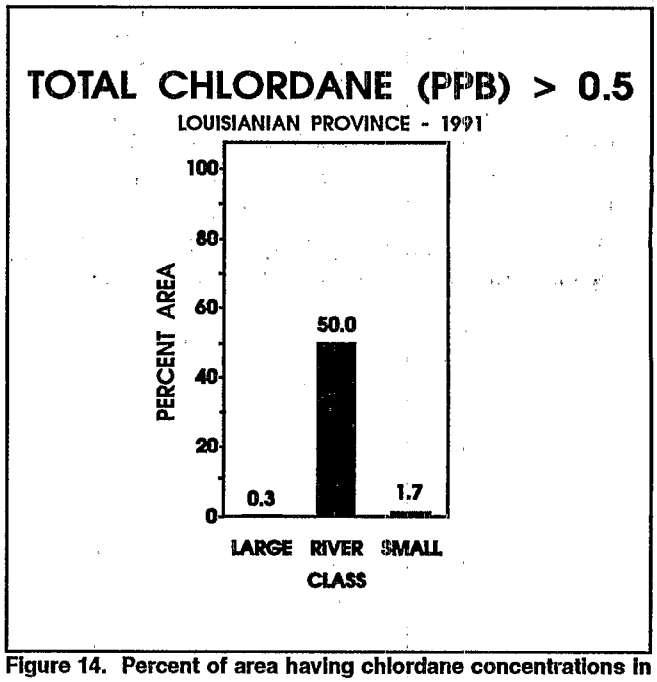

Figure 14. Percent of area having chlordane concentrations in sediments > 0.5 ppb for large estuaries (large), large tidal rivers (river), and small estuaries (small).

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.

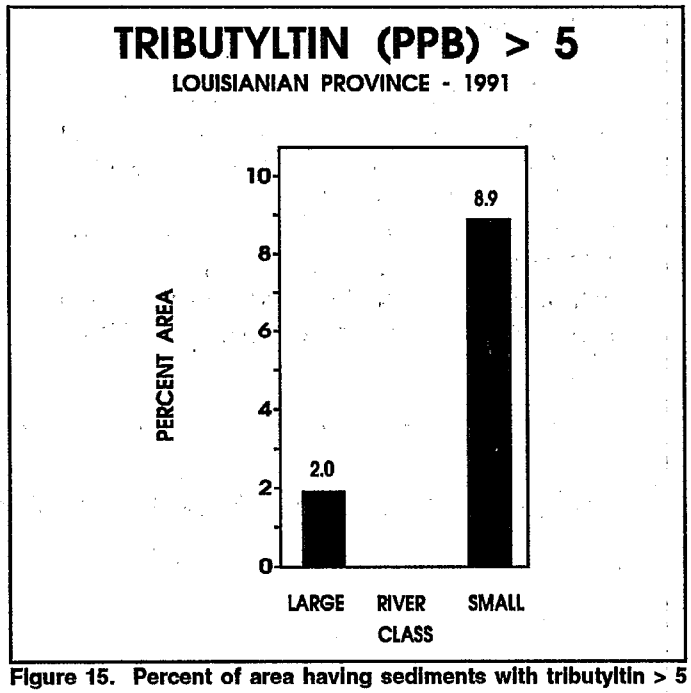

Figure 15. Percent of area having sediments with tributyltin > 5 ppb for large estuaries, large tidal rivers, and small estuaries.

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	101	48	10	43
Estuarine Condition	52(9)	38(11)	95(30)	55(20)
Estuarine Condition[1]	40(9)	28(10)	95(30)	44(18)
BIOTIC CONDITION				
Benthos Index	31(9)	27(10)	80(25)	41(20)
Abundance < 10	19(9)	19(9)	50(31)	36(20)
# Species < 2	4(4)	0(0)	60(30)	12(15)
# Species 5	28(10)	23(11)	80(25)	39(20)
Fish				
Abundance < 5	17(8)	17(10)	44(33)	16(13)
Abundance < 10	32(11)	33(13)	67(31)	29(18)
# Species ≤ 1	15(4)	17(3)	33(31)	11(10)
# Species ≤ 2	21(5)	23(5)	33(31)	17(12)
Fish Pathology[2]	< 1(0)	< 1(0)	< 1(0)	< 1(0)
Fish Contaminants[2]				
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)	0(0)	0(0)	1(2)
Others > FDA Limits	0(0)	0(0)	0(0)	0(0)
Bottom DO[3] < 2 ppm	6(5)	8(7)	0(0)	1(1)
Bottom DO3[3] < 5 ppm	15(8)	15(8)	10(16)	17(17)
Minimum DO < 2 ppm	12(1)	11(9)		16(14)
Sediment Toxicity	8(5)	6(5)	67(30)	14(10)

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[1] Estuarine condition without turbidity as an indicator
[2] Percentage based on sample size rather than estuarine area
[2] Instantaneous dissolved oxygen measurements

Table 5. 95% confidence intervals associated with the proportion of the Louisianian Province and estuarine classes experiencing the levels of the listed parameters.

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	**101**	**48**	**10**	**43**
ABIOTIC CONDITION				
Marine Debris	16(9)	13(9)	30(18)	28(13)
Water Clarity				
PAR < 10%	25(10)	21(9)	0(0)	41(16)
PAR < 25%	55(11)	50(14)	60(28)	68(17)
Silt-Clay Content				
< 20%	4(4)	4(5)	0(0)	3(4)
> 80%	66(10)	64(13)	80(25)	64(17)
Alkanes				
Total > 7000 ppb	11(7)	8(6)	0(0)	12(15)
PAHs				
Total > 1000 ppb	8(6)	0(0)	30(28)	24(20)
Total > 4000 ppb	3(4)	0(0)	0(0)	10(15)
PCBs				
Total > 200 ppb	0(0)	0(0)	0(0)	0(0)
Pesticides				
Chlordane > .5 ppb	2(2)	1(3)	50(31)	2(2)
Dieldrin > .2 ppb	21(9)	23(12)	80(35)	13(9)
Endrin > .02 ppb	1(1)	0(0)	0(0)	4(5)
DDT > 1 ppb	1(1)	0(0)	20(25)	0(0)
DDE > 2 ppb	2(3)	2(3)	10(18)	1(1)
DDD > 2 ppb	1(1)	0(0)	20(25)	0(0)
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	10(6)	11(8)	10(16)	2(1)
Cu > 70 ppm	0(0)	0(0)	0(0)	0(0)
Hg > .15 ppm	22(8)	24(12)	60(29)	1(1)
Ni > 30 ppm	16(7)	15(10)	30(28)	4(4)
Pb > 35 ppm	<1(0)	0(0)	10(16)	1(1)
Sb > 2 ppm	<1(0)	0(0)	10(16)	0(0)
Sn > 3 ppm	<1(0)	0(0)	0(0)	<1(0)
Zn > 120 ppm	6(5)	6(6)	10(16)	4(4)
Tributyltin				
TBT > 1 ppb	13(6)	12(7)	55(29)	16(12)
TBT 75 ppb	4(2)	2(1)	0(0)	9(7)

Table 5 *(cont.)* 95% confidence intervals associated with the proportion of the Louisianian Province and estuarine classes experiencing the levels of the listed parameters.

SECTION 1

INTRODUCTION

The Environmental Monitoring and Assessment Program (EMAP) is a national program initiated by EPA's Office of Research and Development (ORD). 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), the Bureau of Land Management (BLM), the U.S. Fish and Wildlife Service (FWS), the Forest Service (FS), the 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. 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 1991, EMAP-E initiated 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 1991 Demonstration Project by:

- providing preliminary estimates of the current status of Louisianian Province estuarine resources, and
- describing the methods used to develop these estimates.

1.1 OBJECTIVES OF THE 1991 LOUISIANIAN PROVINCE DEMONSTRATION

The specifics of the planning activities of the 1991 Louisianian Province Demonstration are documented in Summers et al. (1991). Specifics related to the conduct of the field sampling in 1991 can be found in Summers et al. (1992). In 1991, EMAP-E conducted the second in its series of in-field demonstrations. This 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 9 July through 30 August spanning 202 sites utilizing 30 field personnel and three program/logistical coordinators.

The objectives of the 1991 Louisianian Province Demonstration were to:

1) assess the condition of estuarine resources in the Louisianian Province using a probability-based sampling design
2) evaluate the ability of a selected suite of

ecological and environmental indicators to discriminate among polluted and unpolluted sites over a regional scale;

3) obtain data on Louisianian Province-specific variability in measured ecological parameters;

4) 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; and,

5) identify and resolve logistical problems associated with sampling estuarine resources in primarily shallow estuaries spanning over 1800 miles of coastline within a 4-6 week sampling period.

Objective #5 was discussed in the Louisianian Province Field Activities Report (Summers et al. 1992). Objectives #1 and #3 are discussed in this report. The remaining objectives (#2 and #4) are discussed in the Louisianian Demonstration Project Report (Summers et al. 1993).

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 submerged aquatic vegetation) 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 structural 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 have external gross pathologies in excess of 0.5%?
- What proportion of estuarine sediments in the Louisianian Province contain

anthropogenic marine debris?

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

- What proportion of estuarine waters in the Louisianian Province have unacceptable levels of 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 poor societal value conditions in the Louisianian Province associated with stressor conditions?

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

1.3 PURPOSE AND ORGANIZATION OF THIS REPORT

The purpose of this report is to report estimates of the ecological condition (and environmental exposures) for the estuarine resources of the Louisianian Province for 1991. In addition, information is provided on the methodologies used to develop these estimates. This report is meant to be a summarization of all the data collected in the 1991 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 4-5 years or in specialized documents such as the Demonstration Report for the Louisianian Province (Summers et al. 1992b). As a result, the Statistical Summaries will provide only overview information concerning sampling methodologies, field logistics, the development of indicators, and design modifications. Since this is the first EMAP-E Statistical Summary, additional or expanded sections have been included for certain areas to assist the reader in the understanding what EMAP-E has done. Also, to demonstrate the flexibility of the EMAP-E sampling design in the Louisianian Province, additional data presentations (i.e., across states) are provided, which may not be presented in other future EMAP-E Statistical Summaries.

This report is organized into sections

addressing the objectives of the 1991 Louisianian Province Demonstration.

Section 2 provides information about the results of the 1991 Demonstration with details of the regional ecological "report card" for the estuaries of the Gulf of Mexico.

Section 3 describes the quality assurance/quality control procedures and results of the 1991 Demonstration, particularly with regard to the dissolved oxygen measurements, sediment contaminant analyses, biotic index construction, and information management.

Section 4 summarizes the conclusions that can be drawn from the 1991 Demonstration in the Louisianian Province as they relate to the stated objectives.

Section 5 lists the literature cited in this report.

Appendix A provides a detailed description of the Louisianian Province statistical design, indicators, and methods.

Appendix B 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.

Appendix C describes the estimation of incremental cancer risk factors associated with fish and shellfish tissue contaminant concentrations.

SECTION 2

STATISTICAL SUMMARY

The EMAP indicator strategy in 1991 includes four types of ecological indicators (Hunsacker and Carpenter 1990): response, exposure, habitat, and stressor. In this section, the statistical results of the 1991 Louisianian Province Demonstration are described for each indicator with each discussion categorized by major indicator type. No stressor indicator information was collected in 1991 as a part of the demonstration. 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

As previously described, 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; Karr et al. 1986). 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 1991 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, number of fish species, abundance of finfish, fish community composition, target species abundances, fish lengths, a fish index of condition, and contaminants in fish (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 by grab ranging from 0 to nearly 90 species (Fig. 2-1). There are no significant differences among the replicates suggesting that, at least for population estimates of species distribution, a single replicate is acceptable. This lack of differences was also supported by

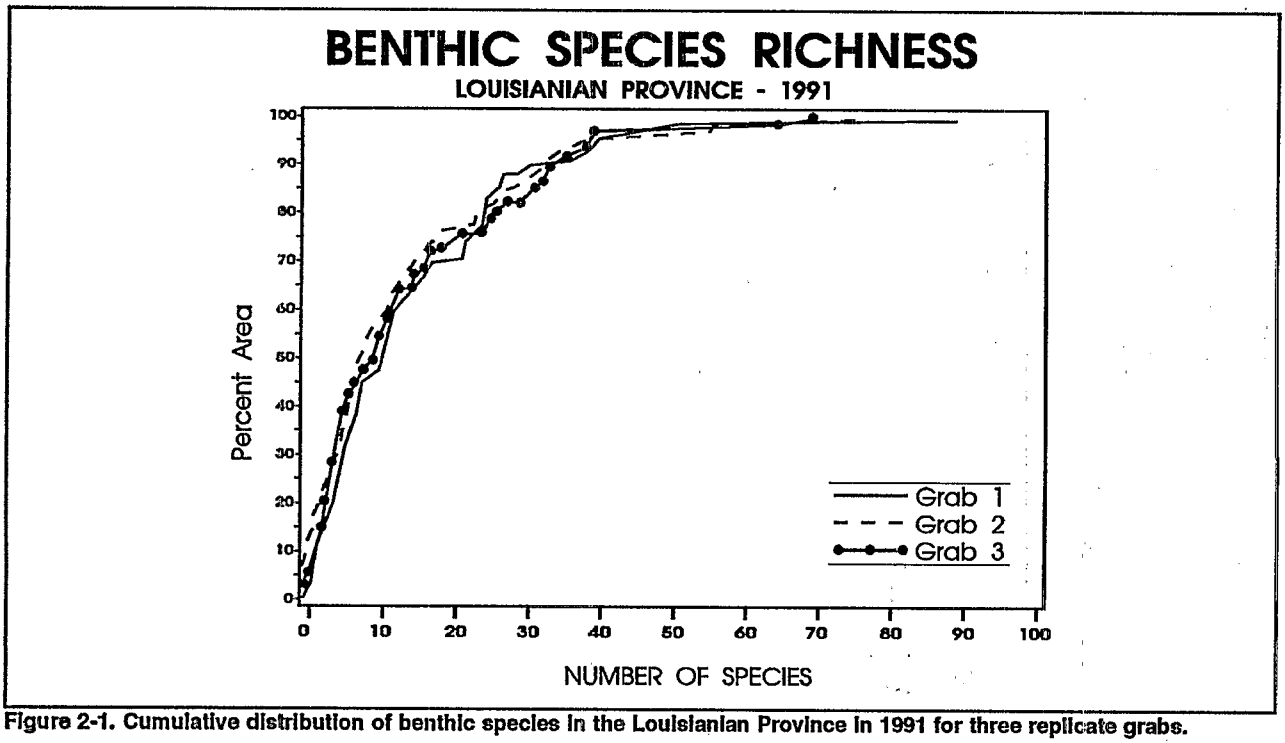


Figure 2-1. Cumulative distribution of benthic species in the Louisianian Province in 1991 for three replicate grabs.

comparison of Monte Carlo results based on randomly selected Grab numbers to construct 500 CDFs. However, species area curves of these data do suggest that considerable diversity is gained by collecting the replicates (Fig. 2-2). While each grab appears to sample roughly the same number of species, they do not sample the same species. Mean species richness in the Louisianian Province is shown in Figure 2-3. Arbitrarily selecting 2 and 5 species as critical values for "diverse" benthic communities results in 3.6% of the sediments in the province having near mono-specific stands of benthos, while 28% of the sediments have communities comprised of 5 or fewer species (Fig. 2-4). These reduced areas of benthic species are primarily located in the large tidal river class and to a lesser extent in small estuaries (Fig. 2-5). Benthic diversity associated with the three grabs varies widely over the province (Fig. 2-6) with 4% of the province having a benthic diversity of < 0.2 and 22% less than 0.4 (Fig. 2-7).

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. Benthic abundance in the three replicates ranged from 0 to over 1200 organisms per grab (Fig. 2-8) with no relative diffrence among the replicates. Mean benthic abundance (Fig.2-9) shows a range in benthic abundance in the Louisianian Province of 0 to about 900 organisms per grab or over 20,000 organisms/m^2. Using 10 organism/grab (about 200/m^2) and 25/grab (about 500/m^2) as indicators of poor

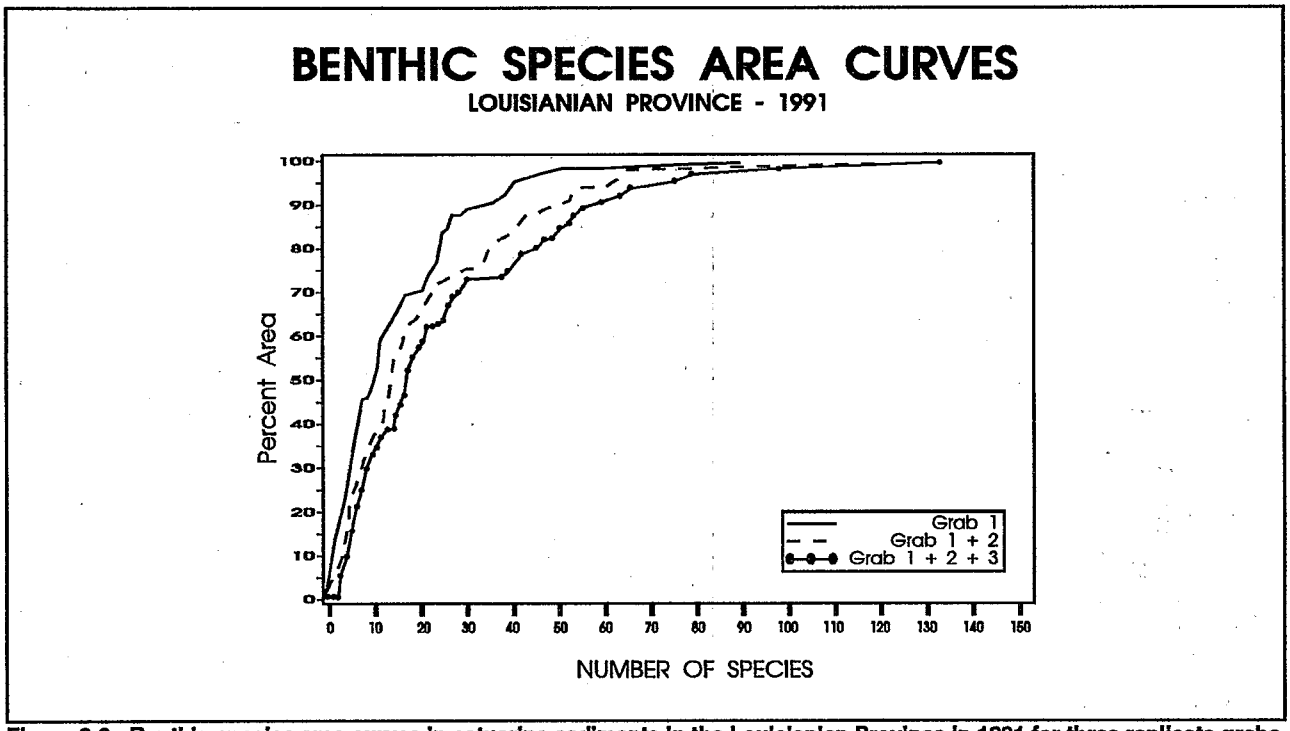


Figure 2-2. Benthic species area curves in estuarine sediments in the Louisianian Province in 1991 for three replicate grabs.

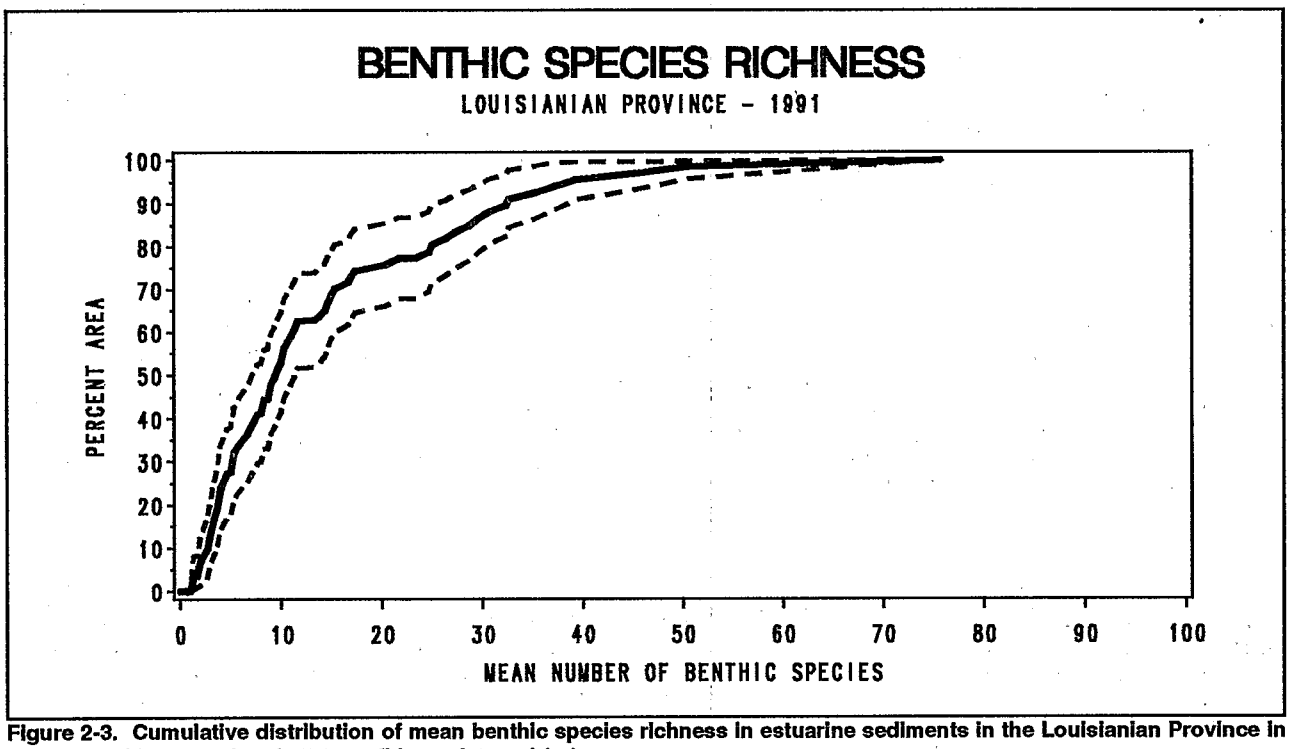


Figure 2-3. Cumulative distribution of mean benthic species richness in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

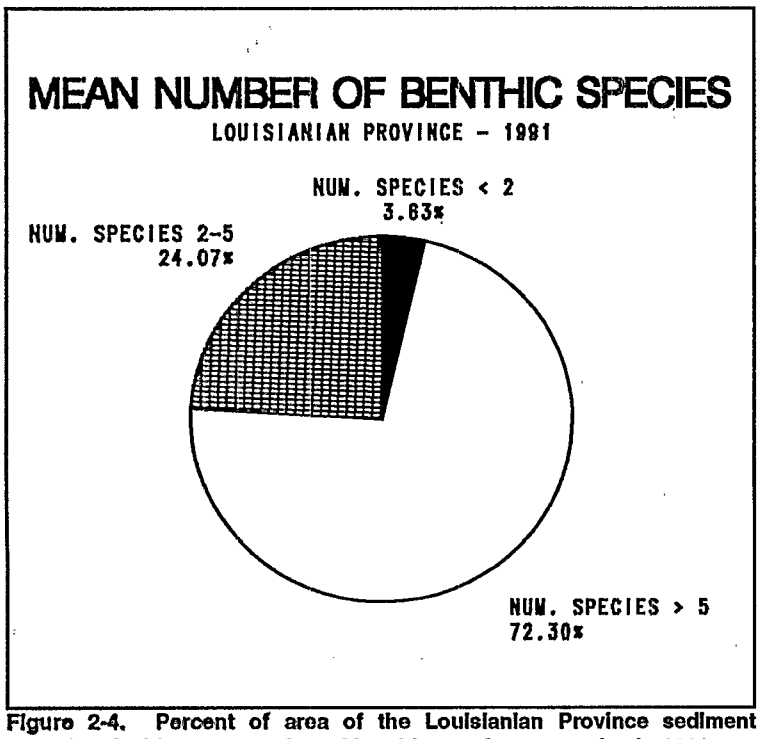


Figure 2-4. Percent of area of the Louisianian Province sediment associated with mean number of benthic species categories in 1991.

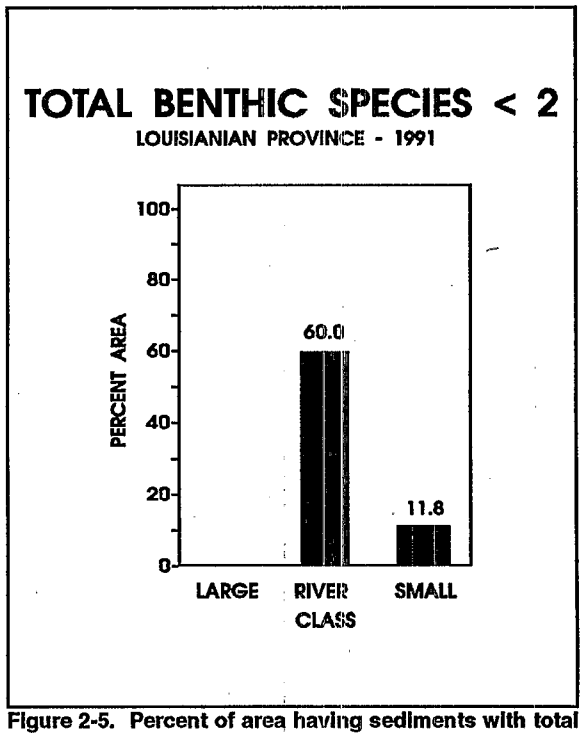


Figure 2-5. Percent of area having sediments with total benthic species < 2 for large estuaries, large tidal rivers, and small estuaries.

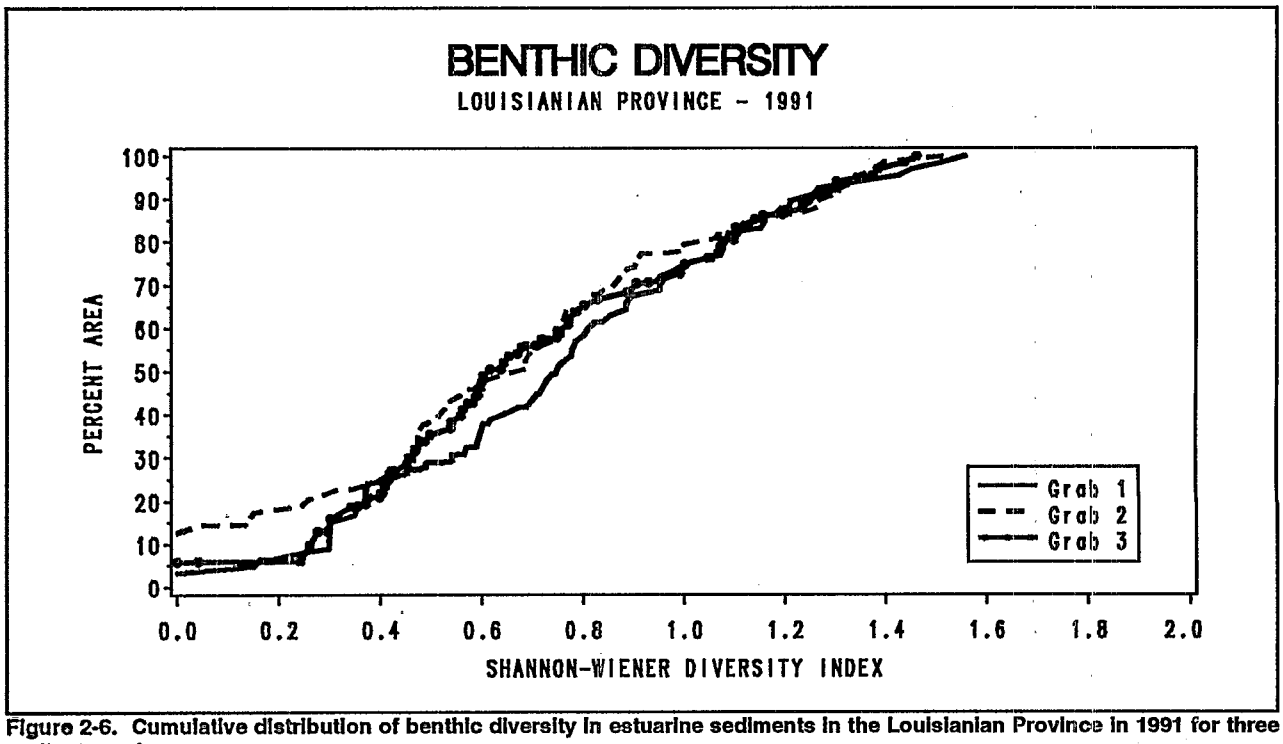


Figure 2-6. Cumulative distribution of benthic diversity in estuarine sediments in the Louisianian Province in 1991 for three replicate grabs.

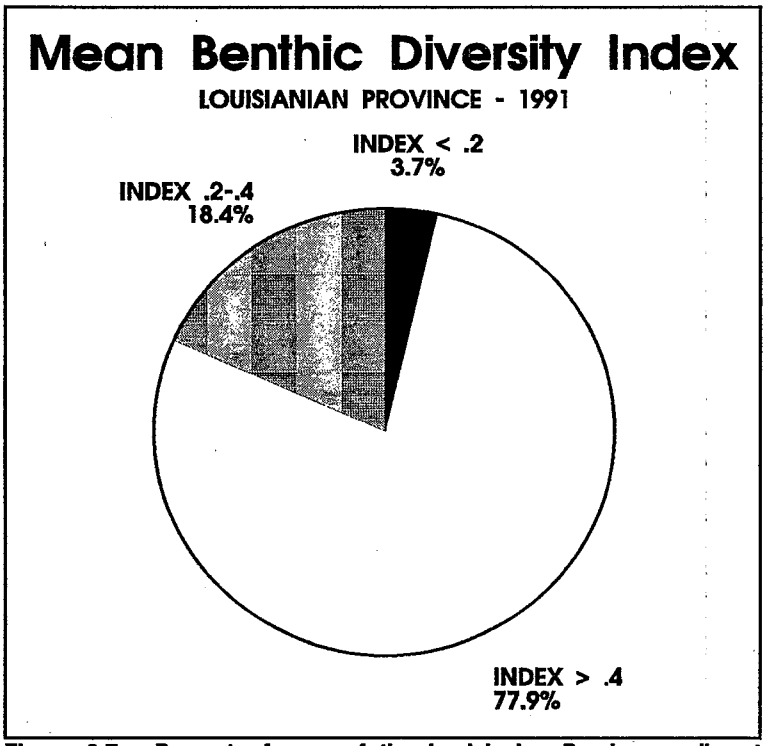


Figure 2-7. Percent of area of the Louisianian Province sediment associated with mean benthic species diversity categories in 1991.

condition and marginal condition, respectively, 19% of Lousianian Province sediments have poor benthic abundance and an additional 11% have marginal abundance (Fig. 2-10). These areas of low abundance are primarily associated with small estuaries and large tidal rivers where 36% and 50%, respectively, of the sediments have benthic abundances < 10 (Fig. 2-11).

2.1.3 BENTHIC ABUNDANCE BY TAXA

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).

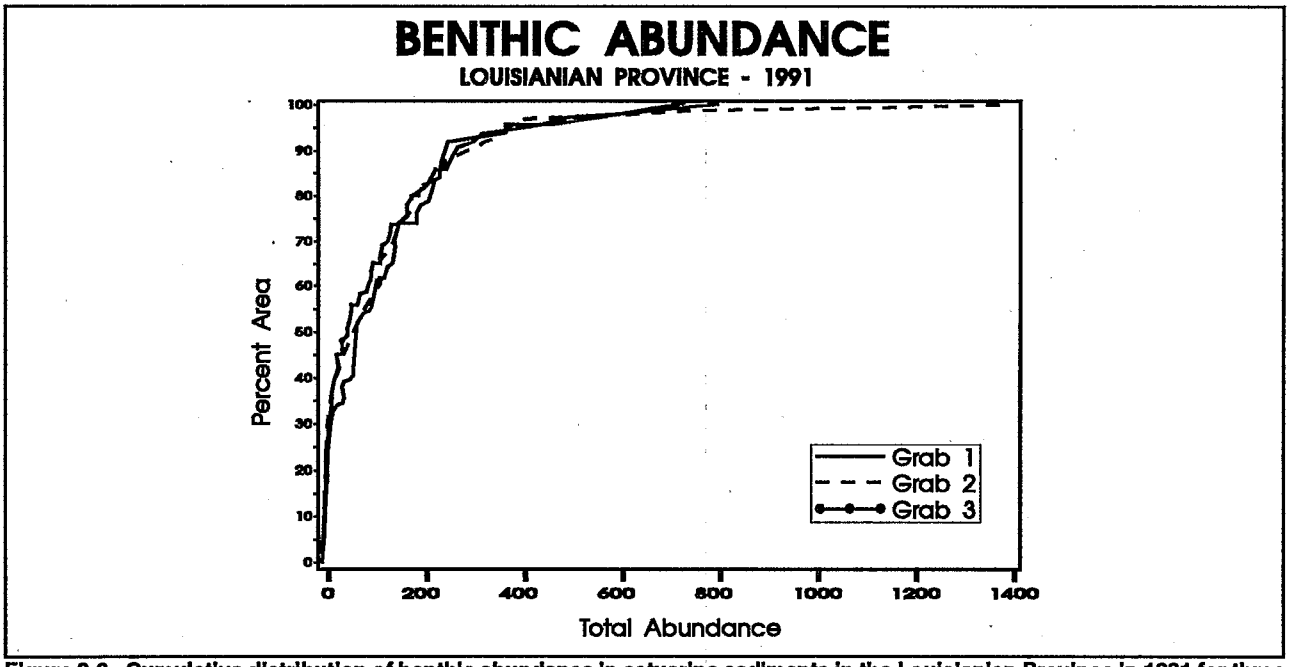


Figure 2-8. Cumulative distribution of benthic abundance in estuarine sediments in the Louisianian Province in 1991 for three replicate grabs.

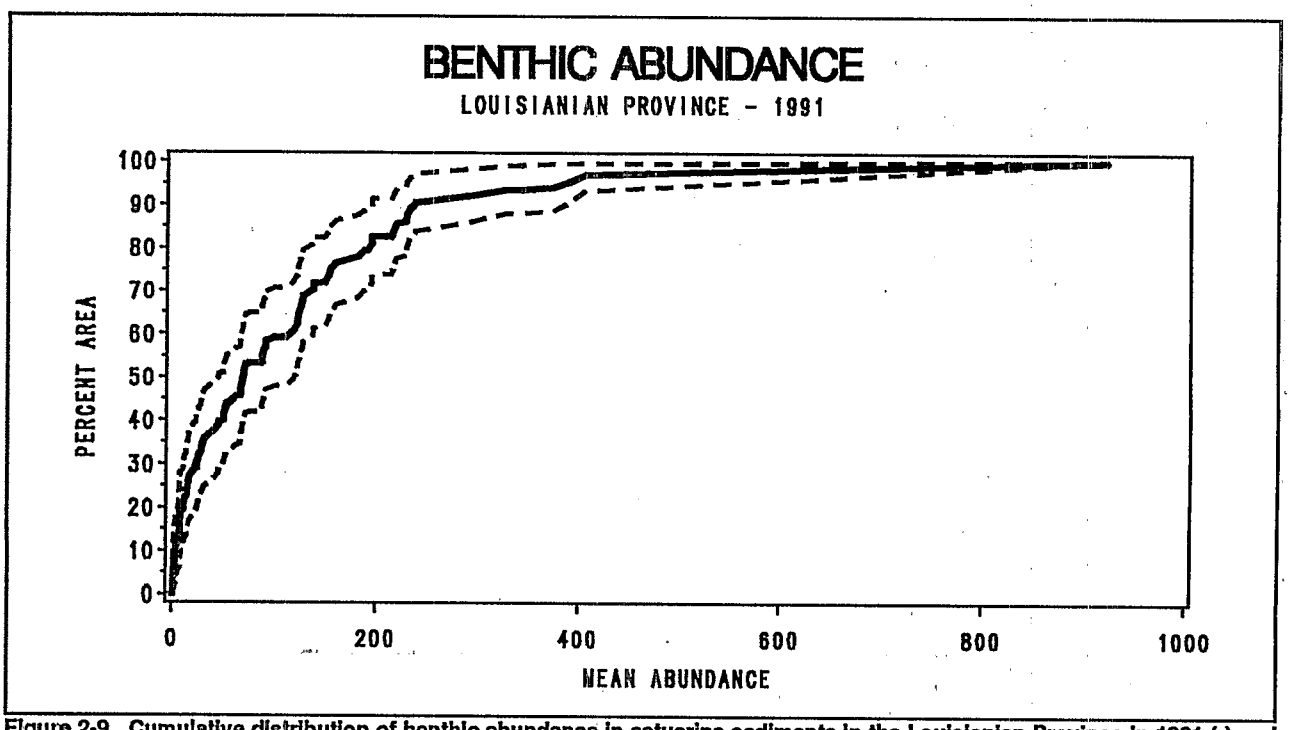


Figure 2-9. Cumulative distribution of benthic abundance in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

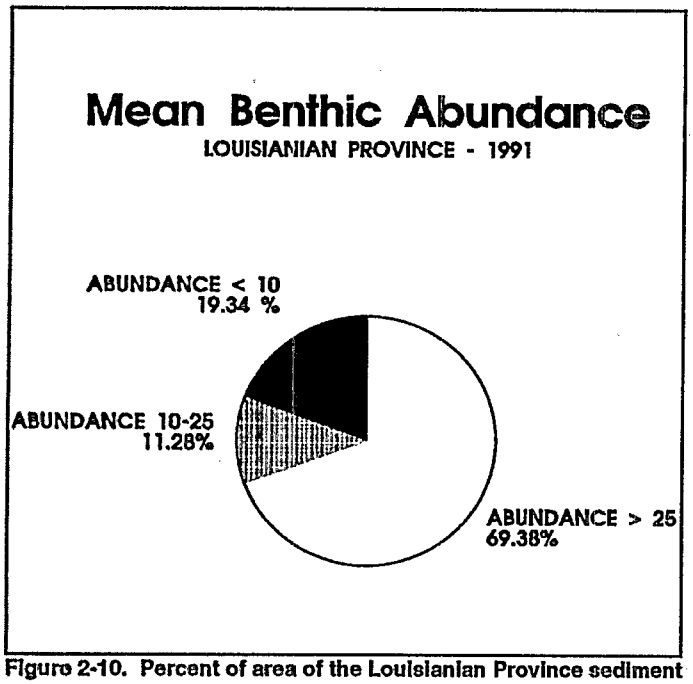


Figure 2-10. Percent of area of the Louisianian Province sediment associated with mean benthic abundance categories in 1991.

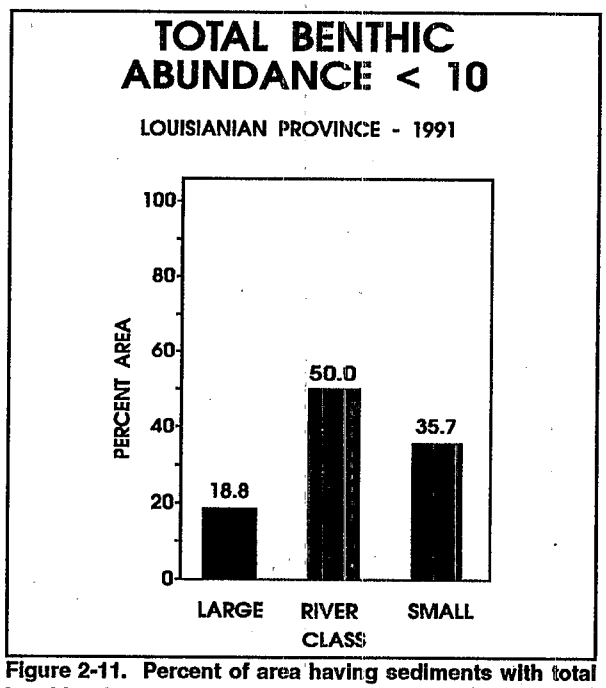


Figure 2-11. Percent of area having sediments with total benthic abundance < 10 for large estuaries, large tidal rivers, and small estuaries.

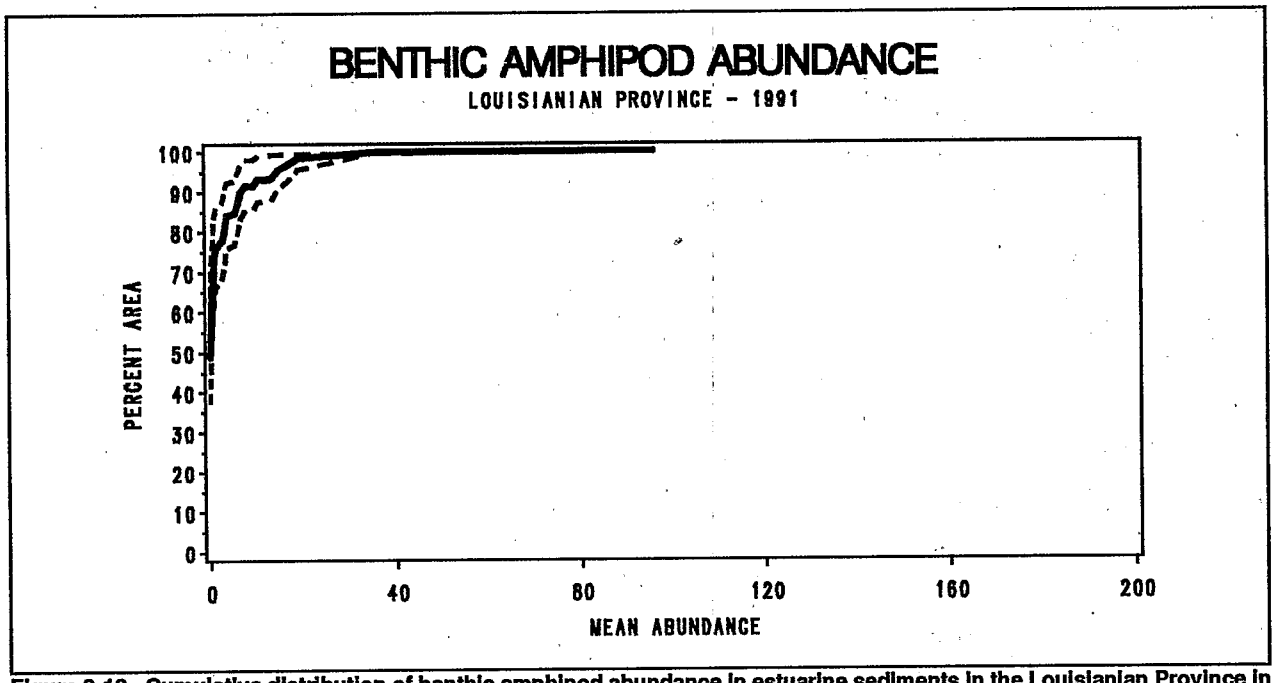


Figure 2-12. Cumulative distribution of benthic amphipod abundance in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (----).

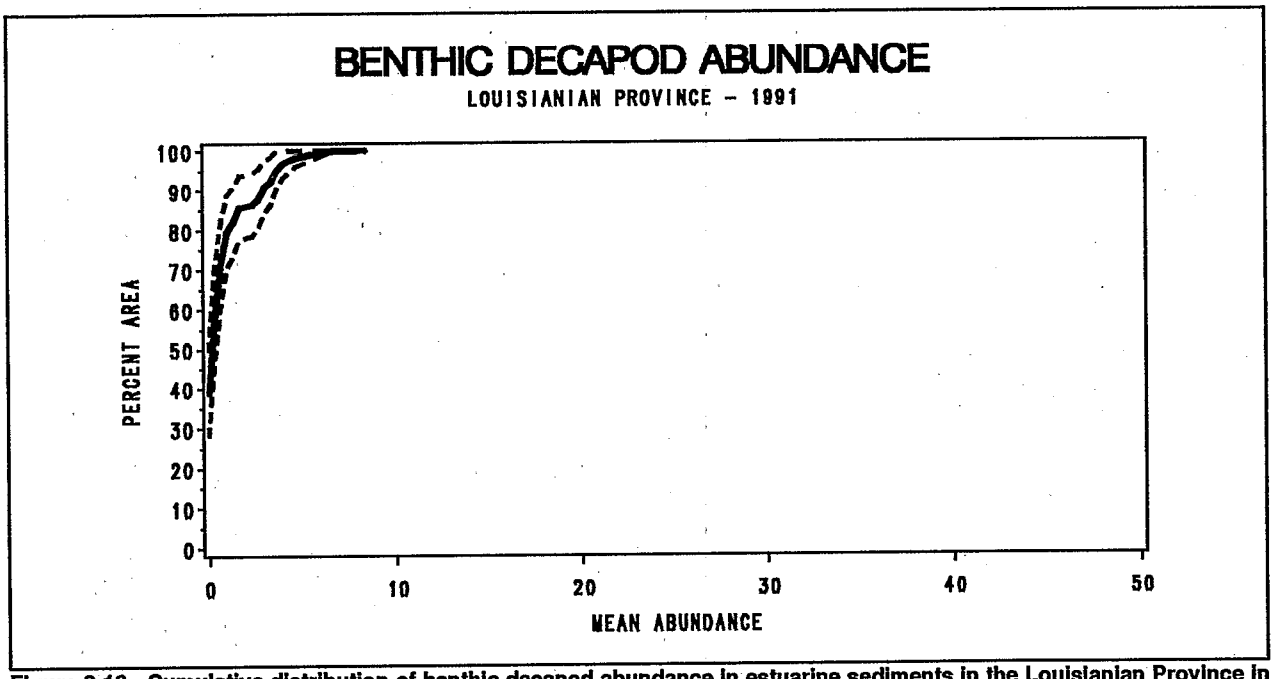


Figure 2-13. Cumulative distribution of benthic decapod abundance in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

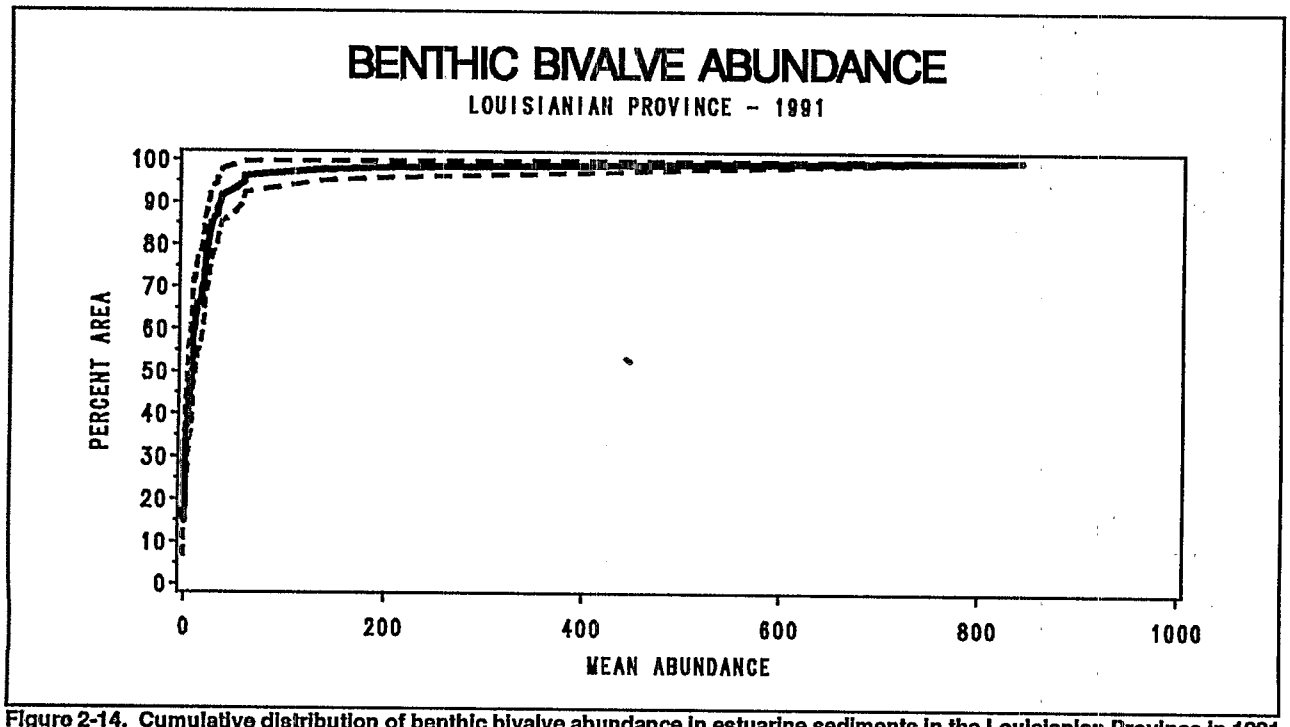


Figure 2-14. Cumulative distribution of benthic bivalve abundance in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

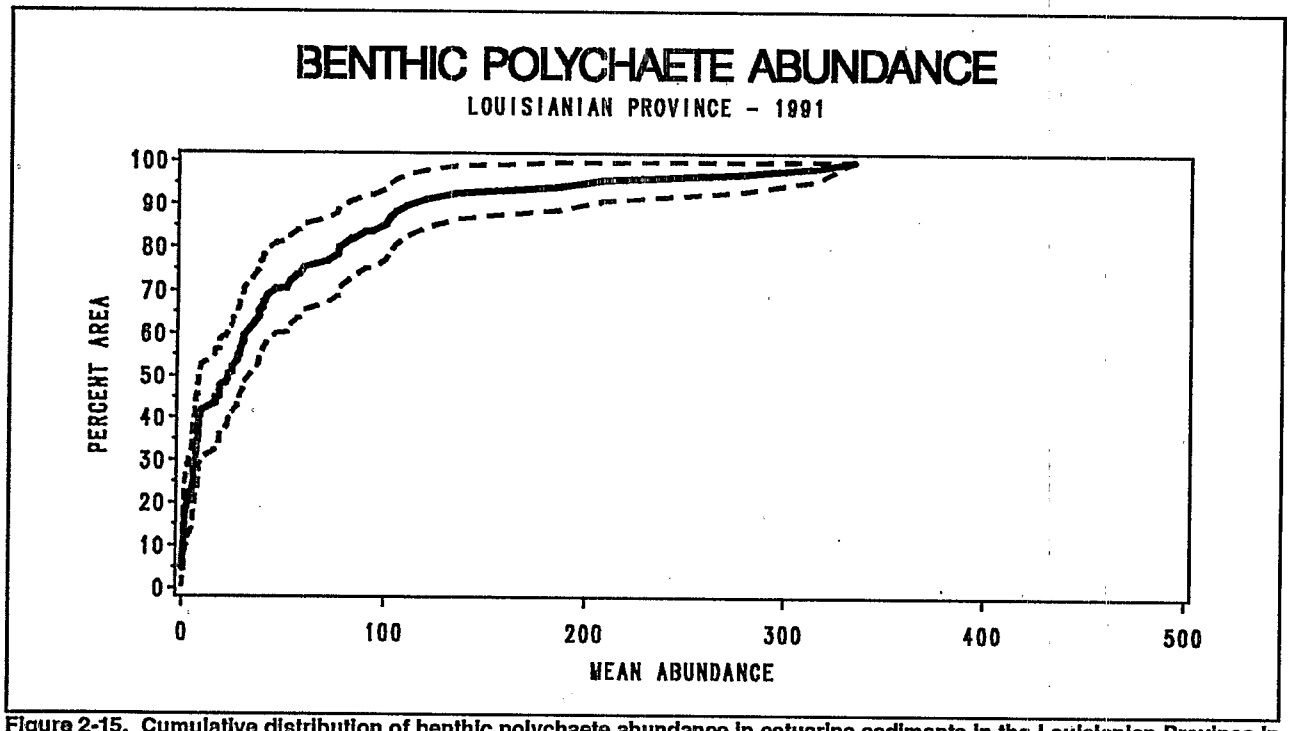


Figure 2-15. Cumulative distribution of benthic polychaete abundance in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

Over 50% of the sediments sampled in the 1991 Louisianian Province Demonstration did not have amphipods as part of the community (Fig. 2-12) while 40% did have decapods. Bivalves and polychaetes were represented in 85-95% of the sediments sampled (Figs. 2-14 and 2-15).

2.1.4 BENTHIC INDEX

The construction of the benthic index is described in Summers et al. (1993) and Engle and Summers (1993). The discriminant model that was developed uses proportion of expected species diversity and proportion of indicator species to differentiate between the a priori selected reference and affected sites according to the relationship:

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

The normalized discriminant scores for the Louisianian Province in 1991 ranged from 0 to 10.8 (Fig. 2-16) . The break point between degraded and undegraded sites was based on the subset of stressed (high sediment contaminants and toxicity and hypoxia) and reference (low sediment contaminants and toxicity and high dissolved oxygen) at 4.1 (Engle and Summers, 1993). About 30% of the sediments in the Louisianian Province contained benthic communities with community structures similar to those observed in heavily stressed environments (Fig. 2-17). The highest proportion of these communities occurring in large tidal rivers (80%) and small estuaries (41%) (Fig. 2-18). However, due to the disparate sizes of the three classes, the large estuaries contain 5000 km^2 of degraded benthos while the small and tidal rivers combined contain 3100 km^2 of poor benthos.

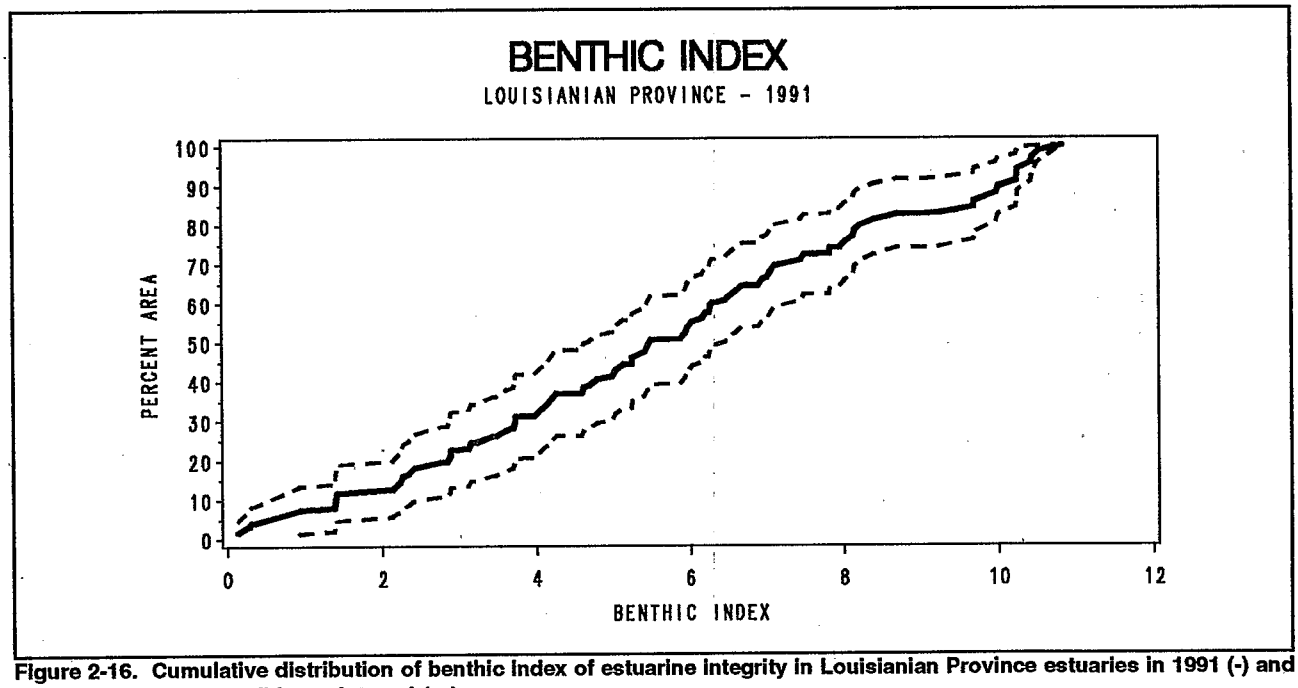


Figure 2-16. Cumulative distribution of benthic index of estuarine integrity in Louisianian Province estuaries in 1991 (-) and its associated 95% confidence interval (---).

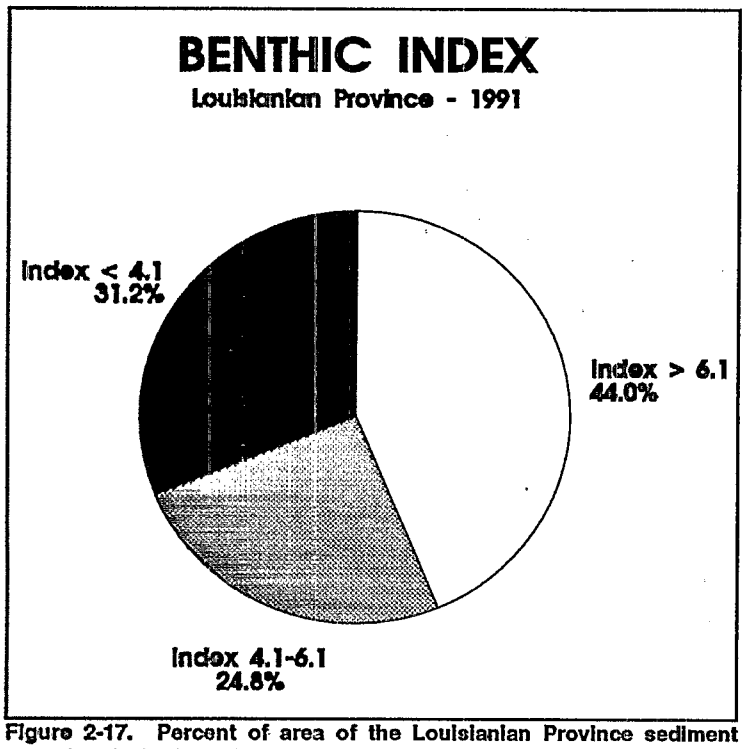


Figure 2-17. Percent of area of the Louisianian Province sediment associated with benthic index categories in 1991.

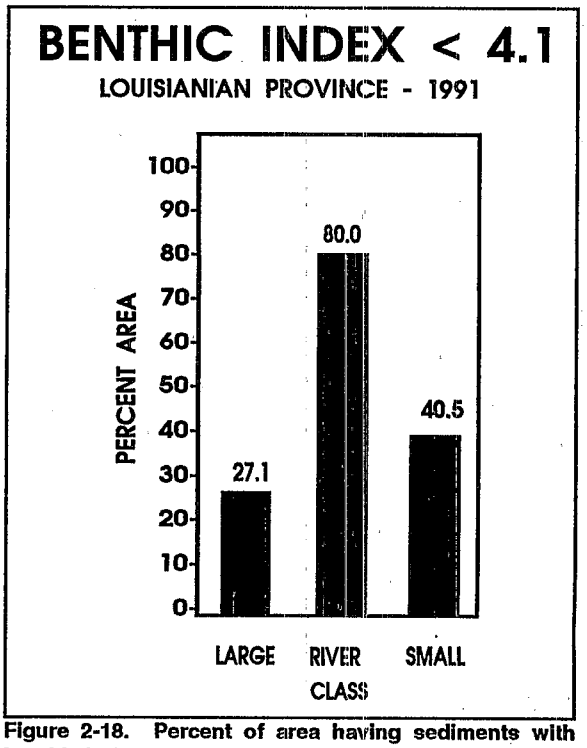


Figure 2-18. Percent of area having sediments with benthic index < 4.1 for large estuaries, large tidal rivers, and small estuaries.

2.1.5 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 location in the Louisianian Province, resulted in a distribution of total number of nekton species per trawl ranging from 0 to 15 species (Fig. 2-19), resulting in 101 species collected throughout the province. If fewer than 5 fish were collected in the trawl, a second trawl was collected. Arbitrarily selecting 0 and 1 species as values for "diverse" fish communities results in 3.5% of the province having no fish taken in multiple trawls, while 15% of the province had nekton communities comprised of 1 or less species (Fig. 2-20). Areas having minimal < 2 nekton species are primarily located in the large tidal river class and to a lesser extent in large estuaries (Fig. 2-21).

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 700 organisms per trawl (Fig. 2-22). Using 2 organisms/trawl and 5/trawl as indicators of poor condition and marginal condition, respectively, 7% of Lousianian Province waters have poor finfish abundances and an additional 14% have marginal abundance (Fig. 2-23). These areas of low abundance are

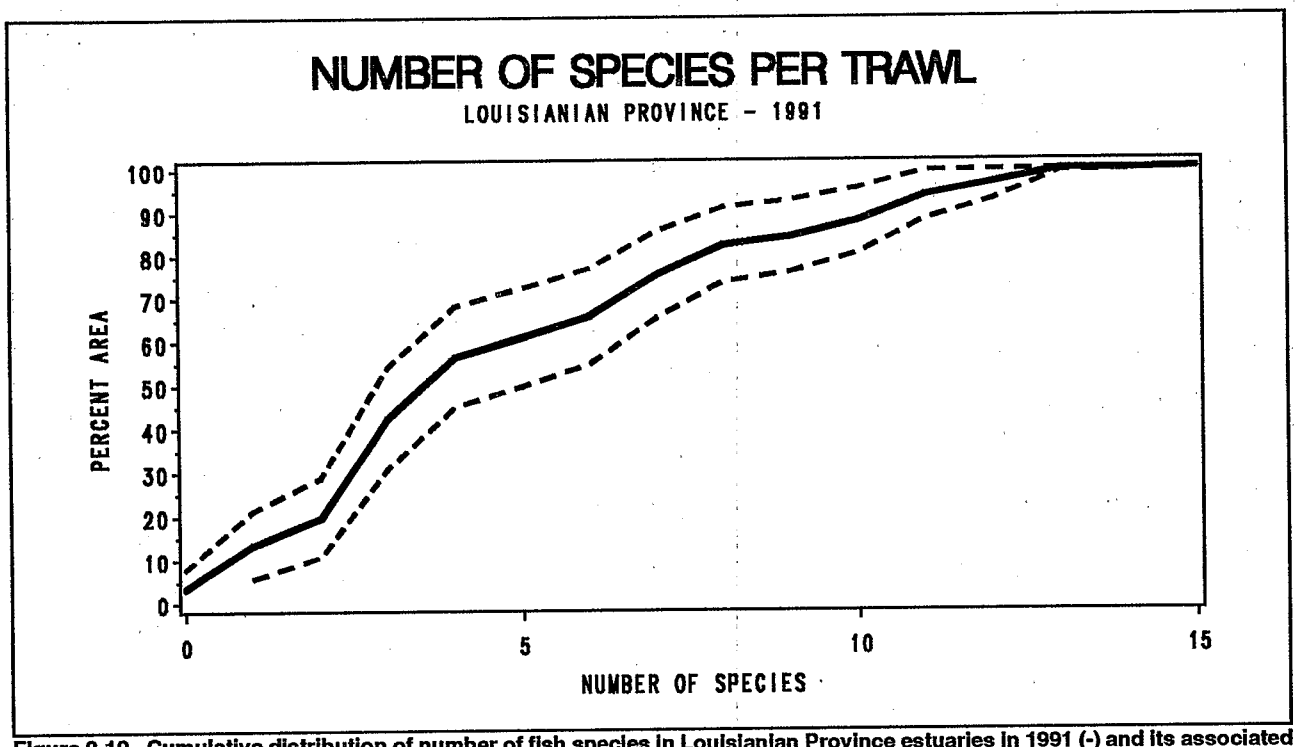


Figure 2-19. Cumulative distribution of number of fish species in Louisianian Province estuaries in 1991 (-) and its associated 95% confidence interval (---).

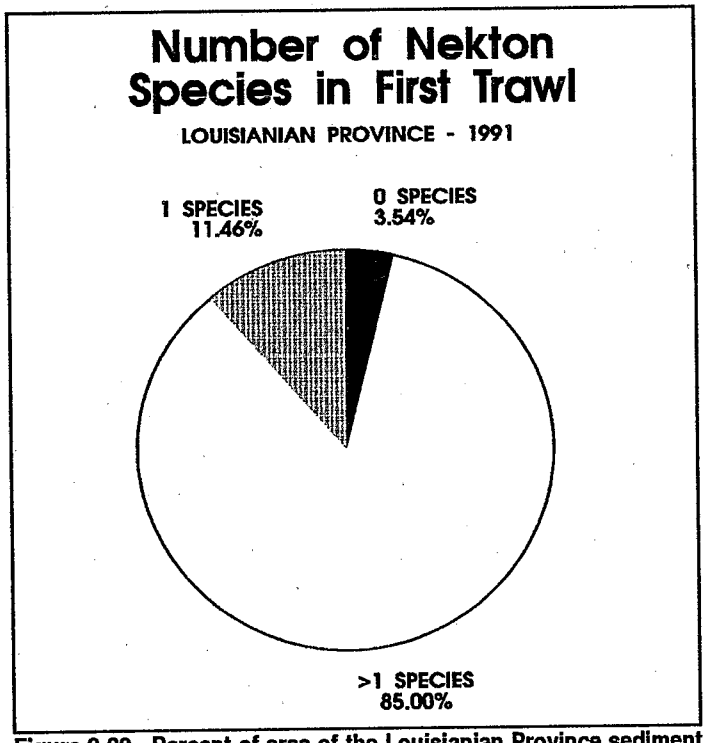


Figure 2-20. Percent of area of the Louisianian Province sediment associated with number of nekton species categories in 1991.

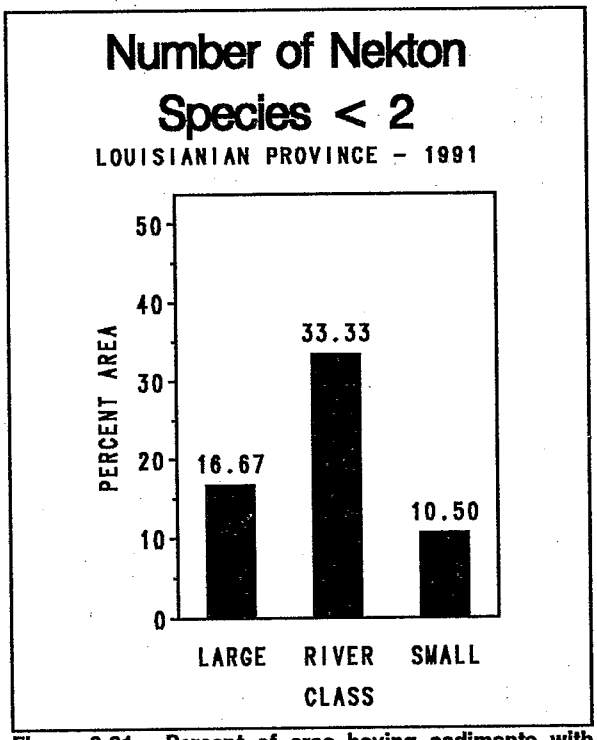


Figure 2-21. Percent of area having sediments with number of nekton species < 2 for large estuaries, large tidal rivers, and small estuaries.

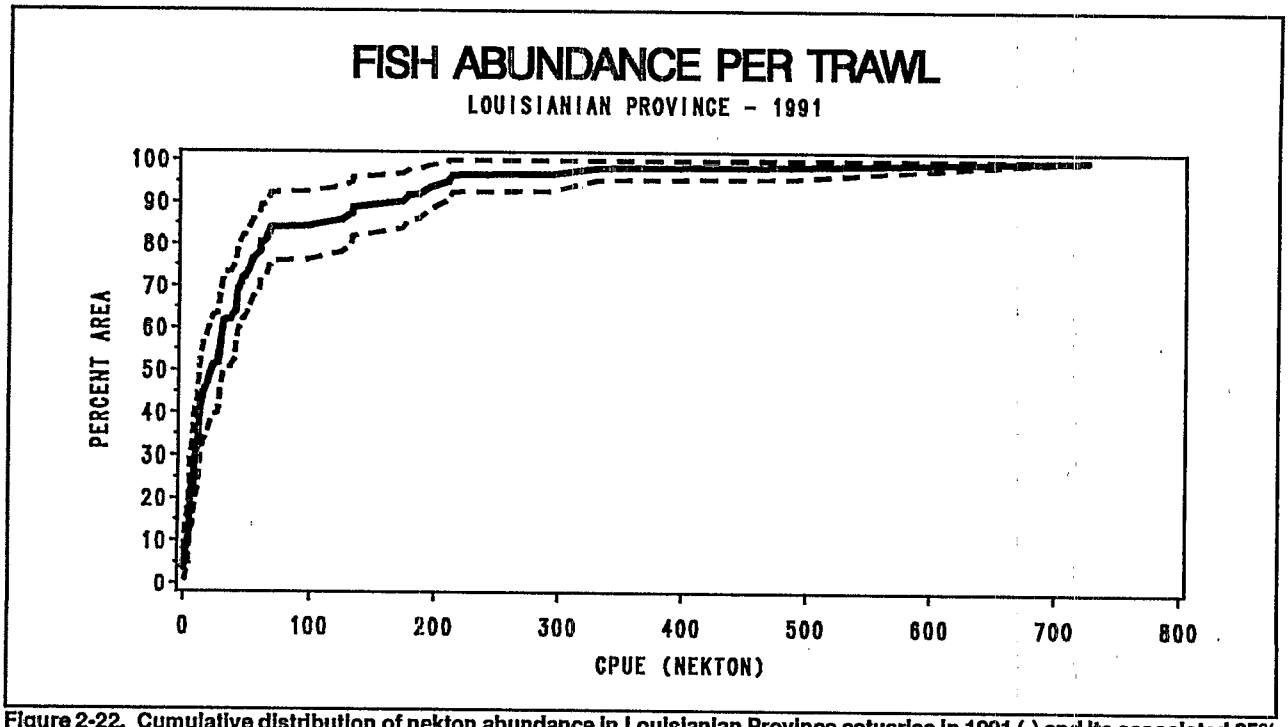


Figure 2-22. Cumulative distribution of nekton abundance in Louisianian Province estuaries in 1991 (-) and its associated 95% confidence interval (---).

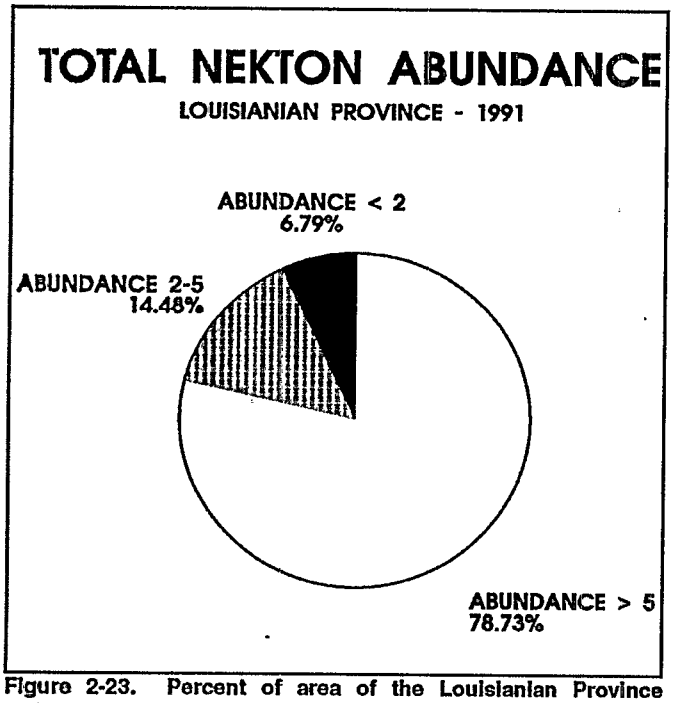


Figure 2-23. Percent of area of the Louisianian Province sediment associated with abundance of nekton categories in 1991.

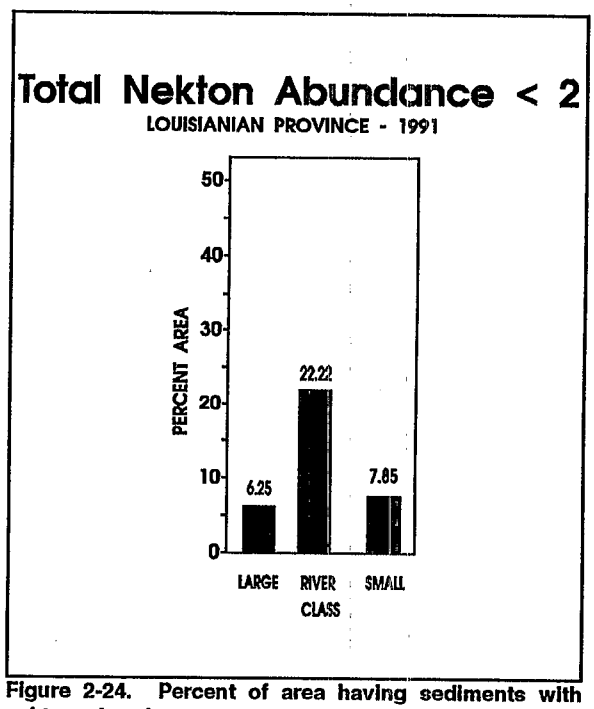


Figure 2-24. Percent of area having sediments with nekton abundance < 2 for large estuaries, large tidal rivers, and small estuaries.

primarily associated with large tidal rivers where 22% of the class waters have finfish abundances < 2 (Fig. 2-24).

2.1.7 GROSS PATHOLOGY

The frequency and type of 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 1991 Louisianian Province Demonstration were examined by the field crews for external gross pathologies, such as tumors and lesions. Over 8000 fish were examined for gross pathologies and a total of 52 external pathologies were noted. Less than 2% of the area of the Louisianian Province produced trawls with > 2 pathologies/trawl (Fig. 2-25). Overall in the province < 1% (6 fish in 1,000) of the fish examined had visible pathological disorders (Fig. 2-26). The prevalence of abnormalities for demersal and pelagic fish (0.7% and 0.8%, respectively) were about the same as the background level observed for all fish (0.6%). However, upper trophic level fish (e.g., piscivores) and commercial and recreational species demonstrated a significantly higher incidence of pathology (3.3% and 1.5%, respectively) (Fig. 2-26). Examples of upper trophic level fish are seatrouts, permits, and spadefish. Commercially and recreationally important species included seatrouts, Atlantic croaker, and permit.

The prevalence of visible pathologies differed somewhat among the three classes of estuarine resources but all demonstrated pathology rates of < 1% (Fig. 2-27). Only the incidence rate in small estuaries was significantly different from the background incidence (a < 0.10). Sand seatrout and threadfin shad had visible pathology rates that were clearly higher than the observed background while Atlantic croaker and sea catfish were somewhat higher. Although statistically significant from the background rate, the higher incidence of pathologies in permit, harvestfish, spottail pinfish,

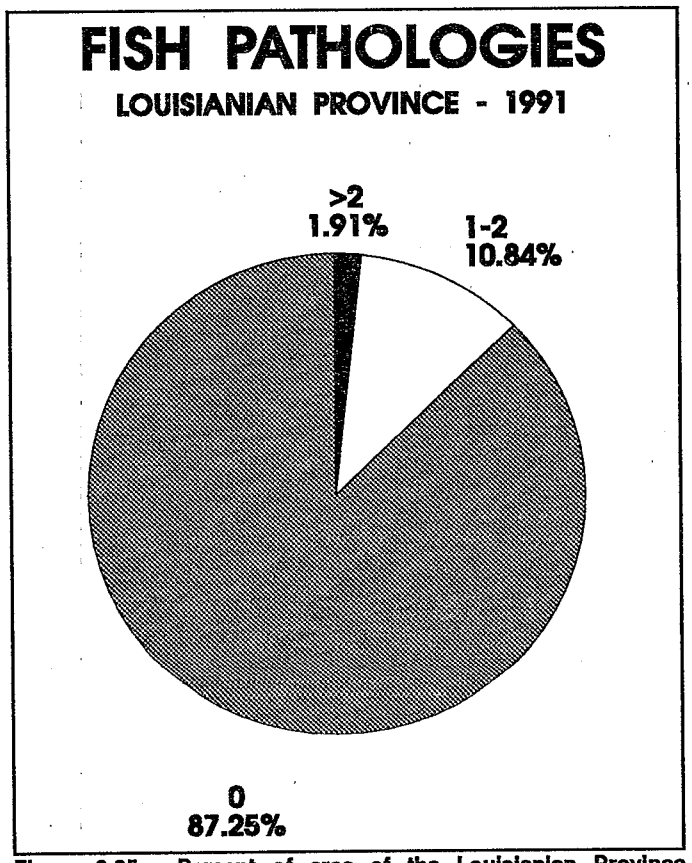


Figure 2-25. Percent of area of the Louisianian Province associated with the indicated numbers of fish pathologies/trawl in 1991.

spadefish, and yellowfin menhaden are not supportable due to the small number of individuals of these species examined (< 100 fish).

2.1.8 MARINE DEBRIS

The presence of marine debris is one of the obvious indicators of estuarine

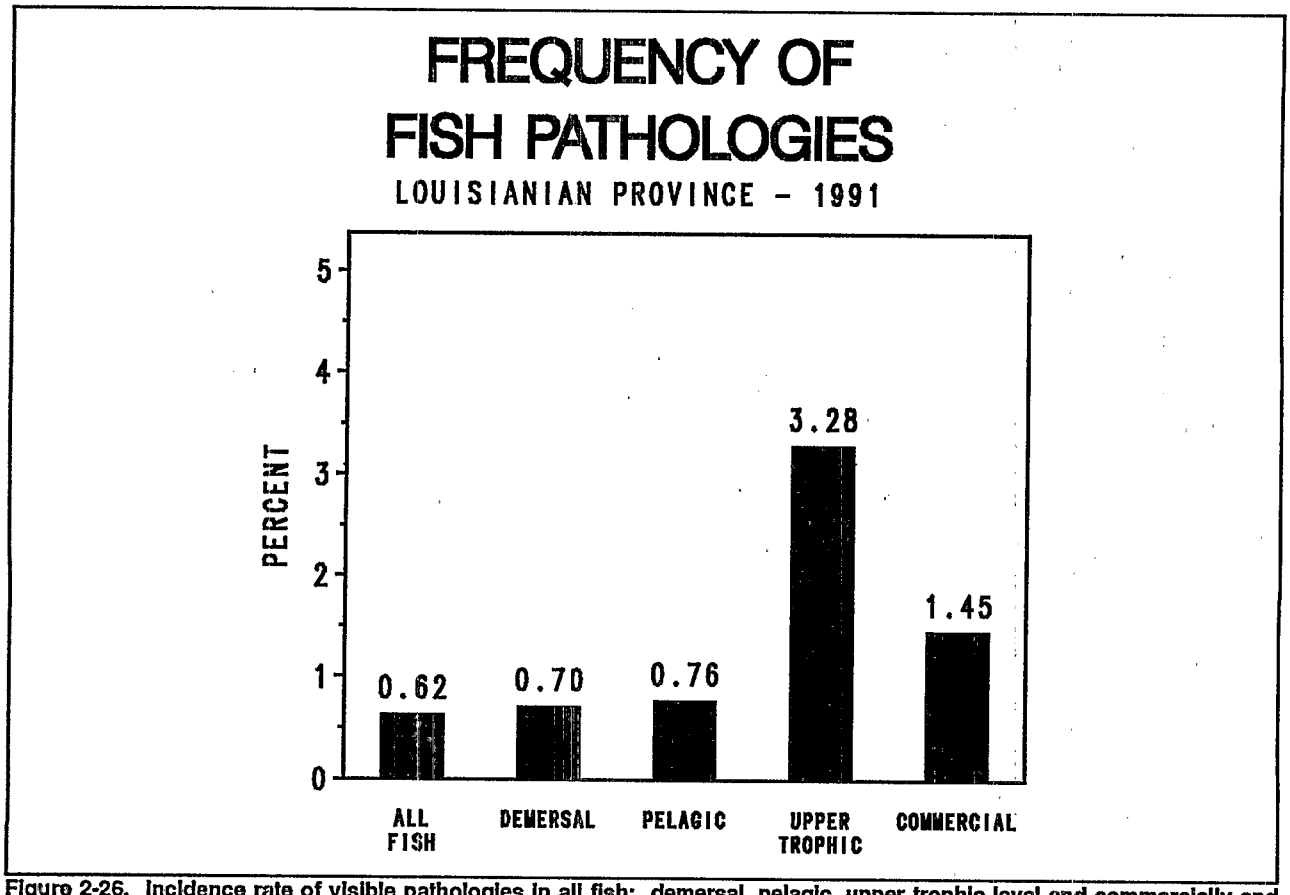


Figure 2-26. Incidence rate of visible pathologies in all fish: demersal, pelagic, upper trophic level and commercially and recreationally important fish observed in Louisianian Province.

"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. During the 1991 Louisianian Province Demonstration the presence of marine debris was noted under these circumstances and the type of the trash was determined (e.g., plastic, anthropogenic wood, metal, glass, etc.). Over 16% of the surface area of the Louisianian Province contained at least one item of marine debris. The estuarine classes with the largest proportion of sediment with marine debris were large tidal rivers with 30% coverage and small estuaries with 25% coverage. Large estuaries, because of their size, had over 2300 km^2 estimated with some trash (12.5%) (Fig. 2-28).

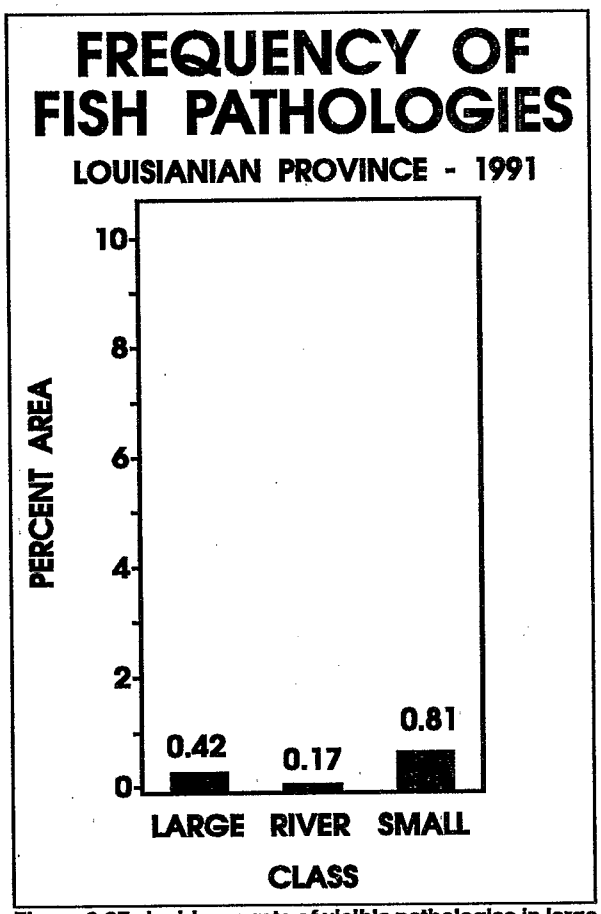


Figure 2-27. Incidence rate of visible pathologies in large estuaries, large tidal rivers, and small estuaries.

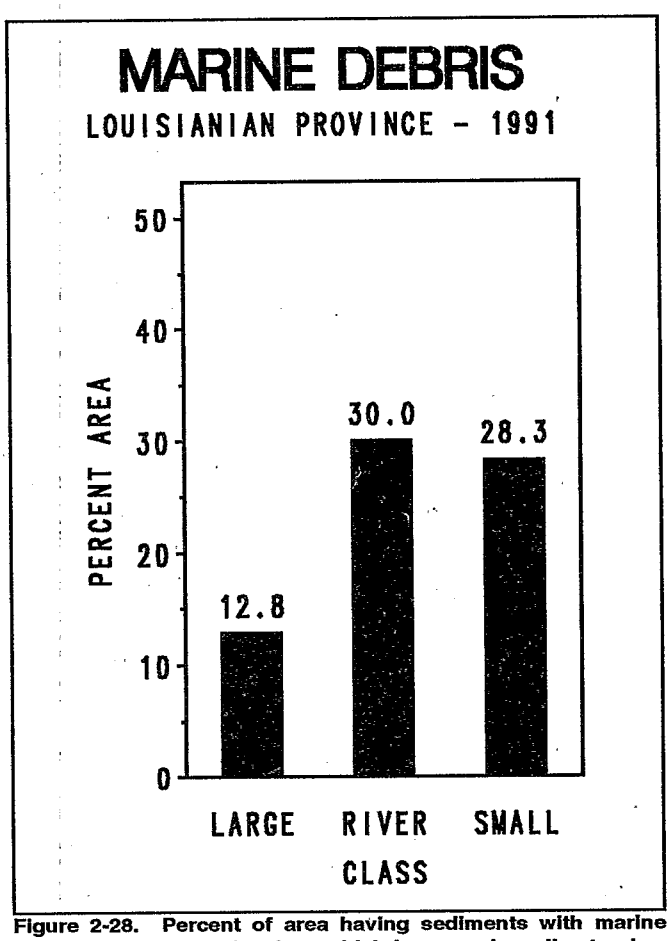


Figure 2-28. Percent of area having sediments with marine debris in large estuaries, large tidal rivers, and small estuaries.

2.1.9 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 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 0.0% to about 90% (Fig. 2-29). 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), 25% of the Louisianian Province experienced turbid water clarity (Fig. 2-30). Alternatively, using 25% transmittance as a measure of moderate clarity (cannot see your toes in waist deep water), resulted in 60% of the Louisianian Province had water clarity that could not pass this visual test. The poorest water clarity occurred in small estuaries with 41% permitting the transmittance of <10% of surface light to a depth of 1 m (Fig. 2-31).

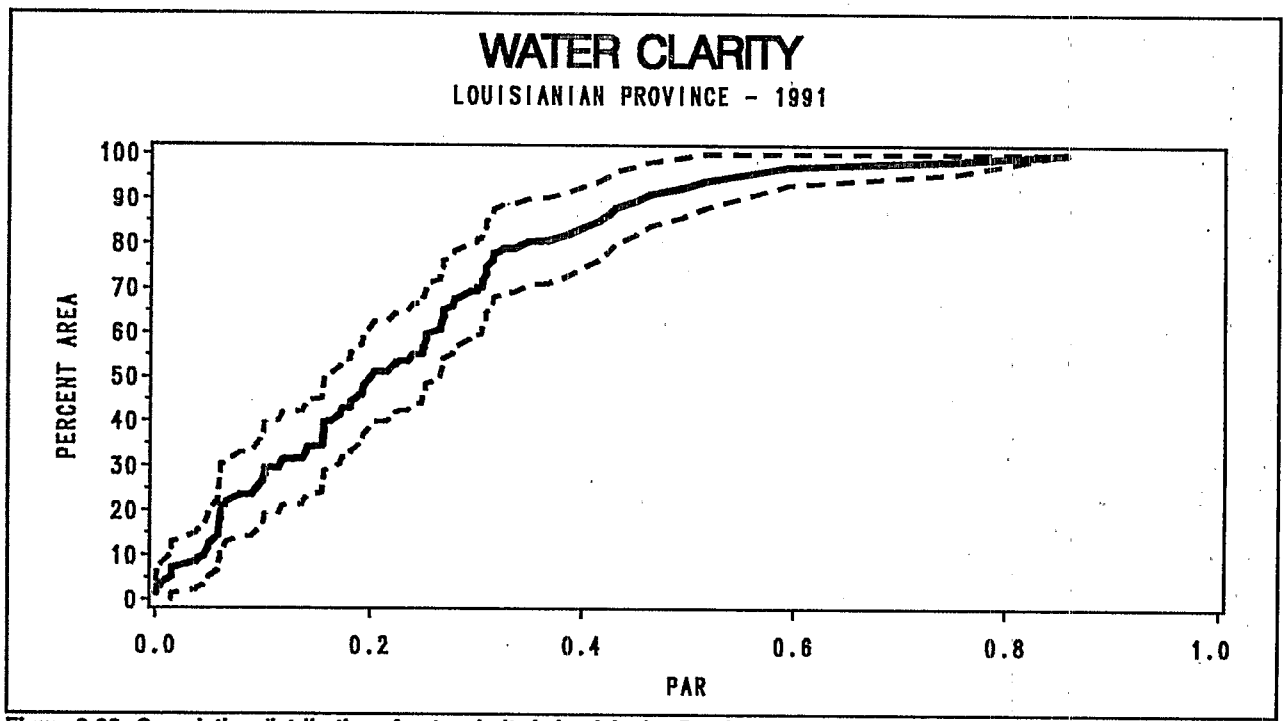


Figure 2-29. Cumulative distribution of water clarity in Louisianian Province estuaries in 1991 (-) its associated 95% confidence interval (---).

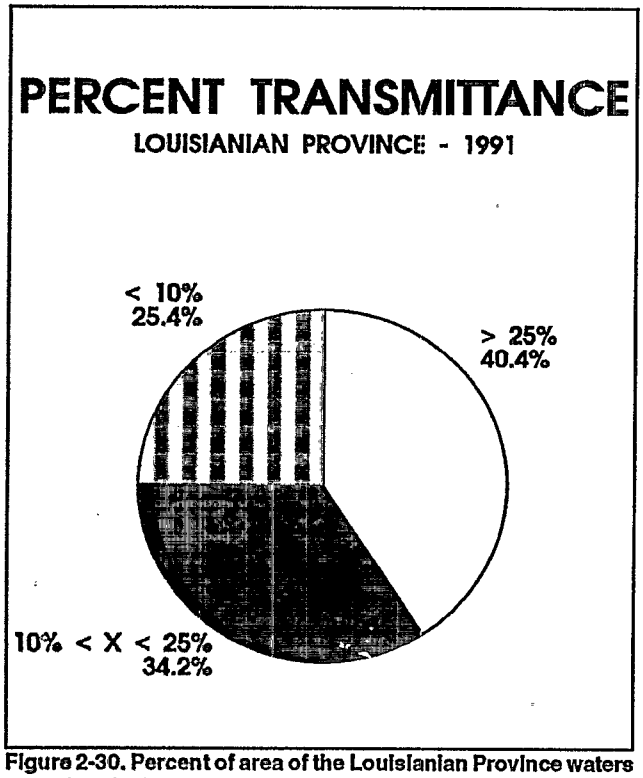


Figure 2-30. Percent of area of the Louisianian Province waters associated with water clarity categories.

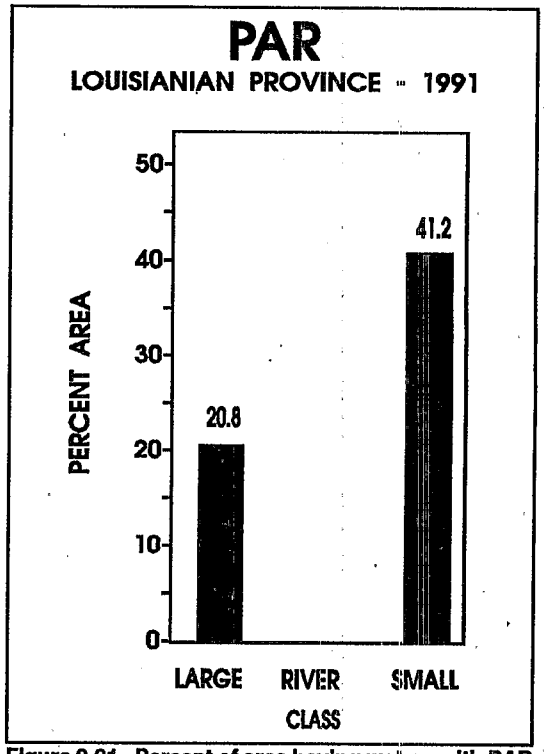


Figure 2-31. Percent of area having waters with PAR ratio < 10% for large estuaries, large tidal rivers, and small estuaries.

2.1.10 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 skin for Atlantic croaker, and as the fillet without skin for the catfish. All samples represented a composite of 4-10 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 American 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).

No pesticide or PCB concentrations exceeding the specified criteria were found in shrimp (Table 2-1). The highest concentration of a pesticide found was 296 ppb DDT (compared to the standard of 5000). However, 4% of the shrimp sampled contained greater than the criteria levels for arsenic while 4% exceeded the chromium standard. Arsenic levels observed in tissue probably reflect a non-toxic form of arsenic (arsenobetaine or arsenocholine) commonly seen in some seafood (Norin et al. 1983, Beauchemin et al. 1988, Siu et al. 1989).

No pesticide or PCB concentrations exceeding the specified FDA action limits

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-4.9	5000	0%
DDE	0-1.7	5000	0%
DDT	0-74.0	5000	0%
Aldrin	0-1.6	300	0%
Chlordane	0-1.9	300	0%
Dieldrin	0-1.6	300	0%
Endosulfan	0-0.0	NA[2]	0%
Endrin	0-12.8	300	0%
Heptachlor	0-0.0	300	0%
Heptachlor Epoxide	0-3.9	300	0%
Hexachlorobenzene	0-2.5	200	0%
Lindane	0-0.0	200	0%
Mirex	0-43.5	100	0%
Toxaphene	0-0.0	5000	0%
Trans-Nonachlor	0-1.3	NA	U[3]
PCBs (ng/g wwt)			
21 Congeners	0-16.1	500	0%
Total PCBs	0-30.3	2000	0%
Heavy Metals (ng/g wwt)			
Aluminum	0-78.5	NA	U
Arsenic	0-3.9	2	4%
Cadmium	0-0.3	0.5	0%
Chromium	0-6.1	1	4%
Copper	0-9.6	15	0%
Lead	0-0.3	0.5	0%
Mercury	0-0.3	1	0%
Nickel	0-9.0	NA	U
Selenium	0-0.3	1	0%
Silver	0-0.3	NA	U
Tin	0-1.1	NA	U
Zinc	1-18.8	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 mean 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=370).

Contaminant	Observed range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-16.0	5000	0%
DDE	0-3.5	5000	0%
DDT	0-24.2	5000	0%
Aldrin	0-3.2	300	0%
Chlordane	0-8.2	300	0%
Dieldrin	0-26.2	300	0%
Endosulfan	0-1.7	NA	U
Endrin	0-22.5	300	0%
Heptachlor	0-5.7	300	0%
Heptachlor Epoxide	0-16.7	300	0%
Hexachlorobenzene	0-77.4	200	2%
Lindane	0-0.0	200	0%
Mirex	0-88.5	100	0%
Toxaphene	0-1800	5000	0%
Trans-Nonachlor	0-1.3	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-40.6	500	0%
Total PCBs	0-62.5	2000	0%
Heavy Metals (ng/g wwt)			
Aluminum	0-6.9	NA	U
Arsenic	0-2.1	2	3%
Cadmium	0-0.1	0.5	0%
Chromium	0-0.3	1	0%
Copper	0-5.3	15	0%
Lead	0-0.3	0.5	0%
Mercury	0-0.4	1	0%
Nickel	0-0.3	NA	U%
Selenium	0-0.3	1	0%
Silver	0-1.8	NA	U%
Tin	0-0.7	NA	U%
Zinc	1-11.8	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 mean of international limits (Nauen 1983)

Table 2-2. Overview of the contaminant levels observed in edible flesh of Atlantic croaker (N=580). NA= Not available; U= Unknown, no criterion level is available.

Contaminant	Observed Range	Criterion[1]	Proportion Exceeding Criterion
Pesticides (ng/g wwt)			
DDD	0-207.4	5000	0%
DDE	0-12.2	5000	0%
DDT	0-39.4	5000	0%
Aldrin	0-2.7	300	0%
Chlordane	0-6.1	300	0%
Dieldrin	0-24.4	300	0%
Endosulfan	0-1.8	NA	U
Endrin	0-10.1	300	0%
Heptachlor	0-5.7	300	0%
Heptachlor Epoxide	0-5.7	300	0%
Hexachlorobenzene	0-4.0	200	0%
Lindane	0-4.1	200	0%
Mirex	0-30.7	100	0%
Toxaphene	0-1400	5000	0%
Trans-Nonachlor	0-4.3	NA	U
PCBs (ng/g wwt)			
21 Congeners	0-19.5	500	0%
Total PCBs	0-67.9	2000	0%
Heavy Metals (ng/g wwt)			
Aluminum	0-105.1	NA	U
Arsenic	0-10.1	2	8%
Cadmium	0-0.4	0.5	0%
Chromium	0-0.8	1	0%
Copper	0-10.3	15	0%
Lead	0-0.4	0.5	0%
Mercury	0-1.2	1	1%
Nickel	0-0.7	NA	U
Selenium	0-0.4	1	0%
Silver	0-0.3	NA	U
Tin	0-1.2	NA	U
Zinc	1-234.0	60	2%

[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 mean of international limits (Nauen 1983)

Table 2-3. Overview of the contaminant levels observed in edible flesh of catfish (N=1130). NA= Not available; U= Unknown as no criterion level is available.

were found in Atlantic croaker (Table 2-2). As with shrimp, some metal concentrations in croaker fillets exceeded the criteria level for several metals. This exceedance was for arsenic where 3% of the croakers examined had > 2 ppm arsenic.

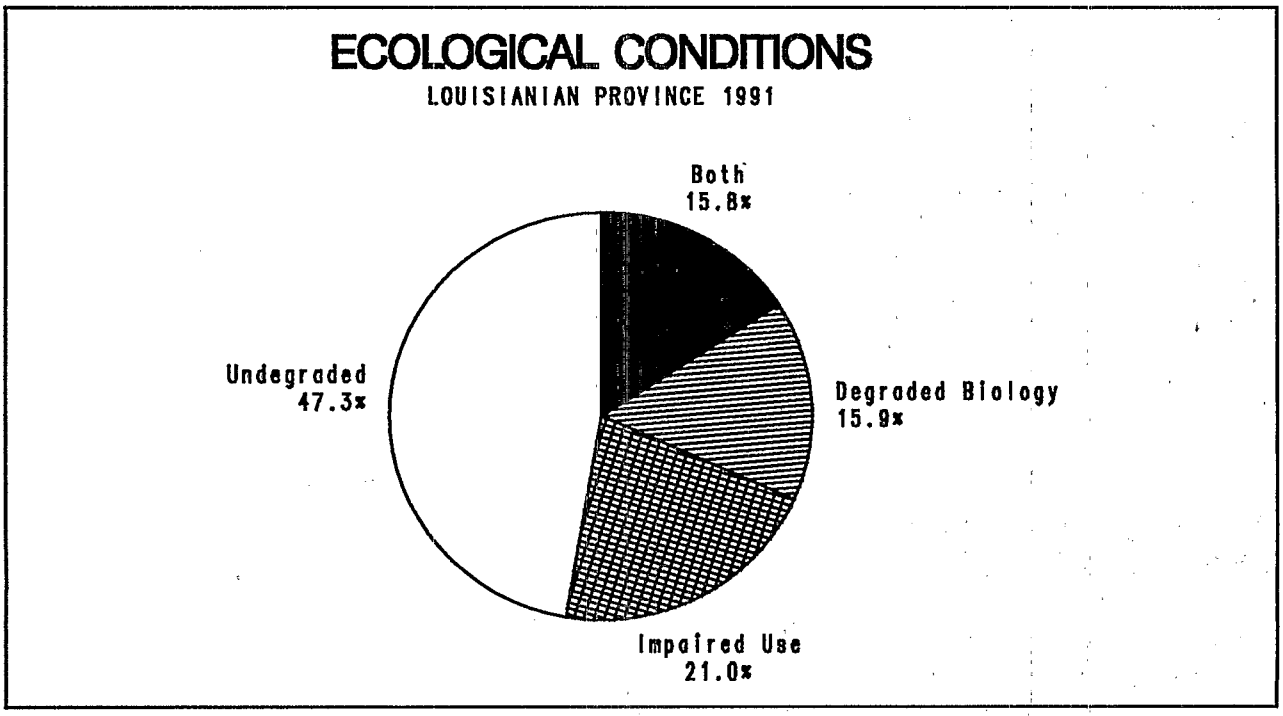
No pesticide or PCB concentrations exceeding the specified FDA action limits were found in marine catfish (Table 2-3). Again, like shrimp and croaker, several heavy metals exceeded the international standards with 8% of catfish in excess of 2 ppm arsenic, 2% in excess of 60 ppm zinc, and 1% in excess of 1 ppm mercury.

2.1.11 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. 2-32). Indicators relating to biotic integrity and aesthetics were used to estimate overall environmental conditions in the estuaries. Fifty-three 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. 2-32). Of the 25,725 km^2 of estuarine surface area in the Louisianian Province, 13,550 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 16% of the estuarine area, whereas degraded biological conditions alone were found in 16% of the province and degraded human use alone was found in 21% of the Louisianian Province.

However, the use of PAR < 0.1 as a degraded human use is questionable. Most of the turbid conditions are observed in southwestern Louisiana and Texas as a result of natural flows of the rivers in Louisiana and eastern Texas. It is debateable whether this represents a negative ecological condition. Overall ecological condition for the Louisianian Province is also displayed without degraded PAR as a variable (Fig. 2-32b) In this instance, the degraded area of the province, 39.8%, corresponds to 10,240 km^2 with 9% experiencing degraded biology and human use. Degraded biology alone is observed in 22% of the province while degraded human use alone is seen in 8% of the Louisianian Province.



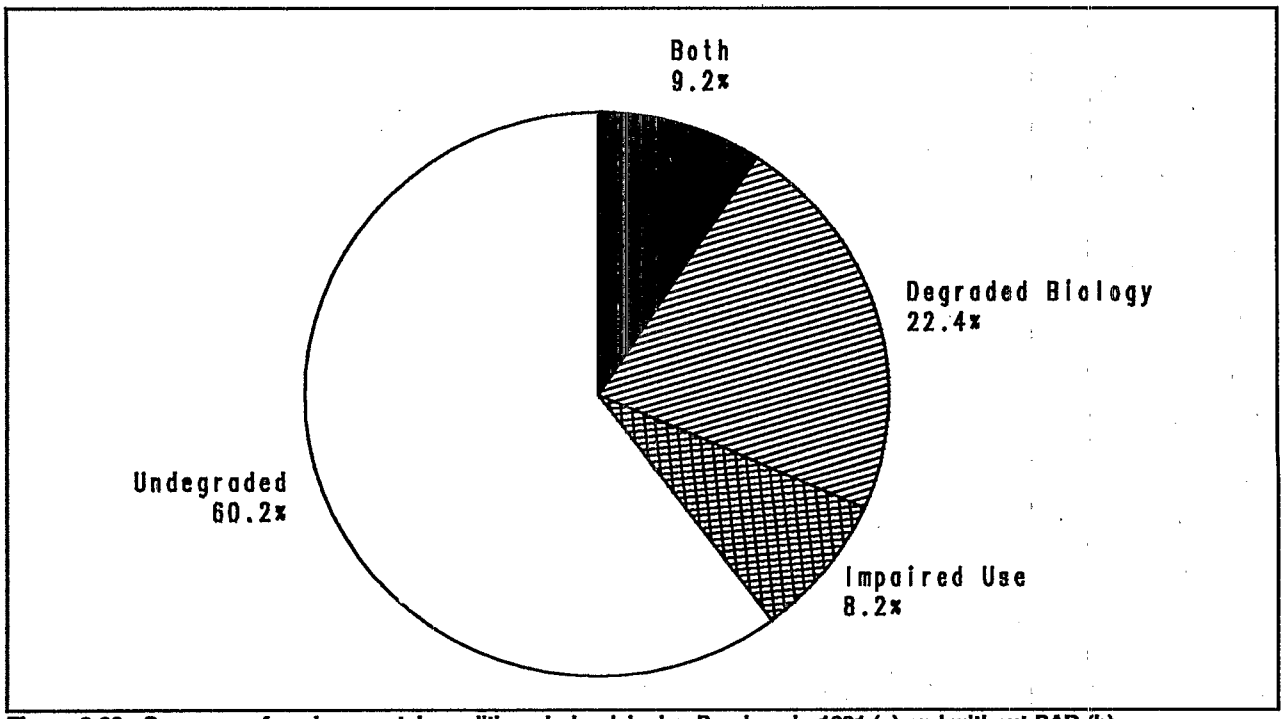


Figure 2-32. Summary of environmental conditions in Louisianian Province in 1991 (a) and without PAR (b).

2.2 EXPOSURE INDICATORS

Exposure indicators have historically been the mainstay of environmental monitoring programs. Indicators of pollutant exposure measured during the 1991 Louisianian Province Demonstration were dissolved oxygen concentration (instantaneous and continuous), sediment toxicity (*Ampelisca* and *mysids*), 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 1991 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.

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 33-37). Minimum DO concentrations derived from province-wide instantaneous estimates decreased from 4.4 ppm at the surface to 4.0 ppm at 1 m, 3.0 ppm at 2.0 m, 0.6 ppm at 3 m, and 0.0 at the bottom. The minima show this steady decline with depth reflecting the

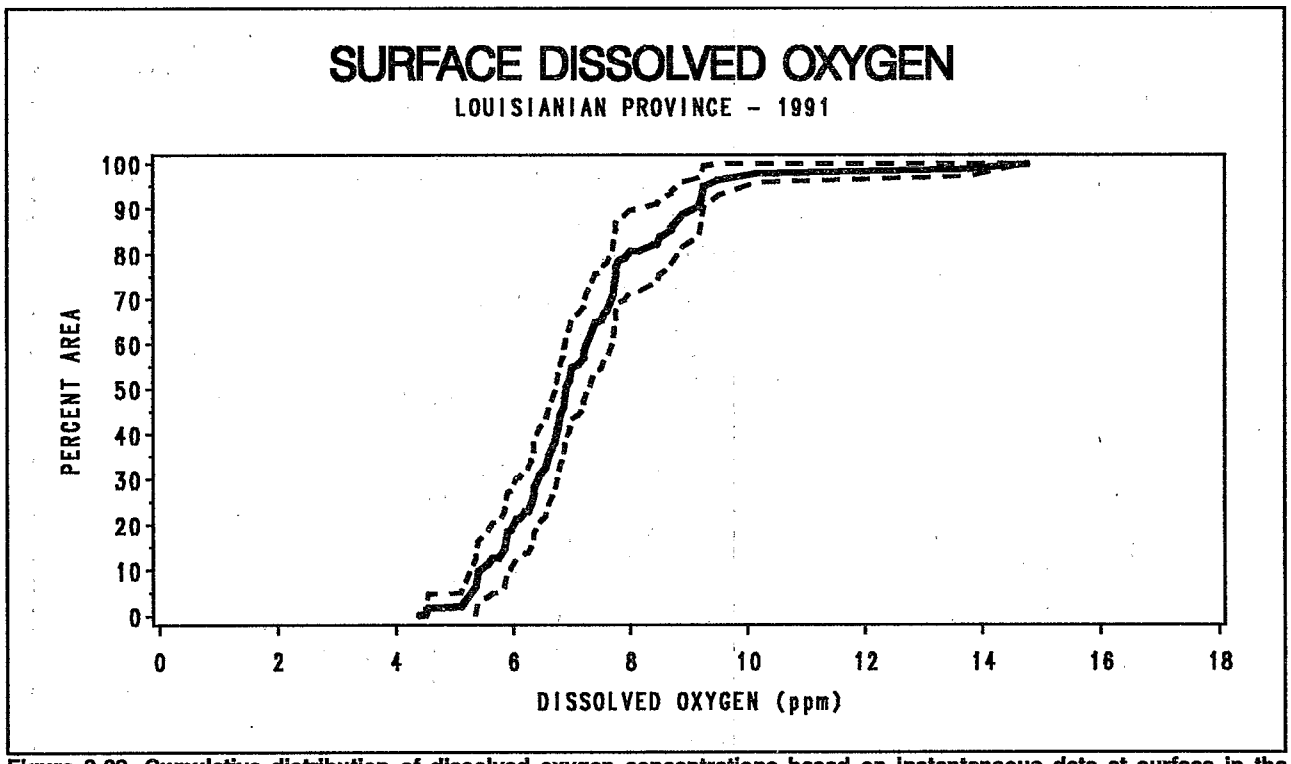


Figure 2-33. Cumulative distribution of dissolved oxygen concentrations based on instantaneous data at surface in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

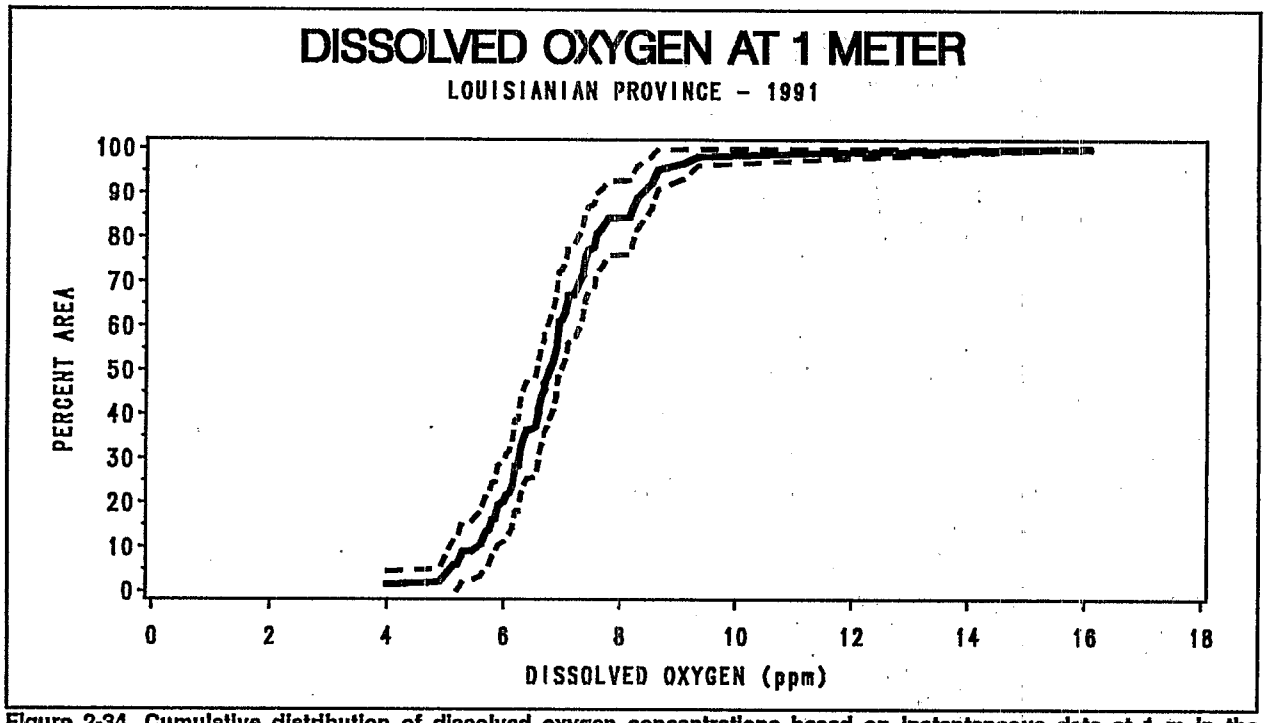


Figure 2-34. Cumulative distribution of dissolved oxygen concentrations based on instantaneous data at 1 m in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

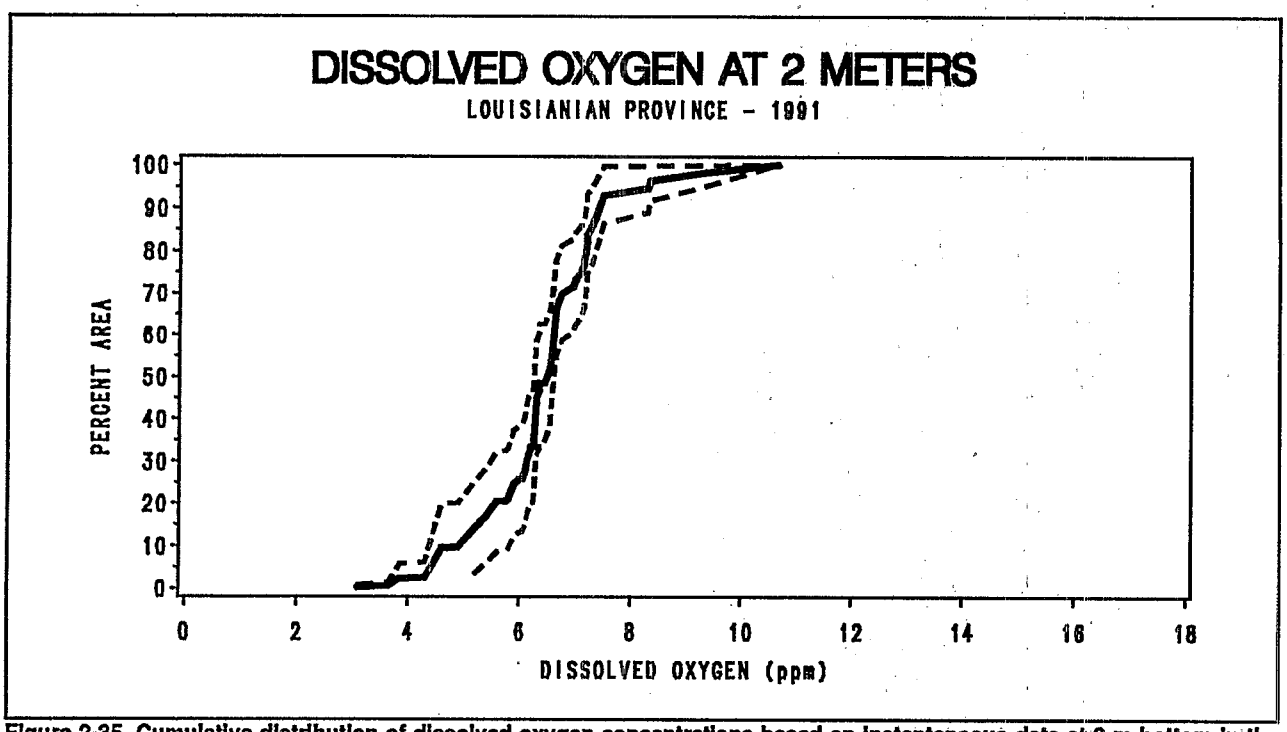


Figure 2-35. Cumulative distribution of dissolved oxygen concentrations based on instantaneous data at 2 m bottom in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

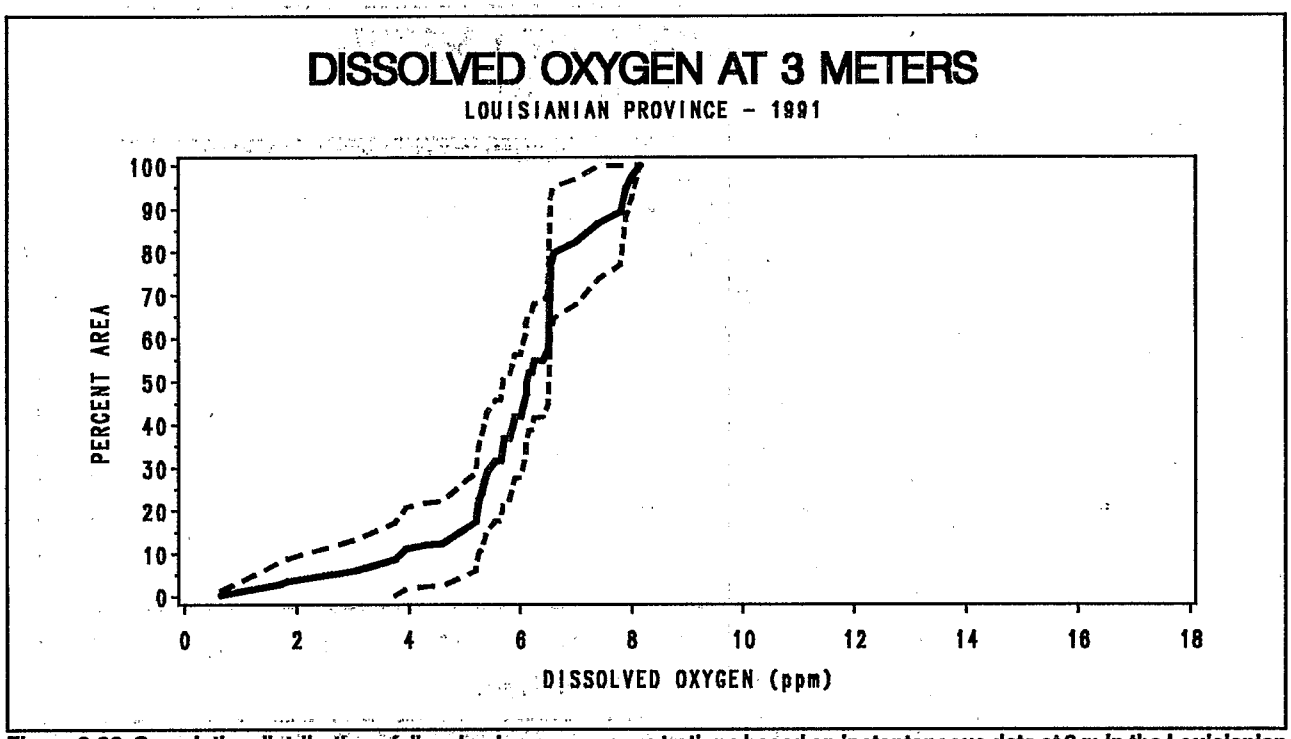


Figure 2-36. Cumulative distribution of dissolved oxygen concentrations based on instantaneous data at 3 m in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

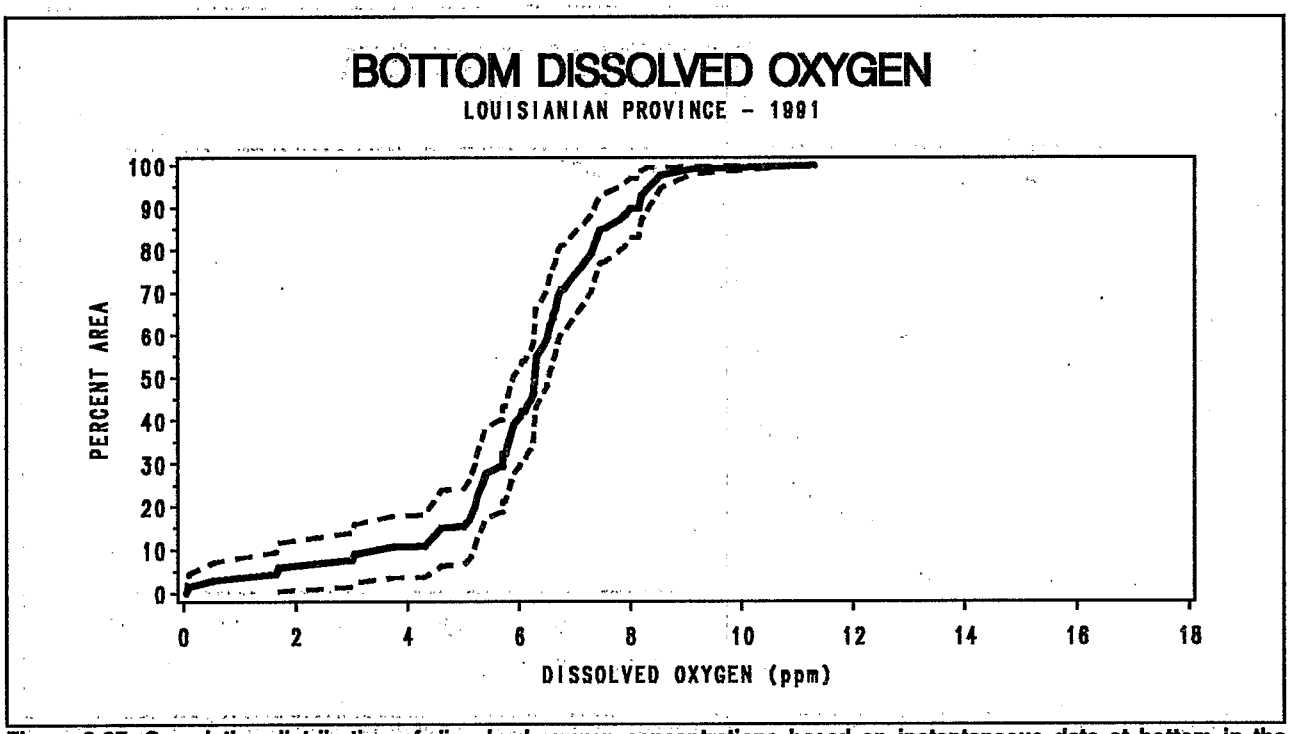


Figure 2-37. Cumulative distribution of dissolved oxygen concentrations based on instantaneous data at bottom in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---)..

stratified nature of some estuaries. However, the median values change very little (ranging from 7.0 at the surface to 6.0 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. 2-38) while bottom DO concentrations were below 5 ppm for 15% of the province and below 2 ppm for 6% of the province (Fig. 2-39). Bottom dissolved oxygen concentrations < 5 ppm were seen in all three estuarine classes with small estuaries displaying the greatest extent at 17% of the class resources, with large estuaries at 15%, and large tidal rivers at 10% (Fig. 2-40). Contrastingly, the proportion of class resources that experienced DO concentrations < 2 ppm were almost exclusively within the large estuary class where 8% 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. 2-41).

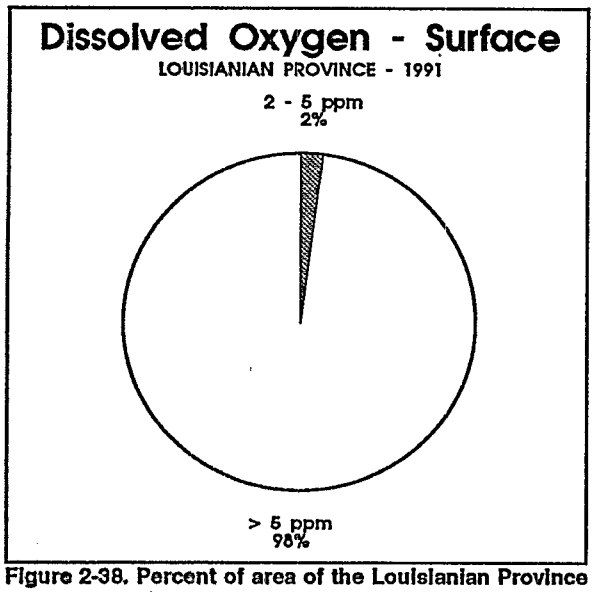


Figure 2-38. Percent of area of the Louisianian Province surface waters associated with major dissolved oxygen concentration categories in 1991.

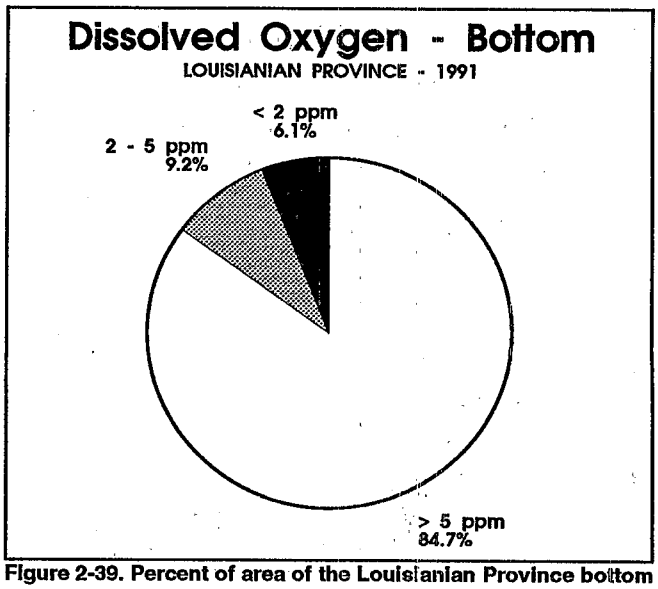


Figure 2-39. Percent of area of the Louisianian Province bottom waters associated with major dissolved oxygen concentration categories in 1991.

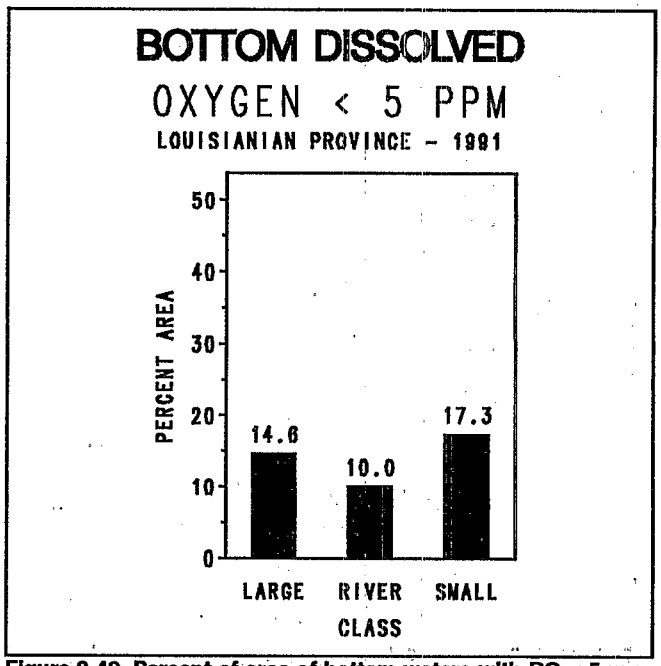


Figure 2-40. Percent of area of bottom waters with DO < 5 ppm for large estuaries, large tidal rivers, and small estuaries.

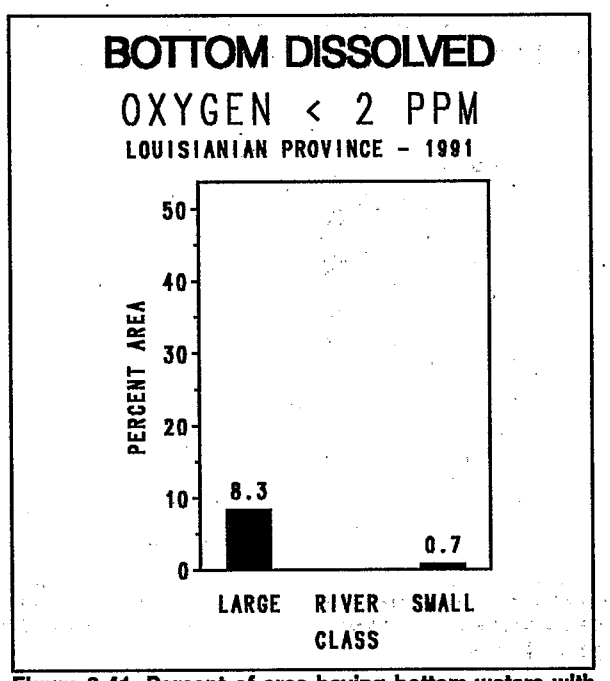


Figure 2-41. Percent of area having bottom waters with dissolved oxygen concentrations < 2 ppm for large estuaries, large tidal rivers, and small estuaries.

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 periods (i.e., night). Continuous bottom DO concentrations in the Louisianian Province ranged from 0-12 ppm (Fig. 2-42) and are somewhat similar to the instantaneous bottom measures (Fig. 37). However, the continuous measurements show an increased prevalence of concentrations below 5 ppm suggesting a significant day-night difference in DO concentrations.

The continuous measures were collected because earlier studies (Summers and Engle 1992) showed that a combination of

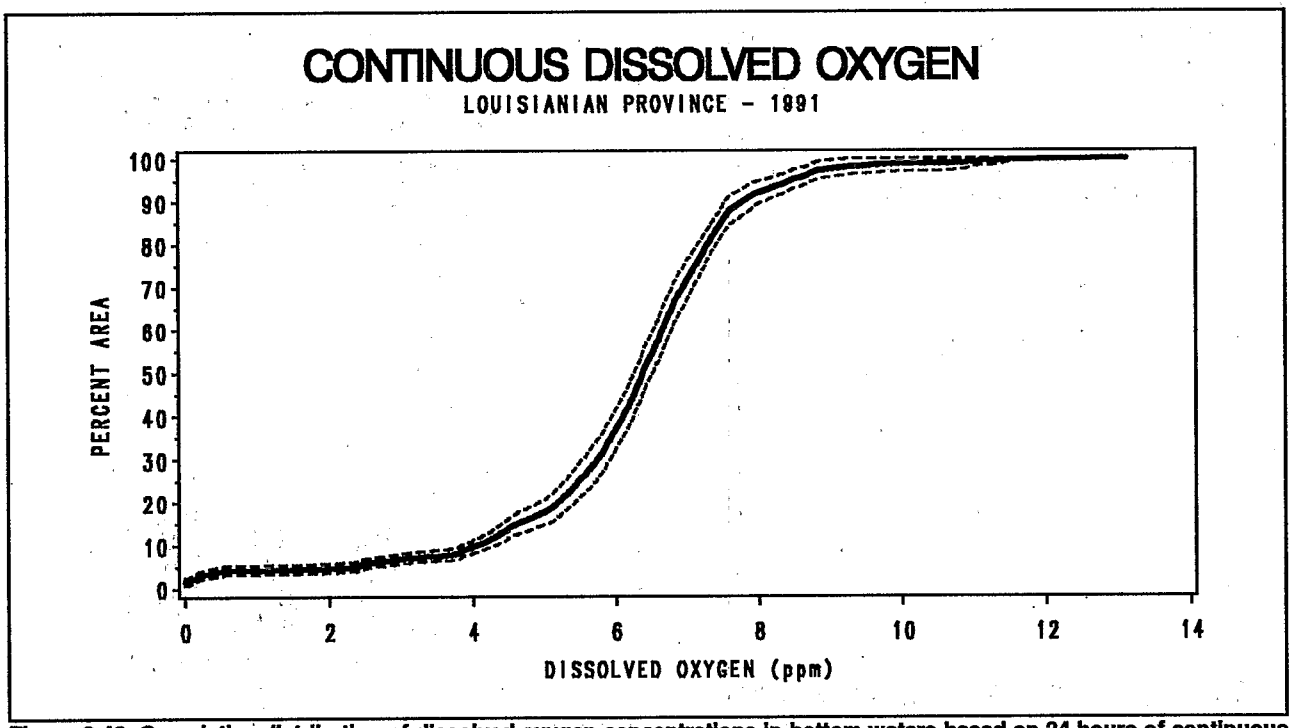


Figure 2-42. Cumulative distribution of dissolved oxygen concentrations in bottom waters based on 24 hours of continuous data in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

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 DO conditions. Minimum DO concentrations resulting from continous recordings showed that 12% of the province experienced DO conditions below 2 ppm (Fig. 2-43) while 37% of the province had minima < 5 ppm (Fig. 2-44). Based on the above estimation technique, this represents a 6% increase in the estuarine bottom area experiencing low DO conditions. Thus, an additional 6% of province estuaries experience low DO conditions at night. Similarly, an additional 12% of estuaries in the Louisianian Province experience DO conditions < 5 ppm. Unlike daylight conditions where large estuaries predominated lower DO conditions, continuous measurements show that small estuaries experience DO conditions below 2 ppm more frequently than large estuaries (Fig. 2-45). Thus, there are two types of low DO conditions in the Louisianian Province: continuous and cyclic. Systems experiencing low bottom DO conditions continuously (day and night) include about 8% of the large estuarine surface area within the province (e.g., Mobile Bay, parts of Chandeleur Sound). However, numerous small estuaries throughout the province (accounting for 16% of the area of this class) exhibit high DO concentrations during the day and low concentrations at night. An additional 3% of large estaurine surface area appears to also cycle enough to experience "hypoxic" DO conditions at night. 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. Typically, daily dissolved oxygen concentrations in these small

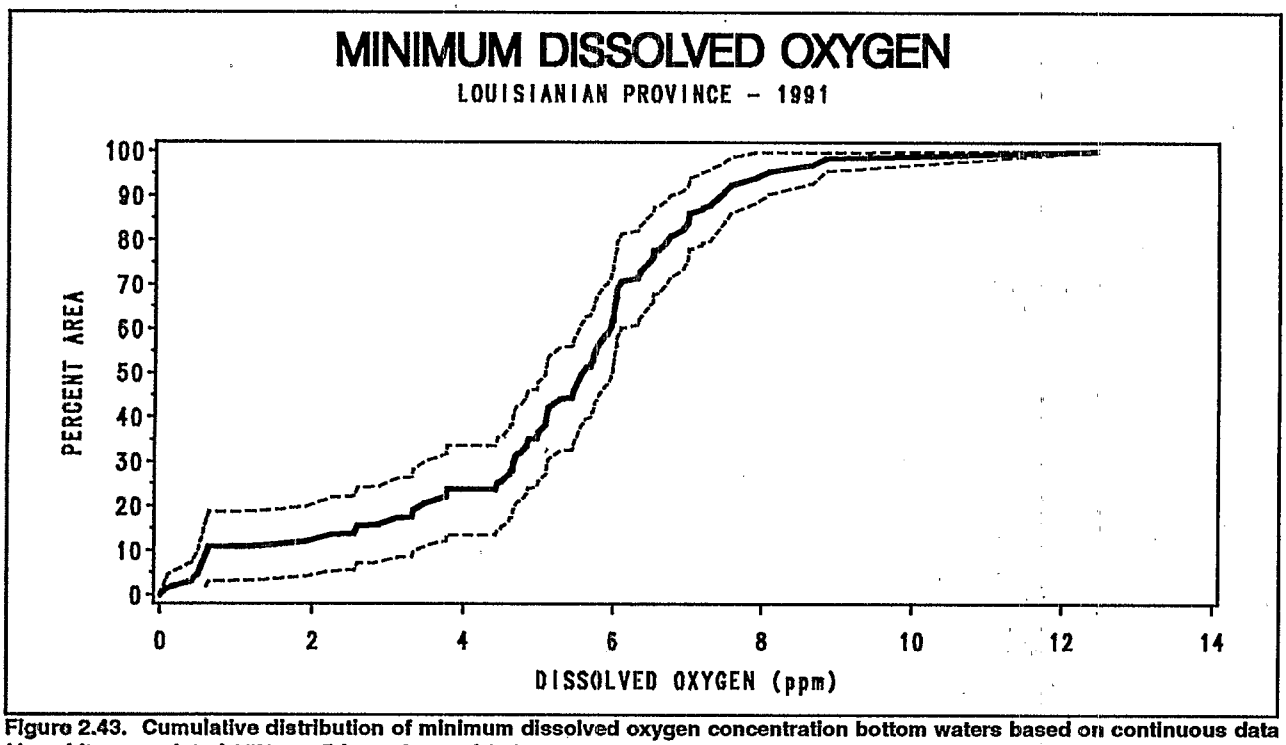


Figure 2.43. Cumulative distribution of minimum dissolved oxygen concentration bottom waters based on continuous data (-) and its associated 95% confidence interval (---).

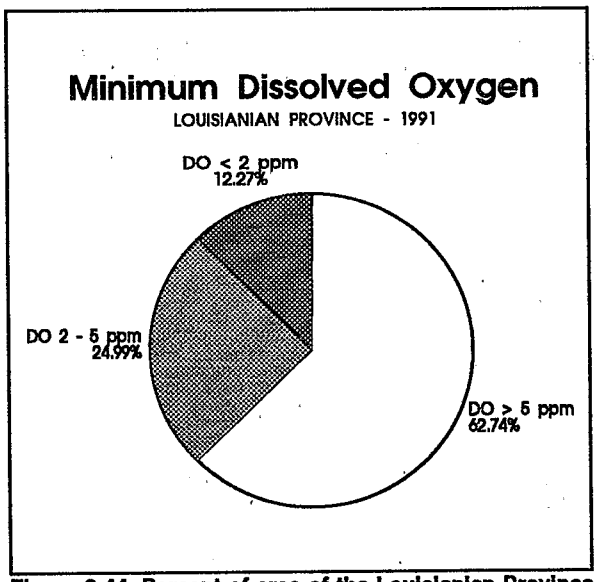


Figure 2-44. Percent of area of the Louisianian Province bottom waters associated with dissolved oxygen minima categories in 1991.

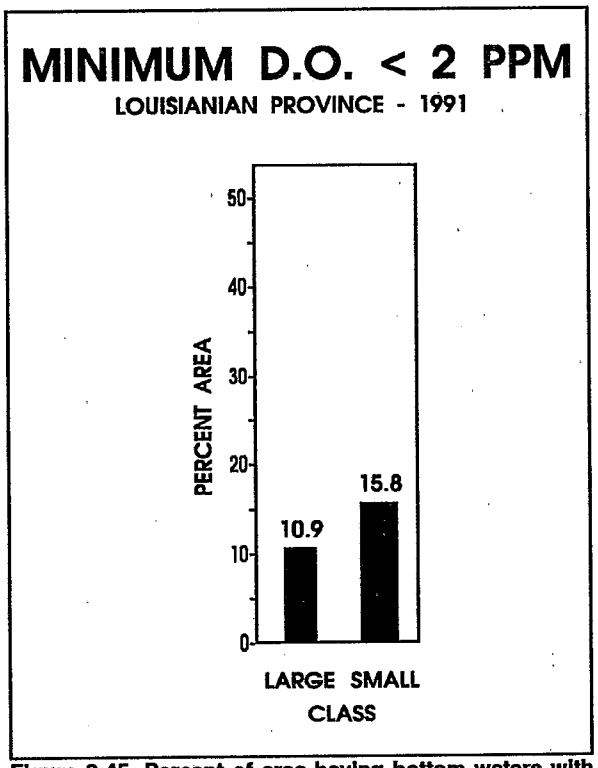


Figure 2-45. Percent of area having bottom waters with dissolved oxygen minima < 2 ppm for large estuaries, large tidal rivers, and small estuaries.

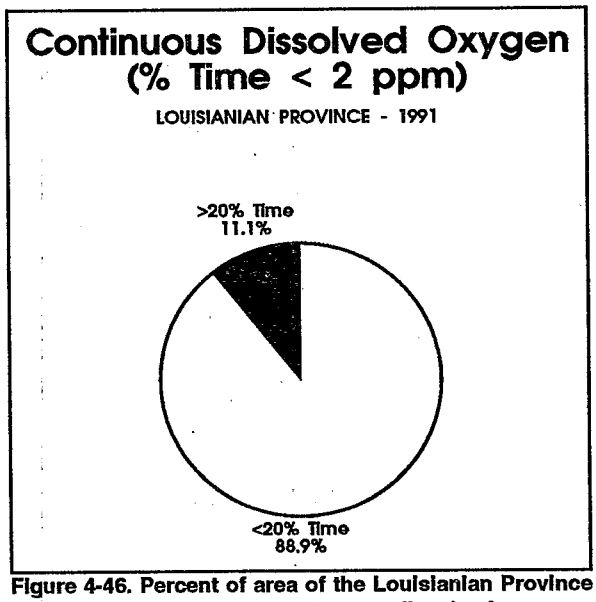


Figure 4-46. Percent of area of the Louisianian Province bottom waters that experience dissolved oxygen concentrations < 2 ppm for > 20% of 24 hour period in 1991.

systems range from 0-2 ppm at night to 6-10 ppm during daylight hours. Examination of the duration of low DO conditions in the Louisianian Province showed that 11% of the province exhibited DO concentrations below 2 ppm for greater than 5 hours during the day (20% of time)(Fig. 2-46). These measurements were about equally partitioned among the large and small estuarine classes (Fig. 2-47). Comparison of the minima values (Fig. 2-43) and the duration values (Fig. 2-47) shows that all large systems experiencing low DO conditions (11%) display these conditions for extended periods of time. However, about 4% of the small estuaries having minimum DO values < 2 ppm experienced these conditions for periods of less than 5 hours. These small systems experiencing low duration, low DO daily events are typical of dystrophic systems like estuarine swamps or bayous.

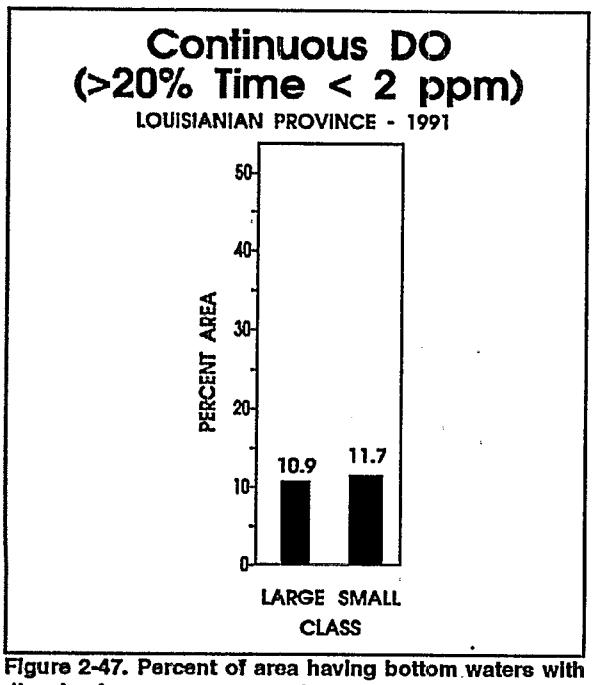


Figure 2-47. Percent of area having bottom waters with dissolved oxygen concentrations < 2 ppm for > 20% of 24 hour period for large estuaries, large tidal rivers, and small estuaries.

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 8% of the sediments collected in the Louisianian Province were toxic to the amphipods. In these sediments, mortality rates were >20% higher than those observed in the controls (Fig. 2-48). The estuarine sampling class with the largest proportion of toxic sediment was the large tidal river class (67%) while small estuaries (14%) and large estuaries (6%) showed toxicity to a lesser extent (Fig. 2-49). However, on a province-wide scale, most of the toxic sediments occur in large estuaries (1110 km^2) with small estuaries contributing 1020 km^2 of toxic sediments and the large tidal rivers only displaying 92 km^2.

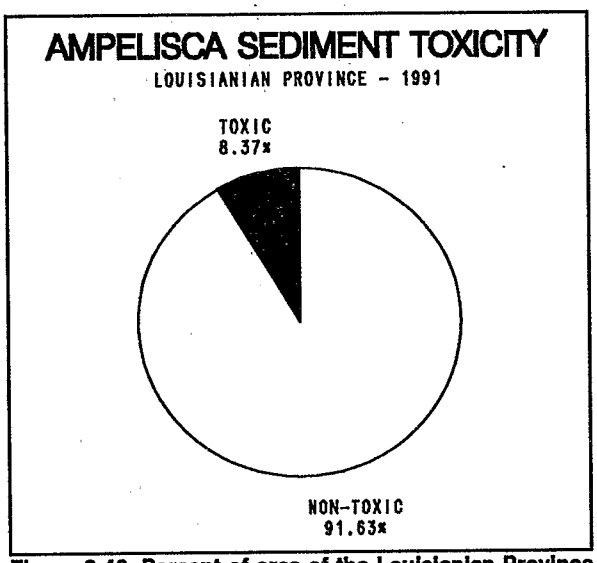


Figure 2-48. Percent of area of the Louisianian Province sediment toxicity categories based on 10-day Ampelisca bioassays in 1991.

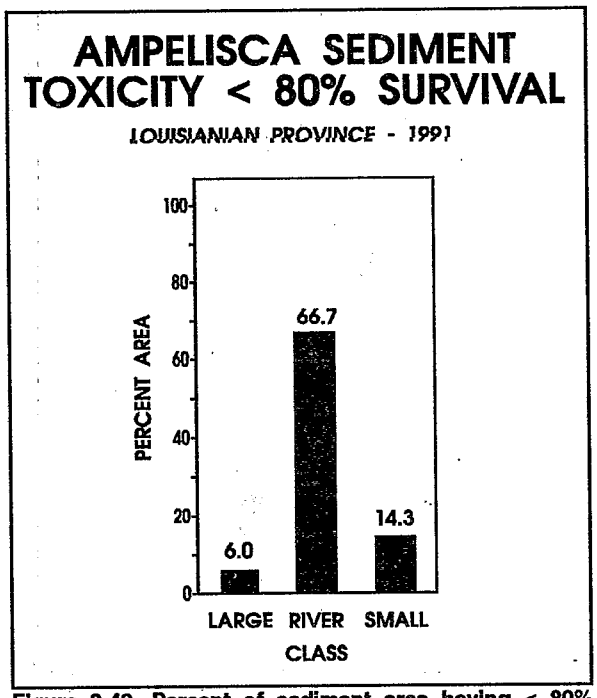


Figure 2-49. Percent of sediment area having < 80% survival rates in 10-day Ampelisca bioassays.

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 insinuate themselves into the sediments. Mysid contact with the sediments is frequent but not continuous whereas the tube-dwelling amphipod is generally involved with the tested sediments. About 7% of the sediments in the Louisianian Province was toxic to mysids resulting in mortalities >20% higher than those observed in control tests (Fig. 2-50). This figure compares favorably with the 8% observed for Ampelisca toxicity. The major differences between Ampelisca

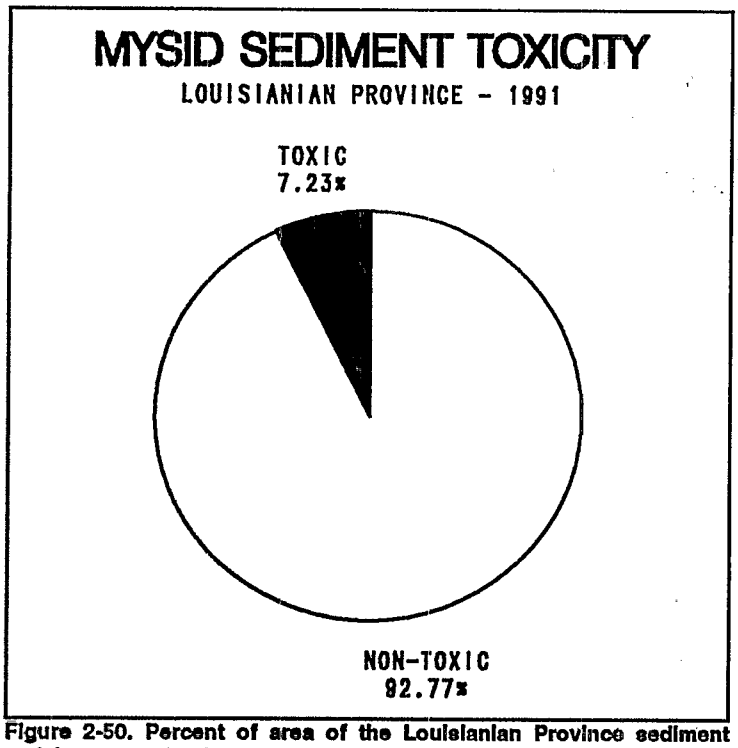


Figure 2-50. Percent of area of the Louisianian Province sediment toxicity categories based on 4-day mysid bioassays in 1991.

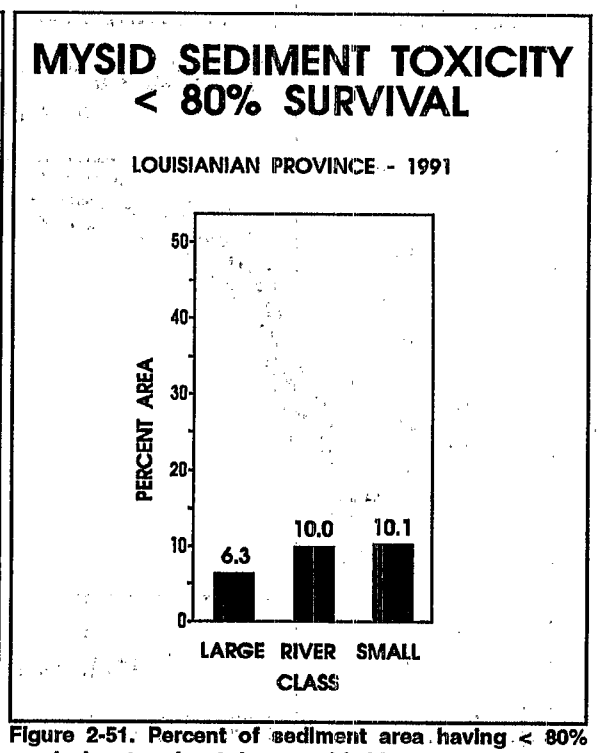


Figure 2-51. Percent of sediment area having < 80% survival rates in 4-day mysid bioassays for large estuaries, large tidal rivers, and small estuaries.

and mysid testing are shown in Figures 2-49 and 2-51 where the percentage of area in the large tidal river class varies widely; 67% for Ampelisca and 10% for mysids. However, the observed toxicities in the large and small estuaries are almost identical. Thus, Ampelisca and mysid testing compare favorably and produce similar results for the extent of toxic sediment in the province (2150 km^2 for Ampelisca and 1880 km^2 for mysids) and comparable class estimates for the large estuaries (1110 km^2 vs. 1165 km^2) and small estuaries (1017 km^2 vs 720 km^2).

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 2-52 depicting concentrations ranging from 65-20,613 ppb. About 8% of the sediments in the province are characterized by alkane concentrations in excess of 7000 ppb (Fig. 2-53). No alkanes at concentrations > 7000 ppb were observed in the large tidal river class but these concentrations were seen in 8.3% of the large estuarine sediments and 11.6% of small estuarine sediments (Fig. 2-54). 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.

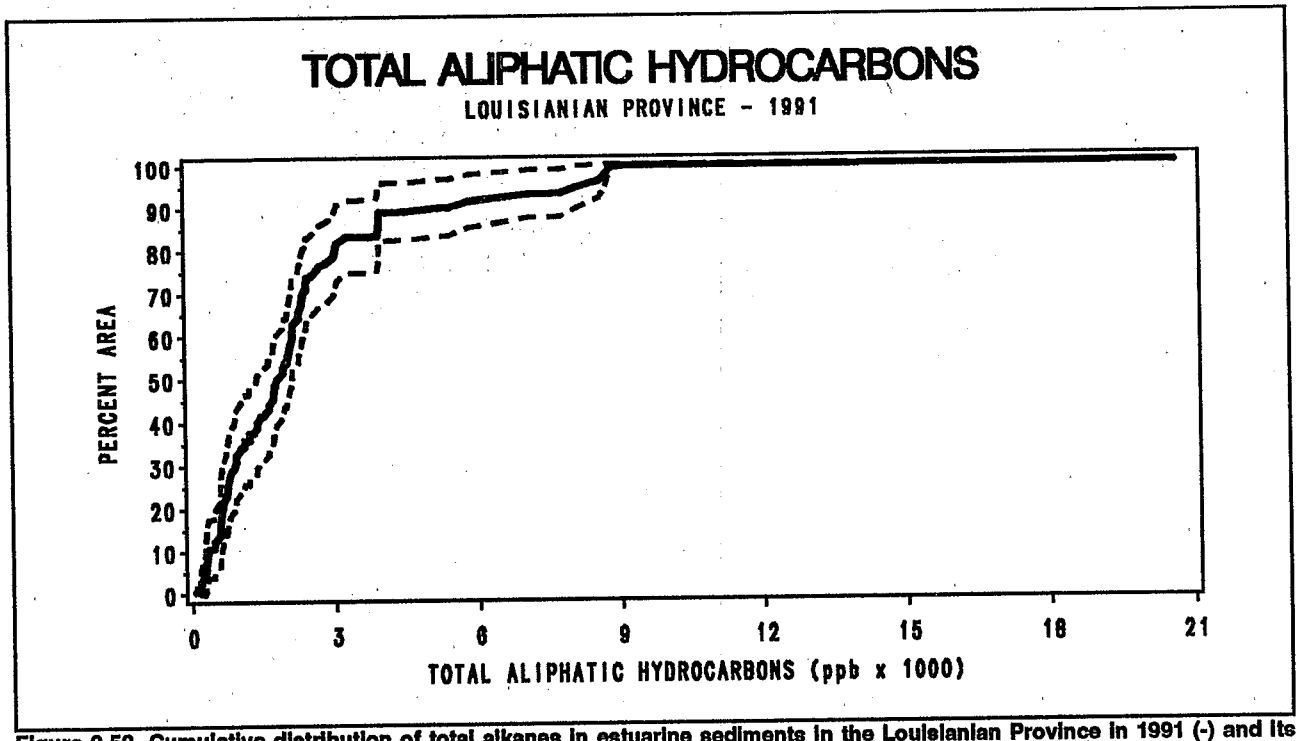


Figure 2-52. Cumulative distribution of total alkanes in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

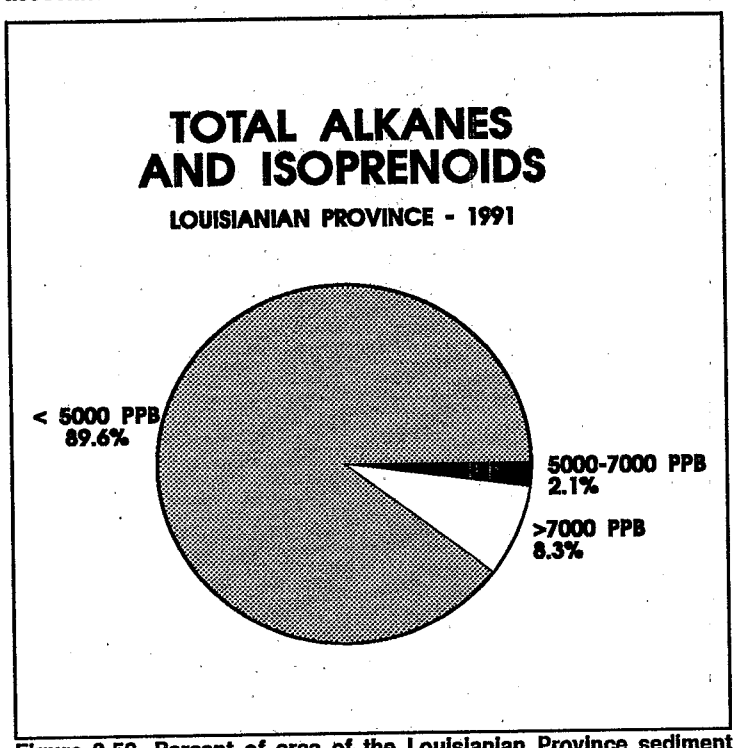


Figure 2-53. Percent of area of the Louisianian Province sediment associated with total alkane concentration categories in 1991.

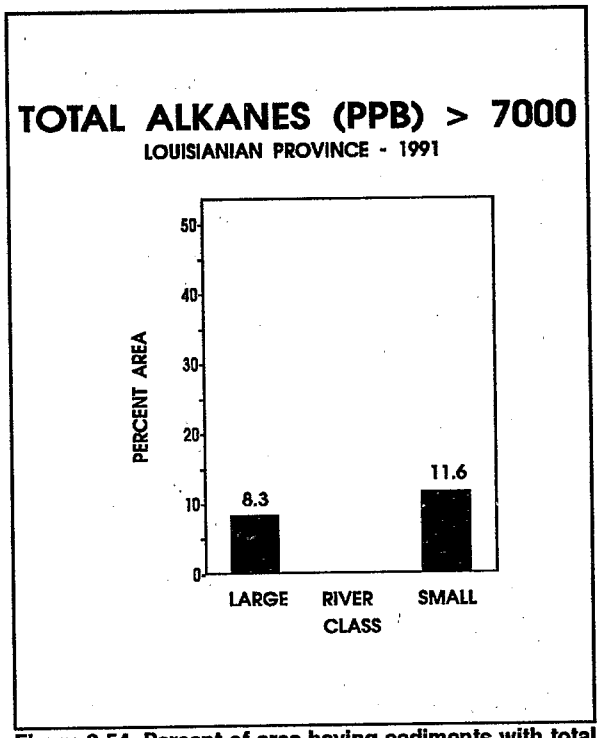


Figure 2-54. Percent of area having sediments with total alkanes > 7000 ppb for large estuaries, large tidal rivers, and small estuaries.

Alkane	Range (ppb)	Percent Area > 1000 ppb
C10	0 - 76	0%
C11	0 - 188	0%
C12	0 - 78	0%
C13	0 - 66	0%
C14	0 - 73	0%
C15	0 - 840	0%
C16	2 - 552	0%
C17	3 - 2503	2%
Pristane	2 - 2062	4%
C18	2 - 623	0%
Phytane	2 - 1860	4%
C19	2 - 739	0%
C20	3 - 289	0%
C21	3 - 368	0%
C22	3 - 75	0%
C23	4 - 342	0%
C24	3 - 202	0%
C25	4 - 706	0%
C26	2 - 253	0%
C27	3 - 1952	3%
C28	3 - 1047	<1%
C29	2 -10246	3%
C30	2 - 587	0%
C31	0 - 2879	5%
C32	0 - 730	0%
C33	0 - 1700	<1%
C34	0 - 153	0%
TOTAL	65 - 20613	8%

Table 2-4. Alkane concentration ranges measured in the 1991 LP 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. 2-55 ranging from 13 ppb to about 7000 ppb. None of the sampled sediments exceeded the median Long and Morgan (1990) criteria of 35,000 ppb although 3% of the sediments did exceed their lower criterion (4000 ppb) for ecological effects (Fig. 2-56). All of the PAH concentrations exceeding 4000 ppb were found in small estuaries.These conditions comprised over 10% of the sediments in that class (Fig. 2-57). The ranges of individuals PAHs, the criteria used, and the extent to which observations exceeded these criteria are shown in Table 2-5.

2.2.7 SEDIMENT CONTAMINANTS - POLYCYCLIC CHLORINATED BIPHENYLS

Twenty polycyclic chlorinated biphenyl (PCB) congeners were analyzed from the Louisianian Province sediments. Concentrations of total PCBs ranged from 13.8 ppb to 127.7 ppb (Fig. 2-58). 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 2-6).

2.2.8 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. 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 7-12 days, its continual release through leaching remains a continuing environmental problem. Determinations of tetrabutyltin, tributyltin,

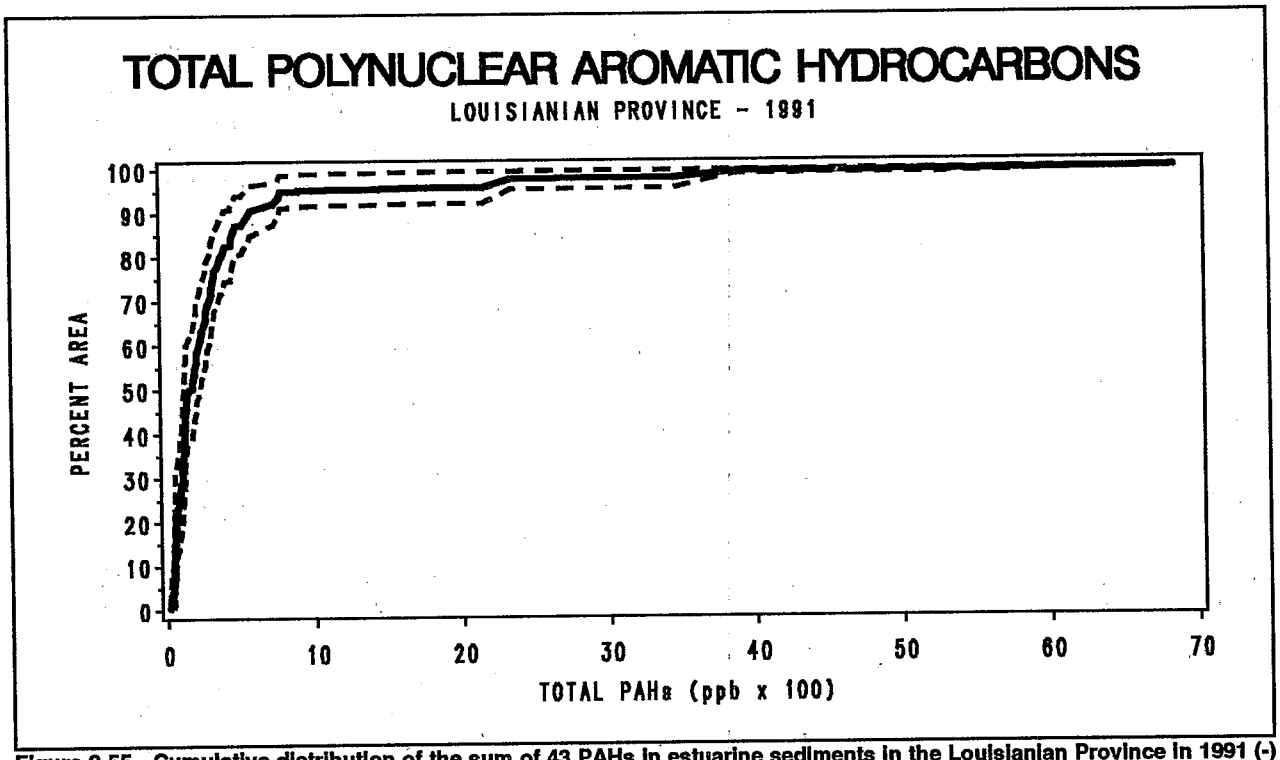


Figure 2-55. Cumulative distribution of the sum of 43 PAHs in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

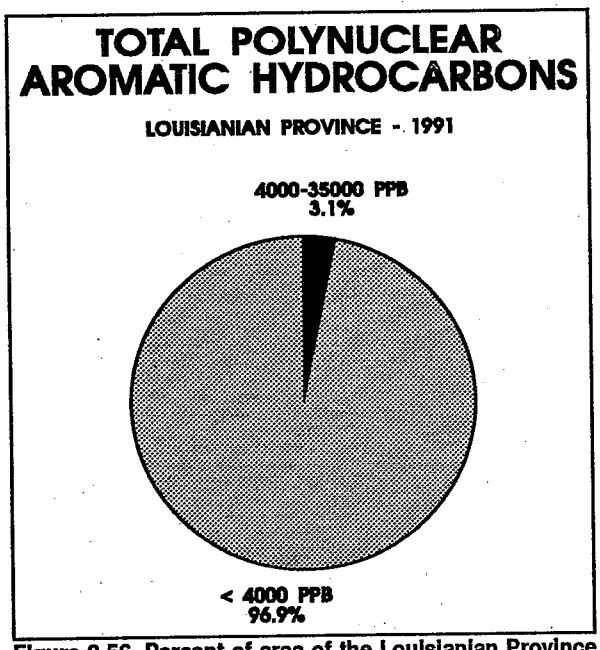


Figure 2-56. Percent of area of the Louisianian Province sediment associated with the sum of 43 PAH concentration categories in 1991.

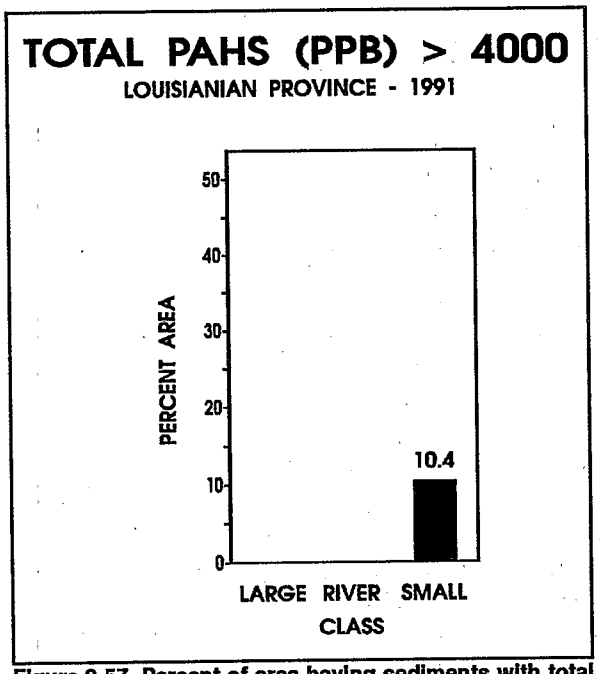


Figure 2-57. Percent of area having sediments with total PAHs > 4000 ppb for large estuaries, large tidal rivers, and small estuaries.

PAH	Range (ppb)	Criteria	Percent Exceeded (10%)	(50%)
Acenaphthene	0 - 11	150/650	0%	0%
Acenaphthylene	0 - 20	NA	U	U
Anthracene	0 - 28	85/960	0%	0%
Benzo(a)anthracene	0 - 155	230/1600	0%	0%
Benzo(a)pyrene	0 - 123	400/2500	0%	0%
Benzo(b)fluoranthene	0 - 279	NA	U	U
Benzo(e)pyrene	0 - 158	400/2500	0%	0%
Benzo(g,h,i)perylene	0 - 60	NA	U	U
Benzo(k)fluoranthene	0 - 122	NA	U	U
Biphenyl	0 - 13	NA	U	U
Chrysene	0 - 226	400/2800	0%	0%
C1-chrysene	0 - 383	400/2800	0%	0%
C2-chrysene	0 - 597	400/2800	0%	0%
C3-chrysene	0 - 297	400/2800	0%	0%
C4-chrysene	0 - 142	400/2800	0%	0%
Dibenzo(a,h)anthracene	0 - 40	60/260	0%	0%
Dibenzothio	0 - 74	NA	U	U
C1-dibenzothio	0 - 226	NA	U	U
C2-dibenzothio	0 - 398	NA	U	U
C3-dibenzothio	0 - 333	NA	U	U
Fluoranthene	0 - 307	600/3600	0%	0%
C1-fluoranthpyrene	0 - 255	NA	U	U
Fluorene	0 - 34	35/640	0%	0%
C1-fluorene	0 - 203	35/640	5%	0%
C2-fluorene	0 - 529	35/640	7%	0%
C3-fluorene	0 - 548	35/640	9%	0%
Naphthalene	0 - 41	340/2100	0%	0%
C1-naphthalene	0 - 52	340/2100	0%	0%
C2-naphthalene	0 - 62	340/2100	0%	0%
C3-naphthalene	0 - 901	340/2100	5%	0%
C4-naphthalene	0 -1807	340/2100	5%	0%
Perylene	0 - 540	NA	U	U
Phenanthrene	0 - 244	225/1380	3%	0%
C1-phenanthrene	0 - 607	225/1380	5%	0%
C2-phenanthrene	0 - 574	225/1380	5%	0%
C3-phenanthrene	0 - 467	225/1380	3%	0%
C4-phenanthrene	0 - 641	225/1380	< 1%	0%
Pyrene	0 - 268	350/2200	0%	0%
(i)1,2,3-c,d-pyrene	0 - 31	NA	U	U
1-methylnaphthalene	0 - 23	NA	U	U

Table 2.5 Ranges of PAH concentrations found in the 1991 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)

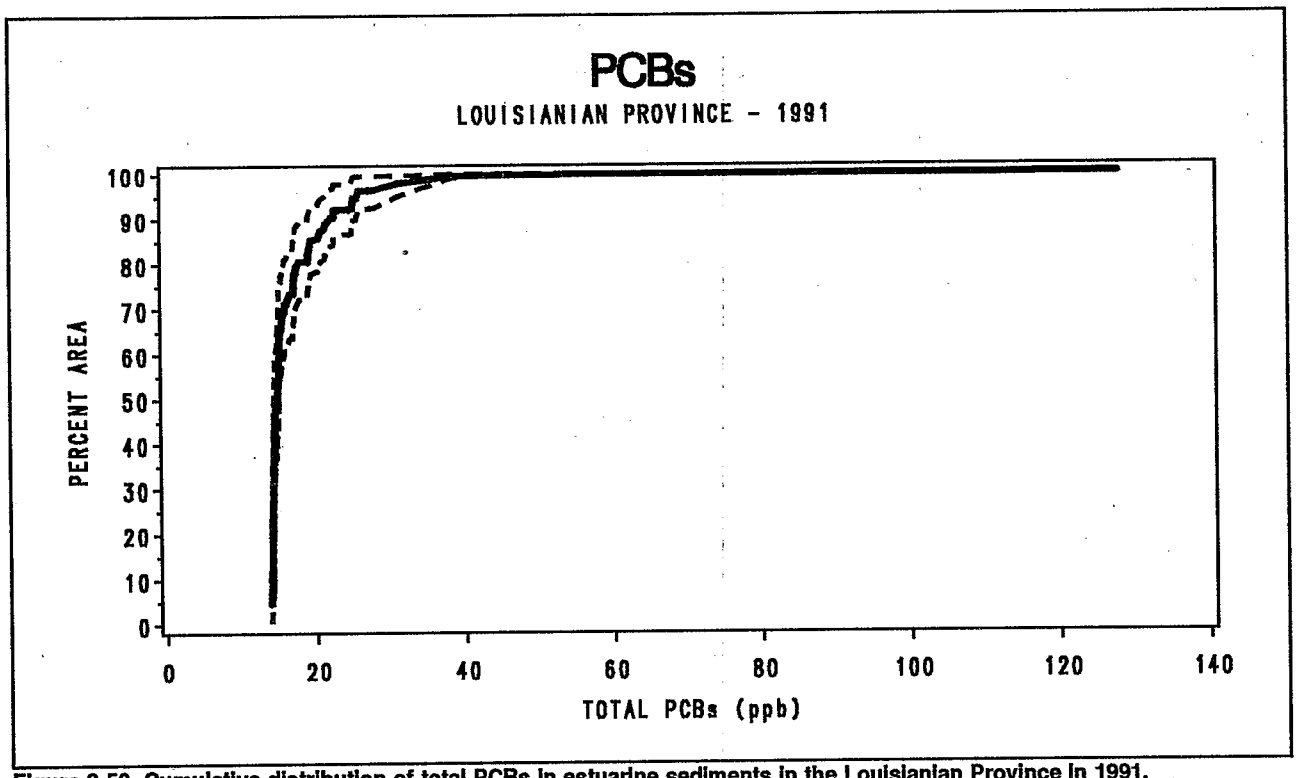


Figure 2-58. Cumulative distribution of total PCBs in estuarine sediments in the Louisianian Province in 1991.

PCB # (Chlorination)	Range (ppb)
8 (CL2)	0 - 0.7
18 (CL3)	0 - 0.3
28 (CL3)	0 - 2.4
44 (CL4)	0 - 0.6
52 (CL4)	0 - 2.1
66 (CL4)	0 - 0.9
101 (CL5)	0 - 4.0
105 (CL5)	0 - 2.1
110/77 (CL5/4)	0 - 5.9
118/108/149 (CL 5/5/6)	0 - 2.8
126 (CL5)	0 - 0.4
128 (CL6)	0 - 2.1
138 (CL6)	0 - 11.4
153 (CL6)	0 - 12.5
170 (CL7)	0 - 8.8
180 (CL7)	0 - 8.6
187/182/159 (CL 7/7/6)	0 - 7.2
195 (CL8)	0 - 1.0
206 (CL9)	0 - 3.1
209 (CL10)	0 - 5.9

Table 2.6 Ranges of polycyclic chlorinated biphenyl concentrations determined from Louisianian Province sediments.

dibutyltin, and monobutyltin were made for all sediments collected in the 1991 Louisianian Province Demonstration with concentrations expressed as ng (sn)g dwt. Over 86% of the sediments analyzed showed no traces (< 1 ppb) of TBT but 13% of the sediments had concentrations of TBT > 0, with 4% having concentrations > 5 ppb (Fig. 2-59). According to Laughlin and Linden (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 small estuaries (9% of sediments) and to a lesser extent in large estuarine sediments (2%) (Fig. 2-60). Using 1 ppb TBT as an indicator of potential ecological effects results in all sampling classes being represented with 55% of the sediments in large tidal rivers,

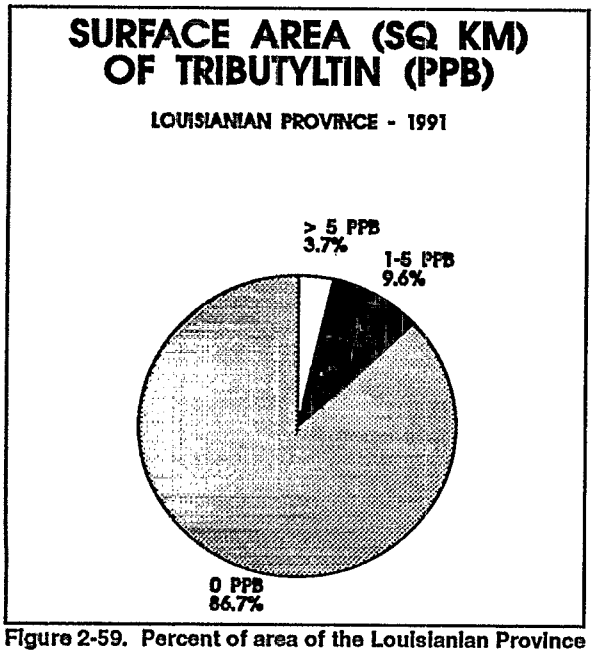


Figure 2-59. Percent of area of the Louisianian Province sediment associated with tributyltin concentration categories in 1991.

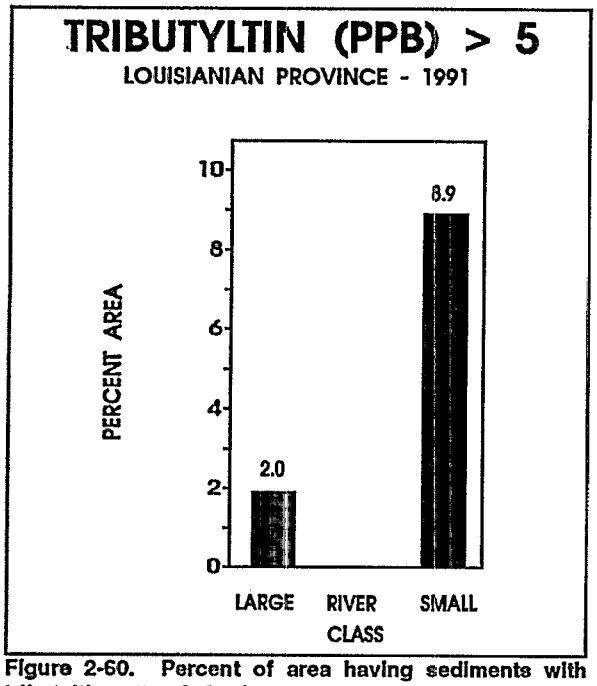


Figure 2-60. Percent of area having sediments with tributyltin > 5 ppb for large estuaries, large tidal rivers, and small estuaries.

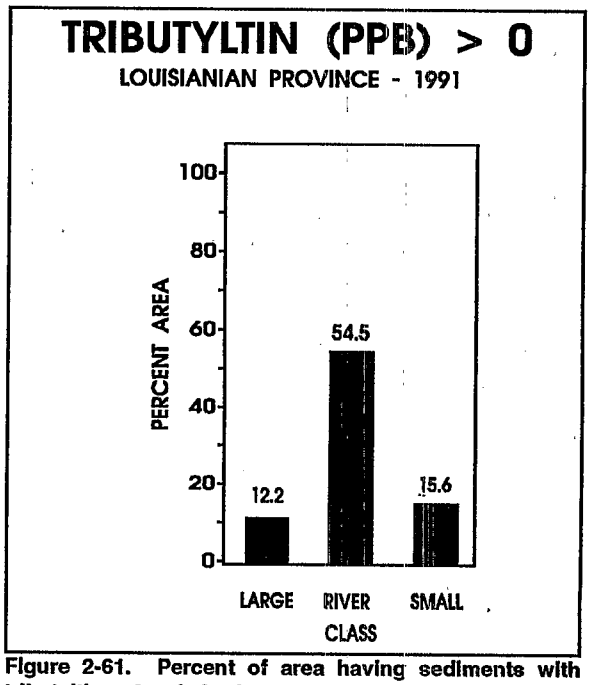


Figure 2-61. Percent of area having sediments with tributyltin > 0 ppb for large estuaries, large tidal rivers, and small estuaries.

16% of sediments in small estuaries, and 12% of sediments in large estuaries having measurable TBT (Fig. 2-61).

2.2.9 SEDIMENT CONTAMINANTS - PESTICIDES

Chlorinated herbicides and 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. 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 2-7.

Pesticide	Range (ppb)	Criteria Exceeded	Percent (10%)	Percent (50%)
2,4'DDD	0 - 0.33	2.0/20	0%	0%
4,4'DDD	0 - 5.16	2.0/20	<1%	0%
2,4'DDE	0 - 2.68	2.0/15	1%	0%
4,4'DDE	0 - 5.10	2.0/15	2%	0%
2,4'DDT	0 - 0.14	1.0/7	0%	0%
4,4'DDT	0 - 1.31	1.0/7	<1%	0%
Aldrin	0 - 0.12	NA	U	U
Alpha-BHC	0 - 0.41	NA	U	U
beta-BHC	0 - 0.22	NA	U	U
delta-BHC	0 - 0.10	NA	U	U
alpha-Chlordane	0 - 0.72	.05/6	4%	0%
gamma-Chlordane	0 - 1.72	.05/6	8%	0%
Dieldrin	0 - 1.46	.02/8	23%	0%
Endosulfan	0 - 0	NA	0%	0%
Endrin	0 - 0.11	.02/45	1%	0%
Hexachlorobenzene	0 - 20.1	NA	U	U
Heptachlor	0 - 0.03	NA	U	U
Heptachlor Epoxide	0 - 3.38	NA	U	U
Mirex	0 - 0.11	NA	U	U
cis-Nonachlor	0 - 0.35	NA	U	U
trans-Nonachlor	0 - 0.58	NA	U	U
Oxychlordane	0 - 0.03	NA	U	U
Toxaphene	0 - 0	NA	0%	0%

Table 2.7 Ranges of pesticide concentrations found in the 1991 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)

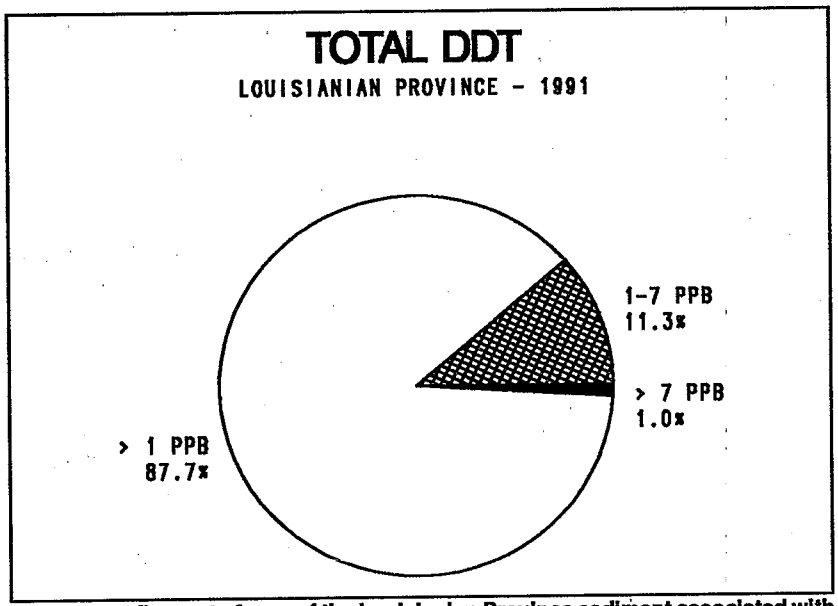


Figure 2-62. Percent of area of the Louisianian Province sediment associated with total DDT concentration categories in 1991.

Total DDT concentrations (2,4'DDT and 4,4'DDT)above the criterion (7 ppb) were found in < 1% of the sediments of the Louisianian Province (Fig. 2-62). These concentrations were found primarily in the large tidal river class (10%) and to a lesser extent in small estuaries (< 1%) (Fig. 2-63).

Total chlordane concentrations did not exceed the criterion of 6 ppb in any sediments in the Louisianian Province but did exceed 0.05 ppb (10% effects criterion) in 8% of estuarine sediments.

Endrin concentration did not exceed its median criterion (45 ppb) in any of the sediments examined from the Louisianian Province; however, 1% 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: however, 23% of sediments had dieldrin concentrations > 0.02 ppb, the 10% effects-level listed by Long & Morgan (1990).

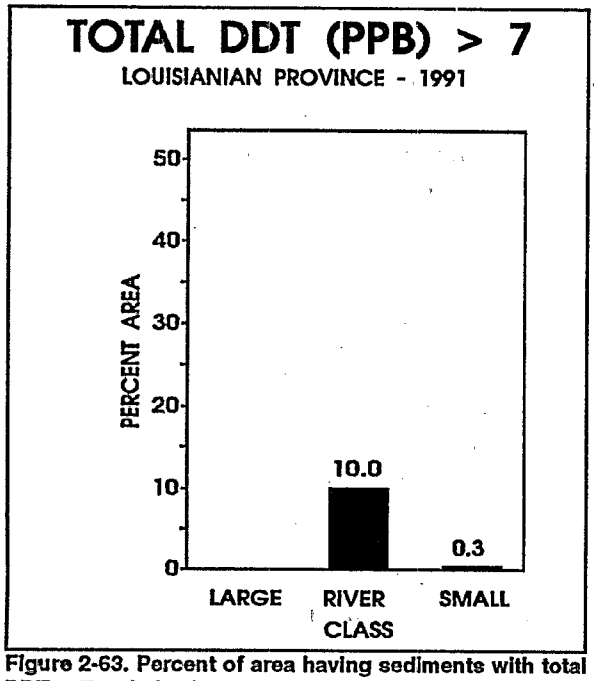


Figure 2-63. Percent of area having sediments with total DDT > 7 ppb for large estuaries, large tidal rivers, and small estuaries.

2.2.10 SEDIMENT CONTAMINANTS - HEAVY METALS

Fifteen heavy metals were analyzed for the sediments collected in the 1991 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.

2.2.10.1 CRITERIA COMPARISONS

Table 2-8 shows the ranges of heavy metals concentrations found during the 1991 Louisianian Province Demonstration and their criteria values for comparison. Only chromium, mercury, nickel, zinc, and to a lesser extent tin, lead, and antimony exceed the selected criteria values (Fig. 2-64). Using the lower criteria (i.e., concentrations resulting in effects 10% of the time), 31.7% of sediments in the Louisianian Province have metal concentrations in excess of these values (Fig. 2-64) whereas only 2% of the sediments exceed the higher criteria. Over 10% of the sediments have two or more metals exceeding the lower criteria values.

These high metal concentrations are primarily found in the large tidal river (80%, Fig. 2-66) and large estuary classes (-40%, Fig. 2-65). Only 9% of the sediments in small estuaries (Fig. 2-67) showed metal concentrations in excess of criteria levels.

2.2.10.2 ANTHROPOGENIC ENRICHMENT

Aluminum concentrations vary over two orders of magnitude (50 ppm-9000 ppm) in the Louisianian Province (Fig. 2-68). As aluminum content in sediments is primarily derived from the natural crust of the earth, this wide variation generally is

Metal	Range (ppm)	Criteria (ppm)	Percent Exceeded (10%)	(50%)
Aluminum	800 - 96100	NA	U	U
Antimony	0 - 2.1	2/25	<1%	0%
Arsenic	1 - 18.5	33/85	0%	0%
Cadmium	0 - 1.4	5/9	0%	0%
Chromium	3 - 119.0	80/145	10%	0%
Copper	0 - 33.7	70/390	0%	0%
Iron	150 - 42600	NA	U	U
Lead	1 - 59.8	35/110	<1%	0%
Manganese	3 - 2130	NA	U	U
Mercury	0 - 2.2	.15/1	22%	2%
Nickel	0 - 45.5	30/50	16%	0%
Selenium	0 - 1.0	NA	U	U
Silver	0 - 0.7	1/2	0%	0%
Tin	0 - 3.3	NA	U	U
Zinc	1 - 167	120/270	6%	0%

Table 2.8 Ranges of heavy metal concentrations found in the 1991 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)

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 Louisianian Province Demonstration data set that were determined to be representative

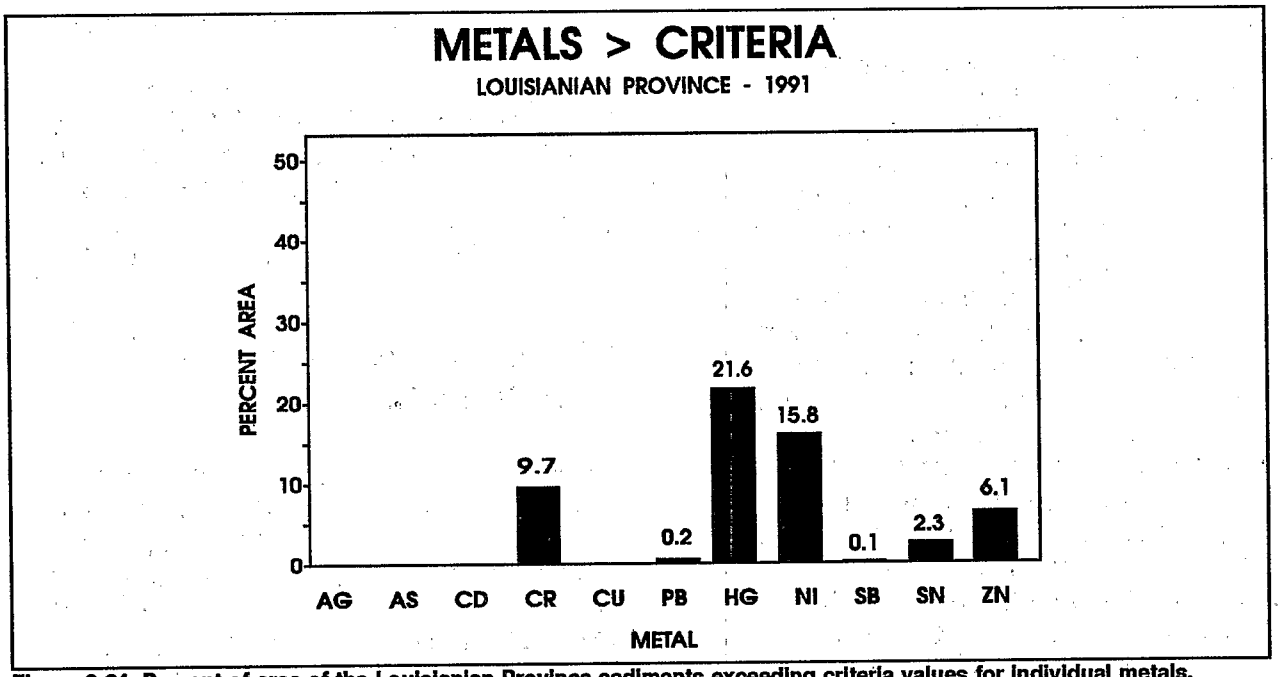


Figure 2-64. Percent of area of the Louisianian Province sediments exceeding criteria values for individual metals.

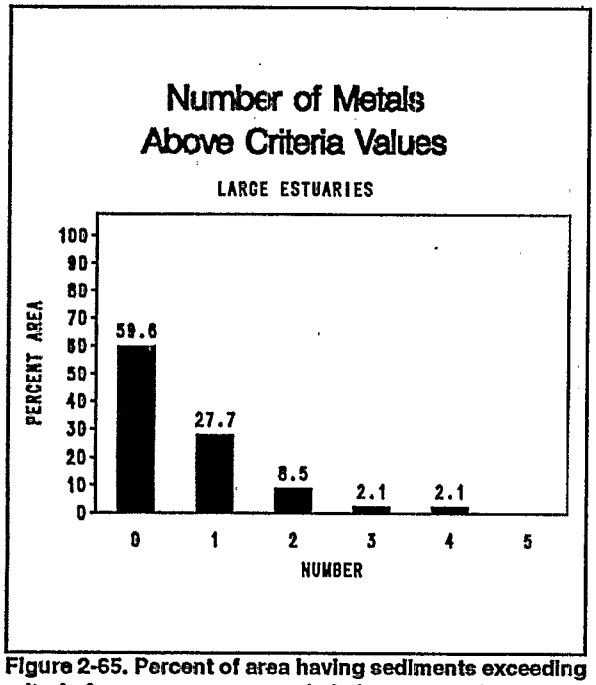


Figure 2-65. Percent of area having sediments exceeding criteria for one or more metals in large estuaries.

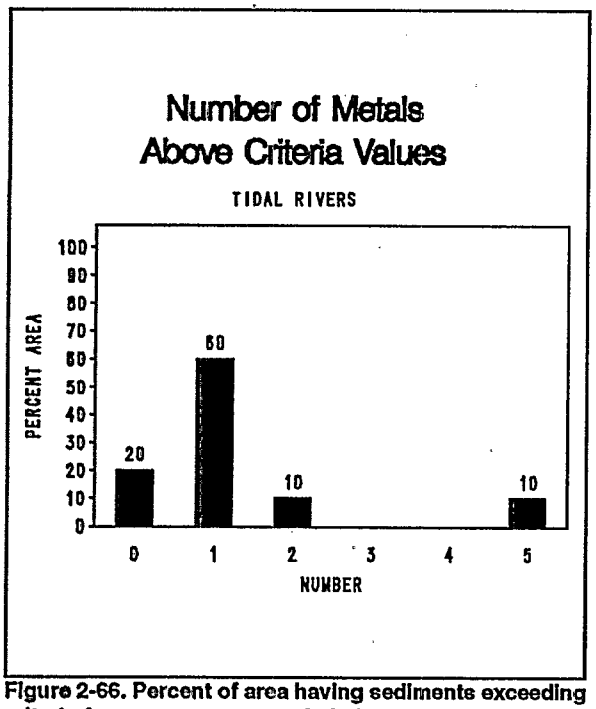


Figure 2-66. Percent of area having sediments exceeding criteria for one or more metals in large estuaries.

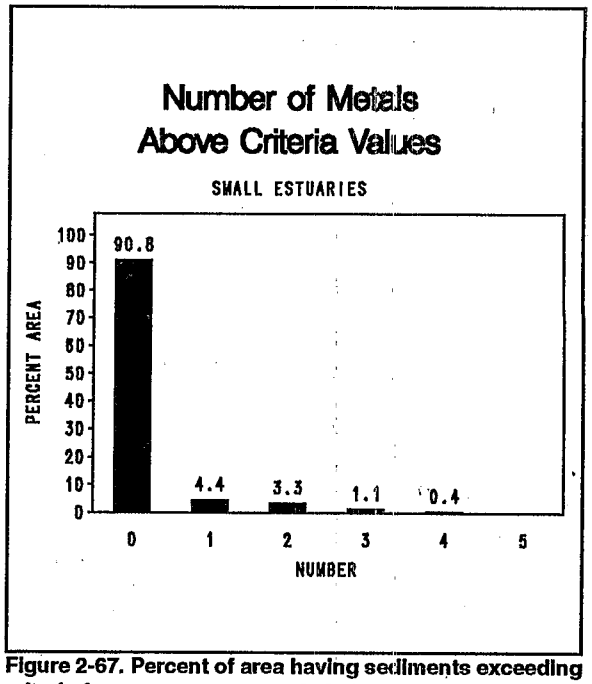


Figure 2-67. Percent of area having sediments exceeding criteria for one or more metals in large estuaries.

of natural, unenriched areas were selected to develop the regressions. An example is shown in Fig. 2-69 for mercury. 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 (Fig. 2-70). The results of these regression analyses for all metals revealed some enrichment of all metals although the technique would be expected to show 1-2% enrichment as a artifact of the technique. Even with this slight bias, clear enrichment of Louisianian Province sediments is evident for mercury (23% of sediments) and to a lesser extent for arsenic, chromium, and lead (Fig. 2-71).

By comparison, the two methods yielded very similar results with 67% of the sediments meeting the criteria levels and

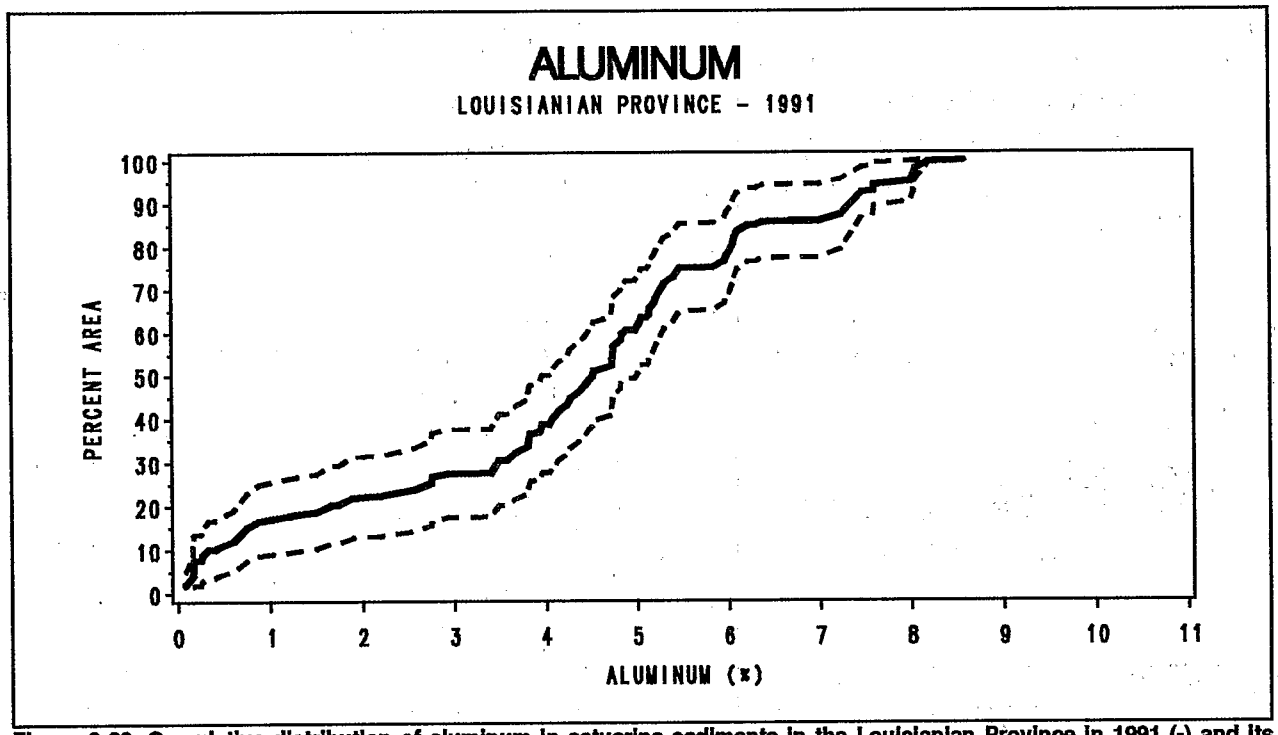


Figure 2-68. Cumulative distribution of aluminum in estuarine sediments in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

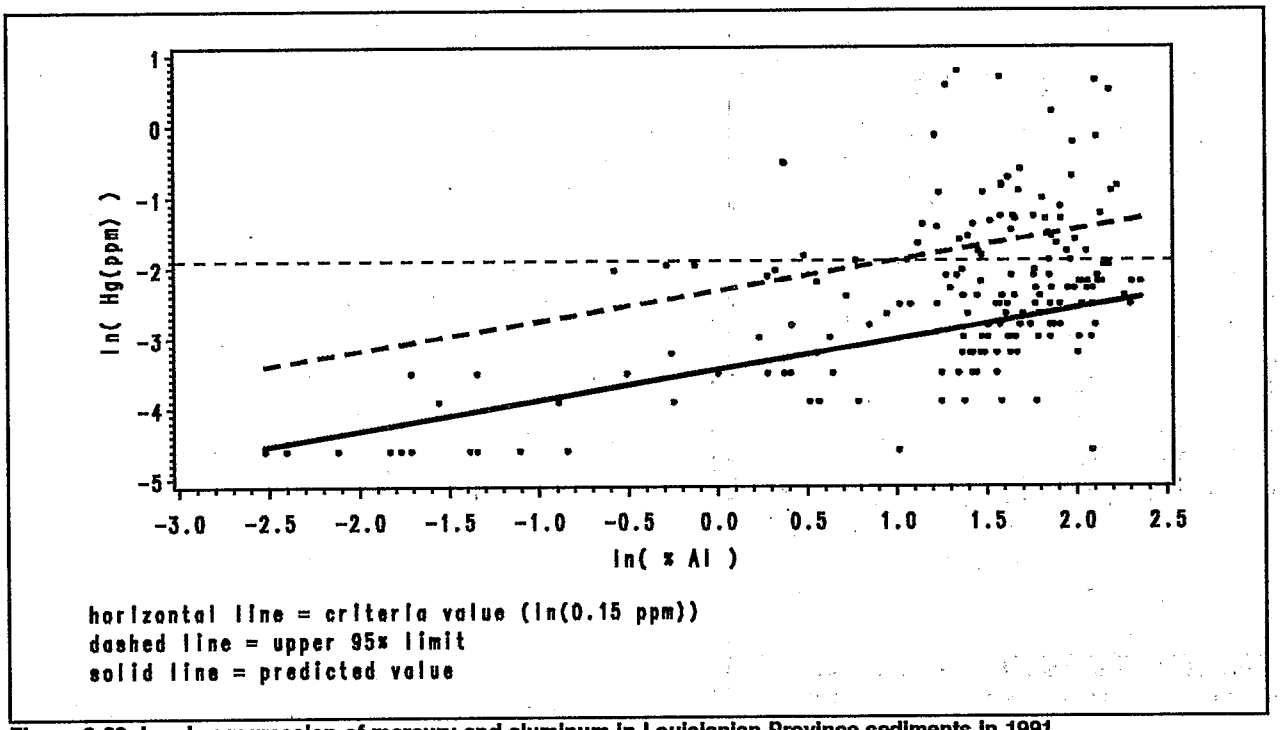


Figure 2-69. Log-log regression of mercury and aluminum in Louisianian Province sediments in 1991.

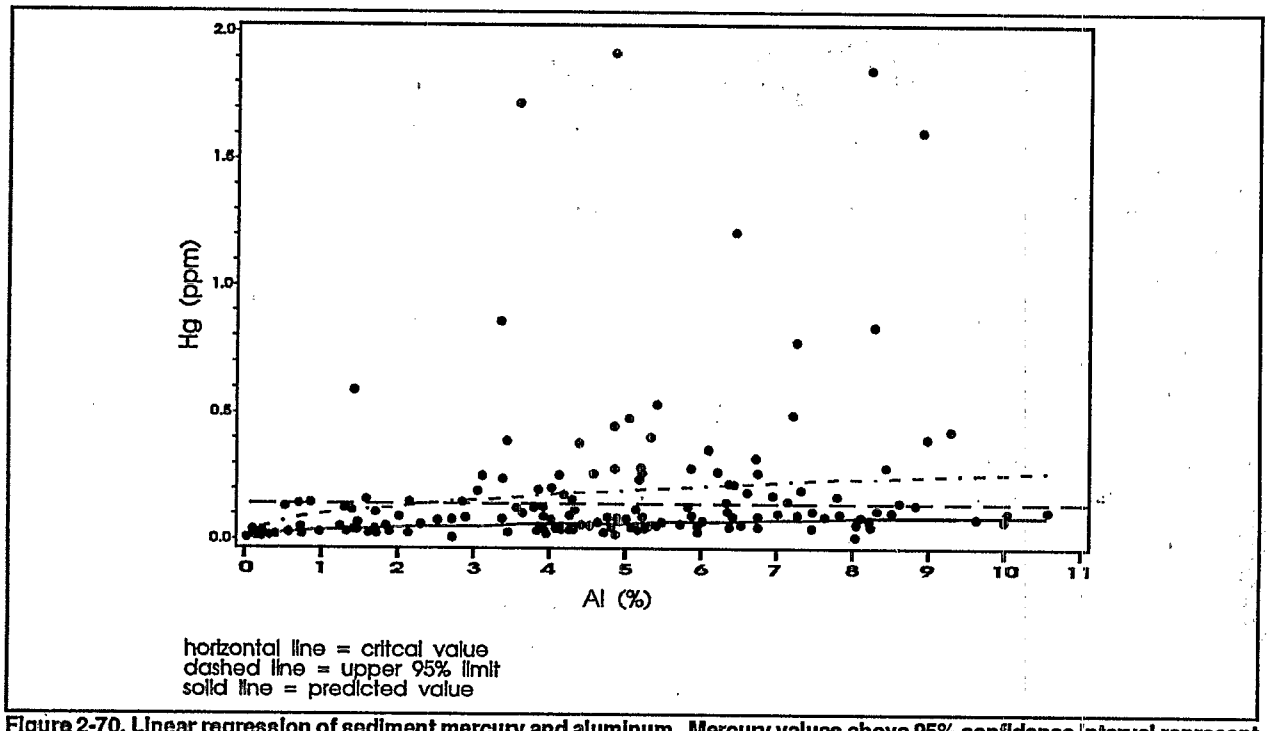


Figure 2-70. Linear regression of sediment mercury and aluminum. Mercury values above 95% confidence interval represent enrichment.

68% of the sediments being "unenriched". The proportion of sediments enriched by a single metal and exceeding the criterion for only a single metal is also similar (21% exceeding and 23% enriched). While the overall picture is the same, inspection of Figs. 2-64 and 2-71 show some marked differences. While mercury levels are exceeded by >20% of the sediments in both cases, nickel exceeds critical values in 16% of sediments while aluminum-adjusted nickel concentrations show relatively little enrichment (2.1%). Zinc concentrations in excess of criterion values also appear to be primarily natural in origin. Conversely, arsenic never exceeds its criterion but based on regressions with aluminum is enriched in 6% of Louisianian Province sediments. A similar relationship is seen for lead.

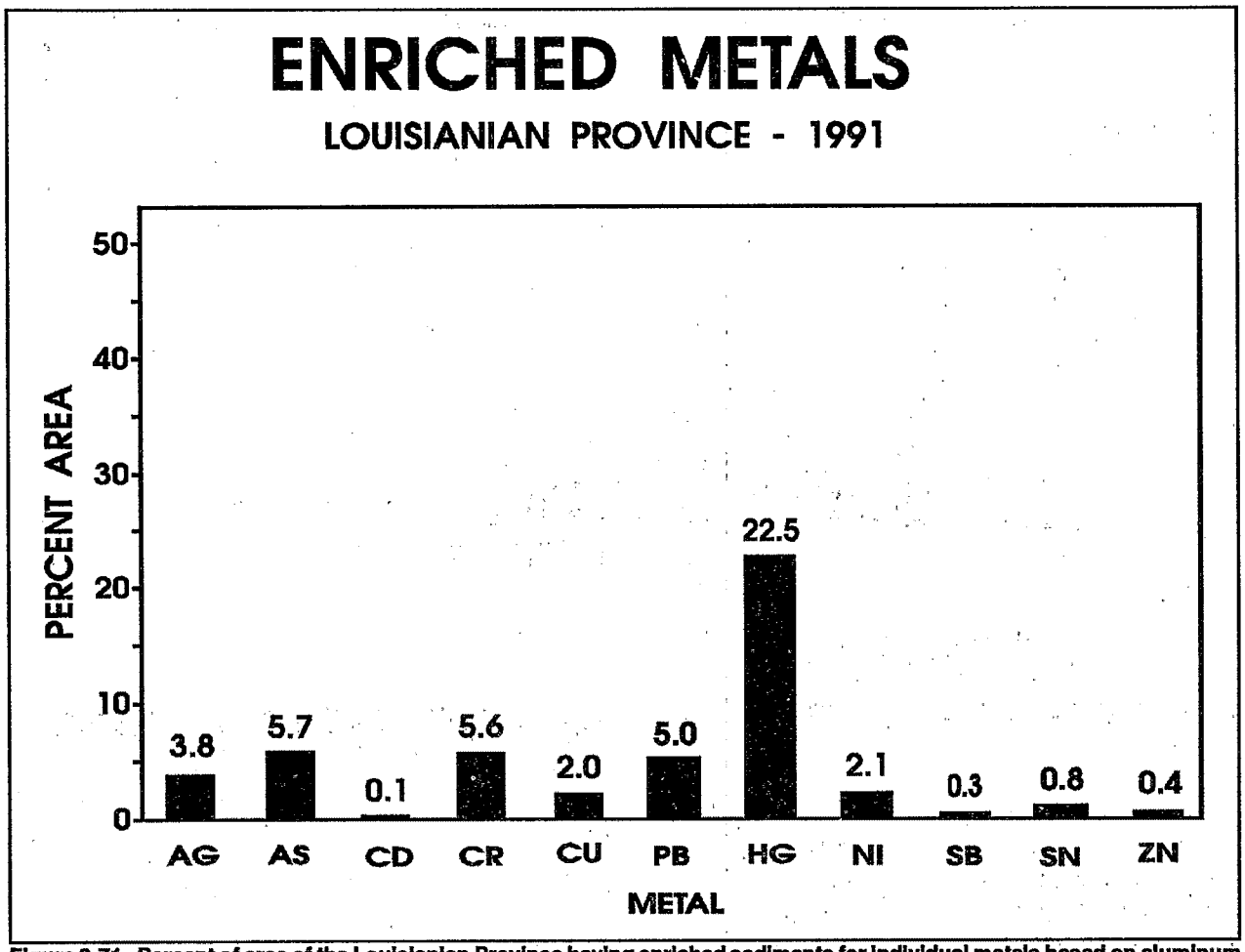


Figure 2-71. Percent of area of the Louisianian Province having enriched sediments for individual metals based on aluminum regressions.

2.3 HABITAT INDICATORS

Habitat indicators describe the natural physical and chemical conditions of the locations sampled in the 1991 Louisianian Province Demonstration. These parameters are discussed below.

2.3.1 WATER DEPTH

The Louisianian Province is comprised primarily of large and small shallow estuaries with water depths rarely exceeding 3-4 m except in dredged channels. The distribution of water depth observed in the Louisianian Province in 1991 is shown in Fig. 2-72. The proportions of the estuarine classes that have water depths of less than two meters are shown in Fig. 2-73 with large and small estuaries showing significant expanses of shallow water (26% of large estuaries and 52% of small estuaries).

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 five degrees Celsius (Fig. 2-74) from 27°C to 32°C. Figure 2-74 is comprised of only daytime observations; however, continuous recorders that collected temperature data every 15 minutes for 24 hours showed only a 4.8°C increase in the observed range (Fig. 2-75). This increase reflects the increased thermal variation depicted by inclusion of night temperatures. Thus, estuarine biota and habitats are exposed to

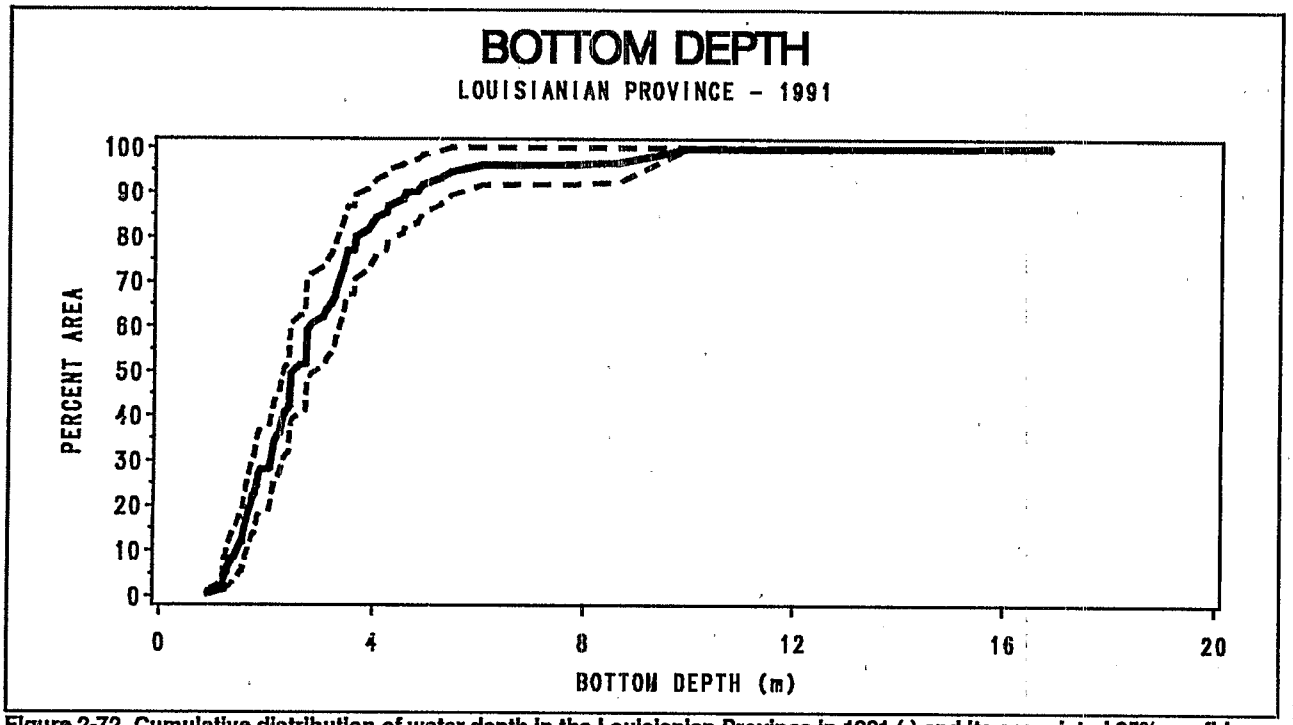


Figure 2-72. Cumulative distribution of water depth in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

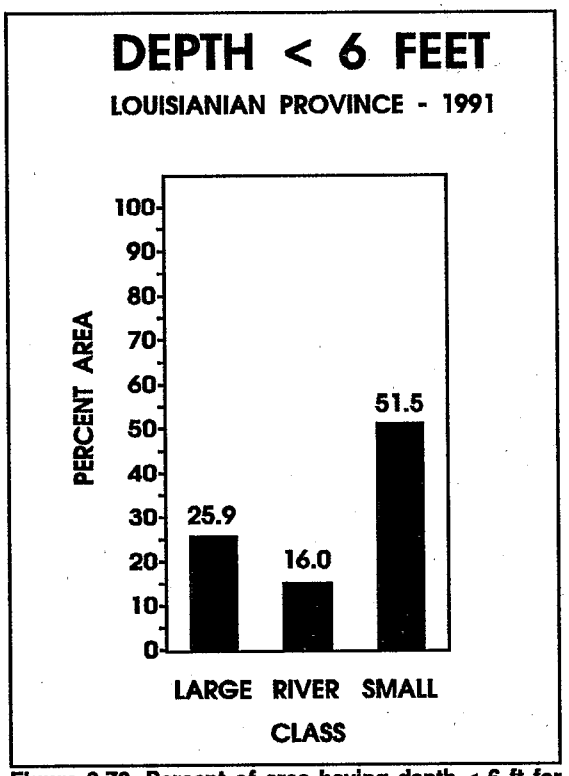


Figure 2-73. Percent of area having depth < 6 ft for large estuaries, large tidal rivers, and small estuaries.

water temperature above 20°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, 1991 was a very wet year, particularly in late spring and early summer. As a result, the Louisianian Province was characterized by a wide variety of salinity conditions. Salinity ranged from 0.0 to 40 ppt throughout the province (Fig. 2-76). Continuous salinity measurements did not increase the observed salinity range but reduced the percentage of freshwater from 14% of the area of the province (based on instantaneous measurements) to 6% of the area of the province (Fig. 2-77). Oligohaline waters (0-5 ppt) comprised

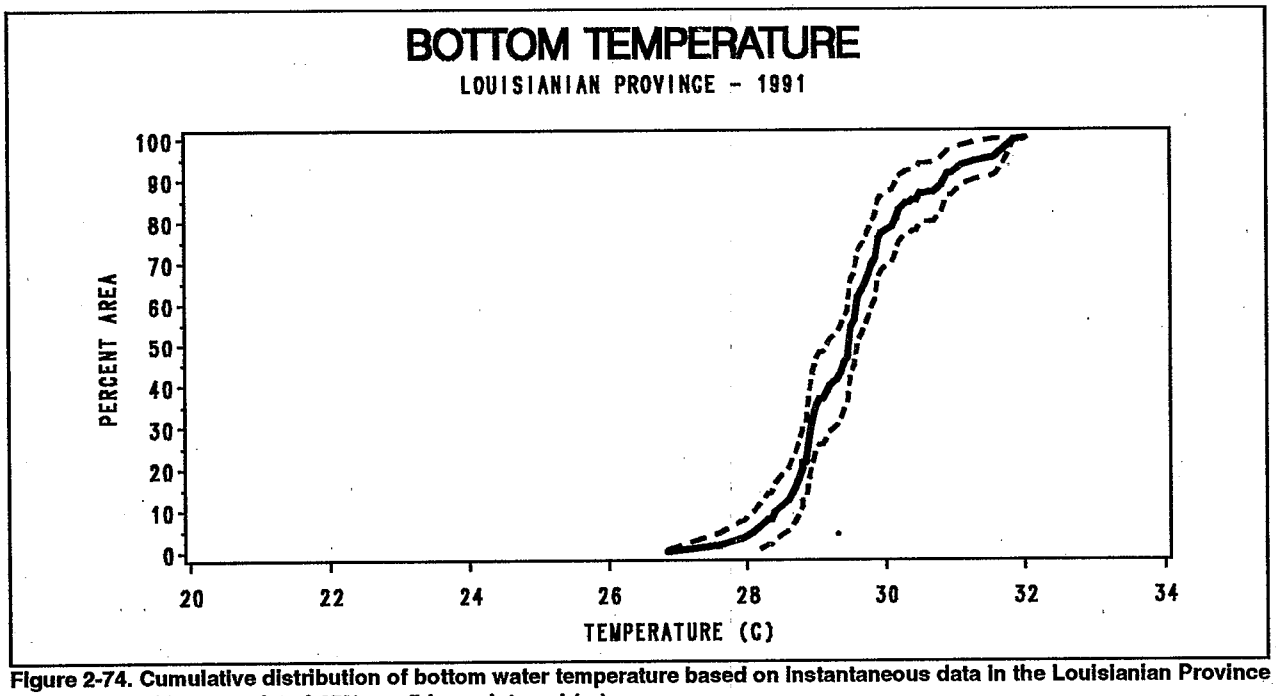


Figure 2-74. Cumulative distribution of bottom water temperature based on instantaneous data in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

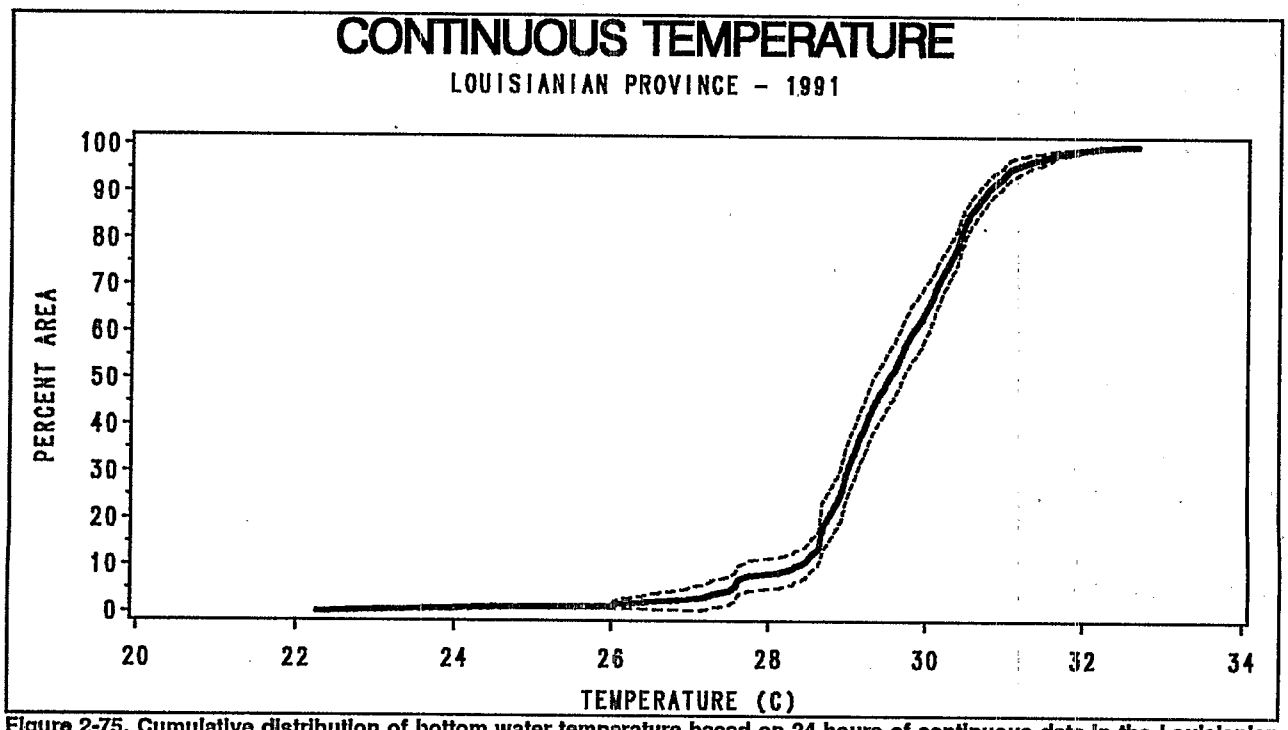


Figure 2-75. Cumulative distribution of bottom water temperature based on 24 hours of continuous data in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

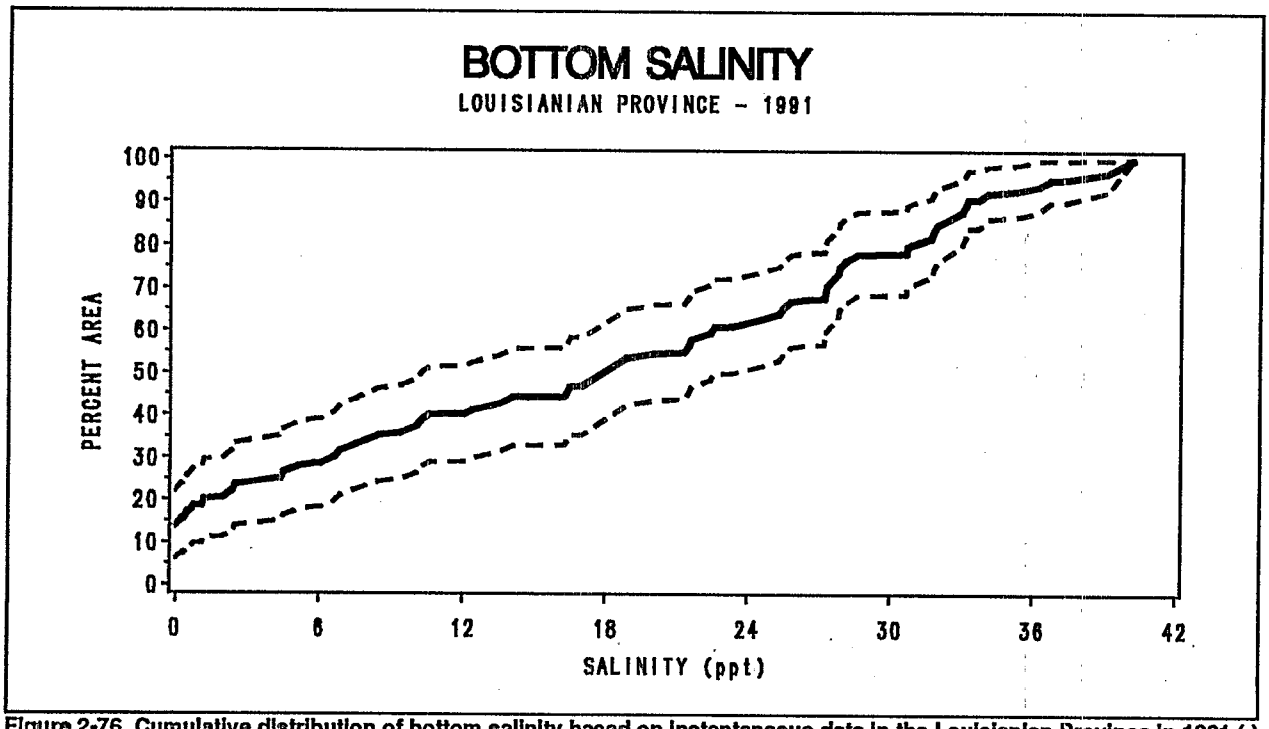


Figure 2-76. Cumulative distribution of bottom salinity based on instantaneous data in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

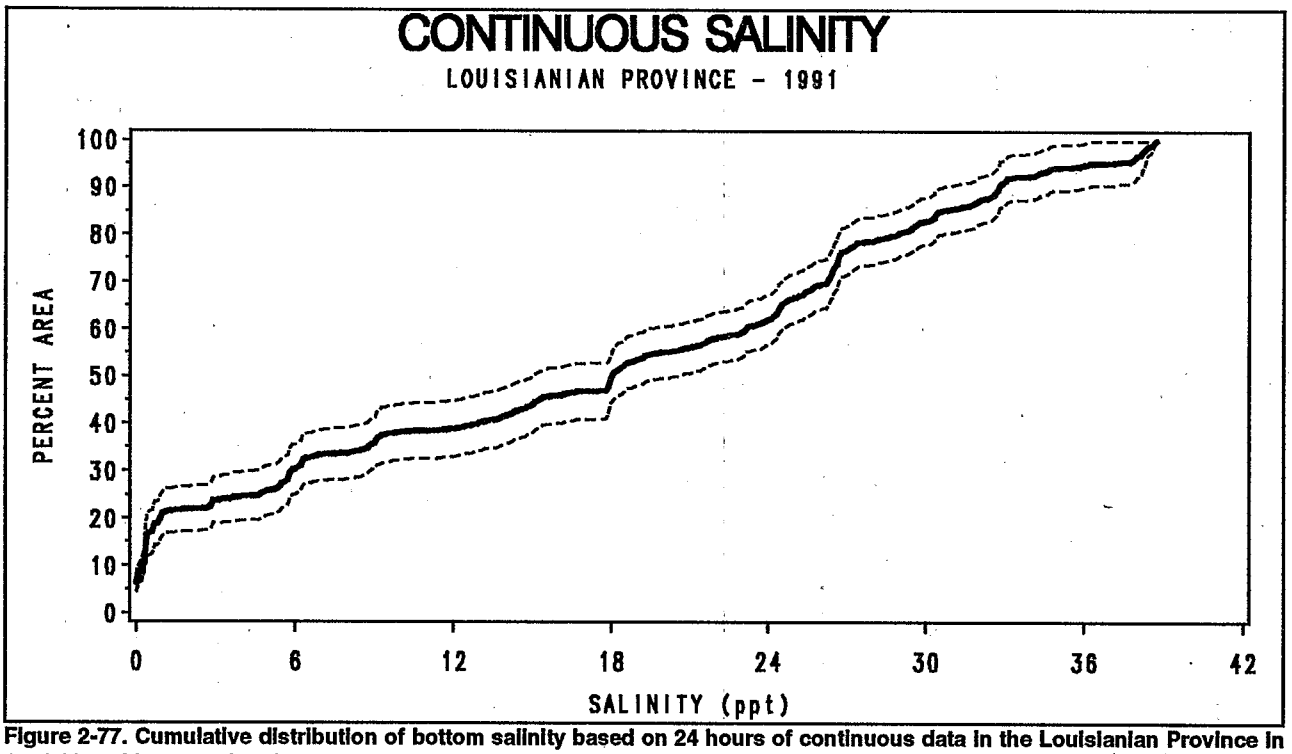


Figure 2-77. Cumulative distribution of bottom salinity based on 24 hours of continuous data in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

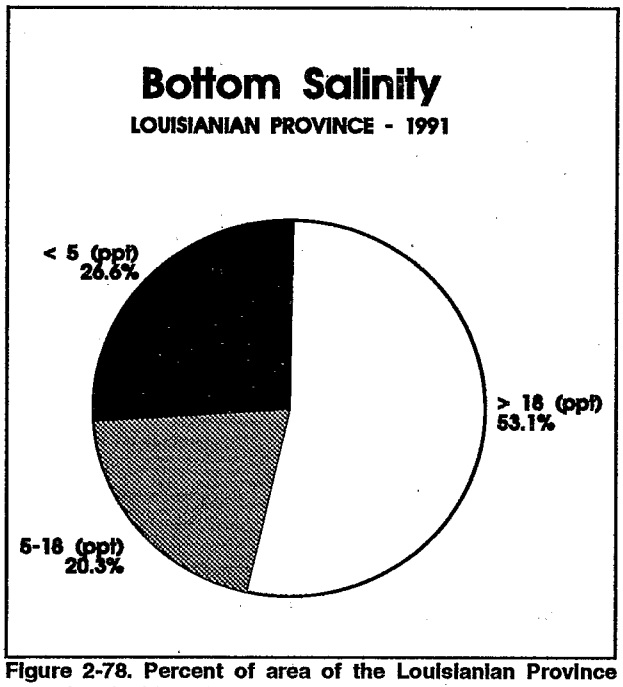


Figure 2-78. Percent of area of the Louisianian Province associated with major salinity categories in 1991.

27% of the province estuarine waters, mesohaline waters (5-18 ppt) contributed 20%, while polyhaline waters made up the majority of the resource at 53% (Fig. 2-78). Oligohaline waters comprised only 27% of the province. As expected, the estuarine waters were primarily polyhaline in 1991 (Fig. 2-78). Large tidal rivers are predominantly (85%) oligohaline, while large and small estuaries are about 29-32% oligohaline (Fig. 2-79). Almost all of the 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 (Fig. 2-80)

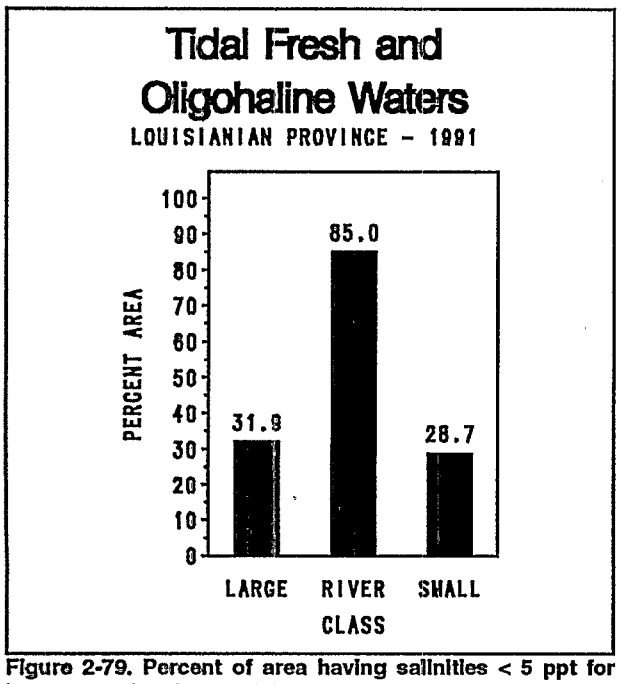


Figure 2-79. Percent of area having salinities < 5 ppt for large estuaries, large tidal rivers, and small estuaries.

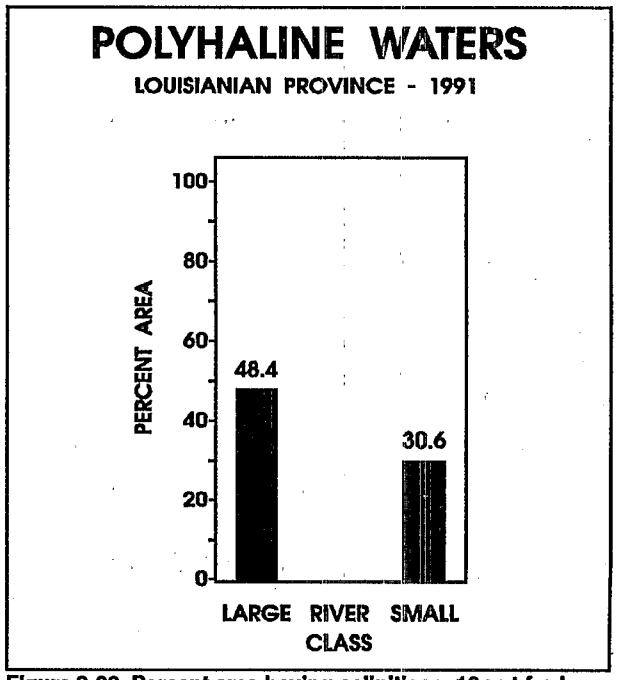


Figure 2-80. Percent area having salinities > 18 ppt for large estuaries, large tidal rivers, and small estuaries.

while small estuarine systems are about evenly split between mesohaline (41%) and polyhaline (31%) salinities (Figs. 2-80, 2-81).

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 1991. Bottom pHs ranged from 5.6 to 10.5 (Fig. 2-82) during the sampling period in 1991 with most of the pH values < 7 occurring in small estuaries (Fig. 2-83).

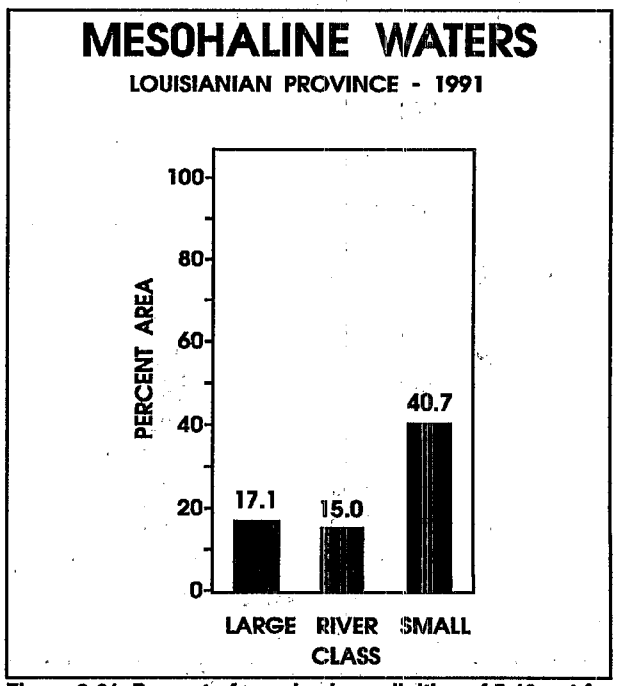


Figure 2-81. Percent of area having salinities of 5-18 ppt for large estuaries, large tidal rivers, and small estuaries.

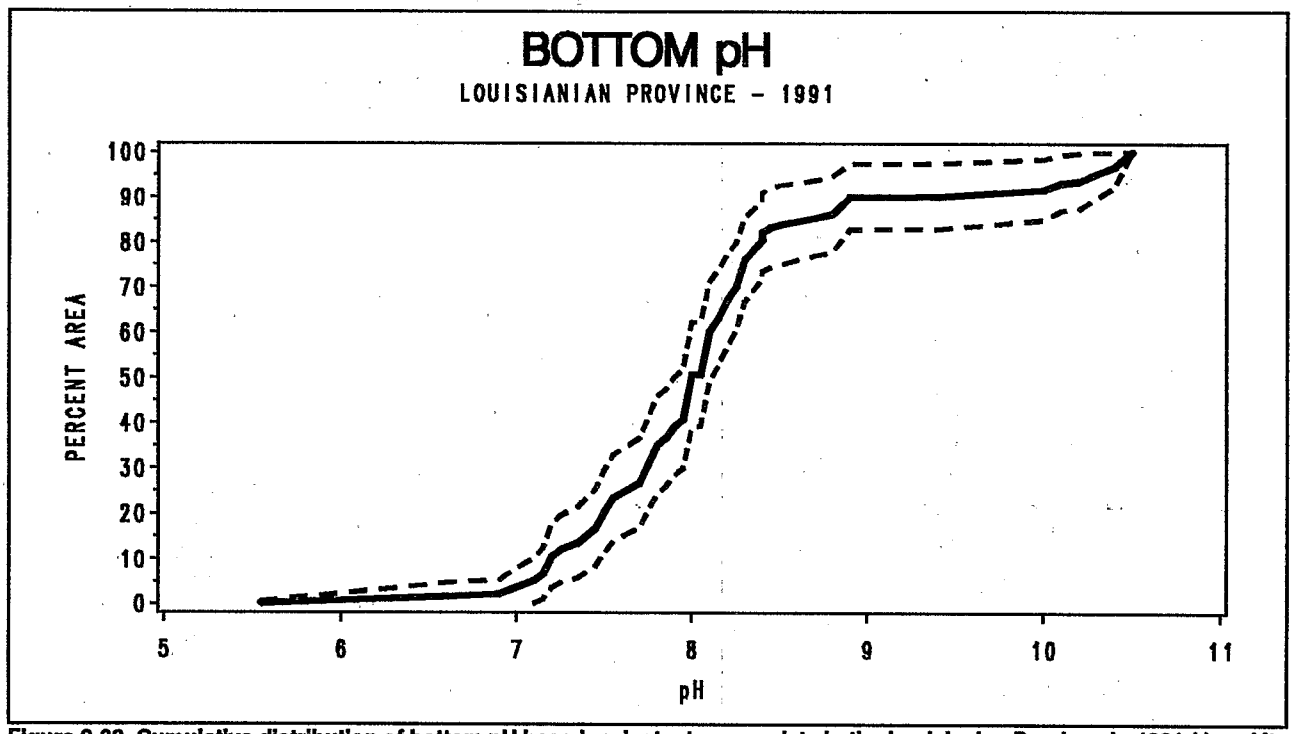


Figure 2-82. Cumulative distribution of bottom pH based on instantaneous data in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

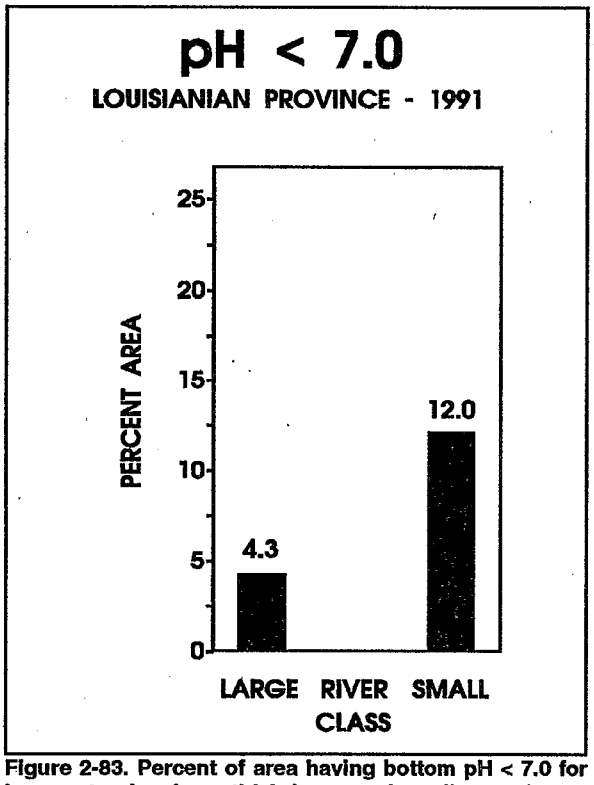


Figure 2-83. Percent of area having bottom pH < 7.0 for large estuaries, large tidal rivers, and small estuaries.

2.3.5 SECCHI DEPTH

Secchi depth is a simple measure of instantaneous water clarity. While often discarded as a useful measure by many ecologists, it can produce useful information if care is taken while deploying the apparatus and a consistent observer is used. In order to confirm the reliability of Secchi measures, we concurrently took PAR measures with a LICOR-1000. Secchi depths ranged from 0.1m to 4m in the Louisianian Province in 1991 (Fig. 2-84). The distribution of observed Secchi depths showed that 24% of the province was characterized by depths of < 0.5 m, 31% by depths of 0.5-1.0 m, and 45% of the province had relatively clear water with Secchi depths of > 1 m (Fig. 2-85). Waters with poor light transmission, characterized by Secchi depths of < 0.5 m, were primarily found in the small estuary class (50%)

although about 20% of large estuaries and large tidal rivers also had poor clarity (Fig. 2-86).

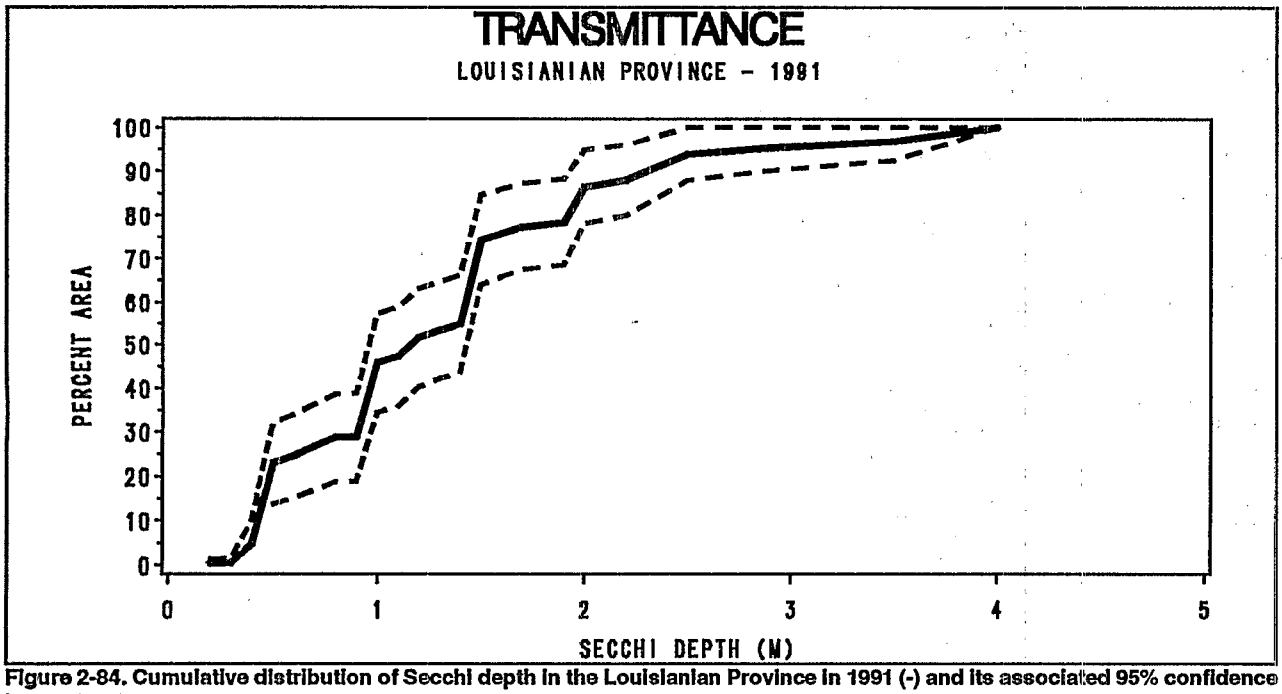


Figure 2-84. Cumulative distribution of Secchi depth in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (—).

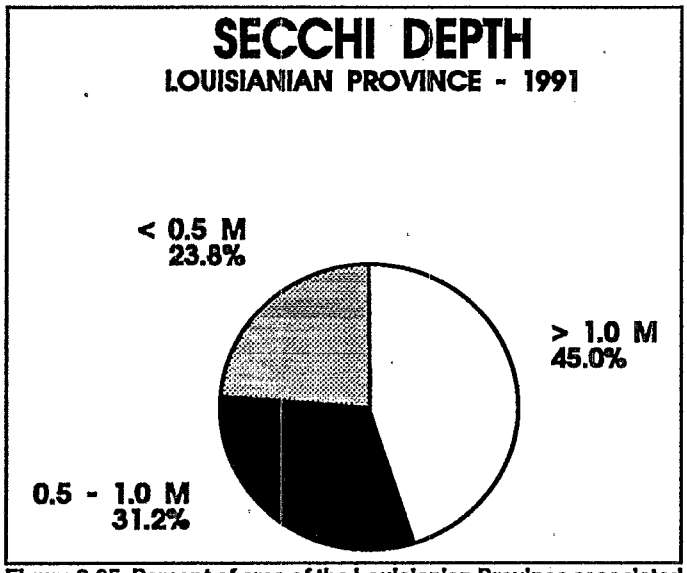


Figure 2-85. Percent of area of the Louisianian Province associated with Secchi depth categories in 1991.

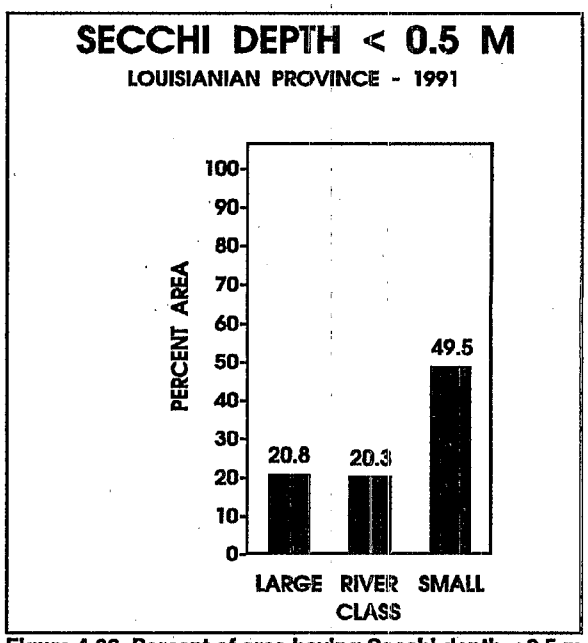


Figure 4-86. Percent of area having Secchi depth < 0.5 m for large estuaries, large tidal rivers, and small estuaries.

2.3.6 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 1991 Louisianian Province Demonstration show that stratification salinity differences range from -2 to 16 ppt often over only 2-3 m of water column (Fig. 2-87). 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 about 15% of the estuarine waters in the province (Fig. 2-87) and is primarily seen in large estuaries and the lower portions of large tidal rivers (Fig. 2-88).

2.3.7 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 Louisianian Province is comprised of 65% mud (> 80% silts and clays), 31% intermediate muddy-sand (20-80% silts and clays), and 4% sand (< 20% silts and clays) (Fig. 2-89). This distribution also holds for the three sampling classes with the exception of large tidal rivers which have no sand and 80% mud (Figs. 2-90-92).

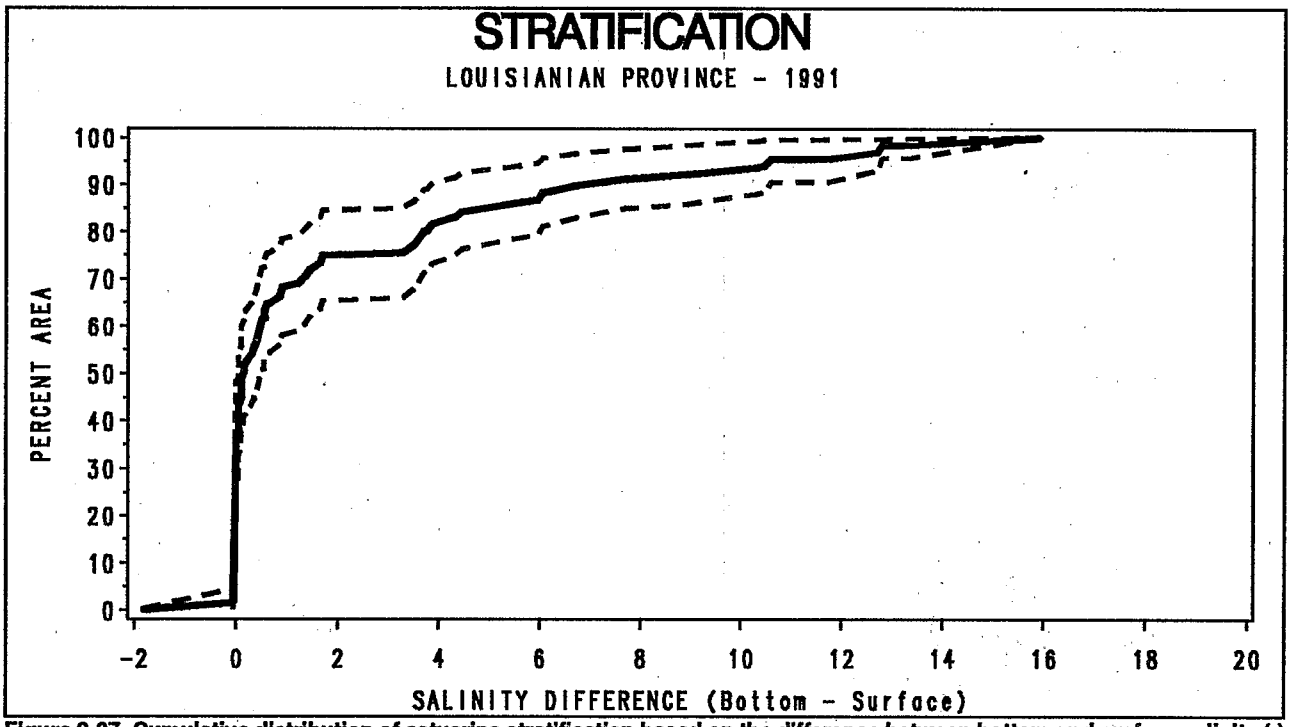


Figure 2-87. Cumulative distribution of estuarine stratification based on the difference between bottom and surface salinity (-) and its associated 95% confidence interval (---).

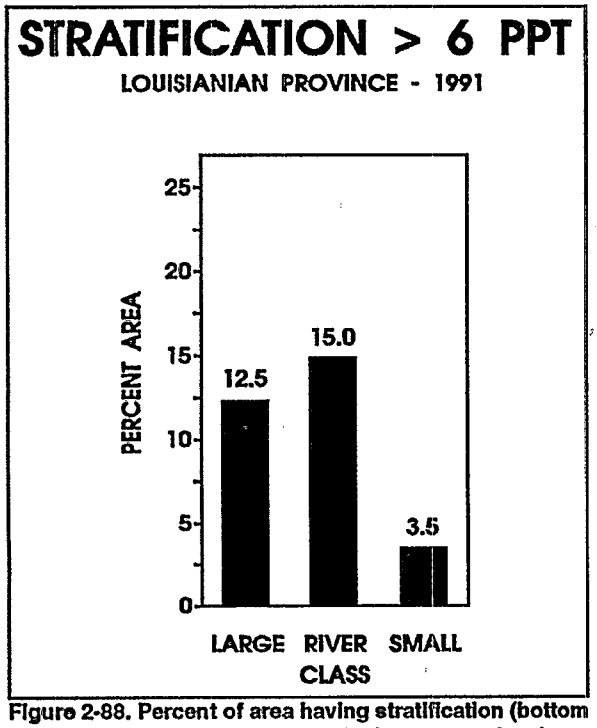


Figure 2-88. Percent of area having stratification (bottom salinity-surface salinity) > 6 ppt for large estuaries, large tidal rivers, and small estuaries.

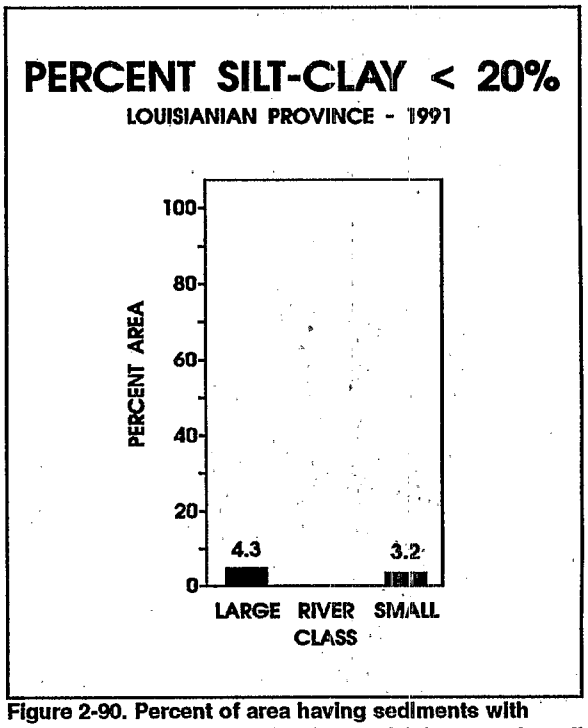


Figure 2-90. Percent of area having sediments with < 20% clay for large estuaries, large tidal rivers, and small estuaries.

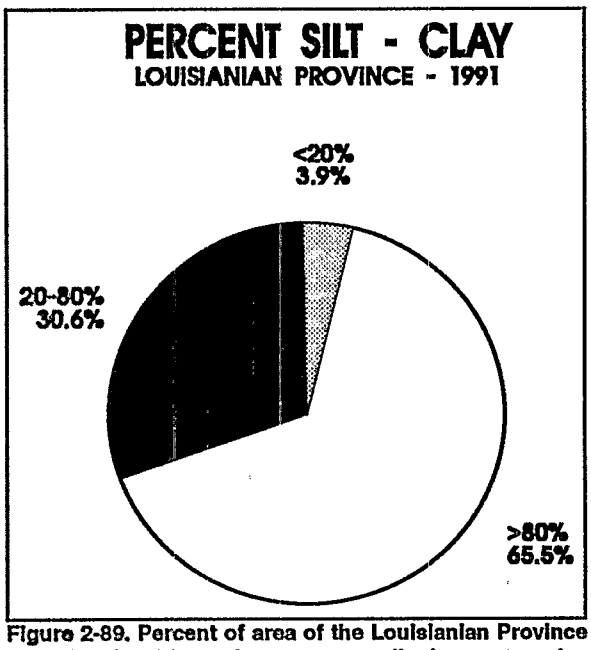


Figure 2-89. Percent of area of the Louisianian Province associated with major percent silt-clay categories (categories in % clay).

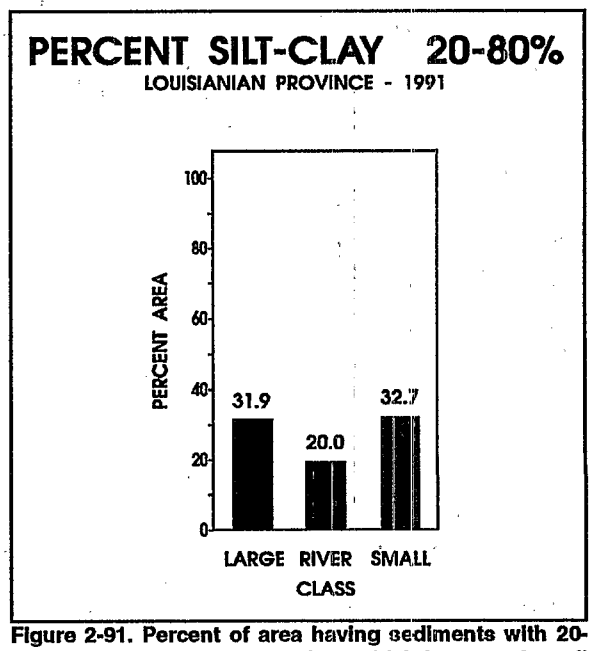


Figure 2-91. Percent of area having sediments with 20-80% clay for large estuaries, large tidal rivers, and small estuaries.

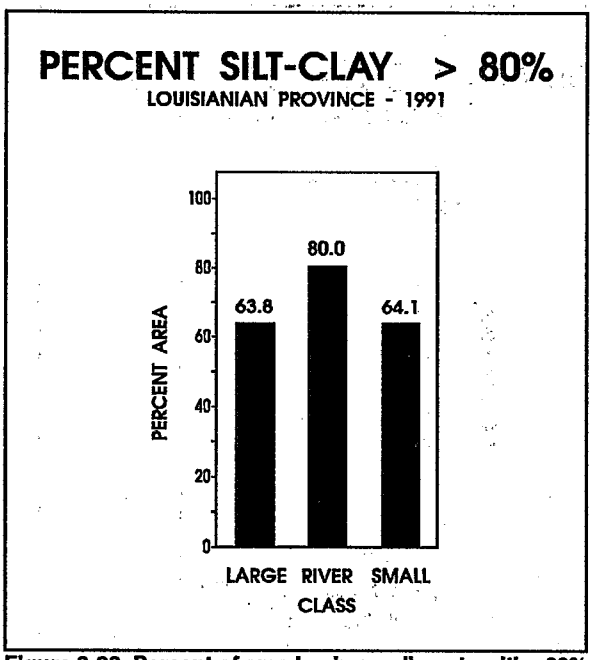


Figure 2-92. Percent of area having sediments with >80% clay for large estuaries, large tidal rivers, and small estuaries.

2.3.8 PERCENT TOTAL ORGANIC CARBON

Another important physico-chemical characteristic of estuarine sediments is the of 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 1991 Louisianian Province Demonstration, sediments in the province range from nearly pure sand (no organic carbon) to highly enriched sediments approaching 13% TOC (Fig. 2-93). Low to normal organic carbon content (0-1%) was found in 54% of province sediments, 24% of the province was slightly enriched, while 22% was enriched

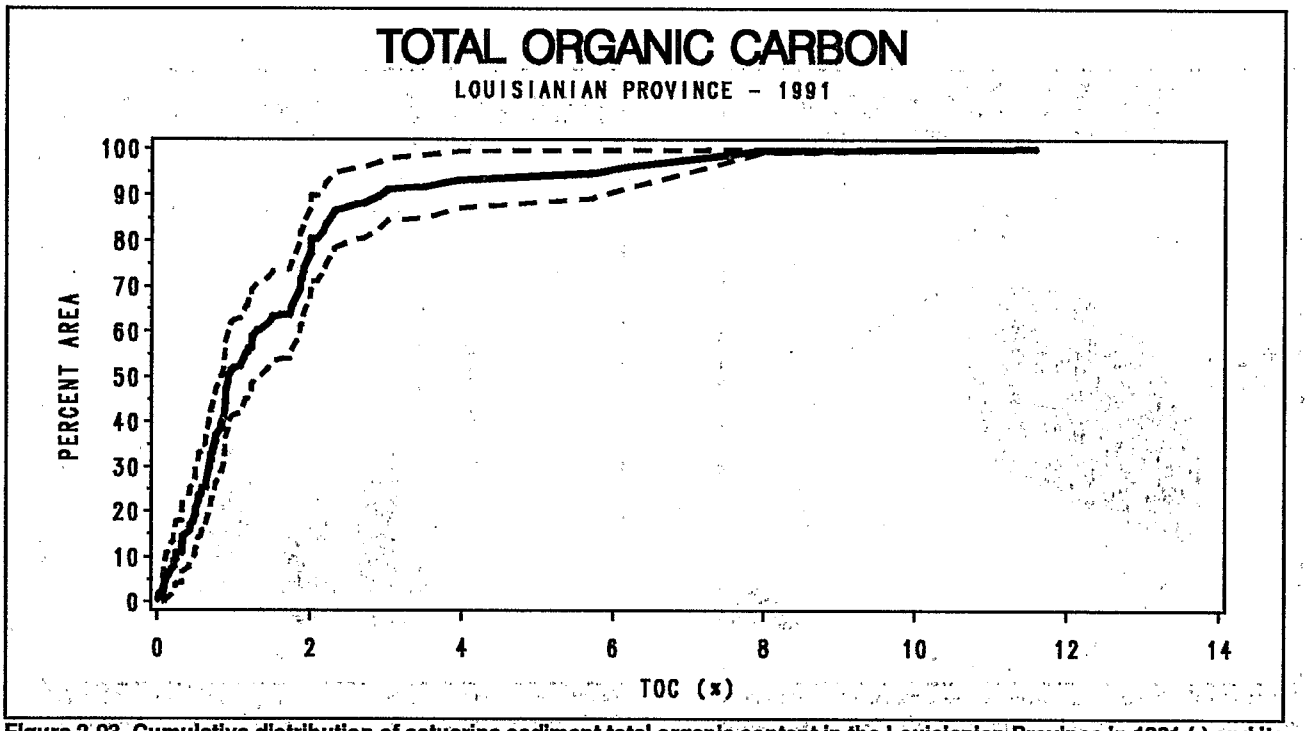


Figure 2-93. Cumulative distribution of estuarine sediment total organic content in the Louisianian Province in 1991 (-) and its associated 95% confidence interval (---).

to the extent of producing a sediment that was > 2% TOC (Fig. 2-94). No organically enriched sediments were found in the large tidal rivers of the province (Fig. 2-95) providing evidence of the generally low productivity and the extensive currents within the river systems. About 21-26% of the sediments from large and small estuarine systems have organic carbon content > 2%.

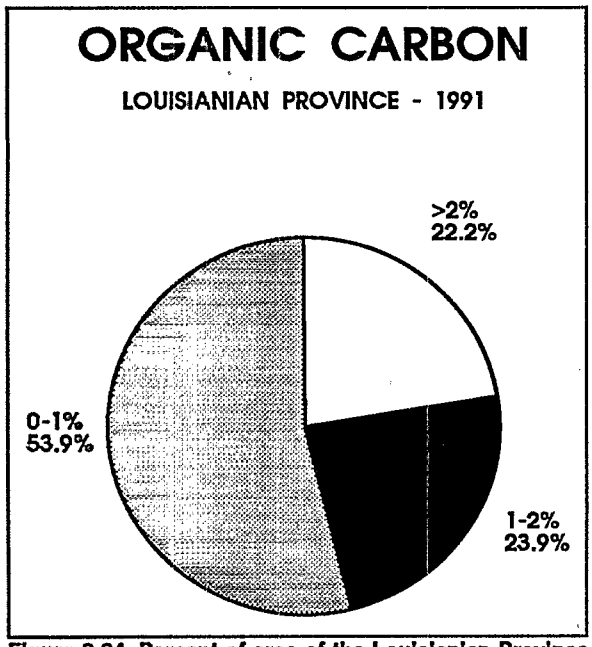


Figure 2-94. Percent of area of the Louisianian Province associated with major percent total organic carbon categories in 1991.

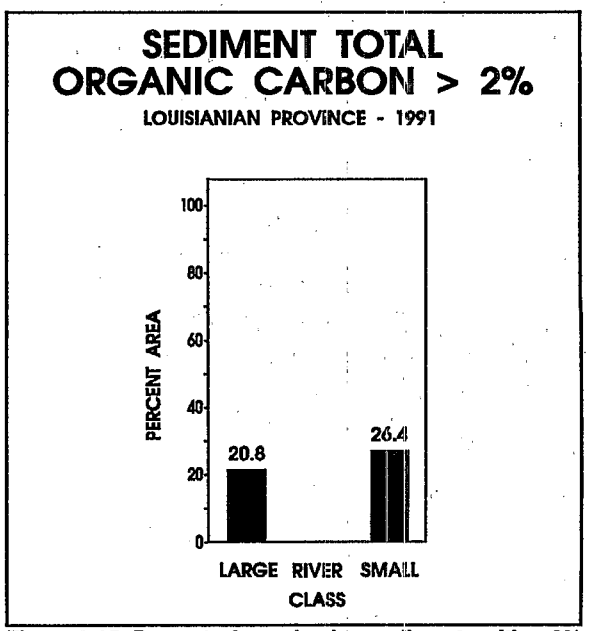


Figure 2-95. Percent of area having sediments with > 2% total organic carbon for large estuaries, large tidal rivers, and small estuaries.

2.3.9 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. 2-96). However, numerous flaws in the collection technique were discovered that permitted the partial oxidation of the sample before analysis. Clearly, most of the AVS were oxidized as 90% of the samples had < 5 mg/kg AVS. Unfortunately, it is impossible to ascertain the extent of oxidation and the assumption that all samples oxidized equally seems unreasonable. For these reasons, AVS was not used further in 1991 analyses. However, collection techniques problems will be corrected in 1992.

2.3.10 REDOX POTENTIAL DISCONTINUITY DEPTH

Redox potential discontinuity depth represents a biogeochemical marker in the estuarine sediments that demarks the transition zone from aoxic to anoxic conditions. The deeper this horizon, the better the sediment is oxygenated and can support deep burrowing benthos. Three replicates (one from each benthic grab) were taken at each sampling location and resulted in RPD depths ranging from 0-110 mm (Fig. 2-97).

While no guidelines exist to develop a criterion for RPD depth, a depth of < 10 mm was selected as representative of relatively anaerobic benthic conditions. An immediate level of 10-50 mm in depth was used as descriptive of situations where the potential for anaerobic conditions existed and depths > 50 mm were categorized as

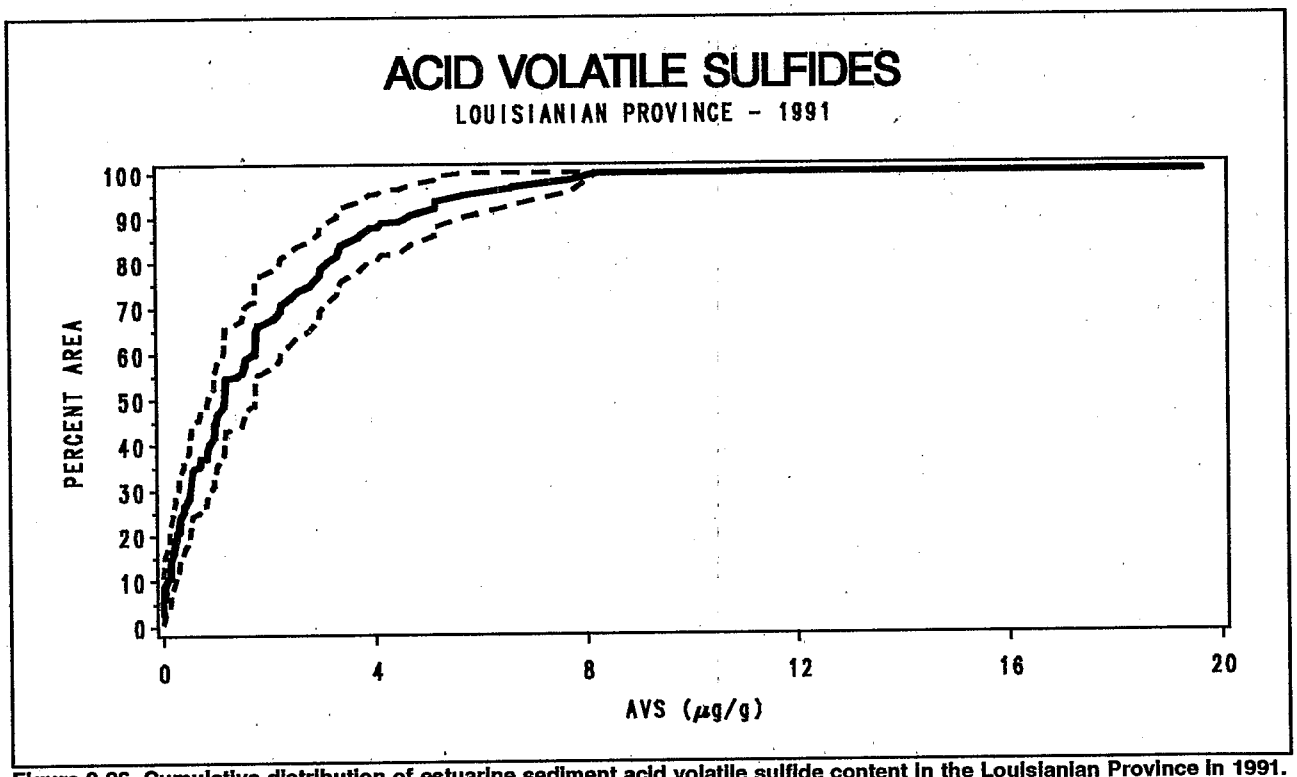


Figure 2-96. Cumulative distribution of estuarine sediment acid volatile sulfide content in the Louisianian Province in 1991.

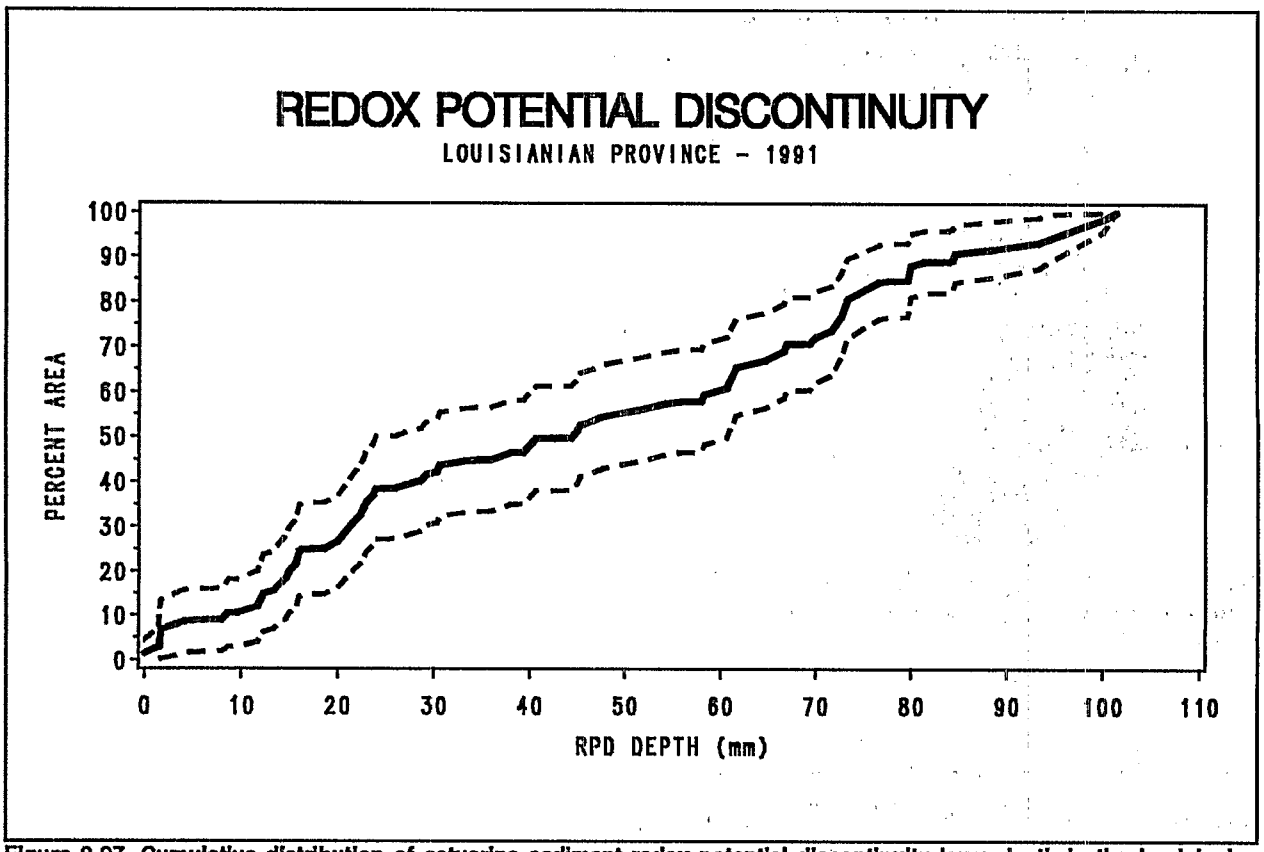


Figure 2-97. Cumulative distribution of estuarine sediment redox potential discontinuity layer depth in the Louisianian Province in 1991.

aerobic. Nine percent of the Louisianian Province was characterized by RPD depths of < 10 mm (Fig. 2-98). These anaerobic conditions occurred primarily in large and small estuaries with 10% and 15% of these classes being characterized by degraded RPD depths (Fig. 2-99).

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 appendix A. Table 2-9 provides these intervals for the major indicators for the proportion of the province and the three estuarine classes.

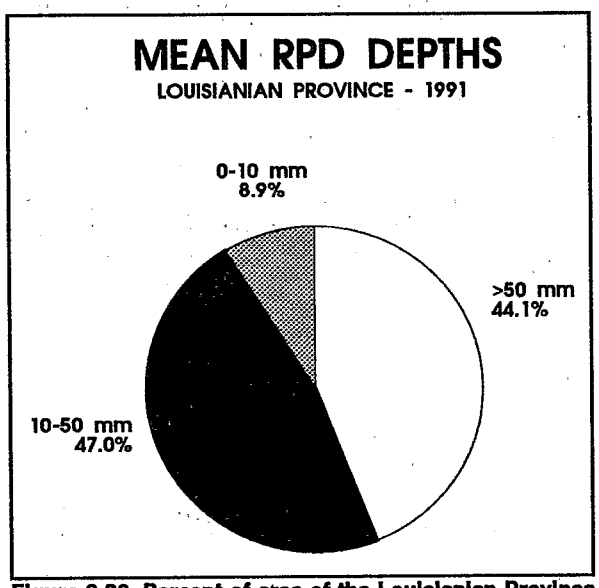


Figure 2-98. Percent of area of the Louisianian Province associated with major redox potential discontinuity depth categories in 1991.

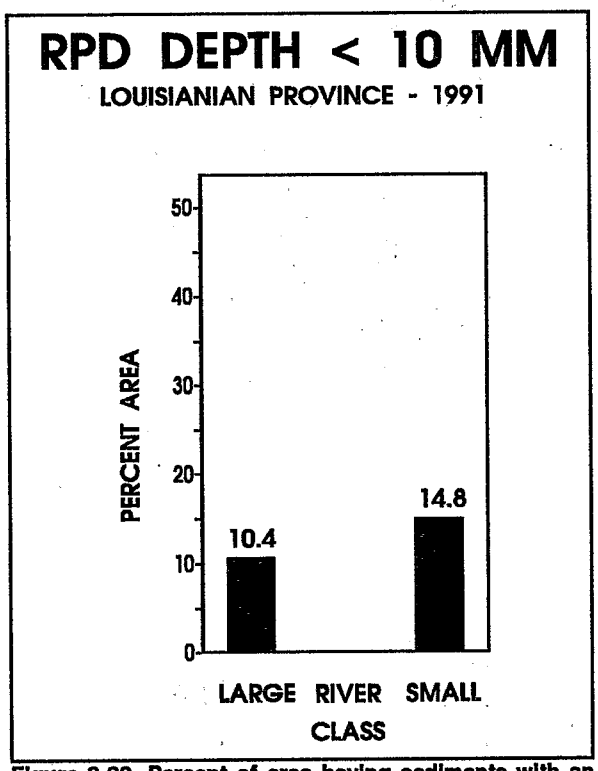


Figure 2-99. Percent of area having sediments with an RPD depth < 10 mm for large estuaries, large tidal rivers, and small estuaries.

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	101	48	10	43
Estuarine Condition	52(9)	38(11)	95(30)	55(20)
Estuarine Condition[1]	40(9)	28(10)	95(30)	44(18)
BIOTIC CONDITION				
Benthos Index	31(9)	27(10)	80(25)	41(20)
Abundance < 10	19(9)	19(9)	50(31)	36(20)
# Species < 2	4(4)	0(0)	60(30)	12(15)
# Species < 5	28(10)	23(11)	80(25)	39(20)
Fish				
Abundance < 5	17(8)	17(10)	44(33)	16(13)
Abundance < 10	32(11)	33(13)	67(31)	29(18)
# Species ≤ 1	15(4)	17(3)	33(31)	11(10)
# Species ≤ 2	21(5)	23(5)	33(31)	17(12)
Fish Pathology[2]	< 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)	0(0)	0(0)	1(2)
Others > FDA Limits	0(0)	0(0)	0(0)	0(0)
Bottom DO[3] < 2 ppm	6(5)	8(7)	0(0)	1(1)
Bottom DO[3] < 5 ppm	15(8)	15(8)	10(16)	17(17)
Minimum DO < 2 ppm	12(1)	11(9)		16(14)
Sediment Toxicity	8(5)	6(5)	67(30)	14(10)

[1] Estuarine condition without turbidity as an indicator
[2] Percentage based on sample size rather than estuarine area
[3] Instantaneous dissolved oxygen measurements

Table 2-9. 95% confidence intervals associated with the proportion of the Louisianian Province and estuarine classes experiencing the levels of the listed parameters.

Parameter	Province	Large Estuary	Large Tidal River	Small Estuary
N	**101**	**48**	**10**	**43**
ABIOTIC CONDITION				
Marine Debris	16(9)	13(9)	30(18)	28(13)
Water Clarity				
PAR < 10%	25(10)	21(9)	0(0)	41(16)
PAR < 25%	60(11)	50(14)	60(28)	68(17)
Silt-Clay Content				
< 20%	4(4)	4(5)	0(0)	3(4)
> 80%	66(10)	64(13)	80(25)	64(17)
Alkanes				
Total > 7000 ppb	11(7)	8(6)	0(0)	12(15)
PAHs				
Total > 1000 ppb	8(6)	0(0)	30(28)	24(20)
Total > 4000 ppb	3(4)	0(0)	0(0)	10(15)
PCBs				
Total > 200 ppb	0(0)	0(0)	0(0)	0(0)
Pesticides				
Chlordane > .5 ppb	2(2)	1(3)	50(31)	2(2)
Dieldrin > .2 ppb	21(9)	23(12)	80(35)	13(9)
Endrin > .02 ppb	1(1)	0(0)	0(0)	4(5)
DDT > 1 ppb	1(1)	0(0)	20(25)	0(0)
DDE > 2 ppb	2(3)	2(3)	10(18)	1(1)
DDD > 2 ppb	1(1)	0(0)	20(25)	0(0)
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	10(6)	11(8)	10(16)	2(1)
Cu > 70 ppm	0(0)	0(0)	0(0)	0(0)
Hg > .15 ppm	22(8)	24(12)	60(29)	1(1)
Ni > 30 ppm	16(7)	15(10)	30(28)	4(4)
Pb > 35 ppm	<1(0)	0(0)	10(16)	1(1)
Sb > 2 ppm	<1(0)	0(0)	10(16)	0(0)
Sn > 3 ppm	<1(0)	0(0)	0(0)	<1(0)
Zn > 120 ppm	6(5)	6(6)	10(16)	4(4)
Tributyltin				
TBT > 1 ppb	13(6)	12(7)	55(29)	16(12)
TBT 75 ppb	4(2)	2(1)	0(0)	9(7)

Table 2-9*cont.* 95% confidence intervals associated with the proportion of the Louisianian Province and experiencing the levels of the listed parameters.

SECTION 3
QUALITY ASSURANCE

The Louisianian Province Demonstration was implemented using a quality assurance program (Heitmuller and Valente, 1991) to ensure that the data collected in the various biogeographical provinces (e.g., Virginian and Louisianian) would be comparable (i.e., collected on the same spatial and temporal scales using the same methods) and of known and acceptable quality. Monitoring problems encountered through the use of multiple field crews and laboratories often produce data that cannot be compared because of methodological or analytical differences. As a result, we implemented multiple quality assurance/ quality/control measures in training, field collection, laboratory certification, and laboratory analysis phases of the demonstration to assure the comparability of the information generated. The following section describes the results of the quality assurance measures implemented in the program and, when appropriate, evaluates the quality of the data in terms of accuracy, precision, and completeness.

3.1 CREW TRAINING AND SAMPLE COLLECTION

The need for thoroughly trained field personnel was recognized early in the planning of a quality assurance program for the Louisianian Province. Field crews were comprised of staff members and students from Texas A & M University, Gulf Coast Research Laboratory, and Technical Resources, Inc. Field crew training was held at the Gulf Breeze Research Laboratory, Gulf Breeze, FL. from May 20 to June 19, 1991. The training was segmented into three sessions -- Crew Chief Training (two weeks), Crew Training (two weeks), and Field Certification (two days). Crew Chief training covered all aspects of the field sampling protocols but also concentrated on in-field decision making and vessel operation. During crew training, the crews joined the Crew Chiefs with their designated crews (boat and land support) for an additional two-week period that was split into approximately 50% of classroom lecture and demonstration and 50% field exercises; many activities completed during crew training were similar to those in Crew Chief training but focused on the development of a functional sampling team.

Corroboration of the crews' understanding of field protocols was determined by the use of field certification exercises. These exercises consisted of a "typical EMAP" 2-day scenario of sampling, sample processing and shipping, and data entry and transfer. The crews were required to conduct all components of the sampling activities at each station and were scored by senior EMAP-E personnel on their abilities to perform over 100 field and laboratory functions. Teams were scored on each activity on a 0-3 basis where a 0 was completely unacceptable; 1, suggested a major change from the accepted EMAP protocol; 2, suggested a minor change from the protocol; and 3, no change. The scores were normalized to percentage and a team score of >90% was required for certification. Field certification scores of the six crews ranged from 91-99.2% with

an average score of 94.8%. Field training was judged to be very successful.

The crews were evaluated on two other occasions during the course of the 1991 field monitoring. Members of the Province management team accompanied and observed each crew for a full day during their initial week of sampling; the purpose was to ensure that each field team "got off on the right foot." Another visit (unannounced) was made by Province inspectors for the purpose of conducting a performance audit. The crews were evaluated and graded in a similar manner as for certification; audit scores were somewhat higher ranging from 94.3-99.5% with an average score of 96.7%.

In addition to field auditing, 4 sites were revisited (by a different crew) to ascertain separate crews' ability to locate the same station and the stability of the ecological indicators used. The 4 sites consisted of base stations in large estuaries (Mississippi Sound [2], Lake Pontchartrain [1]) and small estuarine (Lake St. Catherine, LA [1]). Table 3-1 compares the results of these two visits with regard to water quality, fish, and bivalve parameters.

Station	Value Parameter	Date 1[1]	Date 2[1]	Delta
Mississippi Sound (LA91LR14)	Water Depth (ft)	17.2	17.2	0.0
	Temperature (C)	29.0	29.2	-0.2
	Salinity (ppt)	27.7	30.8	-3.1
	DO (Instantaneous)	5.4	3.3	2.1
	DO (Mean)	3.5	3.8	-0.3
	DO (Minimum)	3.1	2.8	0.3
	DO (% Time < 2ppm)	0	0	0.0
	pH	7.9	7.8	0.1
	Fish Abundance	209	58	151.0[2]
	Pathologies	2	0	2.0[3]
	Bivalve Abundance	0	0	0.0
	Number of Fish Species	2	8	-6.0
Mississippi Sound (LA91LR15)	Water Depth (ft)	12.5	12.0	0.5
	Temperature (C)	29.0	29.9	-0.9
	Salinity (ppt)	24.4	28.2	-3.8
	DO (Instantaneous)	6.0	3.7	2.3
	DO (Mean)	6.6	6.1	0.5
	DO (Minimum)	6.1	4.5	1.6
	DO (% Time < 2 ppm)	0	0	0.0
	pH	8.0	7.9	0.1
	Fish Abundance	16	16	0.0
	Pathologies	0	0	0.0
	Bivalve Abundance	0	0	0.0
	Number of Fish Species	6	7	-1.0
Lake St. Catherine (LA91SR11)	Water Depth (ft)	4.5	4.7	-0.2
	Temperature (C)	29.8	30.9	-1.1
	Salinity (ppt)	2.0	3.8	-1.8
	DO (Instantaneous)	7.5	6.8	0.7
	DO (Mean)	7.9	7.0	0.9
	DO (Minimum)	7.2	5.5	1.7
	DO (% Time < 2 ppm)	0	0	0.0
	pH	7.5	7.5	0.0
	Fish Abundance	23	17	6.0
	Pathologies	0	0	0.0
	Bivalve Abundance	4	7	-3.0
	Number of Fish Species	6	7	-1.0

---

[1] (Dates 1 and 2 are within 10 days of each other).
[2] Difference in fish abundance due to large catch of Atlantic bumper, a schooling fish (208 fish)
[3] Difference in gross pathologies due to parasitism of 2 harvestfish

Table 3-1. Comparison of four stations sampled on two separate dates by separate crews.

Station	Parameter	Value Date 1[1]	Date 2[1]	Delta
Lake Pontchartrain (LA91LR32)	Water Depth (ft)	14.9	8.4	6.5[4]
	Temperature (C)	28.9	31.1	-2.2
	Salinity (ppt)	1.2	2.6	-1.4
	DO (Instantaneous)	8.2	7.4	0.8
	DO (Mean)	8.4	7.3	1.1
	DO (Minimum)	8.1	6.5	1.6
	DO (% Time < 2 ppm)	0	0	0.0
	pH	7.3	7.1	0.2
	Fish Abundance	22	33	-11.0
	Pathologies	0	0	0.0
	Bivalve Abundance	0	7	-7.0
	Number of Fish Species	3	5	2.0

---

[4] Sampling site located on edge of near-shore shelf. Depth on shelf was < 10 ft while depth adjacent to shelf was 13-16 ft.

Table 3-1 *continued.* Comparison of four stations sampled on two separate dates by separate crews.

Most of these parameters (i.e., those expected to be the most variable in the program) show remarkable stability. Even continuous dissolved oxygen measures when categorized to represent acceptable on degraded conditions displayed good correspondence between the multiple visits to these sites.

In summary, crew training proved to be a highly effective quality assurance element. The time and resources invested in training paid off as evidenced by a 100% completion rate for field sampling (183 stations).

3.2 WATER QUALITY MEASUREMENTS -- FIELD QUALITY CONTROL CHECKS

Water quality parameters (e.g., dissolved oxygen [DO], salinity, temperature, pH, and depth) can be key indicators when used in the environmental assessment of estuarine areas. In the Louisianian Province, those parameters were measured at each sampling station, both as an instantaneous profile of the water column (taken at 1m intervals) and as a continuous, overnight (>12 hours) measure at 0.5 m off bottom. Two models of dataloggers manufactured by the Hydrolab® Corporation were utilized in the monitoring, the Surveyor II for instantaneous measurements and the deployable DataSonde 3 for continuous measurements. QC procedures require that all datalogging units be calibrated with documentation within the 24 hour period preceding their scheduled use. In most cases, the initial calibration was maintained within the defined QC guidelines for the duration of the logging event. However, some degree of drift was expected and did occur. In order to determine if the drift exceeded the QC limits, additional checks were performed in the field immediately prior to the deployment and following the retrieval of the DataSonde 3 unit.

The QC check consisted of taking "side-by-side" measurements with the DataSonde and a recently calibrated Surveyor in a bucket of seawater taken at the sampling site; the Surveyor was considered the standard. These values were recorded on a field data sheet. At deployment, if there was not agreement, the DataSonde would be recalibrated prior to initiation of the logging run; upon retrieval, if there was significant disparity, an additional logging run could be scheduled.

After the completion of the summer field monitoring, the QC data from the field checks were compiled and evaluated

statistically to determine frequency of acceptable and unacceptable adherence to the QA guidelines. The QA acceptance criteria based on the field QC checks with the DataSonde 3 units were: (1) Dissolved Oxygen (DO) ± 1 ppm agreement to Surveyor II; (2) Salinity: ± 2 ppt agreement to Surveyor II; (3) pH ± 0.2 agreement to Surveyor II; Temperature: ± 1°C agreement to Surveyor II.

For DO, 139 out of 158 units (88%) were acceptable at the pre-deployment QC check and 19 (12%) were not acceptable. Of those 19, 17 were recalibrated to an acceptable mode but 2 were not recalibrated due to instrument failure or adverse weather conditions. At retrieval, 148 units (94%) were acceptable and 10 (6%) were outside of the QA guidelines.

For salinity, 130 (83%) of the units were acceptable at the pre-deployment QC check and 26 (17%) were outside of the guidelines. Of those, 13 were recalibrated. At retrieval, 120 (77%) were acceptable and 36 (23%) were outside of the guidelines.

For pH, 124 (81%) of the units were acceptable at the pre-deployment QC check and 30 (19%) were outside of the guidelines. Of those, 17 were recalibrated. At retrieval 111 (72%) were acceptable and 44 (28%) were outside the guidelines.

Temperature was acceptable in 158 (99%) of the pre-deployment QC checks. The temperature function cannot be calibrated in DataSondes, therefore, no adjustment was made. At retrieval, 158 units (99%) were acceptable.

Overall, the QC data related to the DataSondes were encouraging. The QA guidelines will be reviewed and possibly broadened, particularly in respect to the pH; ±0.5 units, instead of 0.2, would be reasonable for field purposes.

3.3 LABORATORY CERTIFICATION AND CHEMICAL ANALYSES

EMAP-E requires that all analytical chemistry laboratories must "pass" a certification prior to analyzing any samples. This certification is in addition to any normal quality control measures that would be used during analysis to ensure quality data (e.g., blanks, spikes, controls, duplicates). Standard reference materials (SRMs) with certified values for metals and organics were used by both of the Louisianian Province laboratories to confirm the accuracy and precision of their analyses. The results of these certifications for the laboratory conducting sediment contaminant analyses for the program, Texas A&M's Geochemical and Environmental Group, are shown in Tables 3-2 and 3-3. This laboratory was certified and analyzed 183 sediment samples collected in 1991. The results of the certifications for the laboratory conducting tissue analyses, University of Mississippi's Research Institute of Pharmaceutical Sciences, are shown in Tables 3-4 and 3-5. They, likewise, were certified.

EMAP-E chemistry samples are typically analyzed in batches or runs of ten unknowns (field samples). As mentioned previously, included with each batch are numerous specified QA/QC samples that when properly utilized help maintain control of the run and are indicative of the overall data quality for that run. SRMs are one of the most useful QC samples for assessing the accuracy of a given analysis. They are

Analyte	Certified Concentration	Reported Concentration	Percent Recovery
Al	6.26% as Al	6.64% as Al	106%
As	11.1	10.9	98%
Cd	0.25	0.29	115%
Cu	18.5	19.7	106%
Cr	123.0	125.0	102%
Fe	3.3% as Fe	3.54% as Fe	107%
Pb	22.7	24.9	110%
Hg	0.129	0.134	104%
Mn	229.0	238.0	104%
Ni	55.3	56.2	102%
Se	0.43	0.42	98%
Sn	1.85	2.13	115%
Zn	119.0	118.0	99%

Table 3-2. Certification analysis completed for sediment analysis of metals in Louisianian Province (concentrations in ppm unless otherwise noted).

naturally occurring materials (e.g., marine sediments or oyster tissue) and have certified concentrations for various analytes of interest at levels that are environmentally realistic. EMAP-E recommended control limits for SRM analysis are 70-130% agreement to the certified value for organic analytes and 85-115% agreement for inorganics (metals). It is not expected that every laboratory will be within the recommended control limits for every analyte during every run, but rather, for most analytes, most of the time. The two laboratories that participated in the analyses of the 1991 samples appear to have succeeded in that respect.

Analyte	Certified Concentration	Reported Concentration	Percent Recovery
PAHs			
Acenaphthylene	115	108	94%
Acenaphthlene	52	43	84%
Anthracene	223	239	105%
Benz(a)anthracene	599	606	101%
Benzo(b)fluoranthene	854	970	112%
Benzo(k)fluoranthene	456	528	116%
Benzo(a)pyrene	672	727	108%
Benzo(e)pyrene	754	756	100%
Benzo(g,h,i)perylene	566	567	100%
Biphenyl	115	95	83%
Chrysene	702	792	113%
2,6 dimethylnapthalene	198	152	82%
Fluoranthene	1401	1392	99%
Fluorene	104	83	80%
1-methylnaphthalene	229	184	80%
2-methylnaphthalene	406	312	78%
1-methylphenanthrene	109	86	79%
Naphthalene	1322	985	75%
Perylene	437	398	91%
Phenanthrene	609	575	94%
Pyrene	1238	1230	99%
1,2,3,-c,d pyrene	559	557	100%
Butyltins			
TBT	1.27	1.08	85%
DBT	1.16	0.83	71%
MBT	0.28	0.38	135%

Table 3-3. Certification analysis completed for sediment analysis of organic contaminants in Louisianian Province.(NIST SRM 1941; concentrations in ng/g unless otherwise noted).

From the SRM data submitted with the sediment analyses, 34 organic analytes were selected representing PAHs (22), pesticides (7), and PCBs (5). Statistical analysis of the results for all the selected analytes from 19 batches indicated that the SRM results were within the recommended control limits 79.6 (±0.4)% of the time. However, the same analysis by analyte-type, shows PAH results within limits 99.2 (±0.1)% of the time; pesticides, only 32.3 (±0.5)% of the time; and PCBs, 58.9 (±0.5)% of the time. This is not surprising because the SRM (SRM #1941) is intended primarily for use in PAH validation. The pesticide and PCB analytes are secondary inclusions with reported concentrations that were

Analyte	Certified Concentration	Reported Concentration	Percent Recovery
Aluminum	202.5	212.0	105%
Arsenic	14.0	13.5	96%
Cadmium	4.15	4.39	106%
Chromium	1.43	1.64	115%
Copper	66.3	67.5	102%
Iron	539.0	545.0	101%
Lead	0.371	0.392	106%
Mercury	0.0642	0.0633	99%
Nickel	2.25	2.54	113%
Selenium	2.21	2.36	107%
Silver	1.68	1.69	101%
Tin	3.0	2.6	87%
Zinc	830.0	786.0	95%

Table 3-4. Certification analysis completed for tissue analysis of metals in Louisianian Province. (NIST SRM 1566A; concentrations in ug/g unless otherwise noted)

Analyte	Certified Concentration	Reported Concentration	Percent Recovery
Alpha Chlordane	3.2	3.1	97%
Trans Nonachlor	2.6	3.0	115%
Dieldrin	1.0	1.3	130%
2,4'-DDE	0.72	1.08	150%
4,4'-DDE	5.9	6.4	109%
2,4'-DDD	2.5	3.1	124%
4,4'-DDD	8.4	6.9	82%
2,4'-DDT	0.4	0.3	75%
4,4'-DDT	0.3	0.4	133%
PCB 18	3.0	3.0	100%
PCB 28	7.6	7.4	97%
PCB 44	8.0	6.0	75%
PCB 52	12.0	10.0	83%
PCB 66	13.6	13.1	96%
PCB 101	13.0	12.0	92%
PCB 105	5.6	6.3	113%
PCB 118	13.6	16.1	118%
PCB 128	1.9	2.4	126%
PCB 138	14.0	13.0	93%
PCB 153	18.0	21.0	112%
PCB 180	1.7	1.9	112%
PCB 187	3.7	3.7	100%

Table 3-5. Certification analysis completed for tissue analysis of organics in Louisianian Province. (NIST SRM 1974; concentrations in ng/g unless otherwise noted)

not certified; several occur near or below practical quantification levels. Percent recovery of laboratory spiked samples for the same pesticides and PCBs was typically >90%. Statistical analysis of the SRM results for metals in sediments was similar. For the 14 metal analytes, the SRM results were within recommended limits (85-115% agreement to certified value) 76.7% of the time. Taken as individual analytes the agreements ranged from 100% of the time for Al, Fe, and Mn to 50% for Sn.

The QA guidelines recommended by EMAP-E for ensuring the data quality of chemical analyses are regarded as strenuous. The analytical laboratories that participated in the 1991 Demonstration met those demands and the data that they generated were of a high quality.

3.4 LABORATORY TESTING AND ANALYSES

Protocols and standard operating procedures for the laboratory assays of EMAP-E samples (i.e., sediment toxicity tests, benthic community assessment, fish pathology/histopathology, sediment characterization, and bioindicators) are detailed in the

Laboratory Methods Manual Estuaries (USEPA 1991). The quality of data generated by these laboratories is governed by the adherence to protocols combined with the use of appropriate quality control elements (Heitmuller and Valente, 1991). Such elements include scheduled recounts and resorts for benthic assessments; the use of experimental controls for sediment toxicity testing; scheduled replication for sediment characterizations; and the use of blanks, spikes, and standards for chemical assessments. EMAP-E personnel visited each of the laboratories, at least once, while EMAP-E analyses were ongoing. The staffs were competent and professional; they appeared to realize the need for the quality assurance measures that EMAP-E requires. During the course of the onsite visits, it was ascertained from observations, laboratory documentation, and interviews with technical personnel that the participating laboratories strived to adhere to the protocols and QA/QC elements.

Considerable technical skills are required to effectively conduct any of the previously mentioned laboratory activities. However, certain of these (e.g., benthic community assessment, sediment toxicity test, or fish histopathology) because of their scope and complexity, demand higher levels of expertise gained only through advanced training and experience. Laboratories that express interest in conducting these type assays must be certified prior to analyzing EMAP-E samples.

Benthic community assessments for 1991 EMAP-E were conducted jointly between two affiliates, Gulf Coast Research Laboratory, Ocean Springs, MS and the University of Mississippi, Oxford, MS. EMAP-E chose not to require any pre-analysis certification of the two laboratories based on their highly regarded senior taxonomists and the labs' established reputation for excellence.

Technical Resources, Inc. - Toxicity Testing Section at ERL/GB was certified after successfully completing a performance evaluation in which they demonstrated proficiency in conducting reference toxicity tests with the mysid, *Mysidopsis bahia*, and the marine amphipod, *Ampelisca abdita*.

Other analyses (e.g. sediment characterization) were standardized to the point, that no certification was warranted prior to initiating analyses with EMAP-E samples.

Once the analyses were underway at the various laboratories, the quality control measures for the respective analyses proved to be effective in maintaining the performance of the analyses within EMAP-E recommended guidelines.

An exception to the above occurred during the initial phase of sediment toxicity testing with amphipods. QA guidelines state that an amphipod toxicity test is unacceptable if mortality exceeds 15% in the experimental control. In the first sets of tests with *Ampelisca*, control mortality was > 25%; this condition persisted for several series of tests, then, testing was stopped to allow for the determination of the cause. After two weeks, it was determined that the problem was related to holding the amphipods for a 10-day period before testing. The holding period was decreased to 1-2 days and testing was resumed with no further problems.

That resolved, and repeat tests conducted to replace the initial aborted exposures, the

remaining tests with mysids and amphipods proceeded very smoothly; all totaled, over 400 sediment exposures were successfully completed.

Benthic community assessments with triplicate samples collected from 183 sampling stations progressed smoothly. Scheduled QC resorts and recounts were performed in compliance with QA requirements (i.e., 10% of each technician's work) as were identity checks. Of 558 samples sorted at Gulf Coast Research Laboratory, 64 were randomly pulled for QC resorting by a senior taxonomist; out of the 64 resorts, 7 were determined as having > 10% error. For each of those 7 samples, the responsible technician was required to resort the 9 samples immediately preceding. Checks on the resorted samples showed all samples had 10% error. Of 83 samples pulled for QC re-identification, only 3 were found to have > 10% error. These QC actions are reported only for GCRL. However, the benthic laboratory at the University of Mississippi implemented the same regime of QC checks and their documentation of those checks will be verified at a later date. The benthic evaluations were conducted in full compliance with EMAP QC requirements and the resultant data are of excellent quality.

SECTION 4

SUMMARY OF CONCLUSIONS

The Demonstration Project in the Louisianian Province in 1991 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.

4.1 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 2-260 km^2 of which 47 were selected for sampling in 1991.

- 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.

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

- 19 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 Laguna Madre, TX.

4.2 CONCLUSIONS OF THE 1991 SAMPLING

- Nearly 42% ±9% of the Louisianian Province estuarine resources were determined to be degraded in terms of biotic integrity or human use indicators. Eleven percent of the province experienced only low levels of biotic integrity, 12% ±9% experienced either marine debris or poor water clarity, and 19% ±9% experienced both forms of degradation.

- In terms of proportion of total area in the class, the large tidal river (Mississippi River) experienced the highest level of biotic degradation (80% ±25%) with 41% ±20% of small estuaries and 27% ±10% of large estuaries having degraded estuarine biotic integrity.

- About 16% ±9% of the bottom sediments in Louisianian Province estuaries were littered with marine debris.

- 27% ±10% 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 > 3-9% of the sediments.

- Louisianian Province sediments were shown to be enriched with several heavy metals. 32% ±9% of Louisianian Province sediments were enriched with at least one metal. 22% ±8% of sediments were enriched with mercury, while about 5% ±4% of sediments were enriched with chromium, arsenic, and lead.

- Metal enrichment was primarily observed in large estuaries and the Mississippi River.

- Approximately 8% ±5% of the sediments in the Louisianian Province (2050 km^2) proved to be toxic to tested estuarine organisms. Nearly 70% (±30%) of the Mississippi River sediments were toxic while 14% ±10% of small estuarine sediments and 6% ±5% of large estuary sediments were toxic.

- Tributyltin was measurable in 13% ±6% of Louisianian Province sediments.

- The edible portions of shrimp, Atlantic croaker, and catfish contained contaminant concentrations below FDA limits for PCBs and pesticides. One percent of marine catfish examined exceeded FDA action limits for mercury (i.e., > 1 ppm). Shrimp, croakers and catfish contained levels of arsenic, chromium, and zinc in their edible tissues that was higher than international standards. Four to eight percent of shrimp, marine catfish, and croaker contained total arsenic at levels exceeding 2 ppm. Four percent of shrimp contained chromium levels above 1 ppm and 2% of marine catfish

contained zinc concentrations above 60 ppm.

SECTION 5
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APPENDIX A

SAMPLING DESIGN, ECOLOGICAL INDICATORS, AND METHODS

This section provides the details for the sampling design used in the 1991 Louisianian Province Demonstration. Consistent with the overall objective of EMAP, EMAP-E seeks to make statistically unbiased estimates of ecological condition with known confidence. Therefore, sampling sites were not selected subjectively. Rather, sampling sites were selected by a statistical process that ensures a probabilistic sampling network. As a result, the sampling points represent a statistically valid probability sample; thus, the data collected in the monitoring survey can be expanded, with quantifiable confidence, to yield estimates for the entire Louisianian Province (i.e., the estuarine waters from the Rio Grande, TX through Anclote Anchorage, FL). In addition, these estimates can be combined with other regions collected using consistent procedures to yield national estimates of estuarine condition. Details of the sampling design for the 1991 Demonstration in the Louisianian Province are provided in Summers et al. (1991). A summary of the design is provided here to permit the reader an understanding of the sampling design.

A.1 REGION AND ESTUARINE CLASSIFICATION

EMAP-E monitoring is designed to be conducted at regional and national scales. Standardized methods are employed, and the entire Louisianian Province is sampled simultaneously within a defined time period (July 1 - September 15) to ensure comparability of data within and among sampling years. EMAP-E identified boundaries for 12 estuarine regions (Holland 1990) based on biogeographic provinces defined previously by NOAA and the U.S. Fish and Wildlife Service (Terrell 1979) using major climatic zones and prevailing major ocean currents (Fig. A-1). The 1991 Louisianian Province Demonstration included the estuarine resources located along the irregular coastline of the Gulf of Mexico, between and including, the Rio Grande, TX and Anclote Anchorage, FL.

A review of the literature identified potential classification variables that reduced within-class variability. These variables included physical attributes, salinity, sediment type, depth, and extent of pollutant loadings. The use of salinity, sediment type, and pollutant loadings as classification variables (i.e., a priori strata) would result in the definition of classes for which areal extents could vary dramatically from year-to-year or even over the index sampling period of EMAP-E. This stratification process requires establishment of a sampling frame prior to sampling; thus misclassification of sample sites within a class should be minimal. Stratification by substrate, depth, or salinity was considered to be difficult because detailed maps of sediment and water column characteristics were not

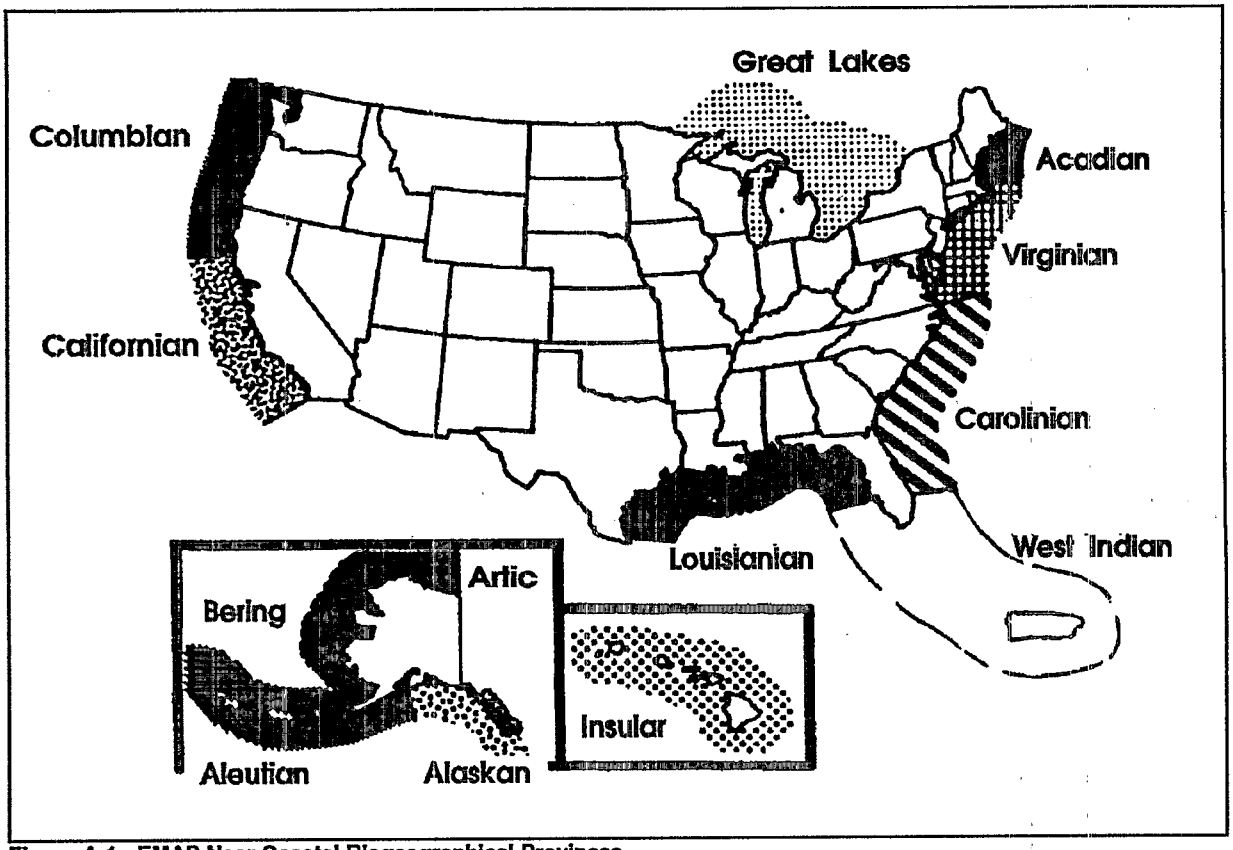

Figure A-1. EMAP Near Coastal Biogeographical Provinces.

available or often unreliable for much of the Louisianian Province. As a result, a simple classification scheme based on the physical dimensions of an estuary was used to develop three classes -- large estuaries, large tidal rivers, and small estuaries/small tidal rivers. Large estuaries in the Louisianian Province were defined as estuaries greater than 250 km^2 in surface area and with aspect ratios (i.e,. length/average width) of less than 20. Large tidal rivers were defined as that portion of the river that is tidally influenced (i.e., detectable tide > 2.5 cm), greater than 250 km^2, and with an aspect of greater than 20. Small estuaries and small tidal rivers (hereafter referred to as small estuaries) were designated as those systems whose surface areas fell between 2.5 km^2 and 250 km^2. These designations excluded estuarine water bodies less than 2.5 km^2 in surface area. These resources were included in the sampling frame by making them a part of the class occupied by their adjacent water body. For example, the myriad of small semi-continuous water bodies adjacent to Chandeleur Sound in Louisiana were included in the surface area of Chandeleur Sound for design and analysis purposes.

Application of the classification scheme to the Louisianian Province estuarine resources resulted in the identification of 28 large estuaries with a total surface area of 18,475 km^2; 1 large tidal river (i.e., Mississippi River) with 138 km^2; and, 156 small estuaries/small tidal rivers comprising

7112 km^2. These estuarine resources are delineated in Summers et al. (1991).

A.2 SAMPLING DESIGN

Sample collection in the Louisianian Province focused on ecological indicators (see Section 2.3) during the index sampling period (July 1-September 15), the period when many estuarine responses to anthropogenic and natural stresses are expected to be most severe. The proposed sampling design combines the strengths of systematic and random sampling with an understanding of estuarine ecosystems in order to provide an unbiased estimate of estuarine status in the Louisianian Province. In addition, some "biased" sites were sampled to collect information for specific hypothesis testing and other specific study objectives. This resulted in sampling four types of sampling sites during the Louisianian Province Demonstration:

- *Base* sites were unbiased sampling sites forming the core of the EMAP-E monitoring design for the Louisianian Province. Data collected from these sites are the basis of the preliminary status estimates for the Louisianian Province.

- *Supplemental* sites were part of a special pilot study to define the appropriate spatial scale for full implementation of EMAP-E monitoring. The selection of these sites is unbiased and permit the comparison of alternative spatial scales for the large estuary class. These sites were not used in Louisianian Province status estimates.

- *Index* sites were part of a special pilot study to determine whether individual "representative" sites can be selected to portray the status of individual small estuaries/small tidal rivers or large tidal river segments. These sites were not used in status estimates for the Louisianian Province. However, these sites were used to provide estimates of the internal spatial variability associated with small estuaries/small tidal rivers.

- *Indicator testing and evaluation (ITE)* sites were part of a special pilot study to determine the reliability, sensitivity, and replicability of indicator responses for discriminating between sites with "known" environmental conditions. These sites were selected on the basis of historical information concerning dissolved oxygen concentrations and sediment contamination. Data from these sites were not included in the status estimates for the Louisianian Province. Rather, these sites were used to develop indices and to test the discriminatory power of specific indicators.

Figure A-2 presents a map of all the unbiased base sites scheduled for sampling in the 1991 Louisianian Province Demonstration. The methods used to select sampling locations for each type of sampling site are provided below.

A.2.1 BASE SAMPLING SITES

The sampling design for base sites was stratified based on size into large estuaries, large tidal rivers, and small estuaries/small tidal rivers. Stratification permitted customizing the sampling frame to the specific geographic features of these different classes. It also allowed allocation of a strata-specific number of samples so that class estimates could be derived with

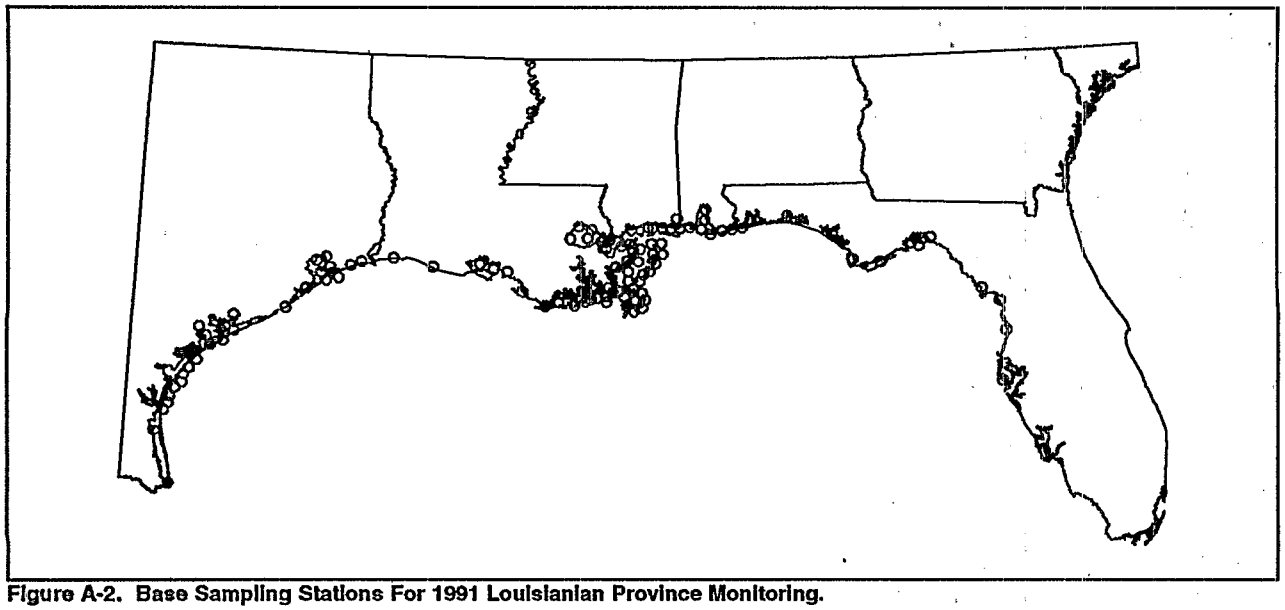

Figure A-2. Base Sampling Stations For 1991 Louisianian Province Monitoring.

a desired level of precision. The specific estuarine systems that comprise each class are delineated in Summers et al. (1991).

Large estuary sampling sites were selected using an enhancement of the systematic sampling grid proposed for use throughout EMAP (Overton 1989). This grid was placed randomly over a map of the United States and intensified to produce 280 km^2 hexagonal cells. Fifty-five sites were located in the 28 large estuaries by selecting a random location within each grid cell located in these estuaries.

Base sampling sites in the large tidal river were selected using a spine and rib approach that is the linear analog of the sampling grid for large estuaries. Segments of equal length (i.e., 25 km) beginning at the mouth of the river and proceeding upriver to the head of tide were used to define sampling strata in the large tidal river. A random location was selected from each large tidal river segment. A total of ten base sampling sites was identified in the large tidal river of the Louisianian Province.

Selection of small estuary/small tidal river sites was based on a list frame of the 156 systems comprising these resources (Summers et al. 1991). Forty-seven (30%) of the 156 systems were selected for sampling during the 1991 Louisianian Province Demonstration. To ensure that the selected systems were geographically dispersed, all small systems in the province were ordered from east to west and grouped into clusters of four. One system of the four in a cluster was randomly selected for sampling and a single random sampling point was selected in each of these systems.

A.2.2 SUPPLEMENTAL SAMPLING SITES

Available data were insufficient to ascertain the spatial scale necessary to represent

the variability in the ecological status of estuarine systems in the Louisianian Province with acceptable precision. To address this problem in large estuaries, Mobile Bay was sampled at a density four times greater than other large estuaries (i.e., hexagonal grid cells of 70 km^2) yielding 13 supplemental sites in Mobile Bay as compared to 3 base sites.

A.2.3 INDEX SITES

Index sites were judgmental samples located in deep, muddy, depositional areas in each large tidal river segment and each small estuary/small tidal river. These locations were assumed to be representative of sites within the small systems and tidal river segments most likely to suffer from low dissolved oxygen stress and/or deposition of contaminants. Ten index sites located in the large tidal river and 47 sites were located in small estuaries/small tidal rivers.

A.2.4 INDICATOR TESTING AND EVALUATION SITES

Based on a review of existing data and expert opinion, 16 indicator testing and evaluation sites were selected for specific geographic location (east versus west of the Mississippi Delta), dissolved oxygen concentration (<2 ppm versus > 5 ppm), and magnitudes of industrial effluents and agricultural runoff (low versus high). These sites were sampled to investigate the reliability of indicator responses for discriminating between degraded and nondegraded sites in the Louisianian Province (Table A-1).

A.2.5 SAMPLE DESIGN OVERVIEW

The 1991 Louisianian Province Demonstration included a total of 198 sites scheduled for sampling between July 1 and September 15; an additional 4 sites were added for quality control. The four QC sites were revisited during the sampling period to examine the temporal variability within the sampling interval.

A.3 INDICATORS

The strategy for the selection of the indicators used in EMAP are described by Knapp et al. (1990). EMAP monitoring focuses on indicators of ecological response to stress and uses measures of exposure to stress as a means for interpreting that response. Traditionally, estuarine monitoring has focused on measures of exposure (e.g., concentrations of contaminants in sediments) and attempted to infer ecological impacts based on laboratory bioassays. The advantage of the ecologically-based approach emphasized in EMAP is that it can be applied to situations where multiple stressors exist, acting separately or in combination, and where natural processes cannot be modeled easily. This is certainly the case in estuarine systems, which are subject to an array of anthropogenic inputs and exhibit a great biotic diversity and complex physical, chemical, and biological interactions.

The implementation plan for the Louisianian Province (Summers et al. 1991) identified 10 indicator categories that were evaluated at all base, supplemental, and index sites and 8 additional indicators that were evaluated only at indicator testing

SITE	Relation to Mississippi Delta[1]	Dissolved Oxygen[2]	Industrial Discharges[3]	Agricultural Runoff[4]
Mobile Bay, AL	E	P	P	P
Watsons Bayou, FL	E	P	P	G
Choctawhatchee River, FL	E	P	G	P
Perdido Bay, AL/FL	E	P	G	G
Escambia Bay	E	G	P	P
Bayou Casotte	E	G	P	G
Wolf Bay	E	G	P	G
Apalachicola Bay	E	G	G	G
Brazos River	W	P	P	P
Houston Ship Channel	W	P	P	G
Arroyo Colorado	W	P	G	P
Calcasieu Lake	W	P	G	G
Lavaca Bay	W	G	P	P
Galveston Bay	W	G	P	G
Laguna Madre	W	G	G	P
San Antonio Bay	W	G	G	G

[1]E = East W = West
[2]P = DO<2ppm; G = DO>5ppm
[3]P = High Discharges; G = Low Discharges
[4]P = High Runoff; G = Low Runoff

Table A-1. List of ITE sites based on historical environmental conditions.

sites. These indicators were categorized as either core, developmental, or research (Table A-2) and as biotic and abiotic condition indicators (Table A-3). Additionally, several of these indicator categories were comprised of multiple specific indicators (Table A-4).

A.4 METHODS

Conducting a monitoring demonstration that covers the 3000 km of coastline comprising the Gulf Coast and produces results within nine months requires extensive planning, training, coordination of laboratory activities, information management procedures, and statistical acumen. This section describes the procedures used to bring all of these activities together to produce a timely annual statistical summary.

Another activity of primary importance during the production phase of EMAP-E in the Louisianian Province is quality assurance/quality control. This activity guarantees the credibility of the data produced by the monitoring and, eventually, the results of the program. Because of the special importance of quality assurance in EMAP, this activity is described in detail in a separate section (Section 5).

A.4.1 FIELD PLANNING

The success of the demonstration was dependent on good and complete initial planning. A draft of the implementation plan for the demonstration was completed

Category	Indicator
Core	Benthic Species Composition and Biomass Habitat Indicators (RPD Depth, Salinity, pH, Temperature, Water Depth, % Silt-Clay)
Developmental	Sediment Contaminants Sediment Toxicity Dissolved Oxygen Concentration Gross Pathology of Fish Contaminants is Fish and Shellfish Tissue Relative Abundance of Large Bivalves Marine Debris Acreage of Submerged Aquatic Vegetation Fish Community Composition and Lengths Percent Light Transmittance
Research (ITE Only)	Histopathology of Fish Skeletal Abnormalities Blood Chemistry Bile Florescence Stable Isotope Ratios Liver Lesions Splenic Macrophage Aggregates Liver Contaminant Concentrations Whole Fish Contaminant Concentrations

Table A-2. Ecological indicators used in the 1991 Louisianian Province demonstration.

Indicator Type	Indicator
Biotic Condition (Response)	Benthic Community Composition Benthic Abundance Benthic Biomass Fish Community Composition Fish Lengths Relative Abundance of Large Bivalves Pathology in Fish Acreage of Submerged Aquatic Vegetation Dissolved Oxygen Concentration
Abiotic Condition (Exposure)	Sediment Contaminants Sediment Toxicity Percent Light Transmittance RPD Depth Salinity Temperature Percent Silt-Clay pH Water Depth Contaminants in Fish and Shellfish Skeletal Abnormalities Bile Florescence Stable Isotope Ratios Liver Lesions Splenic Macrophage Aggegrates Liver Contaminant Concentrations Whole Fish Contaminant Concentrations

Table A-3. Ecological indicators used in 1991 Louisianian Province Demonstration categorized as biotic and abiotic condition indicators.

in October 1990 (Summers et al. 1991). This plan included the results of several pilot programs to select indicators. After the completion of the implementation plan, the Province planning team was ready to implement the pre-sampling demonstration plan that consisted of capital equipment purchases, reconnaissance, manual production, and training.

An important aspect of planning for the Louisianian Province Demonstration was the reconnaissance of selected sampling sites prior to sampling. The purpose of the reconnaissance was to acquire information that would facilitate the development of logistics plans for field implementation. The first phase of reconnaissance consisted of plotting the 202 stations on nautical charts. During this exercise, two (2) stations were found to be located on land and eleven (11) sites were located in water less than 1 meter in depth (i.e., the

Primary Indicator	Subcomponents
Benthos	Total abundance Species composition Species diversity Abundance by species Percentage by taxonomic group Biomass Biomass by taxonomic group
Fish	Total abundance Species composition Species diversity Abundance by species Percentage by taxonomic group Mean length by species
Large Bivalves	Total abundance Species composition Mean length by species
Gross Pathology	Type of disorder Incidence of parasitism
Dissolved Oxygen	Instantaneous at sampling Continuous for 24-hr (15-min intervals)
Sediment Toxicity	*Ampelisca abdita* 10-day test *Mysidopsis bahia* 4-day test
Sediment Contaminants	23 polycyclic aromatic hydrocarbons 27 aliphatic hydrocarbons 15 metals 18 pesticides 22 PCB congeners Butyltins
Sediment Characters	Percent silt-clay Grain size distribution Acid volatile sulfides Total organic carbon
Tissue Contaminants	15 metals 18 pesticides 22 PCB congeners

Table A-4. Subcomponents of ecological indicators.

draft of the sampling vessel), and 18 sites were located in areas of unknown depth. The two landward sites were relocated because they occurred in the small estuary class (i.e., if the sites had been in the large estuary class they would have been excluded). The 29 sites with unknown depths or depths less than 1 meter were "marked" for close reconnaissance.

All 202 sampling sites were visited during multiple reconnaissance periods from February-April 1991. As a result of this activity, 15 sites were assigned "unsampleable" status (Table A-5) and 6 additional stations were assessd to be of marginal depth for sampling. "Unsampleable" sites represent locations selected by the sampling design that are acceptable to all criteria of the sample design but logistically cannot be reached or sampled, usually due to insufficient depth. These sites remain as part of the monitoring program and represent the proportion of the estuarine resources in the Louisianian Province that cannot be sampled by the existing design (depth zone 0-.75 m). The six marginal sites were included in the sampling because tidal action in the winter season produces significantly shallower depths (i.e., tides .3-.6 m) than in the summer season (i.e., tides .1-.3 m). Based on these reconnaissance results, logistics plans (Macauley and Summers 1991a; Phifer et al. 1991) were developed to sample the remaining 187 sites over a six-week period during July-August 1991.

Before training and subsequent sampling could be initiated, several reference documents were compiled to guide training, ensure data quality, standardize field and laboratory methods, and provide logistical support to the field teams. These documents include:

- Field Operations Manual (Macauley and Summers 1991a)

- Quality Assurance/Quality Control Plan (Heitmuller and Valente 1991)
- Logistics Plan - Eastern Region (Macauley and Summers 1991b)
- Logistics Plan - Western Region (Phifer et al. 1991)
- Crew Chief Training Manual (Macauley et al. 1991a)
- Crew Training Manual (Macauley et al. 1991b)
- Laboratory Methods Manual (USEPA 1991)
- Revision of the Implementation Plan (Summers et al. 1991)
- Demonstration Project Report (Summers et al 1992b)

Station	Site	Status
LA91LS13	Mobile Bay	Unsampleable
LA91LS01	Mobile Bay	Unsampleable
LA91LS02	Mobile Bay	Unsampleable
LA91LR04	Choctawhatchee Bay	Unsampleable
LA91LR07	Mississippi Sound	Unsampleable
LA91LR51	Laguna Madre	Unsampleable
LA91LR52	Laguna Madre	Unsampleable
LA91LR53	Laguna Madre	Unsampleable
LA91LR54	Laguna Madre	Unsampleable
LA91SR30	Ecofina River	Marginal
LA91SI30	Ecofina River	Marginal
LA91SR18	Star Lake	Unsampleable
LA91SI18	Star Lake	Unsampleable
LA91SR43	Highland Bayou	Unsampleable
LA91SI43	Highland Bayou	Unsampleable
LA91SR24	Powderhorn Lake	Unsampleable
LA91SI24	Powderhorn Lake	Unsampleable
LA91SR22	Cedar Lakes	Marginal
LA91SI22	Cedar Lakes	Marginal
LA91SR46	Rio Grande	Marginal
LA91SI46	Rio Grande	Marginal

Table A-5. List of unsampleable stations in the 1991 Louisianian Province Demonstration due to insufficient sampling depth based on 1991 reconnaissance.

All of the documents are available from the EMAP Province Manager at the EPA Environmental Research Laboratory at Gulf Breeze, Florida or from EMAP Headquarters in Washington, D.C.

A.4.2 TRAINING

Formal training was held at the Gulf Breeze Environmental Research Laboratory, Gulf Breeze, FL from May 20 to June 19, 1991. A total of 38 participants were trained to conduct sampling in accordance with EMAP protocols. Corroboration of the crews' understanding of the field protocols was determined by the use of final field certification exercises. The crews were required to conduct all components of the sampling activities at each station and were scored by senior EMAP-E personnel on their performance of 100 field and laboratory functions. The scores were normalized to percentage and a team score of > 90% was required for certification. All crews were successfully certified.

A.4.3 FIELD SAMPLING AND LOGISTICS

One of the primary objectives of the 1991 Louisianian Province Demonstration was to evaluate the feasibility of collecting, within a limited sampling period, the kinds and volume of data required to produce a regional assessment of ecological condition. This subsection uses 1991 Demonstration results to address two fundamental questions pertaining to logistics and quality assurance for future EMAP monitoring in estuaries:

- Could the data required for developing a regional assessment of ecological

condition be collected with the level of effort and sampling methods determined by the planning process?

- Does the sampling plan ensure the collection of "usable" data? "Usable" data have satisfied a series of criteria of suitability for the intended use (i.e., quality assurance; see Heitmuller and Valente, 1991).

This subsection also identifies logistical problems encountered in the 1991 Louisianian Province Demonstration.

Three sampling teams (East, Delta, and West), each consisting of two rotating 5-person crews, sampled the 187 sites comprising the Louisianian Province Demonstration according to the logistics plans (Macauley and Summers 1991b, Phifer et al. 1991). Crews worked alternating six-day shifts. Exchanges between crews occurred at pre-designated sites so that information could be exchanged between Crew Chiefs.

The three teams sampled 183 sitesof the 187 intended sites. Four sites were determined to be "unsampleable" due to insufficient depth; two in the Ecofina River, FL (< 0.5 m) and two in the Rio Grande, TX (< 0.7 m at only available ramp and 0.5 m at mouth). Quality control inspections were conducted of each crew during its first six-day tour. On the whole, the 1991 Louisianian Province Demonstration was successful in its attempt to collect large amounts of information and samples over a relatively short time period. The overall effectiveness of the 1991 sampling plan is reflected in the high percentage of stations for which usable data were obtained for the variety of parameters measured (Table A-6). While all stations were sampled as planned, not every site was sampled for every parameter and not every sample was successfully processed and shipped to its corresponding analytical laboratory. The remainder of this subsection delineates the number of samples successfully collected, successfully shipped, successfully completed QC evaluation, and summarizes the percentage completion for each sampled parameter.

Six data sets did not require any laboratory analysis (i.e., collected directly on board the vessel). These include: instantaneous water quality, continuous water quality, marine debris, fish/shellfish abundance and community composition, RPD depth, and large bivalve abundance. Instantaneous water quality measures (i.e., salinity, temperature, pH, dissolved oxygen, % surface light transmittance, and water depth) were successfully collected from all sites at 1-meter intervals from surface to bottom. Continuous water quality parameters (i.e., salinity, temperature, pH, dissolved oxygen, % saturation, and water depth collected every 15 minutes for 24 hours) were successfully obtained from 162 of the scheduled 163 sites (i.e., no continuous meters were deployed in the Mississippi River due to excessive currents). The lack of continuous data from the Mississippi River does not create a problem. General water quality conditions in this water body could be inferred from instantaneous measures because the water column was well-mixed over its 15-40m depth. Variability in all water quality measures was extremely small throughout the 250-km length of the Mississippi River that was sampled (e.g., dissolved oxygen concentrations ranged from 5.0 to 6.5 ppm over the sampled length of the river). The single continuous water quality data gap resulted from a battery malfunction. The high success rate of deploying and retrieving useful

Sample Type	Expected	Collected	Received	Processed	Completed
Water Quality	183	183	183	183	100%
DataSonde III	183	182	182	182	99%
Sediment Profile	764	764	763	763	100%
Benthos	581	581	581	581	100%
Toxicity	398	398	398	398	100%
Chemistry	1098	1098	1095	1095	100%
Fish Trawls	199	196	196	196	98%
Fish Chemistry	366	591	591	300	100%[1]
Bivalve Dredge	158	155	155	155	98%
Stable Isotope	16	16	16	16	100%
Bile Extraction	16	7	7	7	44%
Blood Extraction	16	7	7	7	44%
Skeletal X-Rays	200	436	436	436	100%
Gross Pathology	4500	8613	8613	8613	100%
Hispathology	200	436	436	436	100%

[1]Only 300 samples authorized for analysis, remaining 291 samples are being archived for possible future analysis.

Table A-6. Comparison of number of samples expected, successfully collected, shipped, processed, and completed.

information from the Hydrolab systems indicate the overall feasibility of multi-day deployments of these devices to characterize continuous water quality conditions.

Marine debris was inventoried at all 183 sites; all collections were categorized as: plastic, metal, glass, wood, or other. Only debris of potential anthropogenic origin was catalogued.

Triplicate measures of redox potential discontinuity depth were successfully collected from each site.

Fish trawls were completed at all but 4 sites. These sites represented areas of heavily fouled bottoms (2 base sites and 1 index site) or heavy commercial traffic (1 base site). After repeated sampling attempts resulting in snagged nets or abbreviated trawls, trawling at these 4 sites was discontinued. These sites represent less than 0.1% of the surface area of the estuarine resources being characterized in the Louisianian Province. Fish trawls produced 12,166 fish of which approximately 60% were target species. As a result of the distribution of the ten target species, 4 sites provided no opportunity for the collection of fish for tissue contaminant analysis (i.e., unsampleable). In addition, 2 sites produced no fish from multiple trawls and 15 sites did not produce sufficient tissue biomass to permit contaminant analysis. Thus, 21 of the 183 sites (11%) sampled in 1991 cannot be evaluated with regard to fish contaminant concentrations. While these 21 sites represent 11% of the monitoring sites, they represent only 5% of the surface area of the Louisianian

All but 7 sites of the 163 scheduled locations were sampled for large bivalves using the dredge (i.e., no dredge samples were collected in the Mississippi River due to the abundance of debris on the bottom). Of these 7 sites, 4 sites correspond to locations where we were denied access to privately leased shellfish beds (i.e., Barataria Bay and Little Lake, LA). The remaining 3 sites correspond to the areas where fish trawling was not possible due to bottom debris.

Benthic sampling provided samples for four activities: benthic enumeration (abundance, composition, and biomass), sediment characterization (AVS, % silt-clay, TOC, grain size), toxicity testing (*Ampelisca* and

mysid), and sediment contaminant concentrations. All sites were successfully sampled and all samples were successfully transported to their associated laboratories with one exception. A single sediment characterization core (one of four replicates) was shipped to the incorrect laboratory without ice, making the sample unuseable. This sediment core represents 1 of 4 taken at a specific location and 1 of 764 samples analyzed to characterize this indicator. All laboratory samples associated with the benthic collections produced useable information. Metal analyses for three sites were not completed initially due to a misplacement of the samples at the laboratory. This omission was noted when the incoming data set was quality- control checked. The samples were subsequently located and analyzed. The metals data from these three sites were merged with the existing data set. All other analyses were successful and produced data that met EMAP-E quality control criteria (see Section 6 and Heitmuller and Valente 1991).

A.4.4 INDICATOR SAMPLING METHODS

The EMAP indicator strategy involves four types of ecological indicators (Hunsaker and Carpenter 1990, Knapp et al. 1991): response, exposure, habitat, and stressor (Fig. A-3). Response indicators are ecological characteristics that integrate the responses of living resources to specific or multiple pollutants and other stresses and are used by EMAP to assess overall estuarine condition. Exposure indicators quantify pollutant exposure and habitat degradation and will be used mainly to identify associations among stresses on the environment and degradation in response indicators. Habitat indicators provide basic information about the natural environmental setting and are used to normalize exposure and response indicators to natural environmental gradients. Stressor indicators are used to quantify pollution inputs or stresses and identify the probable sources of pollution exposure. Examples of the relationships between response, exposure, and habitat indicators sampled during the 1991 Louisianian Province Demonstration are given in Fig. A-3. Descriptions of the methods used of individual indicators have been taken from the Near Coastal Program Plan (Holland 1990), the Louisianian Province Implementation Plan (Summers et al. 1991), the Louisianian Province Field Methods Manual (Macauley and Summers 1991a), and the Near Coastal Laboratory Procedures Manual (USEPA 1990). Figure A-4 describes the sampling activities that occurred at base, index, and supplemental sites. Figure A-5 describes these activities at indicator testing and evaluation sites.

A.4.4.1 RESPONSE INDICATORS

A.4.4.1.1 BENTHOS

Benthic invertebrate assemblages are composed of diverse taxa with a variety of reproductive modes, feeding guilds, life history characteristics, and physiological tolerances to environmental conditions (Warwick 1980; Bilyard 1987). As a result, benthic populations respond to changes in conditions, both natural and anthropogenic, in a variety of ways (Pearson and Rosenberg 1978; Rhoads et al. 1978; Boesch and Rosenberg 1981). Responses of some benthic organisms indicate changes in water quality while others indicate changes in sediment quality. Because most benthic organisms have limited mobility, they cannot avoid

exposure to pollution stress as many other estuarine organisms can (e.g., fish). Benthic communities have proven to be a reasonable and effective indicator of the extent and magnitude of pollution impacts in estuarine environments (Bilyard 1987; Holland et al. 1988, 1989) when studied over extended time scales.

Benthic samples for measures of species composition, abundance, and biomass were collected at all sampling sites. Samples were collected with a Young-modified Van Veen grab which samples a surface area of 440 cm^2. Three grabs were collected at each base, index, or supplement site, while five grabs were collected at each indicator testing site. A small core (60cc) was taken from each grab for sediment characterization. The remaining sample was sieved through a 0.5 mm screen using a backwash technique that minimized damage to soft-bodied animals. Samples were preserved in 10% formalin-rose bengal solution and stored for at least 30 days prior to processing.

In the laboratory, macrobenthos were transferred from formalin to an ethanol solution and sorted, identified to lowest practical taxonomic level, and counted. Biomass was measured for selected key taxa; biomass for all other taxa were measured based on groups according to taxonomic type (e.g., polychaetes, amphipods, decapods). Shell-free dry weight was determined using an analytical balance with an accuracy of 0.1 mg after drying at 60 C. Large bivalves were shucked prior to determining biomass. Smaller shells were removed by acidification using a 10% HCl solution.

All compositional and biomass data were transferred to the Environmental Research Laboratory at Gulf Breeze, FL, incorporated into the Louisianian Province Information Management System (LP-IMS), and quality control checked. All data met quality criteria.

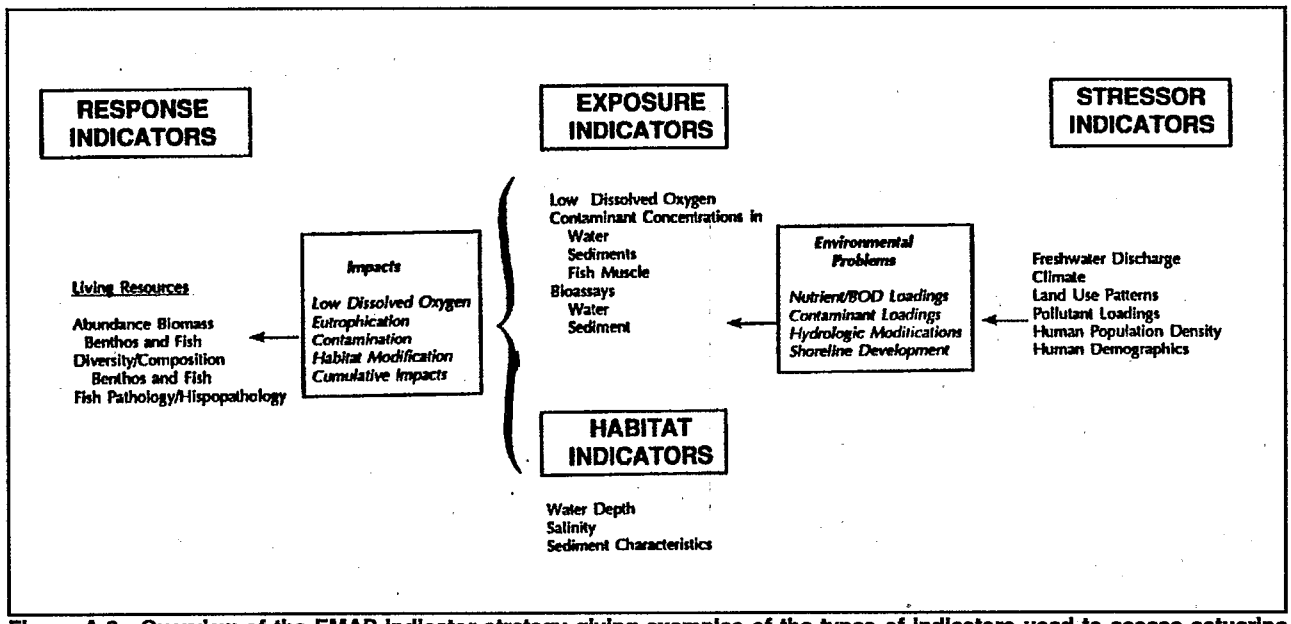

Figure A-3. Overview of the EMAP indicator strategy giving examples of the types of indicators used to assess estuarine status.

A.4.4.1.2 FISH

There are several advantages to using fish as a potential indicator of estuarine condition. Because of their longevity and dominant position at the upper end of the estuarine food web, fish responses can integrate many short-term and small-scale environmental perturbations. Fish are known to respond to most environmental problems of concern in estuaries, including eutrophication, habitat modification, and pathogenic or toxic contamination. However, fish indicators like community composition may vary seasonally and be difficult to evaluate using species-specific gears.

Fish were collected by trawling with a 16-ft, high-rise otter trawl with a 2.5-cm mesh cod end. The net was towed for 10 minutes against the tide (if significant tidal current existed) between 0.7 and 1.0 m/s. All fish caught in the trawl were identified to species and counted; up to 30 individuals of each target species (Table A-7) and up to 20 fish of non-target species from each collection were measured to the nearest millimeter.

Up to 10 indivduals were retained from each trawl for tissue analysis. The specimens were labeled, frozen on dry ice, packaged and shipped to the laboratory where they were stored, frozen, for subsequent tissue contaminant analysis for the contaminants listed in Table A-8. Based upon frequency of catch, composites of individuals were selected for contaminant analysis. Table A-9 depicts the observed catch frequencies for the target species. Based on these frequencies, shrimp (brown or white), catfish (hardhead or gafftopsail), and Atlantic croaker were selected for analysis. These three groups each comprised about 45-55% of the sampled locations. In addition, the non-target species, blue catfish, *Ictalurus furcatus* (the most common oligohaline catfish taken), was included in the catfish group.

Target Species

Brown Shrimp *(Penaeus aztecus)*
Atlantic Croaker *(Micropogonias undulatus)*
White Shrimp *(Penaeus setiferus)*
Hardhead Catfish *(Arius felis)*
Blue Crab *(Callinectes sapidus)*
Spot *(Leiostomus xanthurus)*
Pinfish *(Lagodon rhomboides)*
Southern Flounder *(Paralichtys lethostigma)*
Sand Seatrout *(Cynoscion arenarius)*
Gafftopsail Catfish *(Bagre marinus)*

Table A-7. Target Species in 1991 Louisianian Province Demonstration.

At all stations where fish were collected, all individuals were inspected for gross external pathological disorders. This inspection included checking body surface and fins for skin discoloration, raised scales, white or black spots, ulcers, fin erosion, lumps or growths, parasites, and opercular deformity; the branchial chamber for gill discoloration, erosion, deformity, parasites, and lumps and growths; the buccal cavity for hemmorrhages, parasites,and lumps or growths; the overall morphology of the fish for skeletal malformations; and condition of the eyes. Specimens with observed gross pathologies were preserved in Dietrich's solution for laboratory verification and histological examination. At indicator testing sites, all specimens exhibiting gross pathologies, up to 30 pathology-free specimens of each target species, and up to 20 specimens of each non-target species that were free of external gross pathologies were preserved for quality control checks of field observations. These fish also received histopathological

DDT and It Metabolites

o,p'-DDD
p,p'-DDD
o,p'-DDE
p,p'-DDE
o,p'-DDT
p,p'-DDT

Trace Elements

Aluminum	Mercury
Arsenic	Nickel
Cadmium	Selenium
Chromium	Silver
Copper	Tin
Iron	Zinc
Lead	

Chlorinated Pesticides Other Than DDT

Aldrin	Heptachlor
Alpha-Chlordane	Heptachlor epoxide
Trans-Nonachlor	Hexachlorobenzene
Dieldrin	Lindane (gamma-BHC)
Endrin	Mirex
Endosulfan	Toxaphene

18 PCB Congeners

PCB No.	Compound Name
8	2,4'-dichlorobiphenyl
18	2,2',5-trichlorobiphenyl
28	2,4,4'-trichlorobiphenyl
44	2,2',3,5'-tetrachlorobiphenyl
52	2,2',5,5'-tetrachlorobiphenyl
66	2,3',4,4'-tetrachlorobiphenyl
77	3,3',4,4'-tetrachlorobiphenyl
101	2,2',4,5,5'-pentachlorobiphenyl
105	2,3,3',4,4'-pentachlorobiphenyl
118	2,3',4,4',5-pentachlorobiphenyl
126	3,3',4,4',5-pentachlorobiphenyl
128	2,2',3,3',4,4'-hexachlorobiphenyl
138	2,2',3,4,4',5'-hexachlorobiphenyl
153	2,2',3,4,4',5'-hexachlorobiphenyl
170	2,2',4,4',5,5'-hexachlorobiphenyl
180	2,2',3,3',4,4',5-heptachlorobiphenyl
187	2,2',3,4,4',5,5'-heptachlorobiphenyl
195	2,2',3,3',4,4',5,6-octachlorobiphenyl
206	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
209	decachlorobiphenyl

Table A-8. Contaminents analyzed for in edible fish and shellfish tissue.

Target Species	Expected[1]	Observed
Brown Shrimp	72%	26%
Atlantic Croaker	58%	52%
White Shrimp	53%	23%
Hardhead Catfish	50%	48%
Blue Crab	50%	42%
Spot	47%	28%
Pinfish	48%	25%
Southern Flounder	41%	12%
Sand Seatrout	41%	26%
Gafftopsail Catfish	29%	24%

[1]Expected frequencies were based on the weighted average frequency of catch of the selected species obtained by state monitoring programs during July and August (1980-1990).

Table A-9. Expected versus realized catch frequencies of fish targeted for the 1991 Louisianian Province Demonstration.

examinations to assess the magnitude of liver lesions, spleenic macrophage aggregates, and gill or kidney disfunction. In addition, all of these specimens were X-rayed to assess skeletal aberrations.

A.4.4.1.3 LARGE BIVALVES

The occurrence of large, older bivalves at a site generally indicates that the general absence of toxic environmental conditions at that site over time. The relative immobility of bivalves makes them good integrators of long-term environmental conditions at the site from which they were collected.

A modified oyster dredge was used to collect specimens of large infaunal and epifaunal species. The dredge, equipped with a collection bag, was towed over the bottom for five minutes at approximately 1 m/s. Mollusks were identified to species and counted. Shell length was measured for up to 30 randomly selected individuals of each species in order to provide an indication of the age structure of the

population. Up to 30 individuals of each species collected were frozen on dry ice and shipped to NOAA's Gulf National Status and Trends laboratory for archival purposes.

A.4.4.2 EXPOSURE INDICATORS

A.4.4.2.1 SEDIMENT CHARACTERIZATION

The physical characteristics of estuarine sediments (e.g., grain size, silt-clay content) and certain chemical aspects of sediments (e.g., acid volatile sulfide (AVS) content, total organic carbon (TOC) content) influence the distribution of benthic fauna and the accumulation of contaminants in sediments (Rhoads 1974, Plumb 1981, DiToro et al. 1991). Sediment grain size and silt-clay content were collected to help interpret the response indicators and sediment contaminant accumulations. AVS and TOC were collected not only as interpretive aids but also as potential covariates for toxic contaminant accumulation.

A subsample from each of the benthic and sediment contaminant grabs was retained to determine these sediment characteristics. Samples were shipped, on ice, to the appropriate processing laboratory. Samples for the determination of silt-clay content and grain size distribution were sieved using a 63μm mesh sieve. Both the filtrate and the fraction retained on the sieve were dried in an oven at 60 C and weighed to calculate the proportion of silts and clays in the sample.

Procedures for determining grain size distribution generally followed the framework described for the silt-clay analysis; however, the fraction retained on the sieve was processed through an additional sieve analysis to determine specific grain size percentages. The filtrate was processed using pipette analysis.

Total organic carbon and acid volatile sulfides were determined for each site. TOC was determined by drying a minimum of 5 g wet weight of sediment for 48 hours. Weighed subsamples are ground to fine consistency and acidified to remove sources of inorganic carbon (e.g., shell fragments). The acidified sample was ignited in a furnace at approximately 950° C and the carbon dioxide evolved was measured with a infrared gas analyzer. These peaks were converted to total organic carbon.

Total acid volatile sulfides were determined for each site. AVS was determined by the measurement of amorphorous or moderately crystalline monosulfides. These substances are important in controlling the bioavailability of metals in anoxic sediments. If the molar ratio of metal to AVS exceeds one, then the metal is potentially bioavailable (DiToro et al. 1991).

Unfortunately, the collection methods employed in the 1991 Demonstration permitted the potential release of sulfides when the materials where processed onboard the sampling vessel and in subsequent shipping. The sample was collected from a homogenized composite (i.e., maximal exposure to oxygen) and shipped in a container that allowed a headspace that might encourage the elimination of sulfides. As a result, the accuracy of the AVS measurements were in doubt although the precision may remain reliable as all samples were treated

similarly. Modifications to the collection methods have been determined for the 1992 sampling to prevent a recurrence of these errors.

A.4.4.2.2 SEDIMENT CONTAMINANTS

Metals, organic chemicals, and fine-grained sediments entering estuaries from freshwater inflows, point sources of pollution, and various non-point sources including atmospheric deposition, generally are retained within estuaries and accumulate in the sediments (Turekian 1977, Forstner and Wittman 1981, Schubel and Carter 1984, Nixon et al. 1986, Hinga 1988). Sediment samples for contaminant analysis were collected from all sites. Samples were collected from a homogenate created during sampling by combining the top 2 cm of sediment from 6-10 sediment grabs. The sediment was placed in clean glass jars with foil lid liners, shipped on ice, and stored frozen in the laboratory prior to analysis for organic contaminants. In addition, a subsample was taken from the same homogenate and placed in a plastic bag, shipped on ice, and stored frozen in the laboratory for subsequent analysis for metals. The sediments were analyzed for the NOAA National Status and Trends suite of contaminants and several additional contaminants of particular interest in the Louisianian Province (e.g., alkanes, Table A-10) analyzed using the methods in Table A-11.

A.4.4.2.3 SEDIMENT TOXICITY

Sediment toxicity testing is the most direct measure available for determining the toxicity of contaminants in sediments to sensitive indigenous biota. It improves upon direct measurement of sediment contaminants because many contaminants are tightly bound to sediment particles or are chemically complexed and, therefore, are not biologically available (USEPA 1989). Sediment toxicity testing cannot be used to replace direct measurement of the concentrations of contaminants in sediment because such measurements are an important part of interpreting the results of toxicity tests.

Sediment for the toxicity tests was collected using a Young-modified Van Veen grab used for benthic invertebrate sampling. The top 2 cm of 6-10 grabs was placed in a mixing bowl and homogenized. Care was taken to avoid collecting sediment adjacent to the edges of the collection device and the mixing bowl was stored on ice between grabs to control temperature and avoid extraneous contaminantion. After approximately 3,000 ml of sediment were collected and completely homogenized, the sediment was distributed among containers for sediment toxicity testing, sediment chemistry, and sediment characterization.

Toxicity tests were performed using the composite sediment samples from each station. Tests were conducted using the standard 10-day acute test method (Swartz et al. 1985, ASTM 1990) and the tube-dwelling amphipod *Ampelisca abdita*. Because of the difficulty in obtaining this amphipod (i.e., its abundance in the Gulf region is low and it is not culturable), standard 4-day acute tests using the mysid, *Mysidopsis bahia*, were also conducted. Five replicate tests were completed for each site. The bioassays were completed under static conditions for 4 or 10 days at 20° C and 30 ppt.

Alkanes and Isoprenoid

C10	C16	Phytane	C22	C26	C30
C11	C17	C19	C23	C27	C31
C12	Pristane	C20	C24	C28	C32
C13	C18	C21	C25	C29	C33
C14					C34
C15					

Polyaromatic Hydrocarbons (PAHs)

Acenaphthene	Benzo(e)pyrene	2-methylnaphthalene
Acenaphthylene	Biphenyl	1-methylnaphthalene
Anthracene	Chrysene	1-methylphenanthrene
Benz(a)anthracene	Dibenz(a,b)anthracene	Naphthalene
Benzo(b)fluoranthene	2,6-dimethylnaphthalene	Perylene
Benzo(k)fluoranthene	Fluoranthene	Phenanthrene
Benzo(g,h,i)perylene	Fluorene	Pyrene
Benzo(a)pyrene	Ideno(1,2,3-c,d)pyrene	2,3,5-Trimethylnaphthalene

DDT and its metabolites

o,p'-DDD	p,p'-DDE
p,p'-DDD	o,p'-DDT
o,p'-DDE	p,p'-DDT

Chlorinated pesticides other than DDT

Aldrin	Heptachlor
Alpha-Chlordane	Heptachlor epoxide
Trans-Nonachlor	Hexachlorobenzene
Endrin	Lindane (gamma-BHC)
Endosulfan	Mirex
Dieldrin	Toxaphene

Major Elements

Aluminum
Iron
Manganese

Trace Elements

Antimony	Mercury
Arsenic	Nickel
Cadmium	Selenium
Chromium	Silver
Copper	Tin
Lead	Zinc

PCB Congeners:

PCB No.	Compound Name
8	2,4'-dichlorobiphenyl
18	2,2',5-trichlorobiphenyl
28	2,4,4'-trichlorobiphenyl
44	2,2',3,5'-tetrachlorobiphenyl
52	2,2',5,5'-tetrachlorobiphenyl
66	2,3',4,4'-tetrachlorobiphenyl
101	2,2',4,5,5'-pentachlorobiphenyl
105	2,3,3',4,4'-pentachlorobiphenyl
110/77	2,3,3',4',6-pentachlorobiphenyl/3,3',4,4'-tetrachlorobiphenyl
118	2,3',4,4',5-pentachlorobiphenyl
126	3,3',4,4',5-pentachlorobiphenyl
128	2,2',3,3',4,4'-hexachlorobiphenyl
138	2,2',3,4,4',5'-hexachlorobiphenyl
153	2,2',3,4,4',5'-hexachlorobiphenyl
170	2,2',4,4',5,5'-hexachlorobiphenyl
180	2,2',3,3',4,4',5-heptachlorobiphenyl
187	2,2',3,4,4',5,5'-heptachlorobiphenyl
195	2,2',3,3',4,4',5,6-octachlorobiphenyl
206	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
209	decachlorobiphenyl

Other Measurements

Butyltins Acid volatile sulfides Total organic carbon Grain size distribution %Silt-Clay

Table A-10. Analytical measurements for sediment samples collected during the 1991 Louisianian Province Demonstration.

Compounds	Method
Inorganics:	
Ag, Al, Cr, Cu, Fe, Mn, Ni, Pb, Zn	Total digestion using HF/HN03 (open vessel hot plate) followed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) analysis.
As, Cd, Sb, Se, Sn	Microwave digestion using HN03/HCl followed by graphite furnace atomic absorption (GFAA) analysis.
Hg	Cold vapor atomic absorption spectrometry
Organics:	
Extraction/Cleanup	Soxhlet extraction, extract drying using sodium sulfate, extract concentration using Kudema-Danish apparatus, removal of elemental sulfur with activated copper, removal of organic interferents with GPC and/or alumina.
PAH measurement	Gas chromatography/mass spectrometry (GC/MS)
PCB/pesticide	Gas chromatography/electron capture detection (GC/ECD) with second column confirmation

Table A-11. Analytical methods used in 1991 for determination of chemical contaminant concentrations in sediments.

Additional toxicity tests were run at the indicator testing sites to examine a species of commercial importance, brown shrimp (*Penaeus aztecus*), and a benthic species that was in constant contact with the sediment, the polychaete, *Nereis succinea*.

A.4.4.2.4 DISSOLVED OXYGEN

Dissolved oxygen (DO) is important because adequate levels are a fundamental requirement for maintenance of populations of benthos, fish, shellfish, and other estuarine biota. DO concentrations are affected by environmental stresses, such as point and nonpoint discharges of nutrients or oxygen-demanding materials (e.g., particulates, dissolved organic matter). In addition, stresses that occur in conjunction with low DO concentrations may be even more detrimental to biota (e.g., exposure to hydrogen sulfide, decreased resistance to disease and contaminants). DO levels are highly variable over time, fluctuating widely due to tidal action, wind stress, and biological activity (Kemp and Boynton 1980, Welsh and Eller 1991). One of the objectives of the 1991 Louisianian Province Demonstration was to collect regional data to best represent the dissolved oxygen conditions in the estuaries of the province.

In 1990, pilot studies in northern Gulf of Mexico estuaries were conducted to assess the most accurate short-term measurement of DO that would represent the dynamics of the DO conditions at a site over the entire 6-8 week sampling period. Continuous meters could be deployed at all sampling sites for the 6-week period; however, only at great expense.

The purpose of the pilot studies was to determine if shorter periods of measurement could be effectively used to

characterize sites. Continuous meters that measured DO, percent DO saturation, salinity, temperature, water depth, and pH were deployed at eight locations over a 4-month period. Details of the study design and site locations are described in Summers and Engle (1992). Monte Carlo analysis of the eight 4-month records showed that tidal influences during summer months were small and that day-night differences accounted for most of the observed variability with wind stress accounting for most event-oriented phenomena. These analyses revealed that 1, 2, or 3 random instantaneous measures of DO were likely to misclassify a station with unacceptable DO conditions (i.e., DO < 2 ppm for > 20% of time period) as acceptable at a rate of 60-70%. Furthermore, short-term continuous measures of 24, 48, and 72 hours also tended to misclassify unacceptable sites although not as often as instantaneous DO measures (i.e., 50%). However, the use of the minimum DO concentration observed in a randomly selected 24-hour period coupled with the mean nighttime DO concentration, and the concentration at dawn produced a predictor of DO conditions that was correct for 95% of the Monte Carlo trials. As a result, both continuous 24-hour and instantaneous measures were selected to be measured at all Louisianian Province sites.

Dissolved oxygen was sampled in two ways during the 1991 Louisianian Province Demonstration: 1) point-in-time water column profiles, and 2) continuous 24-hr measurements of bottom concentrations. Both types of measures were taken at all sites. A Hydrolab Surveyor 2 equipped with a DO electrode was used to make the instantaneous measurements. In addition to DO, the Surveyor 2 measured salinity, temperature, depth, and pH. This instrument was calibrated daily using known solutions (Heitmuller and Valente 1991). Vertical profiles of the water column at meter intervals from surface to bottom were taken at all sites.

A Hydrolab DataSonde 3 data logger was also deployed at each site for 24-36 hours (always including the time period 1800-0600) to collect continuous DO data at 15-min intervals. In addition, the DataSonde 3 collected salinity, temperature, percent DO saturation, water depth, and pH. The DataSonde 3s were calibrated prior to every deployment, checked onboard ship immediately prior to deployment by comparison to the Surveyor 2, and checked weekly against air-saturated water. These instruments were deployed approximately 0.5 m from the bottom. Collected data were downloaded to a computer and recalibrated for subsequent deployment at another site.

A.4.4.3 RESEARCH INDICATORS

Research indicators were examined only at ITE sites. The results of these indicators will be documented in the Louisianian Province Demonstration Report to be published in late 1992. The methods are provided here in order to document all indicators that were collected in 1991.

A.4.4.3.1 MACROPHAGE AGGREGATES

Pigment-bearing macrophages are a prominent feature of fish spleen, kidney, and liver (Agius, 1980) and in advanced teleosts they form discrete aggregations called macrophage aggregates (MAs) (Wolke et al. 1985). Suggested functions

for these aggregates include the centralization 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 status, or health of a particular fish species (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. By comparing the MA number and percent area occupied by MAs among fish of the same age and species from various sites, it may be possible to determine their relative conditions at those sites.

Data on MAs are collected from 6 μm histological sections of spleen from selected fish species (i.e., pinfish, Atlantic croaker) of similar size. Sections are stained with Harris' hematoxylin and eosin or Perls' prussian blue method (Luna 1968). Occurrence of MAs are determined by two methods. First, during initial histological evaluation, the occurrence and intensity of MAs are rated using a scale of 0 to 4, with 0 being no MAs present, 1 indicating minimal occurrence, and 2 through 4 indicating light, moderate, and heavy MA intensity, respectively. Secondly, the MA number and individual MA area are estimated from three random fields per spleen using computer image analysis (MicroComp ™ Integrated Image Analysis System Particle Analysis). These data, identified by individual and site, are compiled and analyzed using SAS. Data produced include MAs per mm^2, average MA area (μm^2), and percent area occupied by MAs. Comparisons are then made among sites by species to determine statistical differences.

A.4.4.3.2 SKELETAL ANOMALIES

Measurement of skeletal deformities in fish has been proposed as a means of monitoring pollution effects in marine environments (Bengtsson 1979, Bengtsson and Bengtsson 1983). Likewise, measurements of biochemical composition and mechanical properties of vertebrae have been shown to be indicators of bone development in fish exposed to contaminants in the laboratory (Hamilton et al. 1981, Mayer et al. 1977), and in the field (Mehrle et al. 1982). Skeletal abnormalities in fourhorn sculpin (*Myoxocephalus quadricornis*) have been used to monitor the impacts of ore smelter and pulp mill effluents in the Baltic Sea (Bengtsson et al. 1985).

Effects of organic and inorganic contaminants on bone integrity are similar in that vertebral anomalies are produced, although they may develop through different modes of action. This similarity makes the use of biochemical composition and mechanical properties, as well as vertebral deformities, conducive to assessing the effect of an array of contaminants on fish health. All preserved fishes were x-rayed laterally with a Hewlett Packard™ Faxitron Series X-ray System set at 50kVp for 20 to 50 seconds, depending on the size of the specimen. Kodak™ Industrex M-2 film was used for all radiographs and they were developed for 5 minutes in Kodak™ D-19 developer. Vertebral anomalies were determined from the x-rays by light box and confirmed by low-power light microscopy. Deformaties were classified according to Bengtsson and Bengtsson.

A.4.4.3.3 BLOOD CHEMISTRY

In both human and veterinary medicine, clinical chemistry measurements and routine hematology are used to assess health of individuals. Altered values in serum enzymes or other proteins, electrolytes, or bloodcells of fish can be indicative of tissue damage, tumors, or impaired immunological functions. Blood was collected from all fish greater than 200 mm in total length at all indicator testing and evaluation sites. Blood, removed by vacutainer, was stored on ice, shipped as soon as possible to the laboratory, and analyzed using a Beckman™ Synchron CX-5.

A.4.4.3.4 BILE FLUORESCENCE

Organisms exposed to petroleum compounds often accumulate polynuclear aromatic hydrocarbons (PAH). Tissue analysis for PAHs often show only trace concentrations, even after high-level exposure, because enzymatic-mediated metabolism can rapidly reduce concentrations. The exposure of fish to PAHs can be assessed by measuring the concentration of metabolites in bile. The relative concentration of individual PAH metabolites of benzo(a) pyrene, phenanthrene, and napthalene in bile were determined using PHLC with fluorescence detection. All fish greater than 200 mm in total length collected at ITE sites were examined for bile contaminants.

A.4.4.3.5 HISTOPATHOLOGY

Fish quality was measured as a composite index of the incidence of diseases in resident species. The presence of diseased fish, as evidenced by a high incidence of fin erosion, skin ulcers, and cataracts, cause recreational and commercial fishermen to avoid certain waters. All fish exhibiting gross external pathologies were examined internally to determine the diseased state of the internal organs. Liver, spleen, intestine, gill, and eye tissues were examined microscopically for abnormalities.

A.4.4.4 HUMAN USE

Aesthetic appeal is an important factor in the public's perception of the suitability of an estuary for human use. The presence of trash in the water and the clarity of the water are primary visual methods by which the public assesses the aesthetic quality of an estuary. In addition, published information concerning the level of toxic contaminants in indicator species or directly in the edible portions of commercial and recreational fish are an important factor in whether the public views an estuarine water body as useable for human activities.

A.4.4.4.1 MARINE DEBRIS

The kinds and amounts of floating and submerged (i.e., collected in otter trawls and oyster dredge) marine debris were noted at all stations. Debris was categorized as paper, plastics, metal, glass, wood, and other wastes. Only debris of anthropogenic origin was included. Wastes that were comprised of composited materials (e.g., dining room chair that was metal, wood, and plastic) were categorized based on their dominant material.

A.4.4.4.2 WATER CLARITY

Water clarity was measured using a LICOR™ LI-1000 containing a submersible light sensor. Underwater readings at 1 m increments were measured simultaneously with ambient surface measurements. The ratio of these two measurements provides the proportion of surface light reaching the ascribed depth. In order to standardize this measure, measurements at 1 m depth (available from all sites) were used to assess the general water clarity throughout the province.

A.4.4.4.3 TISSUE CONTAMINANTS

Target species were collected at all sites where fish were caught and shipped, on dry ice, to the laboratory responsible for tissue contaminant analysis. A review of the fish collections showed that only 3 fish/shellfish groups (i.e., 6 species) provided sufficient spatial coverage of the province to be useful in a regional assessment. These fish/shellfish were Atlantic croaker (*Micropogonias undulatus*), hardhead catfish (*Arius felis*), gafftopsail catfish (*Bagre marinus*), the non-target blue catfish (*Ictalurus furcatus*), brown shrimp (*Penaeus aztecus*), and white shrimp (*Penaeus setiferus*).

Where available, four to ten individuals of each of these species was collected, and prepared in the laboratory by removing the fillet from each organism. The fillets were composited, by species and site, into a homogeneous slurry. The fillets included skin for croakers, excluded skin for catfish, and included only tail meat for shrimp to represent the portions of these fish and shellfish that are eaten. This slurry was appropriately digested, extracted, and analyzed for the contaminants listed in Table A-12.

DDT and it Metabolites	
o,p'-DDD	p,p'-DDE
p,p'-DDD	o,p'-DDT
o,p'-DDE	p,p'-DDT
Trace Elements	
Aluminum	Mercury
Arsenic	Nickel
Cadmium	Selenium
Chromium	Silver
Copper	Tin
Iron	Zinc
Lead	
Chlorinated Pesticides Other Than DDT	
Aldrin	Heptachlor
Alpha-Chlordane	Heptachlor epoxide
Dieldrin	Lindane (gamma-BHC)
Endrin	Mirex
Endosulfan	Toxaphene

20 PCB Congeners

PCB No.	Compound Name
8	2,4'-dichlorobiphenyl
18	2,2',5-trichlorobiphenyl
28	2,4,4'-trichlorobiphenyl
44	2,2',3,5'-tetrachlorobiphenyl
52	2,2',5,5'-tetrachlorobiphenyl
66	2,3',4,4'-tetrachlorobiphenyl
77	3,3',4,4'-tetrachlorobiphenyl
101	2,2',4,5,5'-pentachlorobiphenyl
105	2,3,3',4,4'-pentachlorobiphenyl
118	2,3',4,4',5-pentachlorobiphenyl
126	3,3',4,4',5-pentachlorobiphenyl
128	2,2',3,3',4,4'-hexachlorobiphenyl
138	2,2',3,4,4',5'-hexachlorobiphenyl
153	2,2',3,4,4',5'-hexachlorobiphenyl
170	2,2',4,4',5,5'-hexachlorobiphenyl
180	2,2',3,3',4,4',5-heptachlorobiphenyl
187	2,2',3,4,4',5,5'-heptachlorobiphenyl
195	2,2',3,3',4,4',5,6-octachlorobiphenyl
206	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
209	decachlorobiphenyl

Table A-12. Contaminents analyzed for inedible fish and shellfish tissue.

In addition to these species, the remaining target species were analyzed including skin for the indicator testing sites. These species included: sand seatrout (*Cynoscion arenarius*), spot (*Leiostomus xanthurus*), pinfish (*Lagodon rhomboides*), and

southern flounder (*Paralichtys lethostigma*). No blue crab (*Callinectes sapidus*) tissue was analyzed due to an insufficient quantity of tissue.

A.4.5 DATA COLLECTION AND SAMPLE TRACKING

Field crews were supplied with a personal computer and appropriate software to facilitate electronic recording of the data, data transfer, and sample tracking. All samples, shipments, and equipment were labelled with bar-coded labels to facilitate sample tracking and reduce transcription errors. Field computers were equipped with bar code readers to record sample identification numbers. Receiving laboratories were also equipped with bar code readers to facilitate the receiving process and to rapidly convey information concerning lost or damaged shipments.

Copies of all field data entered into the personal computer were stored on the hard disk and copied to diskettes. Information on the hard disk was transferred daily via commercial carrier phone lines to the Information Management Center at Gulf Breeze, FL and backup diskettes and hard copy were shipped weekly to the Center.

All transferred data were examined within 24-48 hours of collection by EMAP-E personnel. Errors were brought to the attention of the field crews for correction and resampling, if required. All electronic data were checked against paper forms for verification. These resulted in a < 1% error rate in transcription. Most errors involved the inaccurate use of taxon codes, an area that will be stressed in 1992 training. Further information on the details of the near coastal data management systems are presented in Summers et al. (1991) and Rosen et al. (1990).

A.4.6 ANALYTICAL METHODS FOR STATISTICAL SUMMARY

Three types of analyses were conducted for this report: 1) direct evaluations of measured indicators, 2) development of modified or adjusted indicators (e.g., metal contaminants in sediments), and 3) development and use of indices based on directly measured indicator values. Additional analyses to partition the observed response effects among exposure indicators, indicator testing and evaluation, and evaluation of sample design will be completed for subsequent reports and are not included in this document. These analyses will be documented in a Louisianian Province Demonstration Report in late 1992.

A.4.6.1 CUMULATIVE DISTRIBUTION FUNCTIONS

All ecological indicators collected during the 1991 Louisianian Province Demonstration were characterized using cumulative distribution functions (CDFs). These functions describe the full distribution of these indicators in relation to their areal extent within the province. All observations are weighted based upon surface area associated with each sampling site. For large estuaries, the area associated with each sampling unit was equal to the hexagonal spaces created by the grid (280 km^2). For the large tidal river class, the area associated with each sampling segment is equal to the area of the individual segment as determined by planimetry. For the small estuary/small tidal river class, the area associated with

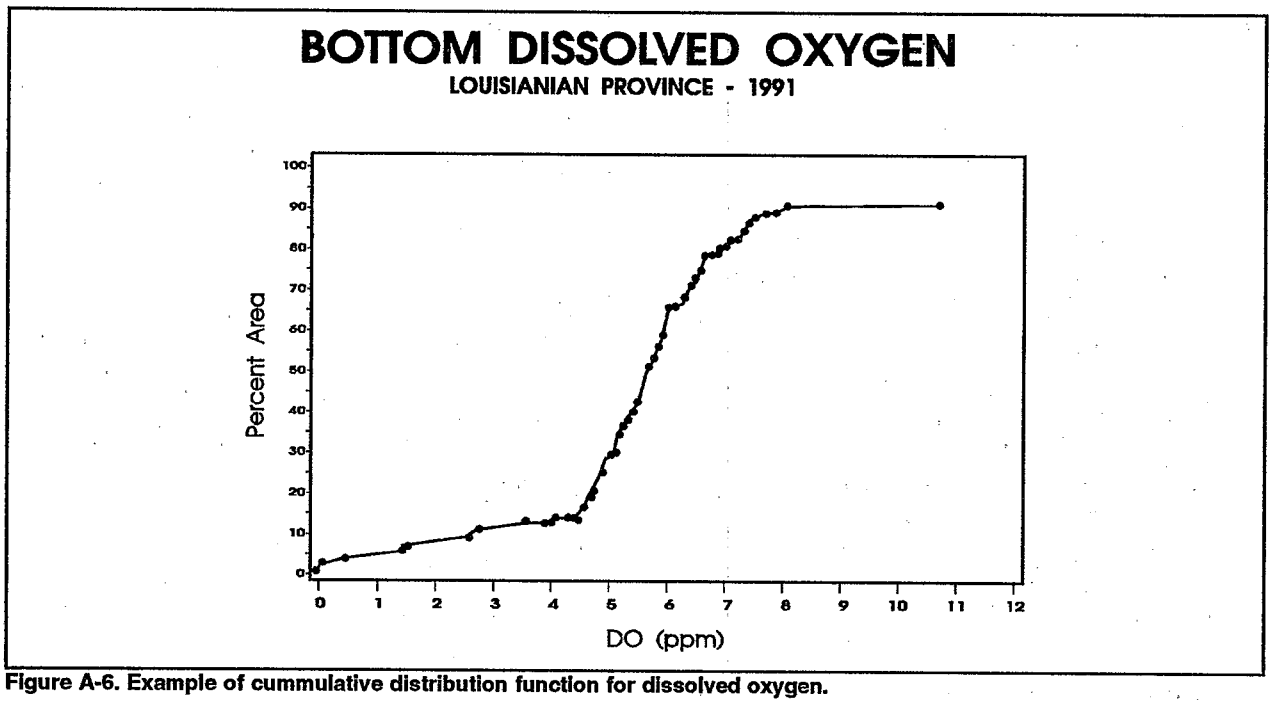

Figure A-6. Example of cummulative distribution function for dissolved oxygen.

the weighting process is equal to the surface area of the water body sampled (e.g., Crystal Bay, Lavaca Bay). The total areas associated with the three classes was: large estuaries - 18,240 km^2; large tidal rivers - 138 km^2; and small estuaries - 7347 km^2.

To generate estimates across classes (strata), weights for stations within each class were adjusted so that the total of the weights for that class was equal to the total area represented within that class. This adjustment primarily affects the small estuary/small tidal river class because this resource is subsampled from the list of all possible systems. Only a portion of the small estuarine class was sampled (i.e., 47 of 156 systems) representing 22% of the total surface area of the small estuary/small tidal river class. As a result,when the estuarine classes were combined to produce Province-wide CDFs, the contribution of the small estuary class was adjusted by a factor of 4.46.

The computation of a CDF represents the full distribution of the values observed for an indicator plotted against the cumulative percentage of area in the class, state, or province. Figure A-6 shows the cumulative distribution of instantaneous bottom dissolved oxygen concentrations for the Louisianian Province. The x-axis represents the DO concentrations observed in 1991 ranging from 0.0 ppm to 11 ppm. The y-axis represents the cumulative percentage of area within the Louisianian Province. The CDF provides the reader with a powerful tool to evaluate the extent of any indicator within the province or class. For example, the reader could be interested in the portion of area within the province that was characterized by 2 ppm or less, a potential biological criterion. This concentration intersects with the cumulative area in the province at 6.1%. The reader might be interested in a state regulatory

criterion of 4 ppm and the CDF shows that, based on the 1991 sampling, 10.7% of the estuarine bottoms waters had DO concentrations below these levels.

Criteria values for the comparison of degraded versus non-degraded areas are often subjective at best. Indeed, many of the criteria values used in this document, though based on reasonable scientific judgement, are debatable. However, the CDF allows the user to select his/her own criterion value and re-evaluate condition in the proportion of area in the Louisianian Province as degraded.

A.4.6.2 ADJUSTMENT TO KNOWN COVARIATES

In several cases, variability in observed indicators might reflect relationships to known habitat or control variables. Examples of these relationships are: variation in estuarine biota resulting from sampling throughout the salinity gradient; variation in sediment toxicity tests with different mortalities associated with the controls; and variation in sediment metals observed at a site resulting from variations in the amount of natural crustal materials at the site. In all these cases, the observed data must be adjusted in order to construct CDFs or to compare observations from different locations.

A.4.6.2.1 ADJUSTMENT FOR NATURAL HABITAT GRADIENTS

Estuarine biota are largely controlled by their environmental settings, both natural and anthropogenic. Natural gradients, particularly in salinity and silt-clay content, are common in estuaries. Many estuarine organisms may represent overlapping discrete distributions along these gradients. Thus, normalization of ecological measures over habitat gradients is a common tool used to interpret information when such normalization is necessary.

Many ecological variables are significantly correlated with natural gradients (i.e., salinity, silt-clay content, water depth). However, these correlations often explain very little of the total variation observed in that variable. Previous EMAP-E efforts in the Virginian Province (Weisberg et al. 1992) suggested that benthic distributions (e.g., number of species, percentage community composition, biomass) needed to be adjusted for salinity gradients because these gradients explained greater than 25% of the total variation in these benthic indicators. Similar analyses using the Louisianian Province data showed that many benthic and fish indicators were significantly correlated to habitat gradients; however none of these correlations accounted for more than 15% of the total variability. As a result, no adjustments for habitat gradients have been made in any of the analyses described in Section 3.

A.4.6.2.2 ADJUSTMENT FOR EXPERIMENTAL CONTROLS

Estimates of the area in the Louisianian province containing toxic sediments were based on the results of toxicity tests using the amphipod, *Ampelisca abdita*, and the mysid, *Mysidopsis bahia*. For this summary, a relative measure of toxicity was created to facilitate comparisons between sites over a series of bioassays. This adjustment is necessary because control mortalities vary among test series. Sediments were determined to be toxic if:

(1) the survival of the test organism in test sediments was less than or equal to 80% of the survival observed in clean, control sediments, and (2) the survival rate in test and control sediments were significantly different ($p < 0.05$). This results in an adjustment to the observed survival rates in test sediments that accounts for variability due to differences in the controls for individual bioassays. These criteria are consistent with those established in USEPA/ACE (1991).

A.4.6.2.3 ADJUSTMENT FOR NATURAL CRUSTAL PROPERTIES

The concentrations of antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc were examined to identify areas containing anthropogenically enriched concentrations of metals. The threshold value for the metals was determined using an aluminum normalization procedure patterned after Windom et al. (1989) and Schropp et al. (1990). For each metal, the data set was reviewed and all values exceeding criteria values (Table A-13) were removed. Log-log regressions were established between metal concentrations (remaining values) and co-occurring aluminum concentrations. Sites with metal concentrations above the 95% confidence interval around the regression line were classifed as enriched.

Because of the subjectivity of selecting sediment enrichment criteria, this regressive approach was not the only method used to assess metal enrichment. Standard CDFs of observed concentrations were constructed and the selected criteria (Table A-13) were used to assess the proportion of estuarine sediments that was enriched.

Metal	Criterion Value (ppm)
Ag	1
As	33
Cd	5
Cr	80
Cu	70
Hg	.15
Ni	30
Pb	35
Sb	2
Sn	3
Zn	120

Table A-13. Threshold criteria used to construct metal-aluminum regressions. Exceedance represents potential enrichment resulting in exclusion for regression analysis. (Based on Long and Morgan 1990).

A.4.6.3 BIOTIC INTEGRITY INDICES

As previously described, response indicators are characteristics of the environment that provide quantitative evidence of the status of ecological resources and biological integrity of the 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 organisms with species compositions, diversity, and functional organization comparable to natural habitats (Karr and Dudley 1981, Karr et al. 1986). Response indicators could include measurements of the kinds and abundances of biota present, the health of individual organisms, and the sustainability of critical ecological processes. These response indicators are the empirical data collected by EMAP-E that are integrated into indices to track the status and trends in ecological integrity.

Two categories of response indicators were

measured during the 1991 Louisianian Province Demonstration: (1) benthic response indicators, and (2) fish response indicators. The general methodology for the construction of the benthic and fish indices are described in Weisberg et al. (1992). The specifics of the Louisianian Province indices will be detailed in an indicator report to be published later this year (Summers et al. 1992b).

A.4.7 PROCEDURES FOR THE CALCULATION OF CONFIDENCE INTERVALS

The approximate 95% confidence intervals for the province were calculated based on the assumption that the CDF estimates were distributed normally. The confidence intervals were obtained by adding and subtracing 1.96 times the estimated standard error (square root of the variance) to the estimated CDF value.

For small estuarine systems, estimates of CDFs and associated variances were computed based on a random selection of small systems within the province, with replicate samples taken from a subset of the selected systems (Cochran 1977). The resulting CDF estimate is:

$$\hat{P}_{Sx} = \frac{\sum_{i=1}^{n} A_i \bar{y}_i}{\sum_{i=1}^{n} A_i}$$

where,

$\hat{P}_{Sx}$ = CDF estimate for value x

$$\bar{y}_i = \frac{1}{m_i} \sum_{j=1}^{m_i} y_{ij}$$

Since replicate samples were only obtained at a subset of the sampled small estuarine systems, the formula for the estimated variance taken from Cochran (1977 eq.

m_i = number of samples at small system i

$$y_{ij} = \begin{cases} 1 \text{ if response is less than } x \\ 0 \text{ otherwise} \end{cases}$$

A_i = area of small system i

n = number of small systems sampled

11.30) was modified to produce the following estimate of the approximate mean squared error (MSE) of the CDF estimate:

$$MSE(\hat{P}_{sx}) = \frac{\frac{N^2}{n}(1-f_1)\frac{\sum_{i=1}^{n} A_i^2(\bar{y}_i - \hat{P}_{sx})^2}{n-1} + \frac{N}{n*}\sum_{i=1}^{n*} \frac{A_i^2 S_{2i}^2}{m_i}}{A^2}$$

where,

N = number of small systems in province (156)

$f_i = n/N$

$n*$ = number small systems with replicate samples.

$$S_{2i}^2 = \frac{\sum_{j=1}^{m_i} (y_{ij} - \bar{y}_i)^2}{m_i - 1}$$

A = the total area of small systems in the province (7,112 km^2).

Estimates of CDFs for large tidal rivers were obtained by applying Horvitz-Thompson estimation (Cochran 1977) with selection probabilities being inversely related to station area. Estimates of CDFs were:

$$\hat{P}_{Tx} = \frac{1}{A}\sum_{i=1}^{n}\frac{y_i}{\pi_i}$$

where,

$\hat{P}_{Tx}$ = Estimate CDF at value x

$y_i = \begin{cases} 1 \text{ if response is less than } x \\ 0 \text{ otherwise} \end{cases}$

π_i = inclusion probability for station i (1/area)

A = total area of sampled tidal rivers

n = number of stations sampled

To achieve unbiased estimates of variance, joint event probabilities π_{ij} must be non-zero. The variance for the CDF estimates was obtained by applying the Yates-Grundy estimate of variance (Cochran 1977) and using approximate joint event probabilities (Stevens et al. 1991):

$$\hat{var}(\hat{p}_{Tx}) = \frac{1}{A^2}\sum_{i=1}^{n}\sum_{j>i}^{n}\left(\frac{\pi_i\pi_j-\pi_{ij}}{\pi_{ij}}\right)\left(\frac{y_i}{\pi_i}-\frac{y_j}{\pi_j}\right)^2$$

where,

π_{ij} = probability that sites i and j are selected for sampling

and

$$\pi_{ij} = \frac{2(n-1)\pi_i\pi_j}{2n-\pi_i-\pi_j}.$$

Estimates of CDFs for large systems were also obtained by applying Horvitz-Thompson estimation with selection probabilities being inversely related to station area. Areas for all large estuary base stations are to be 280 km^2. Formulae for the CDF estimates and corresponding variances are analogous to those presented for large tidal rivers.

Estimates of CDFs for a particular geographic system within the province (e.g. the Florida system) were obtained by applying the above procedures to the small estuarine systems, tidal rivers, and large estuaries sampled within that geographic system. Estimates of the CDFs for the entire province or for a geographic system within the province were computed as weighted averages of the relevant station class CDFs:

$$\hat{P}_x = W_S\hat{P}_{Sx}+W_T\hat{P}_{Tx}+W_L\hat{P}_{Lx}$$

where,

W_S = Relative area of small systems

W_T = Relative area of tidal rivers

W_L = Relative area of large estuaries

In applying these procedures, variance estimation was based on the assumption of a fixed sample size within each resource class. For large tidal rivers and large estuaries, the sample size is a random element depending on the position of the sampling grid. This variance component has not been incorporated into the estimation of variances of CDFs.

APPENDIX B

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.

B.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 proportion to the total

number of sites within the state boundaries. This uncertainty ranges, in general, from a low of about 5-7% for Louisiana (N=60) to a high for Mississippi of approximately 20-30% (N=18). The 95% confidence intervals are shown for each CDF shown in Appendix B and in tabular form for all states at the end of the appendix.

B.1.1 BENTHIC INDEX

The construction of the benthic index is described in Summers et al. (1992b) and Engle and Summers (1992). The cumulative distribution function for the benthic index in Mississippi and Texas are shown in Figures B-1 and B-2. About 45% of the estuarine sediments in Mississippi contained benthic communities similar to those observed at known environmentally degraded sites (Fig. B-3). The highest proportion of degraded benthic communities within the Gulf states in 1991 were found in Alabama, Texas, and Mississippi (Fig. B-4).

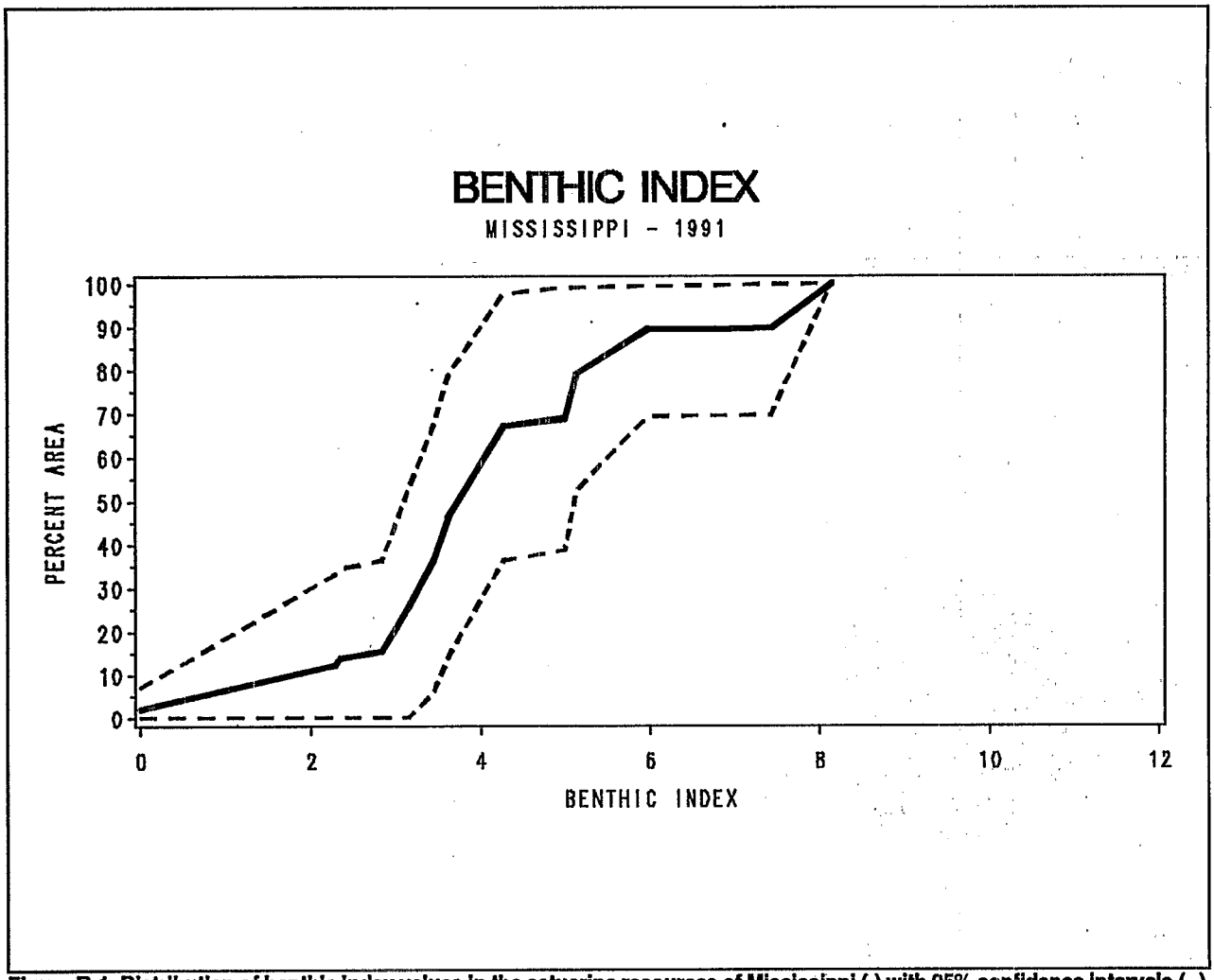

Figure B-1. Distribution of benthic index values in the estuarine resources of Mississippi (-) with 95% confidence intervals (--).

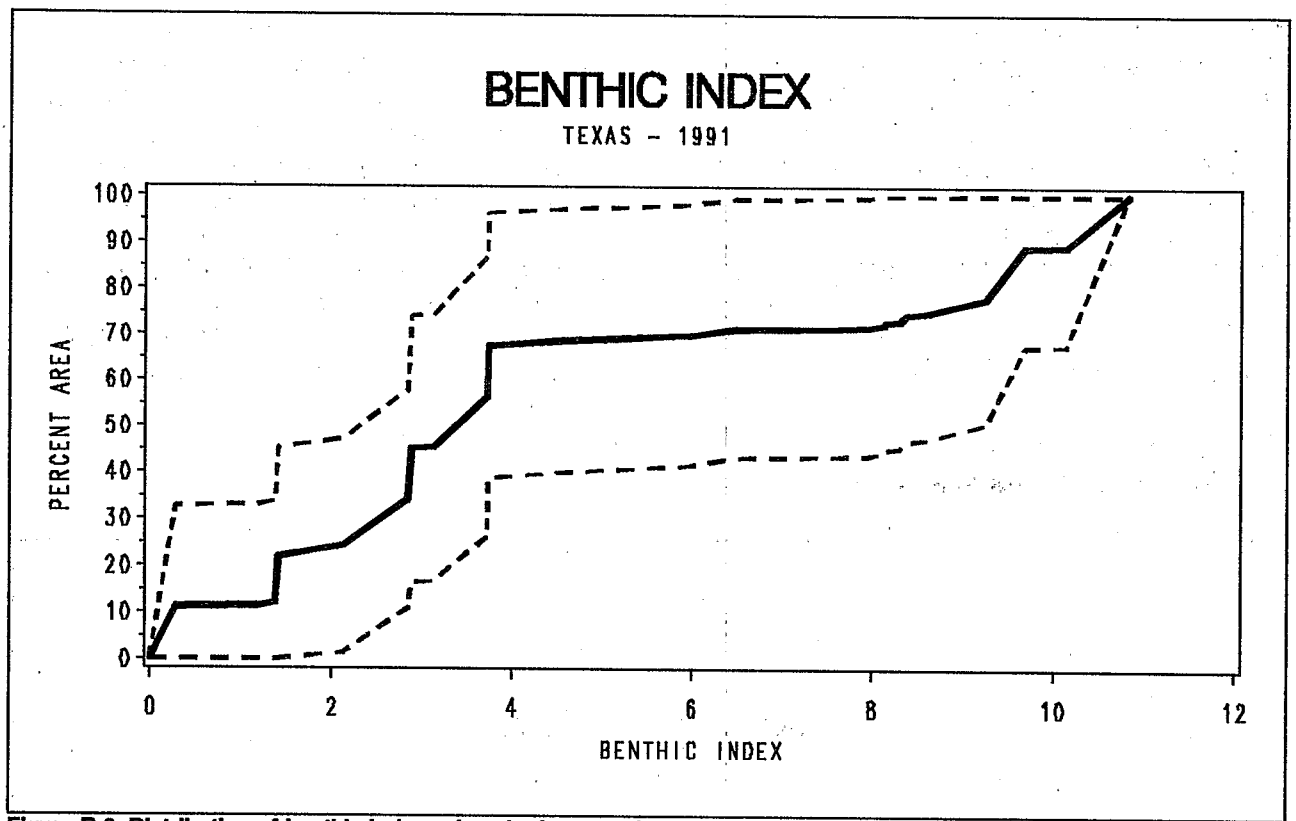

Figure B-2. Distribution of benthic index values in the estuarine resources of Texas (-) with 95% confidence intervals (--).

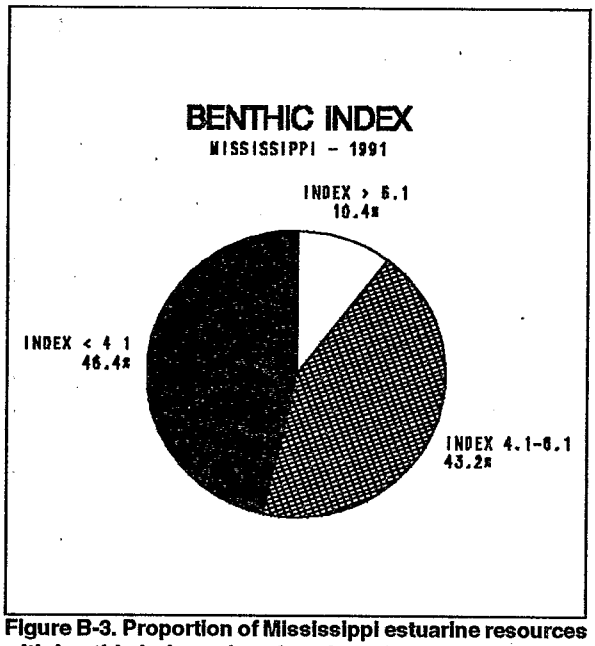

Figure B-3. Proportion of Mississippi estuarine resources with benthic index values in selected categories.

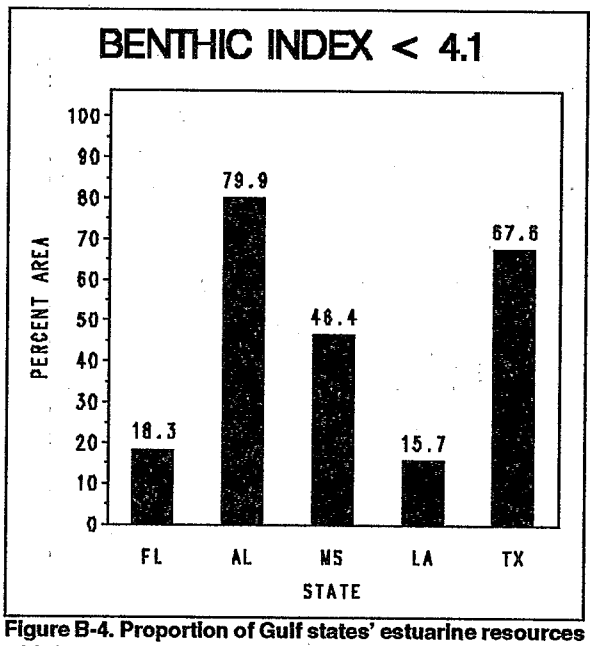

Figure B-4. Proportion of Gulf states' estuarine resources with benthic index values < 4.1.

B.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 Province, resulted in a distribution of total number of species for sites in Louisiana and Texas shown in Figures B-5 and B-6. About 17% of the estuarine waters in Louisiana produced one or fewer species in a single 10-min trawl (Fig. B-7). Ten to 17% of the estuarine waters Louisiana and Mississippi were characterized by these small numbers of species (Fig. B-8).

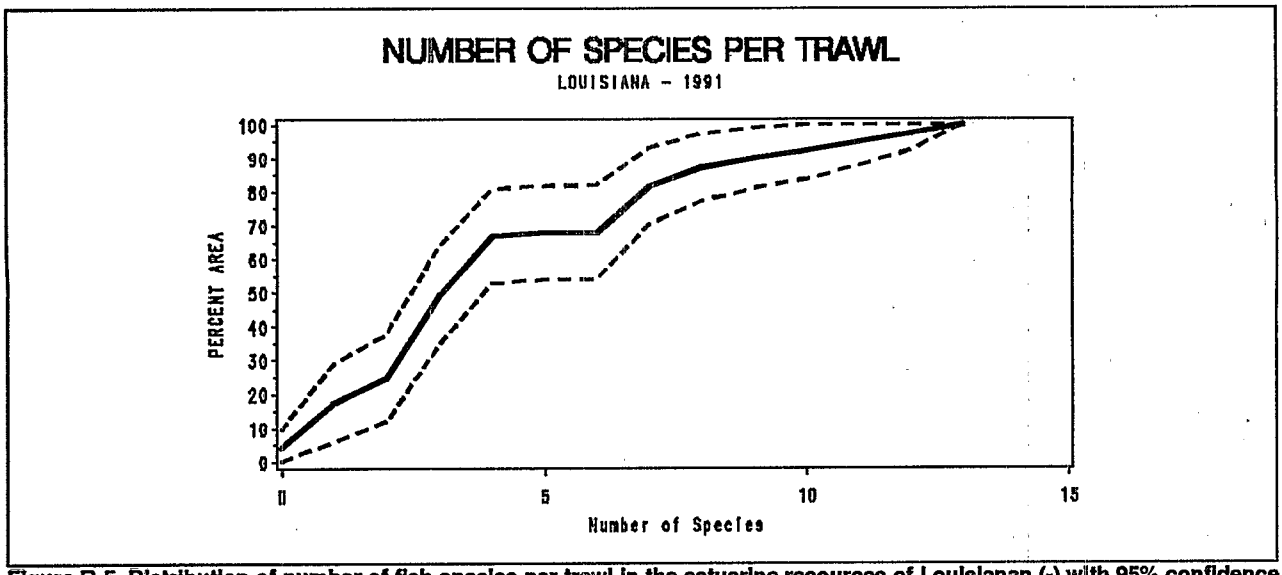

Figure B-5. Distribution of number of fish species per trawl in the estuarine resources of Louisianan (-) with 95% confidence intervals (--).l

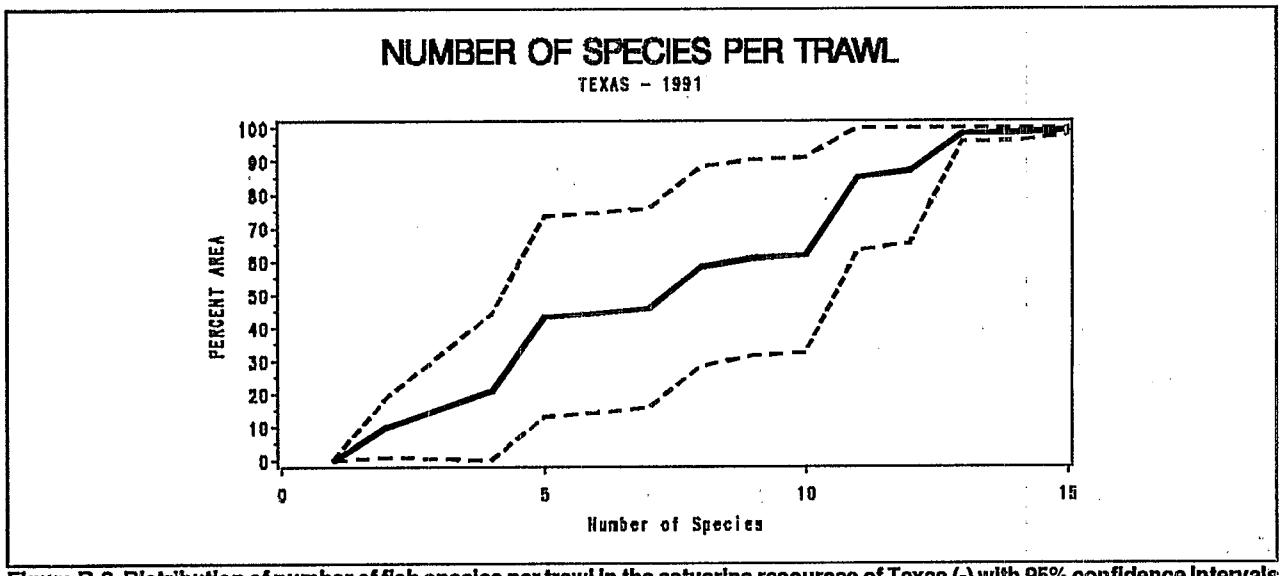

Figure B-6. Distribution of number of fish species per trawl in the estuarine resources of Texas (-) with 95% confidence intervals (--).

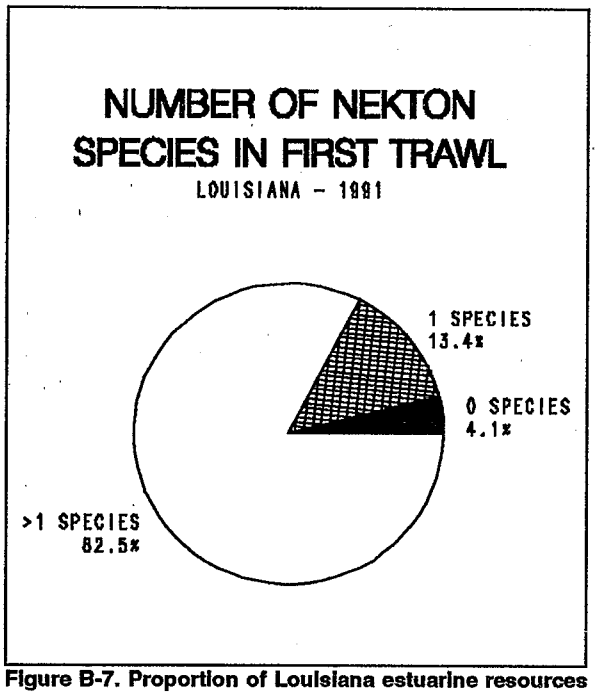

Figure B-7. Proportion of Louisiana estuarine resources with number of fish species per trawl in selected categories.

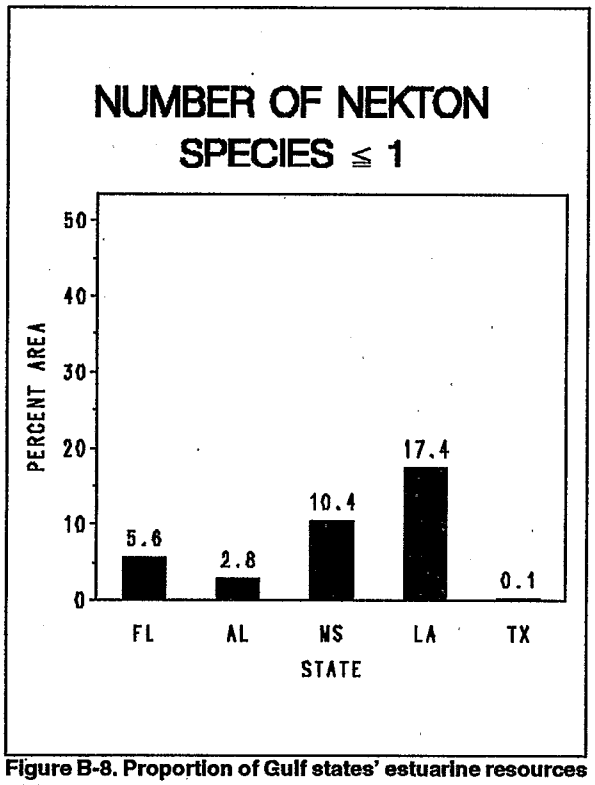

Figure B-8. Proportion of Gulf states' estuarine resources with number of fish species per trawl < 1.

B.1.3 MARINE DEBRIS

The presence of marine debris is one of the obvious indicators of estuarine "degradation" from a human use perspective. Over 50% of the estuarine sediments in Alabama contained marine debris with about 25% of Florida and 38% in Texas estuarine sediments containing marine debris (Fig. B-9).

B.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

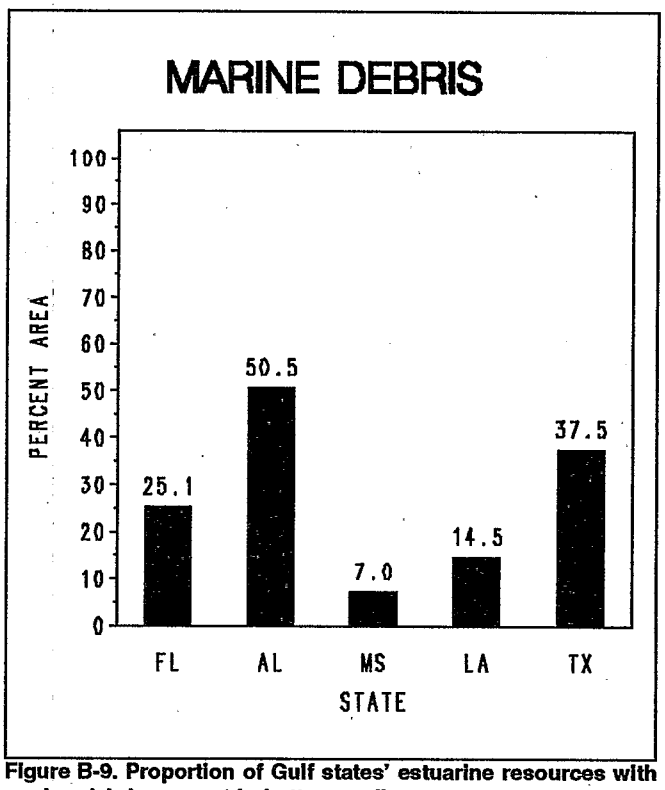

Figure B-9. Proportion of Gulf states' estuarine resources with marine debris present in bottom sediments.

the amount of light reaching 1 meter in depth. The cumulative distribution function for water clarity in Texas is shown in Fig. B-10 where proportional light reaching 1 meter ranged from 0-40%. 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 Texas (53%) and Louisiana (31%) (Fig. B-11).

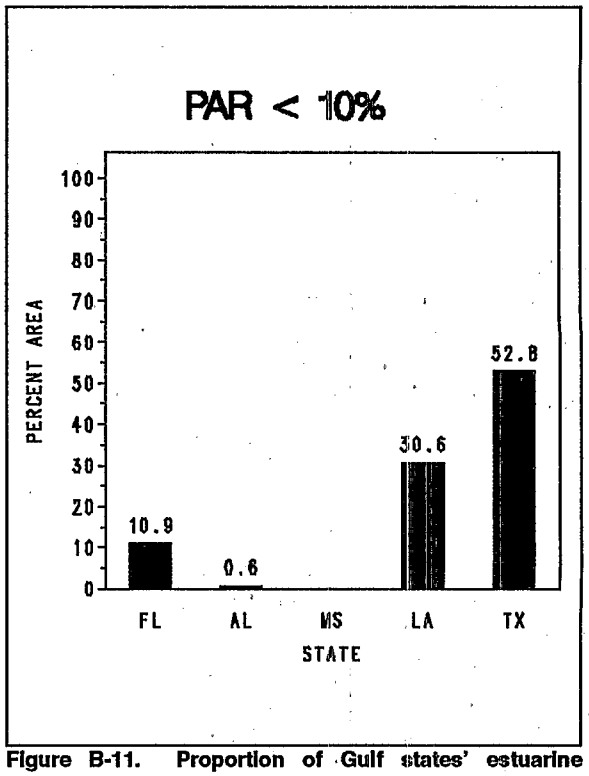

Figure B-11. Proportion of Gulf states' estuarine resources with percent surface light reaching a depth of one meter < 10%.

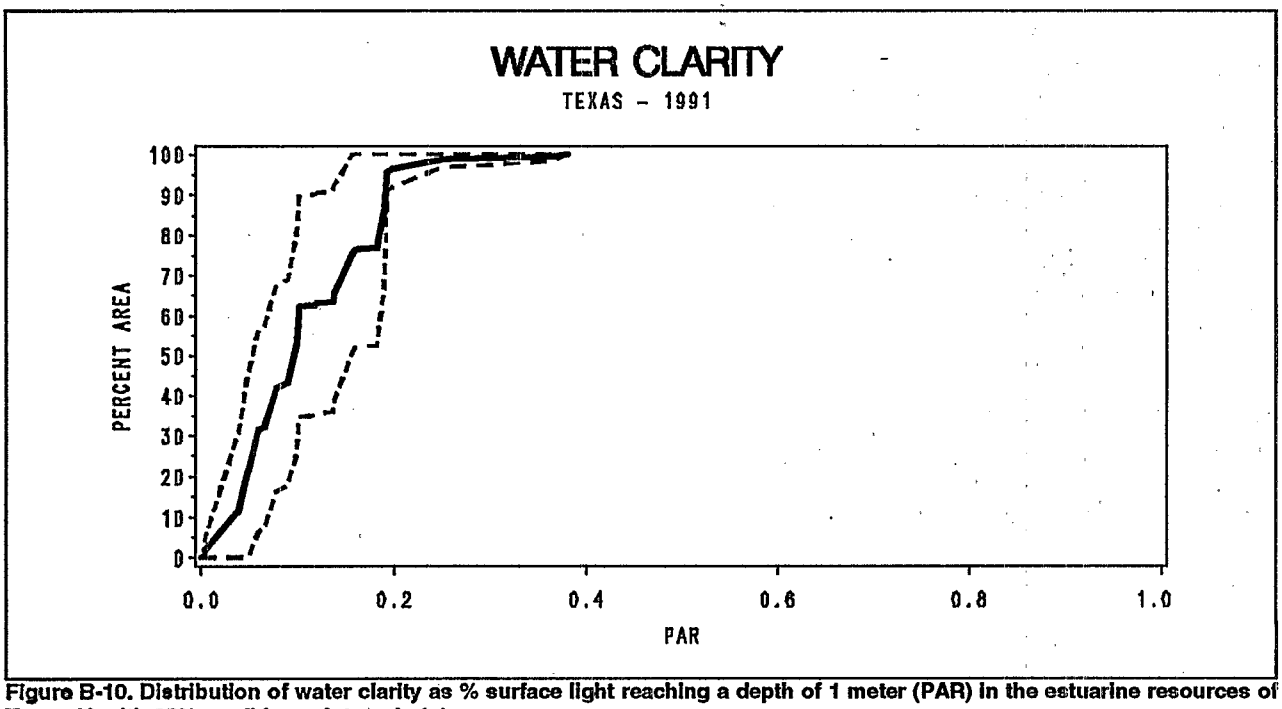

Figure B-10. Distribution of water clarity as % surface light reaching a depth of 1 meter (PAR) in the estuarine resources of Texas (-) with 95% confidence intervals (--).

B.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 B-12a shows that 53% of the estuarine resources in the portion of Florida in the Louisianian Province were degraded with regard to biotic communities or human uses. However, if PAR is removed as a human use variables, 39% of the estuarine resources in Florida were degraded (Fig. 12b). Similar summarizations are shown in Figures B-13 through B-16 for Alabama, Mississippi, Louisiana and Texas, respectively ranging from 25% degraded estuarine area in Louisiana without using water clarity (reduced from 46% with PAR) to 80% of the estuarine area in Alabama degraded. Summarizations for Alabama and Mississippi were not affected by the removal of PAR < 0.1 as sites with these values co-occurred in low benthic index values (Fig. 13 and 14).

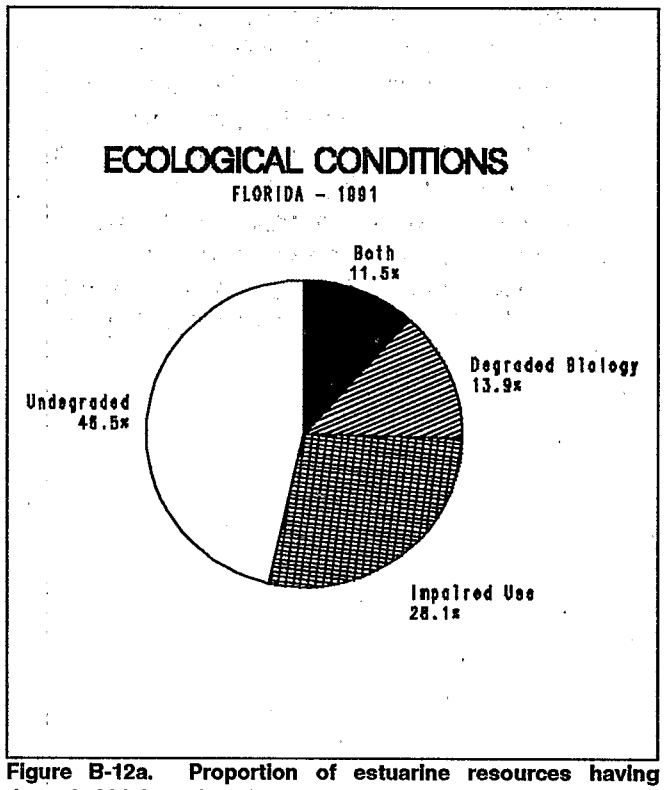

Figure B-12a. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Florida.

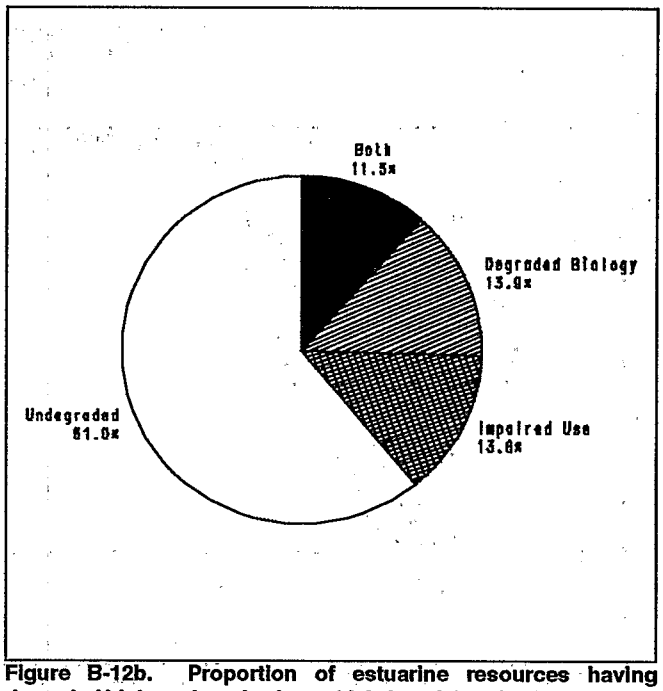

Figure B-12b. Proportion of estuarine resources having degraded biology, impaired use, (debris only), or both in Florida.

B.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.

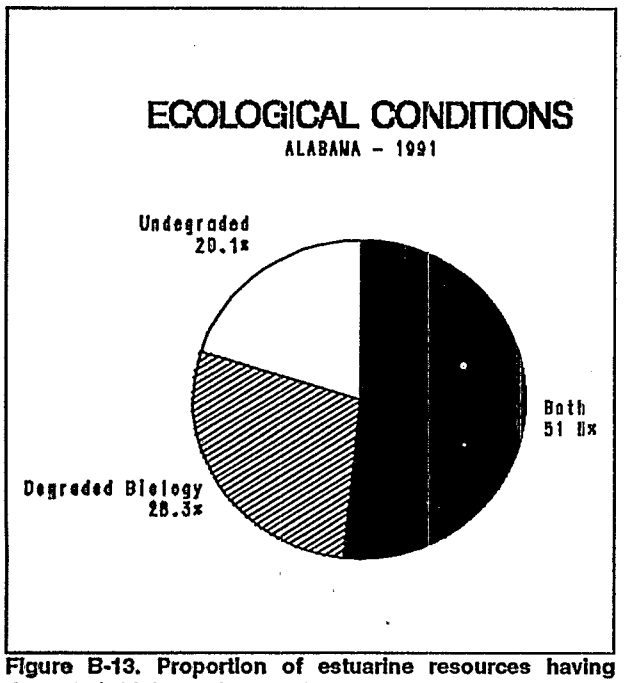

Figure B-13. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Alabama.

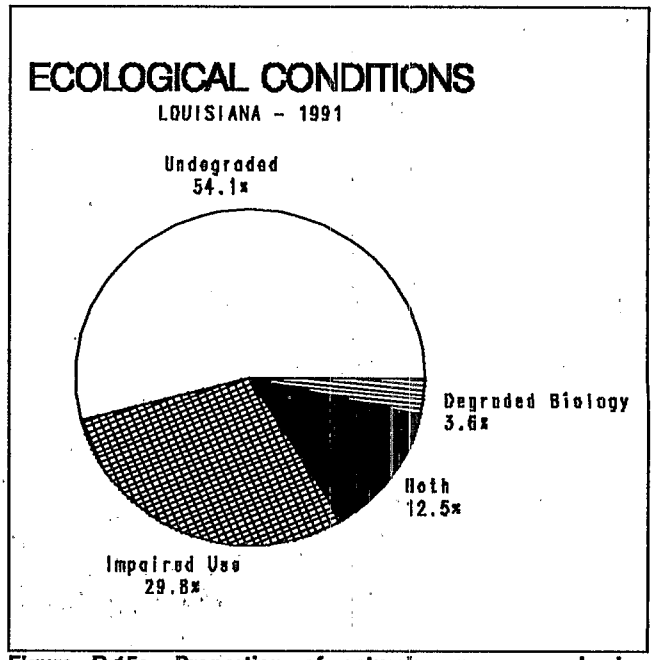

Figure B-15a. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Louisiana.

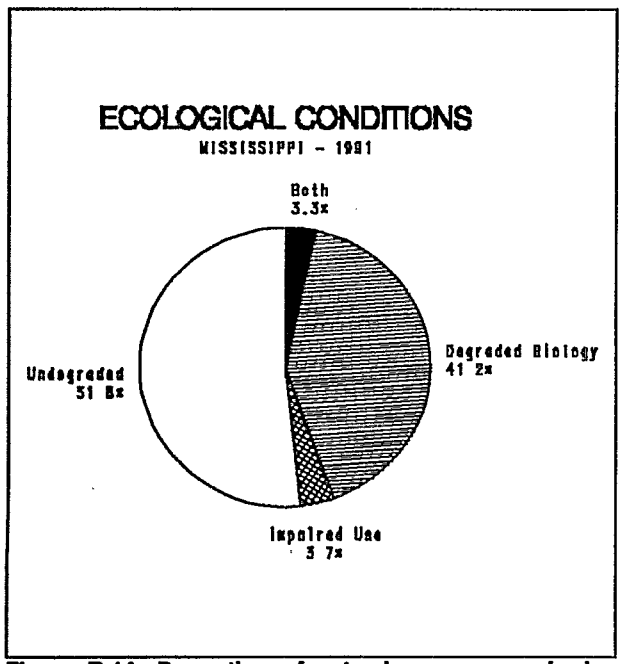

Figure B-14. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Mississippi.

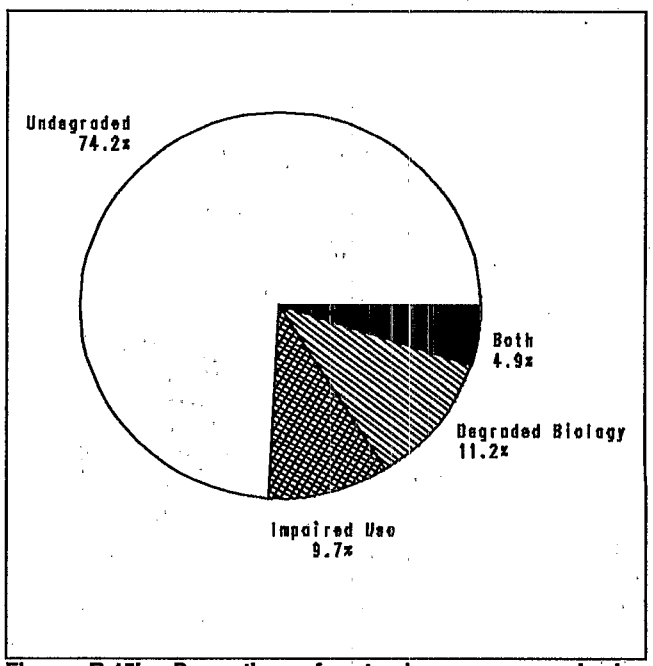

Figure B-15b. Proportion of estuarine resources having degraded biology, impaired use (debris only), or both in Louisiana.

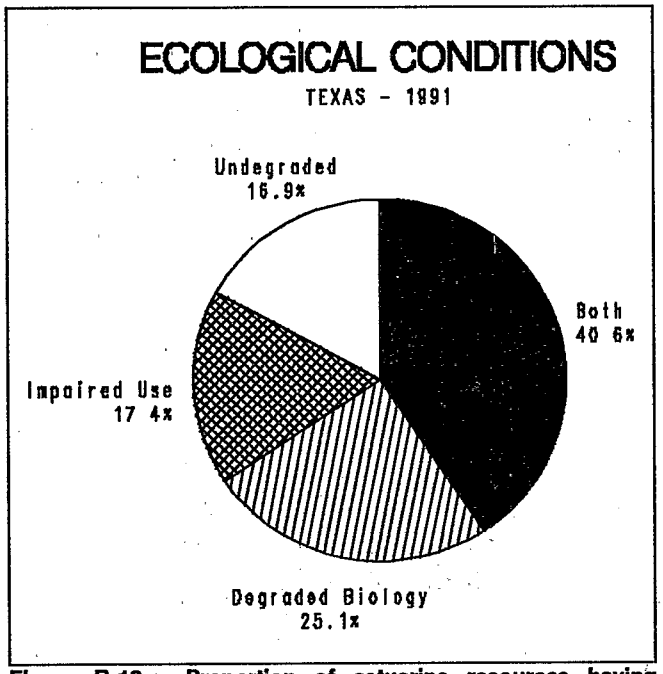

Figure B-16-a. Proportion of estuarine resources having degraded biology, impaired use, or both problems in Texas.

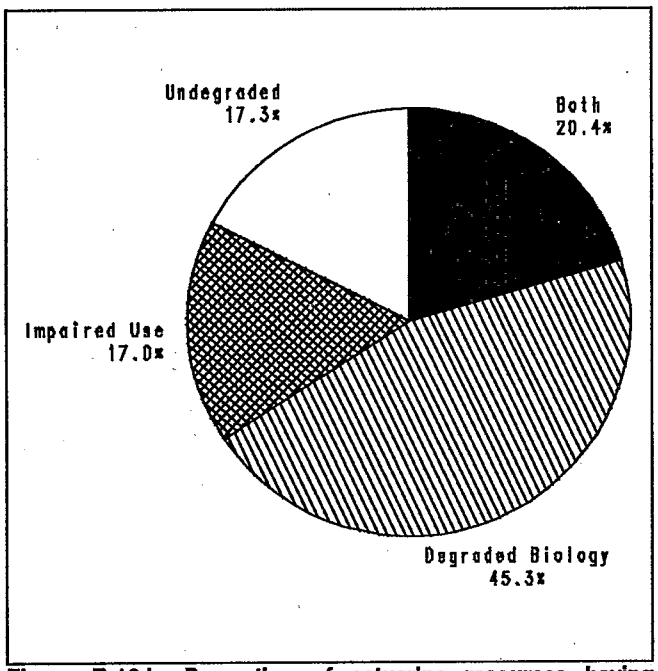

Figure B-16-b. Proportion of estuarine resources having degraded biology, impaired use (debris only), or both in Texas.

B.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 Mississippi estuaries in shown in Figure B-17. All Gulf states experienced DO conditions < 5 ppm but Alabama, Mississippi and Texas predominated with almost 31-53% of their resources below this figure (Fig. B-18). All dissolved concentrations < 2 ppm were primarily observed in Alabama, Mississippi and Louisiana (Fig. B-19).

B.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 0-12 ppm (Fig. B-20). Minimum dissolved oxygen concentrations below 2 ppm were most often observed in Alabama, Louisiana and Florida (Fig. B-21).

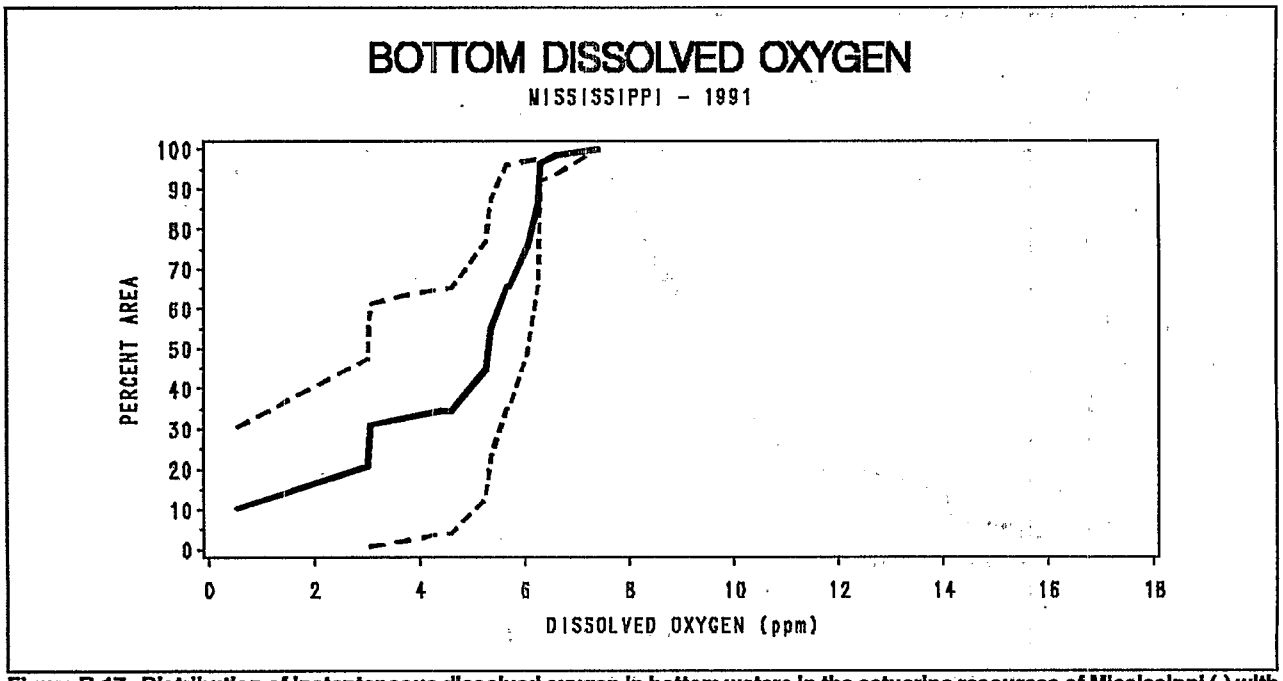

Figure B-17. Distribution of instantaneous dissolved oxygen in bottom waters in the estuarine resources of Mississippi (-) with 95% confidence intervals (--).

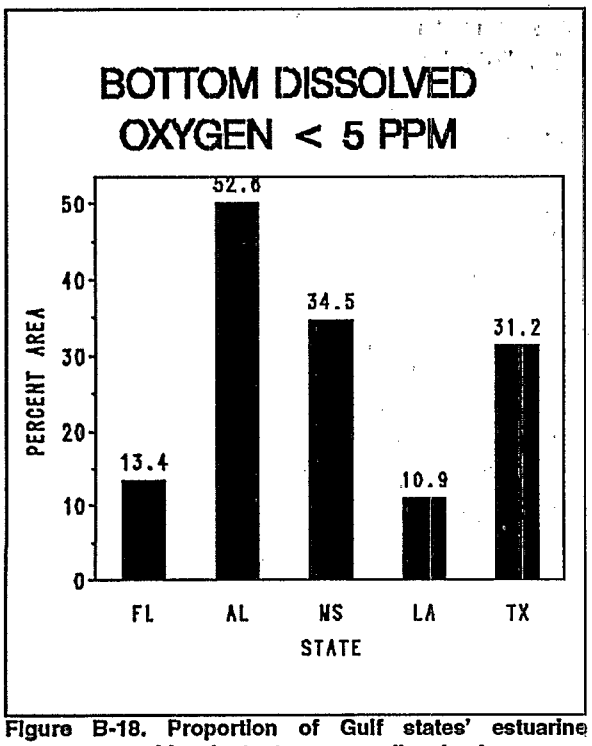

Figure B-18. Proportion of Gulf states' estuarine resources with instantaneous dissolved oxygen concentration < 5 ppm in bottom waters.

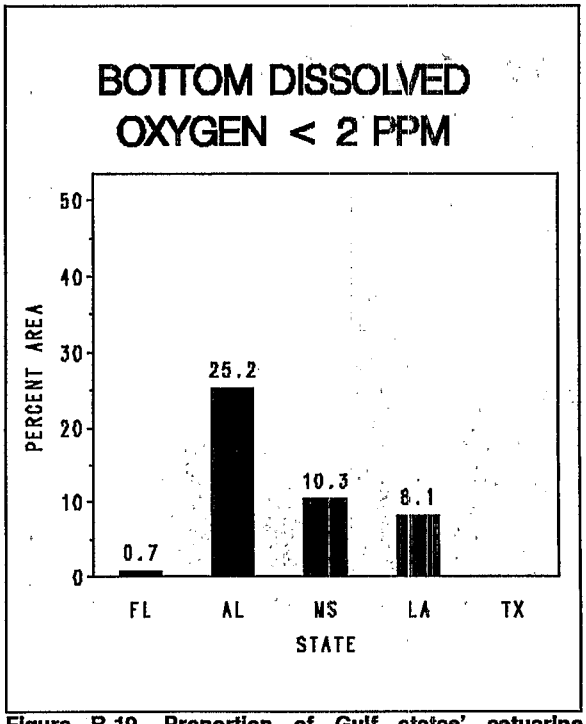

Figure B-19. Proportion of Gulf states' estuarine resources with instantaneous dissolved oxygen concentration < 5 ppm in bottom waters.

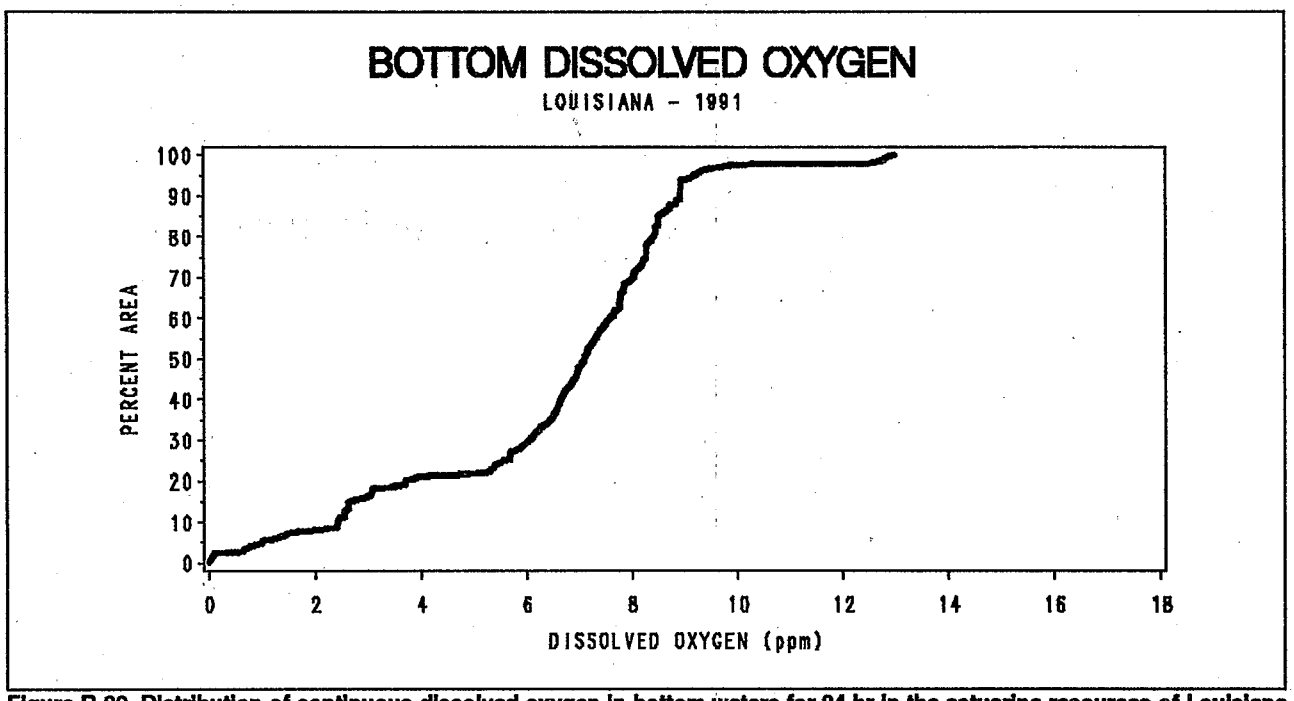

Figure B-20. Distribution of continuous dissolved oxygen in bottom waters for 24 hr in the estuarine resources of Louisiana (-).

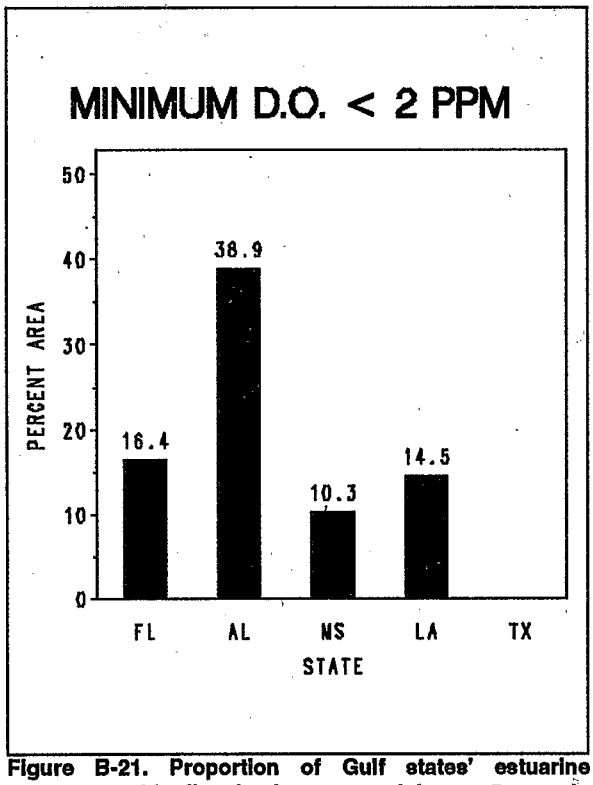

Figure B-21. Proportion of Gulf states' estuarine resources with dissolved oxygen minima < 5 ppm in bottom waters.

B.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 Louisiana in Figure B-22. Most of the sediments proving significantly toxic to Ampelisca (control-corrected survival < 80%) were located in Louisiana (11%) and Alabama (23%) estuarine waters (Fig. B-23).

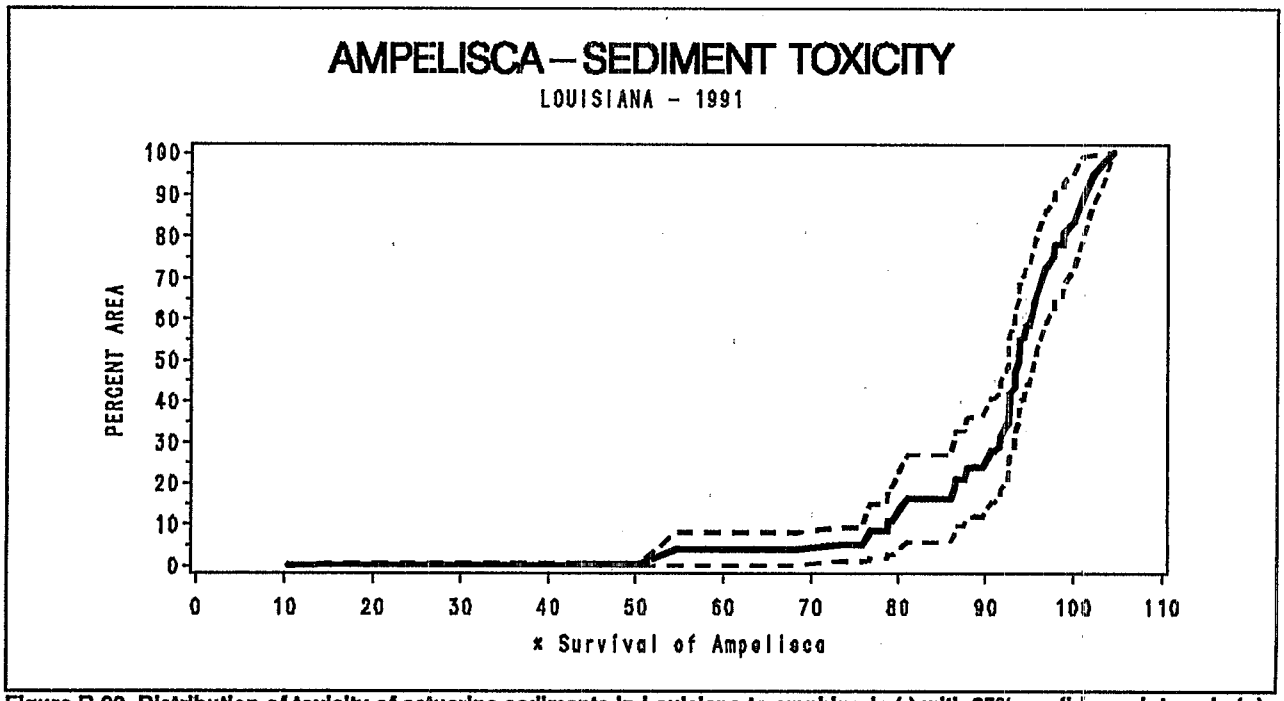

Figure B-22. Distribution of toxicity of estuarine sediments in Louisiana to amphipods (-) with 95% confidence intervals (--).

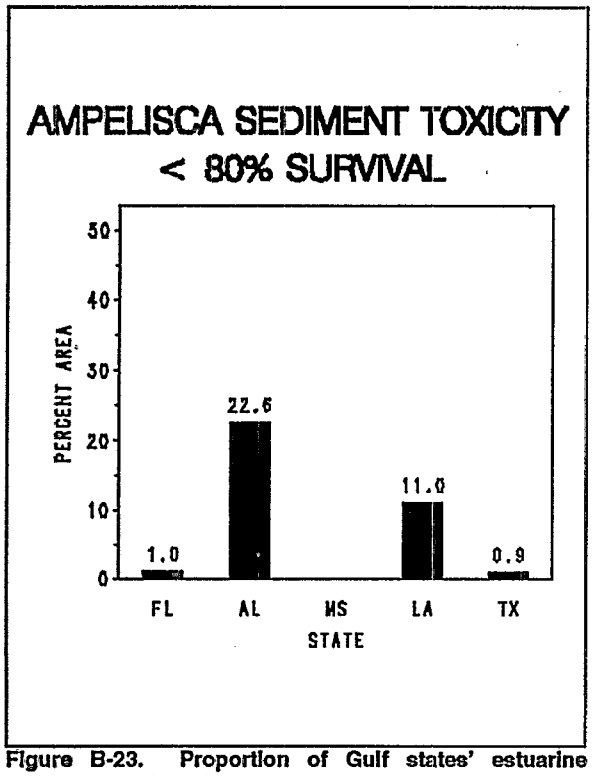

Figure B-23. Proportion of Gulf states' estuarine sediments with toxicity to amphipods resulting in < 80% survival.

B.2.4 ALKANES AND ISOPRENOIDS

Alkanes and isoprenoids are contaminants associated primarily with the petroleum industry. The continuous distribution function for total alkanes and isoprenoids for Texas ranges from 0-9000 ppb/g dwt (Fig. B-24). Total alkane concentrations exceeding 7000 ppb were located primarily in Louisiana (18% of estuarine sediments) and Texas (11% of sediments)(Fig. B-25).

B.2.5 POLYNUCLEAR AROMATIC HYDROCARBONS

Forty three individual polynuclear aromatic hydrocarbons (PAHs) were analyzed from the collected Louisianian Province sediments. The distribution of total c3-fluorene is shown in Fig. B-26 ranges from

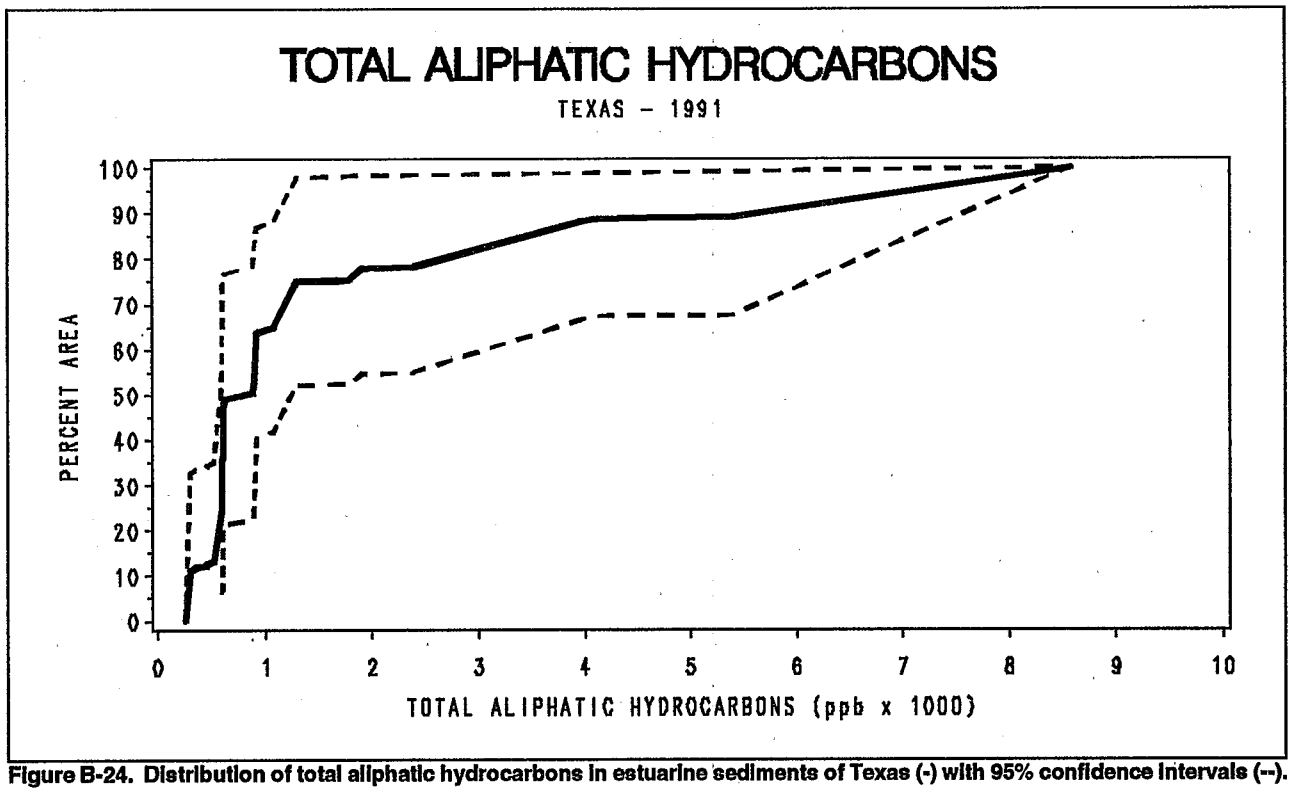

Figure B-24. Distribution of total aliphatic hydrocarbons in estuarine sediments of Texas (-) with 95% confidence intervals (--).

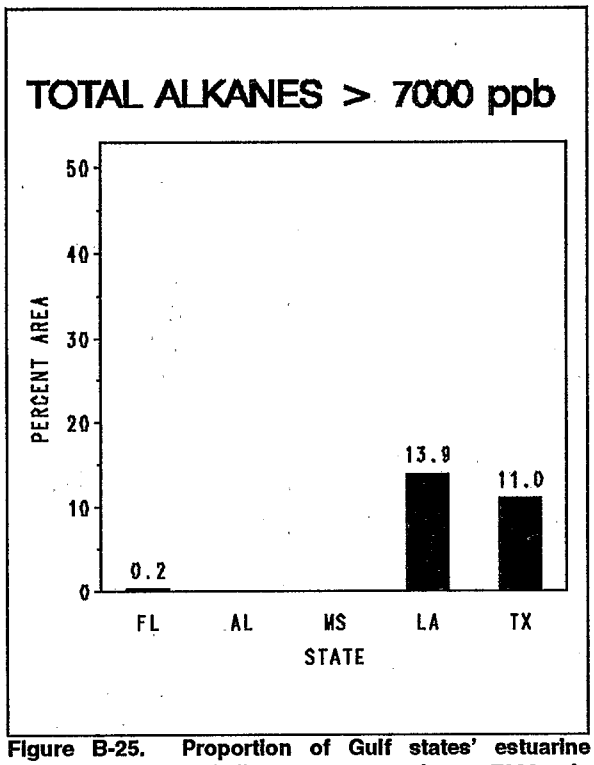

Figure B-25. Proportion of Gulf states' estuarine sediments with total alkanes concentrations > 7000 ppb.

0.1-34.7 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 (5%), Louisiana (1%) and Texas (1%) (Fig. B-27).

B.2.6 POLYCYCLIC CHLORINATED BIPHENYLS

Twenty polycyclic chlorinated biphenyl (PCB) congeners were analyzed from the Louisianian Province sediments. Concentrations of total PCBs in Florida ranged from 14 ppb to 128 ppb (Fig. B-28). Given that the criterion for low-level ecological effects are 400 ppm for total PCBs, no PCB concentrations exceeded these criteria in any of the Gulf states.

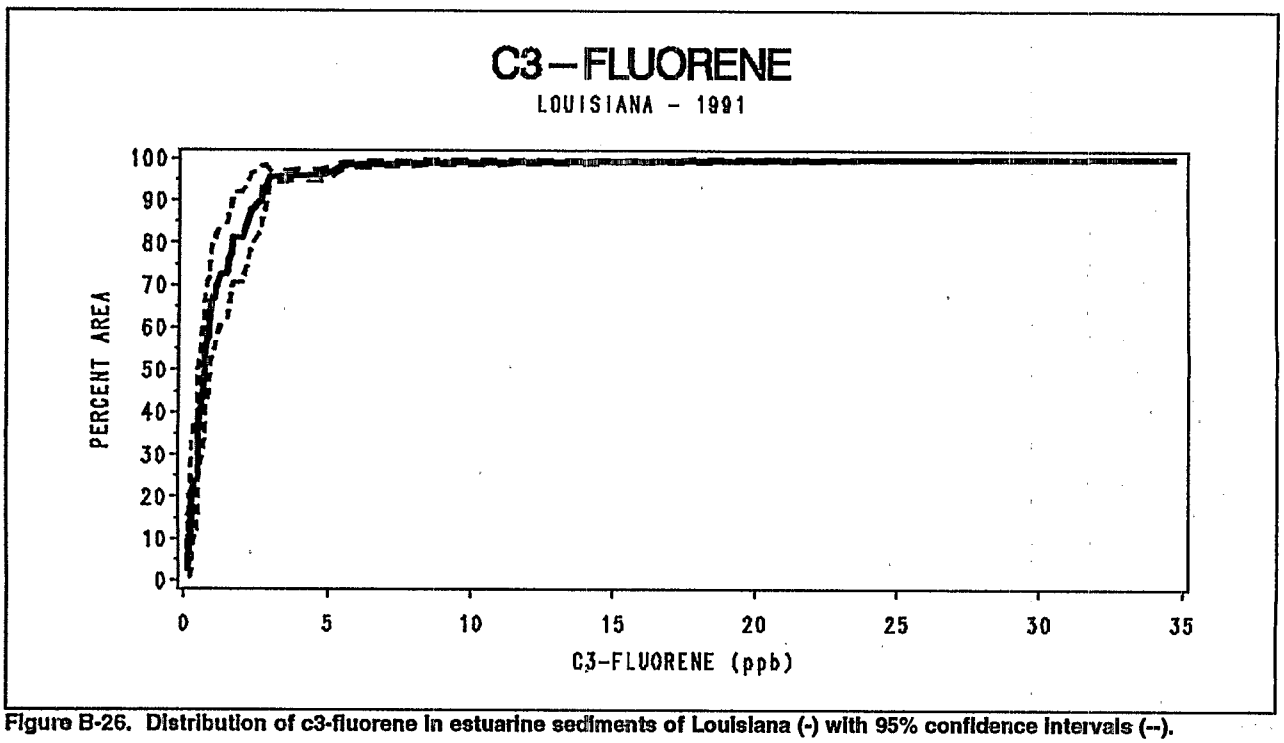

Figure B-26. Distribution of c3-fluorene in estuarine sediments of Louisiana (-) with 95% confidence intervals (--).

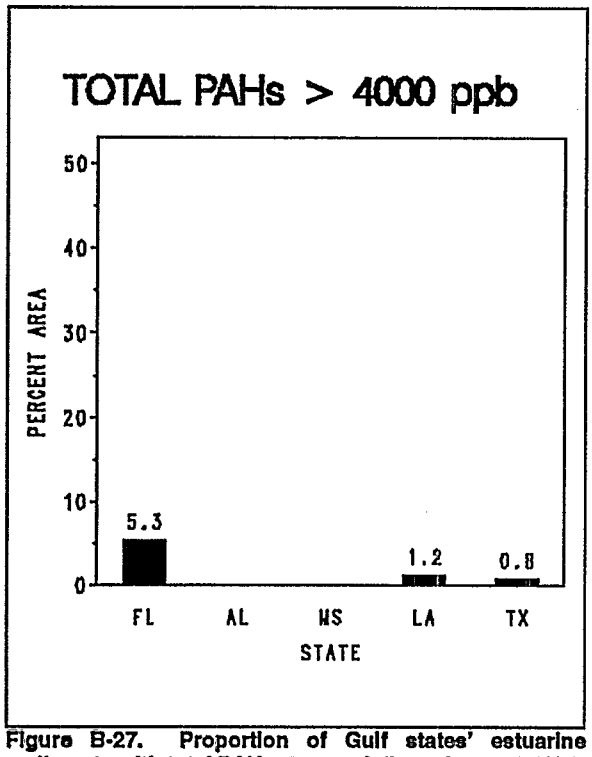

Figure B-27. Proportion of Gulf states' estuarine sediments with total PAH > 4000 ppb (based on 43 PAHs).

B.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. B-29 ranging from 0 to 36 ppb. Most of the high levels of TBT (> 5 ppb) were seen in Texas estuaries (18%) while some sediments in Florida (9%) and Louisiana (2%) contained high levels of TBT (Fig. B-30). Using 1 ppb TBT as an indicator of potential ecological effects results in most of the TBT being found in the estuarine sediments of Texas (41%) and Florida (29%)(Fig. B-31).

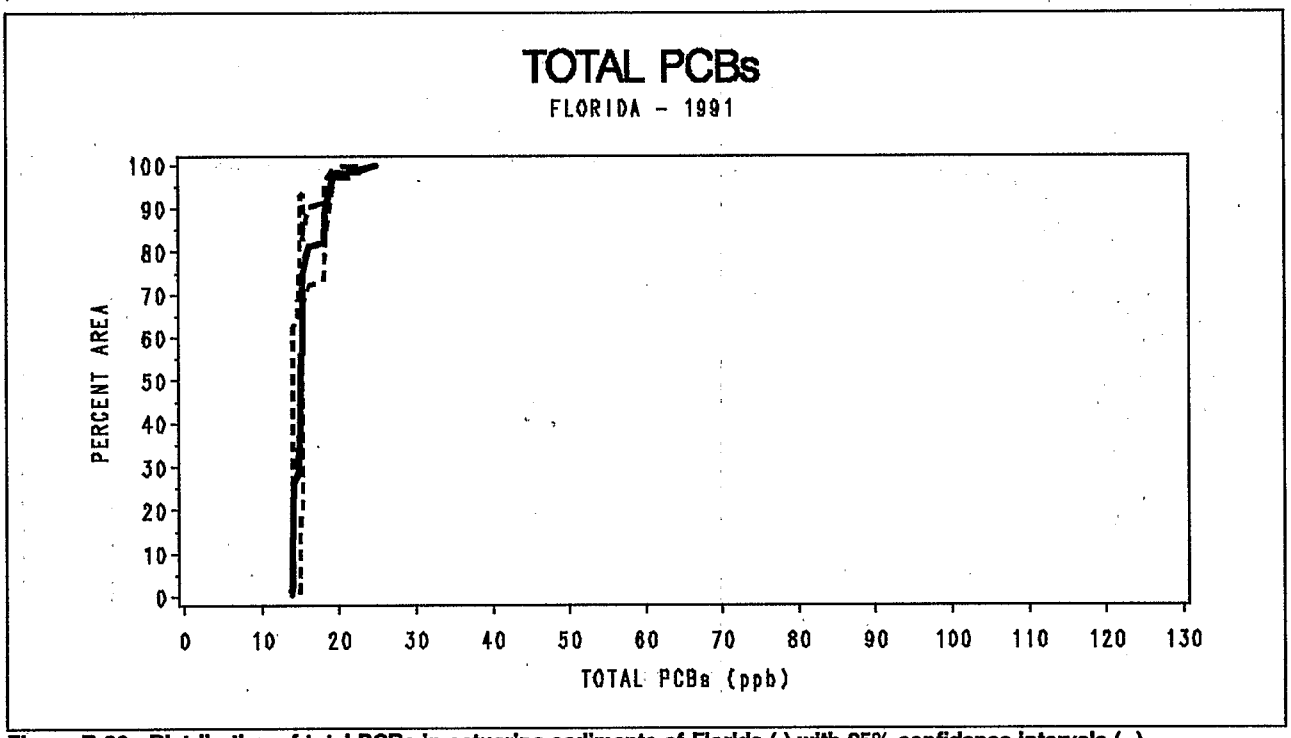

Figure B-28. Distribution of total PCBs in estuarine sediments of Florida (-) with 95% confidence intervals (--).

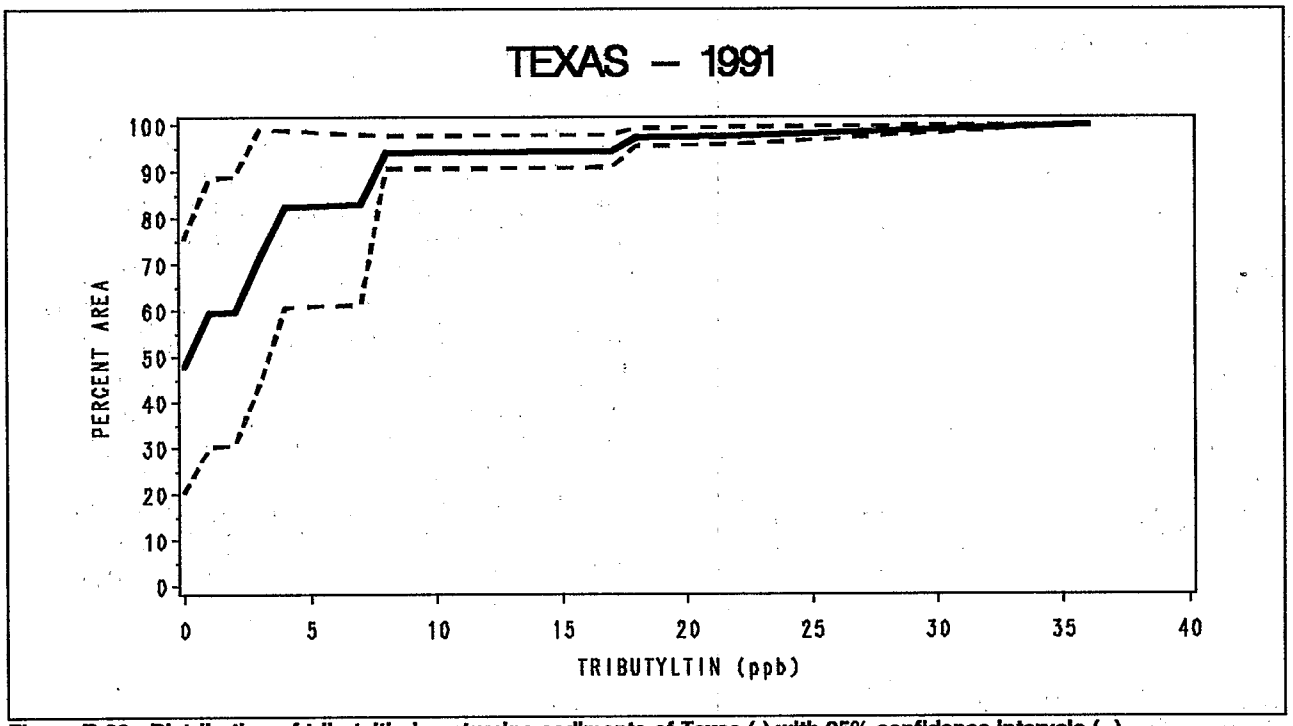

Figure B-29. Distribution of tributyltin in estuarine sediments of Texas (-) with 95% confidence intervals (--).

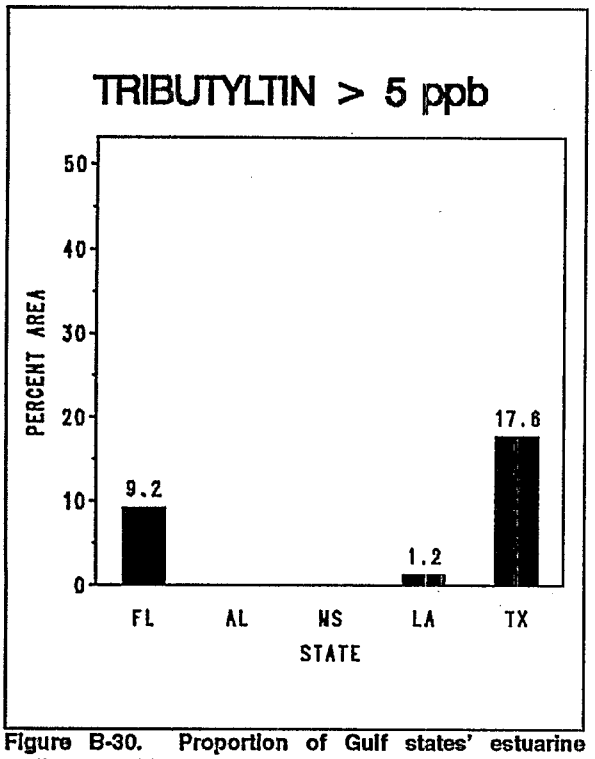

Figure B-30. Proportion of Gulf states' estuarine sediments with TBT > 5 ppb.

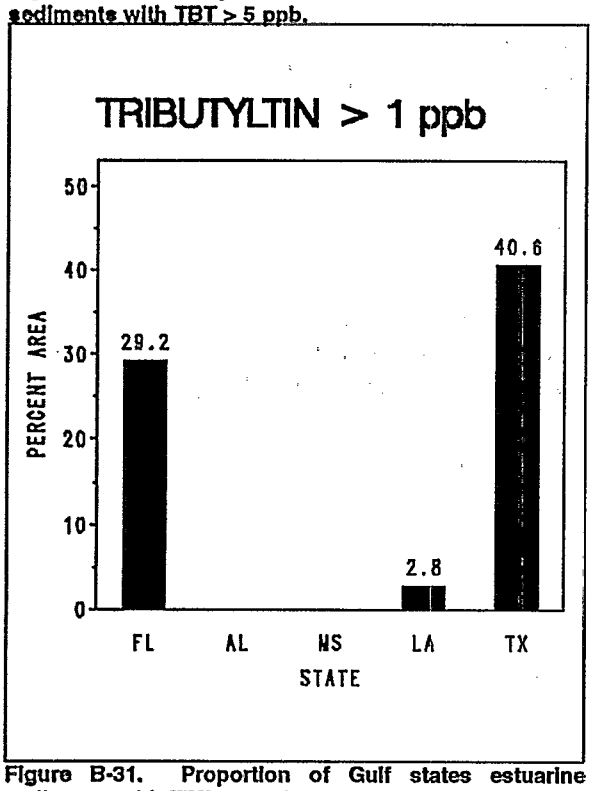

Figure B-31. Proportion of Gulf states estuarine sediments with TBT > 1 ppb.

B.2.8 PESTICIDES

Chlorinated herbicides and 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 Mississippi is shown in Figure B-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 primarily in the estuarine sediments of Alabama (Fig. B-33).

B.2.9 HEAVY METALS

Fifteen heavy metals were analyzed for the sediments collected in 1991. Examining the metal concentrations based on Long and Morgan criteria, several heavy metals exceeded the 10% criteria. The cumulative distribution function of mercury in Florida sediments is shown in Figure B-34. The proportion of estuarine sediments in each of the Gulf states that exceeded 1 ppm mercury (50% criterion) is shown in Figure B-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 B-36 to B-40.

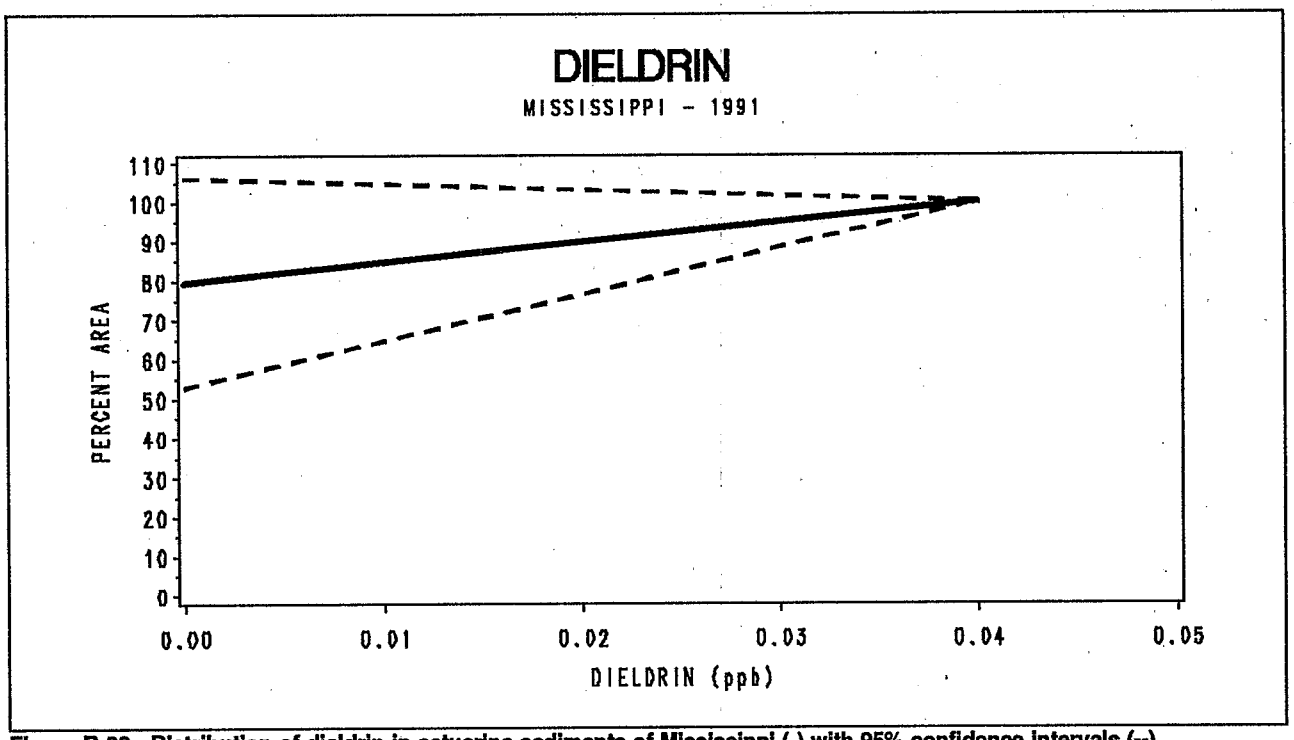

Figure B-32. Distribution of dieldrin in estuarine sediments of Mississippi (-) with 95% confidence intervals (--).

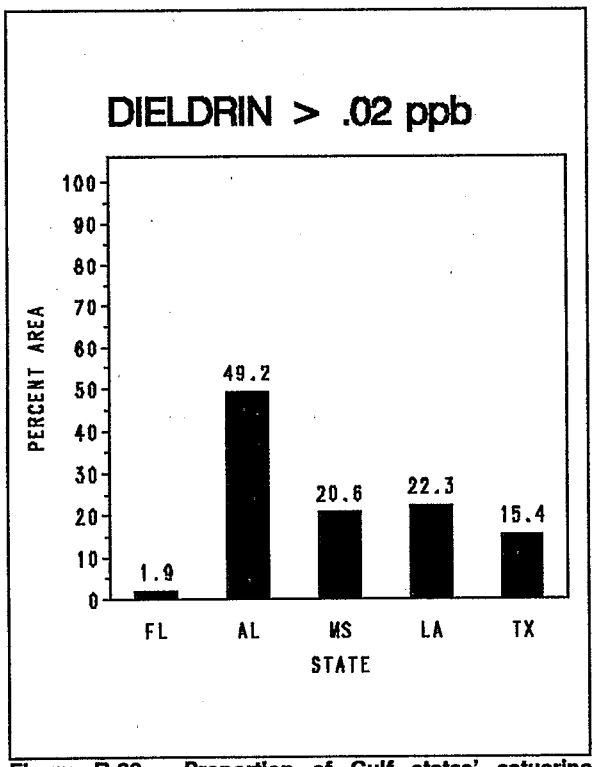

Figure B-33. Proportion of Gulf states' estuarine sediments with dieldrin > 0.02 ppb.

B.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 Appendix A. Table B-1 provides these intervals for the major indicators for the proportion of the five Gulf States assessed as degraded for each parameter.

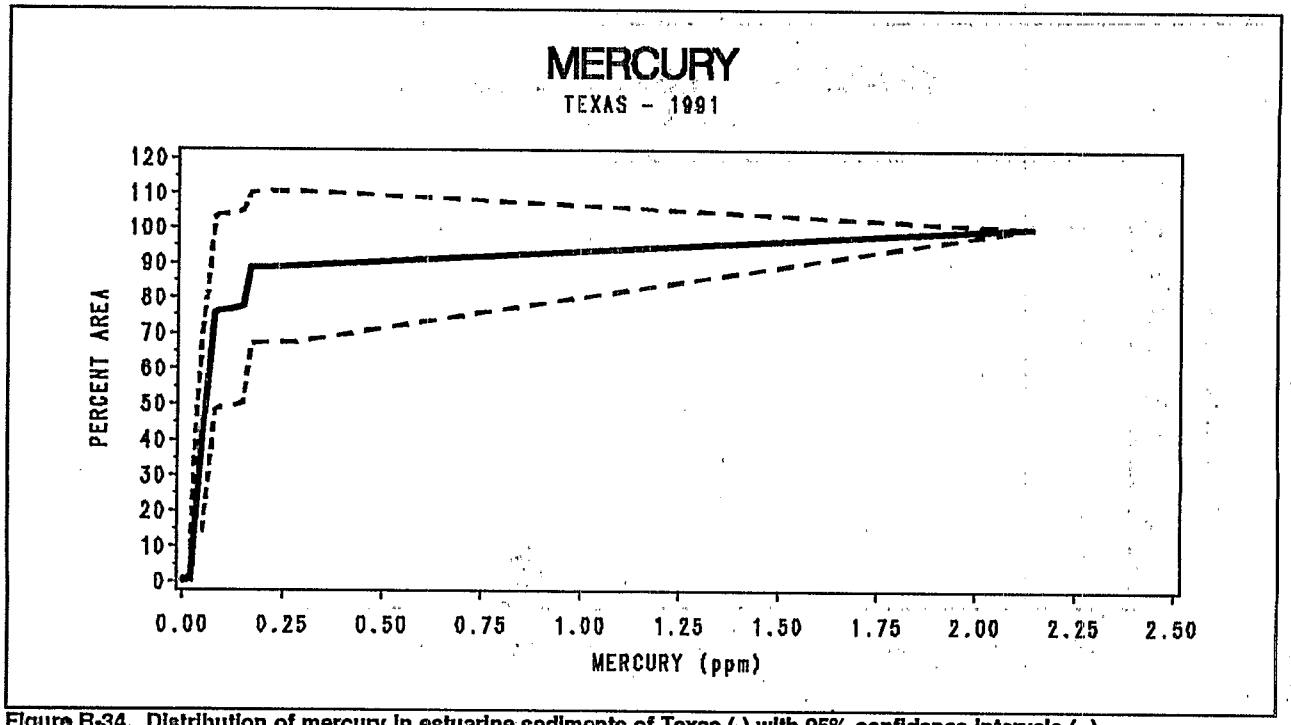

Figure B-34. Distribution of mercury in estuarine sediments of Texas (-) with 95% confidence intervals (--).

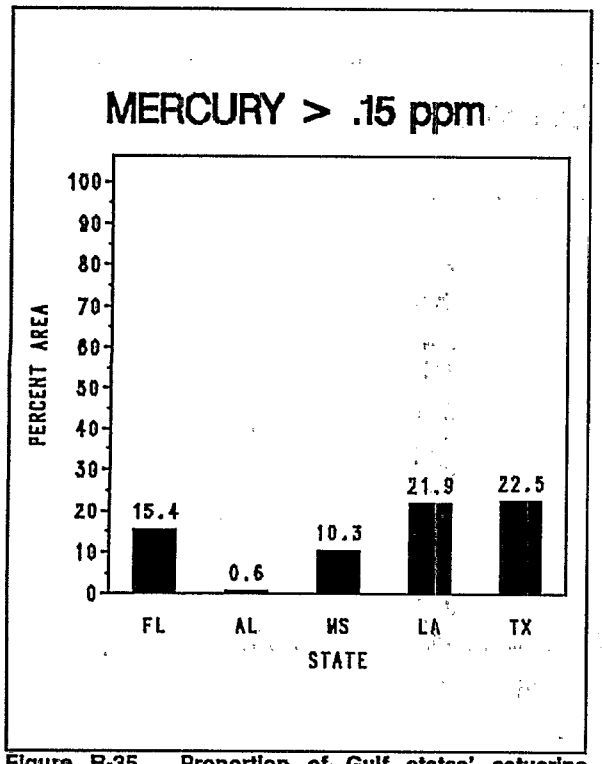

Figure B-35. Proportion of Gulf states' estuarine sediments with mercury > 0.15 ppb.

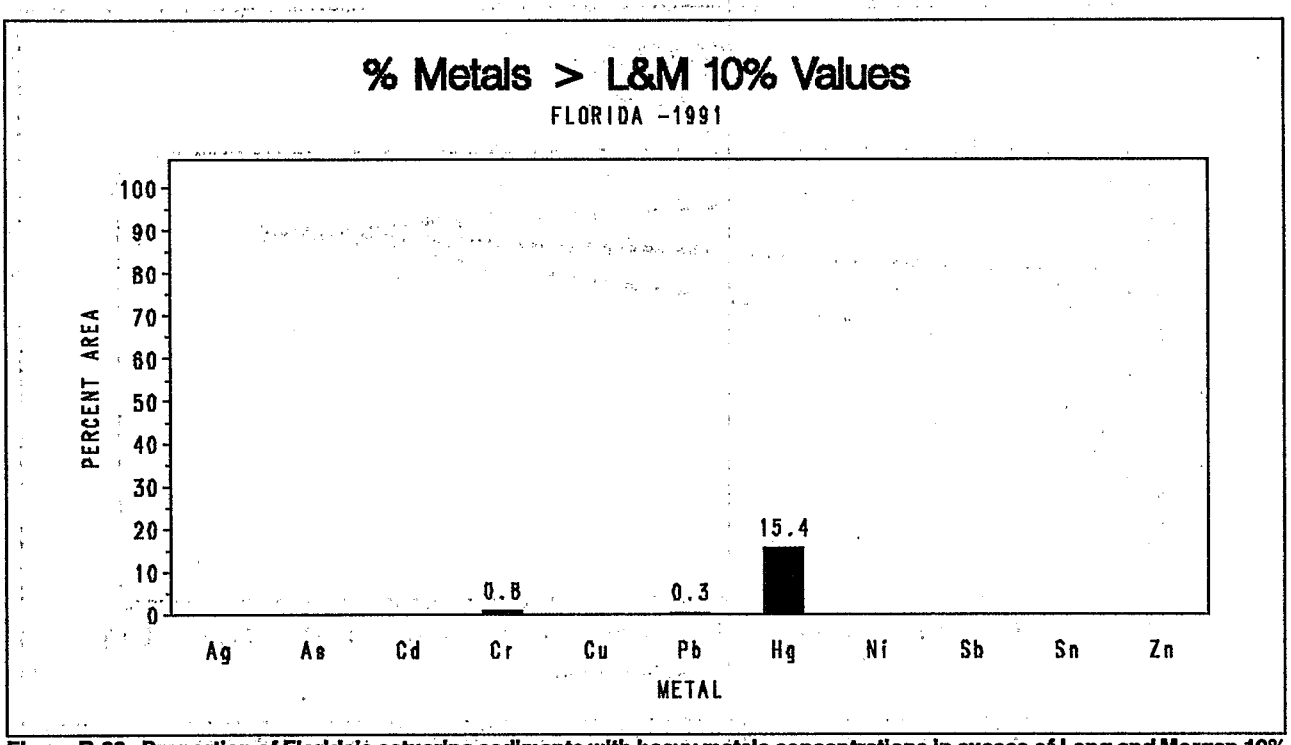

Figure B-36. Proportion of Florida's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria.

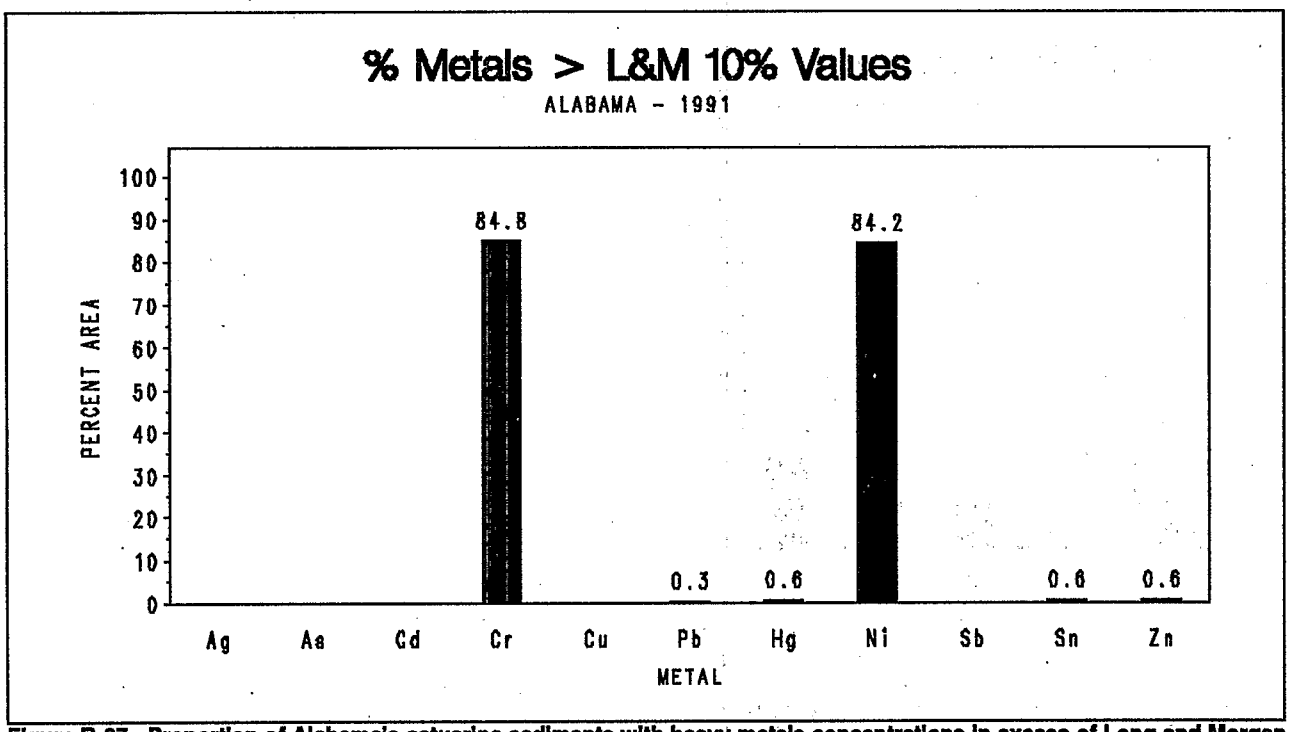

Figure B-37. Proportion of Alabama's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria.

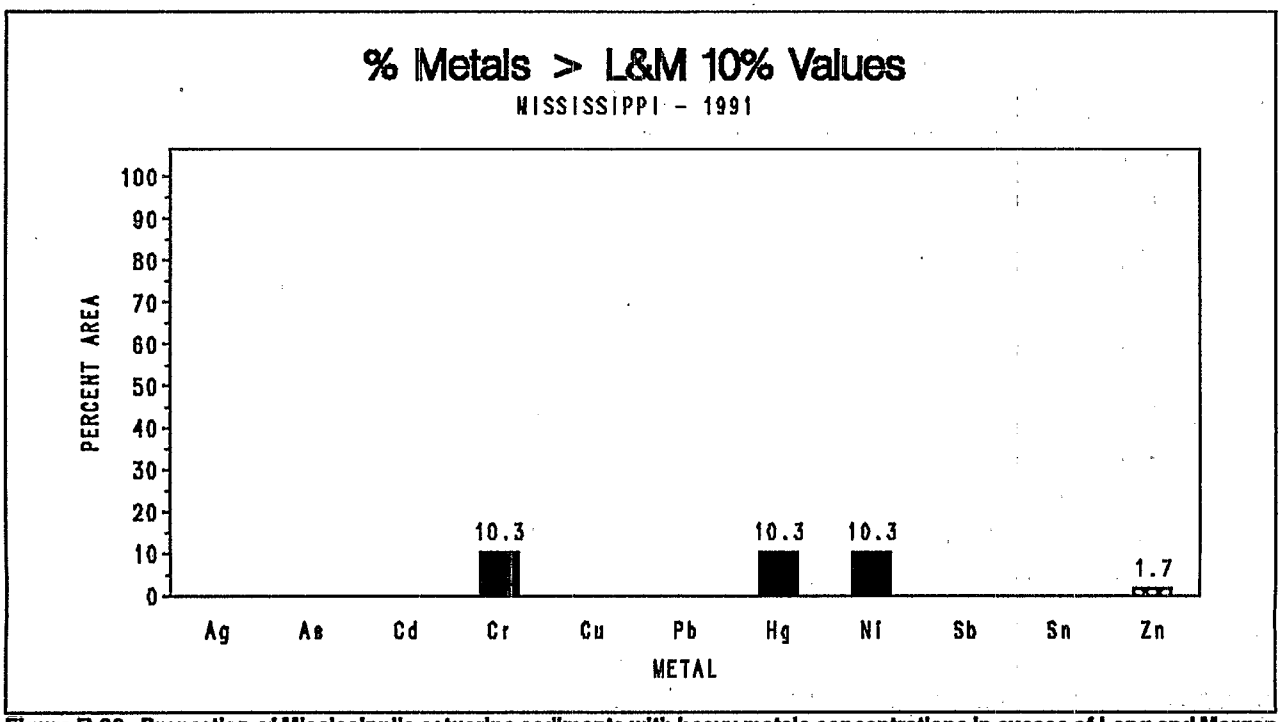

Figure B-38. Proportion of Mississippi's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria.

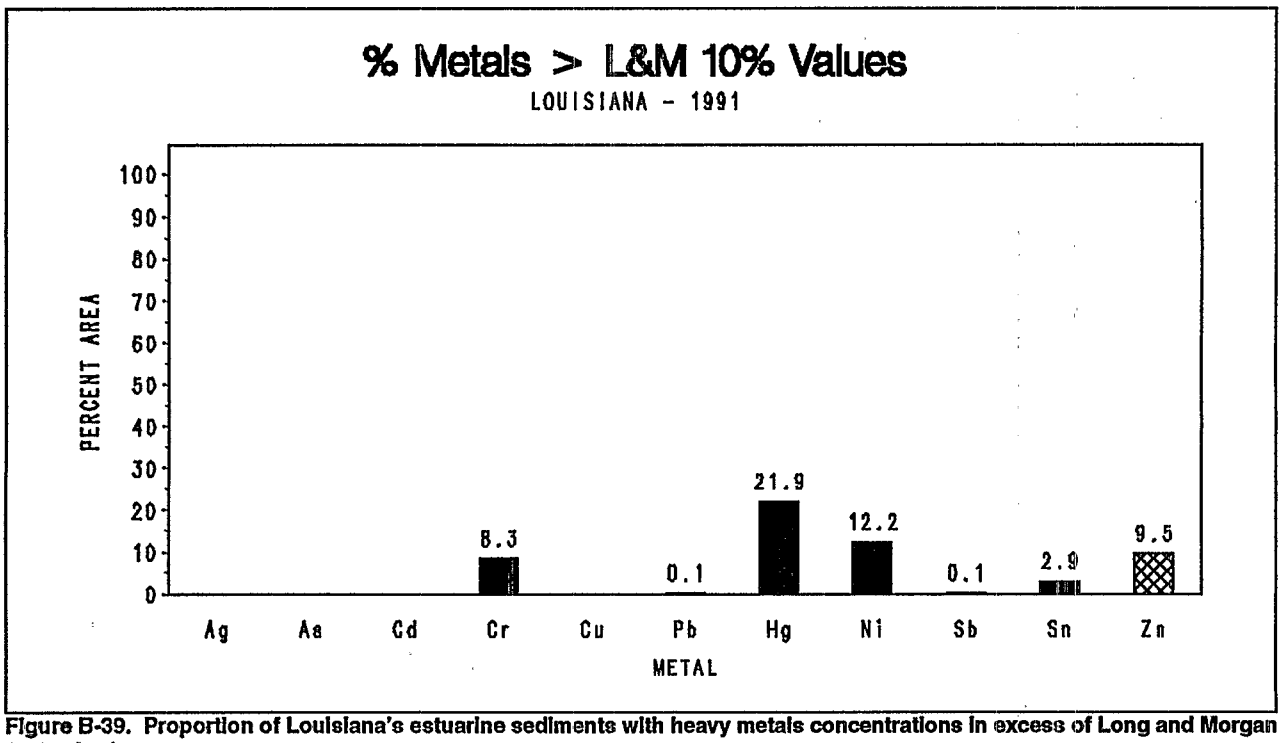

Figure B-39. Proportion of Louisiana's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria.

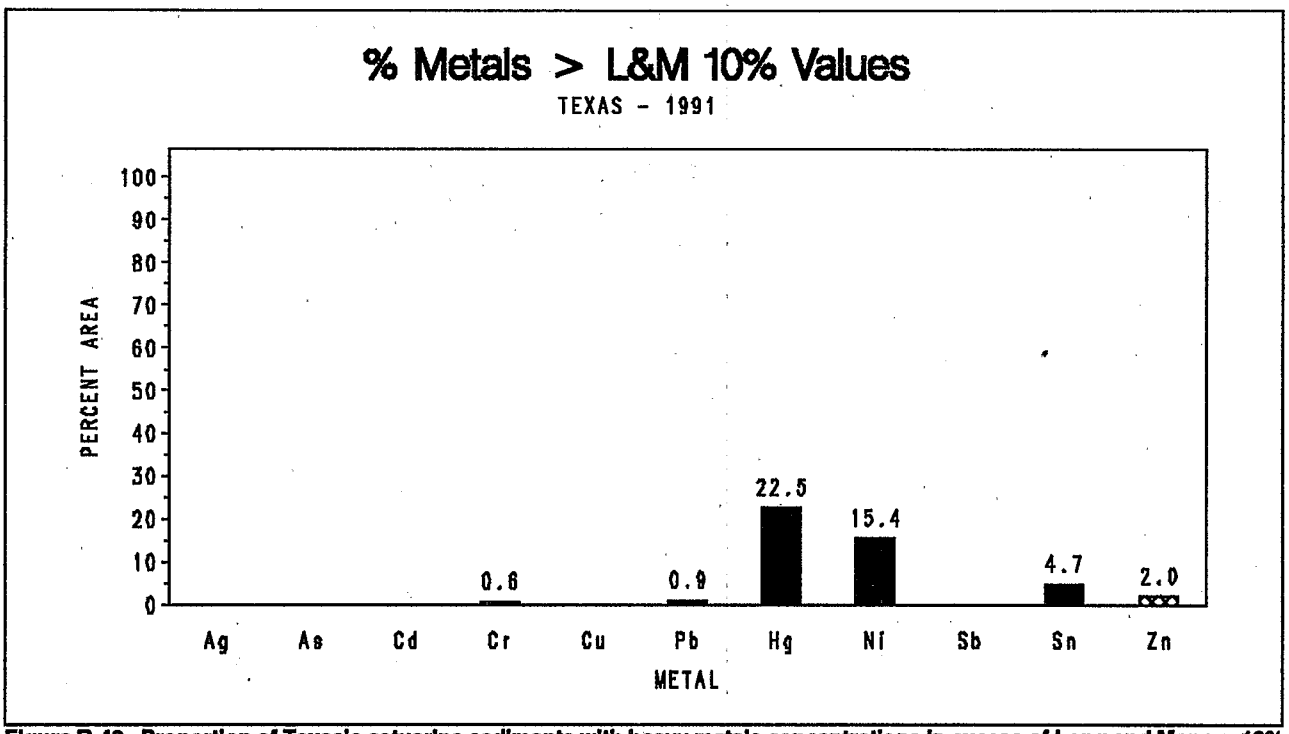

Figure B-40. Proportion of Texas's estuarine sediments with heavy metals concentrations in excess of Long and Morgan 10% criteria.

Parameter	Florida	Alabama	Mississippi	Louisiana	Texas
N	25	20	15	70	30
Estuarine Condition	63	80	48	46	83
Biotic Condition					
Benthos					
Index	18(18)	80(18)	46(32)	16(10)	68(29)
Abundance < 10	17(18)	37(27)	38(30)	1(0)	35(28)
# Species < 2	16(19)	17(22)	2(5)	9(9)	12(22)
# Species < 5	18(18)	72(23)	48(32)	32(14)	47(28)
Fish					
Abundance < 5	6(9)	4(6)	2(5)	20(12)	10(9)
Abundance < 10	11(11)	14(18)	43(32)	36(14)	21(23)
# Species < 1	5(9)	0(0)	0(0)	4(5)	0(0)
# Species < 2	6(9)	3(6)	10(20)	17(12)	0(0)
Fish Pathology	< 1(0)	< 1(0)	< 1(0)	< 1(0)	1(0)
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)	0(0)	1(1)
Others > FDA Limits	0(0)	0(0)	0(0)	0(0)	0(0)
Bottom DO[2] < 2 ppm	1(1)	25(25)	10(20)	8(8)	0(0)
Bottom DO[2] < 5 ppm	13(11)	53(27)	35(30)	11(9)	31(25)
Minimum DO < 2 ppm	16(19)	39(29)	10(20)	15(10)	0(0)
Sediment Toxicity	1(1)	23(23)	0(0)	11(8)	1(1)

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

Table B-1. 95% confidence intervals associated with the proportion of the individual Gulf states experiencing the listed parameters.

Parameter	Florida	Alabama	Mississippi	Louisiana	Texas
N	25	20	15	70	30
Abiotic Condition					
Marine Debris[3]	25	50	7	15	37
Water Clarity					
PAR < 10%	11(14)	1(1)	0(0)	31(13)	53(28)
PAR < 25%	39(38)	23(23)	24(28)	62(14)	96(5)
Silt-Clay Content					
< 20%	19(36)	4(6)	10(20)	0(0)	0(0)
> 80%	19(10)	65(26)	88(21)	76(13)	46(30)
Alkanes					
Total > 7000 ppb	1(1)	0(0)	0(0)	14(10)	11(21)
PAHs					
Total > 4000 ppb	5(4)	0(0)	0(0)	1(0)	1(0)
PCBs					
Total > 200 ppb	0(0)	0(0)	0(0)	0(0)	0(0)
Pesticides					
Chlordane > .5 ppb	1(1)	0(0)	0(0)	13(12)	1(1)
Dieldrin > .02 ppb	2(1)	49(20)	21(25)	22(12)	15(22)
Endrin > .02 PPB	1(0)	0(0)	0(0)	2(2)	0(0)
DDT > 1 ppb	0(0)	0(0)	0(0)	(2)	0(0)
DDE > 2 ppb	1(1)	69(22)	0(0)	0(0)	1(1)
DDD > 2 ppb	0(0)	0(0)	0(0)	1(1)	0(0)
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	1(0)	85(1)	10(20)	8(7)	1(1)
Cu > 70 ppm	0(0)	0(0)	0(0)	0(0)	0(0)
Hg > .15 ppm	15(12)	1(1)	10(20)	22(13)	23(28)
Ni > 30 ppm	0(0)	84(0)	10(20)	12(10)	15(22)
Pb > 35 ppm	0(0)	0(0)	0(0)	0(0)	1(0)
Sb > 2 ppm	0(0)	0(0)	0(0)	0(1)	0(0)
Sn > 3 ppm	0(0)	1(1)	0(0)	3(5)	5(2)
Zn > 120 ppm	0(0)	1(1)	2(2)	10(9)	2(1)
Tributyltin					
TBT > 1 ppb	30(37)	0(0)	0(0)	3(3)	41(28)
TBT > 5 ppb	9(9)	0(0)	0(0)	1(1)	18(15)

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

Table B-1.*(cont.)* 95% confidence intervals associated with the proportion of the individual Gulf states experiencing the listed parameters.

APPENDIX C

RISK ASSESSMENT RELATING TO CONTAMINANTS IN FISH AND SHELLFISH

In the text of this report, measured contaminant concentrations in fish and shellfish tissues were compared to FDA action levels. Only mercury in marine catfish exceeded the FDA limits and for only 1% of the fish sampled. Another procedure to assess contaminant levels in edible fish tissue is to compare measured values with EPA's current human health risk assessment criteria (Stober 1992). These criteria have been determined from back calculations from water quality criteria and bioconcentration factors with the assumption of a specific dietary regime. In general, the acceptable tissue concentration is calculated corresponding to an incremental risk factor of 10^{-6}; however in Tables C-1 through C-3, tissue concentrations associated with other incremental risk factors (10^{-5} and 10^{-4}) are also shown.

Potential upper-bound human cancer risk from consumption of fish or shellfish was estimated using fillet samples for contaminants for which cancer potency factors are available. Fillets were from commercial and recreational species. The risk estimates were performed using standard EPA risk assessment procedures and assumed lifetime exposure. A fish or shellfish consumption rate of 6.5 g/day was used.

The risks presented herein represent a regional screening assessment and not a detailed local assessment of risks to specific populations. Such detailed assessments would consider the number of people exposed and incorporate local consumption rates and patterns. Furthermore, a detailed assessment would require a greater number of tissue samples per site than collected for EMAP. The highest estimated lifetime incremental risk levels for shrimp are associated with arsenic and dieldrin. The incremental risk exceeded 10^{-6} for arsenic and dieldrin in 33% and 14% of shrimp examined, respectively (Table C-2). The third highest incremental risk was associated with mercury where 13% of shrimp examined has estimated incremental risks greater than 10^{-6} for a 6.5 g/day consumption rate. Heptachlor epoxide exceeded 10^{-6} incremental risk for 11% of shrimp. A small portion of shrimp (3%) exceeded the 10^{-6} incremental risk level for total PCBs.

The highest estimated lifetime incremental risk levels for Atlantic croaker are associated with dieldrin and aldrin. The incremental risk exceeded 10^{-6} for dieldrin and aldrin in 17% and 10% of croaker examined, respectively (Table C-2). The third highest incremental risk was associated with arsenic, heptachlor epoxide, total PCBs and toxaphene where 9% of croaker examined has estimated incremental risks greater than 10^{-6} for a 6.5 g/day consumption rate. Mercury exceeded 10^{-6} incremental risk for 7% of croakers. A small portion of croakers (2%) exceeded the 10^{-6} incremental risk levels

for heptachlor and hexachlorobenzene.

The highest estimated lifetime incremental risk levels for marine catfish are associated with arsenic, dieldrin and aldrin. The incremental risk exceeded 10^{-5} for arsenic and toxaphene in 2% and 6% of croaker examined, respectively (Table C-3). The third highest incremental risk was associated with dieldrin, aldrin, and heptachlor epoxide where 12-15% of catfish examined has estimated incremental risks greater than 10^{-6} for a 6.5 g/day consumption rate. Mercury exceeded 10^{-6} incremental risk for 8% of catfish. A small portion of catfish (1-5%) exceeded the 10^{-6} incremental risk levels for DDD, DDT, endosulfan, and heptachlor.

Contaminant	Observed Range	Incremental Risk[1] 10^{-6}	10^{-5}	10^{-4}	Proportion Exceeding Risk Criterion 10^{-6}	10^{-5}	10^{-4}
Pesticides (ng/gwwt)							
DDD	0-4.9	45	449	4490	0%	0%	0%
DDE	0-1.7	32	316	3160	0%	0%	0%
DDT	0-74.0	32	316	3160	5%	0%	0%
Aldrin	0-1.6	<1	6	65	14%	0%	0%
Chlordane	0-1.9	8	83	830	0%	0%	0%
Dieldrin	0-0.0	<1	7	67	8%	0%	0%
Endosulfan	0-0.0	<1	5	54	0%	0%	0%
Endrin	0-12.8	3230	*	*	0%	0%	0%
Heptachlor	0-0.0	2	24	240	0%	0%	0%
Heptachlor Epoxide	0-3.9	1	12	120	11%	0%	0%
Hexachlorobenzene	0-2.5	7	67	673	0%	0%	0%
Lindane	0-0.0	2	17	170	0%	0%	0%
Mirex	0-43.5	NA	NA	NA	U[2]	U	U
Toxaphene	0-0.0	10	98	980	0%	0%	0%
Trans-Nonachlor	0-1.3	NA	NA	NA	U	U	U
PCBs (ng/g wwt)							
Total	0-30.3	25	250	2500	3%	0%	0%
Heavy Metals (ug/g wwt)							
Aluminum	0-78.5	NA	NA	NA	U[3]	U	U
Arsenic	0-3.9	<1	6	62	33%	0%	0%
Cadmium	0-0.3	11	108	1077	0%	0%	0%
Chromium	0-6.1	54	538	5380	0%	0%	0%
Copper	0-9.6	NA	NA	NA	U	U	U
Lead	0-0.3	NA	NA	NA	U	U	U
Mercury	0-0.3	<1	1	10	13%	0%	0%
Nickel	0-9.0	215	2154	**	0%	0%	0%
Selenium	0-0.3	5	54	540	0%	0%	0%
Silver	0-0.3	NA	NA	NA	U	U	U
Tin	0-1.1	NA	NA	NA	U	U	U
Zinc	1-18.8	NA	NA	NA	U	U	U

[1] Criteria were selected from EPA established limits for contaminants (Stober 1992) for human health risk for carcinogens based on water quality criteria and bioconcentration factors
[2] 5% observed at mirex concentrations > 10 ppb
[3] 8% observed at aluminum concentrations > 50 ppb

Table C-1. Overview of the contaminant levels observed in edible flesh of brown shrimp and white shrimp (N=370) compared to EPA human health risk criteria. NA=Not Available; U=Unknown as no criterion level is available.

Contaminant	Observed Range	Incremental Risk[1] 10^{-6}	10^{-5}	10^{-4}	Proportion Exceeding Criterion 10^{-6}	10^{-5}	10^{-4}
Pesticides (ng/gwwt)							
DDD	0-16.0	45	449	4490	0%	0%	0%
DDE	0-3.5	32	316	3160	0%	0%	0%
DDT	0-24.2	32	316	3160	0%	0%	0%
Aldrin	0-3.2	<1	6	65	10%	0%	0%
Chlordane	0-8.2	8	83	830	2%	0%	0%
Dieldrin	0-26.2	<1	7	67	17%	2%	0%
Endosulfan	0-1.7	<1	5	54	5%	0%	0%
Endrin	0-22.5	3230	*	*	0%	0%	0%
Heptachlor	0-5.7	2	24	240	3%	0%	0%
Heptachlor Epoxide	0-16.7	1	12	120	9%	2%	0%
Hexachlorobenzene	0-77.4	7	67	673	2%	2%	0%
Lindane	0-0.0	2	17	170	0%	0%	0%
Mirex	0-88.5	NA	NA	NA	U[2]	U	U
Toxaphene	0-1800	10	98	980	9%	9%	5%
Trans-Nonachlor	0-1.3	NA	NA	NA	U	U	U
PCBs (ng/g wwt)							
Total	0-62.5	25	250	2500	9%	0%	0%
Heavy Metals (ug/g wwt)							
Aluminum	0-6.9	NA	NA	NA	U	U	U
Arsenic	0-2.1	<1	6	62	9%	0%	0%
Cadmium	0-0.1	11	108	1077	0%	0%	0%
Chromium	0-0.3	54	538	5380	0%	0%	0%
Copper	0-5.3	NA	NA	NA	U	U	U
Lead	0-0.3	NA	NA	NA	U	U	U
Mercury	0-0.4	<1	1	10	7%	0%	0%
Nickel	0-0.3	215	2154	**	0%	0%	0%
Selenium	0-0.3	5	54	540	0%	0%	0%
Silver	0-1.8	NA	NA	NA	U	U	U
Tin	0-0.7	NA	NA	NA	U	U	U
Zinc	1-11.8	NA	NA	NA	U	U	U

[1] Criteria were selected from EPA established limits for contaminants (Stober 1992) for human health risk for carcinogens based on water quality criteria and bioconcentration factors
[2] 10% observed at mirex concentrations > 10 ppb

Table C-2. Overview of the contaminant levels observed in edible flesh of Atlantic croaker (N=580) compared to EPA human health risk criteria. NA = Not Available; U = Unknown as no criterion level is available.

Contaminant	Observed Range	Incremental Risk[1] 10^{-6}	10^{-5}	10^{-4}	Proportion Exceeding Criterion 10^{-6}	10^{-5}	10^{-4}
Pesticides (ng/gwwt)							
DDD	0-207.4	45	449	4490	2%	0%	0%
DDE	0-12.2	32	316	3160	0%	0%	0%
DDT	0-39.4	32	316	3160	1%	0%	0%
Aldrin	0-2.7	<1	6	65	15%	0%	0%
Chlordane	0-6.1	8	83	830	0%	0%	0%
Dieldrin	0-24.4	<1	7	67	16%	1%	0%
Endosulfan	0-1.8	<1	5	54	5%	0%	0%
Endrin	0-10.1	3230	*	*	0%	0%	0%
Heptachlor	0-5.7	2	24	240	3%	0%	0%
Heptachlor Epoxide	0-5.7	1	12	120	12%	0%	0%
Hexachlorobenzene	0-4.0	7	67	673	0%	0%	0%
Lindane	0-4.1	2	17	170	0%	0%	0%
Mirex	0-30.7	NA	NA	NA	U[2]	U	U
Toxaphene	0-1400	10	98	980	6%	6%	1%
Trans-Nonachlor	0-4.3	NA	NA	NA	U[3]	U	U
PCBs (ng/g wwt)							
Total	0-67.9	25	250	2500	17%	0%	0%
Heavy Metals (ug/g wwt)							
Aluminum	0-105.1	NA	NA	NA	U[4]	U	U
Arsenic	0-10.1	<1	6	62	23%	2%	0%
Cadmium	0-0.4	11	108	1077	0%	0%	0%
Chromium	0-0.8	54	538	5380	0%	0%	0%
Copper	0-10.3	NA	NA	NA	U	U	U
Lead	0-0.4	NA	NA	NA	U	U	U
Mercury	0-1.2	<1	1	10	8%	1%	0%
Nickel	0-0.7	215	2154	**	0%	0%	0%
Selenium	0-0.4	5	54	540	0%	0%	0%
Silver	0-0.3	NA	NA	NA	U	U	U
Tin	0-1.2	NA	NA	NA	U	U	U
Zinc	1-234.0	NA	NA	NA	U	U	U

[1] Criteria were selected from EPA established limits for contaminants (Stober 1992) for human health risk for carcinogens based on water quality criteria and bioconcentration factors
[2] 8% observed at mirex concentrations > 10 ppb
[3] 9% observed at trans-nonachlor concentrations > 1 ppb
[4] 1% observed at aluminum concentrations > 50 ppm

Table C-3. Overview of the contaminant levels observed in edible flesh of catfish (N=1130) compared to EPA human health risk criteria. NA = Not Available; U = Unknown as no criterion level is available.

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