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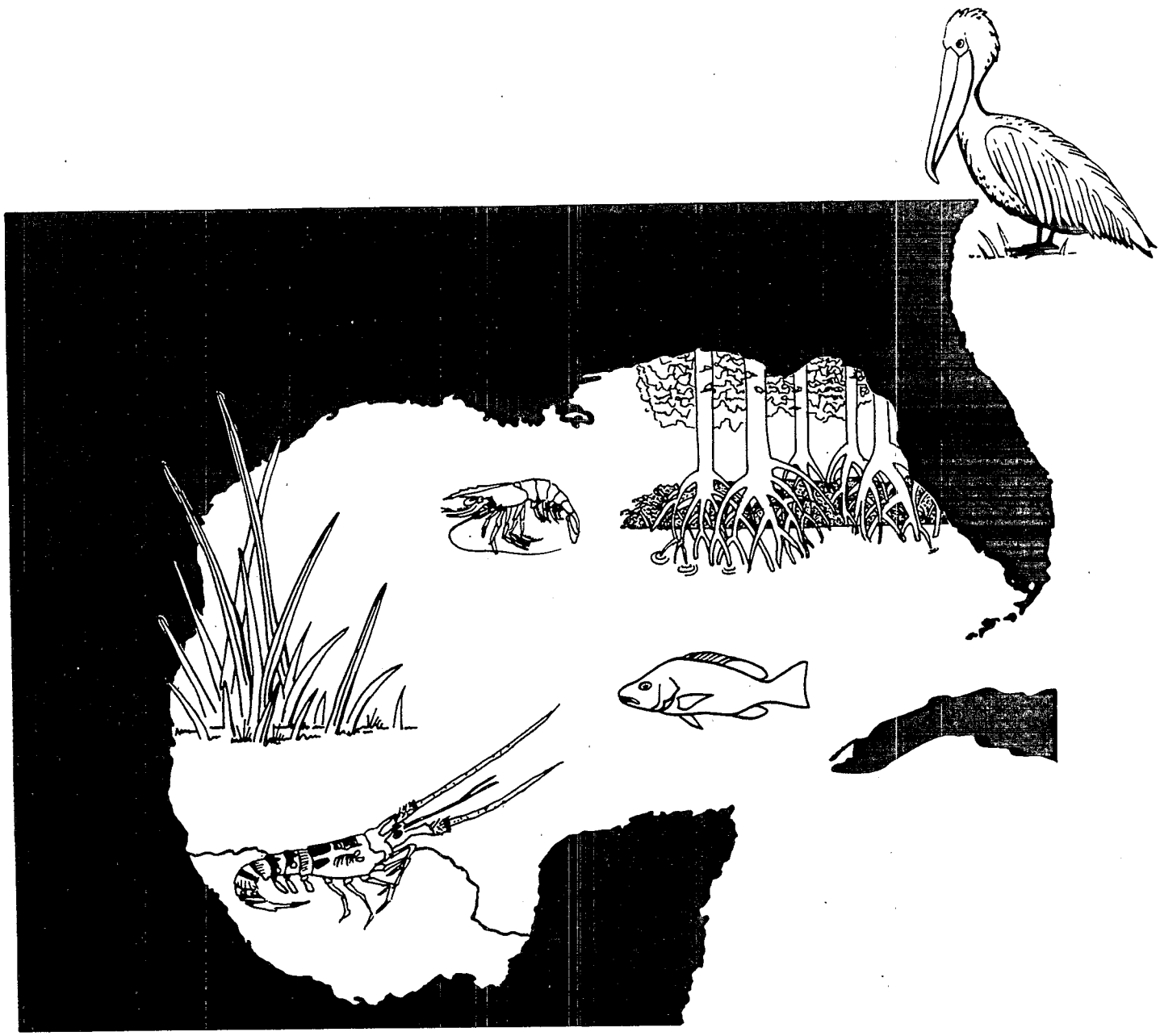
An Updated Summary Of Status And Trends In indicators Of Nutrient Enrichment In The Gulf Of Mexico



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AN UPDATED SUMMARY OF STATUS AND TRENDS IN INDICATORS OF NUTRIENT ENRICHMENT IN THE GULF OF MEXICO

by

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prepared for

Gulf of Mexico Program
Technical Steering Committee
Nutrient Enrichment Subcommittee
Stennis Space Center, MS 39529

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DISCLAIMER

The text of this report was generated by Nancy N. Rabalais of LUMCON, who accepts full responsibility for its content. Parts of the report were developed as articles or proceedings that have been published elsewhere (Turner and Rabalais, 1991a,b), but which formed the basis for the framework of this report. Data and literature incorporated into the report were those available through April 1992. Given the dynamic nature of estuaries, the complex interactions of nature and human factors on the environmental condition of estuaries, and the temporal scales involved in translating research and data into information useful to environmental managers, the findings presented in this report are expected to undergo continual modification. The report does, however, provide a "current" status of the indicators of nutrient enrichment in Gulf of Mexico estuaries and coastal waters.

The report has been reviewed and accepted by the Nutrient Enrichment Subcommittee of the Gulf of Mexico Program. Acceptance does not signify that contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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EXECUTIVE SUMMARY

The Gulf of Mexico region ranks first among those of U.S. coastal areas in total square miles of estuarine drainage area and in total water surface area (NOAA, 1990a). Although the Gulf of Mexico region is not as densely settled as other U.S. coastal areas, it is expected to be the second fastest growing coastal region in the nation (Culliton *et al.*, 1990; NOAA, 1990a). Many of the environmental quality problems affecting Gulf coast estuaries result from human-induced pollution, both within and upstream of the estuarine drainage area. These include industrial facilities, municipal wastewater treatment plants, power plants, urban runoff, suburban development, agriculturally applied nutrients, and other agricultural waste runoff. Although the Gulf of Mexico is viewed as one of the most healthy and productive of our coastal environments, during recent decades the Gulf and its estuaries have begun to show signs of deteriorating environmental quality. Nutrient enrichment, as an important factor in water quality, was identified by the Gulf of Mexico Program of the U.S. Environmental Protection Agency as an issue of particular importance to the Gulf.

The purpose of this report is to summarize the status and trends in Gulf coastal environments with respect to the effects of nutrient enrichment. Identifiable effects of nutrient enrichment include such direct effects as increases in nutrient concentrations (particularly N and P), loads and seasonal delivery and changes in nutrient ratios (*cf.*, stoichiometric ratios of 20Si:16N:1P). Biological responses to nutrient changes include the obvious, direct responses of increased phytoplankton production, biomass, and abundance, and changes in species composition. Less obvious, indirect effects of nutrient enrichment include noxious algal blooms, turbidity increases and shading effects, changes in submerged aquatic vegetation, changes in secondary production, altered energy flow pathways, altered habitats, fish kills, and increase in extent, duration, and severity of oxygen-depletion events.

Long-term quality changes in the Mississippi River have been documented (Walsh *et al.*, 1981; Turner and Rabalais, 1991a). Loadings of nitrogen and phosphorus in the Mississippi River (Turner and Rabalais, 1991a) and for the entire Gulf coast (Smith *et al.*, 1987) have risen dramatically over the last three decades. On a broad scale of relevance to the receiving Gulf of Mexico, the flow of the Mississippi River, which drains 40 % of the U.S. and parts of Canada, dwarfs the input from any other Gulf coast system (90 % of Gulf of Mexico freshwater inflow). The implications to coastal food webs and extensive areas of hypoxia (Rabalais *et al.*, 1991) are complex and a concern. Other rises in nitrate loading in Gulf coastal estuaries were documented by Kircher *et al.* (1984), Smith and Alexander (1984), and Smith *et al.* (1987). On a smaller scale of relevance to Gulf estuarine complexes, increases in nutrients are coupled with features of low tidal energy, variability in freshwater runoff of an aperiodic nature, high biological productivity, and warm temperatures. Subsequent increases in phytoplankton production and its indirect effects may quickly result in deterioration of water quality and environmental health.

Assessing the status of effects of nutrient enrichment is problematic. Data bases and literature, where they exist are diverse, or often insufficient in resolution or duration to indicate trends in increasing or decreasing water quality. In many instances, data bases or literature are nonexistent or not readily accessible. These features are complicated by the need to draw comparisons across all Gulf of Mexico coastal and estuarine areas (presented in Table 11).

A large body of literature, both published and "gray," exists on many Gulf of Mexico estuarine systems and coastal areas. Some of these documents proved useful in the assessments of eutrophication status of the water body (Appendix D). In addition, much data that would indicate conditions of eutrophication (*e.g.*, nutrient concentrations, turbidity, dissolved oxygen levels) reside with state and federal agencies and research laboratories (Appendix B). Time constraints prevented a thorough analysis of the many data sets available. Several were examined for frequency, duration and severity of oxygen depletion. Some data bases have been examined by

various authors, and their results were presented in the review. Still, a vast amount of unanalyzed data exists, and some sets may be worthy of a more detailed analysis.

Based on the literature and data bases reviewed, a matrix is developed which focuses on key indicators of nutrient enrichment for each estuarine or coastal area in the Gulf of Mexico region. Fifty-eight (58) water bodies are keyed in the Status Matrix (Table 11) according to a condensed list of nutrient enrichment indicators of:

(1) Nutrient Increases, Loadings, Concentrations,
(2) Nutrient Ratio Changes,
(3) Nutrient Seasonality Changes,
(4) Phytoplankton, primary production, biomass, abundance, species composition
(5) Toxic or Noxious Algal Blooms
(6) Turbidity
(7) SAV or Macroalgal Changes
(8) Oxygen Depletion
(9) Fish Kills
(10) Secondary Production

Keys for the indicators in each water body are:

Y - Yes, there is evidence of the particular indicator in the estuary, or a sub-unit of the estuary.

P - There are indicators of a potential problem with regards to the indicator but no strong support from long-term data sets; some indicators that the estuary, or a sub-unit of the estuary, may be on the brink of water quality problems.

N - No, there is no evidence of the particular indicator in the estuary, or sub-unit of the estuary, where the data or literature exist that would identify such indicators if present.

? - There are insufficient data to determine whether an indicator of nutrient enrichment is present in the estuary, or sub-unit of the estuary. Insufficiency of data includes lack of recent data (*e.g.*, circa 1985 to present).

Given the caveats above for the extent and uniformity of literature and data available, classifications of each estuary by indicators of nutrient enrichment were treated as uniformly as possible, based upon the synthesis of similar types of information, assumed to be of uniform quality. A more thorough knowledge of the conditions or status of any of the estuaries may reside with several authorities in any area. A single individual, however, reviewed all literature for all estuaries as a basis for the categorizations. As additional data or information become available, the matrix should be revised.

The final column of the matrix (Table 11) is a summary of the previous indicators. This column, coded similarly to the others, indicates whether there is a problem with regards to the condition of the estuary based on the indicators of nutrient enrichment as defined earlier, and in more detail in the "Perspectives" section of the text. These codes are:

Y - Yes, there is a problem in estuarine condition due to nutrient enrichment.

P - There is a potential problem, no real data but some indicators that the estuary, or a sub-unit of the estuary, may be on the brink of water quality problems.

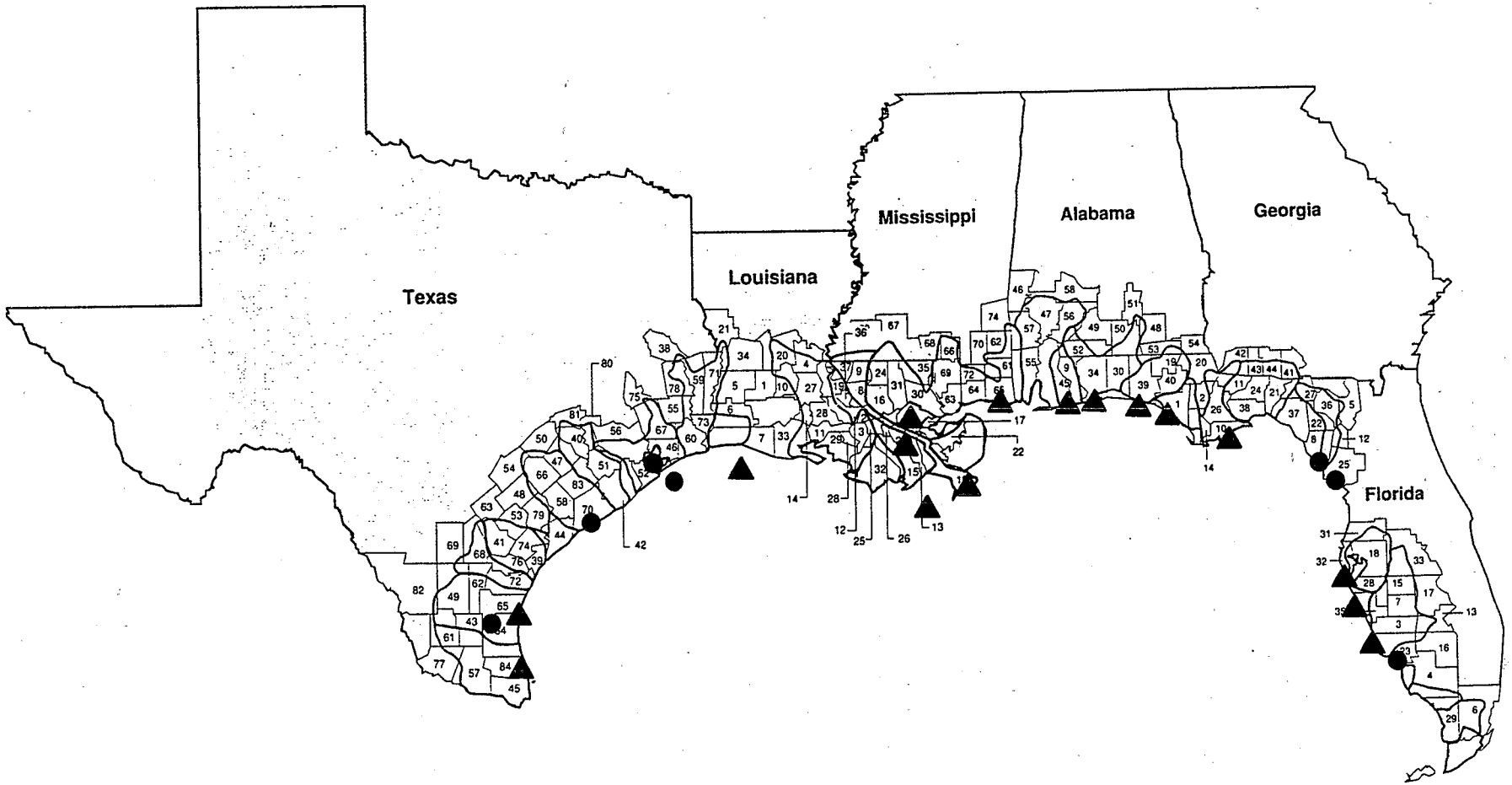
N - No, there is not a problem.

? - There are insufficient data to make a determination, but limited data may support a tentative conclusion of Yes, No or Potential.

All 58 estuaries in the matrix have been placed into one of the above categories. A compilation of these is given in the following table along with a graphic representation of those coded "Yes" or "Potential." There are a notable number of "?"s, indicating the lack of sufficient data to draw conclusions across the Gulf of Mexico. The "Yes" and "Potential" categories, however, are not short lists, and no state is excluded. Areas with known or potential problems related to nutrient enrichment should receive our attention. The number of estuaries in the "?, but No" and "No" lists outweigh the "Yes" and "Potential" lists. We should not be complacent about these estuaries, however, as land use and water management practices may change and other human-induced changes or factors may be impinging on these water bodies (*e.g.*, altered freshwater inflow, dredging, chemical pollution). The compilation condenses a large body of information into a single page. The reader is advised to consider the full text of the report, including the "Perspectives" section and details for any estuary, when using the lists to develop management options, priorities for remedial action, or identify site-specific problems or causative or contributing factors.

Compilation of Status Matrix Indicators of Nutrient Enrichment

Yes	Potential	?, but Yes	?, but Potential	?, but No	No
Charlotte Harbor	Caloosahatchee R.	Mississippi Sound	Mobile Bay	Chatham Bay	Whitewater Bay
Sarasota Bay	Suwanee R.	Pascagoula Bay	Breton/Chandeleur	Apalachee Bay	Big Lostman's Bay
Tampa Bay	Deadmans Bay		Terrebonne Bay	East Miss. Sound	Flor. Inner Shelf (SW)
St. George Sound	Galveston Bay			St. Louis Bay	Crystal River
St. Andrews Bay	Matagorda Bay			Pearl River	Withlacoochee R.
Choctawhatchee Bay	Baffin Bay			Lake Borgne	Waccasassa Bay
Pensacola Bay	Texas Inner Shelf, part			Caillou Bay	Aucilla River
Perdido Bay				Vermilion Bay	Ochlockonee Bay
Biloxi Bay				Mermentau	Apalachicola Bay
Lake Pontchartrain				Lake Calcasieu	Flor. Inner Shelf (Panhandle)
Louisiana Inner Shelf				Sabine Lake	Alabama Inner Shelf
Mississippi River				Brazos River	Mississippi Inner Shelf
Barataria Bay				E. Matagorda Bay	Atchafalaya R./Bay
Upper Laguna Madre				Colorado River	Texas Inner Shelf, part
Lower Laguna Madre				San Antonio Bay	
				Aransas Bay	
				Corpus Christi Bay	
				Rio Grande Tidal	



Gulf of Mexico estuaries and coastal areas with symbols indicating status of indicator of nutrient enrichment as listed in Table 11, Status Matrix, and explained in text; in this case, category of "PROBLEM?" Closed triangle (▲) = Yes; closed circle (●) = Potential.

INTRODUCTION

Impetus for Study

The U.S. Environmental Protection Agency (EPA) Gulf of Mexico Program was established to develop and implement a comprehensive strategy for managing and protecting the resources of the Gulf. Although the Gulf is viewed as one of the most healthy and productive of our coastal environments, during recent decades the Gulf has begun to show signs of deteriorating environmental quality. Issues of particular importance to the Gulf were selected for detailed study. Nutrient enrichment was identified as an important issue because of effects of hypoxia on fisheries and their supporting food web, cause of noxious algal blooms that may have toxic effects on marine life or humans consuming tainted seafood, and indirect effects such as periphytic and phytoplanktonic shading of submerged aquatic vegetation, changes in nutritional value of primary producers, and changes in energy flow pathways. To this end the Nutrient Enrichment Subcommittee of the Technical Steering Committee proposed two projects which were literature and data base reviews on 1) sources and quantities of nutrients entering the Gulf of Mexico and its tributaries (Purdue Univ., 1991) and 2) the effects of nutrient enrichment on the Gulf ecosystem. The purpose of this report is to summarize the status and trends of Gulf coastal environments with respect to the effects of nutrient enrichment, especially updating the 1984 inventory and assessment compiled by the National Oceanic and Atmospheric Administration's Ocean Assessment Division (NOAA/OAD) (Rabalais *et al.*, 1985; Whitledge, 1985; Windsor, 1985).

Marine pollution concerns in the United States have often focused heavily on toxic substances (heavy metals, petroleum, and other organic compounds), the effects of specific discharges (power plants, industrial plants, municipal wastewaters), and dumping activities (sewage sludge, dredged material, and industrial wastes). Other, less identifiable, sources of pollutants enter rivers, estuaries, and coastal areas from urban runoff, agricultural runoff, and rural communities. Many of these nonpoint sources contribute labile organic material, nutrients, and chemicals to the receiving water bodies. There is increasing concern in the United States and other nations that eutrophication of coastal waters from multiple sources may be having pervasive effects on living resources. One of the manifestations of coastal eutrophication is the widespread and catastrophic depletion of dissolved oxygen that has been observed in coastal areas worldwide (New York Bight, Swanson and Sindermann, 1979; Falkowski *et al.*, 1989; Swanson and Parker, 1988; Louisiana continental shelf, Renaud, 1986a,b; Pokryfki and Randall, 1987; Rabalais *et al.*, 1991; Adriatic Sea, Stachowitsch, 1984; Faganeli *et al.*, 1985;, Justić *et al.*, 1987; Black Sea, Tolmazin, 1985; Scandinavian waters, Rosenberg, 1986, 1990; Rosenberg and Loo, 1988; North Sea and German Bight, Westernhagan and Dethlefsen, 1983; Westernhagan *et al.*, 1986). Oxygen-depleted waters have also been identified in numerous estuaries of the United States (Whitledge, 1985). Eutrophication may be manifested in additional ways as detailed later.

In 1984, the NOAA Ocean Assessment Division conducted, through a series of subcontractors, a review of the available literature and data bases for the identification of conditions of oxygen depletion and eutrophication in estuarine and coastal waters (Whitledge, 1985). While the word "eutrophication" was in the title of the project, the emphasis was placed on identifying areas where dissolved oxygen concentrations of bottom waters fell below a critical level (as defined by NOAA/OAD as 4 mg/l). Because of time and funding constraints, information on eutrophication was peripheral in most of the regional reports, especially for the estuaries of the Gulf of Mexico.

Following the completion of the NOAA/OAD reviews, a workshop was convened to discuss the findings of the regional experts and focus on areas of concern. Within each of the five regions (Northeast, Southeast, Florida, Gulf Coast, and West Coast), individual estuaries or coastal regions were characterized as either experiencing low dissolved oxygen conditions, experiencing severe or regularly occurring hypoxia, potentially experiencing hypoxia or worsening of current problems, or lacking sufficient data to be categorized. A final synthesis (Whitledge, 1985)

identified the following categories into which several Gulf of Mexico estuarine and coastal areas fell:

Priority Hypoxia Areas - areas that have a demonstrated hypoxia and/or eutrophication problem.

- Perdido Bay
- Tampa Bay
- Mobile Bay
- Louisiana inner continental shelf
- Lake Pontchartrain

Potential Hypoxia Areas - found to be borderline cases where no strong hypoxia was noted but the conditions for a serious problem occurring were judged to be possible in the future.

- Pensacola and Escambia Bays
- Mississippi Sound
- Galveston Bay
- Calcasieu estuary

Areas with Lack of Data but with Potential Dissolved Oxygen Problems.

- no additional Gulf of Mexico regions, although lack of data was identified for several of those listed in the above two categories.

Most of these initial assessments have proven to be accurate with respect to the categories based on hypoxia criteria. Low dissolved oxygen concentrations, however, are not caused exclusively by nutrient enrichment. Many physical features of the estuary and water column contribute to the formation of hypoxic water masses. There are, in addition, other indicators of nutrient enrichment that may not be manifested in low oxygen conditions. For example, noxious algal blooms may result from nutrient enrichments and/or changes in relative concentrations of nutrients. Indicators in the form of algal blooms, or other features discussed below, may be evident in estuarine basins not identified previously in the 1985 assessments as areas of concern.

Importance of Gulf Coastal Waters

A recent NOAA report (1990a) compiled basic data from the National Estuarine Inventory (NEI) program by Atlantic (3), Gulf of Mexico, and Pacific regions. Excerpts from this report (NOAA 1990a) are given here to place the Gulf of Mexico estuaries within context of all estuarine areas of the U.S. "Estuaries in the Gulf of Mexico contain the greatest amount of water surface area, are the most shallow overall, and receive the largest freshwater inflow among regions, even when the Mississippi River is not considered" (see Table 1). As a result, they support the largest wetlands area in the U.S. and, according to the report, are the least susceptible to pollution retention. The Gulf of Mexico penaeid shrimp fishery is the Nation's second most valuable fishery and ranks first in value among fisheries of the conterminous 48 states (see Table 2). Other valuable fisheries in the Gulf of Mexico depend on menhaden, blue crabs, and oysters. The organisms of these top four valued fisheries in the Gulf of Mexico use estuaries extensively in portions of their life histories.

The Gulf of Mexico region ranks first among those of the U.S. in total square miles of estuarine drainage area and in total water surface area. Within the Gulf of Mexico region, the estuaries vary substantially with respect to size, relative size of fluvial drainage area, amount of freshwater inflow, hydrologic characteristics, variability in freshwater inflow, precipitation patterns, tidal cycles, and land use patterns. Selected characteristics of Gulf of Mexico estuaries are shown in Figure 1 taken from the NOAA (1990a) report on the estuaries of the U.S.

Table 1. Summary of selected characteristics of the Nation's estuaries (from NOAA, 1990a).

Region	PHYSICAL and HYDROLOGIC FEATURES: Estuarine Drainage Area (1000 sq. mi.)	Total Drainage Area (1000 sq. mi.)	Water Surface Area (1000 sq. mi.)	Average Depth (ft.)	Avg. Daily Freshwater Inflow (1000 cfs)	Volume (trillion cu. ft.)	NATURAL RESOURCES: Wetlands (100 sq. mi.)	Classified Shellfish Waters (100 sq. mi.): Approved	Classified Shellfish Waters (100 sq. mi.): Total	ECONOMIC ACTIVITIES: Population Density, 1980 (per sq. mi.)	Land Use (% of EDA): Urban	Land Use (% of EDA): Agriculture	Point Sources of Pollution (100): Industrial	Point Sources of Pollution (100): MWTP	Public Recreation (1000 Sites)
North Atlantic	23	36	2	48	65	4	12	10	12	211	7	7	2	1	3
Middle Atlantic	48	123	7	20	172	6	35	63	74	822	19	27	18	9	10
South Atlantic	55	148	4	12	158	2	92	30	40	104	4	22	4	8	3
Gulf of Mexico	96	1,562	12	8	970	3	166	38	88	122	5	30	20	13	4
Pacific	38	362	2	37	449	9	18	1	5	529	12	11	7	3	7
National	**260**	**2,231**	**27**	**23**	**1,814**	**24**	**323**	**142**	**219**	**309**	**9**	**23**	**51**	**34**	**27**

Note: All values are rounded.

Table 2. Economic value of selected, commercially important estuarine-dependent fisheries, 1989 (millions of dollars) (from NOAA, 1990a).

Region	FISHES: Pacific Salmon	Menhaden	Summer Flounder	INVERTEBRATES: Penaeid Shrimp	Blue Crab	Oyster (meat)	Hard Clam (meat)	Dungeness Crab	Soft Clam (meat)	All Commercial Fisheries
North Atlantic	0	<1	4	8	0	1	3	0	13	250[a]
Rank	-	*40*	*18*	*13*	-	*28*	*19*	-	*8*	-
Middle Atlantic	0	1	18	0	42	22	26	0	7	500[a]
Rank	-	*31*	*9*	-	*2*	*7*	*6*	-	*14*	-
South Atlantic	0	2	11	54	18	3	12	0	0	169
Rank	-	*16*	*6*	*1*	*2*	*12*	*5*	-	-	-
Gulf of Mexico	0	52	<1	374	24	41	<1	0	0	648
Rank	-	*2*	*26*	*1*	*4*	*3*	*30*	-	-	-
Pacific[b]	84	0	0	0	0	16	4	37	0	337
Rank	*1*	-	-	-	-	*5*	*14*	*2*	-	-
Total	**84**	**55**	**33**	**436**	**84**	**83**	**45**	**37**	**20**	**1,904**

Note: All values are rounded. Rank indicates rank among all commercial fisheries in region.
a. Values are estimated.
b. Does not include Alaska fisheries values.
Source: NOAA, 1990f, and unpublished 1989 statistics

Although the Gulf of Mexico region is not as densely settled as other regions, it is expected to be the second fastest growing coastal region in the nation (Culliton *et al.*, 1990; NOAA, 1990a). Between 1970 and 1980, the population grew by more than 30 percent, and is expected to grow by 144 % between 1960 and 2010. Major urban areas surround port cities such as New Orleans, Houston, and Tampa, and dense populations surround Sarasota Bay, Galveston Bay, and Tampa Bay. Western Florida has been and will continue to be the most rapidly growing area in the Gulf; its population is expected to increase by more than 1.5 million over the next two decades (Culliton *et al.*, 1990). Texas is the next most rapidly growing state; its coastal population is expected to increase by over 1.1 million persons during this same period (Culliton *et al.*, 1990).

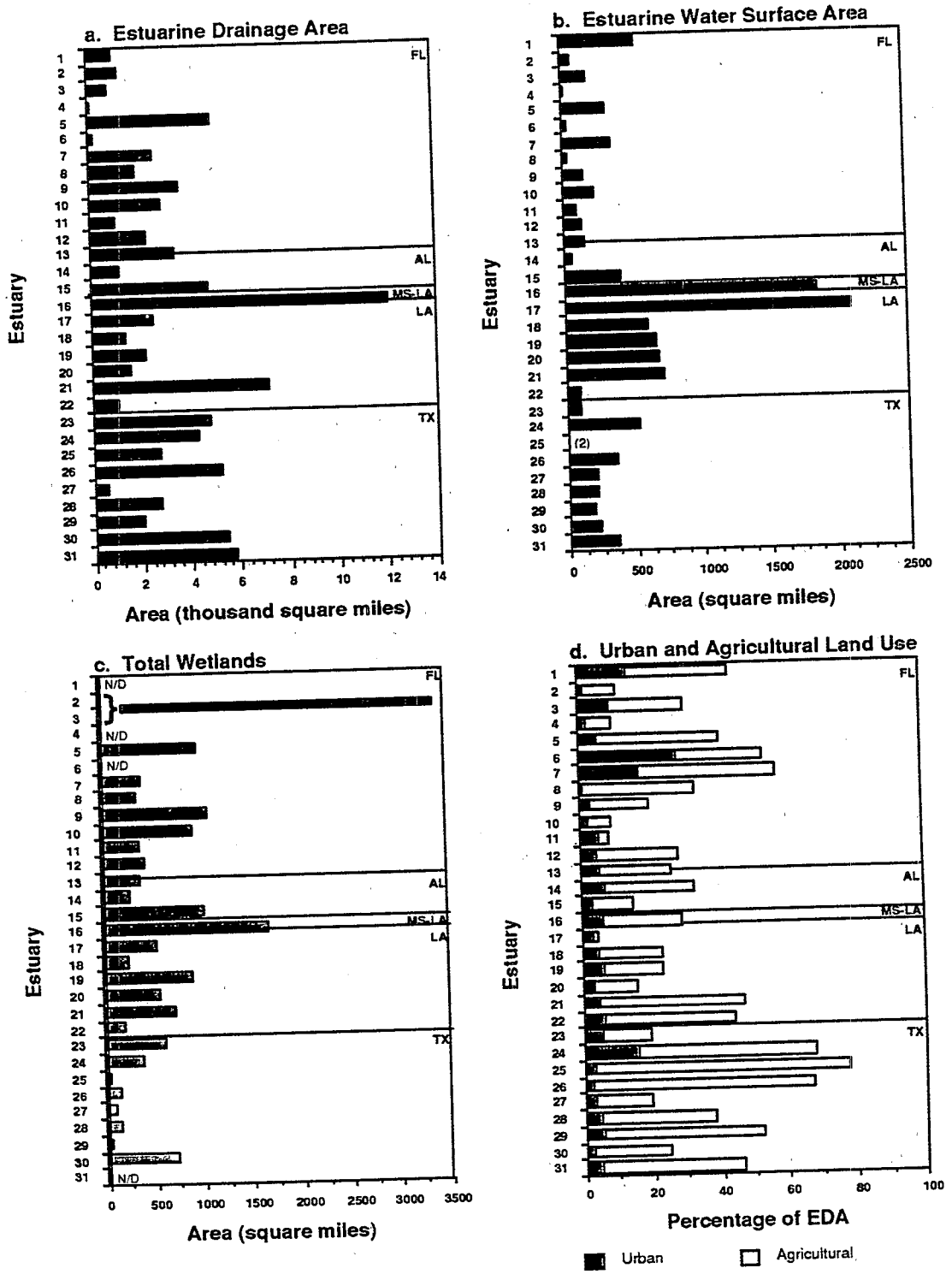
Many of the environmental quality problems affecting Gulf coast estuaries result from natural processes and human-induced pollution both within and upstream of the estuarine drainage area. These include industrial facilities, municipal wastewater treatment plants, power plants, agriculturally applied nutrients and pesticides, and other agricultural waste runoff. The Gulf of Mexico region contains the greatest number of point sources among the regions described in the NOAA (1990a) report (see Table 3), as well as 436 power plants (NOAA, 1990a) . In addition, the northern Gulf of Mexico is the recipient of the flow of a major river system, the Mississippi and Atchafalaya Rivers, which drains 40 % of the U.S. and parts of Canada (Figure 2). The inflow from this river dwarfs the input from any other Gulf coast (90 % of Gulf of Mexico freshwater inflow) or Atlantic coast system (Figure 3).

Long-term water quality changes in the Mississippi River have been documented (Walsh *et al.*, 1981; Turner and Rabalais, 1991a) (Figure 4). Loadings of the Mississippi River (Figure 5) (Turner and Rabalais, 1991a) and for the entire Gulf coast (Table 4) (Smith *et al.*, 1987) have risen dramatically over the last three decades. The implications to coastal food webs and extensive areas of hypoxia are complex and of potential concern (Turner and Rabalais, 1991a). Other rises in nitrate loading in Gulf coast estuaries were documented by Kircher *et al.* (1984), Smith and Alexander (1984), and Smith *et al.* (1987) (Figure 6). The relative differences between loads and concentrations of dissolved solids, phosphorus, and inorganic nitrogen along the Gulf coast as pointed out in these two documents further emphasizes the importance of the Mississippi River system in the contribution of nutrients to the Gulf coastal systems.

The characteristically low tidal energy of the Gulf of Mexico region, high runoff of an aperiodic nature (bringing nutrients and organic material and resulting in density stratification), high biological productivity, and warm temperatures places many of the coastal water bodies "on the brink," such that additional organic inputs or enhanced isolation of bottom waters from reoxygenation may quickly result in depletion of dissolved oxygen.

Expanded Information Bases

The two reviews completed for the NOAA/OAD Nationwide Review were conducted by Rabalais *et al.* (1985) for Texas, Louisiana, Mississippi and Alabama and by Windsor (1985) for Florida. Both investigators conducted literature reviews, but much of the oxygen depletion data was not reported in the scientific literature nor was it listed in government or contractor project reports. Direct access to Federal or State agency data bases proved the most useful source of data. Still, data did not exist for many of the estuaries, other studies were for a specific limited purpose and were not sufficient in resolution or duration to indicate trends in increasing or decreasing water quality, most data were not computerized, quality assurance was minimal prior to 1982, and data were not uniformly reported. Many of the same limitations still hamper the data used for this report. On the other hand, the computer facilities of most State agencies are now updated, old data have been entered, and currently collected data are entered in a timely fashion. This has expanded considerably the data bases available for examination.



Notes: Sub-estuaries are not shown separately. All values are in Appendix B. N/D - no data.

Figure 1. Selected characteristics of Gulf of Mexico estuaries (from NOAA, 1990a). Codes to estuaries listed in Table 3.

Table 3. Selected characteristics of Gulf of Mexico estuaries (from NOAA, 1990a).

Map ID#	NOAA Code	ESTUARY	PHYSICAL and HYDROLOGIC FEATURES: Estuarine Drainage Area (100 sq. mi.)	Total Drainage Area (100 sq. mi.)	Water Surface Area (sq. mi.)	Average Depth (ft.)	Avg. Daily Freshwater Inflow (100 cfs)	Volume (billion cu. ft.)	NATURAL RESOURCES: Wetlands (sq. mi.) [a]	Classified Shellfish Waters (sq. mi.): Approved	Classified Shellfish Waters (sq. mi.): Total	ECONOMIC ACTIVITIES: Population Density, 1980 (per sq. mi.)	Land Use (% of EDA): Urban	Land Use (% of EDA): Agriculture	Point Sources [b] of Pollution: Industrial	Point Sources [b] of Pollution: MWTP	Susceptibility to Pollution: Dissolved Con. Potential	Susceptibility to Pollution: Particle Retention Efficiency
		GULF OF MEXICO																
1	G010	Florida Bay	11	11	538	8	N/D	110	N/D	N/D	N/D	17	14	30	0	3	-	-
2	G020	South Ten Thousand Islands [f,i]	13	13	77	7	N/D	14	3,383	43	70	29	2	9	0	0	-	-
3	G030	North Ten Thousand Islands [f,i]	9	21	192	6	N/D	31	-	-	-	3	9	22	0	3	-	-
4	G040	Rookery Bay	2	2	14	5	N/D	2	N/D	N/D	N/D	31	2	8	0	1	-	-
5	G050	Charlotte Harbor	50	50	311	8	48	73	975	86	176	105	5	36	56	22	M	M
5a	*G050a*	*Caloosahatchee River*	*14*	*14*	*26*	*5*	*19*	*3*	*N/D*	*0*	*5*	*127*	*4*	*29*	*10*	*6*	*H*	*L*
6	G060	Sarasota Bay [c]	3	3	44	6	4	8	N/D	N/D	N/D	923	28	26	6	11	H	M
7	G070	Tampa Bay [c]	26	26	346	13	24	123	394	9	88	476	17	40	69	29	H	H
8	G080	Suwannee River	19	102	42	5	112	6	358	10	26	24	1	33	3	3	M	L
9	G090	Apalachee Bay	37	46	159	10	53	45	1,087	0	33	64	3	17	21	5	M	M
10	G100	Apalachicola Bay	30	205	214	9	291	54	924	1	175	15	2	7	3	4	M	L
11	G110	St. Andrew Bay [i]	11	11	94	12	45	31	392	0	100	65	5	3	12	7	M	M
12	G120	Choctawhatchee Bay	23	54	129	14	85	51	438	0	97	42	4	24	3	8	M	M
13	G130	Pensacola Bay	35	70	143	13	116	51	382	0	147	72	5	21	6	6	M	M
14	G140	Perdido Bay	12	12	50	7	22	10	266	0	0	121	7	26	6	12	H	M
15	G150	Mobile Bay	49	446	409	10	793	113	1,023	0	407	85	3	12	101	41	L	L
16	G160	Mississippi Sound [g]	121	269	1,850	11	436	568	1,670	413	1,857	125	6	23	197	173	M	M
16a	*G160a*	*Lake Borgne*	*79*	*148*	*282*	*9*	*251*	*74*	*N/D*	*293*	*391*	*134*	*9*	*26*	*1*	*119*	*H*	*L*
16b	*G160b*	*Lake Pontchartrain*	*55*	*55*	*710*	*11*	*107*	*220*	*N/D*	*0*	*710*	*122*	*7*	*27*	*1*	*116*	*H*	*M*
17	G170	Breton/Chandeleur Sounds [h]	25	25	2,086	8	103	420	532	1,534	1,592	384	3	1	1	9	M	H
18	G180	Mississippi River [h,i]	19	11,317	600	26	4,644	386	251	0	0	326	4	19	11	16	L	L
19	G190	Barataria Bay [c,h]	22	22	646	5	55	90	897	158	199	203	6	17	1	21	H	M
20	G200	Terrebonne/Timballer Bays [c,h]	16	16	680	6	46	110	561	465	583	67	3	13	0	30	M	M
21	G210	Atchafalaya/Vermilion Bays [i]	72	1,006	703	7	2,238	137	721	20	718	76	3	34	7	71	L	L
22	G220	Calcasieu Lake	11	43	99	9	63	26	191	39	88	117	6	38	1	8	H	M
23	G230	Sabine Lake	48	209	94	8	172	21	615	0	0	92	5	14	164	56	M	L
24	G240	Galveston Bay [c,i]	45	245	540	6	152	92	374	0	547	665	16	50	747	566	M	M
25	G250	Brazos River [i]	28	468	2	8	74	<1	31	0	2	57	5	71	40	49	H	L
26	G260	Matagorda Bay [i]	59	503	422	7	53	78	134	0	375	26	2	58	113	46	M	M
27	G270	San Antonio Bay	5	109	205	4	41	25	105	0	238	10	3	16	17	2	H	M
28	G280	Aransas Bay	28	28	208	5	10	31	152	99	212	33	4	34	104	16	H	M
29	G290	Corpus Christi Bay	20	176	192	8	12	42	46	171	225	152	5	47	183	21	H	H
30	G300	Upper Laguna Madre [i]	55	55	216	3	6	15	704	794	848	84	2	23	50	13	-	H
30a	*G300a*	*Baffin Bay*	*35*	*35*	*92*	*4*	*4*	*11*	*N/D*	*74*	*93*	*27*	*1*	*31*	*18*	*7*	*H*	*M*
31	G310	Lower Laguna Madre [i]	58	58	366	3	3	26	N/D	N/D	N/D	19	4	42	79	41	-	H
		Total	**962**	**15,621**	**11,671**	**8**	**9,701**	**2,789**	**16,606**	**3,842**	**8,803**	**122**	**5**	**30**	**2,000**	**1,293**	-	-

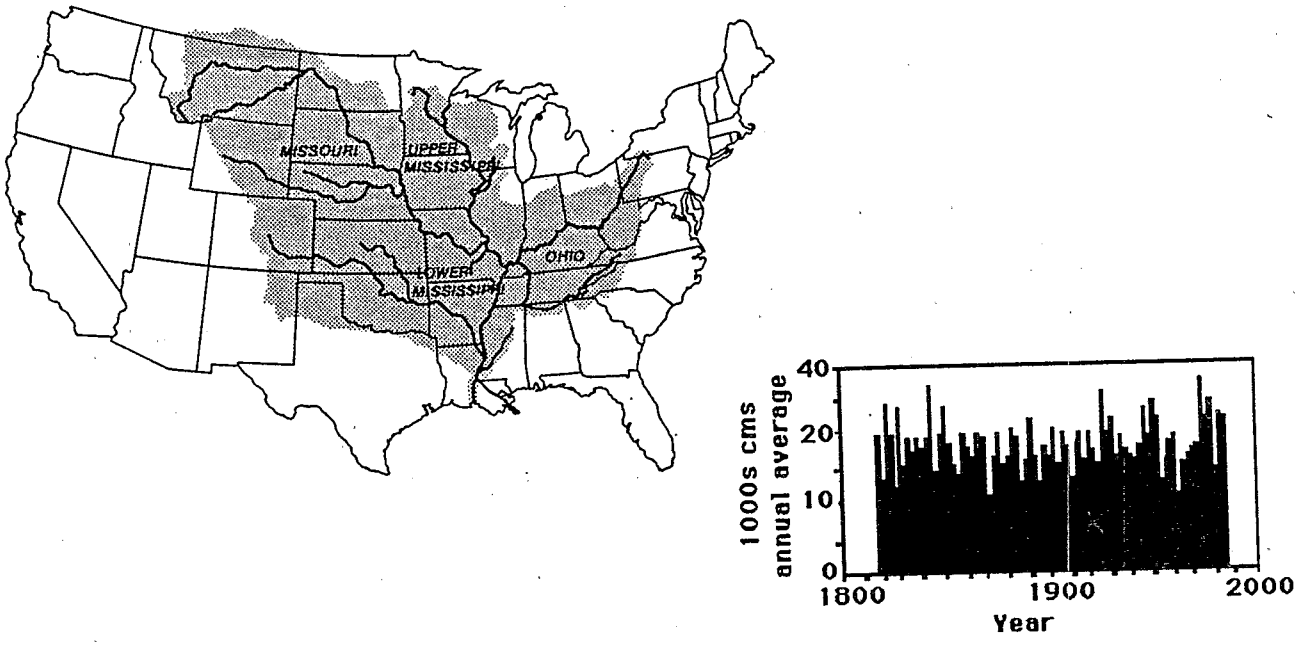


Figure 2. The drainage basin of the Mississippi River and the annual discharge at Vicksburg, Mississippi (from Turner and Rabalais, 1991a).

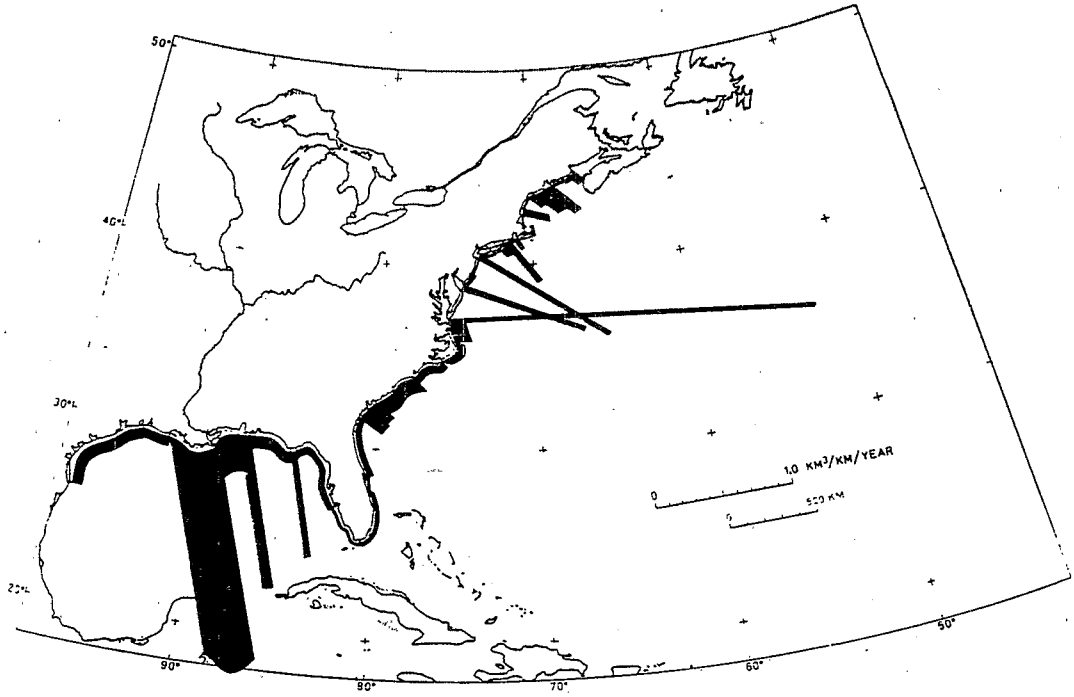


Figure 3. Average annual runoff to ocean in terms of km^3/ linear km of coast (from Emery and Uchupi, 1972).

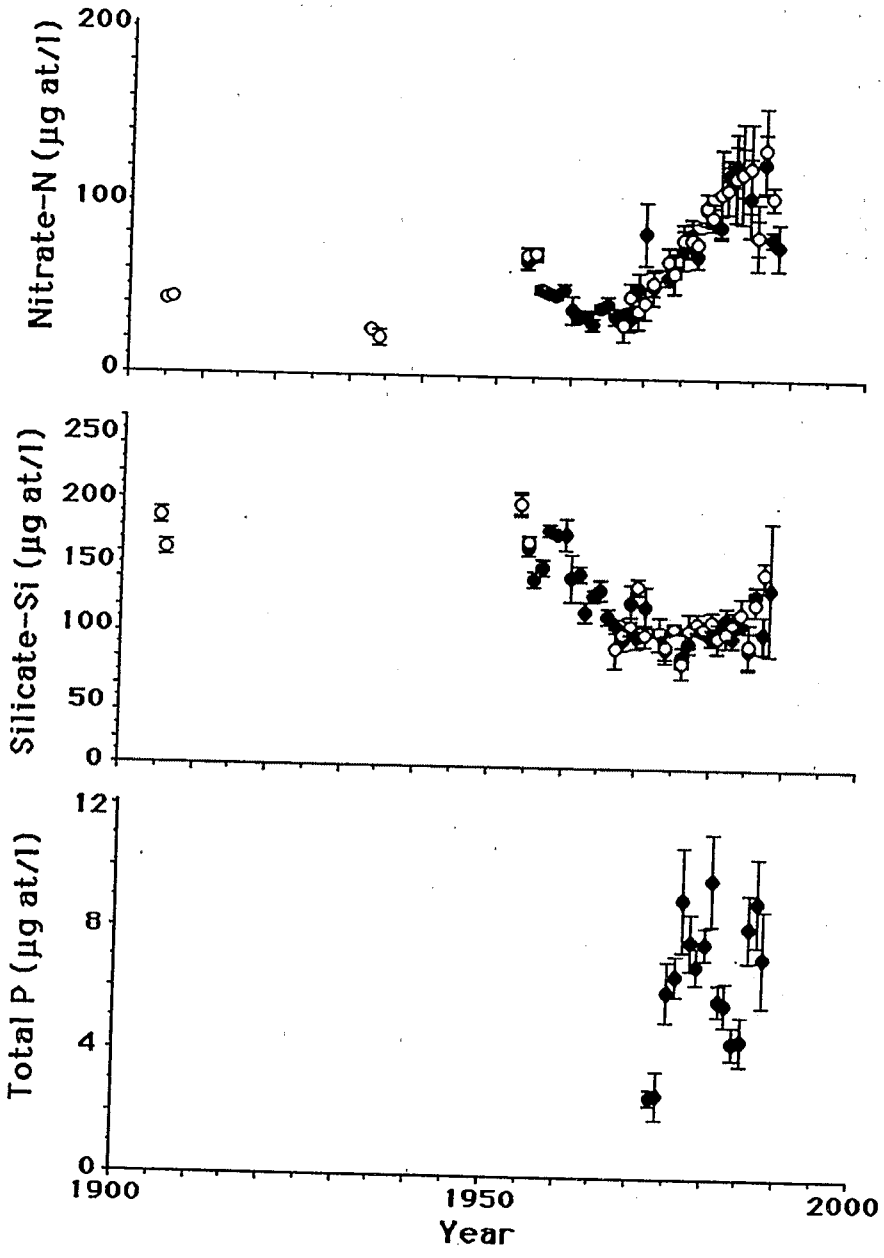


Figure 4. Changes in nitrate, silicate and total phosphorus in the lower Mississippi River at St. Francisville (closed circles) and New Orleans (open circles). Bars are ± 1 standard error of the annual average of monthly means (from Turner and Rabalais, 1991a).

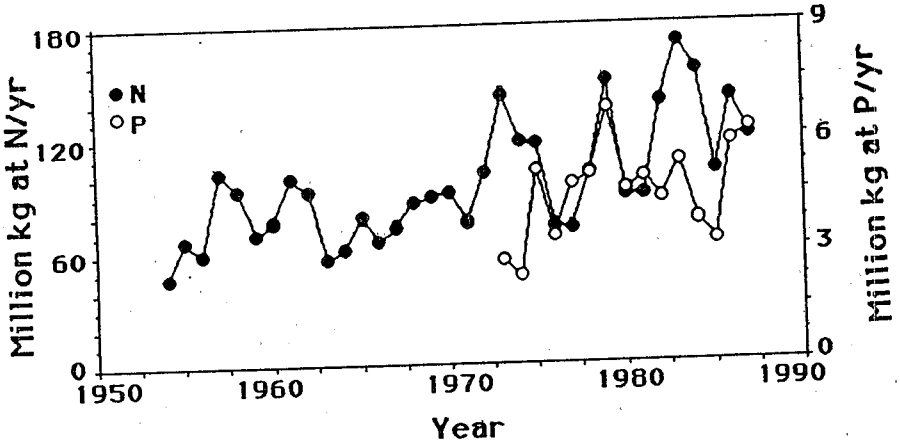


Figure 5. Nitrogen and phosphorus loading from the Mississippi and Atchafalaya rivers to the Gulf of Mexico from 1954 to 1987 (revised from Turner and Rabalais, 1991a).

Table 4. Changes in delivery of nutrients to coastal areas (modified from Smith *et al.*, 1987).

Region	Change in Load, 1974-1981	
	Total Nitrate (%)	Total Phosphorus (%)
Northeast Atlantic Coast	32	-20
Long Island Sound/New York Bight	26	-1
Chesapeake Bay	29	-0.5
Southeast Atlantic Coast	20	12
Albemarle/Pamlico Sound	28	0
Gulf Coast	**46**	**55**
Great Lakes	36	-7
Pacific Northwest	6	34
California	-5	-5

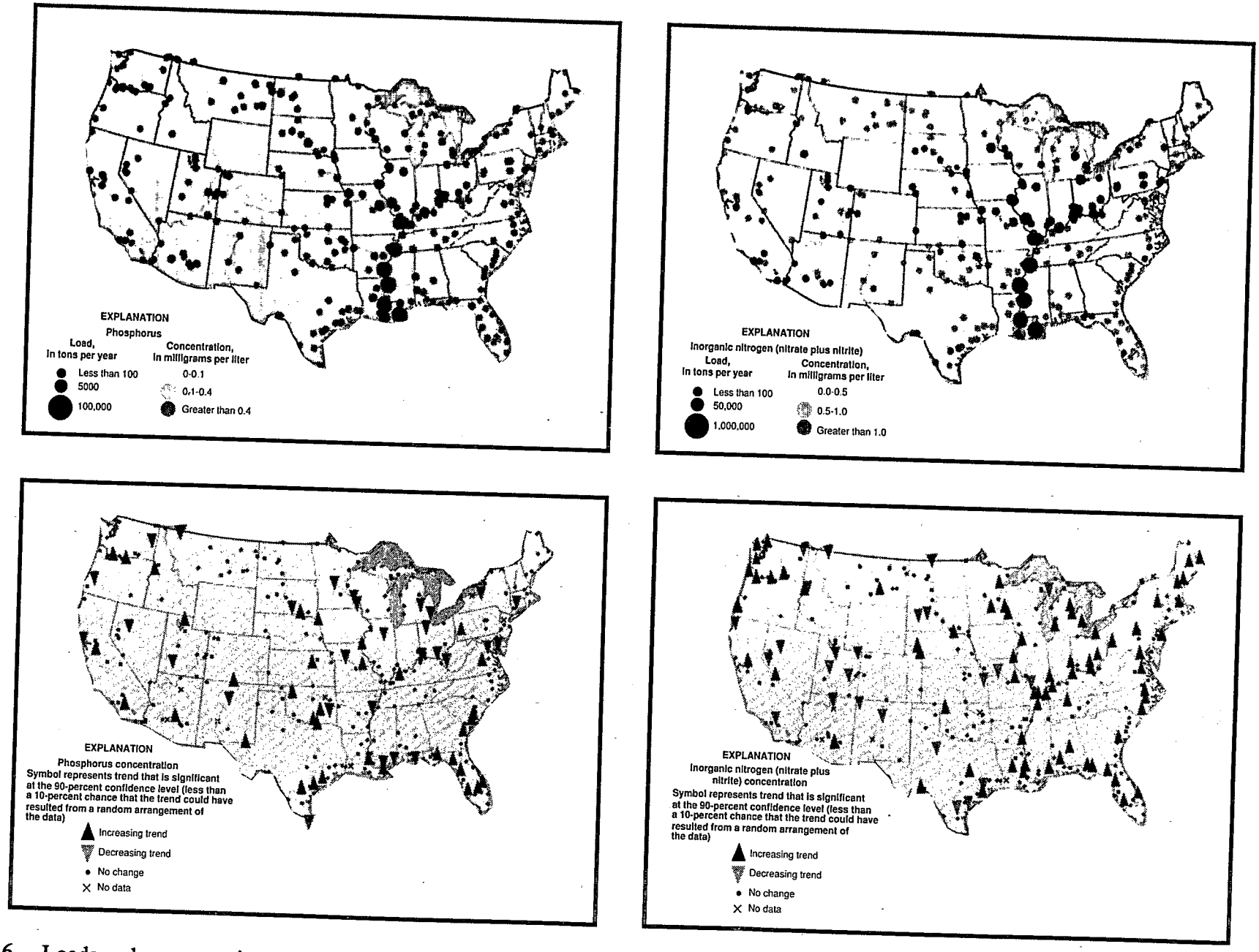


Figure 6. Loads and concentrations of phosphorus (upper left) and inorganic nitrogen (upper right) and trends in concentrations of phosphorus (lower left) and inorganic nitrogen (lower right) for U.S. waters (from Kircher *et al.*, 1984; Smith and Alexander, 1984).

Other activities have expanded the data base available for Gulf of Mexico activities. These are primarily the result of data collection by the NOAA Ocean Assessments Division for the National Coastal Pollutant Discharge Inventory, assessment of Publicly Owned Treatment Works in Coastal Areas of the U.S., Agricultural Pesticide Use in Estuarine Drainage Areas, draft data summaries on Point Source Discharges in Coastal Areas of Alabama and Mississippi, the National Estuarine Inventory (NEI), the NEI Project to Characterize Salinity in the Nation's Estuaries, National Coastal Wetlands Inventory, Estuarine Living Marine Resources Project, Susceptibility of Estuaries to Pollutant Effects synthesis, National Status and Trends program, NOAA's Inventory of Fish Kills in Coastal Waters (NOAA 1991), the NOAA/EPA Team on Near Coastal Waters assessment of the Susceptibility and Status of Gulf of Mexico Estuaries to Nutrient Discharges, and the EPA Environmental Monitoring and Assessment Program (EMAP). The EMAP program conducted pilot studies in the Gulf of Mexico in 1990 and will initiate the full program in 1991. Within some states, *e.g.*, Texas, there have been expanded studies of bay systems (San Antonio Bay, Laguna Madre), and long-term deployment of oxygen meters; both initiatives of the Texas Department of Water Resources. Other ecosystem-level studies are underway or have been completed in Fourleague Bay (Louisiana), Mobile Bay, Perdido Bay, and Apalachicola Bay.

In the intervening years between the 1984 Nationwide Review and the present, several estuaries have become designated areas under several Federal programs. Sarasota Bay, Tampa Bay, Galveston Bay, and the Barataria/Terrebonne Estuarine Complex are included in EPA's National Estuary Program. National Marine Sanctuaries (Rookery Bay, Florida) and National Estuarine Reserves (Weeks Bay, Alabama) have been established. As a result, more focused research programs have been initiated in each of these areas for the improved understanding of the status of the estuary and the processes important in maintaining estuarine health.

All these activities have resulted in expanded data sets for many Gulf of Mexico estuaries and coastal areas, increased research and monitoring activities, and several completed studies on selected estuarine basins. Several national programs have focused on the causes and effects of nutrient enrichment. These include:

- the NOAA/EPA Team on Near Coastal Waters Strategic Assessment of Near Coastal Waters in the preparation of Susceptibility and Status of Gulf of Mexico Estuaries to Nutrient Discharges (NOAA/EPA Team on Near Coastal Waters, 1990),

- the NOAA Coastal Ocean Program Nutrient Enhanced Coastal Ocean Productivity program which is focusing on the influence of the Mississippi and Atchafalaya Rivers on the adjacent Gulf of Mexico [NECOP Mississippi-Atchafalaya River (MAR) Implementation Plan],

- the NOAA National Ocean Pollution Program Office studies of long-term trends in water quality in selected estuaries and its relationship to fishery resources (*e.g.*, Stanley, 1992),

- the NOAA Strategic Environmental Assessments Division National Estuarine Eutrophication Project (Hinga *et al.*, 1991), and

- NOAA's Coastal Ocean Program Resource Information Delivery component (COP/RID) which is scheduled to fund, among other synthetic efforts, a comparative review of the problems stemming from nutrient over-enrichment and harmful algal blooms in U.S. coastal waters.

In summary, many Federal and State programs are approaching the study of nutrient enrichment, its effects, and mechanisms for control. This report represents one of many ongoing efforts to synthesize available information on the indicators of nutrient enrichment in the Gulf of Mexico.

PERSPECTIVES ON NUTRIENT ENRICHMENT AND EUTROPHICATION

Definitions

The words, "nutrient enrichment," "nutrient over-enrichment" and "eutrophication," are often used interchangeably but often without similarly intended meanings. For this review, the "over-" prefix will be dropped from the word enrichment, since enrich already means "to increase the proportion of a valuable or desirable ingredient."

There has been considerable discussion and usually lack of agreement on the definition of "eutrophication." In many instances it is used interchangeably with "nutrient enrichment." Others, however, chose to limit the meaning of "eutrophication" to a condition resulting from excessive nutrient loading which stimulates primary production and results in extremely rapid growth and large standing stocks of phytoplankton. An example of these inconsistencies was obvious in the series of discussions at the recent workshops for the National Estuarine Eutrophication Project (Hinga *et al.*, 1991). No definition evolved from this group; and, as noted by Garber and Pennock in the proceedings of the workshop, no clear definition of "eutrophication" evolved from a National Academy of Science (NAS) symposium on eutrophication in 1967 (NAS, 1969). "Eutrophication" as defined in the NAS (1969) proceedings meant "a natural or artificial addition of nutrients to bodies of water and to the *effects* of added nutrients." This is the definition that will be followed for this report.

The word "increase" dictates change in a positive direction. The measurement of this increase thus requires a data base with adequate temporal resolution. These data are sorely needed, or the analyses of existing data bases are sorely needed, because the examples in the literature which document long-term changes in nutrient supply are limited. Notable examples are given in subsequent sections. Also, not all nutrient increases are detrimental. An adequate supply of essential nutrients is required to support food webs, and intentional nutrient additions have been shown to increase fish stocks in some experimental systems. It is generally perceived, however, that aquatic systems are limited in their assimilative capacities and that the effects of eutrophication are deleterious.

This review is to focus on the indicators of nutrient enrichment. Experimentally or empirically derived relationships between changes in nutrients and biological and/or chemical effects provide the solid basis for determining how nutrient enrichment effects estuarine and coastal systems. Other relationships are not as straightforward, and complex interactions obscure direct lines of evidence. Many examples are given of the expression of eutrophication effects.

The nutrient inputs and concentrations within an estuarine body or coastal area originate from sources outside the system (allochthonous) and from within the system (autochthonous). It is largely accepted that increased allochthonous loadings of nutrients can lead to increased primary production (Nixon *et al.*, 1986; Oviatt *et al.*, 1986b; Malone, 1987). The quantification of these relationships and paths of nutrient uptake and regeneration are not, however, adequately known. Several studies suggest that recycled nutrients account for a greater percentage of the ambient nutrient concentration than the "new" load entering the system each year (Boynton *et al.*, 1982; Kemp *et al.*, 1982; Fisher and Doyle, 1987). Although autochthonous loadings are essentially unmanageable, an understanding of their contributions is necessary in understanding the effects of all sources of nutrient inputs.

Nitrogen and phosphorus are the primary anthropogenic nutrient inputs of concern in coastal waters. Nitrogen is considered the most important nutrient in marine and coastal waters; phosphorus, in freshwater systems. Both nitrogen and phosphorus are important in estuaries, depending on the season, total nutrient loadings, and various physical and chemical conditions. Silica availability, an indirect consequence of phosphorus loading, may strongly influence the

occurrence of deleterious effects of eutrophication. The relative proportion of nutrients will likely vary down the stem of the estuary, and the subsequent responses of phytoplankton to differing concentrations will also change. Other chemical constituents such as carbon, trace metals, dissolved organic compounds (*e.g.*, amino acids) and chelators may also be important in specific systems and under certain conditions. Physical features (*e.g.*, light or temperature) also control primary production.

How Much (of What) Is Too Much?

Water quality data are reported in a multitude of forms and units (Appendix A). Commonly used measures are total Kjeldahl nitrogen (TKN) and dissolved inorganic nitrogen (DIN). TKN includes all forms of N quantified in a Kjeldahl test, which typically transforms organic N to NH_3-N. Thus, TKN is the sum of total NH_3-N and organic N. TKN can be for either dissolved or particulate samples. DIN normally includes nitrate plus nitrite, but may also include ammonia. Total N usually combines TKN + nitrate + nitrite. Concentration of a constituent is usually expressed as mass per unit volume of water and reported as milligrams per liter (mg/l), but units of μM and μg-at/l are also common.

Most phosphorus is either dissolved as phosphate ions and organic phosphorus molecules or suspended in association with inorganic suspended sediment and organic particulate matter. Phosphorus may be reported as total phosphorus (TP), usually in units of mg/l, and may represent either the dissolved or particulate fraction or both. Inorganic dissolved phosphorus is in the form of phosphate and usually reported in units similar to dissolved inorganic nitrogen. Silicate, minus a small fraction considered not to be biologically available, is reported in units similar to DIN and TP; USGS Water Resources data report silica dissolved as SiO_2 in mg/l.

Phytoplankton is measured in several ways, either as the rate of primary production, biomass (concentration of chlorophyll), or number of individuals. Primary production is traditionally measured by experimental incorporation of radio-labelled carbon and expressed as mg $C/m^2/d$, mg $C/m^3/d$, or an annual average, but new instrumentation allows for the calculation of these rates based on fluorescence and light measurements. Phytoplankton biomass is usually determined fluorometrically or spectrophotometrically for the major constituent of phytoplankton (chlorophyll *a*) and expressed in units of mg/m^3, μg/l, or mg/m^2 if integrated over the water column. Abundance of phytoplankton is often determined by total and taxon specific cell counts. More recently, phytoplankton biomass and community composition are determined frequently by high pressure liquid chromatography (HPLC).

The concentration of dissolved oxygen in bottom waters has become a standard measurement technique to determine the general health of a water body. Instrumentation or chemical titration provides concentrations in units of mg/l (ppm) or ml/l. Units to be used throughout this report will be mg/l. [For conversion, 1 mg/l, or ppm, = 0.7 ml/l.] Bottom water dissolved concentrations of <2 mg/l are considered hypoxic (see below). Values approaching zero or anoxia are difficult to measure (depending on the method), especially near industrial effluents, but concentrations below 0.1 mg/l are usually considered anoxic. Surface or mid-water column dissolved oxygen concentrations may also prove informative in the determination of the eutrophication status of an estuary (see section on Oxygen Depletion).

Turbidity is often a water quality measurement, and the constituents and units depend primarily on the method of measurement (see Appendix A). The suspended sediment load may be measured directly as a mass per unit volume (mg/l) or indirectly by Secchi disk depth. Various instruments may be used to measure light penetration, or light backscattering characteristics.

Dissolved inorganic solids, which are a concern in freshwater systems as a general indicator of water quality and of the suitability of water for various uses, are not a concern in estuarine or coastal systems. Dissolved inorganic solids are the makeup of sea water (= sodium, potassium, calcium, magnesium, carbonate, bicarbonate, chloride, and sulfate ions).

The NOAA/EPA Team on Near Coastal Waters (1990) has determined a categorization for estuarine basins based on predicted concentrations of nitrogen (TKN) and phosphorus with different concentrations for each nutrient for three categories. For nitrogen, concentrations less than 0.1 mg/l are low, between 0.1 and 1.0 mg/l are medium, and greater than 1.0 mg/l are high. For phosphorus, concentrations less than 0.01 mg/l are low, between 0.01 and 0.1 mg/l are medium, and greater than 0.1 mg/l are high. This classification scheme (which follows a continuum) was based on observed estuarine characteristics at the different nutrient levels as reported for the Chesapeake Environmental Quality Classification Scheme (EPA, 1983). In this classification an estuary with low concentrations of nutrients is characterized by maximum diversity of aquatic life whereas an estuary with high nutrient concentrations is characterized by high chlorophyll levels, low species diversity, and occasional red tides. The Chesapeake system is also characterized by hypoxia/anoxia in warm months (Officer *et al.*, 1984).

Phytoplankton growth requires nitrogen and phosphorus in the approximate proportion (atomic) of 16:1, the Redfield Ratio (Redfield, 1934, 1958). The NOAA/EPA Team on Near Coastal Waters (1990) suggested that N:P ratios between 10:1 to 20:1 were the range for which a potentially limiting nutrient could not be determined with any assurance without site-specific information. Where N:P ratios fall between 10:1 and 20:1, the potentially limiting nutrient may be highly dependent upon the species of phytoplankton present. Outside of this range, there may be insufficient nitrogen to balance all of the available phosphorus, or vice versa. Silica is also an important nutrient for phytoplankton growth and likely limits diatom growth when there are adequate supplies of the other nutrients. Silica is required by diatoms in proportions of Si:N:P = 20:16:1 (Redfield, 1958).

Changes in a single, or multiple nutrients with time and the relative proportion of these nutrients are important indicators of nutrient enrichment. These changes are important to understand, if only because nitrogen is commonly thought to be limiting phytoplankton growth in coastal and oceanic waters. (*e.g.*, Harris, 1986; Valiela, 1984). However, not all coastal systems are nitrogen limited (*e.g.*, the Huanghe in China is phosphorus limited; Turner *et al.*, 1990), nor is changing nutrient loading the only factor influencing phytoplankton growth (Skreslet, 1986). Marine phytoplankton may also respond differently to nutrient additions if introduced gradually or suddenly, with changing flushing rates or salinity, and with cell density (Sakshaug *et al.*, 1983; Sommer, 1985; Suttle and Harrison, 1986; Turpin and Harrison, 1980).

Anthropogenic Factors

The factors that may be affecting the water quality of an estuarine basin are many, and implicating specific actions on the eventual effects on natural resources is tenuous and complicated by natural factors. The coastal regions of the Gulf of Mexico have experienced rapid population growth in recent years along with its associated burdens. The most significant burdens are changes in land use patterns as more land becomes urbanized (or suburbanized) and municipalities must deal with the treatment and discharge of sewage. There are 1293 municipally-owned waste water treatment plants in the Gulf of Mexico estuarine basins (NOAA, 1990a; see Table 3). Waste treatment loads in Florida are expected to increase by more than three hundred percent by the year 2000 (Windsor, 1985); similar trends can be expected elsewhere. Sewage outfalls are a dramatic, but only symptomatic fruition, of the more basic rise in consumption of basic commodities, and of the need to dispose of the undesirable byproducts.

The Gulf of Mexico region has more point sources of pollution (over 3,700) than any other region in the U.S. (NOAA, 1990a). Industrial activities are concentrated along the coast and major rivers, oil and gas production and development activity is high, and the petrochemical industry is large. Major shipping centers are found in each of the Gulf states. Other industrial activities include wood and pulping operations and fertilizer mining and processing. With increased demands for industrialization, urban land use and residential areas, natural resources are impinged upon as dredge and fill activities alter the landscape.

Agriculture activity accounts for 31 % of the land use in the Gulf of Mexico region (NOAA, 1990a; see Figure 1). With this land use comes the application of fertilizers. In 1982, application of fertilizer to agricultural lands in the Gulf of Mexico estuarine drainage areas was the highest among the regions of the U.S. The greatest applications within the Gulf of Mexico were in the Galveston Bay, Matagorda Bay, and Lower Laguna Madre estuaries. Fertilizer runoff is a significant nutrient source [>25 % of the total inputs of either phosphorus or nitrogen in South Ten Thousand Islands, North Ten Thousand Island, Charlotte Harbor, Suwannee River, Lower Laguna Madre, Apalachee, Choctawhatchee, Pensacola, Perdido, Matagorda, San Antonio, Aransas and Corpus Christi Bays (NOAA, 1990a)]. Fertilizer application within the U.S. has increased steadily since the 1940s, although there has been a leveling-off in recent years (Figure 7). The implications of these nutrient contributions to rivers, estuarine systems, and coastal waters is a matter for concern and long-term changes in coastal systems have been documented worldwide where major rivers deliver nutrient enriched waters to coastal seas (Nehring, 1984; Fransz and Verhagen, 1985; Rosenberg, 1985; Lancelot *et al.*, 1987; Andersson and Rydberg, 1988; Wulff and Rahm, 1988; Turner and Rabalais, 1991a). (See section G-9.)

An example of water quality changes in the U.S. is represented by the nitrate and silicate concentrations in the Mississippi River, which drains 40 % of the U.S. and is the dominant freshwater inflow source into the Gulf of Mexico (Figures 2 and 3). The average annual nitrate-nitrogen concentration doubled after 1950, and the silicate concentration was reduced by half (Figure 4) (Turner and Rabalais, 1991a). The average annual nitrate concentration is positively related to nitrogen fertilizer use; the annual silicate concentration in the river is inversely related to phosphorus fertilizer use, presumably because phosphorus stimulates diatom growth and diatom tests sink to lake and reservoir sediments, thus storing silica that would otherwise go into the water column and downstream (Figure 8) (Turner and Rabalais, 1991a).

The global nitrogen budget for new nitrogen sources from fertilizer applications exceeds by far contributions from the combustion of fossil fuels (Turner, 1991). World fertilizer consumption has been increasing since World War II when industrial processes evolved for fixing atmospheric nitrogen into fertilizers, and mining of P-rich mineral deposits expanded rapidly (Figure 9) (Turner and Rabalais, 1991b). Additional nutrients are released through de-vegetation, farming, soil erosion, weathering, etc. A linear relationship between fertilizer application and water quality is not always expected, because of the interaction of various ecosystem components, and subsequent adjustments by microorganisms, in particular (see *e.g.*, Aber *et al.*, 1989)

Industrially-produced nitrogen is recycled through the atmosphere, and into water supplies. The worldwide rise in the concentration of nitrogen in rainfall and snowfall is symptomatic of the extent of these human activities on the environment. The importance of atmospheric inputs of essential nutrients has only recently been understood, but is clearly important and changing (*e.g.*, Morris, 1991). For example, the inputs from precipitation and river runoff are equal in Chesapeake Bay (Correll, 1981; Correll and Ford, 1982), an estuarine system often described as eutrophic. The nitrogen concentration in precipitation has recently increased in the eastern and upper midwest of the U.S. and in Europe (*e.g.*, Likens and Borman, 1979; Brimblecome and Pitman, 1980; Morris, 1991). These changes are so pervasive as to appear in snowfall in the Antarctic (Mayewski and Legrand, 1990). Turner (1991) suggests that the precursor for these polar snow deposits could also be from recently deposited nitrate in fertilizers rather than from fossil fuel sources, as

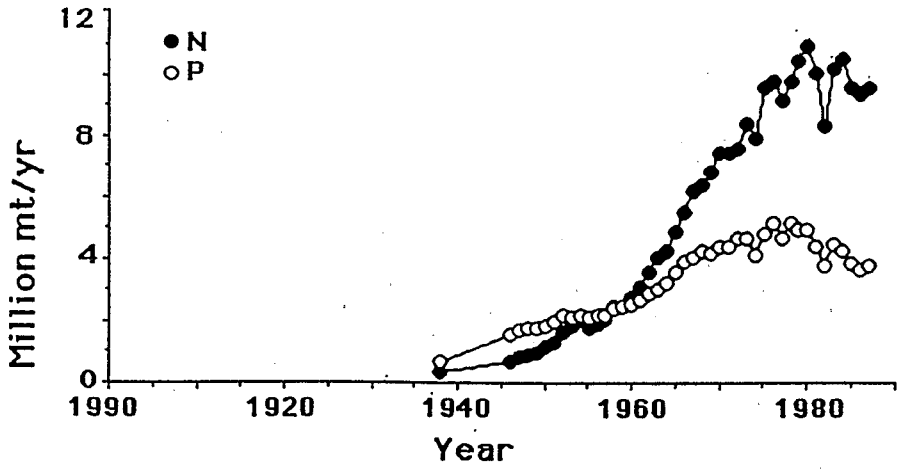


Figure 7. Nitrogen (as N) and phosphorus (as P_2O_5 equivalent) fertilizer use this century in the U.S. up to 1987-1988 (from Turner and Rabalais, 1991a).

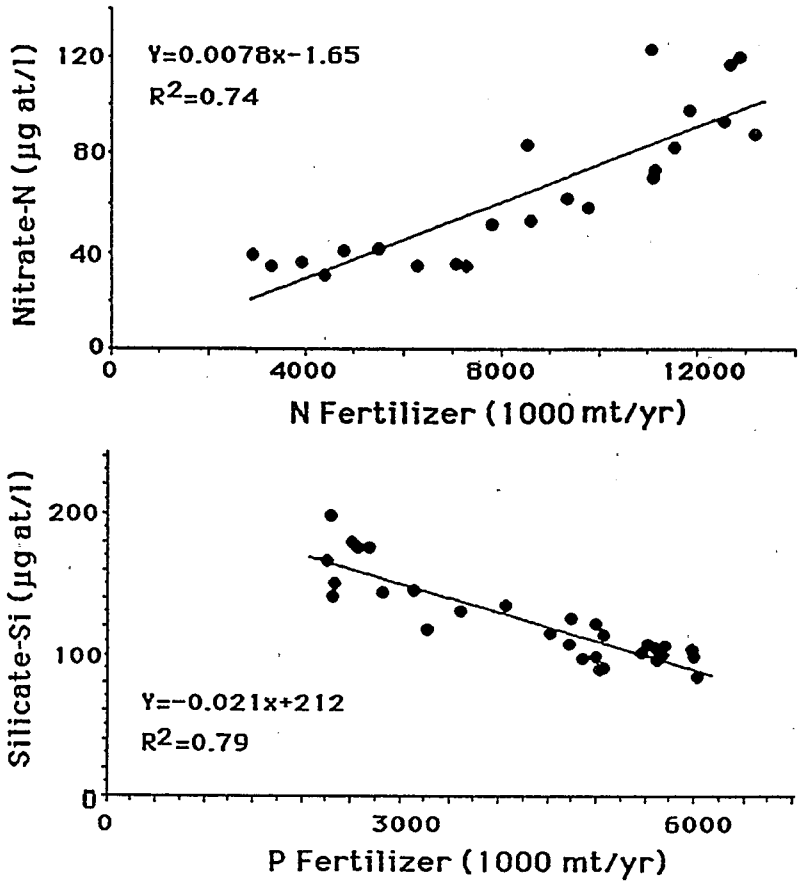


Figure 8. The relationship between fertilizer use and water quality at St. Francisville, Louisiana. Fertilizer forms as in Figure 7, data for nitrogen fertilizer use from 1960 to 1985, data for phosphorus fertilizer use from 1950 to 1987 (from Turner and Rabalais, 1991a).

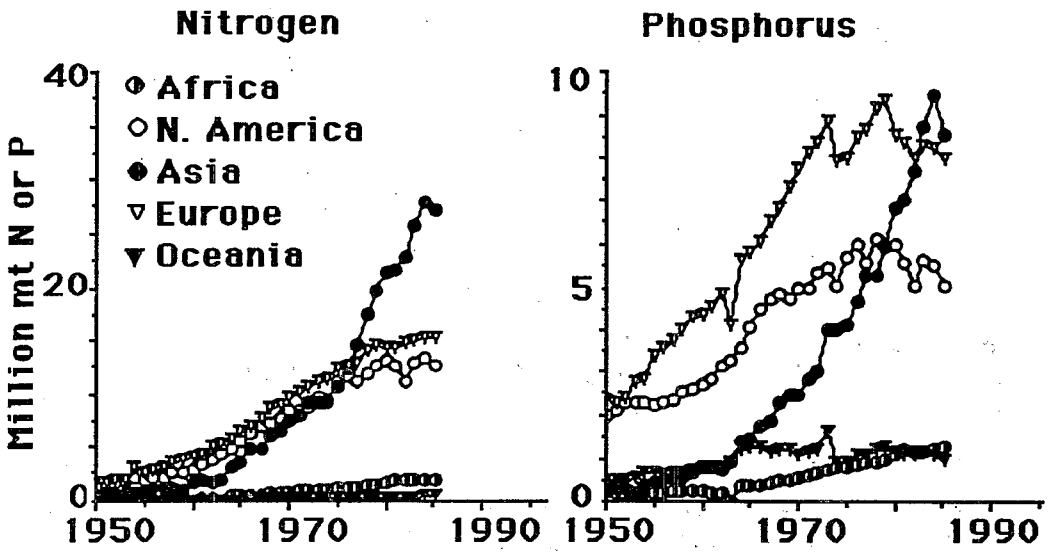


Figure 9. World and U.S. nitrogen and phosphorus fertilizer consumption since 1950 (Turner and Rabalais, 1991b).

suggested by Mayewski and Legrand (1990). Most landscapes have been subjected to significantly increased nitrogen loading this century, and the increase in fertilizer use exceeds the fossil fuel consumption rate (Turner, 1991). Atmospheric sources of NH_4^+ may also be generated from livestock wastes in areas of intensive stockbreeding (Morris, 1991). In addition, the viewpoint of eutrophication as a local and perhaps point-source problem manageable on a regional scale is changing to a phenomenon that is the cumulative result of many small actions throughout the world, and whose scale of management is vastly expanded and more expensive.

Consequences of Nutrient Enrichment

The potential and observed consequences of nutrient enrichment for coastal habitats are often documented in bold newsprint that announces a major fish kill, dead zones, red tides, catastrophic decline of seagrass beds, or reduced fisheries landings. Few such reports, however, have specifically linked increases in nutrient supplies to subsequent eutrophication, low dissolved oxygen levels, algal blooms, long-term changes in community structure, or altered habitat biodiversity. Many anthropogenic factors, as mentioned above and not to exclude overfishing, dredging and filling, industrial pollutants, and population expansion, can contribute to reduction in coastal water quality and changes in natural resources. Climatic factors and long-term global changes may also be implicated in subtle changes in resources.

There are several major categories of ways that nutrient enrichment may affect coastal habitats: through changes in food source quantity, food source quality, habitat suitability, alterations of predator-prey relationships, catastrophic events, ecosystem predictability, and intraspecific competition. A National Estuarine Eutrophication Project Workshop was convened in January 1990 to specify the potential range of eutrophication effects and associated factors which influence estuarine environments (Hinga *et al.*, 1991). A table listing effects attributed to eutrophication was presented to the workshop participants and modified following their discussions and input. The resultant table is shown in Table 5. The table lists effects attributed to eutrophication, appropriate measures of each effect, and factors that may potentially influence the expression of the effects. The table also lists the relationships to be tested between nutrient loading and effects, and the factors controlling them. Some general examples of the effects of nutrient enrichment are given in

Table 5. Factors influencing the expression of eutrophication effects (from Hinga *et al.*, 1991).

Effect	How Measured	Factors	Hypothesized Relationships
Phytoplankton Primary Production (gross)	mg C m^{-2} Day^{-1} mg C m^{-3} Day^{-1} Total system Annual average Seasonal distribution	Loading rate: N, P, & Si by species Temporal Pattern of loadings Concentration of N or P Light and light penetration Temperature Salinity Stratification Phytoplankton assembledge Bordering Wetlands	$1°=f$(N: moles $area^{-1}$ $time^{-1}$) $1°=f$(N,P: avg. measured moles kg^{-1}) $1°=f$(N,P: ave calculated moles kg^{-1}) $1°=f$(N,P: Light availability)
Net Ecosystem Production	grams C exported and deposited per year	Loading rate: N, P, &Si Water residence time	Net ecosystem C production = 105 x moles P $time^{-1}$
Phytoplankton Abundance	Chl-a m^{-3} Chl-a m^{-2} total cell counts g C m^{3} g C m^{2}	Loading rate: N, P, & Si by species Temporal Pattern of loadings Concentration of N or P Seasonal variability in loading rate Depth Stratification Grazing Turbidity Water residence time Temporal distribution of vertical mixing energy Abundance of grazers	[C]=f(specific growth rate, population size, grazing, export, settling)
Phytoplankton assemblage (Diatom vs flagellate) (size) (beneficial species)	Ratio of total diatoms to total flagellates Average size	N:Si ratio in sewage effluent P:Si ratio in sewage effluent Succcession Bad water (modification)	Flagellates become dominant in high nutrient loadings Shift to smaller species in high loadings Posioning of water for "good" species

Table 5. Continued.

Effect	How Measured	Factors	Hypothesized Relationships
Appearance of nuisance (and toxic) algal blooms	Interval between recorded blooms Areal extent of blooms Duration of Blooms Record of first appearance	Horizontally distinct water mass A vertically stratified water column Warm weather conditions High photosynthetically active radiation Enhanced allochthonous organic matter loading Enhanced allochthonous inorganic nutrient loading Adequate supply of essential metals (e.g. iron, selenium) Sediment "seed beds" Algal-bacterial synergism Algal-micrograzer synergism Selective activities of macrograzers Rate of change of nutrient or other contaminant loadings Vectors for invasion Virus-phytoplankton interactions Rain events Climate changes	"A combination of the factors will most likely lead to bloom sensitive waters"
Abundance of submerged aquatic vegetation (decrease)	Areal extent of coverage Density in covered areas	Nutrient concentration Turbidity, light color Phytoplankton abundance Epiphyte abundance Bottom substrate, Sedimentation Depth, pigment type Water flow rates, mixing Mechanical disturbance Wave action Seaweed abundance Climate changes Toxins Benthic environment changes	Decrease in Abundance is a result of phytoplankton lowering nutrient and light availability $1°=f$(N;P,Light, water flow)

Table 5. Continued.

Effect	How Measured	Factors	Hypothesized Relationships
Seaweeds	Areal extent of coverage Density in covered areas Diversity	Nutrient concentration Turbidity, light color Phytoplankton abundance Epiphyte abundance Bottom substrate, Sedimentation Depth, pigment type Water flow rates Mechanical disturbance Wave action Grazers	
Floating Algal Scums	Visual reports areal extent Duration Bloom interval	Quisecent waters	
Bottom water oxygen concentrations	µmoles O_2 L^{-1} Volume of low O_2 waters Area of Low O_2 coverage Length of time of low O_2 concentrations Fish Kills	Bottom water residence time Depth Stratification Rate of organic matter decay Temperature Organic loadings DIN and DIP loadings Particle settling velocity Rate and timing of primary production Statistics of isolation events Rate of oxygen decrease	$[O_2]=f$ (organic carbon input rate, organic carbon decay rate, re-aeration rate)
Secondary production (commercial harvests)	Tons of yield y^{-1} Single species Total harvest	Primary production Fraction of areas open for harvest Trophic transfer efficiency Overfishing maintaining low population stocks	yield = f (food chain length)

Table 5. Continued.

Effect	How Measured	Factors	Hypothesized Relationships
Abundance of benthic organisms (increase)	No. macrofauna m^{-2} Gr. macrofauna m^{-2} Bioturbation	Primary production Depth Organic carbon input Grazing rates (top down control)	Abundance is equal to f (carbon supply)
Abundance of benthic organisms (decrease)	No. macrofauna m^{-2} Gr. macrofauna m^{-2} Bioturbation	Oxygen concentrations Sediment quality Grazing rates (top down control)	Abundance is equal to f (oxygen concentration)
Benthic species composition	Diversity indicies Presence of "desirable" species Bioturbation	Primary production Oxygen concentrations Food Quality Sediment quality Organic carbon input Salinity variability	Composition is equal to f (carbon supply)
Mephitic Waters	Records of foul odor	Low oxygen concentrations Algal species Algal density	
Turbidity	Light extinction coefficient mg suspen. matter l^{-1}	Inorganic sediment inputs, runoff Sediment resuspension Storm events Phytoplankton abundance DOC concentration and adsorptivity	
Bacterial activity	Glucose or amino acid metabolism Thymidine uptake	Increased populations responding to increased organic matter	
Disease organisms (for marine populations)	Reports of diseased organisms	Altered conditions promoting survival of pathogens Altered conditions reducing resistance of organisms	

Table 6 (Turner and Rabalais, 1991b), with some brief examples provided to illustrate the major points. We know more about what is on these lists, which is seemingly all-encompassing, than of the scientific understanding of the subtle interactions.

Table 6. Examples of coastal eutrophication and its effects (after Turner and Rabalais, 1991b).

Area	Probable or Observed Effect[1]	Reference
Adriatic Sea	ox.; turb.; food chain	Krstulović and Šolić, 1990; Justić, 1991; Faganeli, 1985; Stachowitsch, 1986
Baltic Sea, incl. Kattegat and Skagerrak	ex. al.; food chain; ox., macrophyt. gain; incr. sec. prod.	Rosenberg, 1985, 1986; Rosenberg and Loo, 1988; Cederwall and Elmgren, 1980; Andersson and Rydberg 1988; Ankar 1980
Bayou Texar, FL	ox., food chain, health, nox.	Moshiri *et al.*, 1981
Chesapeake Bay	food chain, incr. prod., ox.	Seliger *et al.*, 1985
Great South Bay, Long Island, NY	ex. al.	Ryther, 1954
Lac de Tunis, Tunis, Tunisia	ex. al.; ox.; macrophyt. loss; macrophyte gain; food chain	Kelly and Naguib, 1984
Mississippi River Delta Bight, U.S.	changes in area and extent of hypoxia	Rabalais *et al.*, 1991
Southern Bight of the North Sea	ex. al.; incr. prod., food chain; nox.; incr. sec. prod.	van Bennekom *et al.*, 1975; Beukema and Cadée 1986; Westernhagen and Dethlefson, 1983; Lancelot *et al.*, 1987
Tampa Bay, FL	macrophyt. loss; turb; healt.; ox.; nox.; food chain	Johansson and Lewis, 1991 Santos and Simon, 1980

[1]Key to abbreviations:

ex. al.	= excessive algal growth (including filamentous and attached)
food chain	= food chain alterations affecting important fisheries species, including fish kills, loss of benthic organisms
incr. al. prod.	= increased primary productivity
incr. sec. prod.	= increased secondary productivity, including benthos
nox.	= noxious algal blooms
healt.	= health problems with seafood consumption
macrophyt. loss	= loss of important macrophytes
macrophyt. gain	= gain of macrophytes
macrophyt. inv.	= invasion of undesirable macrophytes
ox.	= low oxygen levels
turb.	= increased turbidity from phytoplankton growth

Altered Trophic Structure

Nitrogen and phosphorus are the primary anthropogenic nutrient inputs of concern in coastal waters. Nitrogen is considered the most important nutrient in marine and coastal waters; phosphorus, in freshwater systems. Both nitrogen and phosphorus are important in estuaries, depending on the season, total nutrient loadings, and various physical and chemical conditions. Other chemical constituents such as silica, carbon, trace metals and chelators may also be important in specific systems and under certain conditions. Many factors interact to influence changes in primary producer and consumer populations, including the supply, relative availability, and timing of nutrient inputs, and various physical characteristics of the estuary or coastal water body such as temperature, turbidity, currents and water column stratification.

Increased phytoplankton production and biomass is the likely result in an otherwise nitrogen-limited coastal food web (the current paradigm for many coastal systems) (Harris, 1986; Valiela, 1984). Although there are no phytoplankton indicator species of incipient or advanced stages of coastal eutrophication presently identifiable, Smayda (1983, 1989, 1990, 1991) and others (Richardson, 1989; Cherfas, 1990; Cadée, 1990) have identified a significant shift in phytoplankton community structure at the phylogenetic level occurring globally in response to coastal nutrient enrichment. Smayda (1991) further notes that this phylogenetic shift has been towards increased abundance and seasonal dominance of flagellates and non-motile, nannoplankton chrysophytes and, in some cases, N-fixing blue-green algae. Many of these species may be noxious, harmful, or toxic in increased concentrations, and their sinking and decomposition in the water column or at the seabed may contribute to increased hypoxic/anoxic episodes.

Diatoms are thought to provide the primary energy source for traditional food webs that support teleosts as top predators. The abundance of coastal diatoms is influenced by the silicon supplies, whose Si:N atomic ratio is about 1:1 (the Redfield ratio). Diatoms out-compete other algae in a stable and illuminated water column of favorable silicate concentration. Anthropogenic enrichment of N and P, leading to long-term increases in these nutrient loadings, has also lead to long-term declines in the Si:N (Figure 10a,b) (Turner and Rabalais, 1991a,b) and Si:P ratios. When nitrogen increases and silicate decreases, flagellates may increase in abundance (Officer and Ryther, 1980). The decline in the Si:P and Si:N ratios has particularly favored non-diatom blooms and is a key factor associated with the global epidemic of novel toxic and harmful phytoplankton blooms and phylogenetic shifts in phytoplankton biomass predominance in coastal seas (Smayda 1989, 1990, 1991); similar shifts may be occurring in the waters adjacent to the Mississippi River (Dortch and Whitledge, 1992). In particular, noxious blooms of flagellates are becoming increasingly common in coastal systems, according to Smayda; and there is evidence for an ongoing global increase in the frequency, number of occurrences, and dynamics of toxic and harmful phytoplankton blooms (Siddall, 1987; Dundas *et al.*, 1989; Richardson, 1989; Cherfas, 1990; Cadée, 1990; Smayda, 1990, 1991). Evidence comes from the Baltic Sea, Kattegat, Skagerrak, Dutch Wadden Sea, Black Sea, Tolo Harbour (Hong Kong, Korea, Seto Inland Sea, and northeastern coastal waters of the United States). (See also Table 7 and many more examples in Shumway, 1990; Shumway *et al.*, 1990).

Less dramatic evidence for shifts in phytoplankton community composition comes from the work of others who have documented species present in the plume of the Mississippi River during the last few years (1989-1991) (Q. Dortch, personal communication) compared to earlier surveys (Thomas and Simmons, 1959). *Melosira distans* which used to be a dominant phytoplankton species in the waters adjacent to the Mississippi River delta (Thomas and Simmons, 1959) have not been found in any recent surveys (Q. Dortch, personal communication). The Si:N ratio of the river inflow to the coastal Gulf of Mexico has decreased from 4:1 to approximately 1:1 over the same period (Turner and Rabalais, 1991a).

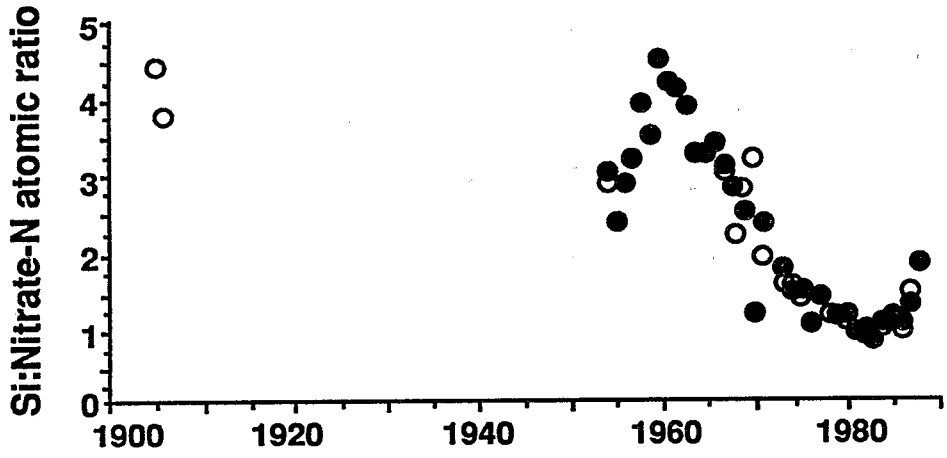


Figure 10a. Changes in the atomic ratio of silicate:nitrate-nitrogen this century at two stations on the lower Mississippi River (St. Francisville = closed circles; New Orleans = open circles) (adapted from Turner and Rabalais, 1991a).

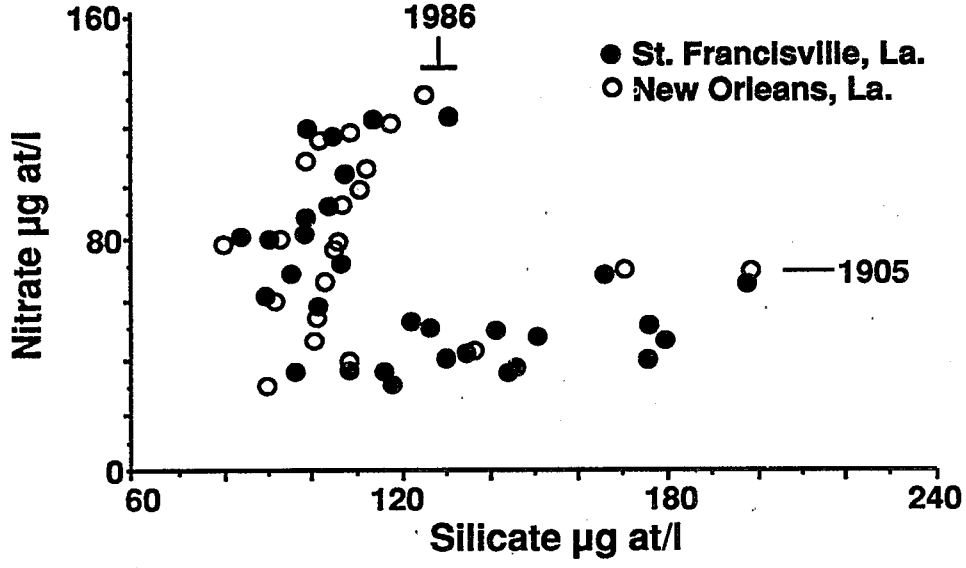


Figure 10b. Average annual nitrate and silicate concentration in the lower Mississippi River (adapted from Turner and Rabalais, 1991b).

Table 7. Examples of the appearance of noxious blooms in coastal waters (after Turner and Rabalais, 1991b).

Area	Species	Year(s)	Reference
East coast of Florida	*Synechoccus* sp.	1972, 73	Mitsui *et al.*, 1989
Laguna Madre, TX	"brown" tide	1990	Stockwell and Buskey, pers. comm.
Long Island bays	brown tide	1985, 86	Cosper *et al.*, 1987
Narraganset Bay, RI	*Aureococcus*	1985	Tracey, 1988
North Carolina	*Ptychodiscus brevis*	1987	Summerson and Peterson, 1990
Swedish west coast	*Prorocentrum minimum* and *Gyrodinium aureolum*	since 1980	Granéli *et al.*, 1986
Texas coast	*Gymnodinium splendens, Pthychodiscus brevis*	1955, 1984, 86	Riley *et al.*, 1989; Harper and Guillen, 1989
Norway	*Chrysochromulina polyepis*	1988	Cherfas, 1990
West coast of Florida	*Gymnodinium breve*	common	Eng-Wilmont and Martin, 1977

Phylogenetic shifts within phytoplankton communities may alter the food supply available to herbivorous organisms. Evidence suggests that smaller, "less desirable" flagellate- and cyanobacterial-dominated communities are less acceptable as food for grazers (Smayda, 1983). Zooplankton, the main consumers of whole diatoms and a staple of juvenile fish, are thus affected by these nutrient changes in a cascading series of interactions. Alternatively, changes in type and distribution of higher trophic-level herbivores and predators may have a cascading effect down the food web to primary producers.

The widespread occurrence of changes in nutrient loading to coastal zones has also changed the annual and seasonal variability of nutrient concentrations. Fertilizers, a major contributor to the nitrogen and phosphorus budget, are usually applied in the spring, just before or during the planting period. An example is shown for the lower Mississippi River at St. Francisville and New Orleans, Louisiana (Figure 11) (Turner and Rabalais, 1991a) where a spring rise in nitrate concentration is now evident. [*N.B.*, A previous seasonal signal in silicate concentration is no longer evident.]

A change in the timing of the spring bloom that supports fish entering estuaries to feed during critical recruitment periods may also be an important consequence of eutrophication. Townsend and Cammen (1988) point out that the timing of the spring plankton bloom in high latitudes is important to the benthic-pelagic couplings upon which fisheries recruitment is dependent. The timing of a bloom, is often very sensitive to light conditions, but declines from nutrient depletion.

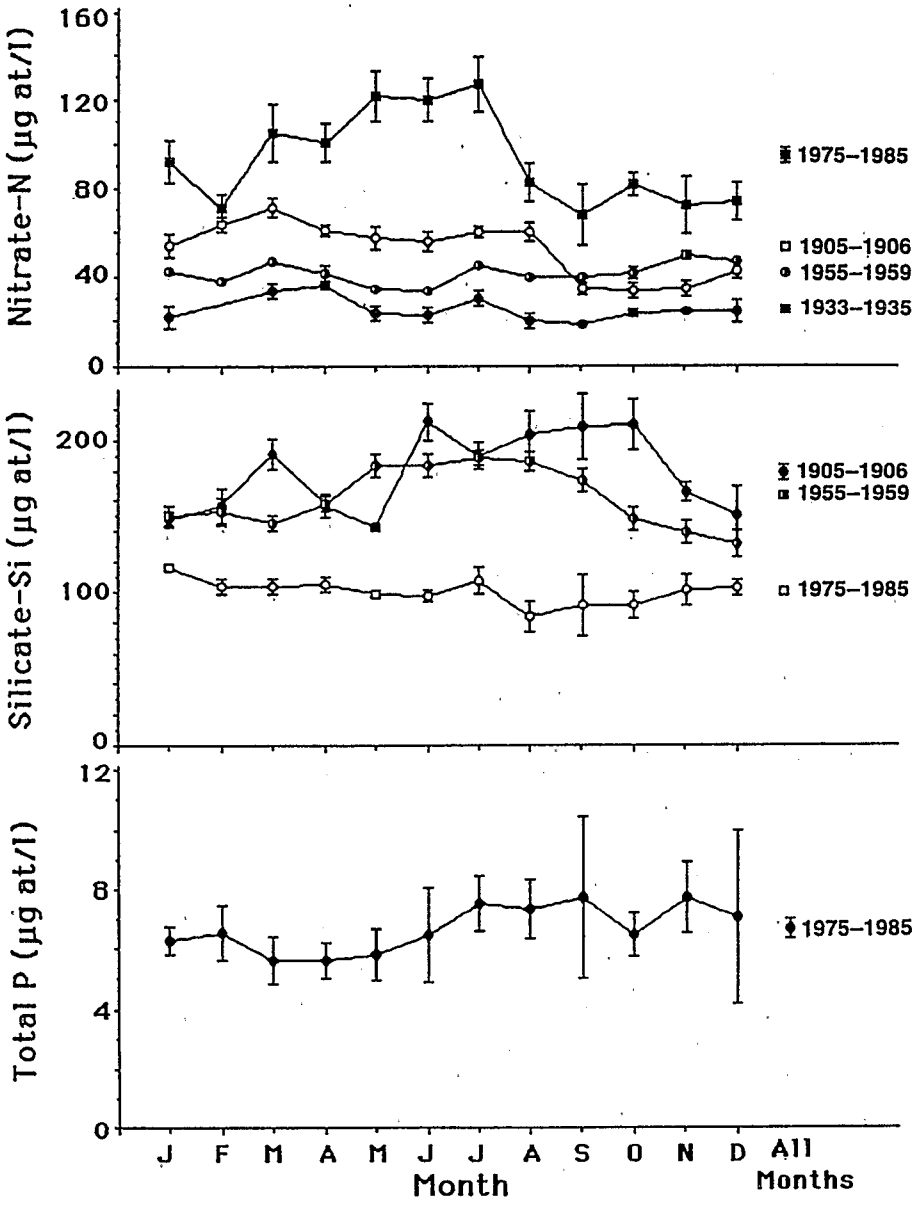


Figure 11. Monthly average nitrate, silicate, and total phosphorus for 1905-1906 and 1933-1935 from the New Orleans water plant at Carrollton and for 1955-1959 and 1975-1985 from St. Francisville, Louisiana. The bars are ± 1 standard error of the monthly averages (from Turner and Rabalais, 1991a).

Changes in the nutrient loading, and timing, could affect recruitment success through a mis-match of larval recruitment and food supply, as well as an altered food chain. Early blooms with a greater sedimentation to the benthos could positively affect demersal fishes, but late blooms positively affect pelagic fisheries through a zooplankton food chain. Zooplankton graze on diatoms extensively, so that changes in nutrient loading and the ratio of nutrients could affect the balance and timing of the demersal and pelagic food webs.

Supportive evidence of this benthic-pelagic coupling is the work of Cederwall and Elmgren (1980) who demonstrated a rise in macrobenthos around the Baltic islands of Gotland and Oland, which they attributed to eutrophication, a known event (Nehring, 1984). Other examples of increased benthic production are in Ankar (1980) (Tables 5 and 6). In other instances, nutrient enrichment may be linked to decreased secondary benthic production (see section below on habitat suitability).

Oxygen Depletion

Oxygen-depleted waters are obvious manifestations of nutrient enrichment. Where eutrophication occurs, oxygen depletion often follows presumably as a consequence of the increase in organic loading which is stimulated by increased nutrients. Excessive production of organic material in surface waters may sink to the bottom, either directly, as grazed material, or advected. Decomposition of these materials may lead to oxygen depletion, especially in stratified water columns where the rate of depletion of oxygen is greater than the reaeration of the water column from surface oxygen production or diffusion.

A good discussion of the chemical, geological and biological terminology of oxygen deficient environments is given in Tyson and Pearson (1991). The term "hypoxic" has long been used by physiologists to describe conditions or responses produced by stressful levels of oxygen deficiency. The application of "hypoxic" ("hypoxia") to oxygen deficient environments began to be common in the late 1970s, especially by those working in the Gulf of Mexico, and it is now in widespread use by marine biologists and ecologists (Tyson and Pearson, 1991). Based on laboratory and/or field observations on oxygen stress responses in invertebrate and fish faunas, hypoxic has been variously defined as corresponding to dissolved oxygen levels lower than a range of 3.0-0.2 ml/l, with the consensus being in favor of 2 mg/l (=1.4 ml/l) (Tyson and Pearson, 1991).

The largest, most severe and most persistent zone of hypoxia (operationally defined by dissolved oxygen levels <2 mg/l, or 1.4 ml/l, based on effects on local biota; see below) in the United States coastal waters is found in the northern Gulf of Mexico on the continental shelf off Louisiana (Figure 12). Equal to or larger than similar but less frequent phenomena off the northeastern coast of the United States (Garside and Malone, 1978; Swanson and Sindermann, 1979; Falkowski *et al.*, 1980; Swanson and Parker, 1988; Welsh, 1991), these hypoxic zones occur at the terminus of the largest river in North America and amidst the Nation's richest and most extensive fishing grounds.

For the NOAA/OAD Nationwide Review project (Rabalais *et al.*, 1985; Whitledge, 1985; Windsor, 1985), a dissolved oxygen concentration of <4 mg/l (2.8 ml/l) was determined as the minimum level acceptable for coastal waters. In that review, estuaries or coastal areas were categorized as having marginal and/or deteriorating water quality with respect to this level of dissolved oxygen concentration. For 55 estuaries categorized by Rabalais *et al.* (1985) and Windsor (1985), 37 were listed as experiencing hypoxia (< 4 mg/l) in part or all of the area for any records. Within the 36 estuaries categorized by Rabalais *et al.* (1985) for Alabama, Mississippi, Louisiana, and Texas, 12 were categorized with severe or regularly occurring hypoxia in part or all the estuary. A similar category was not provided by Windsor (1985); instead, he listed seven of 19 estuaries as having potential problems or deteriorating water quality. For both studies, a little over half (56 %) of the estuaries were categorized as having adequate data for evaluation.

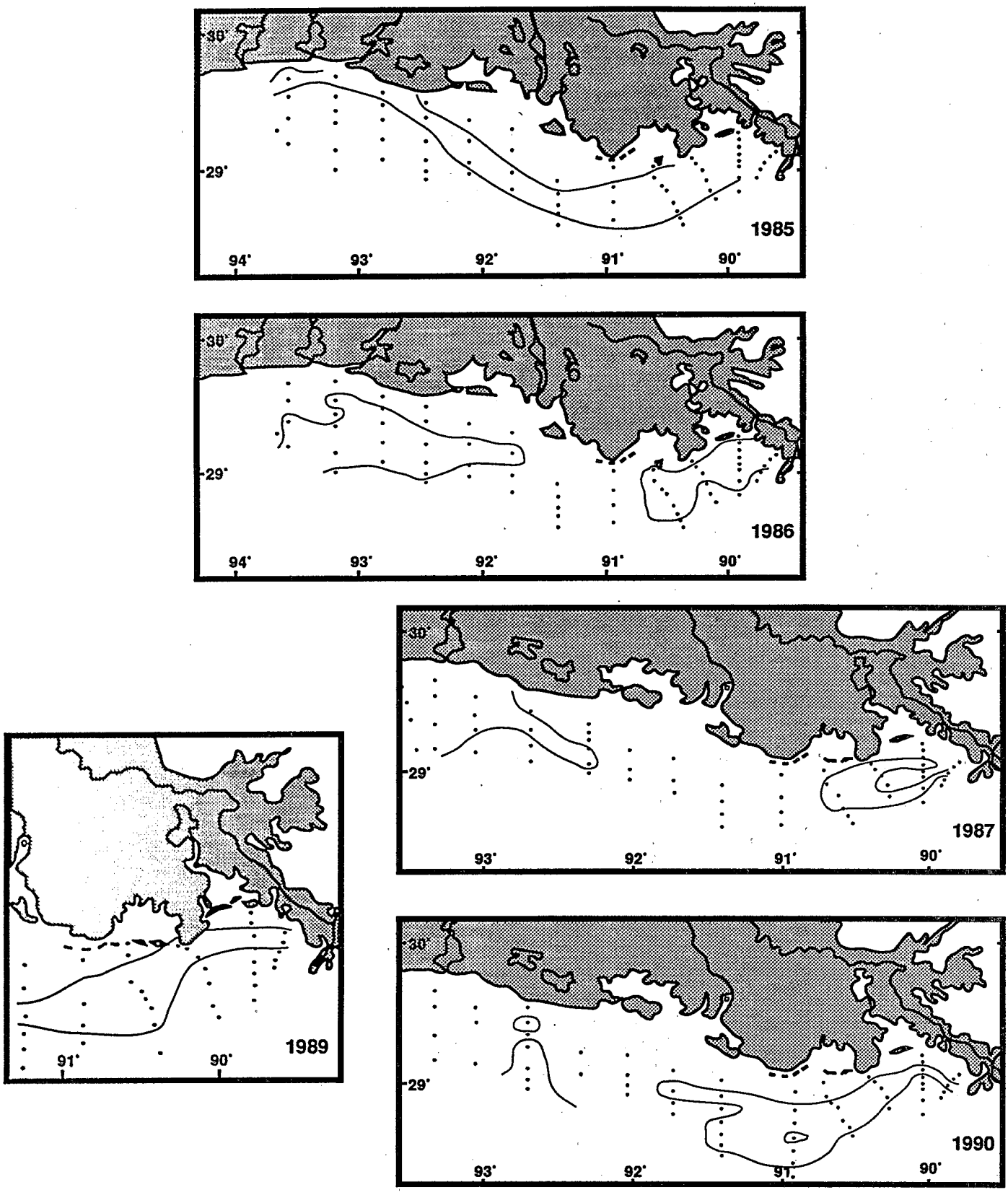


Figure 12. Distribution of hypoxic bottom waters on the Louisiana continental shelf in mid-summer for the years indicated. Shaded areas are <2 mg/l dissolved oxygen. Note, figures differ in station coverage and scale, longitude provides relative distance (adapted from Rabalais *et al.*, unpublished data).

Contrary to the previous reviews (Rabalais *et al.*, 1985; Windsor, 1985), concentrations of ≤ 2 mg/l may be more biologically realistic in the warmer waters of the Gulf of Mexico. Values below 2 mg/l have been noted in field studies to affect populations of demersal fishes and macroinvertebrates (Pavela *et al.*, 1983; Leming and Stuntz, 1984; Renaud, 1986b; Murrell and Fleeger, 1990; Boesch and Rabalais, 1991; Rabalais, unpublished data). Dissolved oxygen concentrations of 2 mg/l equate to an oxygen saturation level of 25-27 % in northern Gulf of Mexico waters. Values below this are associated with reduced benthic macroinfauna, and values below 0.5 mg/l (or 7 % oxygen saturation) are associated with severely reduced numbers of benthic infauna (Figure 13). Trawling for demersal species and not catching anything when the dissolved oxygen falls below 2 mg/l is not proof that fish and shrimp are absent because of the low oxygen concentrations; however, these relationships have been consistently observed (Figure 14) (Bedinger, 1981; Pavela *et al.*, 1983; Leming and Stuntz, 1984; Renaud, 1986b). Experimental work of Renaud (1986a) indicated that white shrimp (*Penaeus setiferus*) detected and significantly avoided intruding water containing ≤ 1.5 ppm dissolved oxygen and brown shrimp (*Penaeus aztecus*) were more sensitive and avoided water of dissolved oxygen concentrations ≤ 2.0 ppm. **For this review, a value of 2 mg/l has been set as the limit that characterizes oxygen-deficient waters (or hypoxia).**

It should be pointed out that not all oxygen depletion results from nutrient enrichment. Where increased nutrients contribute to organic loading and subsequent decomposition of material and depletion of oxygen, these features are usually coupled with a physical phenomenon of a stratified water column. This density stratification, controlled by temperature or salinity differences, prevents the reaeration of the bottom waters at a rate sufficient to offset the depletion of oxygen during respiration. In many deep channels, this density stratification may occur and oxygen may be depleted without increased organic inputs. Very often, however, the oxygen demand in the bottom waters of deeper channels, especially near industrialized and urbanized areas, may be related to chemical oxygen demand or organic loading from sewage outfalls. Other deep channels or topographically lower features may be consistently hypoxic in the bottom waters just because of the physical structure and lack of mixing of the water column. In submerged aquatic vegetation beds (*e.g.*, seagrass meadows or heavily vegetated creeks and bayous), a normal diel cycle of oxygen concentration will produce low oxygen levels in the early morning hours following extensive respiration of the vegetation during the dark cycle. In other instances, the movement of naturally stagnant swamp waters into other bodies of water following a flushing event may contribute temporarily to a low oxygen condition.

The oxygen concentrations of surface waters may also be a key to the eutrophication status of a water body. Nutrient enrichment which stimulates phytoplankton growth may result in the supersaturation of oxygen in surface waters. Values of oxygen saturation >100 % are commonly found in Louisiana coastal waters when high chlorophyll *a* biomass is coincident. Justić (1991) documented long-term trends in dissolved oxygen content of both the surface and bottom layers of the northern Adriatic Sea for the period 1911-1984 (Figure 15). An increase in the surface layer and a decrease in the bottom layer were observed in all seasons except winter (Justić, 1991). The presence of an oxygen minimum zone with depth, particularly above a pycnocline, may also indicate high respiration rates in the water column. These conditions are prevalent on the Louisiana shelf.

A word of caution should be given regarding the use of dissolved oxygen data in water quality monitoring data sets. Continuous oxygen measurements [*e.g.*, Longley, 1992 (see Figure T13); Summers and Engle (1992)] indicate diel variability in dissolved oxygen levels in most environments. Water quality monitoring conducted primarily during daylight hours may skew distributions of dissolved oxygen measurements.

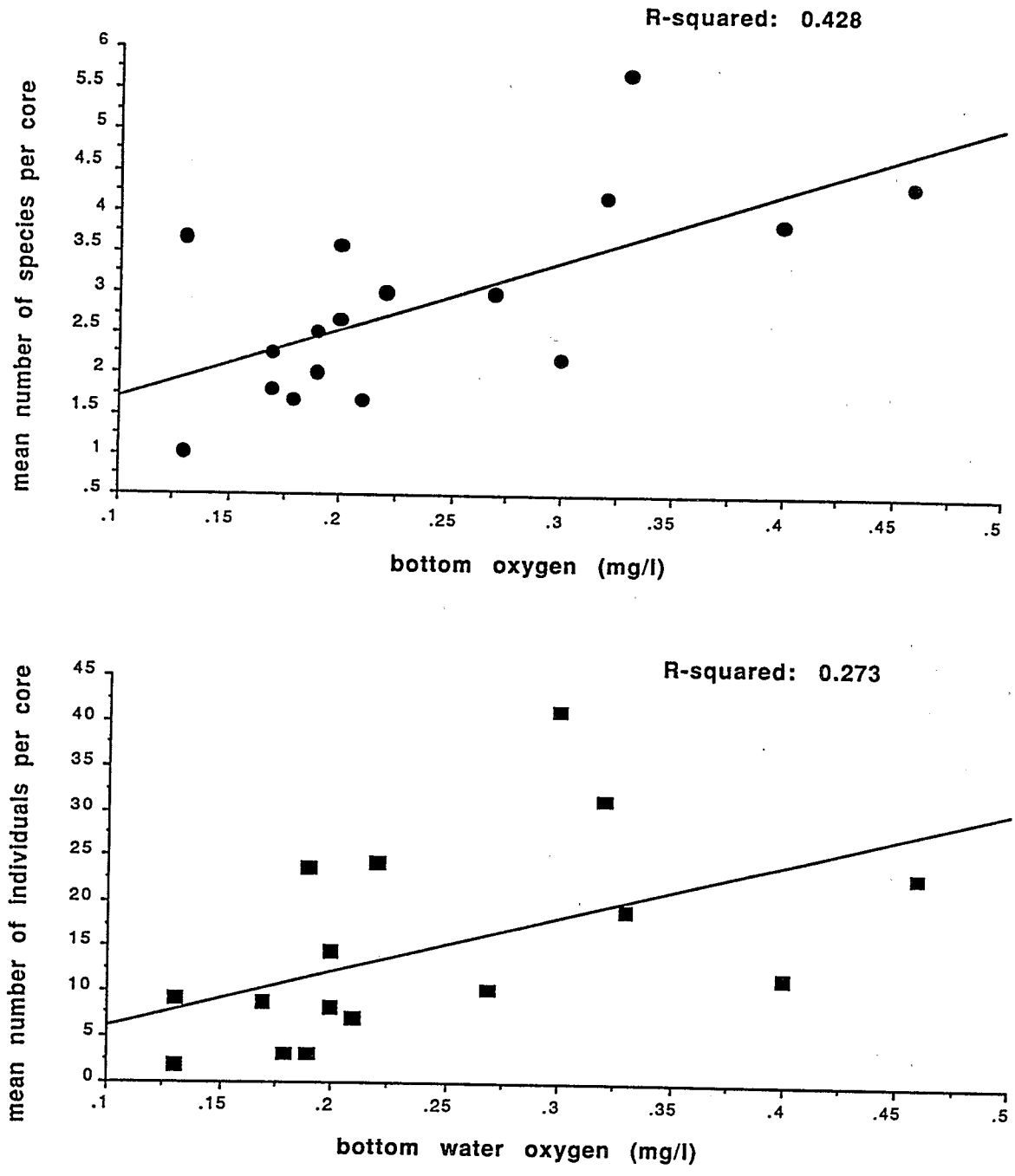


Figure 13. Relationship of mean number of individuals per core and mean number of species per core for benthic macroinfauna for bottom water oxygen concentrations ≤0.5 mg/l at a station in 20 m water depth off Terrebonne Bay that is consistently subjected to low oxygen concentrations through the warmer months of the year (Rabalais *et al.*, unpublished data).

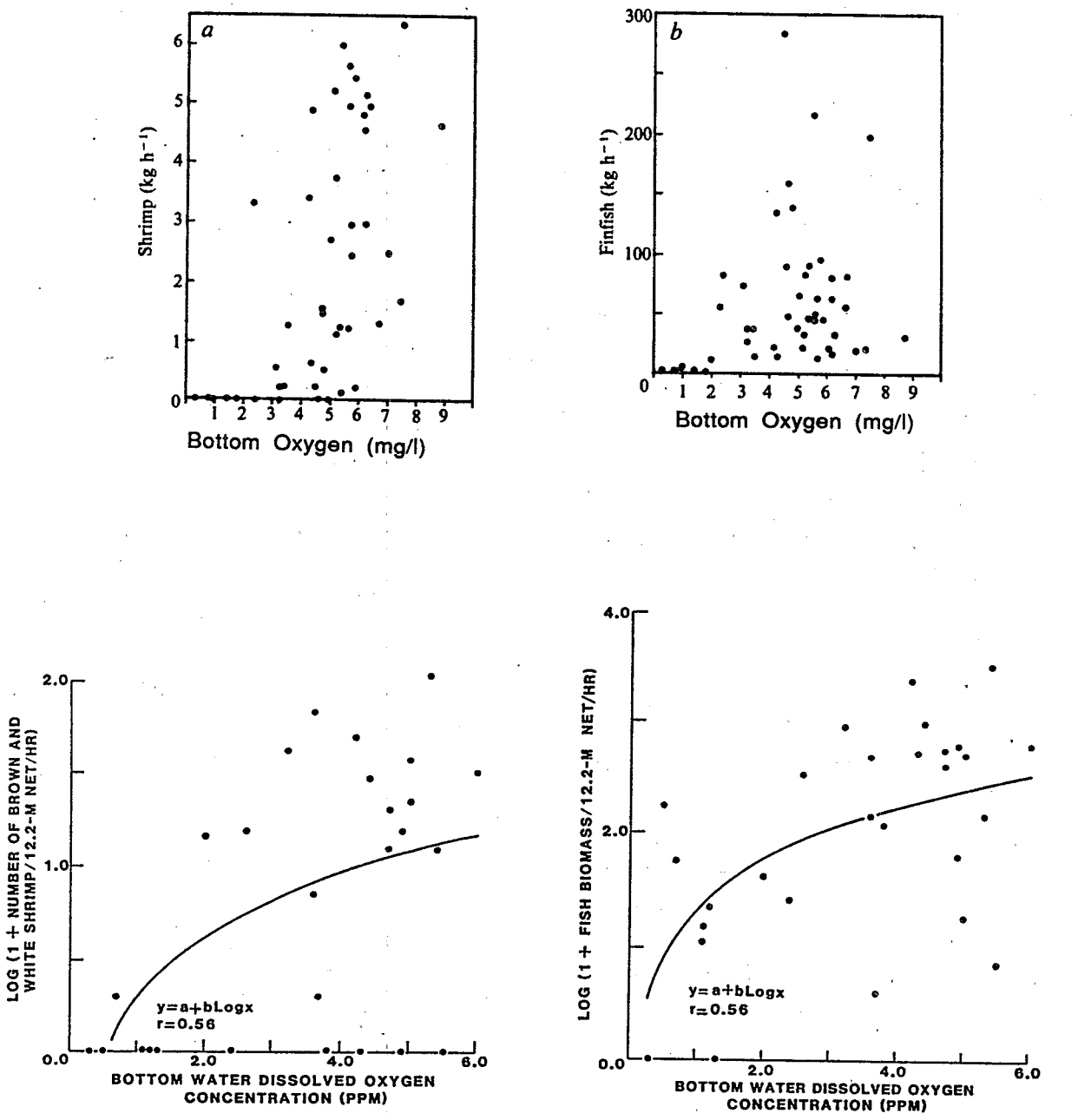


Figure 14. Upper panel: Shrimp and finfish catch rates plotted against bottom oxygen concentration at trawl stations for June 1982 (from Leming and Stuntz, 1984). Lower panel: Offshore shrimp abundance and fish biomass in relation to bottom water dissolved oxygen concentration for trawl samples collected between 1972 and 1983 (from Renaud, 1986a).

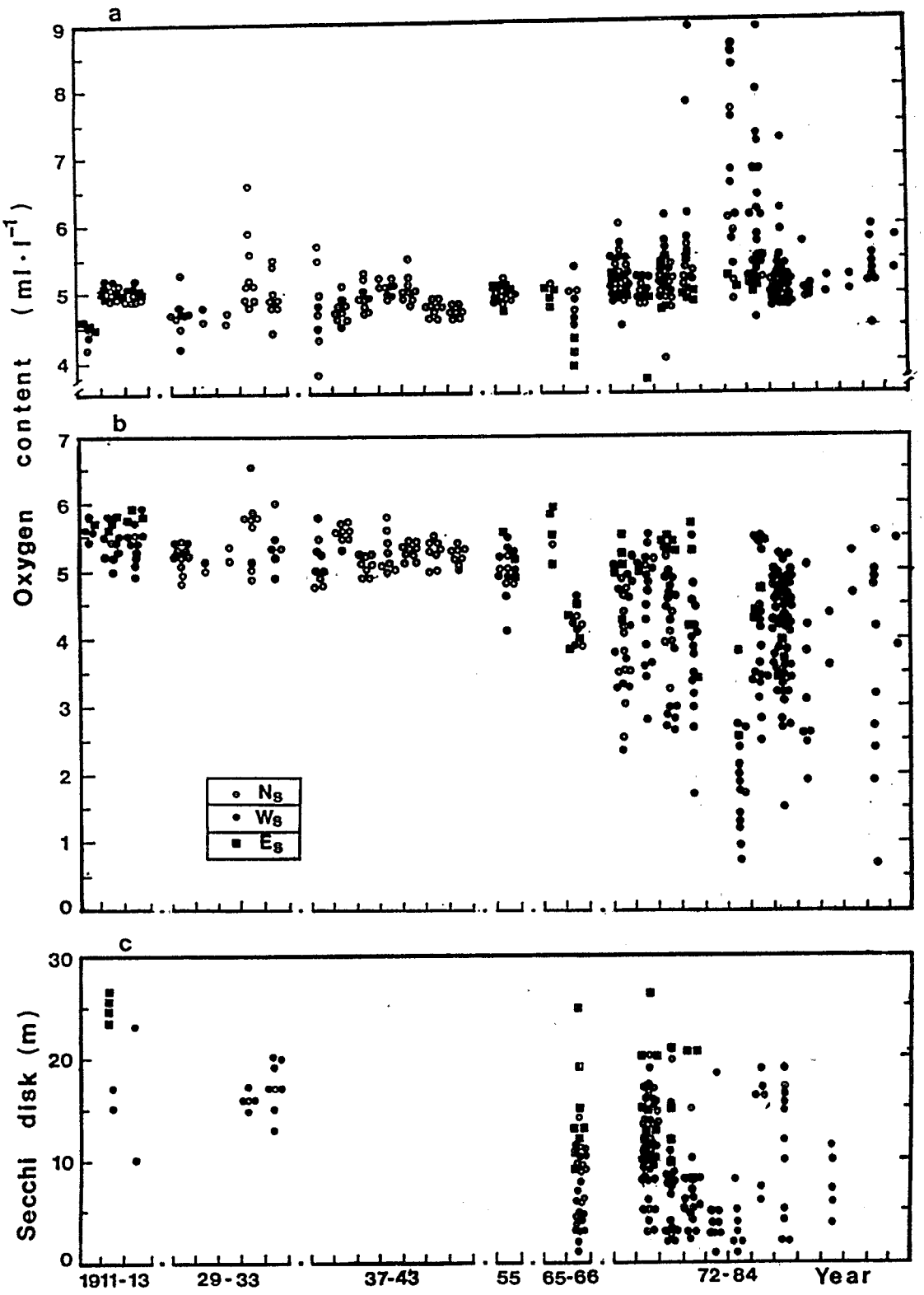


Figure 15. Oxygen content of the water column during August-September and Secchi disk visibility during April-May, in the northern Adriatic Sea from 1911 to 1984; a: surface layer, b: 2 m above the bottom; symbols refer to eastern, northern and western subareas (from Justić, 1991).

Habitat Alteration

Excessive nutrient loading can cause accelerated eutrophication; the resultant increase in planktonic biomass decreases the distance that light can penetrate through the water column. Reduced light penetration has been shown to inhibit photosynthesis in deeper waters of some eutrophic estuaries (Pennock, 1986; Pennock and Sharp, 1987) and to affect photosynthetic microorganisms as well as submerged aquatic vegetation (Short, 1987, 1991; Johansson and Lewis, 1991). Excessive nutrient loading in an estuary can eliminate an eelgrass system in three ways according to Short (1991): 1) change to a plankton-dominated ecosystem, 2) change to a macroalgal-dominated ecosystem, and 3) change to a system with excessive amounts of epiphytic algal growth. All three possible changes have been observed in the field and have been directly associated with documented eelgrass declines (Short, 1987, 1991). The loss of seagrass beds following decreased water clarity is often observed (Cambridge and McComb, 1984; Cambridge *et al.*, 1986; Johansson and Lewis, 1991). It is also well established that certain coastal fisheries species seem to require a physical structure to escape from predators while young. Where the area of estuarine macrophytes declines or improves, fisheries harvest is observed to respond proportionally (*e.g.*, Turner and Boesch, 1987). In this manner, nutrient enrichment and eutrophication can contribute to the loss of emergent and submerged macrophytes that limit fisheries species during critical recruitment periods, leading one to conclude that the potential harvest of dependent fisheries will probably decline too. Such subtle changes are difficult to detect without substantial amounts of long-term data (two examples are in Turner and Boesch, 1987).

Long-term changes in the turbidity of the water column as measured by changes in Secchi disk depth have been documented for the northern Adriatic Sea (Justić, 1991). These long-term changes are related to nutrient enrichment of the Adriatic from the Po River and a coincident long-term decline in the oxygen concentration of the water column (see Figure 18). Other long-term changes in the turbidity of the water column in coastal systems may be related to the reduction of the suspended sediment load of a major freshwater source. This appears to be the case in the waters adjacent to the Mississippi River, where a long-term increase in the Secchi disk depth is perhaps related to increased water clarity as a result of the reduction of the suspended sediment load and/or changes in phytoplankton community composition (Meade and Parker, 1985; Turner *et al.*, 1987; Turner *et al.*, unpublished data). Increased water clarity adjacent to the Mississippi River delta may have implications for increased phytoplankton production and biomass in a system where turbidity is a factor limiting phytoplankton growth at various levels of light intensity.

There are numerous examples of the impacts of low oxygen conditions on reduced benthic fauna, in terms of fewer species, lower abundance, or both (Rosenberg, 1977; Gaston, 1985; Gaston *et al.*, 1985; Rosenberg and Loo, 1988; Stachowitsch, 1984, 1986; Westernhagen *et al.*, 1976; Harper *et al.*, 1991; Boesch and Rabalais, 1991; Rabalais *et al.*, unpublished data). The level of effect depends on the level or organic enrichment and/or concentration of dissolved oxygen in the overlying waters and whether hydrogen sulfide is generated from the sediments during anoxic events (Boesch and Rabalais, 1991; Harper *et al.*, 1991; Rabalais *et al.*, unpublished data). A reduction in the benthic fauna is a habitat alteration that may have an indirect impact on other parts of the food web, *e.g.*, reduction in adequate food supplies for other species, such as demersal fish and shrimp.

Areas impacted by low oxygen are a concern with respect to fisheries resources. For example, the largest, most severe zone of hypoxia in the U.S. occurs at the terminus of the Mississippi River and amidst the Nation's richest and most extensive fishing grounds. The area impacted by and duration of hypoxia on the Louisiana shelf is important since Louisiana fisheries landings are 28 % of the U.S. total. Trawl samples indicate that the demersal catch is reduced or virtually zero when the bottom water dissolved oxygen levels fall below 2 mg/l (see Figure 14). The processes involved--direct mortalities, avoidance by bottom-dwelling shrimp and finfish, altered migration (Renaud, 1986a), reduction in available habitat, changes in food resources, or increased

susceptibility to predation--are not known. Although dead or decaying fish have been pulled up in trawls where hypoxia occurs (Pavela *et al.*, 1983), the trawls are usually empty under reduced bottom water oxygen. These organisms move out of the area or up into the water column (Rabalais and Harper, unpublished data). In either case, the area of suitable habitat is reduced and the individuals may be more susceptible to predation. In addition, the stress incurred by fish, from, for example, experiencing low oxygen tensions or starvation following oxygen depletion is believed to be a contributing factor to the development of disease in fish; the areas off the Danish west coast that experience oxygen depletion in the early 1980s are regions where high disease frequencies have been observed compared to regions where oxygen depletion has not been recorded (Nielsen and Mellargaard, 1989).

Less motile invertebrates are stressed by low oxygen conditions and either adapt behaviorally or are killed. Dead and decaying invertebrates have been observed on the seabed where oxygen levels are severely reduced (Stachowitsch, 1984; Faganeli *et al.*, 1985; Rabalais and Harper, unpublished data). Behavior modifications include movement to the sediment surface, extending body parts above the sediment surface, or finding topographically higher locations (Rabalais and Harper, unpublished data), all of which expose the typically infaunal organisms to increased predation pressure.

The potentially enormous consequences of oxygen depletion to living resources in the northern Gulf of Mexico are a regional and national concern. The potential exists for certain life stages of penaeid shrimp to be affected by hypoxic bottom waters (Figure 16). Critical periods in the life history of both brown and white shrimp occur during May through September when hypoxia is present. Figure 16 illustrates the temporal and spatial overlap of hypoxic bottom waters with major spawning, larval recruitment and emigration events for brown and white shrimp. The effects of hypoxia on shrimp populations are not clear but can be predicted based on the results of other studies. Renaud (1986a) suggested that decline in the shrimp catch of Louisiana could be related to hypoxic events, particularly those recorded from May 1983 to May 1984 and in 1982. He also pointed out, based on a shrimp mark-release study, that hypoxic bottom water could act as a physical barrier to juvenile shrimp emigration offshore and to postlarval migration into estuaries. He further stated that the presence of hypoxia during critical periods in the development of penaeids implicate it as a source of variation in annual shrimp yields.

Habitat suitability is the result of several interacting conditions, including oxygen. Low oxygen levels in the water column, typically below 2 mg/l, are generally not satisfactory fish habitat. Because nutrient enrichment and eutrophication frequently leads to low oxygen levels, an indirect effect of eutrophication may be the contraction of suitable habitat necessary for reproduction and growth. A recent example of this interaction is provided by Coutant and Benson (1991). They examined the summer habitat conditions of the striped bass, *Morone saxatilis*, an important commercial and recreational fisheries species in Chesapeake Bay, where the frequency and duration of low oxygen events appears to be increasing (Officer *et al.*, 1984; Seliger *et al.*, 1985). They estimated habitat suitability as the thickness of the July water column that had temperature and oxygen conditions suitable for striped bass (for the central basin); they then compared the changes in the habitat to an empirically-derived estimate of juveniles. Among the annual variations usually attributable to climatic influences is a coincidental decline in both parameters (Figure 17). In effect, the decline in suitable upper water column thickness appears to have compromised the habitat suitable for juvenile reproduction. Without the long-term surveys of juvenile abundance, the relationships might have gone unnoticed, because the adults are harvested over a much larger area.

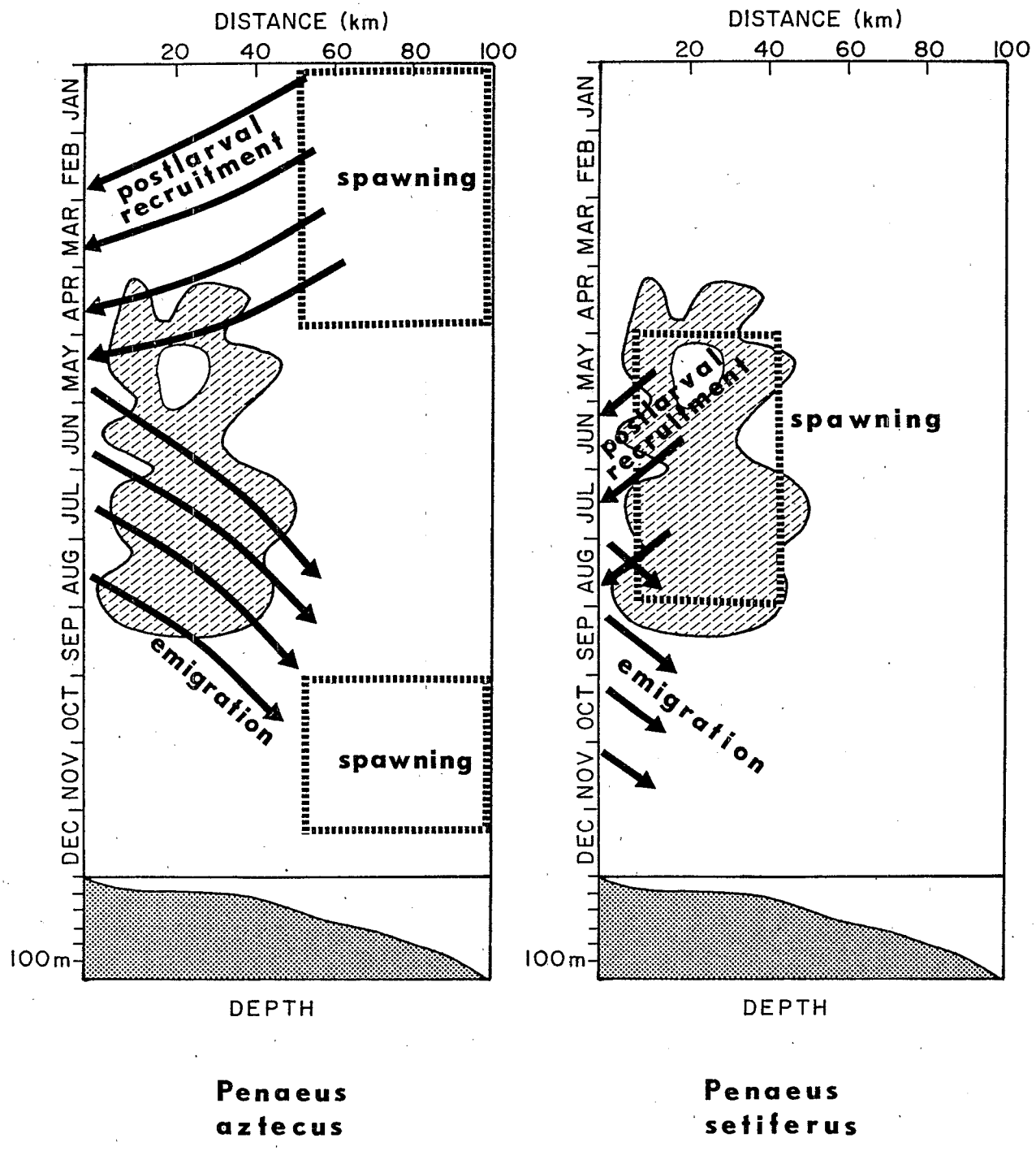


Figure 16. Major events in the life cycle of the brown shrimp (left panel) and the white shrimp (right panel) through a year and in reference to the location on the continental shelf. The shaded area represents the occurrence of hypoxia in bottom waters along a transect across the shelf offshore of Terrebonne Bay through time. (Rabalais, unpublished.)

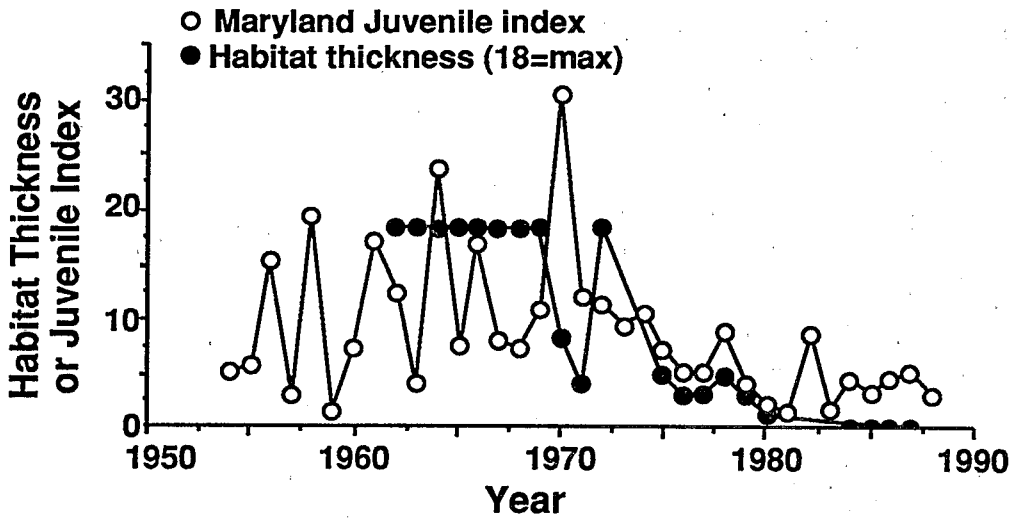


Figure 17. Decline in habitat suitability and the abundance of juvenile striped bass in Chesapeake Bay from 1954 to 1988 (from data in Table 1 of Coutant and Benson, 1991). The maximum value for the area of suitable habitat is 18 m, and is based on the water column with a temperature below 25°C and dissolved oxygen above 2 mg/l during July. The juvenile index is based on summer-time beach seining surveys of 100 day-old striped bass at standard locations (adapted from Turner and Rabalais, 1991b).

Reversal of Eutrophication

There are a few examples of what happens when eutrophication is reversed. Four are discussed here: 1) Bayou Texar, Florida, 2) Tampa Bay, Florida, 3) Seto Inland Sea of Japan and 4) Kaneohe Bay, Hawaii.

The eutrophication of Bayou Texar, near Pensacola, Florida was studied by Moshiri *et al.* (1981) to determine the causes and remedies for extensive fish kills (up to five weeks), closure to recreational use, dinoflagellate blooms (primarily *Ceratium* sp. and *Gymnodinium* sp.), chrysophytes (primarily from the genera *Chrysochromulina* and *Chromulina*), diatoms (*Navicula* and *Cyclotella*), and high algal biomass which contributed to low dissolved oxygen levels. In 1974, a retention reservoir and weirs in the upstream channels were built, and sewage plants repaired. The authors reported an almost total reduction in fish kills, a 90 % reduction in phytoplankton primary production, and a virtual elimination of algal blooms. Fish kills in recent years (1988-1990) indicate that the problem has not disappeared (D. Flemer, personal communication).

Johansson and Lewis (1991) documented a decline in water quality and then restoration in Hillsborough Bay, near Tampa Bay, Florida. Tampa Bay was "grossly polluted" from cannery wastes and poorly treated municipal wastewater discharges in the 1960s. A principal concern was the loss of submerged macrophytes (*Halodule wrightii*), presumably because of increased turbidity following eutrophication. Anoxia and high coliform counts were additional concerns. Following improved sewage treatment, the nitrogen loading to Hillsborough Bay was reduced 30 %, primarily between 1979 and 1980. It was not until four years later that the ambient chlorophyll *a* concentration decreased substantially, which was coincident with the decline in a nuisance planktonic blue-green alga, *Schizothrix calcicola sensu* Drouet. Turbidity decreased.

A major change in seagrasses, reduced to 20 % of the areal coverage of 100 years ago, occurred following improvements in water quality around 1984. The areal coverage of seagrasses in Hillsborough Bay and Middle Tampa Bay doubled from 1986 to 1989. Seagrasses in most shallow areas, however, have not yet recovered and high concentrations of chlorophyll *a* persist. Major sources of nitrogen and phosphorus remain in the fertilizer plants and storage facilities, as well as leakage at loading terminals. This partial recovery has followed partial reduction of nutrient loads, but the system was still responding after five years of the initial nutrient load reduction.

The third example is a report by Cherfas (1990) of a summary by Smetacek. The annual incidence of red tides in the Seto Inland Sea of Japan increased from 40 to more than 300 annually, from 1965 to 1972, as nutrient loading increased. In 1972 nutrient loading was reduced in half, and the frequency of red tides peaked in 1975 and has been declining ever since.

Smith (1981), described the impacts of nutrient loading and restoration in Kaneohe Bay, Hawaii, a subtropical coral reef/estuary complex. Effluent from a large sewage treatment plant provided 80-90 % of the inorganic nitrogen and phosphorus loading to the bay before being diverted to an ocean outfall in 1977-1978. The initial sewage addition resulted in enhanced plankton biomass near the outfall (frequently a bloom developed), with only small increases in nutrient concentration, but a significant increase in benthic biomass. Following the diversion to the outfall, the plankton biomass dropped quickly, but the benthic biomass dropped more slowly. The authors explain the different response times as being a function of the washout characteristics of the two compartments: the phytoplankton have low storage of nutrients, high nutrient turnover, and a fast washout time. In contrast, the benthic community has a slower nutrient recycling rate of the larger nutrient storage pool, hence the biomass remained nearly the same as before the diversion after three years.

These four studies, particularly the discussion by Smith (1981), illuminates the obvious possibilities for recovery following a reduction in nutrient loading. When the causes of eutrophication are reversed, the symptoms may be reversed. But recovery varies with the cycling rate of various stored nutrients, and the flushing rate of the estuary. Seagrasses, at least those that are inhibited by the reduced light penetration that often accompanies eutrophication, may recover, but only over a decade or more.

Management Options

Most aspects of the policy implications of eutrophication are well stated in other places and the basis for numerous legislation. Some less obvious issues, however, are related to the interrelationship of the national policy of nutrient control in freshwater and the impact, or lack of impact, on coastal systems. Management of eutrophication on a national scale has not sufficiently integrated freshwater and estuarine systems. The national freshwater policy is to control phosphorus, and is based on the numerous excellent laboratory and field studies of the stimulatory effect of phosphorus on freshwater ecosystems. Coastal systems, however, are usually thought to be nitrogen limited.

A national policy in common to both freshwater and coastal systems is sewerage treatment, in general. But as is shown for the Mississippi river (Turner and Rabalais, 1991a), the terrestrial system is very leaky, and treatment does not mean a reduction of loading to the estuary via water and precipitation. A second understated issue, therefore, is that sewerage treatment upstream does not necessary equate to controlling nutrient loading to downstream estuaries. The minimization and mitigation of uses seems a less prudent management policy than an outright reduction in use. The ecosystem is simply too leaky to control all flows of important nutrients from use to arrival in the estuary. Of course, getting people to accept that reduction in use is another issue.

The Clean Water Act of 1972 dictates efforts to restore the quality of the Nation's water. Many of these waters, however, remain heavily polluted. The EPA estimates that nonpoint sources of water pollution account for more than half of the pollutants entering national waters. Pollution from nonpoint sources, such as feedlots, landfills, and agriculture, are five to six times the pollution load from municipal and industrial point sources (testimony, U.S. House of Representatives, Subcommittee on Oversight and Review, Committee on Public Works and Transportation, July 17, 1979). Historically, Congress has been reluctant to deal directly with nonpoint source pollution (EOS, June 25, 1991). The Water Quality Act of 1987 expanded EPA's role but leaves primary responsibility for nonpoint pollution with the state because the problem is considered a local issue. Development of methods for monitoring and control of nonpoint sources of pollution, however, appears to be a national need when multi-state sources contribute to the nutrient loading of an estuary or coastal system. Cooperative programs are not insurmountable. A major goal of the multi-state Chesapeake Bay Program is to reduce inputs of phosphorus and nitrogen 40 % by the year 2000. The U.S. EPA and states of New York and Connecticut are developing plans to guarantee that the level of nutrients does not increase in Long Island Sound where there is an oxygen depletion problem. Cooperative initiatives can also be international, for example, the Agreement on Conservation of the Marine Environment of the Gulf of Maine drawn between the Canadian provinces of Nova Scotia and New Brunswick and the states of Maine, Massachusetts and New Hampshire. The Gulf of Maine initiative began at the local level, in lieu of no national or international policy, to respond to recognized needs for action to protect a shared environment

DATA ACQUISITION

The data for this review were obtained from several sources. Initial literature searches were facilitated by the works conducted during the NOAA/OAD Nationwide Review (Rabalais *et al.*, 1985; Windsor, 1985) and supplemented by new computer searches. Many of the data sources identified during these previous reviews were reassessed and supplemented with others. In addition, as mentioned above, many new and ongoing programs have been completed or are in progress in many of the Gulf states.

Literature Searches

A large body of literature, both published and "gray," exists on the many Gulf of Mexico estuarine systems and coastal areas. Some of these documents proved useful in the assessments of eutrophication status of the water body, while others were useful in providing the descriptive information for an estuary within which to assess the status. Other literature was relevant to Gulf coast estuaries but provided no directly useful information for assessing the status and trends of eutrophication. In addition, many worthwhile references on nutrient cycling, eutrophication, oxygen deficient waters, noxious and toxic algal blooms, and long-term changes in coastal water quality were relevant to this report. Most of the relevant and useful pieces of literature that were identified are included in the two bibliographies in Appendix D.

Initial literature searches were guided by the bibliographies developed in the Rabalais *et al.* (1985) and Windsor (1985) sections for the Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters (Whitledge, 1985). Several other bibliographies proved useful: Dennis *et al.* (9184), Renaud (1985), Schroeder *et al.* (1988) and a personal bibliographic reference manager (J. Hand, 1990, Florida Department of Environmental Regulation, M. Freidmann, personal communication).

Computerized data bases were searched through DIALOG (1950 to present), GEOREF (1987 through September 1990), ASFA (Aquatic Sciences and Fisheries Abstracts, 1987 through February 1991), and the Louisiana Database, Coastal Information Repository, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana. Libraries, federal agencies, state agencies for fish and wildlife, natural resources, and water quality, and university-affiliated marine

laboratories were sources of information. The libraries of the Louisiana Universities Marine Consortium (LUMCON) Marine Center, Cocodrie; Coastal Information Repository, Center for Wetland Resources, Louisiana State University (LSU), Baton Rouge; The University of Texas Marine Science Institute, Port Aransas Marine Laboratory; Marine Environmental Sciences Consortium, Dauphin Island Sea Lab; and Gulf Coast Research Laboratory, Ocean Springs, Mississippi, were used to locate obscure manuscripts and reports. Copies of most literature and reports are retained within the libraries of the Louisiana Universities Marine Consortium, the Coastal Information Repository at LSU, or the personal collection of the principal investigator, N.N. Rabalais at LUMCON. Other literature was obtained through Interlibrary Loan services.

The references listed in Bibliography I (Appendix D) were used to develop the status and trends reported in this volume. These references are annotated with a short abstract describing the contents of the volume and/or results. Details of the manuscript, especially where relevant to identification of eutrophication indicators, are included in the text of this volume. The references are coded to identify the estuary or coastal area of concern. References identified as "not in hand" were listed in either Rabalais *et al.* (1985) or Windsor (1985), but could not be located for further examination for this report.

Data Sources

Computerized literature searches were useful, but much of the data that would indicate conditions of eutrophication (*e.g.*, nutrient concentrations, turbidity, dissolved oxygen levels) are not reported in the scientific literature and much of it does not even occur in government or contractor project reports. Most data reside with state and federal agencies and research laboratories, and are not fully accessible. It was necessary to conduct telephone and personal interviews with agency representatives and regional experts to determine what data sets existed and which were available for examination (see Appendices B and C). Our experience indicates that it was more efficient and the data were quality-controlled in a better fashion if we accessed data directly from an agency (*e.g.*, Louisiana Department of Environmental Quality or the U.S. Geological Survey) rather than by obtaining it from the EPA STORET data base.

Our efforts in examining data bases were hampered by the nature of the data collected. Many studies or monitoring programs have a specific limited purpose and are not sufficient in their resolution or duration to indicate trends in increasing or decreasing water quality. The link between any observable trends are also difficult to attribute to anthropogenic activities. Some data bases have already been examined by various authors, and their results are presented in this review. Still a vast amount of unanalyzed data exists (see Appendix B), and some sets may be worthy of a more detailed analysis.

A general description of the data sets obtained for this review are given in Appendix B. Where a data set was examined for frequency, duration and severity of oxygen depletion, a discussion of those data follows.

Water quality data for Florida are maintained by several agencies including the various Water Management Districts; county agencies, such as the Hillsborough County Environmental Protection Commission; and the Florida Department of Environmental Regulation. Site specific studies have been conducted by these state agencies; federal agencies, such as NOAA and EPA; and university collaborators. The most extensive studies have been conducted in the Tampa Bay estuary, Apalachicola Bay, Pensacola and Escambia Bays, and Perdido Bay.

The Marine Resources Division of the Alabama Department of Conservation and Natural Resources has been collecting hydrographic data in conjunction with its fisheries assessment and monitoring program since October 1980 (S. Heath, personal communication). Sixty-six stations have been established in the State's coastal waters for trawl, seine, surface plankton and benthic

plankton samples. A suite of stations is sampled monthly. Some stations have been sampled for the duration of the program; others have ben discontinued or added as fisheries management information needs have changed. From 1977 to 1980, a brown shrimp survey was conducted from April through October at various stations throughout the State's coastal waters. These monitoring data sets have been computerized and are managed by the department at its Gulf Shores office (S. Lazauski, personal communication). Data from field reports of the Alabama Department of Environmental Management were provided by J.C. Carlton (personal communication). Additional data for Alabama were available from literature and technical reports based on studies conducted by researchers at the Dauphin Island Sea Lab, Dauphin Island, Alabama (W.W. Schroeder, T.S. Hopkins, G.F. Crozier, M. Dardeau, J. Pennock, personal communications).

Information for Mississippi was obtained primarily from personnel of the Gulf Coast Research Laboratory, Ocean Springs. The most extensive data base was provided by the Fisheries Monitoring and Assessment project (F.C. Sutter, T. Warren, personal communications). This group has been collecting hydrographic data with its trawl and seine samples at 36 stations in the coastal waters and Mississippi Sound since 1973. Some stations have been sampled for the duration of the program; others have been discontinued or added as fisheries management information needs have changed. Additional hydrographic data have been collected with various research programs conducted by scientists at the laboratory (*e.g.*, Mississippi Sea Grant Project R/LR-11, K. Stuck, personal communication; Eleuterius and Beaugez, 1979; H. Perry, personal communication). Hydrographic data were also obtained from the Mississippi Department of Natural Resources, Bureau of Pollution Control, in the form of technical reports (R.H. Seyfarth, personal communication).

Information on water quality in Louisiana was obtained from initial literature searches in BIOSIS and the Louisiana Database of the Coastal Information Repository, Center for Wetland Resources, Louisiana State University, Baton Rouge. Computerized data, field reports, and 305(b) reports were obtained from the Louisiana Department of Environmental Quality (M.H. Schurtz, J. Boydstun, S. Braden, personal communications). Additional hydrographic data for various Louisiana estuaries were provided by G. Gaston, R.E. Turner, and Q. Dortch (personal communications).

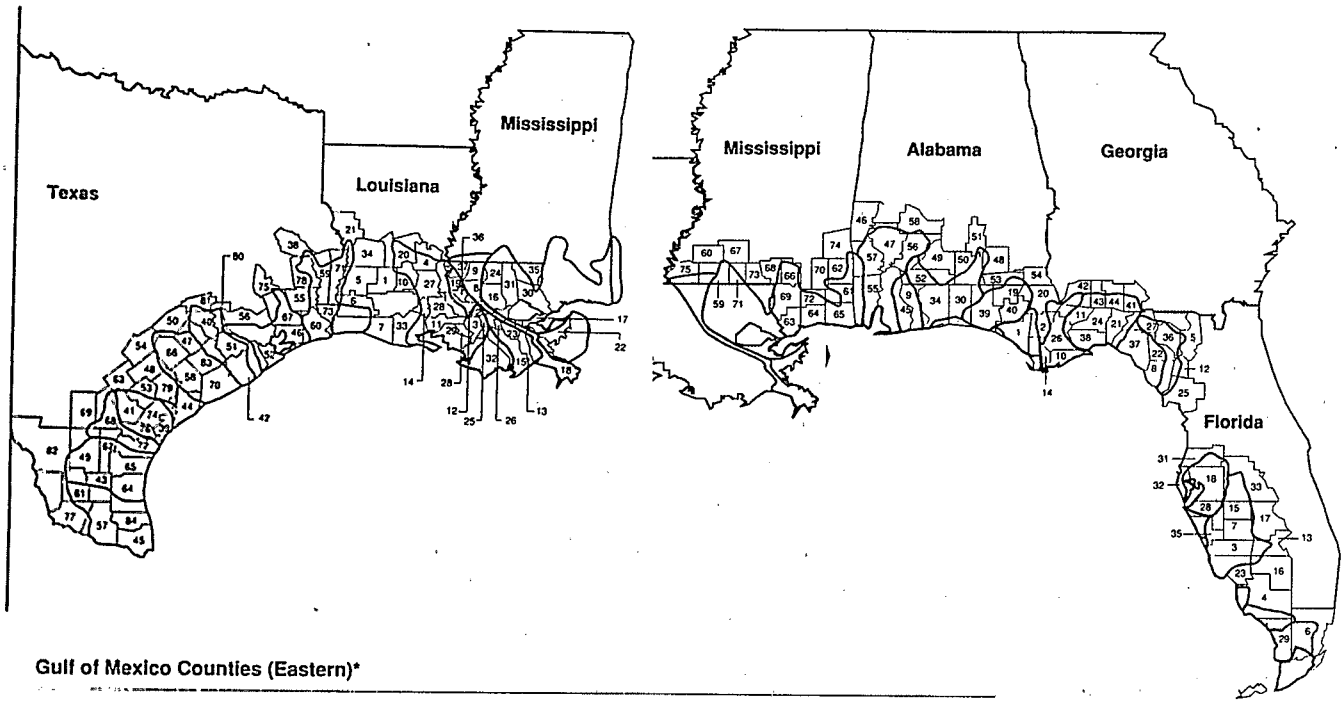
The majority of the data for the coastal waters of Texas was obtained from the Texas Water Development Board (G. Powell, personal communication). The Coastal Data System is based on a State and Federal (USGS) cooperative program started in the late 1960s. In addition to the data collected statewide, the TWDB has conducted a series of species studies in a number of Texas estuaries (see Appendix C, Univ. of Texas Marine Science Inst.). The TWDB also maintains a data set, the Statewide Monitoring Network, which contains water quality data from collections since January 1968 in or near waste outfall areas and channels and harbors. The data base contains both hydrographic and biological data; samples may be taken at several depths in the water column and possibly more than once a dat. These data sets are managed by the Texas Natural Resources Information System. Additional long-term, automated hydrographic monitoring data were obtained from draft reports by G. Powell (personal communication). The Texas Parks and Wildlife Department collects hydrographic data with some fisheries data. Data prior to 1976 are reported in Martinez (1969-1970 *et seq.*). Data collected since 1975 are recorded on standardized forms, submitted to the Austin headquarters, and have now been computerized (M. Osborn, personal communication). Since 1975 monthly shrimp trawl samples have been taken in all major bay systems and are accompanied by bottom water samples. Monthly bag seine samples and seasonal gill net samples are accompanied by surface to mid-depth water samples in 0.2 to 1 m of water. The types of collections and station locations are outlined in Texas Parks and Wildlife Department publications (*e.g.*, Benefield *et al.*, 1983; Hegen, 1983).

Several unpublished and agency reports were available from the University of Texas Marine Science Institute, Port Aransas Marine Laboratory library. Additional raw data and reports with

hydrographic data for the inner continental shelf were provided by D.E. Harper, Jr. (pers. comm.).

One of the data bases analyzed for indicators of nutrient enrichment was NOAA's Inventory of Fish Kills in Coastal Waters, 1980-1989 (draft data base, March 1991; Lowe *et al.*, 1991). The information contained in the fish kill inventory may be useful as indicators of coastal waters that are currently degraded or that are beginning to show symptoms of decline. Fish kills are a clear sign of acute stress; however, the source of the stress may be anthropogenic or natural, or a complex combination of natural and man-induced factors. The fish kill inventory data are useful in that many states compile the information and there is a potential to evaluate changes in the water quality of an estuary where the data set is adequate.

The data examined for fish kill reports were from all Gulf states for all counties within the estuarine drainage basins as outlined in Figure 18 (taken from NOAA, 1990a). Only the data for counties which directly bordered an estuary were used; this was to avoid the preponderance of freshwater systems in the upper drainage area of the estuary. Even within the counties to which the analysis was limited, there are a number of freshwater streams. It was beyond the limitations of this study, however, to precisely identify the water body and its salinity characteristics. We tabulated all fish kills for an estuary by determining where the majority of the county occurred geographically. We then noted the number of fish kills attributed to causes outlined by the inventory as: 1 - low dissolved oxygen, 4 - eutrophication, 18 - nutrients, either from applied ammonia or septic tank leachate, 22 - red tide, 88 - unknown, and 99 - unspecified. Other causes that were listed in the data base are given in Table 10 and were not attributable to nutrient enrichment either directly or indirectly. A data base is only as worthwhile as the quality of the data entered; we are cautious in applying too much emphasis to this analysis. The percentages of fish kills that can be attributed to the causes most directly linked to nutrient enrichment can provide some measure of the status of the estuary.



Gulf of Mexico Counties (Eastern)*

Florida				*Georgia*		*Alabama*		*Mississippi*	
		20	Jackson						
		21	Jefferson						
1	Bay	22	Lafayette	41	Brooks	45	Baldwin	59	Amite
2	Calhoun	23	Lee	42	Decatur	46	Choctaw	60	Franklin
3	Charlotte	24	Leon	43	Grady	47	Clarke	61	George
4	Collier	25	Levy	44	Thomas	48	Coffee	62	Greene
5	Columbia	26	Liberty			49	Conecuh	63	Hancock
6	Dade	27	Madison			50	Covington	64	Harrison
7	De Soto	28	Manatee			51	Crenshaw	65	Jackson
8	Dixie	29	Monroe			52	Escambia	66	Lamar
9	Escambia	30	Okaloosa			53	Geneva	67	Lincoln
10	Franklin	31	Pasco			54	Houston	68	Marion
11	Gadsden	32	Pinellas			55	Mobile	69	Pearl River
12	Gilchrist	33	Polk			56	Monroe	70	Perry
13	Glades	34	Santa Rosa			57	Washington	71	Pike
14	Gulf	35	Sarasota			58	Wilcox	72	Stone
15	Hardee	36	Suwannee					73	Walthall
16	Hendry	37	Taylor					74	Wayne
17	Highlands	38	Wakulla					75	Wilkinson
18	Hillsborough	39	Walton						
19	Holmes	40	Washington						

*Counties completely or partially in EDAs

Gulf of Mexico Counties (Western)*

Louisiana					*Texas*						
		17	Orleans	35	Washington			50	Fayette	68	Live Oak
		18	Plaquemines	36	West Baton Rouge			51	Fort Bend	69	McMullen
1	Allen	19	Point Coupee	37	West Feliciana			52	Galveston	70	Matagorda
2	Ascension	20	Rapides					53	Goliad	71	Newton
3	Assumption	21	Sabine					54	Gonzales	72	Nueces
4	Avoyelles	22	St. Bernard					55	Hardin	73	Orange
5	Beauregard	23	St. Charles	38	Angelina			56	Harris	74	Refugio
6	Calcasieu	24	St. Helena	39	Aransas			57	Hidalgo	75	San Jacinto
7	Cameron	25	St. James	40	Austin			58	Jackson	76	San Patricio
8	East Baton Rouge	26	St. John the Baptist	41	Bee			59	Jasper	77	Starr
9	East Feliciana	27	St. Landry	42	Brazoria			60	Jefferson	78	Tyler
10	Evangeline	28	St. Martin	43	Brooks			61	Jim Hogg	79	Victoria
11	Iberia	29	St. Mary	44	Calhoun			62	Jim Wells	80	Waller
12	Iberville	30	St. Tammany	45	Cameron			63	Karnes	81	Washington
13	Jefferson	31	Tangipahoa	46	Chambers			64	Kenedy	82	Webb
14	Lafayette	32	Terrebonne	47	Colorado			65	Kleberg	83	Wharton
15	Lafourche	33	Vermilion	48	De Witt			66	Lavaca	84	Willacy
16	Livingston	34	Vernon	49	Duval			67	Liberty		

*Counties completely or partially in EDAs.

Gulf of Mexico Estuaries

1	Florida Bay
2	South Ten Thousand Islands
3	North Ten Thousand Islands
4	Rookery Bay
5	Charlotte Harbor
5a	Caloosahatchee River
6	Sarasota Bay
7	Tampa Bay
8	Suwannee River
9	Apalachee Bay
10	Apalachicola Bay
11	St. Andrew Bay
12	Choctawhatchee Bay
13	Pensacola Bay
14	Perdido Bay
15	Mobile Bay
16	Mississippi Sound
16a	Lake Borgne
16b	Lake Pontchartrain
17	Breton/Chandeleur Sounds
18	Mississippi River
19	Barataria Bay
20	Terrebonne/Timbalier Bays
21	Atchafalaya/Vermilion Bays
22	Calcasieu Lake
23	Sabine Lake
24	Galveston Bay
25	Brazos River
26	Matagorda Bay
27	San Antonio Bay
28	Aransas Bay
29	Corpus Christi Bay
30	Upper Laguna Madre
30a	Baffin Bay
31	Lower Laguna Madre

Figure 18. Maps of estuarine drainage areas for Gulf of Mexico estuaries and counties for each state (modified from NOAA, 1990a).

Table 8. NOAA's Fish Kill Inventory - Worksheet for Classifying Sources and Causes (J.A. Lowe, personal communication).

CODE	LAND USE (Name & Description)
1	Agricultural - Land uses related to food production, including cropping, fish hatcheries, feedlots, animal production, orchards, etc. Includes special cases such as plant nurseries and bulb farms.
2	Industrial - Land uses related to manufacture or production of goods or materials.
3	Urban - A broad category of land uses covering residential uses, commercial uses such as retailing and distribution of materials and goods, construction activities, and activities related to population centers such as wastewater treatment and landfill.
4	Impoundment - Land being used as a reservoir, lake, ditch, canal, or slough.
5	Coastal Waters (saline) - Salt or brackish water areas including estuaries and near shore waters.
6	Coastal Waters (fresh) - fresh , running waterbodies including streams and rivers.
7	Silviculture - Land uses related to management and cropping of trees.
8	Wildland - Unmanaged or undeveloped land.
9	Mining - Land used for mining and/or drilling activities.
10	Military - Land used for military installations.
88	Unknown
99	Unspecified - No land use specified.

CODE	EVENT
1	Runoff - An event in which pollutants (chemicals, sediments, etc.) are carried into a water body as a result of a precipitation event. Includes precipitation caused discharges from agricultural areas, wildlands, and urban areas (e.g., piles of animal waste or other materials).
2	Routine Release (Planned) - An introduction of a pollutant into a water body from a discrete containment area such as a holding pond (e.g. those used in industry, feedlots, landfills, construction sites, agriculture, mining areas, and WWTPs) or from combined sewer overflow discharges (e.g., boat bilge, pipe flushing at a construction site).
3	Accidential Release (Unplanned) - An introduction of a pollutant into a water body from a discrete containment area such as a holding pond or combined sewer overflow that is unscheduled (e.g., pump failure, broken pipeline).
4	Spill - The introduction of a pollutant into a water body as a direct result of the pollutant being spilled into or near a water body, or being washed into the water body as a result of a clean-up effort. A spill is different from a release in that a spill introduces the pollutant directly to the water body whereas a pollutant release passes through or originates from a discrete containment structure specifically designed to hold wastes (includes dumping).
5	Spraying - Involves the distribution of a jet of liquid containing a pollutant that enters a water body as a result of overspray or immediate runoff into the water body.
6	Natural - An event or condition that is not immediately or directly related to man's activities. These conditions include eutrophication, depressed dissolved oxygen levels, temperature and salinity fluctuations, turnover of water layers, weather events, and natural toxins (includes river drying up).
7	Drawdown - The removal of water, usually from an impoundment which is carried out to facilitate the maintenance of a water body or to facilitate the maintenance or repair to a power generating or drinking water supply facility (includes water being shut off by irrigation district).
8	Dredging or Drilling Activities
88	Unknown
99	Unspecified

CODE	CAUSE	SPECIFIC POLLUTANT
1	Low Dissolved Oxygen	Turnover, Hydrogen Sulfide, Extreme Low Tides, Overcrowding, Dairy Wastes, Algal Bloom, Raw Sewage, High FCB Counts, Wind Induced Turnover, Predatory Stress, Anoxic Intrusion
2	Temperature	High or Low
3	Sedimentation	
4	Eutrophication	Algal Bloom, Toxic Blue-Green Algae
5	Disease	IPN
6	Bacteria	
7	Virus	
8	Fungus	
9	Stranding	
10	Storm Event	Wind Induced Turnover, Manure, Pesticide
11	Wastewater	Raw Sewage, (Chlorine) Treated Sewage, Piggery Wastes Boat Bilge, Slaughter Wastes, Industrial Wastes, Domestic Sewage, H2S Generated by Sewage Sludge
12	Animal Waste	Manure, Milk, Dairy Wastes, Ammonia
13	pH	Cement
14	Organic	Xylene, Hydrocarbons, Formaldehyde, Urea, Rotenone Halogenated Organic Substances, Molasses, Wood Sugars & Glue, Creosote, Aromatic Hydrocarbons, Benzene, Isopropyl Acetone, Para & Trichlorobenzenes
15	Inorganic/Metals	H2S, Alkali, Ammonia (Spill), Soda Ash, Hydroxylamine, Muratic Acid, Sodium Flouride, Hydrazine, Sulfides, Iron, Shield Liquid DPA, Cyanide, Hydrochloric Acid, Potassium Hydroxide, Aluminum Anodizing Material Ferric Sulfate, Trace Elements, Heavy Metals, Chromium Acid, Acrylonitrile Chromic Acid, Anhydrous Ammonia, Sodium Hydroxide, Ferric Chloride, High Phosphorus Fertilizer, Zinc-Cyanide, Hypochlorus Acid, Phenols, Sulfuric Acid
16	Mixed	Landfill Leachate, Plating/Cleaning Agents, Paint Waste, Food Additives Fire Retardant, Road Sealant, Industrial Waste, Dyes, Antifreeze, Pulp Sludge, Paint Thinner, Soap & Oil
17	Pesticides	PCP, DDT, Thiodan, Busan 72A, 2,4-D, Chlordane, Guthion, Diquat, Simazine, Methyl Parathion, Copper Sulfate, Dursban, Endosulfan, Oftanol, Acrolein, Molinate, Dichloropropane, Diazinon, 33 Plus, Amitrol, Sevin, Malathion, Pentachlorophenol, Methoxychlor, Fenthion
18	Nutrient	Ammonia (Applied), Septic Tank Leachate
19	Salinity Changes	Fresh or Salt Water Inflow
20	Petroleum	Gasoline, Diesel, Jet-A Fuel, Crude Oil, Heavy Fuel Oil, #2 Fuel Oil
21	Chlorine	Ferric Chlorine
22	Red Tide	
23	Predation	
88	Unknown	
99	Unspecified	

ESTUARY AND COASTAL AREA UNITS

The 1985 Nationwide Review conducted for NOAA Ocean Assessments Division (NOAA/OAD) provided for the division of the Gulf of Mexico estuaries and coastal regions into standard hydrographic units for Florida (Windsor, 1985) and the remaining Gulf states (Rabalais *et al.*, 1985). These codes were expanded where necessary (in Rabalais *et al.*, 1985, and this report) to accommodate additional hydrographic units. The codes from the previous reports were retained for the current work, even though other coding structures have since been developed by NOAA for various data compilations. The codes used in this report are listed in Table 9 and illustrated in the accompanying maps (Figures 22-26). The site specific summaries and literature annotations refer to these codes. Literature and hydrographic data sets for 59 coastal areas (Table 9) in the five-state region (western Florida, Alabama, Mississippi, Louisiana, and Texas) were examined. Areas of concern were limited to inner shelf offshore waters, coastal and estuarine waters, and the tidal reaches of freshwater streams, bayous and rivers. A cross-listing of the various codes in current use is given in Table 10.

Table 9. List of codes for Gulf of Mexico coastal areas (after Rabalais *et al.*, 1985; Windsor, 1985).

CODE	*ESTUARY OR COASTAL AREA*
F-9	Whitewater Bay
F-10	Big Lostman's Bay
F-11	Chatham Bay/River
F-12	Caloosahatchee River
F-13	Charlotte Harbor/Peace/Myakka Rivers
F-14	Sarasota Bay
F-15	Tampa/Old Tampa/Hillsborough Bays
F-15.1	Florida inner continental shelf (sw)
F-16	Crystal Bay/River
F-17	Withlacoochee River
F-18	Waccasassa Bay
F-19	Suwannee River/Sound
F-20	Deadmans Bay/Steinhatchee River
F-21	Aucilla River
F-22	Apalachee Bay/St. Marks River
F-23	Ochlockonee Bay
F-23.5	St. George Sound
F-24	Apalachicola Bay/River/East Bay
F-24.1	Florida inner continental shelf (panhandle)
F-25	St. Andrew/West/North/East Bays
F-26	Choctawhatchee Bay
F-27	Pensacola/East/Escambia Bays
F-28&G-1	Perdido Bay/River
G-2	Mobile Bay/River/Tensaw River
G-2.1	Alabama inner continental shelf
G-2.2	East Mississippi Sound
G-2.3	Mississippi Sound, Gulf Islands area and mid-Sound
G-3	Pascagoula Bay/River/Escatawpa River
G-4	Biloxi/Back Bays
G-5	St. Louis Bay/Wolf/Jourdan Rivers
G-5.1	Mississippi inner continental shelf (outside Gulf Islands)

Table 9. Continued

CODE	*ESTUARY OR COASTAL AREA*
G-6	Pearl River
G-7	Lakes Pontchartrain/Maurepas
G-7.1	Louisiana inner continental shelf
G-8	Lake Borgne
G-8.1	Breton/Chandeleur Sounds
G-9	Mississippi River
G-10	Barataria Bay
G-11	Terrebonne/Timbalier Bays
G-11.1	Caillou Bay
G-12	Atchafalaya Bay/River
G-13	Vermilion/West Cote Blanche/East Cote Blanche Bays
G-14	Mermentau River/Grand/White Lakes
G-15	Calcasieu River/Lake/Pass
G-16	Sabine Lake/Pass (Sabine-Neches Estuary, includes Sabine Lake, Sabine Pass)
G-17	Galveston/East/West Bays (Trinity-San Jacinto Estuary, includes Galveston, East, West, and Trinity Bays, Bolivar Pass, GIWW)
G-18	Brazos River (Brazos River Estuary, includes Brazos River, San Bernard River, Freeport Ship Channel)
G-19	East Matagorda Bay
G-20	Colorado River (Colorado Estuary)
G-21	Matagorda/Lavaca Bays (Lavaca-Tres Palacios Estuary, includes Lavaca, Matagorda and Tres Palacios Bays)
G-22	San Antonio/Espiritu Santo Bays (Guadalupe Estuary, includes San Antonio, Espiritu Santo and Mesquite Bays)
G-23	Aransas/Copano Bays (Mission-Aransas Estuary, includes Mission, Aransas, Copano and Redfish (part) Bays and Aransas Pass)
G-24	Corpus Christi/Nueces Bays (Nueces Estuary, includes Nueces, Corpus Christi and Redfish (part) Bays and Aransas Pass)
G-25	Baffin Bay
G-26	Laguna Madre
G-26.1	Upper Laguna Madre
G-26.2	Lower Laguna Madre (includes Arroyo Colorado, South Bay, Brownsville Ship Channel and Brazos Santiago Pass)
G-26.3	Rio Grande Tidal
G-27	Texas inner continental shelf

Table 10. Cross-listing of codes used in this report with other coding structures of NOAA and EPA.

This study	System Name	NOAA[a] NEI	NOAA/OAD[b] 1990	NOAA/EPA[c] Abbreviation
--	Florida Bay	--	G010	
--	Ten Thousand Islands	3.01		TTI
F-9	Whitewater bay	--	--	
--	South Ten Thousand Islands	--	G020	
F-10	Big Lostman's Bay	--	--	
F-11	Chatham Bay	--	--	
--	North Ten Thousand Islands	--	G030	
--	Rookery Bay	--	G040	
F-12	Caloosahatchee River	--	G050a	
F-13	Charlotte Harbor	3.02	G050	CHR
F-14	Sarasota Bay	3.24	G060	
F-15	Tampa Bay	3.03	G070	TAM
F-15.1	SW Florida Shelf	--	--	
F-16	Crystal Bay/River	--	--	
F-17	Withlacoochee River	--	--	
F-18	Waccasassa Bay	--	--	
F-19	Suwannee River	3.04	G080	SUW
F-20	Deadmans Bay/Steinhatchee R.	--	--	
F-21	Aucilla River	--	--	
F-22	Apalachee Bay	3.05	G090	AEE
F-23	Ochlockonee Bay	--	--	
F-23.5	St. George Sound	--	--	
F-24	Apalachicola Bay	3.06	G100	APA
F-24.1	Florida Panhandle Shelf	--	--	
F-25	St. Andrew Bay	3.07	G110	AND
F-26	Choctawhatchee Bay	3.10	G120	CHO
F-27	Pensacola Bay	3.08	G130	PEN
F-28&G-1	Perdido Bay	3.09	G140	PER
G-2	Mobile Bay	3.11	G150	MOB
G-2.1	Alabama Shelf	--	--	
G-2.2	East Mississippi Sound	3.12	G160	MSS
G-2.3	Mississippi Sound	3.12	G160	MSS
G-3	Pascagoula Bay	3.12	G160	MSS
G-4	Biloxi Bay	3.12	G160	MSS
G-5	St. Louis Bay	3.12	G160	MSS
G-5.1	Mississippi Shelf	--	--	
G-6	Pearl River	--	--	
G-7	Lake Pontchartrain	3.12b	G160b	
G-8	Lake Borgne	3.12a	G160a	
G-8.1	Breton/Chandeleur Sounds	3.25	G170	
G-9	Mississippi River	3.13	G180	MIS
G-10	Barataria Bay	3.26	G190	
G-11	Terrebonne/Timbalier Bays	3.27	G200	
G-11.1	Caillou Bay	--	--	
G-12	Atchafalaya River/Bay	3.14	G210	A/V

Table 10. Continued

This study	System Name	NOAA[a] NEI	NOAA/OAD[b] 1990	NOAA/EPA[c] Abbreviation
G-13	Vermilion/Cote Blanche Bays	3.14	G210	A/V
G-14	Mermentau/Grand/White	--	--	
G-15	Calcasieu Lake	3.15	G220	CAL
G-16	Sabine Lake	3.16	G230	SAB
G-17	Galveston Bay	3.17	G240	GAL
G-18	Brazos River	3.18	G250	BRZ
G-19	East Matagorda Bay	--	--	
G-20	Colorado River	--	--	
G-21	Matagorda Bay	3.19	G260	MAT
G-22	San Antonio Bay	3.20	G270	ANT
G-23	Aransas Bay	3.21	G280	ARA
G-24	Corpus Christi Bay	3.22	G290	COR
G-25	Baffin Bay	3.23a	G300a	
G-26	Laguna Madre	3.23	--	LAG
G-26.1	Upper Laguna Madre	--	G300	
G-26.2	Lower Laguna Madre	--	G310	
G-26.3	Rio Grande Tidal	--	--	
G-27	Texas Shelf	--	--	

[a]NOAA (1985).
[b]NOAA (1990a).
[c]NOAA/EPA Team on Near Coastal Waters (1990), uses the same code as the NOAA (1985) NEI.

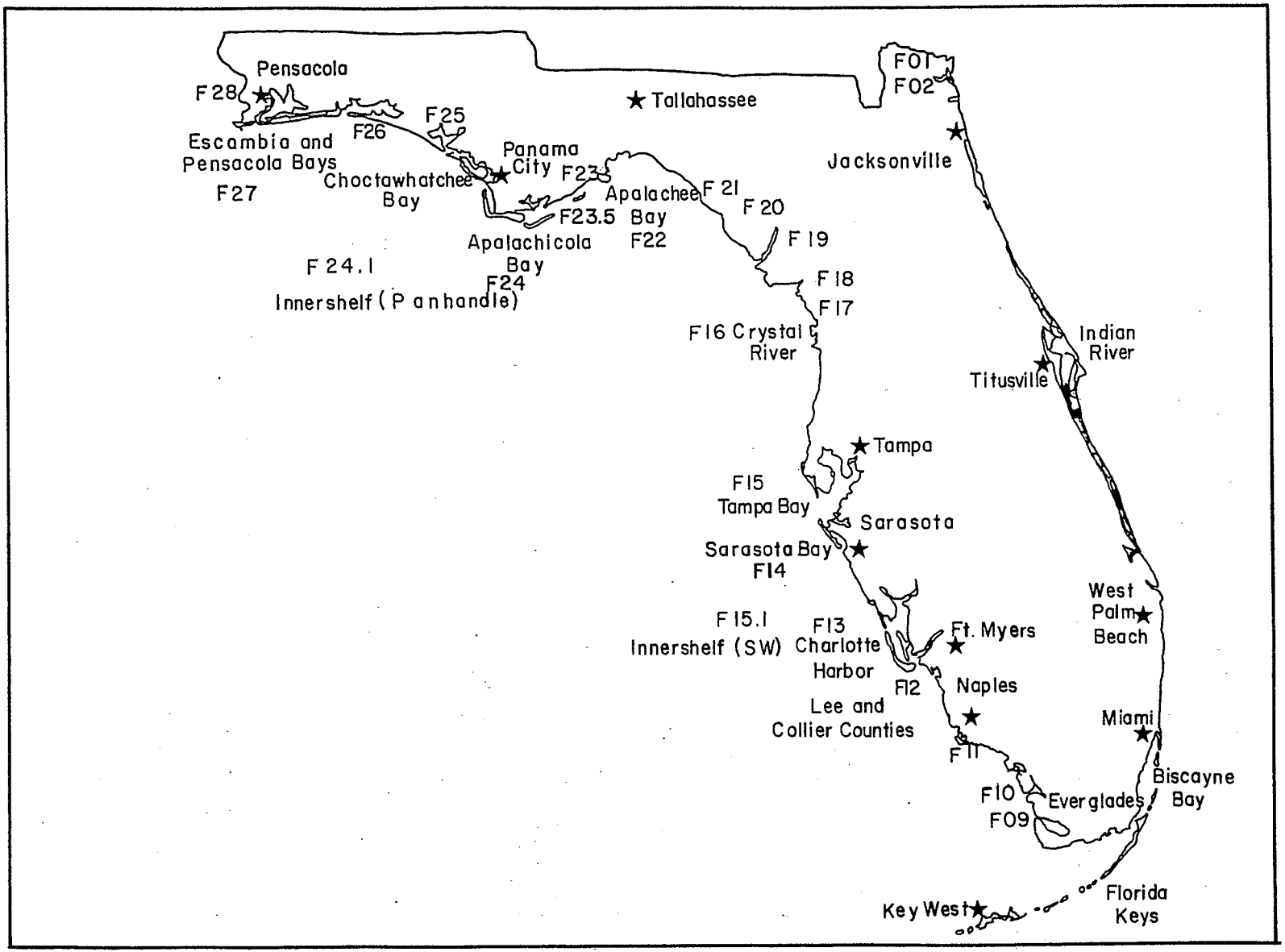


Figure 19. Coastal areas of Florida with codes as indicated (F-9 through F-28) [after Windsor (1985)].

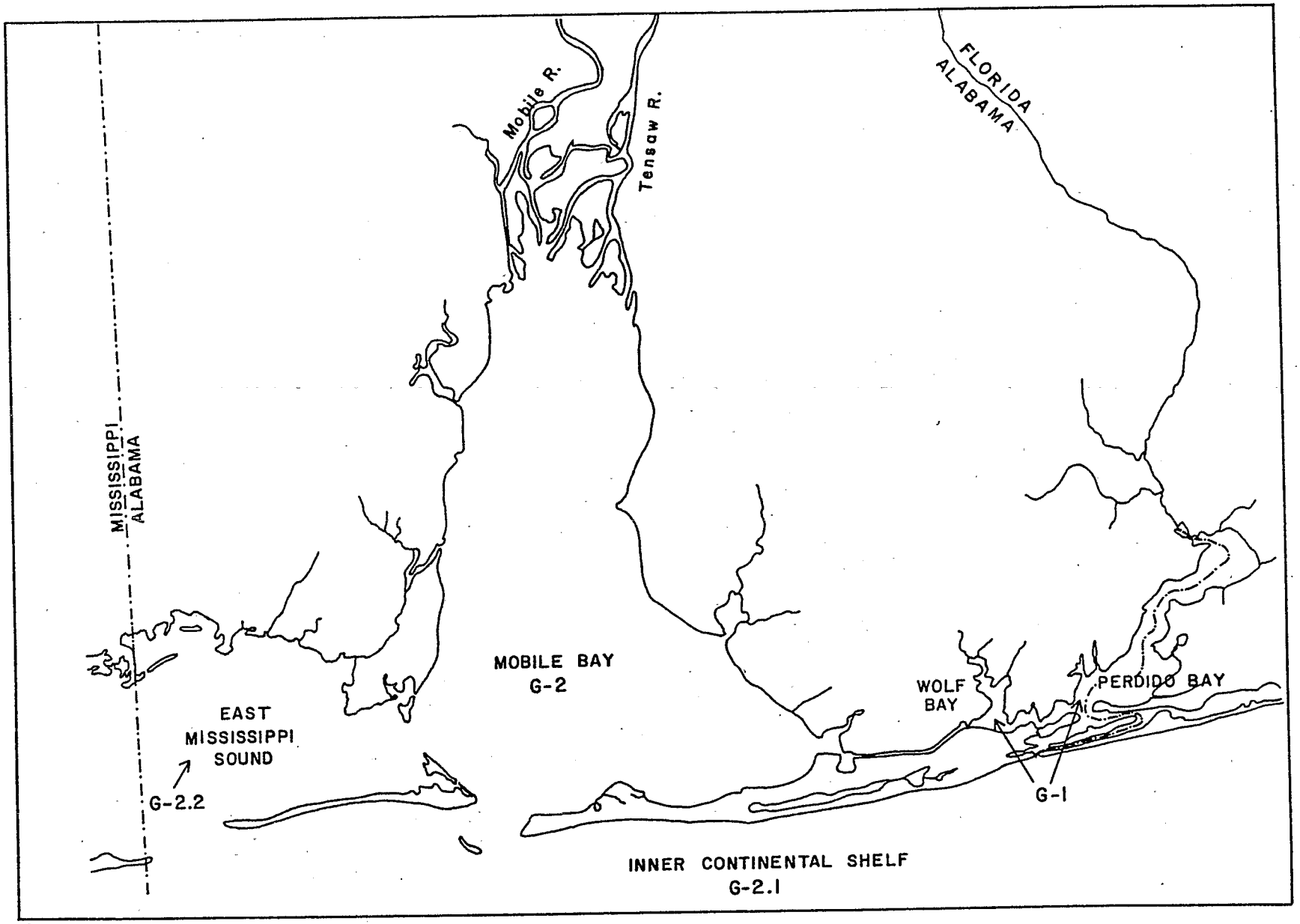


Figure 20. Coastal areas of Alabama with codes as indicated (G-1 through G-2.2) [after Rabalais *et al.* (1985)].

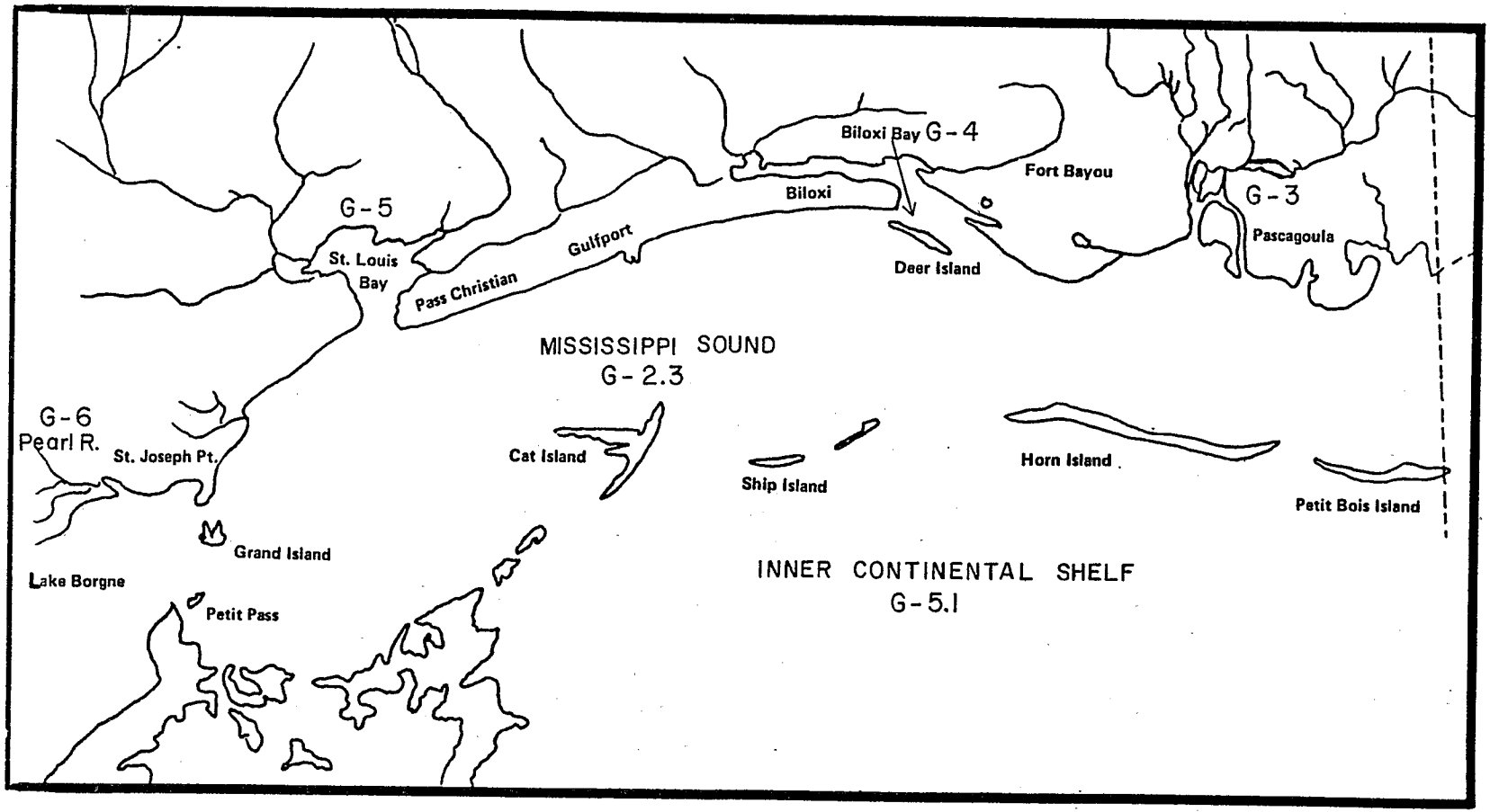


Figure 21. Coastal areas of Mississippi with codes as indicated (G-2.3 through G-6) [from Rabalais *et al.* (1985)].

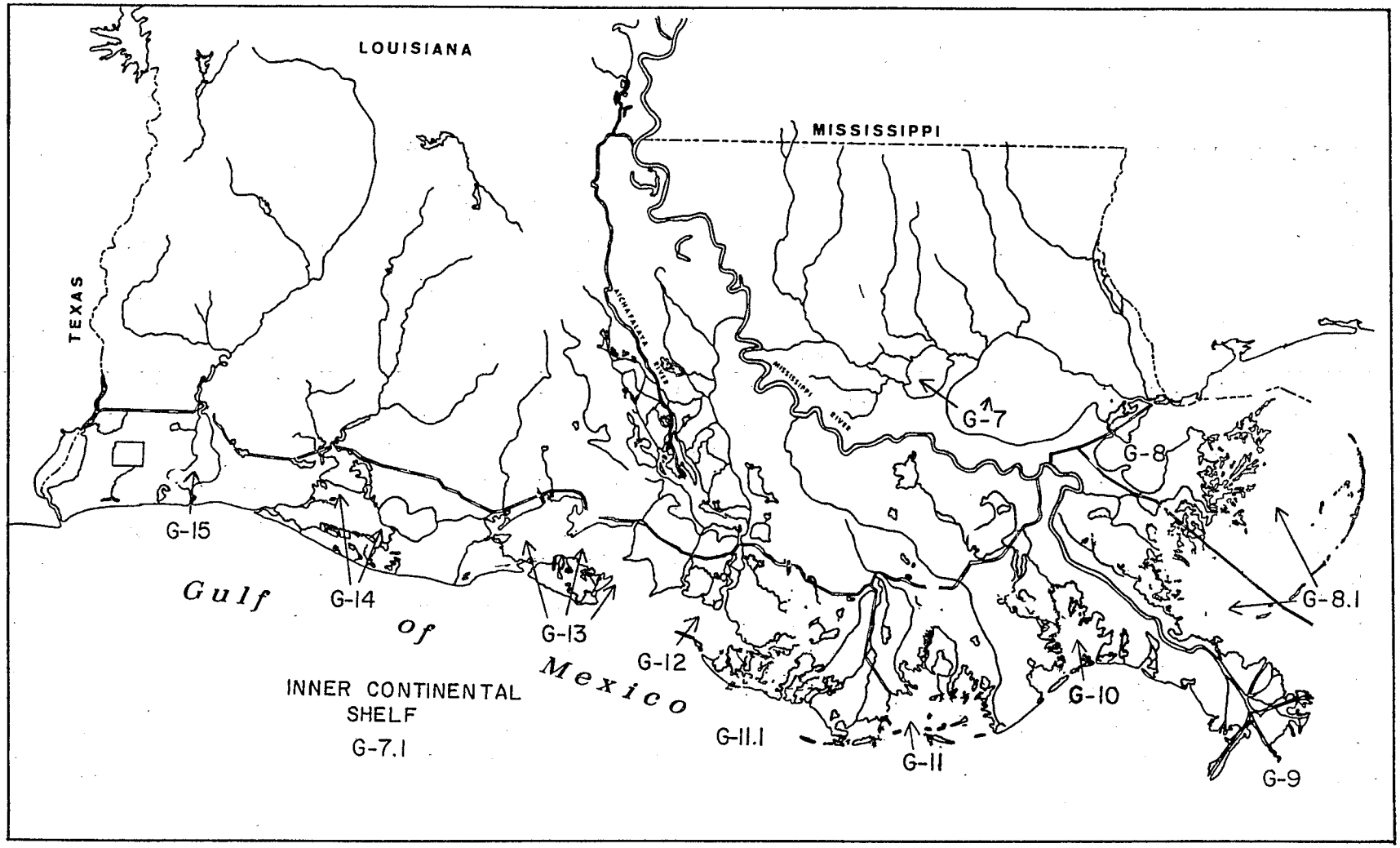


Figure 22. Coastal areas of Louisiana with codes as indicated (G-7 through G-15) [after Rabalais *et al.* (1985)].

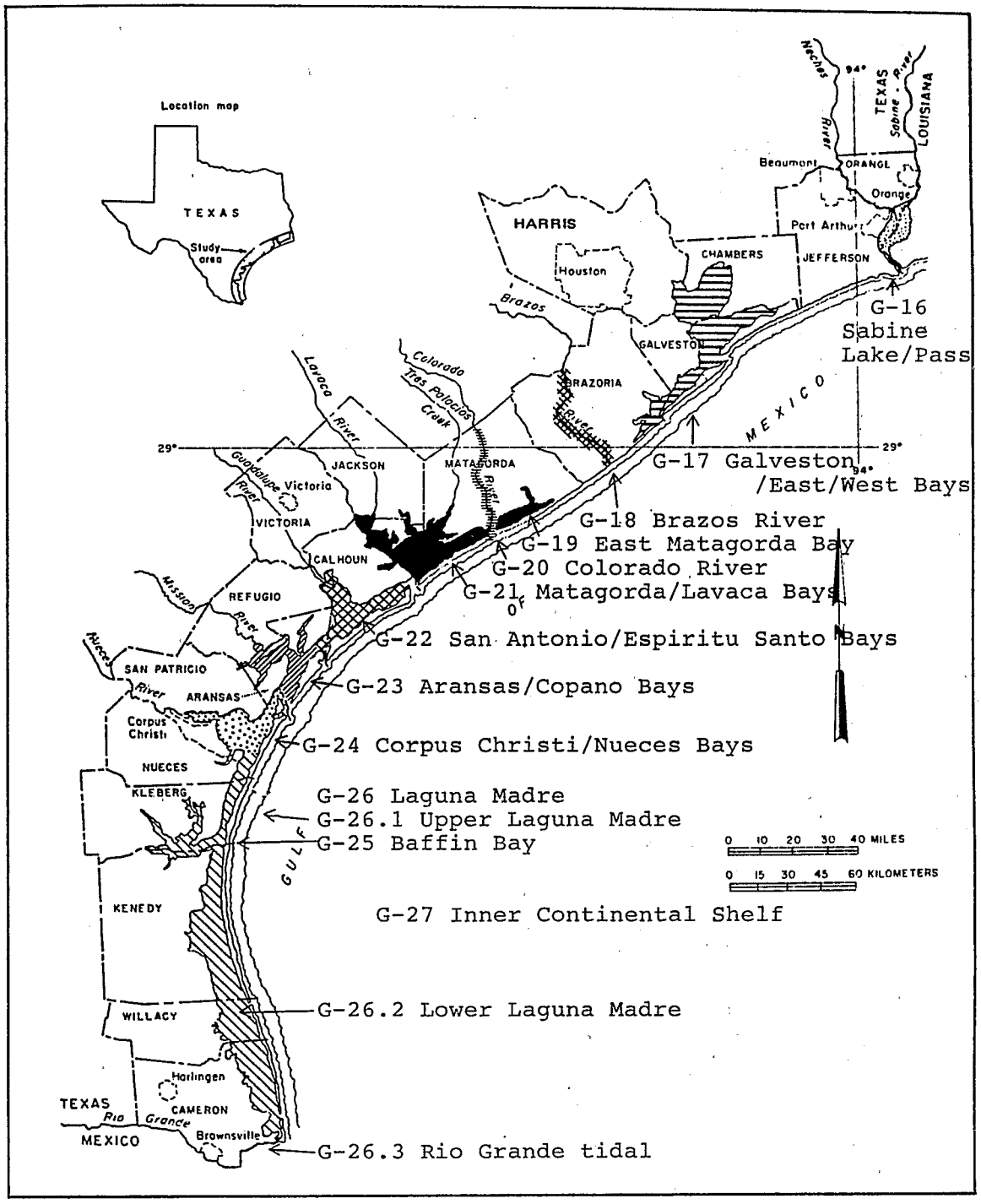


Figure 23. Coastal areas of Texas with codes as indicated (G-16 through G-27) [after Rabalais *et al.* (1985)].

STATUS MATRIX

The 1985 Nationwide Review of Oxygen Depletion and Eutrophication (Rabalais *et al.*, 1985; Whitledge, 1985; Windsor, 1985) developed a matrix which identified the status of the individual estuarine basins and coastal areas of the Gulf of Mexico with regards to dissolved oxygen concentrations of bottom waters. The critical level (as defined by NOAA/OAD as 4 mg/l) was used to establish priority hypoxia areas with a demonstrated hypoxia and/or eutrophication problem, potential hypoxia areas which were borderline cases where no strong hypoxia was noted but where conditions for a serious problem occurring were judged to be possible in the future, and areas with lack of sufficient data to make a determination (some of which were also classified as "potential").

Also, as mentioned earlier, the critical level of 4 mg/l may not be appropriate for Gulf coast estuaries, and other indicators of nutrient enrichment may be evident in a system. On the other hand, additional factors affect the water quality of an estuary and may not be related to nutrient enrichment. [*E.g.*, chemical contamination may be a problem within an estuary, whereas there are no indicators of nutrient enrichment.] A matrix has been developed based on the previous reviews which incorporates:

1) information obtained in the previous reviews related to nutrient enrichment but not considered in the categories based on oxygen levels,

2) a more appropriate oxygen level of 2 mg/l,

3) additional indicators of nutrient enrichment as outlined in the section on perspectives,

4) new literature or information obtained between the previous reviews (data circa 1984) and this document.

The matrix is presented in Table 11. Each estuary or coastal area is listed along the left margin with its code which is keyed to a map in Figures 19-23. (More detailed names of each estuary and/or other coding options are listed in Tables 9 and 10.) All water bodies within an estuary are included in the assessment for the estuary. An indicator of nutrient enrichment may affect only part of the estuary and may not be representative of the whole estuary. The status of indicators, however, shown in the matrix may target part of the estuary rather than summarize data for the whole basin. For example, low dissolved oxygen levels may be present in a secondary bay but not in the primary bay. The status for that estuary under the heading of "Oxygen Depletion" would indicate the presence of that indicator.

Across the top of the matrix are several indicators of nutrient enrichment as outlined earlier in the "Perspectives" section. The categories are broad, because there is usually not sufficient detail within any single water body to provide a status for all indicators. Other categories not listed may be detailed in the text of an individual estuary.

The codes chosen to indicate the status of an estuary with regards to a particular indicator are:

Y - Yes, there is evidence of the particular indicator in the estuary, or a sub-unit of the estuary.

P - There are indications of a potential problem with regards to the indicator but no strong support from long-term data sets; some indicators that the estuary, or a sub-unit of the estuary, may be on the brink of water quality problems.

N - No, there is no evidence of the particular indicator in the estuary, or sub-unit of the estuary, where the data or literature exist that would identify such indicators if present.

? - There are insufficient data to determine whether an indicator of nutrient enrichment is present in the estuary, or sub-unit of the estuary. Insufficiency of data includes lack of recent data (*e.g.*, circa 1985 to present).

The last column of the matrix is a summary of the previous indicators. This column, coded the same as the others, indicates whether there is a problem with regards to the condition of the estuary based on the indicators of nutrient enrichment as defined earlier. The categories are:

Y - Yes, there is a problem in estuarine condition due to nutrient enrichment.

P - There is a potential problem, no real data but some indicators that the estuary, or a sub-unit of the estuary, may be on the brink of water quality problems.

N - No, there is not a problem.

? - There are insufficient data to make a determination, but limited data may support a tentative conclusion of Yes, No or Potential.

Few data sets within the Gulf of Mexico study area are temporally or spatially adequate to draw definitive conclusions on the various indicators of nutrient enrichment (notable exceptions are detailed in the appropriate sections). The results of literature and data searches are synthesized for each estuarine area. The data and/or information are assumed to be of uniform quality. The details of any estuary are provided in the subsequent area-by-area descriptions where citations to literature, data bases, or individuals are given.

The matrix was developed from the available literature and analyzed data. A more thorough knowledge of the conditions or status of any of the estuaries may reside with several authorities in any area. A single individual, however, reviewed all literature for all estuariess as a basis for the categorizations. The classifications of each estuary by indicators of nutrient enrichment were treated as uniformly as possible based upon the synthesis of similar types of information. As additional data or information become available, the matrix should be revised. A graphic representation of three indicator categories and the summary for the estuarine areas are shown in Figures 24-27.

Area-by-area descriptions follow the status matrix. Literature citations specific to an estuary are listed within each estuary. General references which cover an entire state, or sub-unit such as the eastern Gulf of Mexico, are not repeated within each area description but are listed at the end of the general introduction for the state and before the beginning of the area-by-area descriptions. Parameter units are presented as given in the literature source. Equivalents and conversion tables are listed in Appendix A, along with definitions of terms. Information concerning data bases and individuals familiar with particular geographic areas or issues are provided in Appendices B and C. Bibliographies are located in Appendix D.

Table 11. Status matrix (see appropriate section of text for details).

Code	Area Name	Nutrient Increases Loadings Concentrations	Nutrient Ratio Changes	Nutrient Seasonality Changes	Phytoplankton primary production biomass abundance species composition	Toxic or Noxious Algal Blooms
F-9	Whitewater Bay	N	?	?	?	P
F-10	Big Lostman's Bay	N	?	?	?	Y
F-11	Chatham Bay	?, N	?	?	?	P
F-12	Caloosahatchee River	Y, part	?	?	Y, part	Y
F-13	Charlotte Harbor	Y	?	Y	Y	Y
F-14	Sarasota Bay	Y	?	?	Y	Y
F-15	Tampa Bay	Y	Y	?	Y	Y
F-15.1	Florida Inner Shelf (SW)	N	?	?	Y	Y
F-16	Crystal River/Bay	Y, part	?	?	Y, part	Y, part
F-17	Withlacoochee River	N	?	?	N	N
F-18	Waccasassa Bay	N	?	?	?	N
F-19	Suwanee River	Y, part	?	?	?	N
F-20	Deadmans Bay/Steinhatchee R.	Y, part	?	?	?	Y
F-21	Aucilla River	N	?	?	?	Y
F-22	Apalachee Bay	?, N	?	?	?	Y
F-23	Ochlockonee Bay	N	?	?	N	Y
F-23.5	St. George Sound	Y	?	?	Y	Y
F-24	Apalachicola Bay	N	?	?	N	Y
F-24.1	Inner Shelf (Panhandle)	?, N	?	?	Y	Y
F-25	St. Andrews Bay	Y, part	?	?	Y, part	Y
F-26	Choctawhatchee Bay	Y	?	?	Y, part	P
F-27	Pensacola Bay	Y	?	?	Y	Y
F-28 & G-1	Perdido Bay	Y	?	?	Y, part	Y, part
G-2	Mobile Bay	?, Y	?	?	Y	Y, min.
G-2.1	Alabama Inner Shelf	N	?	?	?	Y, min.
G-2.2	East Mississippi Sound	?, N	?	?	?	Y, min.
G-2.3	Mississippi Sound	?, N	?	?	?	Y
G-3	Pascagoula Bay	?, Y	?	?	?	N
G-4	Biloxi Bay	?, Y	?	?	?	Y
G-5	St. Louis Bay	?, Y	?	?	?	N, but P
G-5.1	Mississippi Inner Shelf	?, Y	?, Y	?, Y	?	Y, min.

Table 11. Continued.

Code	Area Name	Nutrient Increases Loadings Concentrations	Nutrient Ratio Changes	Nutrient Seasonality Changes	Phytoplankton primary production biomass abundance species composition	Toxic or Noxious Algal Blooms
G-6	Pearl River	?	?	?	?	N
G-7	Lake Pontchartrain	Y	?	?	Y, part	N
G-7.1	Louisiana Inner Shelf	?, Y	?, likely	?	Y	Y
G-8	Lake Borgne	?	?	?	?	N
G-8.1	Breton/Chandeleur Sound	?	?	?	?	Y
G-9	Mississippi River	Y	Y	Y	Y	N
G-10	Barataria Bay	Y	?	?	Y	Y
G-11	Terrebonne Bay	N	N	N	N	N, but P
G-11.1	Caillou Bay	?	?	?	?	N
G-12	Atchafalaya Bay/River	Y	Y	Y	Y	P, not in bloom
G-13	Vermilion Bay	P	P	P	?	N
G-14	Mermentau/Grand/White Lakes	?	?	?	?	N
G-15	Lake Calcasieu	?	?	?	?	P, not in bloom
G-16	Sabine Lake	?	?	?	?	N
G-17	Galveston Bay	N, Y	Y	?	Y, part	Y
G-18	Brazos River	?	?	?	?	N
G-19	East Matagorda Bay	?	?	?	?	N
G-20	Colorado River	?	?	?	?	N
G-21	Matagorda Bay	?, P	?	?	Y	Y
G-22	San Antonio Bay	?, P	?	?	Y	Y
G-23	Aransas Bay	?	?	?	?	Y
G-24	Corpus Chrsti Bay	?	?	?	Y	Y
G-25	Baffin Bay	?	?	?	?	Y
G-26	Laguna Madre					
G-26.1	Upper Laguna Madre	Y	?	?	?	Y
G-26.2	Lower Laguna Madre	Y	?	?	?	Y
G-26.3	Rio Grande Tidal	?	?	?	?	N
G-27	Texas Inner Shelf	N	N	N	Y, part	Y

Table 11. Continued.

Code	Area Name	Turbidity	SAV or Macro-algal Changes	Oxygen Depletion	Fish Kills	Secondary Production	PROBLEM ?
F-9	Whitewater Bay	?	Y	N	Y	?	N
F-10	Big Lostman's Bay	?	?	N	Y	?	N
F-11	Chatham Bay	?	Y	N	Y	?	?, N
F-12	Caloosahatchee River	Y, part	?	Y, part	?	?	P
F-13	Charlotte Harbor	Y	?	Y	Y	?	Y
F-14	Sarasota Bay	Y	Y	Y, part	Y	Y	Y
F-15	Tampa Bay	Y	Y	Y	Y	Y	Y, but improving
F-15.1	Florida Inner Shelf (SW)	?	?	N	Y	?	N
F-16	Crystal River/Bay	?	?	Y, part, natural	?	?	N
F-17	Withlacoochee River	?	?	Y, natural	?	?	N
F-18	Waccasassa Bay	?	?	N	?	?	N
F-19	Suwanee River	?	?	Y, part	?	?	P
F-20	Deadmans Bay/Steinhatchee R.	Y, but	Y, but	Y, part	N	Y, but pulp	P
F-21	Aucilla River	?	?	N	N	?	N
F-22	Apalachee Bay	?	?	?	N	?	?, N
F-23	Ochlockonee Bay	Y, natural	?	?	?	?	N
F-23.5	St. George Sound	?	Y	?	?	Y	Y
F-24	Apalachicola Bay	Y, natural	N, N/A	N	N	N	N, other probls.
F-24.1	Inner Shelf (Panhandle)	?	N/A	N	N	N	N
F-25	St. Andrews Bay	?	Y, part	N	N	?	Y, part
F-26	Choctawhatchee Bay	?	?	Y, part	P	Y, part	Y
F-27	Pensacola Bay	Y, dredging?	Y	Y, part	Y	Y	Y, but improving
F-28 & G-1	Perdido Bay	Y, color	Y	Y	Y	Y	Y
G-2	Mobile Bay	N, natural	?	Y	Y	Y	?, P
G-2.1	Alabama Inner Shelf	N	N/A	Y, part	Y, min.	?	N
G-2.2	East Mississippi Sound	?, N	?	Y, part	?	?	?, N
G-2.3	Mississippi Sound	?	?	Y, infreq.	?, Y	?	?, Y, part
G-3	Pascagoula Bay	?	?	Y, part	?, Y	?	?, Y, part
G-4	Biloxi Bay	?	?	Y, infreq.	?, Y	?	Y, part
G-5	St. Louis Bay	?	?	N	?, Y	?	N
G-5.1	Mississippi Inner Shelf	?	N/A	Y, infreq.	?	Y, infreq.	?, N

Table 11. Continued.

Code	Area Name	Turbidity	SAV or Macro-algal Changes	Oxygen Depletion	Fish Kills	Secondary Production	PROBLEM ?
G-6	Pearl River	?	N/A	N	?	?	?, N
G-7	Lake Pontchartrain	Y, but	Y	Y	Y	Y	Y, other probls.
G-7.1	Louisiana Inner Shelf	N, decrease	N/A	Y	Y	Y	Y, ?
G-8	Lake Borgne	?	?	N	N	?	?, N
G-8.1	Breton/Chandeleur Sound	?	?	N	N	?	?, N
G-9	Mississippi River	N, natural	N/A	N	N	?	Y
G-10	Barataria Bay	Y, N	?	N	Y	N	Y
G-11	Terrebonne Bay	N, natural	N/A	N	Y	N	?, P
G-11.1	Caillou Bay	N, natural	N/A	N	?	?	?, N
G-12	Atchafalaya Bay/River	N, natural	N/A	N	P	?	N
G-13	Vermilion Bay	N, natural	N/A	N	N	?	?, N
G-14	Mermentau/Grand/White Lakes	?	N/A	?	?	?	?, N
G-15	Lake Calcasieu	N, natural	N/A	Y, part	N	?	?, N, other probls.
G-16	Sabine Lake	N, natural	N/A	Y, part	N	?	?, N, other probls.
G-17	Galveston Bay	N	Y, part	Y, but improv	Y	Y, pollut.	P, other probls.
G-18	Brazos River	N, natural	N/A	N	Y	?	?, N
G-19	East Matagorda Bay	?	?	N	?	?	?, N
G-20	Colorado River	?	N/A	N	?	?	?, N
G-21	Matagorda Bay	?	?	Y, part	Y	?	P
G-22	San Antonio Bay	N, natural	?	N	Y	?	?, N
G-23	Aransas Bay	N, natural	?	Y, part	Y	N	?, N
G-24	Corpus Chrsti Bay	N, natural	?	Y, part	Y	N	?, N
G-25	Baffin Bay	N, natural	?	Y, infreq.	?	Y	P
G-26	Laguna Madre						
G-26.1	Upper Laguna Madre	Y, other	Y	Y, part	N	Y	Y
G-26.2	Lower Laguna Madre	Y, other	Y	Y, part	N	?	Y
G-26.3	Rio Grande Tidal	?	N/A	Y	?	?	?, N
G-27	Texas Inner Shelf	N	N/A	Y, part	Y	Y, part	part P, mostly N

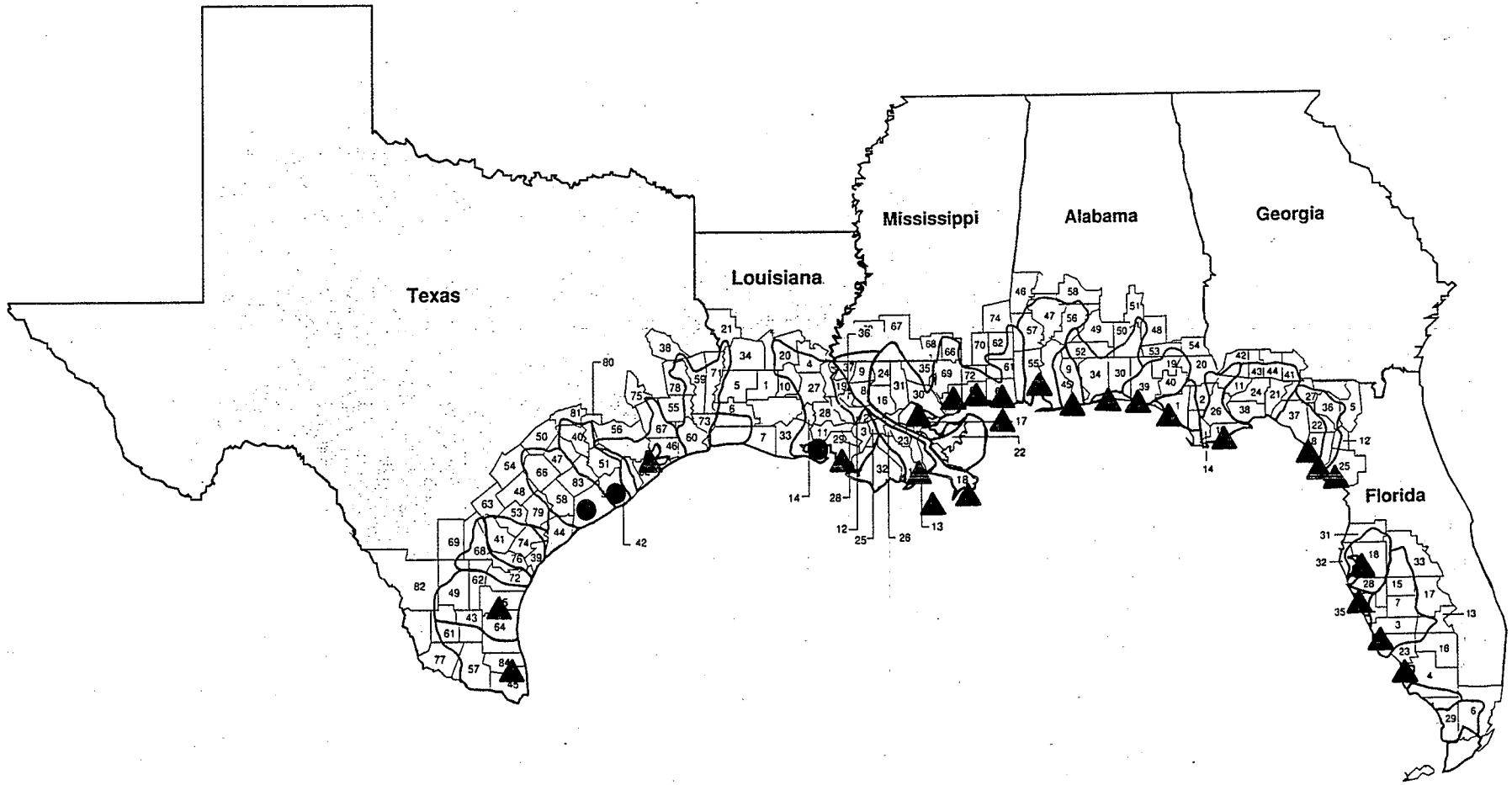


Figure 24. Gulf of Mexico estuaries and coastal areas with symbols indicating status of indicator of nutrient enrichment as listed in Table 11, Status Matrix, and explained in text; in this case, category of "Nutrient Increases, Loadings, Concentrations." Closed triangle (▲) = Yes; closed circle (●) = Potential.

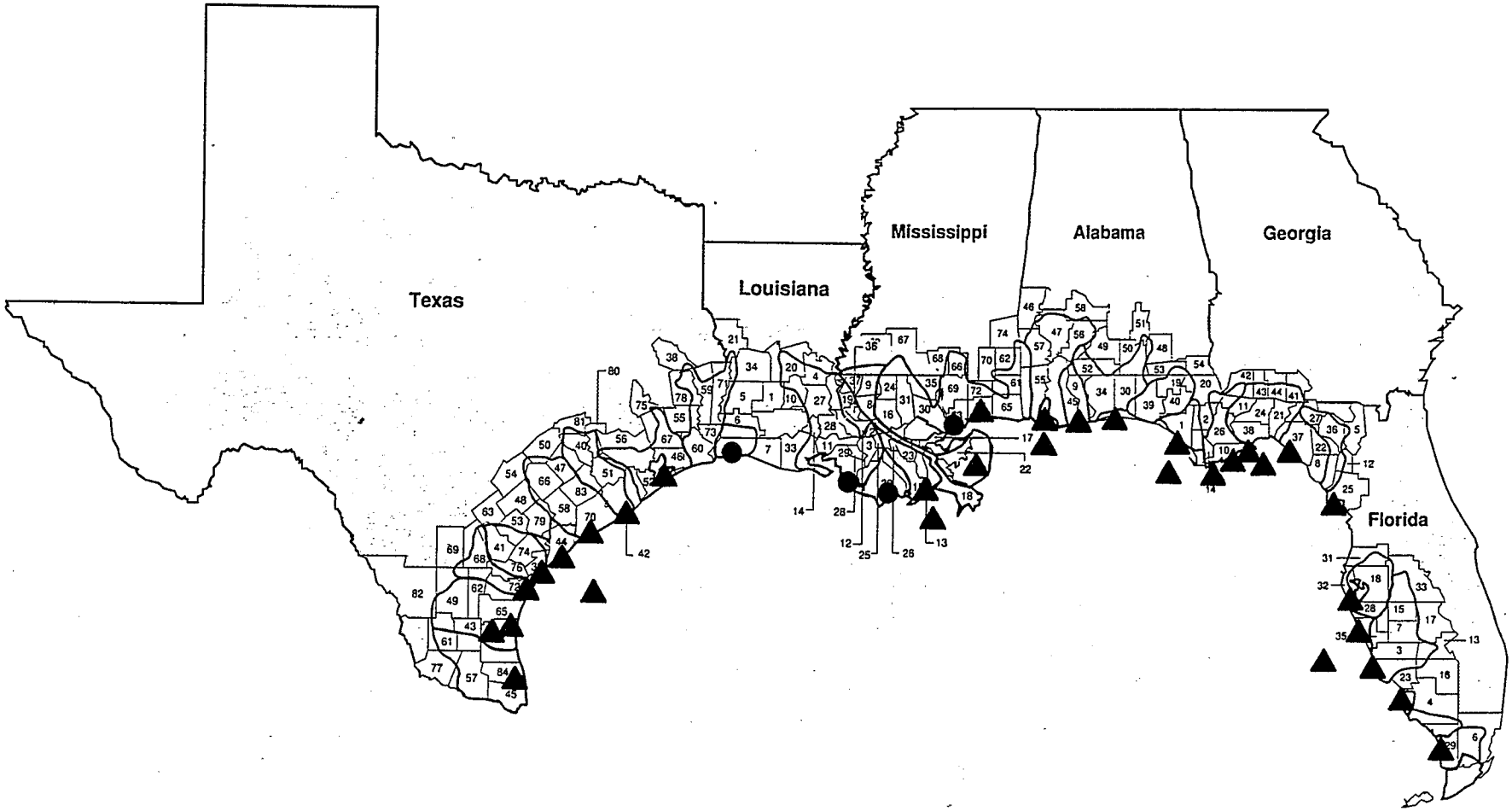


Figure 25. Gulf of Mexico estuaries and coastal areas with symbols indicating status of indicator of nutrient enrichment as listed in Table 11, Status Matrix, and explained in text; in this case, category of "Toxic or Noxious Algal Blooms." Closed triangle (▲) = Yes; closed circle (●) = Potential.

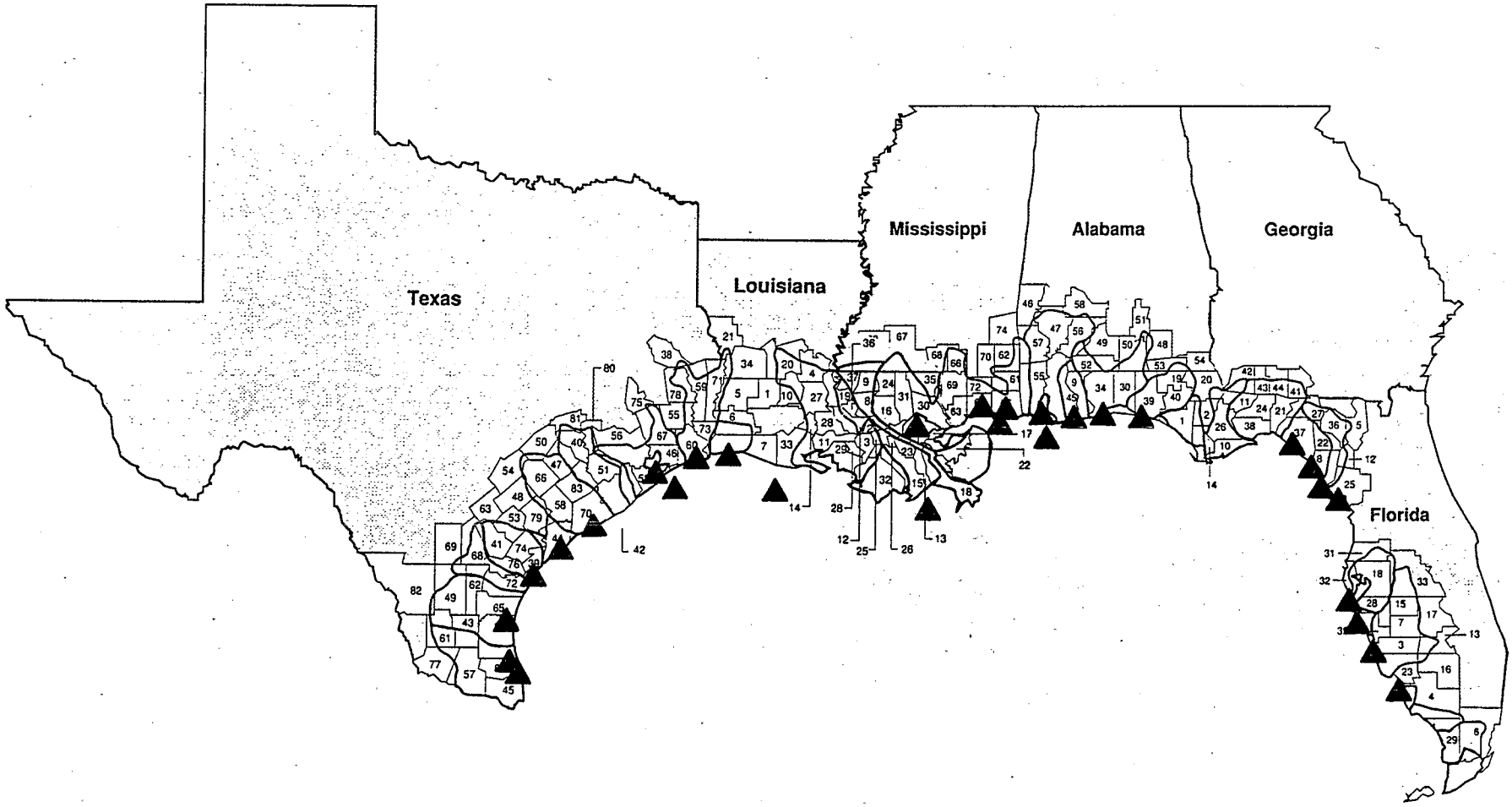


Figure 26. Gulf of Mexico estuaries and coastal areas with symbols indicating status of indicator of nutrient enrichment as listed in Table 11, Status Matrix, and explained in text; in this case, category of "Oxygen Depletion." Closed triangle (▲) = Yes.

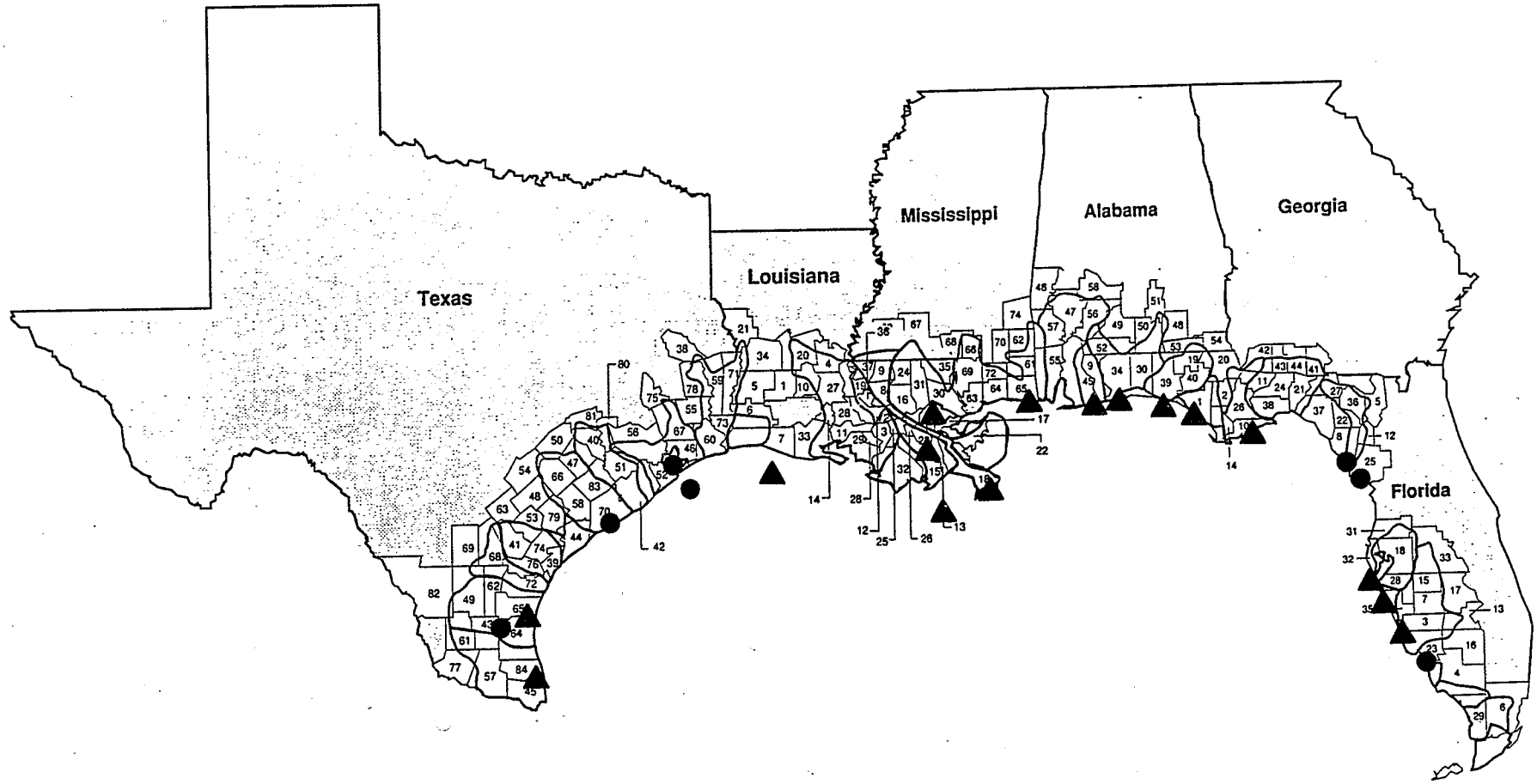


Figure 27. Gulf of Mexico estuaries and coastal areas with symbols indicating status of indicator of nutrient enrichment as listed in Table 11, Status Matrix, and explained in text; in this case, category of "PROBLEM?" Closed triangle (▲) = Yes; closed circle (●) = Potential.

UPDATED SUMMARY OF STATUS AND TRENDS IN INDICATORS OF NUTRIENT ENRICHMENT

FLORIDA

The length (770 statute miles) and biological diversity of the Florida Gulf coast exceed those of any other Gulf state (McNulty *et al.*, 1972). The climate varies from subtropical to temperate. Tidal swamps and marshes fringe the coast and submerged vegetation covers the seabed of most shallow-water bottoms. The mangrove swamps of the southern and central coasts are gradually replaced by tidal marshes north of Cedar Key (Figure F1) (McNulty *et al.*, 1972).

The activities which impact Florida's estuaries are many (Estevez *et al.*, 1984). The Port of Tampa is the seventh largest port in the U.S. and largest on Florida's west coast. The impacts of maritime transportation and industry include dredge and fill activities, retention structure failure, long-term overall effects of increased turbidity, resuspension of contaminants, and filling of intertidal areas. Fisheries declines have been attributed to pollution, overfishing and habitat loss. Other habitat alterations result from dredging activities for fill material, either sand or oyster shell, and thermal effluents from power generating facilities.

Several estuarine areas of Florida are receiving major flows of pollutants (Figure F2) (McNulty *et al.*, 1972). Industrial pollution from wood processing and phosphate processing plants are prevalent along the western panhandle and southwest Florida coasts, respectively. Activities from phosphate extraction are expected to increase in Manatee and Sarasota Counties and may begin near Charlotte Harbor (Estevez *et al.*, 1984). The 1972 (McNulty *et al.*, 1972) status outlined high levels of domestic pollution in Tampa Bay, eutrophication, increased primary production and algal growth, decreased species richness of mollusks, and evidence of eutrophication in Boca Ciega Bay. The Fenholloway River carries heavy loads of paper mill wastes to the Gulf at Apalachee Bay. The St. Marks River is subject to domestic sewage pollution and occasional oil spills. Industrial pollutants have altered the water quality and biota of St. Joseph Bay. Fish kills and other evidence of pollution have been documented in Pensacola and Escambia Bays, and the upper section of Escambia Bay is in a state of accelerated eutrophication. Heavy pollution has been documented in the northern part of Perdido Bay (McNulty *et al.*, 1972). Several of the Florida embayments have recorded fish kills attributed to low oxygen levels, eutrophication or nutrients (Table F1).

The 1988 Florida Water Quality Inventory for EPA 305(b) reporting requirements (Hand *et al.*, 1988a-o) were particularly helpful in assessing the status of the water quality of Florida embayments. Where not available, the assessments provided in Windsor (1985) were used; these were based on the Hand and Jackman (1984) reports.

GENERAL REFERENCES: FLORIDA

ASIWPCA (1984)
Basta and Bower (1985)
Burrage (1989)
Culliton and Blackwell (1989)
Delfino (1989)
Ehler and Basta (1985)
EPA (1974, 1978)
Fernald (1981)
Flor. Bd. of Conservation (1966, 1975)
Friedemann and Hand (1989)
Hand *et al.* (1988o)
Jones *et al.* (1973)
Keys (1975)
Mahadevan *et al.* (1984)
Main *et al.* (1987)
McNulty *et al.* (1972)
NOAA/EPA Team (1990)
Pechmann *et al.* (1986)
Steidinger and Joyce (1973)

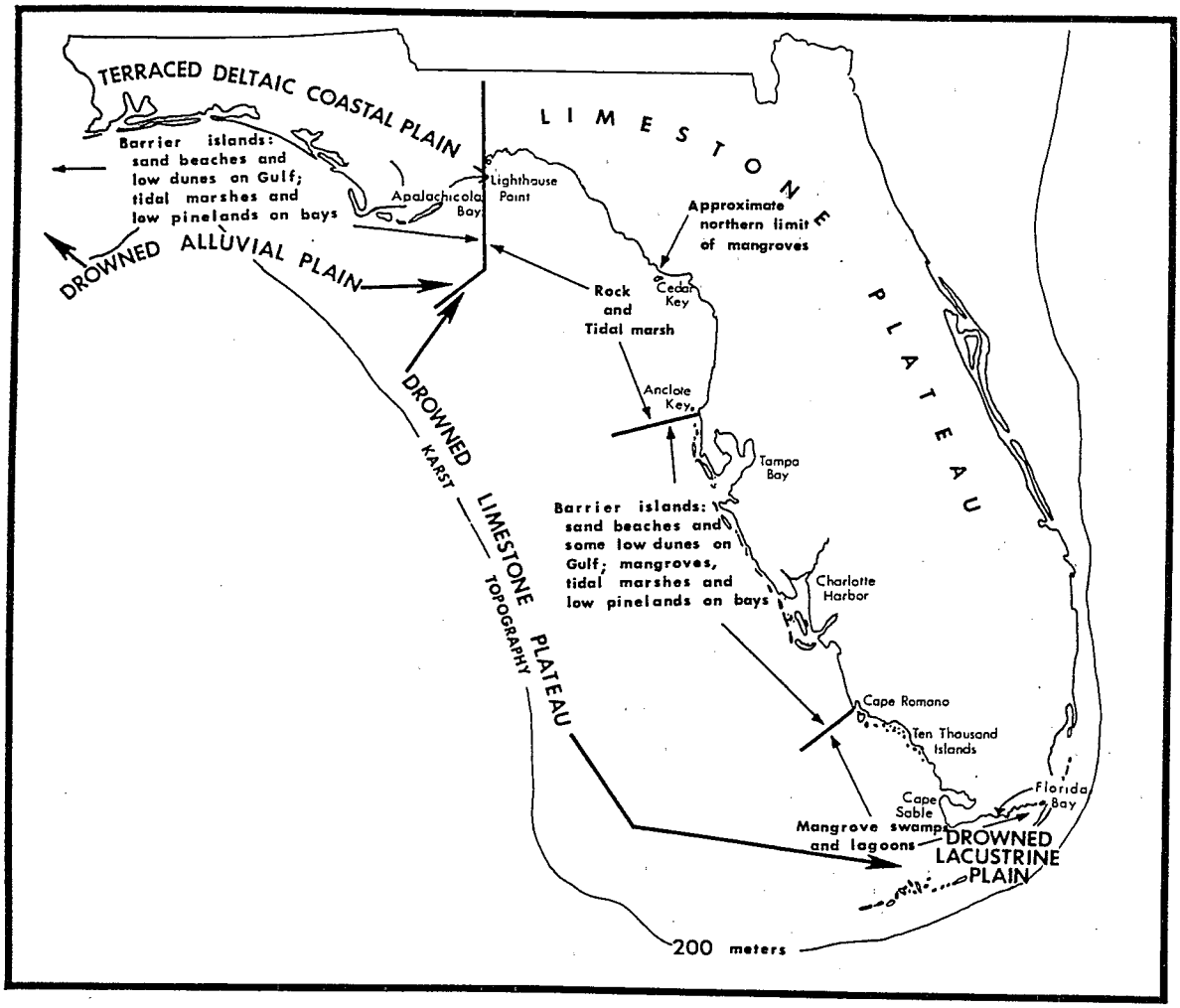


Figure F1. The major coastal types of the west coast of Florida (from McNulty *et al.*, 1972).

Ten Thousand Islands Area

It is difficult to distinguish separate embayments along the extensive barrier island system of the southwestern Florida coast. The area is generally referred to as the Ten Thousand Islands. Various sources of literature divide the area into South and North Ten Thousand Islands. Within these areas fall several designated water quality units: Whitewater Bay, Big Lostman's Bay, Catham Bay and River, and Rookery Bay. The area receives drainage from the Florida Everglades, Everglades National Park, Cypress National Preserve, and Corkscrew Swamp Sanctuary (Figure F3). The construction of freshwater control structures, canals and channels has significantly altered the landscape of the area. The first significant river north of this area is the Caloosahatchee River which flows past Ft. Meyers and into San Carlos Bay.

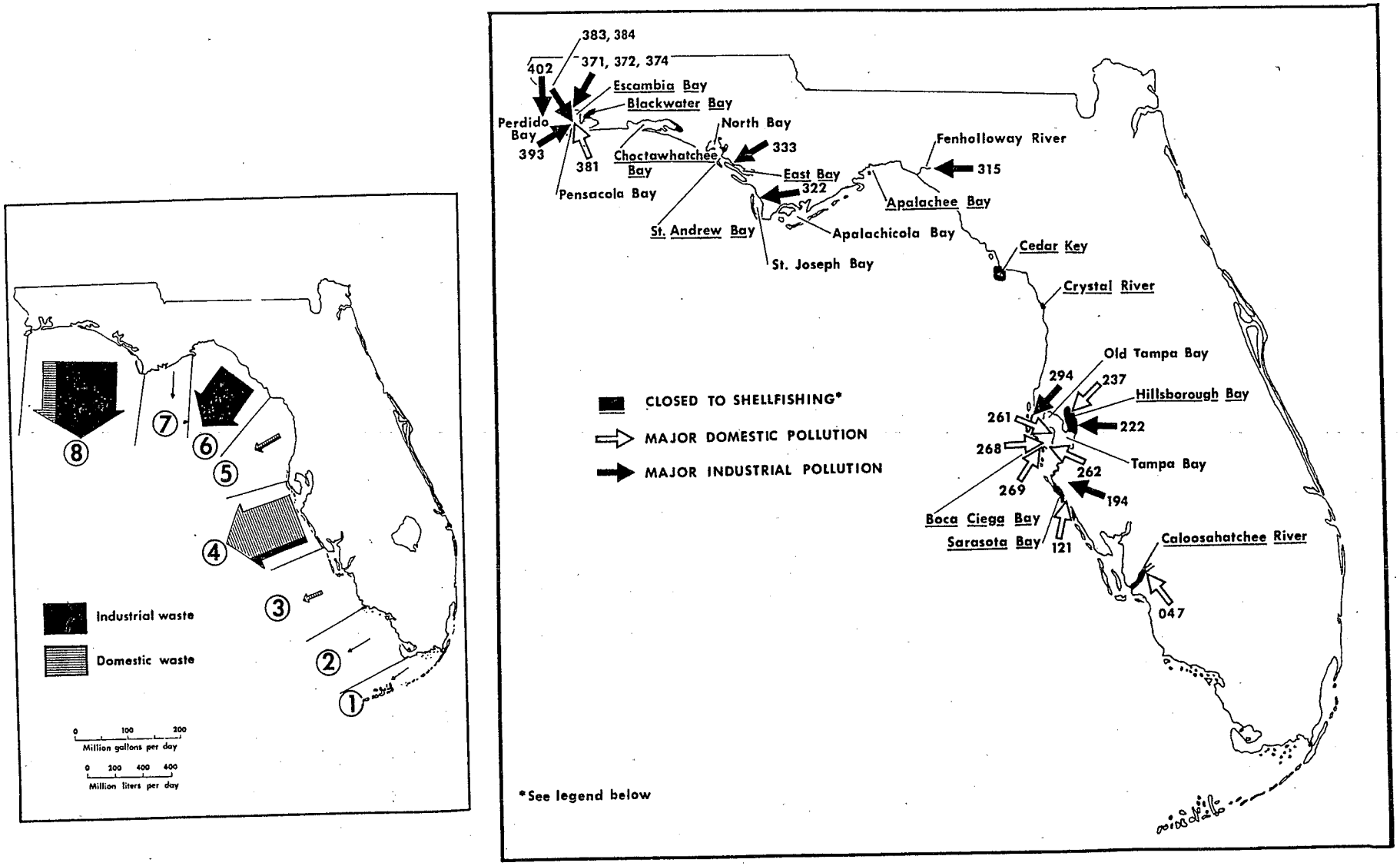


Figure F2. The flow of pollutants into estuarine areas by coastal segment (left panel); the distribution of major sources of pollution and areas that are closed to shellfishing (only estuarine areas that are affected by pollution are named; underlined locations are those where at least some of the area is closed to shellfishing (right panel) (from McNulty *et al.*, 1972).

Table F1. Summary of NOAA Fish Kill Inventory Data for Florida (draft data base, 1991; J.A. Lowe, personal communication; see section on Data Sources).

AREA County	Records per County	Cause Low DO	Cause Eutrophication	Cause Red Tide	Cause Nutrient	Cause Unknown or Unspecified
TEN THOUSAND ISLANDS						
Monroe	11	7	0	0	0	0
ROOKERY BAY						
Collier	93	70	13	0	3	4
CHARLOTTE HARBOR						
Charlotte	18	12	0	0	0	0
Lee	22	12	4	0	0	0
SARASOTA						
Sarasota	13	10	0	0	0	3
WACCASASSA						
Levy	7	0	0	0	0	0
SUWANEE						
Dixie	0	0	0	0	0	0
TAMPA						
Hillsborough	30	12	3	0	0	4
Manatee	7	7	0	0	0	0
Pinellas	25	20	0	0	0	3
APALACHEE						
Jefferson	0	0	0	0	0	0
Taylor	6	0	0	0	0	0
Wakulla	0	0	0	0	0	0
APALACHICOLA						
Franklin	7	1	0	0	0	0
Gulf	10	0	0	0	0	1
ST. ANDREW						
Bay	11	0	0	1	2	2
CHOCTAWATCHEE						
Walton	13	1	0	0	5	4
PENSACOLA						
Okaloosa	17	11	0	0	1	1
Santa Rosa	30	1	5	0	0	2

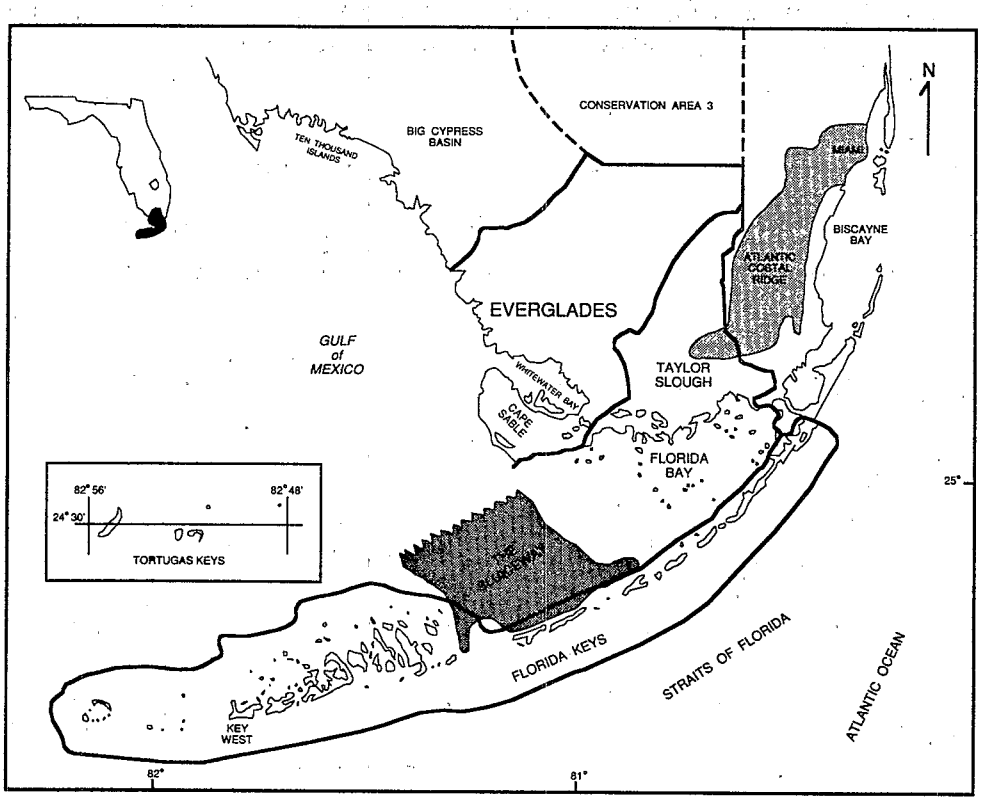


Figure F3. Map of Everglades west coast area (adapted from Schomer and Drew, 1988).

F-9 Whitewater Bay

Whitewater Bay receives drainage from the Lower Everglades (Schomer and Drew, 1982), a broad expanse of sawgrass marsh studded with occasional tree islands, or hummocks (Figure F4). A definite fresh to brackish to marine environment has prevailed along the northeast/southwest axis of the bay for the past 5000 years (Schomer and Drew, 1982). The timing of the wet and dry seasons in Whitewater Bay, as reflected in minimum and maximum salinities, has been shown to be approximately 3 mo out of phase with flow from the Tamiami Canal to the north. Extreme losses to evapotranspiration often lead to salinities greater than in open sea water.

Population in the area is very low (<1000 inhabitants), and no sewage treatment facilities or industries discharge their effluents into these waters (Windsor, 1985). No dissolved oxygen violations were noted during 1982-1983 (Hand and Jackman, 1984, cited in Windsor, 1985), but there are very few water quality data available. Water flow in the drainage basin is sluggish and typically low in dissolved oxygen, but this occurrence is considered to be a natural process throughout most of the Everglades drainage basin (Windsor, 1985).

REFERENCES: F-9

Dragovich *et al.* (1961)
Finucane (1964)
Schomer and Drew (1982)
Williams *et al.* (1990)

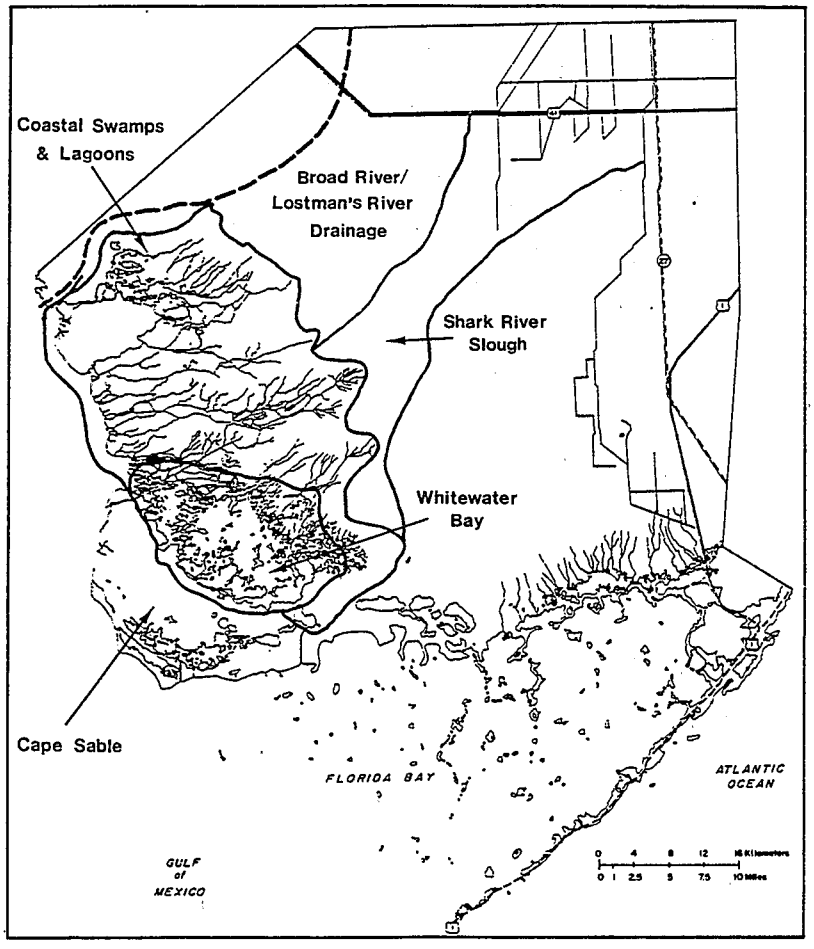


Figure F4. Map of lower Everglades physiographic zones (from Schomer and Drew, 1988).

F-10 Big Lostman's Bay

This area coincides with the North Ten Thousand Islands area (see Figure F4 in Section F-9), and partially within the Everglades West Coast Basin 305(b) reporting area of Hand *et al.* (1988f). The area is considered to be unpopulated and has no discharges from sewage treatment plants or industry affecting the water quality. No dissolved oxygen violations were noted during 1982-1983 (Hand and Jackman, 1984, cited in Windsor, 1985), but there are limited water quality data. The area between Rookery Bay and South Ten Thousand Islands was designated as good overall water quality (limited 1970-1987 STORET data) (see Figure F5 in Section F-11).

REFERENCES: F-10

Dragovich *et al.* (1961)
Finucane (1964)
Hand *et al.* (1988f)
Schomer and Drew (1982)

F-11 Chatham Bay/River

The Chatham River estuarine system lies within the Everglades National Park. Population is low (<1000) and no industries or sewage treatment plants are present in the drainage basin. The area north of Everglades National Park, however, is experiencing rapid growth characteristic of much of southwest Florida.

The Rookery Bay area has been designated a National Estuarine Research Reserve and has been the focus of comprehensive environmental and water quality monitoring studies, resulting in a land use plan which called for an extensive preservation system. A baseline water quality monitoring study began in 1980 and will be used to establish the characteristics of a nearly pristine estuary (Florida Dept. of Natural Resources, program in progress, as cited in Delfino *et al.*, 1984). Other water quality studies are being performed in Naples Bay to determine the pollutant loadings to the Bay from various land use categories during storm events to monitor changes occurring in the Bay as a result of land use and sewage disposal practices.

This area coincides partially within the Everglades West Coast Basin 305(b) reporting area of Hand *et al.* (1988f). The basin has a very limited STORET water quality data set. The areas of Rookery Bay and Naples Bay were designated as good overall water quality (1970-1987 STORET data) (Figure F5), but the water quality of the Tamiami Canal and Gordon River which empty into Naples Bay were rated as fair. Representative water quality data for Naples Bay and Estero Bay are shown in Figures F6 and F7, respectively. The Hand *et al.* (1988f) report indicates that the wastewater treatment plant for the City of Naples has been upgraded and is due to go entirely to spray irrigation. Land use in the area, however, is scheduled for extensive water control structure construction, and the potential to disturb the character and productivity of Rookery Bay, Naples Bay and Faka Union Bay is great. The previous 305(b) report (Hand and Jackman, 1984) indicated poor water quality for the Gordon River based on very low historic dissolved oxygen values (Windsor, 1985). Windsor (1985) also indicated low dissolved oxygen levels in Naples Bay, but had little water quality data available for a thorough analysis.

Work of Thayer *et al.* (1985) in Faka Union Bay has focused on the effects of excessive freshwater inflow. During 1982, the salinity of the bay was lower than adjacent bays to the east and west, and salinity changes in the bay in response to rainfall patterns were slower. There has been a decrease in the extent of seagrasses in Faka Union Bay since the early 1970s (Carter *et al.*, 1973, cited in Thayer *et al.*, 1985).

REFERENCES: F-11

Dragovich *et al.* (1961)
Finucane (1964)
Sheridan (1992)
Thayer *et al.* (1985)
Williams *et al.* (1990)

F-12 Caloosahatchee River

The major surface water draining this area is the Caloosahatchee River which flows past Ft. Meyers and into San Carlos Bay. The upper-end system is Lake Okeechobee. Flow in the Caloosahatchee River has been altered since the late 1800s with locks and dams, and its basin is a maze of canals and ditches (LaRose and McPherson, 1983). Land use in the basin is dominated by rangeland with some agriculture, particularly in the upper basin.

Severe algal blooms occur periodically in the river and pose a particular threat to drinking water supplies, and lush growth of aquatic plants limits light penetration and contributes to severe oxygen depletion (LaRose and McPherson, 1983). An assessment of the Caloosahatchee River (LaRose and McPherson, 1983) indicates that the contributions of nitrate plus nitrate,

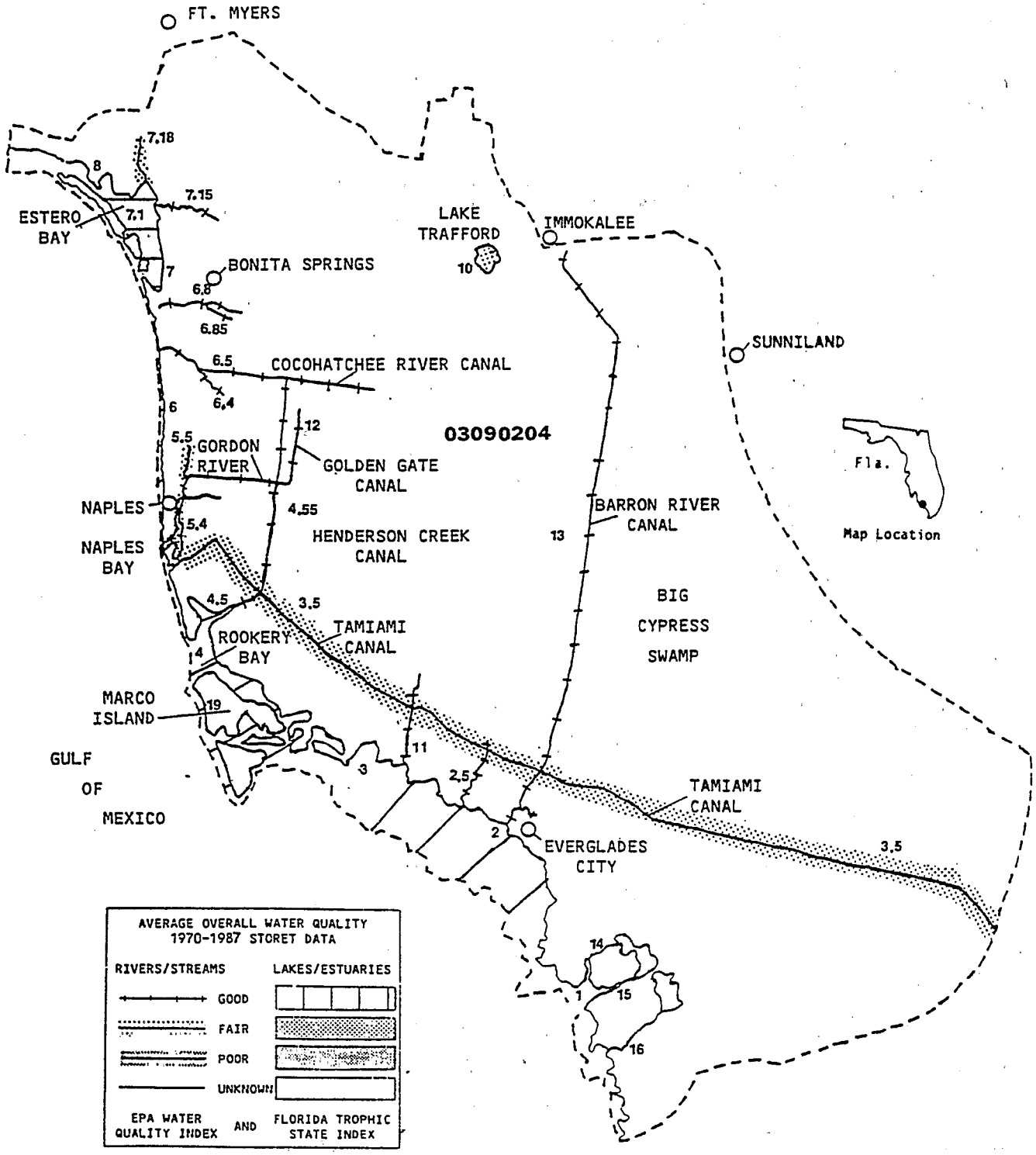


Figure F5. Everglades West Coast basin [from 305(b) report of Hand *et al.* (1988f)].

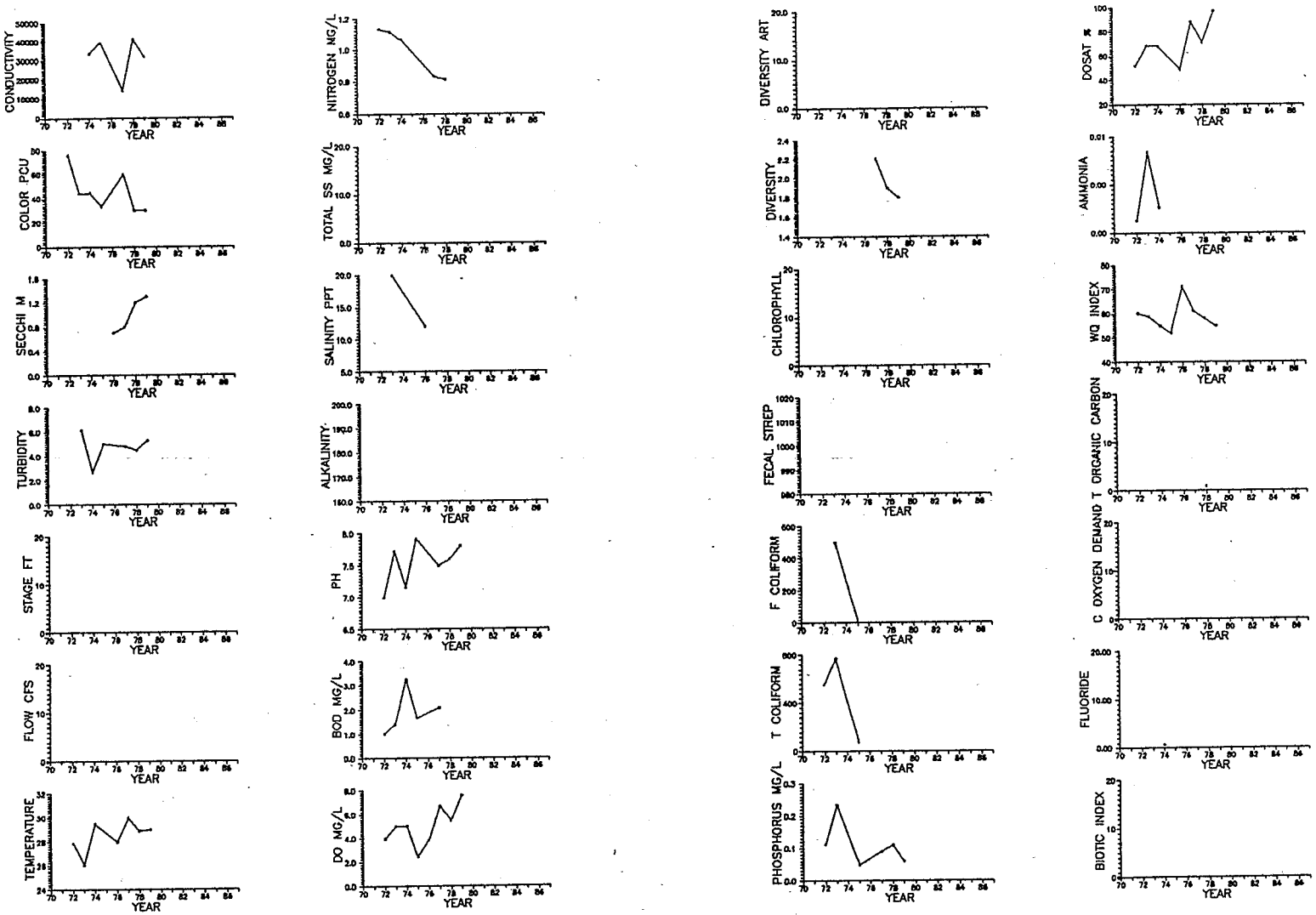


Figure F6. Representative water quality data from Naples Bay (from Hand *et al.*, 1988f).

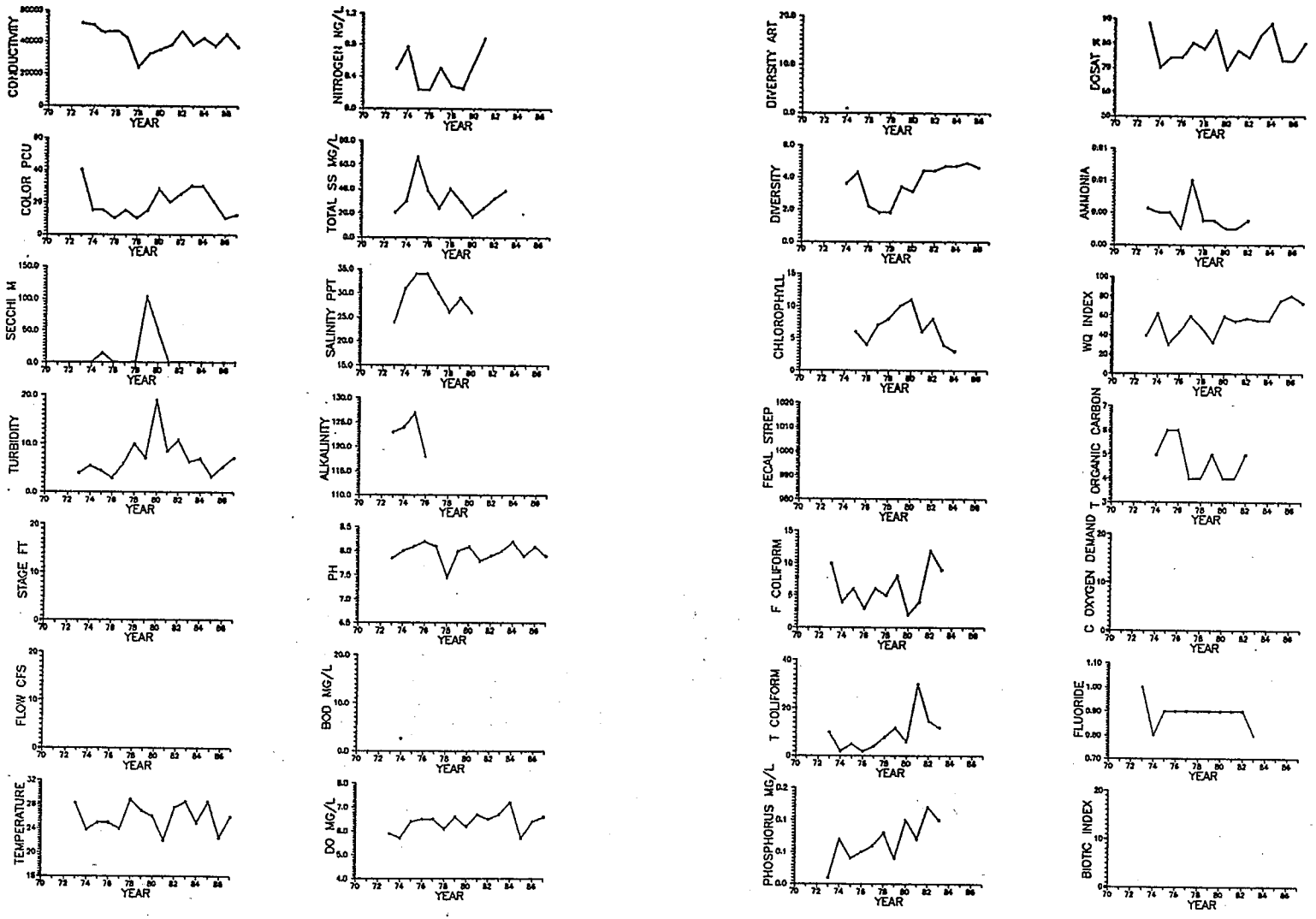


Figure F7. Representative water quality data from Estero Bay (from Hand *et al.*, 1988f).

orthophosphate and total phosphorus from the basin and the river substantially exceeded input from Lake Okeechobee, while concentrations of ammonia from the river and basin were quite small compared to input from the lake. In most tributaries, concentrations of nitrogen and phosphorus compounds were lower than those in the river.

The phosphorus concentrations of the Caloosahatchee River were investigated as a comparison to the Peace River, located further north, and the adjacent Gulf of Mexico (Graham *et al.*, 1954). The phosphorus concentrations of the Caloosahatchee were higher than the nearshore Gulf waters, but averaged five times less than the concentrations of the Peace River (see Figure F10 in Section F-13).

The Caloosahatchee River from the Franklin locks at the town of Olga broadens over 30 miles into a tidally influenced estuarine system. Major urban centers are not present in the upper basin, but the cities of Fort Myers, North Fort Myers and Cape Coral are located on the estuarine portion of the Caloosahatchee River.

According to the 305(b) report of Hand *et al.* (1988b), the water quality in the upper basin of the Caloosahatchee River is rated good; however, animal waste products and agriculture area runoff have been identified as the likely source of nutrient laden waters affecting some low dissolved oxygen problems. The estuarine segment of the river and some of its tributaries have had problems with elevated nutrient concentrations, particularly phosphorus, and with low Secchi disk transparencies (Hand *et al.*, 1988b). The most recent Intensive Survey (1987) revealed high chlorophyll values. The overall water quality rating for the estuarine portion of the system is fair, with several of the tributaries rated poor (Figure F8) (Hand *et al.*, 1988b). Representative water quality data from the lower reaches of the Crystal River are shown in Figure F9. The domestic waste discharges in the estuary have either been eliminated or significantly upgraded (Fort Myers wastewater treatment plant), and new wasteload allocations are being developed. However, the area is highly developed, and nonpoint source pollution will continue to impact water quality (Hand *et al.*, 1988b). San Carlos Bay receives inflow from both the Caloosahatchee River to the east and Charlotte Harbor from the north. Water quality in San Carlos Bay was rated fair in the most recent 305(b) report of Hand *et al.* (1988c). They state that nutrient loading in San Carlos Bay may be resulting from urban runoff in the Ft. Myers area of the lower Caloosahatchee River. The only serious pollution problem in the basin was in Sanibel River (see Figure F11 in Section F-13) located on Sanibel Island at the mouth of Charlotte Harbor (but included in the section for the estuarine segment of the Caloosahatchee River) (Hand *et al.*, 1988c). The Sanibel River has previously received domestic wastewater and runoff from the island's more developed areas. Leachate from local wastewater treatment plants has been controlled, but stormwater runoff remains a problem. Samples in the mid 1970s showed significant nutrient and dissolved oxygen problems in the river; however, there are no recent data to verify the continued existence of this problem (Hand *et al.*, 1988c).

Often, red tides of *Gymnodinium breve* move from offshore waters (see Section F-15.1) into San Carlos Bay (Finucane, 1964). A red tide caused by the toxic dinoflagellate, *Gonyaulax monilata*, was widespread along the west coast of Florida in August 1966 as well as within San Carlos and Estero Bays (Williams and Ingle, 1972).

REFERENCES: F-12

Degrove (1980)
Dragovich *et al.* (1961)
Finucane (1964)
Gunter and Hall (1965)
Graham (1954)
Hand *et al.* (1988b)
LaRose and McPherson (1983)
McPherson and LaRose (1982)
Post *et al.*, Inc. (1984)
Williams and Ingle (1966)
Williams *et al.* (1990)

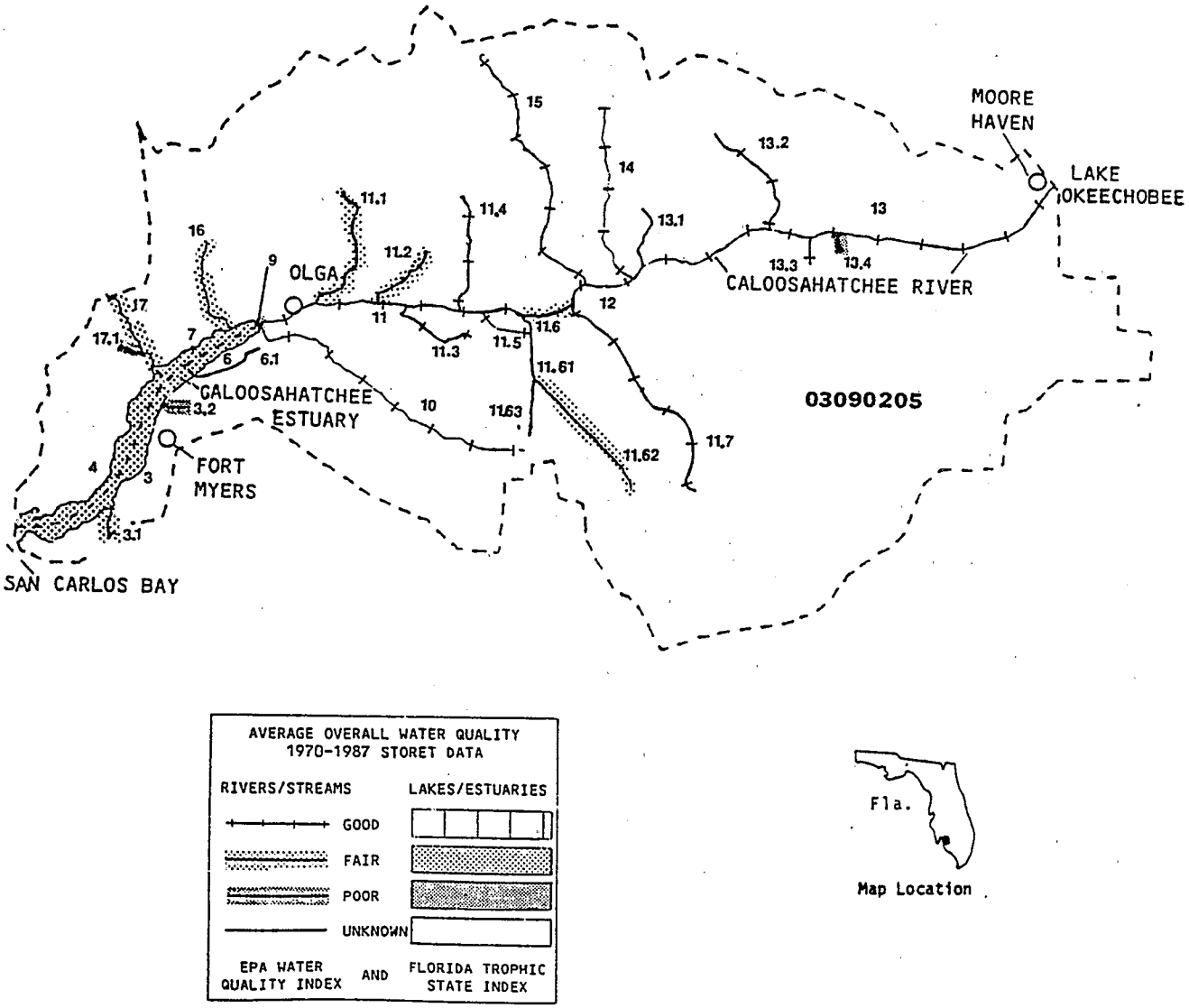


Figure F8. Caloosahatchee River basin [from 305(b) report of Hand *et al.* (1988b)].

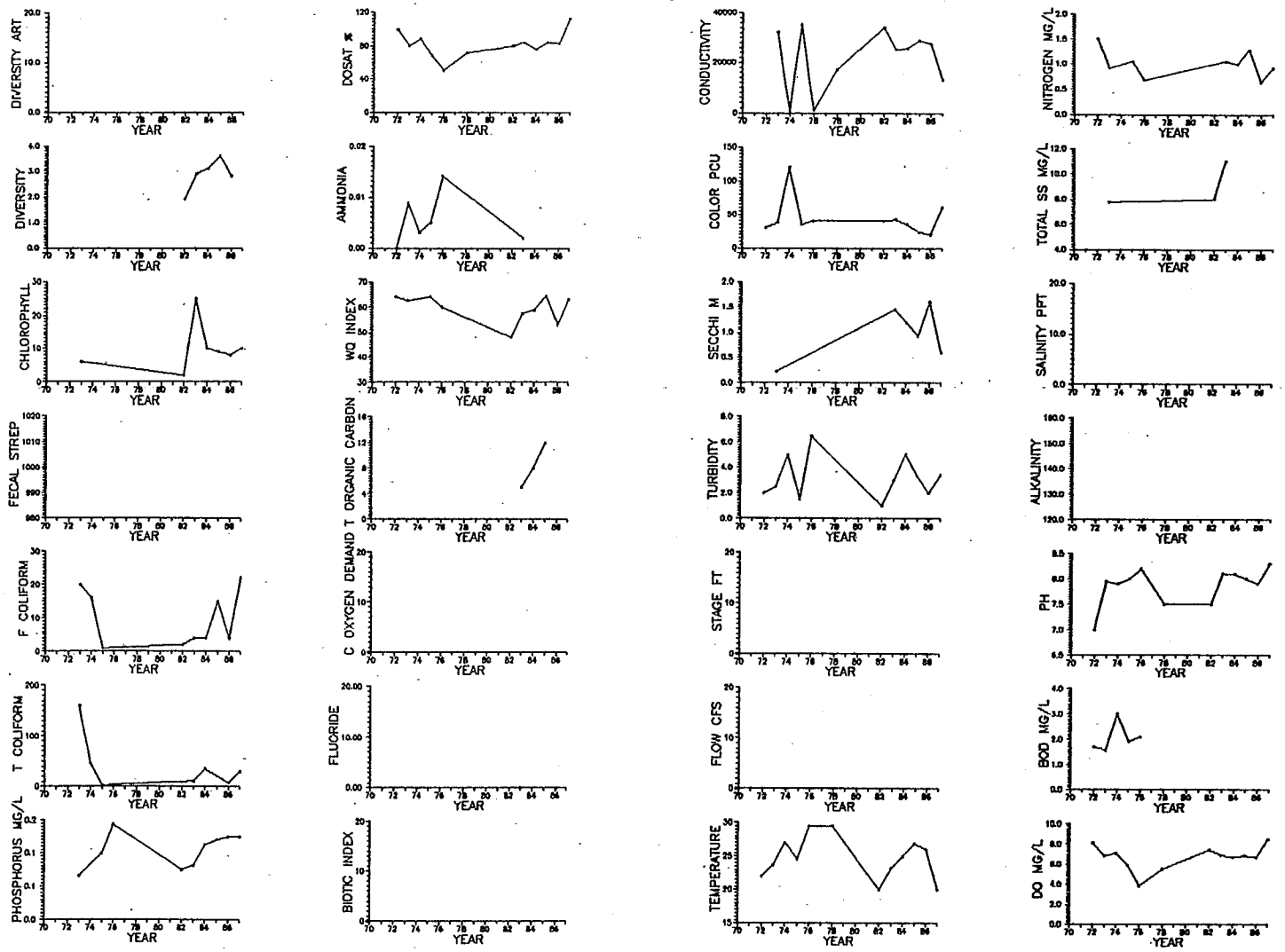


Figure F9. Representative water quality data from Caloosahatchee River above Gulf of Mexico (from Hand *et al.*, 1988b).

F-13 Charlotte Harbor/Peace/Myakka Rivers

Charlotte Harbor is a major embayment which receives inflow from two main tributaries: the Peace and Myakka Rivers, both of which have been altered to control stream flow. Both are polluted to some degree from pastureland, citrus groves and cultivated ground [Taylor, 1974(1975)]; in addition, the Peace River traverses a large area containing phosphate strip mines. Until the 1980s the area was not heavily developed, but rapid growth has occurred since then. Little historic data is available for this estuarine basin, but several studies were in progress in the mid-1980s as outlined by Delfino *et al.* (1984). The studies focus on three areas: the impact of land development on water quality, the distribution of hydrocarbons in the sediments, and water quality problems related to the influx of nutrients and other constituents from tributaries.

The nearshore habitats of the Charlotte Harbor area have been lost to filling and stabilization for housing and commercial development, including construction of extensive finger fill canal systems (Estevez *et al.*, 1984), and other marshes have been impounded for mosquito or urban runoff control and creation and maintenance of navigation channels. Dredging for fill material as oyster shell was at one time a large industry in the Charlotte Harbor area. The number of shell dredging leases declined sharply by the mid 1970s, and current regulations limit the leases and dredging activities (Estevez *et al.*, 1984).

Water quality studies in Charlotte Harbor have emphasized the influx of nutrients, particularly phosphates, from the drainage basin. The major source of phosphate is the Peace River where levels are influenced by mining activities upstream. The impact of the phosphate discharges was studied by Harriss *et al.* (1972) [cited in Delfino *et al.* (1984)] who found that the phosphate waste discharges, in combination with domestic wastes, were causing eutrophic conditions to occur in certain areas of the Harbor. Fraser and Wilcox (1981) [cited in Delfino *et al.* (1984)] noted seasonal pulses in nutrients transported by tributaries into the Harbor and found that the wet summer season provided the highest loads of phosphate and nitrate compared to other seasons. Plankton productivity responded directly to the nutrient pulses, with the highest productivity occurring near the tributary mouths and then decreasing towards the mouth of the Harbor. Similar results were found in an investigation by Graham *et al.* (1954) to determine whether the outflow of the Peace River caused any enrichment of the local Gulf of Mexico waters. The system is believed to be nitrogen-limited as opposed to phosphorus- because of the high phosphate content of the freshwater inflow [Taylor, 1974(1975)]. The concentrations of phosphorus in the Peace River are extremely high as compared with those in the Caloosahatchee River, Charlotte Harbor, or in the open Gulf (Figure F10) (Graham *et al.*, 1954). In this study, however, the high concentrations in the Peace River were not reflected in the concentrations in Charlotte Harbor, with one exception.

Radium-226 and radon-222 activities are greater in the estuarine waters of northern Charlotte Harbor and the lower tidal Peace and Myakka Rivers than in either the freshwater reaches of the rivers or waters of the lower estuary and the Gulf of Mexico (Miller *et al.*, 1990). The geologic strata for the rivers is phosphate rich, and phosphate mining and processing can expose these deposits and may accelerate transport of suspended radium-226 in streams (Upchurch *et al.*, 1985, cited in Miller *et al.*, 1990). The highest radium-226 activities in upper Charlotte Harbor occur in brackish, nearshore waters. Radium-226 in oyster shells and radon-222 in water confirm that the tidal Myakka and Peace Rivers and their embayments are a major source of radium-226. Inflow of artesian ground water that is high in radium-226 appears to be the dominant source of radium-226 in upper Charlotte Harbor and the lower reaches of the Peace and Myakka Rivers.

In the most recent 305(b) report (Hand *et al.*, 1988c), Charlotte Harbor and the associated estuaries between it and the Caloosahatchee River (see Section F-12) compose an area of critical concern due to its rapidly expanding population with the potential for severe damage. Water quality is generally good (Figure F11), although nutrient levels, particularly phosphorus, are elevated, and Secchi disk readings are somewhat low in areas (Figure F12). Upper Charlotte Harbor is probably impacted to

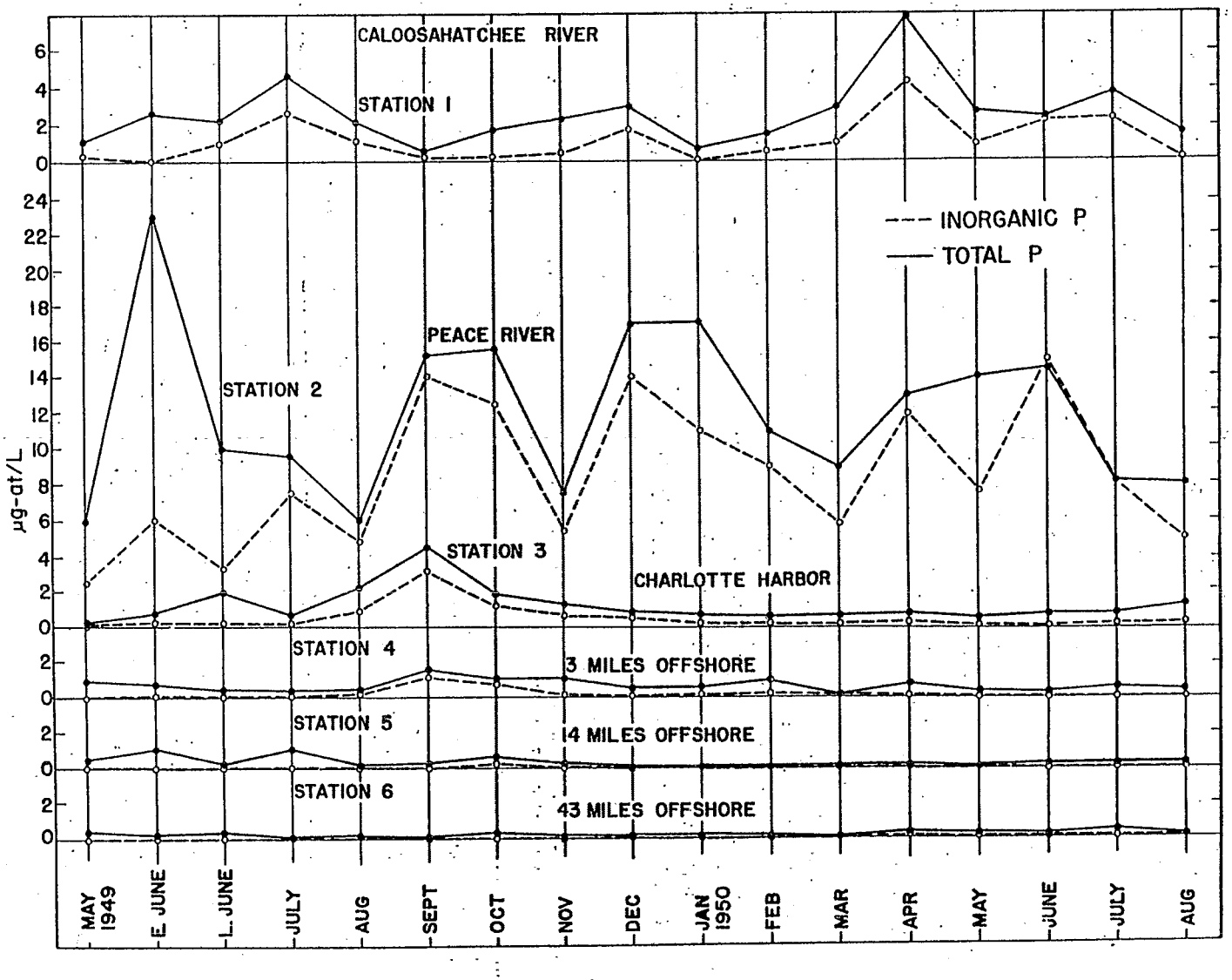


Figure F10. Inorganic and total phosphorus at the surface (approx. 1m) at Stations 1 to 6 for the 16-month survey of the named rivers (from Graham *et al.*, 1984).

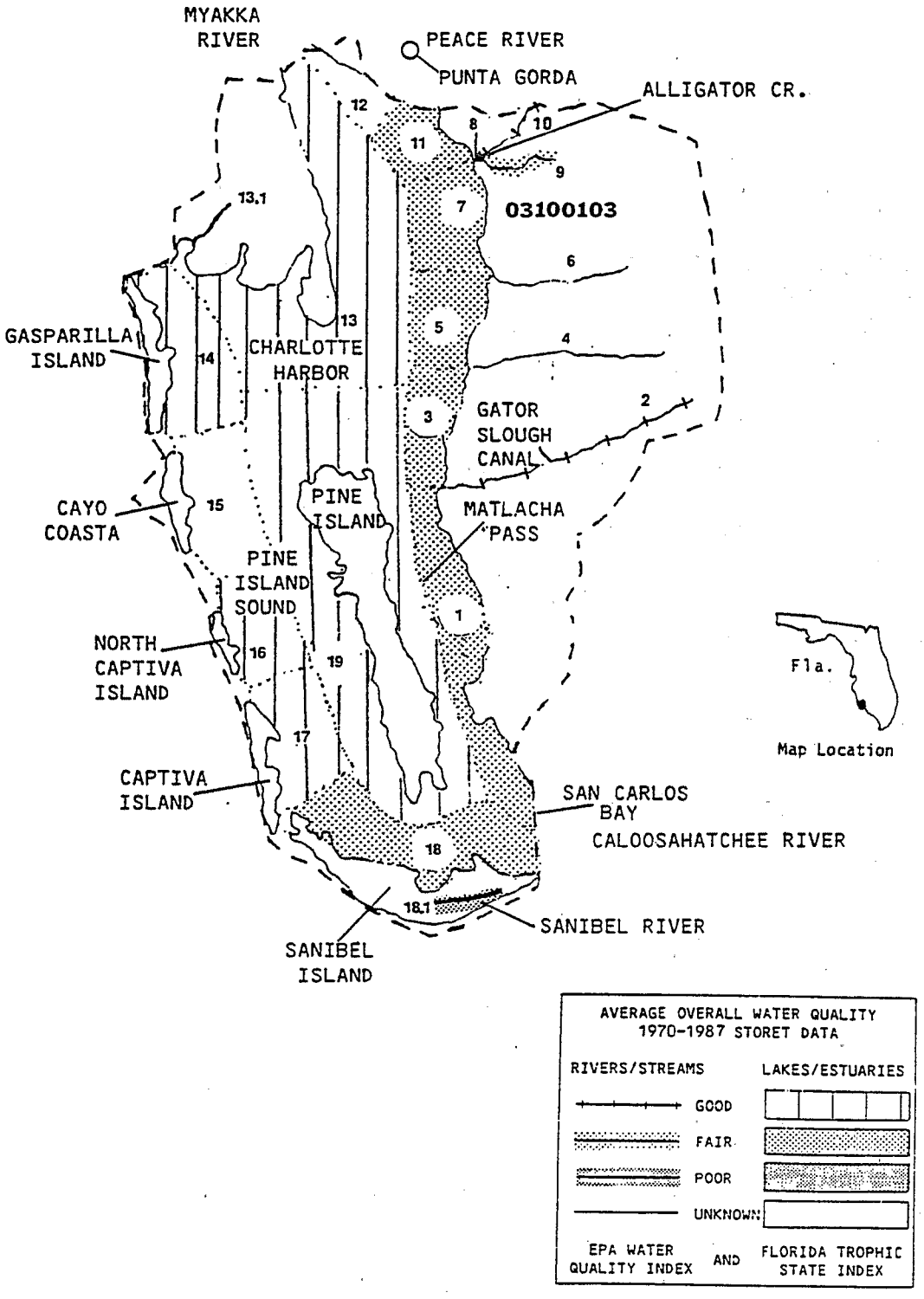


Figure F11. Charlotte Harbor basin [from 305(b) report of Hand *et al.* (1988c)].

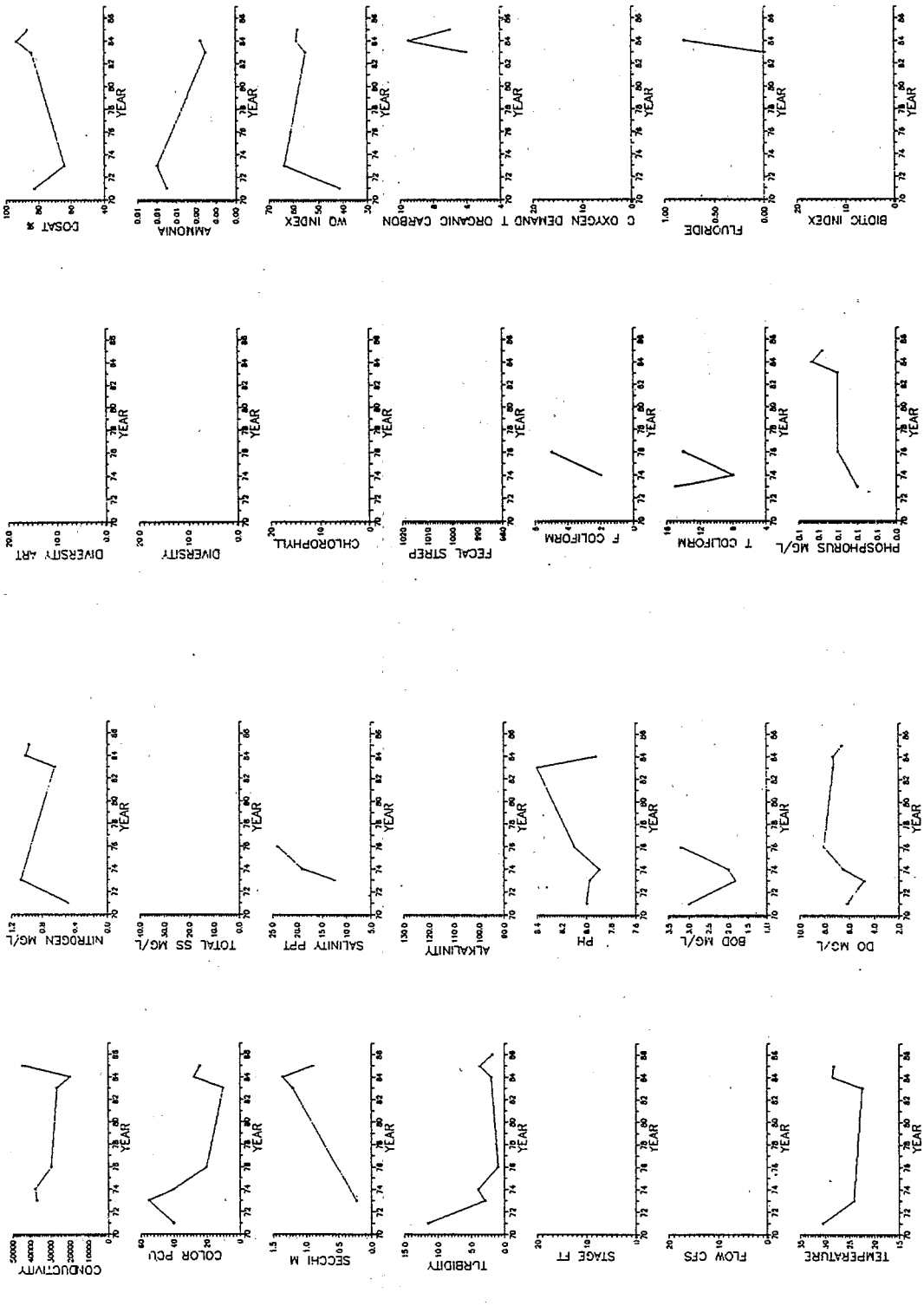


Figure F12. Representative water quality data from Charlotte Harbor above Caloosahatchee River (from Hand *et al.*, 1988c).

some degree by urbanization at the mouth of the Peace River. Because of the rapid urbanization in the basin, a comprehensive environmental assessment of the area is being conducted by the U.S. Geological Survey.

The long-term (1976-1984) water quality characteristics in upper Charlotte Harbor were examined for evidence of temporal trends (Fraser, 1986). The data suggested an increasing trend for temperature and orthophosphate and a decreasing trend for near-surface dissolved oxygen (Figure F13). The temperature trend was related to low winter temperatures early in the period. The orthophosphate trend was related to a major source, the Peace River. The source of the dissolved oxygen trend was not identified, but a relation with primary producers was likely. Evidence of a trend was not found for total phosphate, reactive silica, and organic nitrogen (Figure F14). Nitrate plus nitrite and ammonia data were not sufficient for analysis.

Often, red tides of *Gymnodinium breve* move from offshore waters (see Section F-15.1) into Charlotte Harbor (Finucane, 1964). A compilation by Estevez *et al.* (1984) counted 24 red tides in the Charlotte Harbor region since 1900 (along with other natural "catastrophes" such as hurricanes and freezes).

REFERENCES: F-13

Dragovich *et al.* (1961)
Dragovich *et al.* (1966)
Estevez *et al.* (1984)
Finucane (1964)
Fraser (1985)
Graham (1954)
Hand *et al.* (1988c)
Huang and Goodell (1967)
Miller *et al.* (1990)
Taylor (1974/75)
Williams and Ingle (1966)
Williams *et al.* (1990)

F-14 Sarasota Bay

Sarasota Bay connects with the Gulf of Mexico through three tidal passes and is also connected with Tampa Bay through Anna Maria Sound to the north which receives the inflow of the Manatee River. Little Sarasota Bay and Lemon Bay are connected to Sarasota Bay on the southern end through tidal passes. Three freshwater streams contribute to the freshwater inflow to Sarasota Bay. To various degrees, all tributaries to Sarasota Bay have been channelized or otherwise modified to facilitate stormwater drainage (Flannery, 1989). Because Sarasota Bay does not possess any significant water flow-through characteristics and net tidal transport through the system is minimal, any pollutants entering the Bay will have relatively long residence times prior to eventually being flushed out into the Gulf of Mexico (Delfino *et al.*, 1984).

The Sarasota Bay area is experiencing many of the growth-related problems that are occurring elsewhere in the region, although most of its development having adverse environmental impact has occurred only in the last 50 years (Estevez and Merriam, 1989). The barrier islands are completely developed, and nearly the entire upland watershed is also developed. Most development is residential, light commercial and tourist with no heavy industry; percentage of agricultural land is low and decreasing due to urbanization. Direct and indirect effects of dredging and filling have not been evaluated with respect to water quality but are considered serious (Estevez and Merriam, 1989). The bay supports an extensive recreational industry and is showing signs of overuse (Estevez and Merriam, 1989). Sarasota Bay was identified in the National Estuarine Program for priority consideration as a national estuary (Hand *et al.*, 1988i) in 1987 and was designated by the U.S. EPA as part of the National Estuary Program in July 1988.

A series of comprehensive studies were conducted to assess the environmental status of the Bay [Tiffany (1980) cited in Delfino *et al.* (1984)]. Turbidity was suggested as being responsible for the decline in the seagrass community, while biological diversity indices indicated that Sarasota

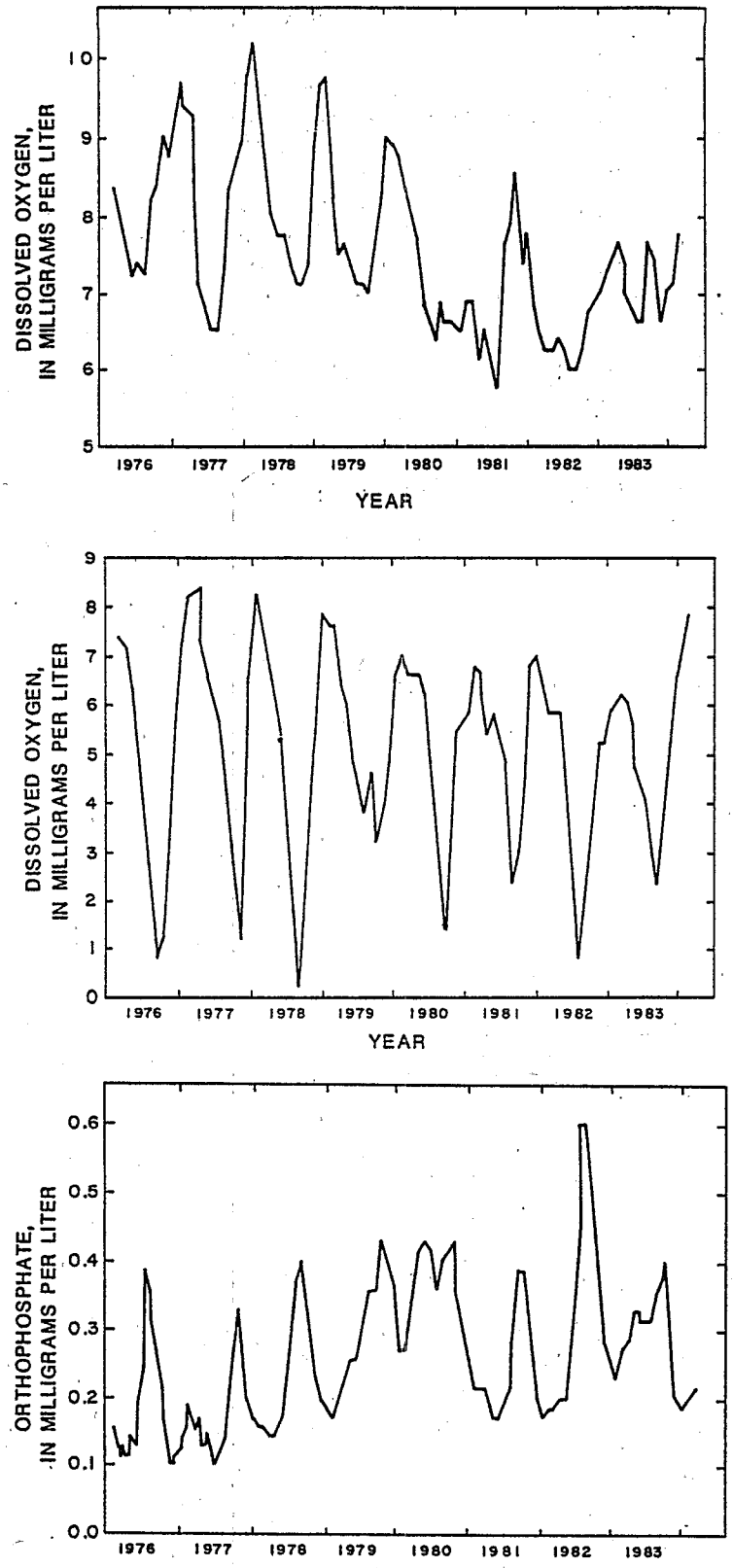


Figure F13. Three-month moving average for near-surface dissolved oxygen (upper panel), near-bottom dissolved oxygen (middle panel, and near-surface orthophosphate, as P (lower panel) for upper Charlotte Harbor (from Fraser, 1986).

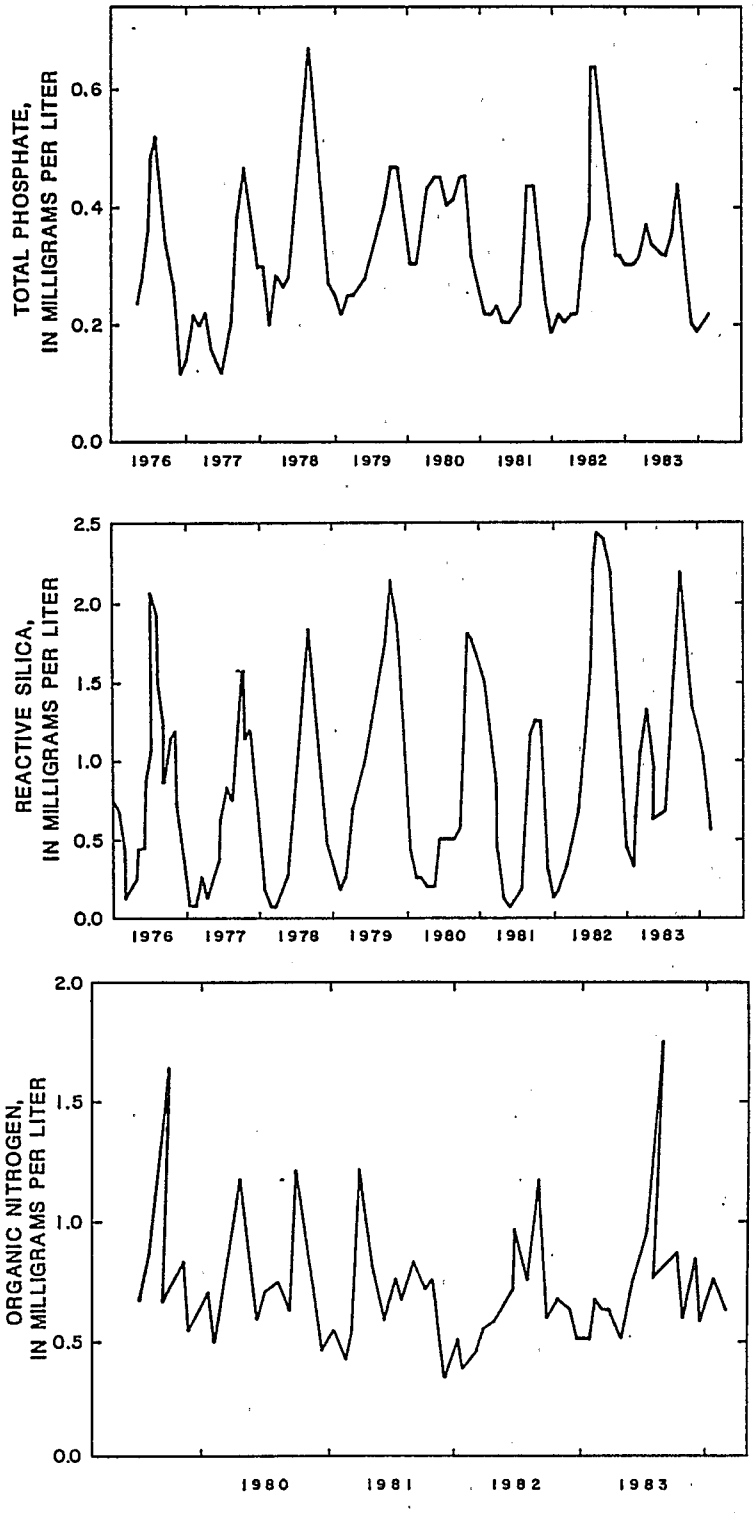


Figure F14. Average monthly near-surface and near-bottom total phosphate concentration, as P (upper panel), average monthly near-surface and near-bottom reactive silica concentration, as Si (middle panel), and three-month moving average for near-surface organic nitrogen, as N (lower panel) for upper Charlotte Harbor (from Fraser, 1986).

Bay is a moderately stressed ecosystem. High zinc concentrations were found in organisms from the Bay and indicated an anthropogenic influence on the biota. A variety of water quality parameters (including nutrients, turbidity and dissolved oxygen) were measured on a monthly basis since 1960 (Larkin and Tiffany, 1984) [also cited in Delfino *et al.* (1984)].

Water quality data are available for the tributaries to Sarasota Bay including the two largest drainage systems, Whitaker Bayou and Phillippi Creek (Table F2 in Section F-15) (Flannery, 1989). Nutrient concentrations are very high near the mouth of Whitaker Bayou due to discharges from the City of Sarasota's wastewater treatment plant. The plant discharges an average of 8.3 mgd of secondarily treated effluent during 1987, but all discharges to the bayou were scheduled to cease in late 1988. The City's wastewater treatment plant is overloaded due to rapid development (Hand *et al.*, 1988I) and has a long history of enforcement actions. Phillippi Creek, which is highly channelized and drains into Little Sarasota Bay, similarly receives domestic wastewater discharges in addition to stormwater runoff. Nutrient concentrations at one station in the creek, particularly for nitrogen species, were high (Table F2 in Section F-15), with greater concentrations found upstream closer to point source discharges. Agricultural and urban stormwater runoff is a problem in the basin (Hand *et al.*, 1988i), and many of the streams running through developed areas are affected by septic tanks. Tributaries and direct runoff supply the bay systems with heavy nutrient loading. Seagrass beds are declining in upper Sarasota Bay, especially the eastern side, presumably because high algal concentrations are reducing transparency (Hand *et al.*, 1988i). Runoff from the Bradenton area and the Manatee County wastewater treatment plant sprayfields (a flower farm) provide further nutrient loading.

According to the most recent 305(b) report (Hand *et al.*, 1988i), the water quality of the bays is rated good to fair; that of the tributaries, rated fair to poor (Whitaker Bayou) (Figure F15). Representative water quality data for Sarasota Bay are shown in Figure F16. Nearly all the streams which enter the Sarasota Bay estuarine system have dissolved oxygen problems, similar to other southern Florida areas. Sarasota Bay, Little Sarasota Bay (Figure F17) and Lemon Bay have been declared Outstanding Florida Waters, which should afford them greater protection from both point source and nonpoint source pollution. However, all are threatened by increased boat traffic, landscape alterations, and replacement of mangroves by lawns and drainage canals. Lemon Bay and Little Sarasota Bay have the most pronounced degrading trends (Hand *et al.*, 1988i). Incomplete nutrient and other data suggest a general trend of improvement and a decline in salinity which has been most evident along the mainland shore (Figure F15). The decline in salinity has been attributed to urban stormwater runoff (Heyl and Dixon, 1988, cited in Estevez and Merriam, 1989). The water quality rating in the Hand *et al.* (1988i) report was downgraded from that of the Hand and Jackman (1984) assessment given in Windsor (1985).

Between 1948 and 1979, there was a 54 % decrease in seagrass cover along the eastern bay; a 65 % loss around New Pass; and an 83 % loss around Whitaker Bayou (Sauers and Patten, 1981, cited in Estevez and Merriam, 1989). Baywide losses are estimated at 20 to 30 % (Steidinger and Phillips, 1988, cited in Estevez and Merriam, 1989). Causes of these losses are not definitely known, but turbidity from dredging and organic enrichment are suspected (Estevez and Merriam, 1989). Loss of suitable habitat indirectly effects secondary production (e.g., scallop, oyster and hard clam populations; blue crab, bait shrimp and mullet landings, red drum and snook stocks).

Often, red tides of *Gymnodinium breve* move from offshore waters (see Section F-15.1) into Sarasota Bay (*e.g.*, 1971) and can cause fish kills (Finucane, 1964; Steidinger, 1973). A red tide caused by the toxic dinoflagellate, *Gonyaulax monilata*, was widespread along the west coast in August 1966 as well as within Sarasota Bay and adjacent waters (Williams and Ingle, 1972).

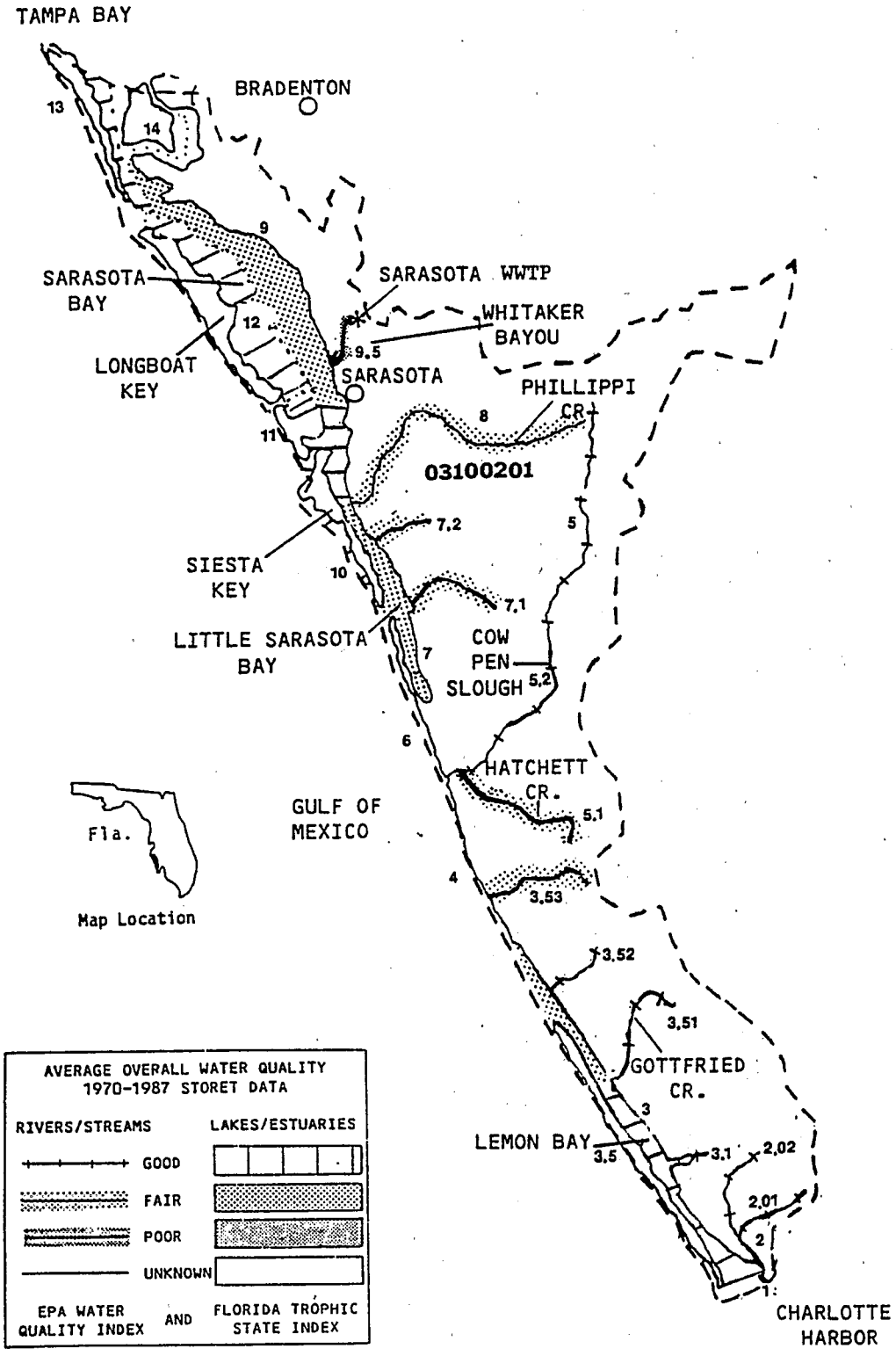


Figure F15. Sarasota Bay basin [from 305(b) report of Hand *et al.* (1988i)].

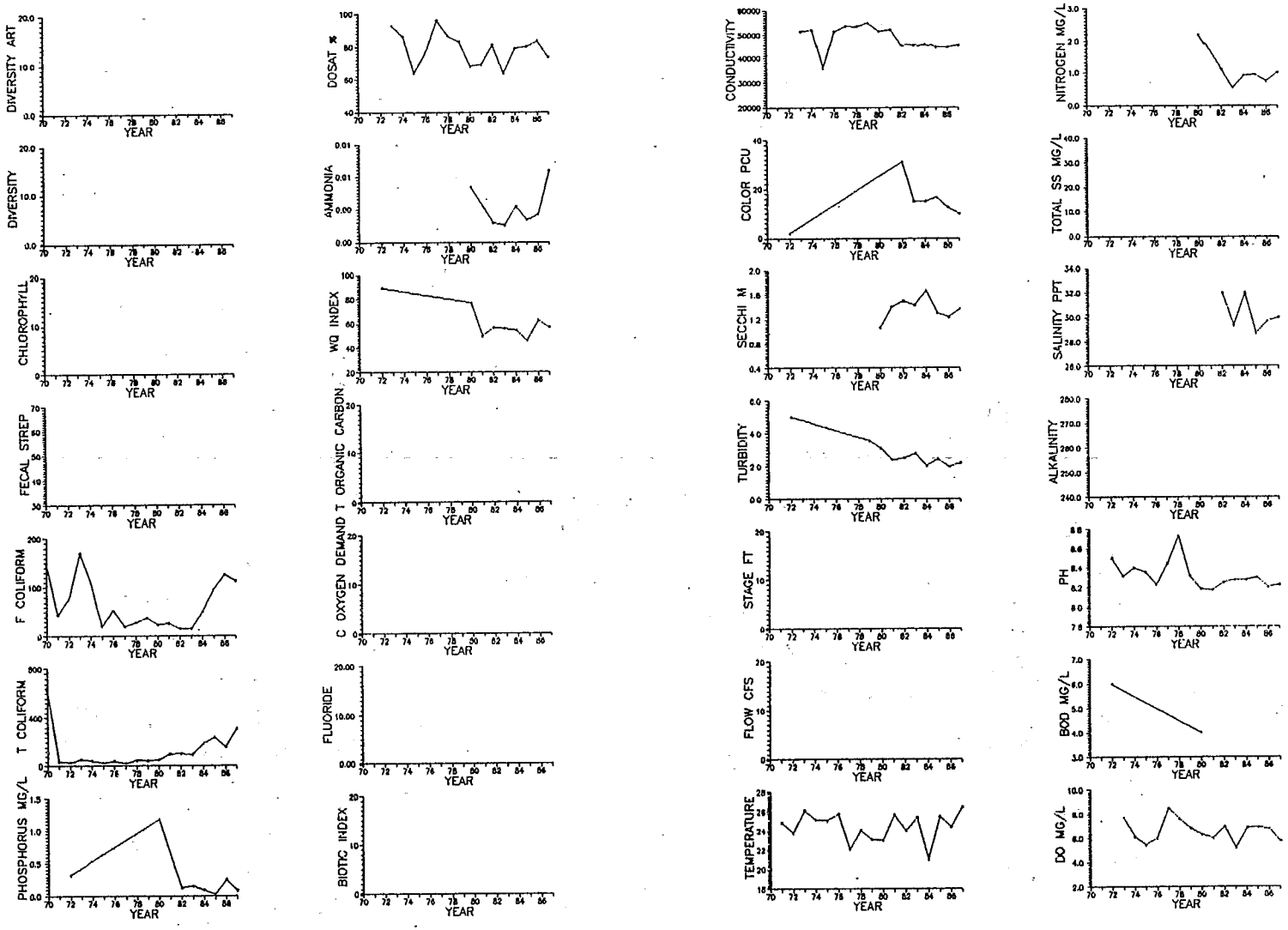


Figure F16. Representative water quality data from Longboat Key above Sarasota Bay (from Hand *et al.*, 1988i).

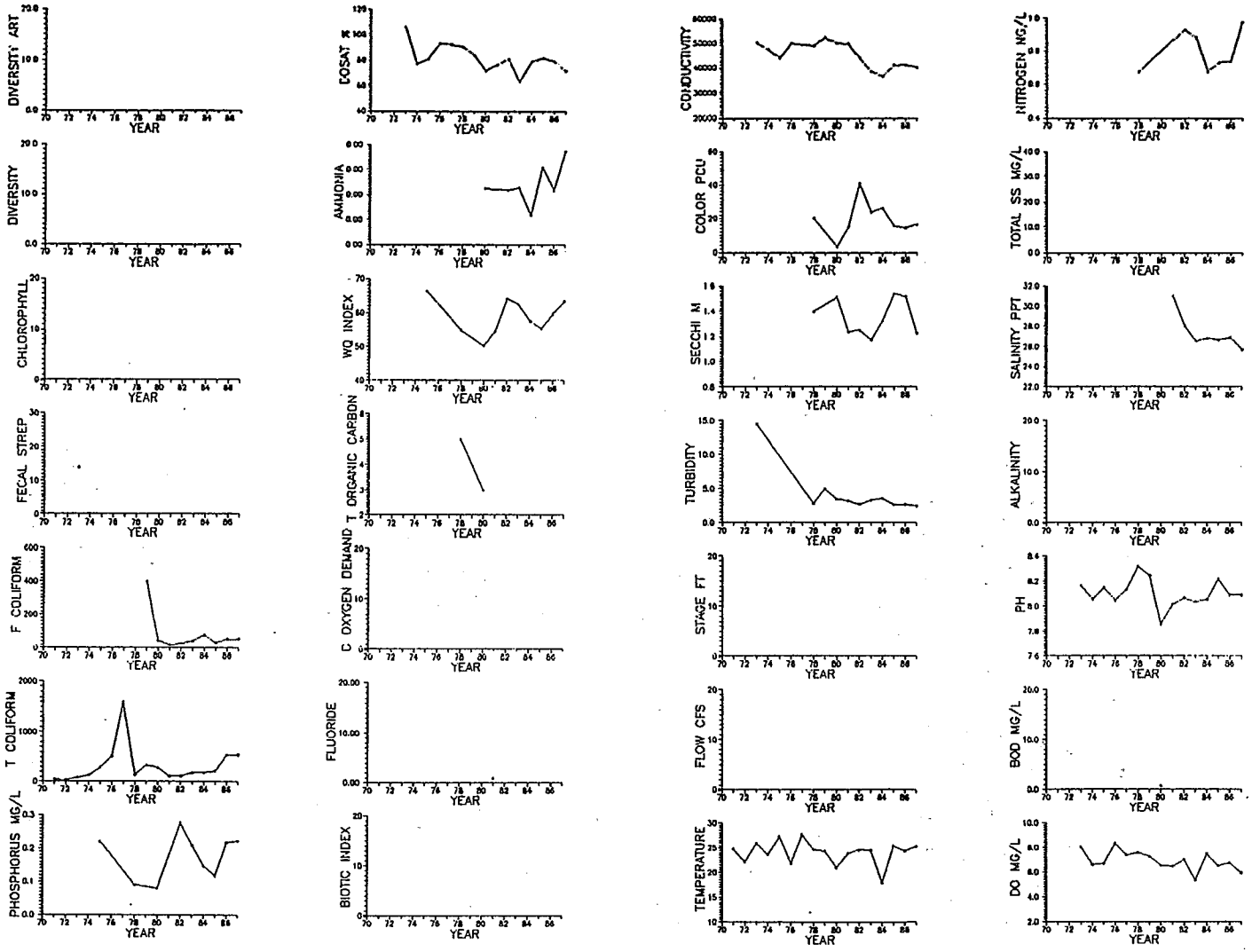


Figure F17. Representative water quality data from Little Sarasota Bay above Catfish Creek (from Hand *et al.*, 1988i).

REFERENCES: F-14

Buck and Pierce (1989)
Dragovich *et al.* (1961)
Estevez (1989)
Finucane (1964)
Flannery (1989)
Graham (1954)
Hand *et al.* (1988i)
Lewis (1989)
Williams and Ingle (1966)

F-15 Tampa/Old Tampa/Hillsborough Bays

Tampa Bay is the largest of Florida's estuaries. It is subdivided into a number of distinct water bodies including Old Tampa Bay, Hillsborough Bay, Middle and Lower Tampa Bay, Terra Ceia Bay, and Boca Ciega Bay (Figure F18). Major surface waters that flow into the bay include the Alafia, Hillsborough, Manatee, Braden and Palm Rivers, and Booker, Bullfrog, and Sweetwater Creeks (Figures F18 and F19); small tributaries and tidal creeks are additional important components of the Tampa Bay estuarine drainage area. Tampa Bay and its contiguous water bodies have been the site of numerous studies.

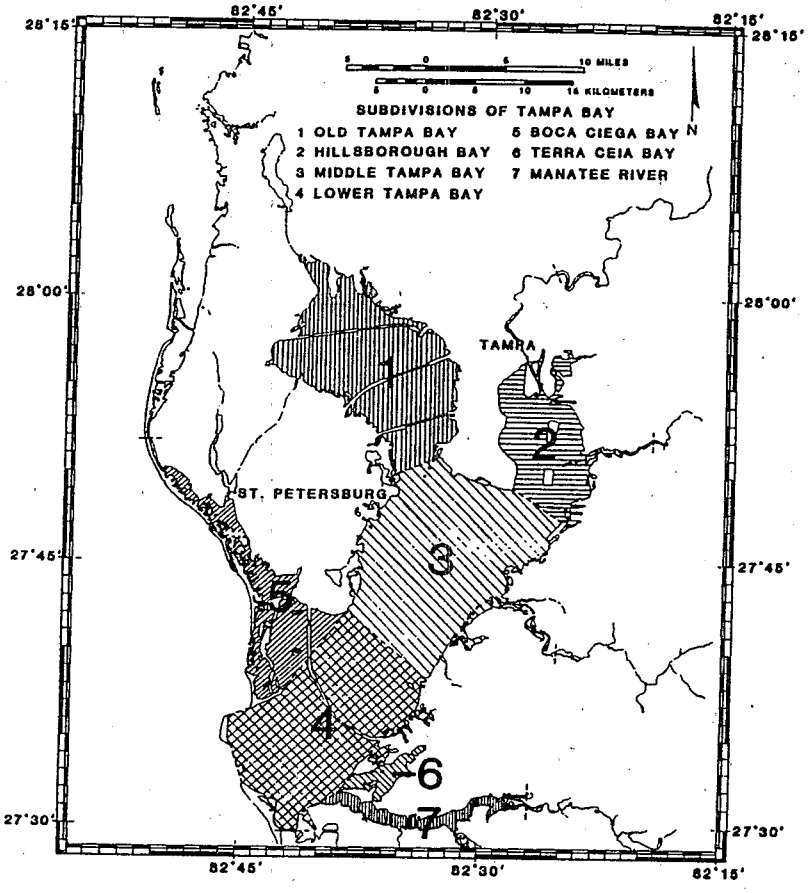


Figure F18. Subdivisions of Tampa Bay (from Clark and MacAuley, 1989).

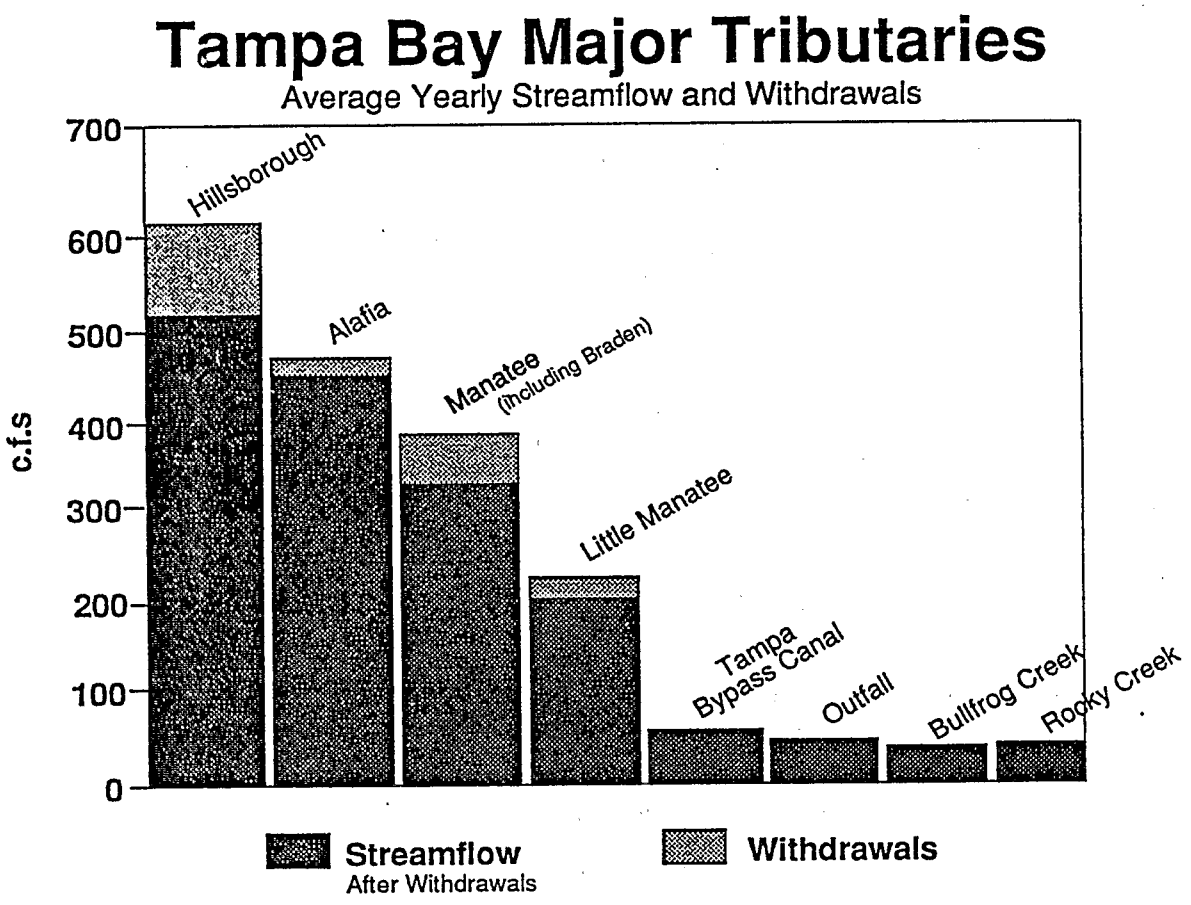


Figure F19. Average yearly streamflow and withdrawals from eight tributaries to Tampa Bay (from Flannery, 1989).

Many activities impact the water quality of this system. The estuary is urbanized, and development activities have substantially altered natural processes (Lewis and Estevez, 1988). Water quality has degraded in much of the bay because of the current discharge of treated sewage and industrial wastes, historical discharges of untreated or poorly treated wastes, and urban stormwater discharges. Population is expected to increase by 50 % per decade; continued expansion of the Port of Tampa is expected (Lewis and Estevez, 1988).

Tampa Bay receives more domestic waste than other Florida Gulf coast areas (Figure F20, see also Figure F2). For years, the Tampa Sewage Treatment Plant provided primary treatment and the others secondary (Estevez *et al.*, 1984); the result has been a progressive eutrophication of Hillsborough Bay. The reversal of these trends is documented below. Phosphate mineral extraction and processing is a prevalent industrial activity in the Tampa Bay area. Studies of the discharges indicated elevated levels of total phosphorus, fluorides and radionuclides in the thermal effluents; impacts to the fauna have been documented (several studies cited in Estevez *et al.*, 1984). Dredging for fill material, either as sand or as oyster shell, was at one time a large industry in the Tampa Bay system. Oyster shell has been dredged from Hillsborough Bay for some time (Estevez *et al.*, 1984), and impacts were seen as increased turbidity, and immediate species loss, density

decline and biomass decrease (several studies cited in Estevez *et al.*, 1984). Current regulations limit the leases and dredging activities.

Water quality data for streams flowing to Tampa Bay is quite extensive and was summarized by Flannery (1989). Overall, tributaries to Tampa Bay contain high levels of nutrients, both total phosphorus and nitrogen species (Figure F21). Mean total phosphorus values listed in Table F2 ranged from 0.3 to 0.77 mg/l, with the exception of Alafia River and Delaney Creek with mean values of 2.4 and 2.7 mg/l. For the remaining tributaries, phosphorus values were highest for those impacted by urban runoff or point source discharges. The concentration of nitrogen species in tributaries is important because primary production in Tampa Bay is primarily nitrogen limited.

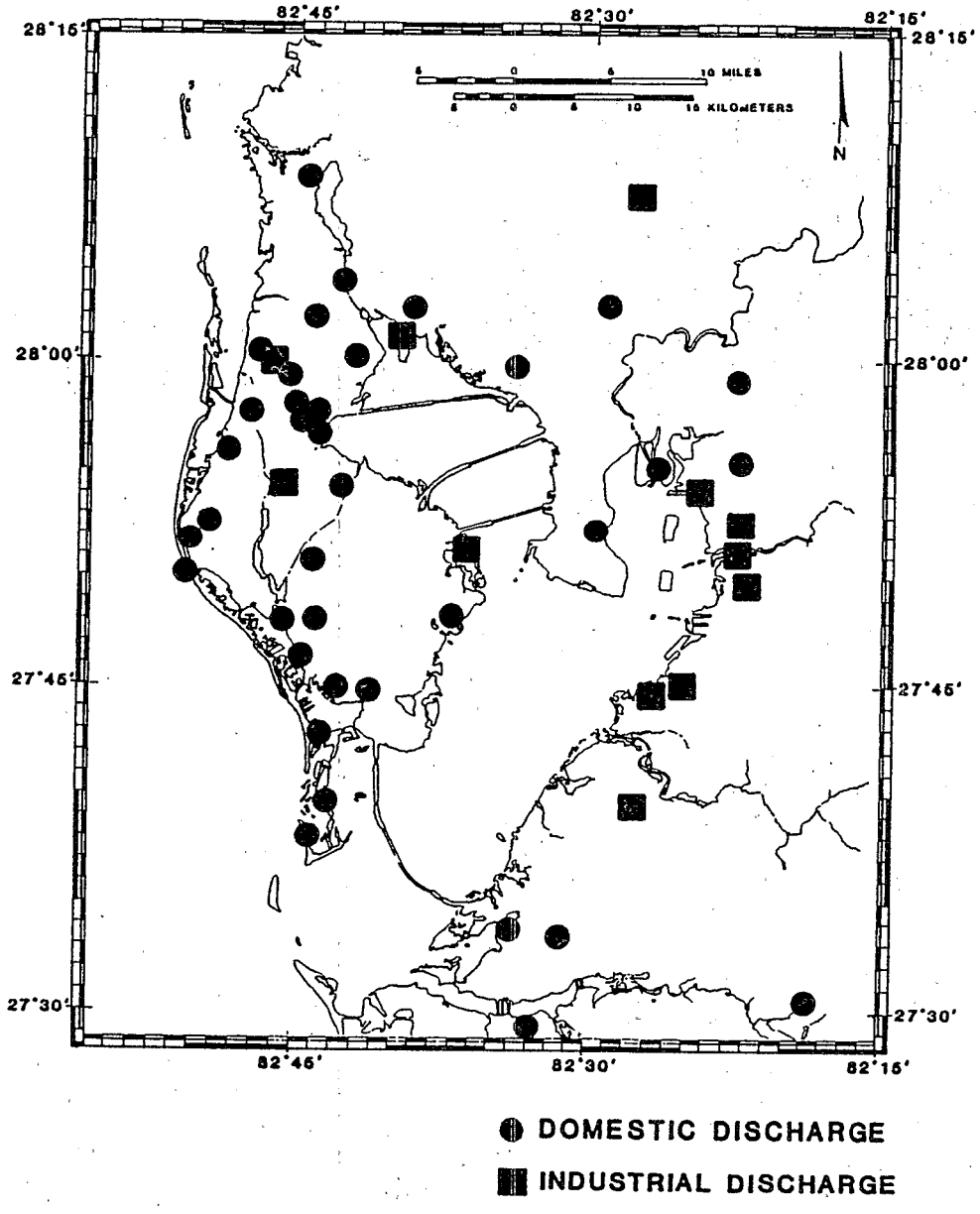
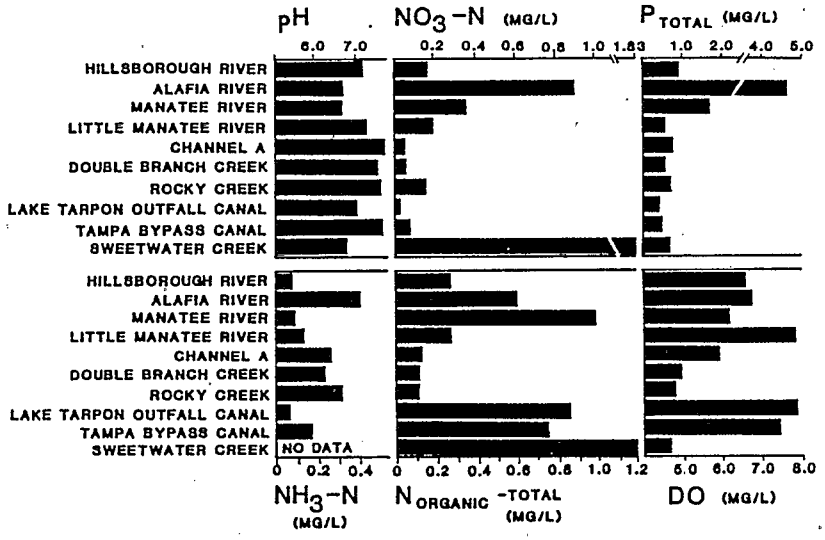
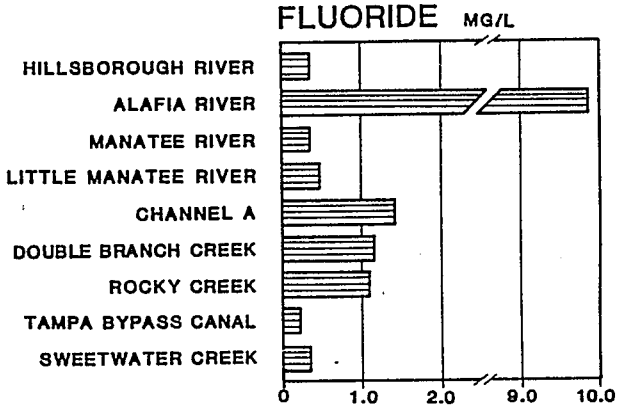


Figure F20. Reported discharge sources, Tampa Bay area, 1980 (from Moon, 1985).





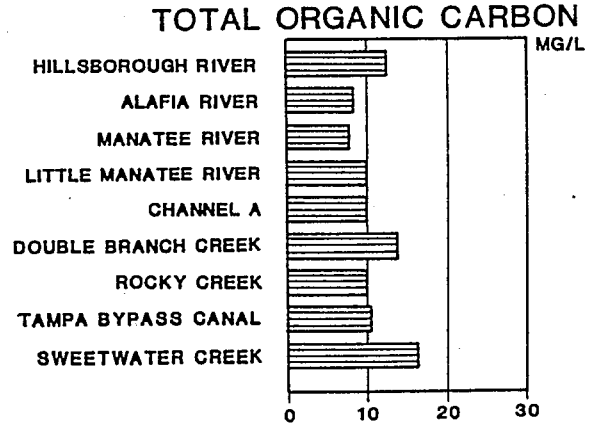


Figure F21A. Conductance of selected streams entering Tampa Bay.
Figure F21B. Data for selected chemical parameters for streams entering Tampa Bay.
Figure F21C. Mean concentrations of fluoride and total organic carbon for streams entering Tampa Bay (from Dooris and Dooris, 1985).

Table F2. Mean concentrations of selected nutrients for nineteen tributaries to Tampa and Sarasota Bays (from Flannery, 1989).

Tributary	Period	N[1]	Total P	Total N	Organic N	NO_{3+} NO_2	NH_3 N	Color	BOD	Source
1. Booker Creek[2]	07/75-05/80	11	0.50	2.40	2.10	0.16	0.14	—	4.9	Lopez & Giovannelli 1984
2. Allen Creek[2]	07/75-05/80	28-34	0.52	2.40	1.80	0.45	0.22	—	5.6	Lopez & Giovannelli 1984
3. Alligator Creek	10/83-09/85	13	0.45	1.36	0.93	0.29	0.14	—	2.0	USGS 1986a, 1986b
4. Lake Tarpon	10/83-09/85	12	0.06	0.65	0.47	0.09	0.09	55	—	USGS 1986a, 1986b
5. Double Branch Creek[3]	01/84-12/85	24	0.33	1.19	0.98	0.06	0.14	80	1.7	HEPC 1986
6. Rocky Creek (upper)	10/83-09/85	12	0.78	1.27	0.67	0.47	0.13	—	—	USGS 1986a, 1986b
7. Sweetwater Creek[3]	01/84-12/85	24	0.31	1.33	0.89	0.19	0.25	32	1.7	HEPC 1986
8. Gandy Blvd. Ditch[2]	07/75-05/80	20	0.30	0.76	0.66	0.24	0.40	—	5.0	Lopez & Giovannelli 1984
9. Hillsborough R. (Fowler Ave.)	10/83-09/85	12	0.34	1.06	0.66	0.37	0.04	55	—	USGS 1986a, 1986b
10. Hillsborough R. (S.R. 585)	01/84-12/85	24	0.36	1.17	0.93	0.11	0.13	43	1.8	HEPC 1986
11. Tampa Bypass Canal	01/84-12/85	24	0.54	1.50	1.19	0.11	0.20	24	3.4	HEPC 1986
12. Delaney Creek[3]	01/84-12/85	24	2.67	24.10	4.00	9.70	11.30	67	5.1	HEPC 1986
13. Alafia River	01/84-12/85	24	2.40	1.87	0.49	1.30	0.08	39	0.08	HEPC 1986
14. Little Manatee R.	01/84-12/85	24	0.38	1.32	0.60	0.63	0.09	52	1.3	HEPC 1986
15. Manatee R. (upper)	10/83-09/85	4	0.29	0.44	0.34	0.04	0.05	65	1.1	USGS 1986a, 1986b
16. Manatee R. (reservoir site 1)	01/84-12/85	24	0.21	0.91	0.71	0.10	0.10	131	2.5	Manatee Co. Unpubl. data
17. Manatee R.[3] (lower zone 3)	02/82-03/83	12	0.20	1.43	1.28	0.11	0.04	—	1.8	Manatee Co. & Camp, Dresser & McKee, Inc. 1984
18. Whitaker Bayou[3]	01/84-12/85	6-9	1.53	6.14	2.37	0.24	3.53	—	—	Sarasota Co. 1985, 1986
19. Phillippi Creek	01/84-12/85	6-9	0.97	2.98	1.20	1.03	0.75	—	—	Sarasota Co. 1985, 1986

All units expressed as mg/l except color (Pt-Co units).

[1]Number of observations.
[2]Stormwater runoff samples, flow-weighted average.
[3]Brackish stations.

Table F3. Estimated average annual loading of selected nutrients for seven tributaries to Tampa Bay. Asterisks denote results that should be viewed with caution, as they do not account for substantial downstream nutrient additions (from Flannery, 1989).

	AVERAGE ANNUAL LOADING (Kg/Year)			
Tributary	Total P	Total N	Organic N	NO_{2+} NO_3
Alafia River (14) and Lithia Springs	9.2×10^5	8.6×10^5	1.9×10^5	6.4×10^5
Hillsborough River (9)*	1.7×10^5	5.2×10^5	3.2×10^5	1.8×10^5
Manatee River (16)*	6.9×10^4	3.0×10^5	2.3×10^5	3.3×10^5
Little Manatee River (15)	7.9×10^4	2.7×10^5	1.2×10^5	1.3×10^5
Tampa Bypass Canal (12)	2.7×10^4	7.6×10^4	6.0×10^4	5.5×10^3
Rocky Creek (6)*	2.6×10^4	4.2×10^4	2.2×10^4	1.5×10^4
Lake Tarpon Outfall (4)	2.2×10^3	2.4×10^4	1.7×10^4	3.3×10^3

With the exception of Delaney Creek, mean ammonia concentrations in Table F2 ranged from 0.05 to 0.40 mg/l, with the highest values reported from streams with point source discharges or large urban runoff. Mean nitrate concentrations for the Alafia River (1.23 mg/l) and Delaney Creek (9.7 mg/l) were exceptionally high compared to other stations, which ranged 0.06-0.63 mg/l. Organic nitrogen and total nitrogen values were also high in many of the same tributaries named above (Table F2). The seven tributaries for which nutrient loading estimates were made (Flannery, 1989) are listed in Table F3. In total, the seven tributaries listed are estimated to contribute an average of 1.95×10^5 kg/yr total nitrogen and 1.35×10^5 kg/yr total phosphorus to Tampa Bay (substantial nutrient additions to the lower reaches of certain rivers not accounted for). These summed nutrient loading values gives a N:P ratio of 1.6, indicating that tributary inflow to the bay is very phosphorus enriched, much of which is due to the load of the Alafia River. The causes for these high phosphorus loadings include leaching of phosphate beds, agricultural runoff and point source discharges (Flannery, 1989).

Extensive data bases exist for Tampa Bay. A series of hydrographic surveys in Tampa Bay and the adjacent Gulf of Mexico, over a several year period, were conducted by Saloman and Taylor (1971a,b, 1972) and Saloman (1973, 1974), primarily as a supplement to red tide investigations, and provide an excellent historical baseline. Other data are collected by the Hillsborough County Environmental Protection Commission (HCEPC), 1972-1987, (*e.g.*, Boler, 1987), and many reviews and reports are available. The material presented below is taken from the summary of Lewis and Estevez (1988). Their review concentrated on water column chemical properties, rather than sediment chemistry, largely because the latter largely corroborates trends and patterns depicted by water quality data.

The general conclusions of Lewis and Estevez (1988) were that 1) Tampa Bay is not grossly "polluted," certainly not beyond the point of rehabilitation; 2) parts of the bay are "cleaner" than others for natural as well as cultural reasons; and 3) levels of some pollutants have been declining over the past decade, while others have increased. A generalized scheme of water quality based on ranked averaged values for total coliform bacteria, turbidity, chlorophyll *a* and organic or biochemical oxygen demand is given in Figure F22. Water quality in the lower bay is generally good to excellent, although the HCEPC documented a decline to poor in 1978 because of increased turbidity caused by harbor deepening. In summary, general water quality is good to excellent for much of Tampa Bay, declining in Old Tampa Bay, and undesirable in Hillsborough Bay. Terra Ceia Bay has very good water quality and has recently been declared an Outstanding Florida Water (Hand *et al.*, 1988m). Development around this bay threatens it with increased runoff and mangrove cutting; although there have been some enforcement cases which will deter the latter (Hand *et al.*, 1988m). The Pinellas County portion of Tampa Bay is also designated as an Outstanding Florida Water to protect it from further degradation; however, under current law, many of the existing discharges to the bay will be allowed to continue. Point sources throughout the Tampa Bay system, especially sewage treatment plant effluents, greatly affect water quality but improved effluents have resulted in improved water quality (Lewis and Estevez, 1988).

The water quality status of the components of Tampa Bay as reported in the 305(b) reports (Hand *et al.*, 1988m) summarizes water quality data from 1970-1987 (Figure F23), and general categorizations follow those given above in Lewis and Estevez (1988). Degradation of the water quality of Tampa Bay spurred intensive efforts over the last ten years (1975-1985) by local scientists, environmental organizations, politicians and engineers to reverse the trends. Protective management policies, legislation and regulation have been adopted. As a result, at least one portion of the Bay, Hillsborough Bay, has shown some recovery (Hand *et al.*, 1988m, and see below). Data for the Boca Ciega Bay section were included in the Crystal River 305(b) report (Hand *et al.*, 1988e). Water quality for the bay was rated as fair and tributaries to it, as fair to poor (see Figure F35 in Section F-16). Although only one station in Boca Ciega Bay has been consistently sampled, it appears that the bay has extremely high phosphorus values and moderately

high nitrogen and chlorophyll values (Figure F24). All of the tributaries in the area have pollution problems usually with elevated coliform and nutrient concentrations and depressed dissolved oxygen values. Two of these problems creeks, Long Bayou and the Cross Bayou Canal, have not been sampled recently, but the point and nonpoint pollution sources have not changed significantly since the last sampling. Bear Creek, which also receives urban drainage, appears to have organic and metal toxicity problems (Hand *et al.*, 1988e).

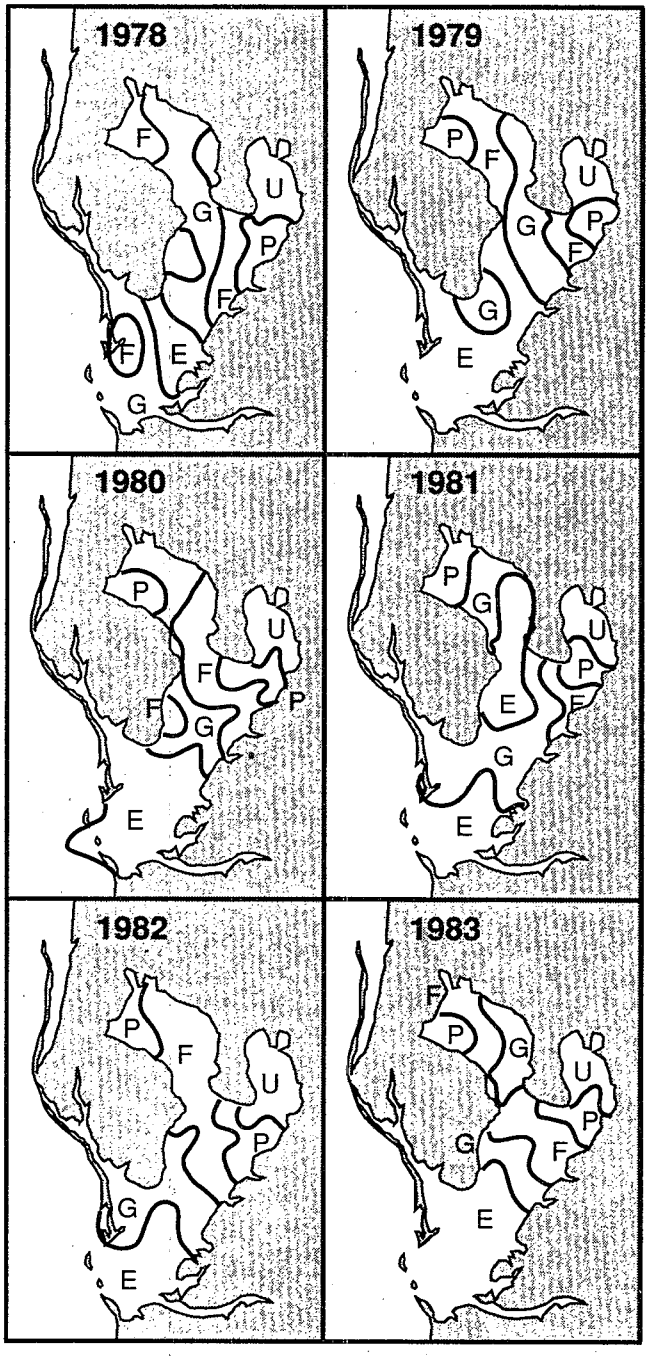


Figure F22. Trends in water quality for body contact in Tampa Bay since 1977 (HCEPC, 1978-1983). E=excellent, G=good, F=fair, P=poor, U=undesirable (adapted from Lewis and Estevez, 1988).

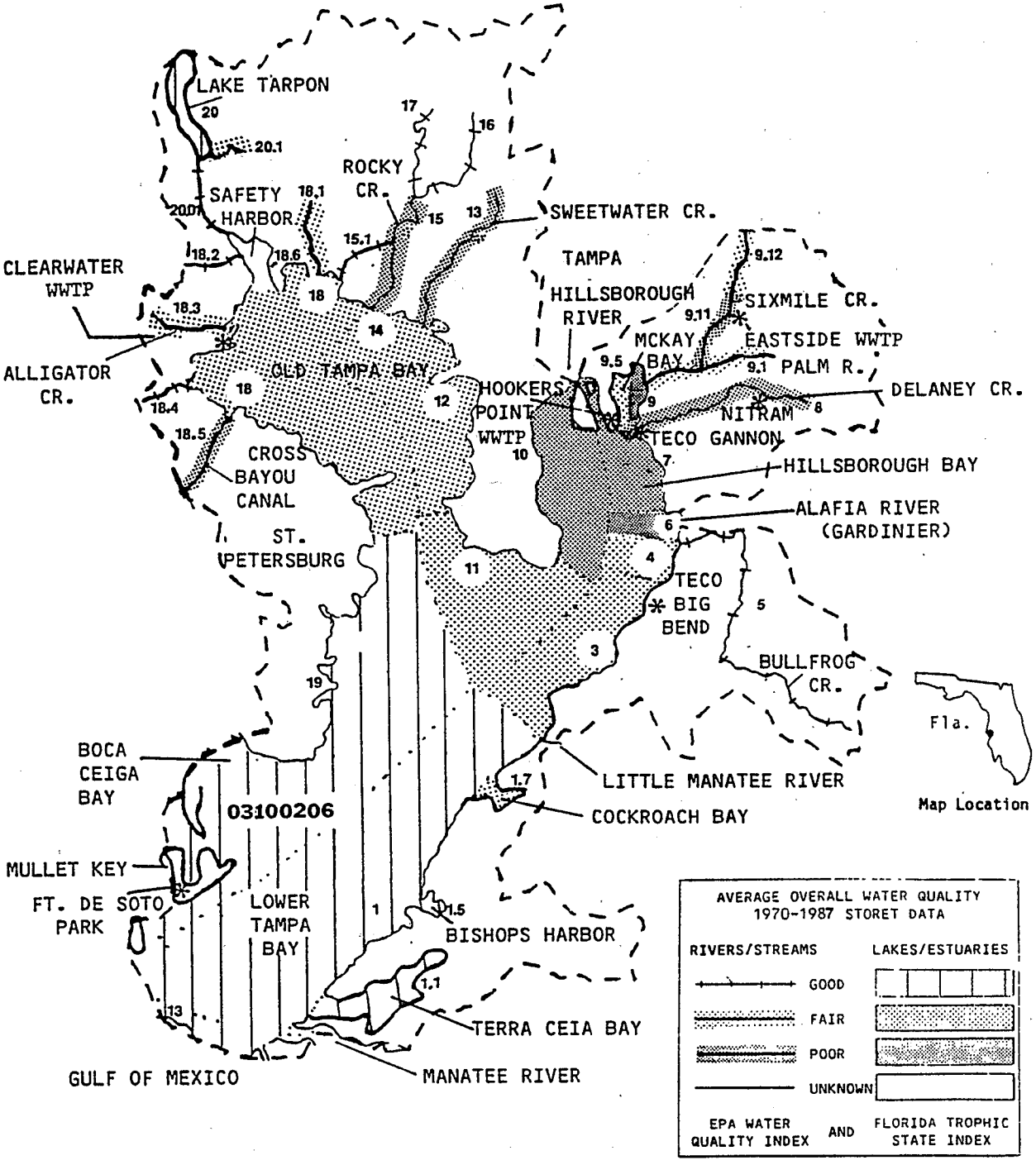


Figure F23. Tampa Bay basin [from 305(b) report of Hand *et al.* (1988m)].

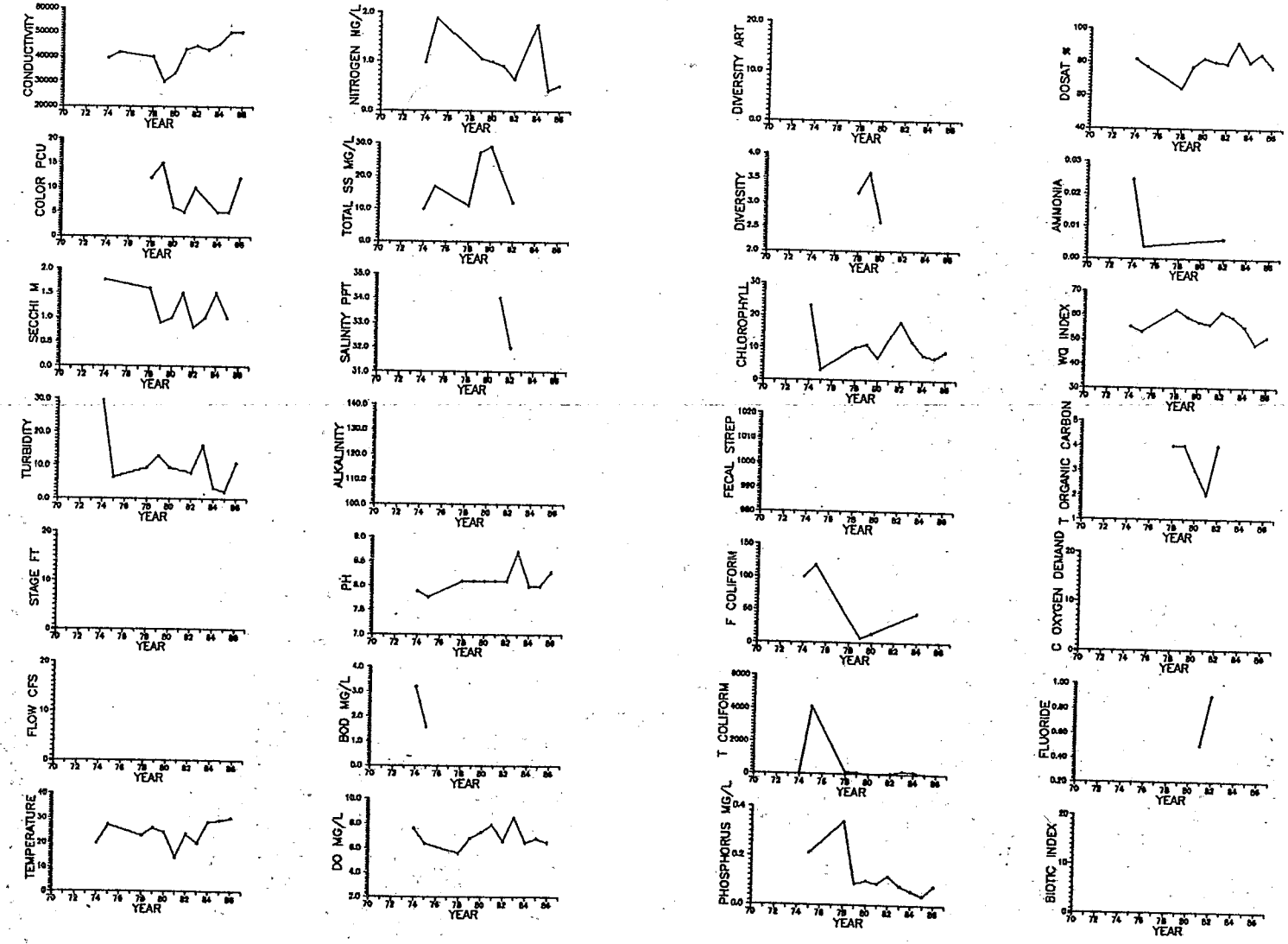


Figure F24. Represenative water quality data from Boca Ciega Bay above Tampa Bay (from Hand *et al.*, 1988e).

Low dissolved oxygen concentrations in parts of the Tampa Bay system are, in part, related to density stratification, especially in deeper waters of Tampa Bay and in Hillsborough Bay (Figure F25a), but also to phytoplankton blooms that are more frequent and prolonged in Hillsborough Bay. Mean dissolved oxygen levels vary among the components of the Tampa Bay system (Figure F25b) but have generally shown a decline (1975-1983), with the exception of Hillsborough Bay which has always been substantially lower (Figure F25c). The degree of oxygen stress in the Tampa Bay systems varies with the component areas (Lewis and Estevez, 1988). In Hillsborough Bay, annual anoxia affects density and diversity patterns of benthic invertebrates (Santos and Simon, 1980); fish kills are common in residential canals. The extent to which anoxic or near anoxic conditions in Tampa Bay are natural or cultural in origin is not known, but all circumstantial evidence implicates municipal wastes as the primary factor. Another measurement of the indirect effects of nutrient loadings to the system are seen in Secchi disk depths, which indicate a difference by bay component as well as a general decline from 1974-1985 (Figure F25d)

Tampa Bay is considerably enriched in phosphate (Lewis and Estevez, 1988), but there has been a reduction in mean annual phosphate concentration in Hillsborough Bay and other bay segments since 1972 (Figures F26-F28). The Alafia River is regarded as the primary source of phosphorus to Hillsborough Bay (see above), but this does not explain elevated levels of the nutrient in Tampa Bay. Also, the Little Manatee River drains similar geological formations, but concentrations and loads of phosphorus are very much lower. Contributions by the phosphate industry have been reduced by changes in technology and reduction of effluents.

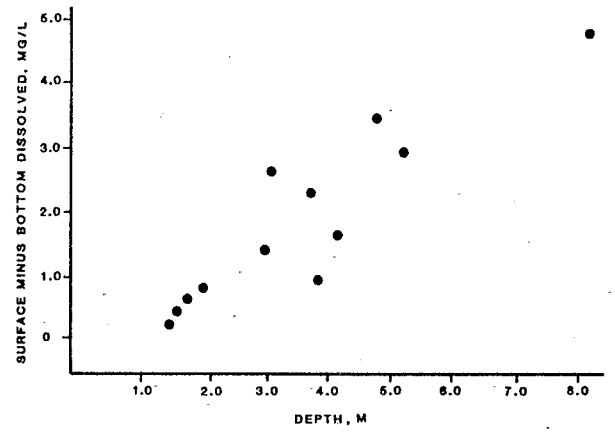
Nitrogen is generally regarded as the limiting macronutrient for primary production in Tampa Bay. The nitrogen loadings of the various tributaries was given above (see Table F3). A comparison made by Goetz and Goodwin (1980, as cited in Lewis and Estevez, 1988) showed high levels of organic nitrogen in Old Tampa Bay, medium values in upper Tampa Bay and at or below the same level in the lower bay, with little interannual or seasonal variability (Figure F29). Mean organic nitrogen concentration in Hillsborough Bay was much greater, and so was temporal variability. Nitrite and nitrate concentrations were low and steady everywhere in the bay, except in Hillsborough Bay. Ammonia levels were variable in all zones. Seasonality was evident for total inorganic nitrogen, which decreased substantially after rainy seasons (Lewis and Estevez, 1988).

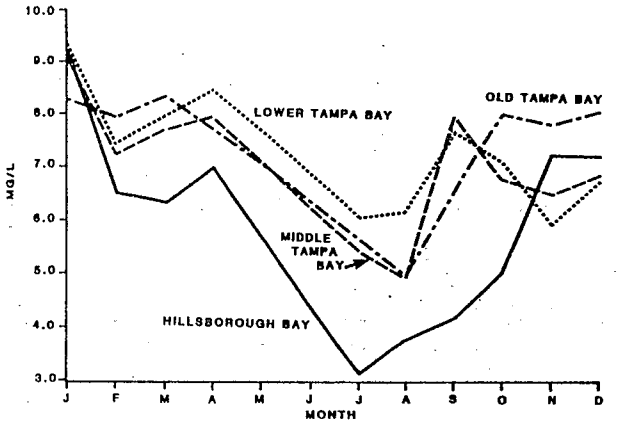
Fanning and Bell (1985, as cited in Lewis and Estevez, 1988) calculated a N:P ratio of 0.3 in 1971 and 1.3 in 1981 and concluded that phytoplankton have been nitrogen-limited since 1972. They cautioned, however, against an interpretation that nitrogen limitation has declined, because lower phosphate levels indicate that plants may be consuming more of the available phosphate.

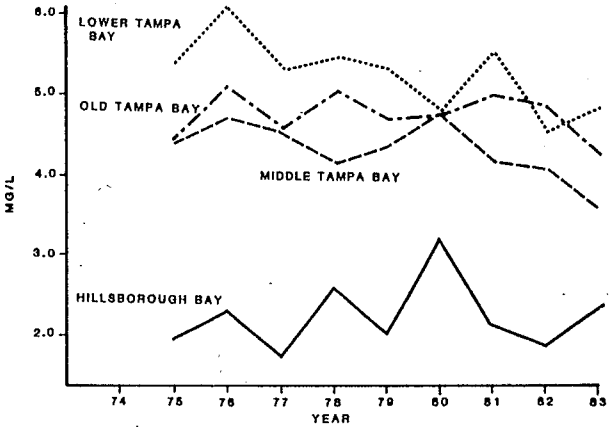
Both commercial and recreational fisheries are on a decline in Tampa Bay (Lewis and Estevez, 1988). Harvests of scallops and oysters have collapsed; shellfish landings peaked in 1956. Finfish landings peaked in 1964 and have shown a steady decline (Figure F30).

It is estimated that 44 % of the original intertidal wetlands and 81 % of the original seagrass meadow cover in the bay have been destroyed either by dredging and filling or pollution (Lewis and Estevez, 1988). Nutrient enrichment from improperly treated sewage discharges would contribute to increased phytoplankton standing stock in the water column and subsequent reduction in downwelling light and growth of epiphytic algae on the leaves of macrophytes; both would impact the biomass of submerged macrophytes.

Often, red tides of *Gymnodinium breve* move from offshore waters (see Section F-15.1) into the lower reaches of Tampa Bay (Dragovich *et al.*, 1963; Finucane, 1964; Steidinger, 1973). The red tide in 1971 lasted 3.5 mo and caused locally limited fish kills. Larger red tides occurred in 1946-1947, 1953-1954 and 1957 (Steidinger, 1973).







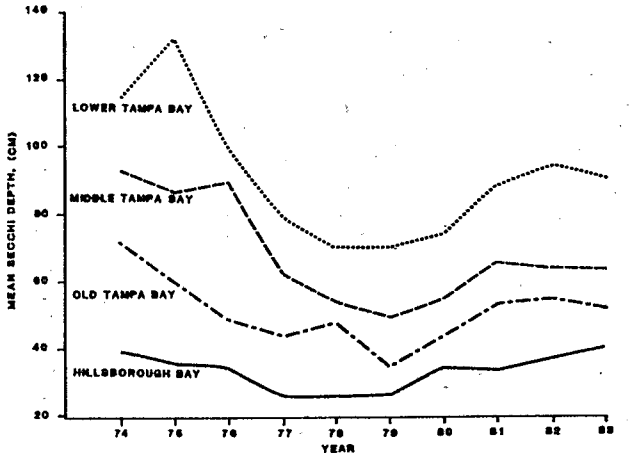


Figure F25A. Stratification of dissolved oxygen in Hillsborough Bay in relation to depth, 1981-1983.
Figure F25B. Mean monthly dissolved oxygen in 1982 near the bottom in Tampa Bay.
Figure F25C. Mean annual dissolved oxygen near the bottom in Tampa Bay.
Figure F25D. Mean annual effective Secchi disk depth (light penetration) in Tampa Bay (from Lewis and Estevez, 1988).

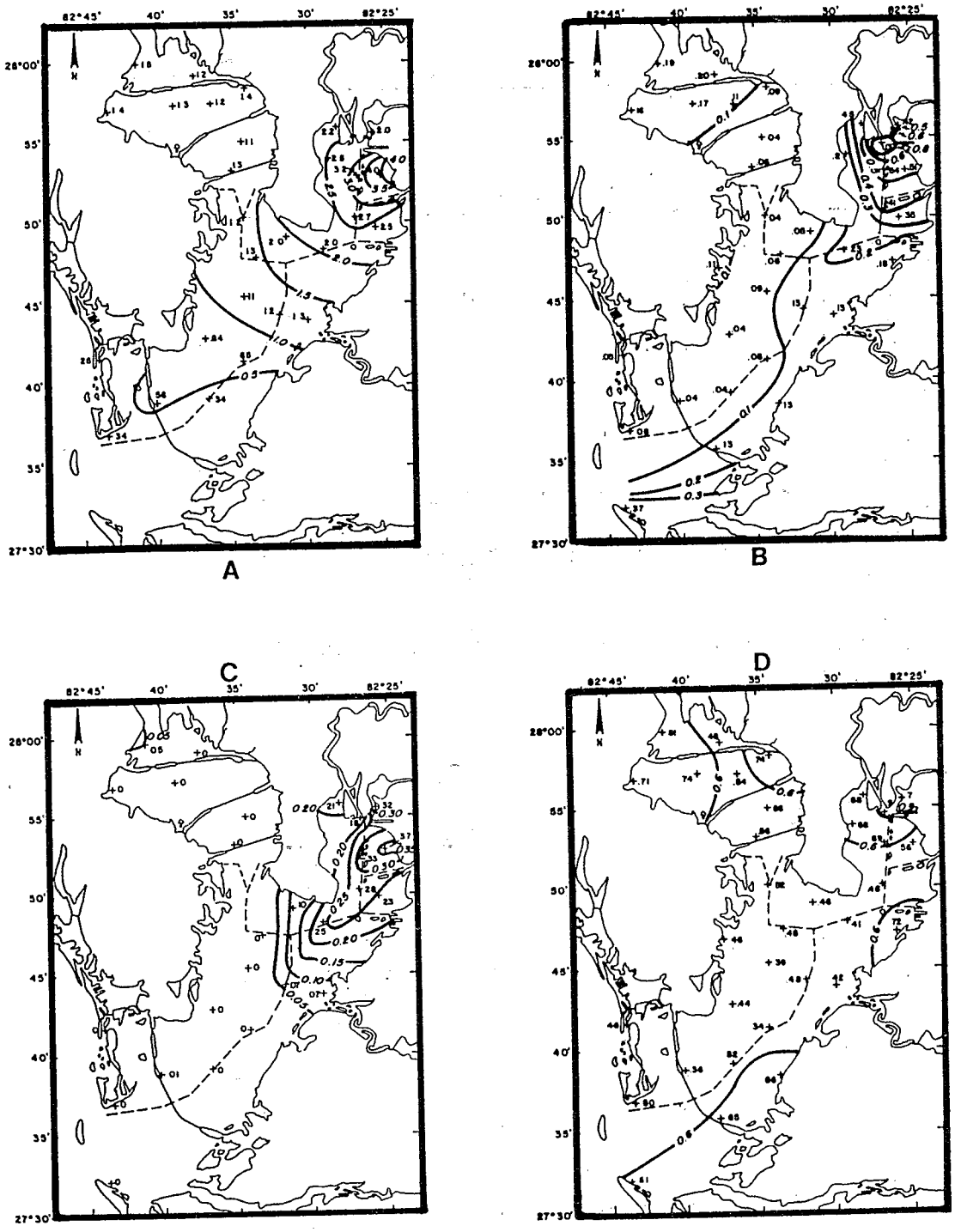


Figure F29. Nutrient distributions (in mg/l) in Tampa Bay. A, orthophosphate, Sept. 1972; B, ammonia, Dec. 1973; C, nitrate, Dec. 1972; D, organic-N, Dec. 1973 (from Lewis and Estevez, 1988).

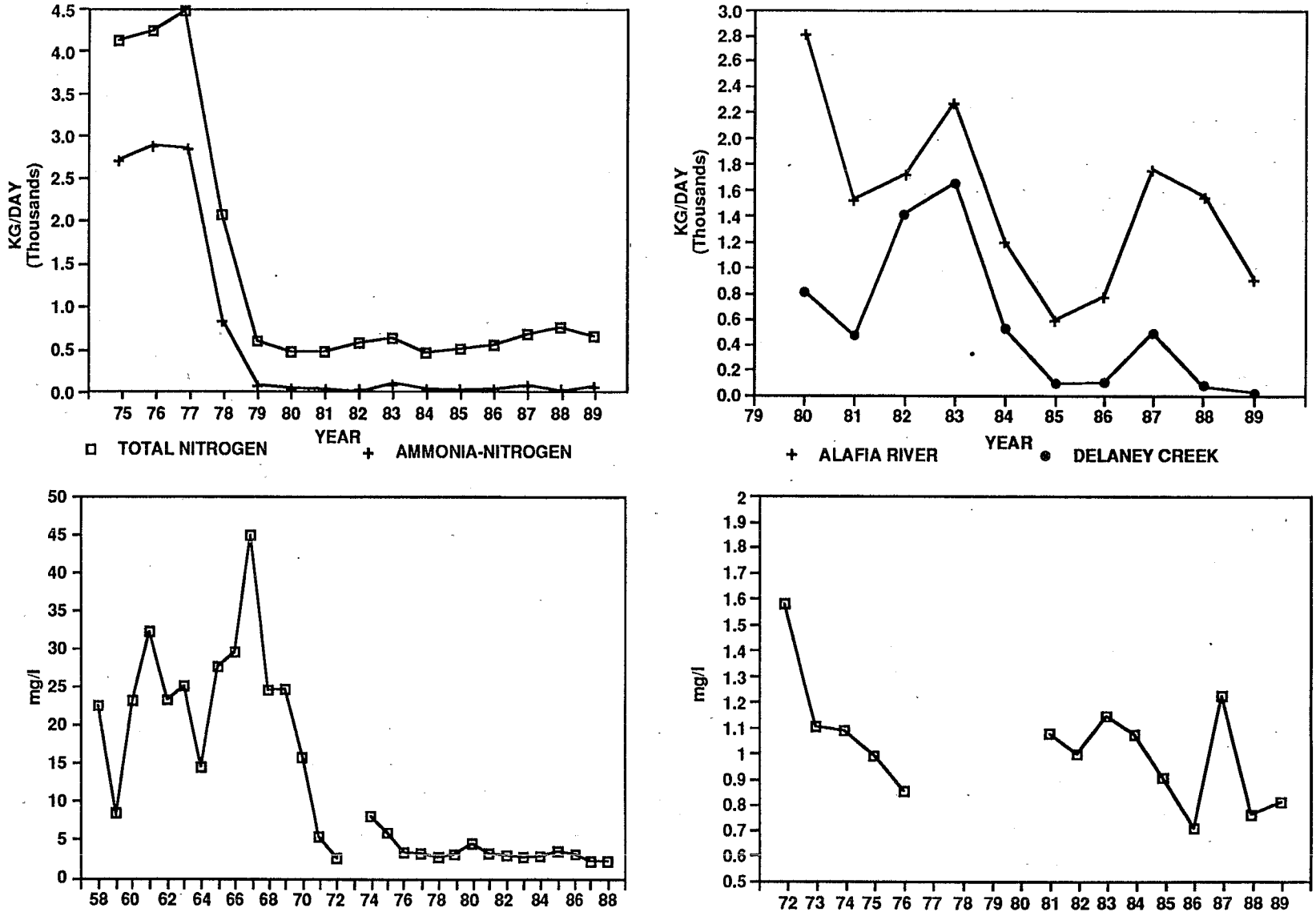


Figure F31. A, loading of total nitrogen and ammonia nitrogen from the Hooker's Point Wastewater Treatment Plant; B, phosphorus concentrations in the Alafia River; C, total nitrogen loading to Hillsborough Bay from Alafia River and Delaney Creek; D, Total Kjeldhal nitrogen concentrations in Hillsborough Bay (adapted from Johansson and Lewis, 1991).

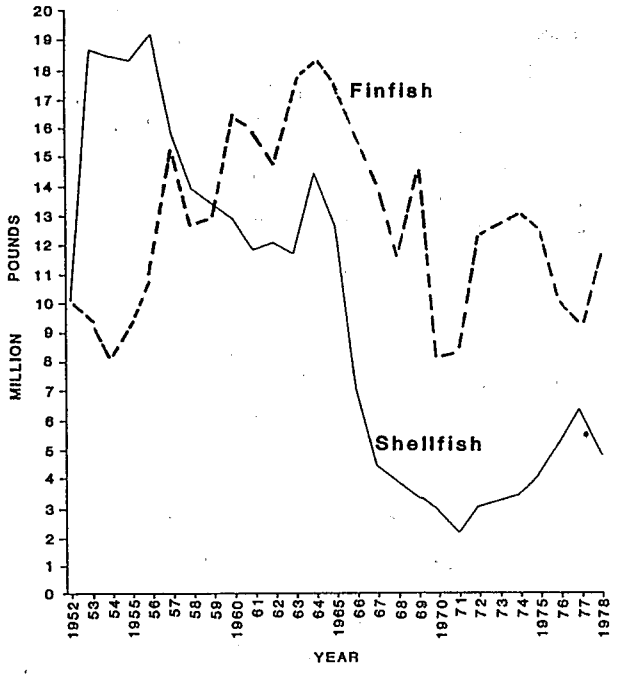


Figure F30. Tampa Bay commercial shellfish and finfish landings (from Lewis and Estevez, 1988).

As mentioned on page 48, improvements in sewage treatment and pollution abatement from fertilizer processing plants has reduced the nutrient loadings and phosphorus concentrations in Hillsborough Bay and its tributaries (Figure F31) (Johansson and Lewis, 1991). A time lag of several years appears to exist between reduced nitrogen loading and the response of ambient chlorophyll *a* concentrations in Hillsborough Bay (Figure F32). The substantial decrease of chlorophyll *a* correlates with the loss of a planktonic filamentous blue-green alga, which prior to 1984 dominated the phytoplankton population from late summer to early winter (Figure F32). Water column light transparency has also improved as measured by Secchi disk depth (Figure F32). Modest seagrass recolonization was observed in 1984 in Middle Tampa Bay, just south of Hillsborough Bay, and in 1985 in Hillsborough Bay proper. The new seagrass growth followed the substantial decrease in chlorophyll *a* concentration and increase in water column light penetration. Further, test plantings of the seagrass *Halodule wrightii* have been successful at several locations in Hillsborough Bay (Figure F33).

REFERENCES: F-15

Boler (1987)
Cardinale and Boler (1984)
Dauer (1984)
Dauer and Simon (1976)
Dennis *et al.* (1984)
Dooris and Dooris (1985)
Doyle (1985)
Dragovich *et al.* (1961, 1963, 1966)
Drew *et al.* (in review)
Lewis and Estevez (1988)
Lindall *et al.* (1974)
Lopez and Giovannelli (1984)
McCoy and Bell (1985)
Moon (1985)
Robison (1985)
Saloman (1973, 1974)
Saloman and Taylor (1968, 1971a,b)
Saloman *et al.* (1964)

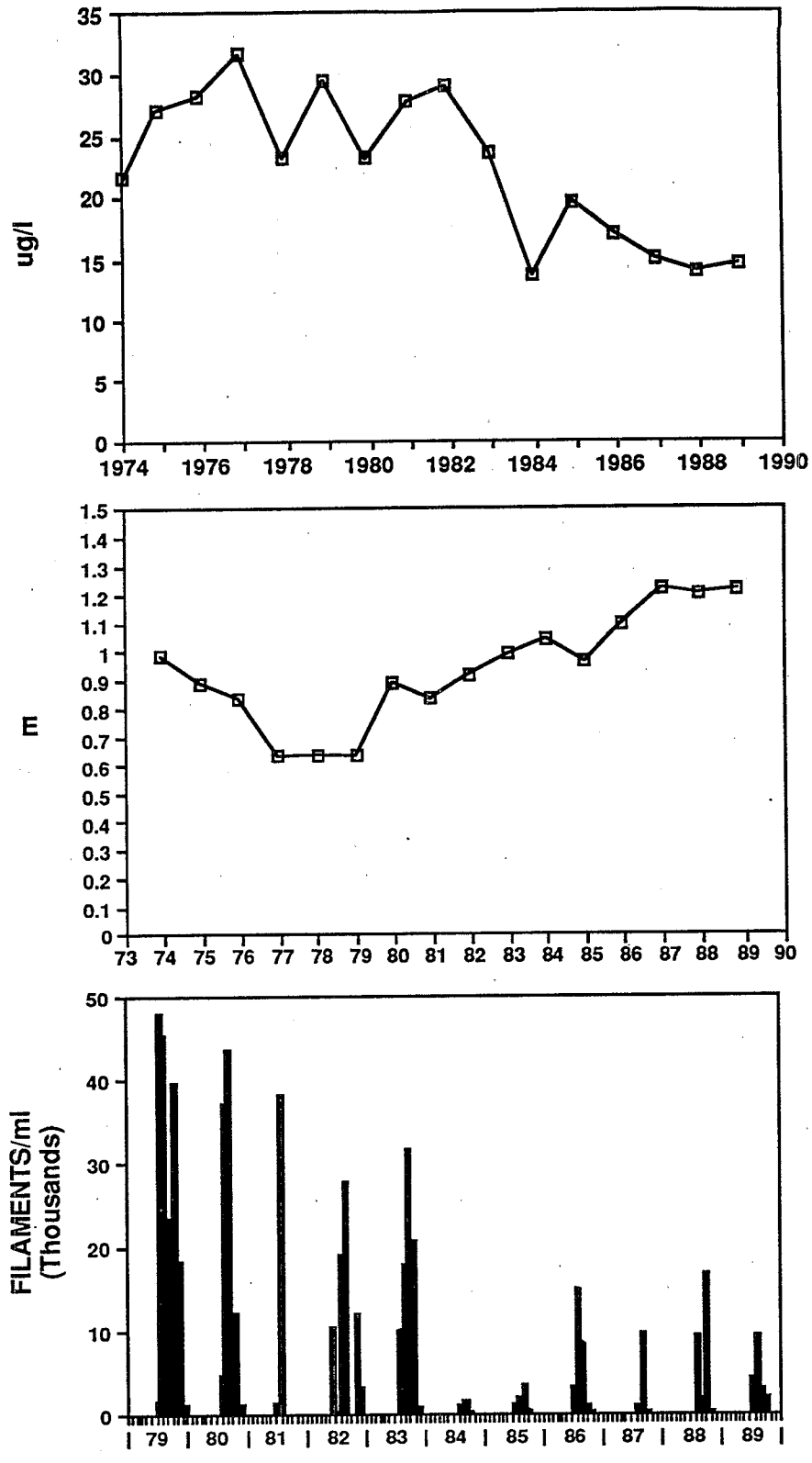


Figure F32. A, chlorophyll *a* concentrations in Hillsborough Bay; B, monthly concentrations of a filamentous blue-green alga (*Schizothrix calcicola sensu* Drouet) in Hillsborough Bay; C, Secchi disk depth in Hillsborough Bay (adapted from Johansson and Lewis, 1991).

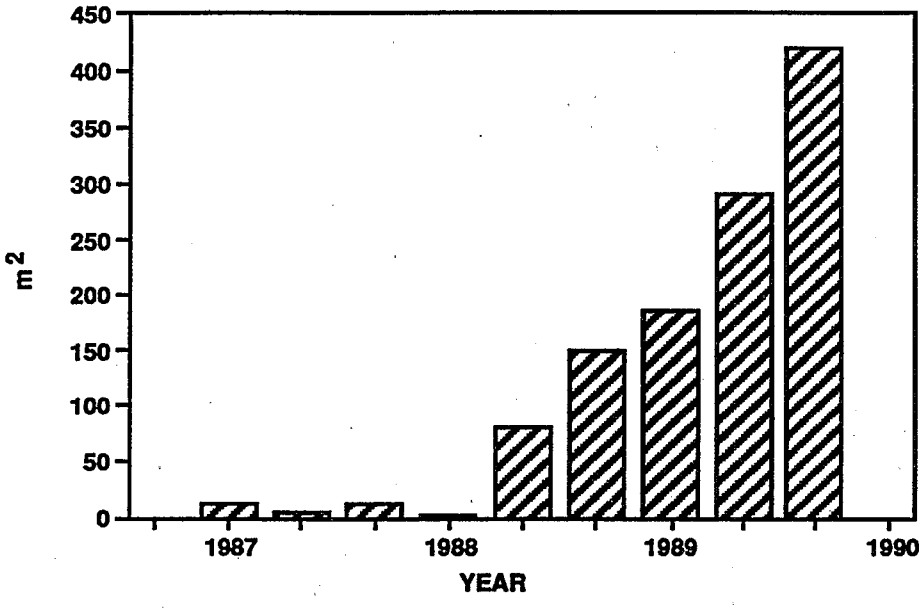


Figure F33. Area coverage of *Halodule wrightii* test plantings in Hillsborough Bay (adapted from Johansson and Lewis, 1991).

Estevez (1989)
Estevez and Merriam (1989)
Fanning and Bell (1985)
Fehring (1985)
Finucane (1964)
Finucane and Dragovich (1966)
Flannery (1989)
Graham (1954)
Hand *et al.* (1988m)
Johansson and Lewis (1990)
Johansson *et al.* (1985)
Lewis (1989)
Santos and Simon (1980)
Simon (1974)
Steidinger (1973)
Steidinger and Gardiner (1985)
Taylor (1970)
Treat *et al.* (1985)
Van Vleet (1985)
Weiss and Phillips (1985)
Williams and Ingle (1966)
Williams *et al.* (1990)
Wolfe and Drew (1990)
Zieman and Zieman (1989)

F-15.1 Florida inner continental shelf (sw)

Examination of water quality along the Florida west coast has been conducted in conjunction with monitoring of red tide blooms (Graham *et al.*, 1954; Dragovich *et al.*, 1961, 1963). In the surface water, there is a gradual decrease in phosphorus content with increase in distance from shore out to a distance of 130 km (Graham *et al.*, 1954). At distances ≥24 km from the Florida west coast, the concentration of total phosphorus in the surface water was usually below 0.25 µg-at/l; the concentration of inorganic phosphorus usually below 0.1 µg-at/l; and the amount of organic phosphorus usually exceeded the inorganic (Figure F34) (Graham *et al.*, 1954). Higher concentrations of phosphate below 50 m water depth were attributed to upwelling features. There was no indication that the contributions of the Peace River or the Caloosahatchee River contributed significantly to the phosphorus content of nearshore coastal waters.

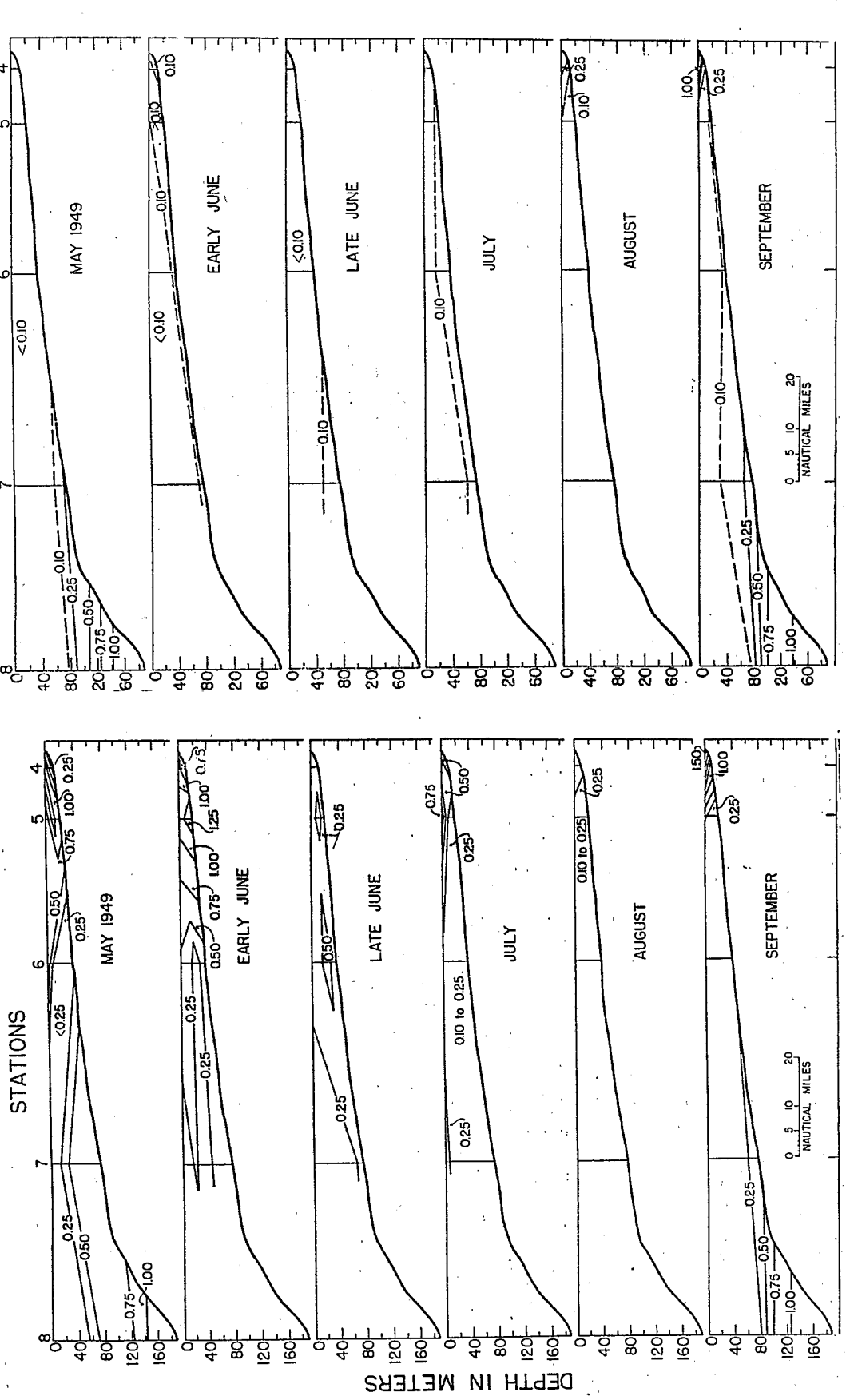


Figure F34. Total phosphorus (µg-at/l) sections extending westward from Charlotte Harbor to 120 miles offshore (left panel) and inorganic phosphorus (µg-at/l) sections for same area (right panel) (from Graham *et al*, 1984).

A series of hydrographic surveys in Tampa Bay and the adjacent Gulf of Mexico, over a several year period, were conducted by Saloman and Taylor (1971a,b, 1972) and Saloman (1973, 1974), and supplement the data of Graham and Dragovich to provide an excellent historical baseline. More recent studies (Danek and Lewbel, 1986) supplement these data with those from 1982-1984 for the southwest Florida shelf (Table F4), and represent typical oceanographic data.

The occurrence of *Gymnodinium breve* red tides have been scientifically documented along Florida's west coast since 1946-1948, although records of similar outbreaks date back to 1844 (Steidinger and Joyce, 1973; Roberts, 1979). Substantial red tides caused by the unarmored dinoflagellate occur periodically along the west coast of Florida. In addition to causing toxicity in shellfish, *G. breve* directly kills large numbers of fish and some marine invertebrates, produces a highly irritating aerosol in coastal areas, and can rarely cause contact dermatitis (Quick and Henderson, 1975). Red tides initiate in offshore waters where populations increase for approximately two weeks, then the bloom in transported into inshore areas depending on meteorologic and hydrologic conditions (Steidinger, 1975; Roberts, 1979). Offshore blooms can either subside offshore, become established inshore and subside offshore, or continue offshore, periodically seeding inshore areas (Steidinger, 1975). The progression of the September-December 1976 red tide off southwest Florida supported the prediction of offshore initiation, and support and maintenance with subsequent movement inshore. Red tides most commonly occur between an area bounded by Tarpon Springs on the north and the Ten Thousand Islands area on the south (Steidinger, 1973), but do occur along the Florida panhandle (see Section F-24.1). *G. breve* is a coastal species rarely found in estuaries, but on occasion survives and prospers in bays when recruitment from coastal waters coincides with higher than normal estuarine salinities and favorable nutrient conditions. Dinoflagellates are known for their facility to thrive in nutrient-poor water; dinoflagellate blooms often follow diatom blooms when inorganic macronutrients are less readily available (Ryther, 1955). Correlation of heavy rainfall with initiation of red tides has implicated chelated iron and naturally occurring chelators (*e.g.*, humic substances) in land runoff following rain (Steidinger, 1973). It has been suggested that red tide blooms occur every year in coastal areas of the Gulf, and that with optimal conditions for development (calm seas, gentle onshore winds, suitable salinity and temperature) the bloom will progress to a major outbreak.

Another toxic dinoflagellate, *Gymnodinium monilata*, was responsible for an extensive red tide along the west coast of Florida in August 1966 (Williams and Ingle, 1972). Bloom proportions, discolored waters, and reports of dead marine life persisted through most of the month, but dissipated in September. This red tide was prevalent in many of the adjacent bays.

Blooms of *Trichodesmium* are common along the Florida west coast and often cover the waters surface with a thick scum that may wash onshore (Graham *et al.*, 1954). Heavy blooms occur in water containing very little inorganic phosphorus, but high concentrations of total phosphorus; however, *Trichodesmium* is able to live in water of very low phosphate concentration and by its drifting nature can accumulate a large volume of water and phosphorus content.

REFERENCES: F-15.1

Atwood (1981)
Churgin and Halminsta (1974)
Cons. Perm. Int. Exp. Mer (1936)
Danek and Lewbel (1986)
Dragovich and Kelly (1966)
Dragovich *et al.* (1961)
El-Sayed *et al.* (1972)
Fanning *et al.* (1982)
Finucane (1964)
Finucane and Dragovich (1966)
Freeberg *et al.* (1979)
Graham (1954)
Roberts (1979)
Saloman (1973, 1974)
Saloman and Taylor (1968, 1971a,b)
Saloman *et al.* (1964)
Stuntz *et al.* (N.D.)
Thompson and Bane (1986a,b)
Thompson *et al.* (1988)
Williams and Ingle (1966)

Table F4. Summary of near-bottom hydrographic and water chemistry characteristics from 5-yr field study of southwestern Florida continental shelf (from Danek and Lewbel, 1986).

Station Number	Salinity (°/oo)	Temperature (°C)	DO (mg/l)	Transmissivity (%)	Light Pen. (K^1)	Chl. a (mg/m^3)	$NO_3 - NO_2$ (umole)	PO_4 (umole)	SiO_2 (umole)
44	34.8 - 36.0	20.3 - 29.6	5.6 - 10.1	77-100	0.14 - 0.38	ND	ND	ND	ND
55	35.8 - 36.5	22.0 - 28.0	5.9 - 9.3	83-94	0.11 - 0.19	ND	ND	ND	ND
7	35.6 - 36.5	19.1 - 27.8	7.7 - 9.4	90-99	0.08 - 0.17	0.1 - 0.9	0.1 - 0.3	<0.1 - 0.1	1.0 - 3.0
52	35.1 - 36.3	17.0 - 30.8	6.3 - 9.4	67-100	0.11 - 1.13	ND	ND	ND	ND
21	35.9 - 36.7	19.5 - 27.3	6.1 - 10.3	82-100	0.08 - 0.68	0.5 - 1.0	0.1 - 0.3	<0.1 - 0.1	1.0 - 2.0
23	36.1 - 36.7	17.5 - 24.3	6.1 - 9.3	87-97	0.06 - 0.11	0.3 - 0.6	0.8 - 4.0	0.1 - 0.4	1.0 - 3.5
29	36.1 - 36.6	17.5 - 26.0	6.4 - 8.6	86-98	0.07 - 0.19	0.1 - 0.6	2.0 - 4.0	0.2 - 0.3	1.0 - 2.0
36	36.1 - 36.7	15.0 - 23.8	4.4 - 6.6	88-98	0.06 - 0.08	<0.1 - 0.1	5.0 - 10.0	0.6 - 0.7	3.0 - 5.0

*Notes with respect to individual parameters:
Salinity—ranges are based on 4 to 12 data points collected during 1 to 5 years.
Temperature—Ranges are based on periodic measurements as well as continuous measurements over 1 to 2 years.
Dissolved Oxygen—same as salinity.
Transmissivity—same as salinity. Years 4 and 5 data adjusted by cruise so that the maximum was 100 percent.
Light Penetration—calculated using $1.7/D_s$, where secchi readings (D_s) were made during Years 4 and 5.
Chlorophyll a—ranges are based on 4 data points (Years 1 and 2) except for Station 36 (Year 2 only).
$NO_3 - NO_2$—same as Chlorophyll a.
PO_4—same as Chlorophyll a.
SiO_2—same as Chlorophyll a.

F-16 Crystal Bay/River

The coastal basin from the north of Tampa Bay to Crystal Bay/River consists of many short meandering streams, many of which have tidal characteristics (Hand *et al.*, 1991). Three of the rivers, Weekiwatchee, Homossasa and Crystal, have headwaters which are major Florida springs; spring fed rivers are naturally low in dissolved oxygen and the bacteria levels are high. Crystal River has been designated an Outstanding Florida Water (Hand *et al.*, 1988e). There are two streams in the central portion of the basin, the Pithlachascotee and Anclote Rivers, which are affected by urban growth, especially in the lower segments (Hand *et al.*, 1988e). The Crystal Bay estuary drains an area of 1290 mi^2 with an average freshwater inflow of 975 cfs (Windsor, 1985). Population in the area is approximately 7000 inhabitants, with one sewage treatment plant, seven hazardous waste treatment facilities, and two power plants in the basin (Windsor, 1985).

The springfed rivers in the northern basin generally have very good water quality, although some have naturally low dissolved oxygen levels (Figure F35) (Hand *et al.*, 1988e). Crystal River is also subject to summertime algal blooms and mats in the King's Bay area possibly due to the Crystal River wastewater treatment plant discharge and stormwater runoff. In addition, the Homasassa River has some bacterial problems of unknown source. The lower Pithlachascotee has some bacteria problems, presumably from septic tank drainage and/or New Port Richey runoff.

Few recent water quality data are available for Crystal Bay (Windsor, 1985). The main focus of research activity in the Crystal River area has been the potential impacts of thermal and radiological discharges from a power plant, and more recently the protection of manatees (Delfino *et al.*, 1984).

REFERENCES: F-16

Hand *et al.* (1988e)

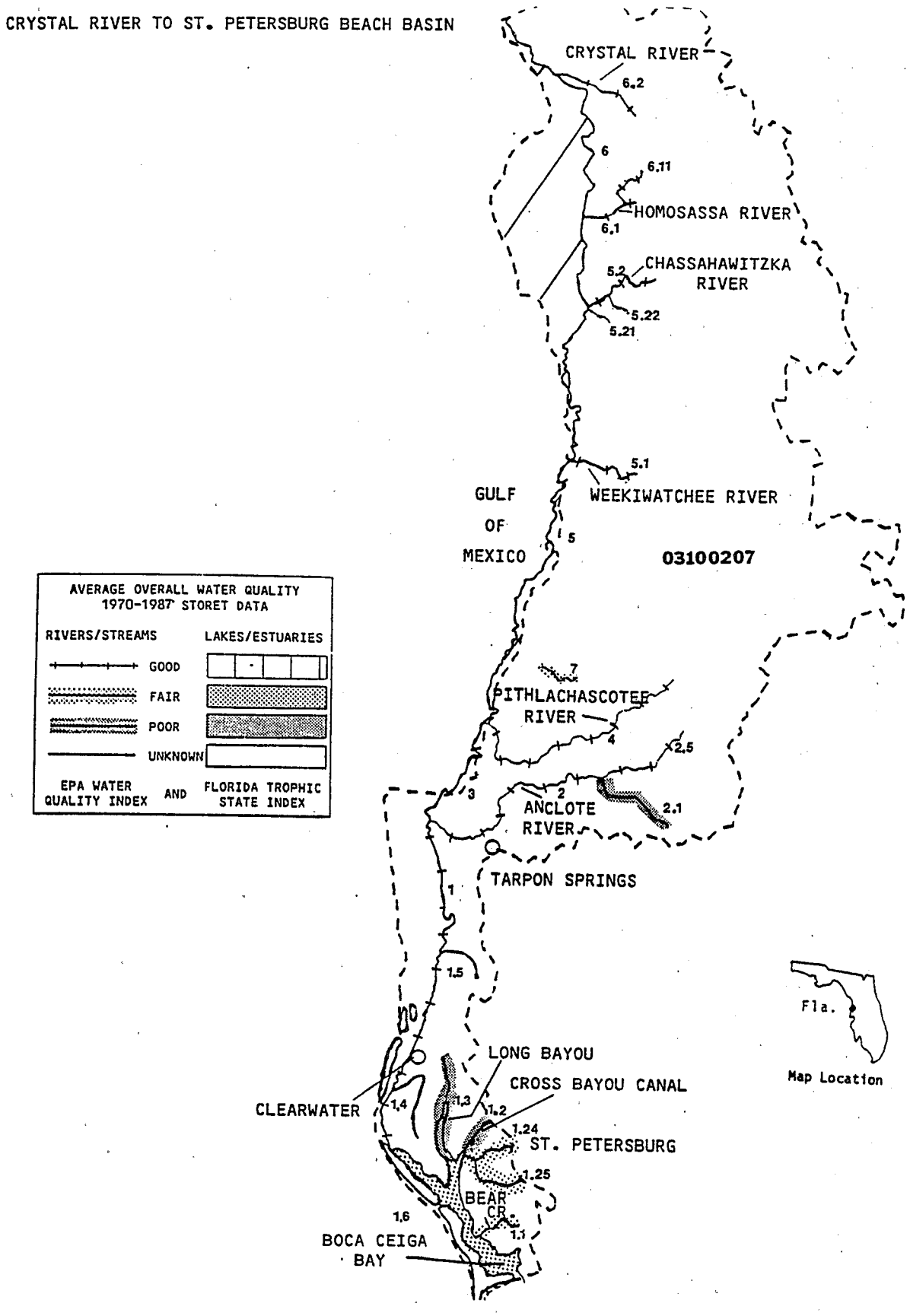


Figure F35. Crystal River to St. Petersburg Beach [from 305(b) report of Hand *et al.* (1988e)].

F-17 Withlacoochee River

The Withlacoochee River estuary is located north of Crystal Bay/River. The river is open to the Gulf of Mexico. No additional information was available since the Windsor (1985) review, parts of which are repeated here.

Population within the river basin is approximately 99,300, and land use is primarily agriculture in the upper reaches and forestry in the lower reaches. There are two sewage treatment plants, five hazardous waste treatment facilities and two textile plants. The report of Hand and Jackman (1984) (cited in Windsor, 1985) stated that water quality in the basin is generally good with some low dissolved oxygen, due primarily to natural conditions; the tributaries to the Withlacoochee River drain swampy areas. Low dissolved oxygen has been measured near the Wysong Dam and at the Cross Florida Barge Canal Control Structure, where waters are not well mixed. A paper mill effluent discharged to the northern Withlacoochee has had little impact on water quality below the plant. Water quality for the estuarine portion are limited, but coliform bacteria are not a problem within the estuary where shellfish beds remain open for harvesting (Windsor, 1985).

F-18 Waccasassa Bay

The Waccasassa River drains forest land and wetland with an average flow of approximately 300 cfs. The area is sparsely populated (11,400) (Windsor, 1985), and there are no major urban areas. The Waccasassa Bay estuary has a surface area of 82 mi^2. No major industries discharge their effluents into the bay (Windsor, 1985). The only point source discharge in the basin is a wastewater treatment plant on Cedar Key, located on the western end of Waccasassa Bay (Hand *et al.*, 1988n).

Historically this river basin has very good water quality and few sources of pollution (Figure F36) (Hand *et al.*, 1988n). Forestry clear-cutting in the basin could be a potential nonpoint source of pollution. The river has a relatively high sediment load, possibly from forest runoff (Hand *et al.*, 1988n).

REFERENCES: F-18

Hand *et al.* (1988n)

F-19 Suwannee River/Sound

The Suwannee River receives the flow of many tributaries, the Withlacoochee, Alapha and Santa Fe Rivers, and it opens into the Gulf of Mexico in Suwannee Sound. No additional information was available since the Windsor (1985) review, parts of which are repeated here.

Population in the area is approximately 42,700. Major land uses in the basin are forestry and agriculture; developed and urban areas are minimal. Little or no domestic or industrial effluent is discharged to the lower river. Dissolved oxygen concentration violations have been recorded fairly frequently in the tributaries of the Suwannee River and in the lower river basin; and bacterial levels were also high in some locations.

The Hand and Jackman (1984) report (cited in Windsor, 1985) reported the water quality to be good in all reaches of the lower Suwannee River. Phosphorus concentrations were as high as 21 mg/l below mining operations. Elevated phosphate concentrations were evident to the mouth of the river; however, eutrophication is apparently not a problem to the system, because flushing is so rapid. Effects of elevated levels of phosphate have not yet been thoroughly examined for the Suwannee Sound.

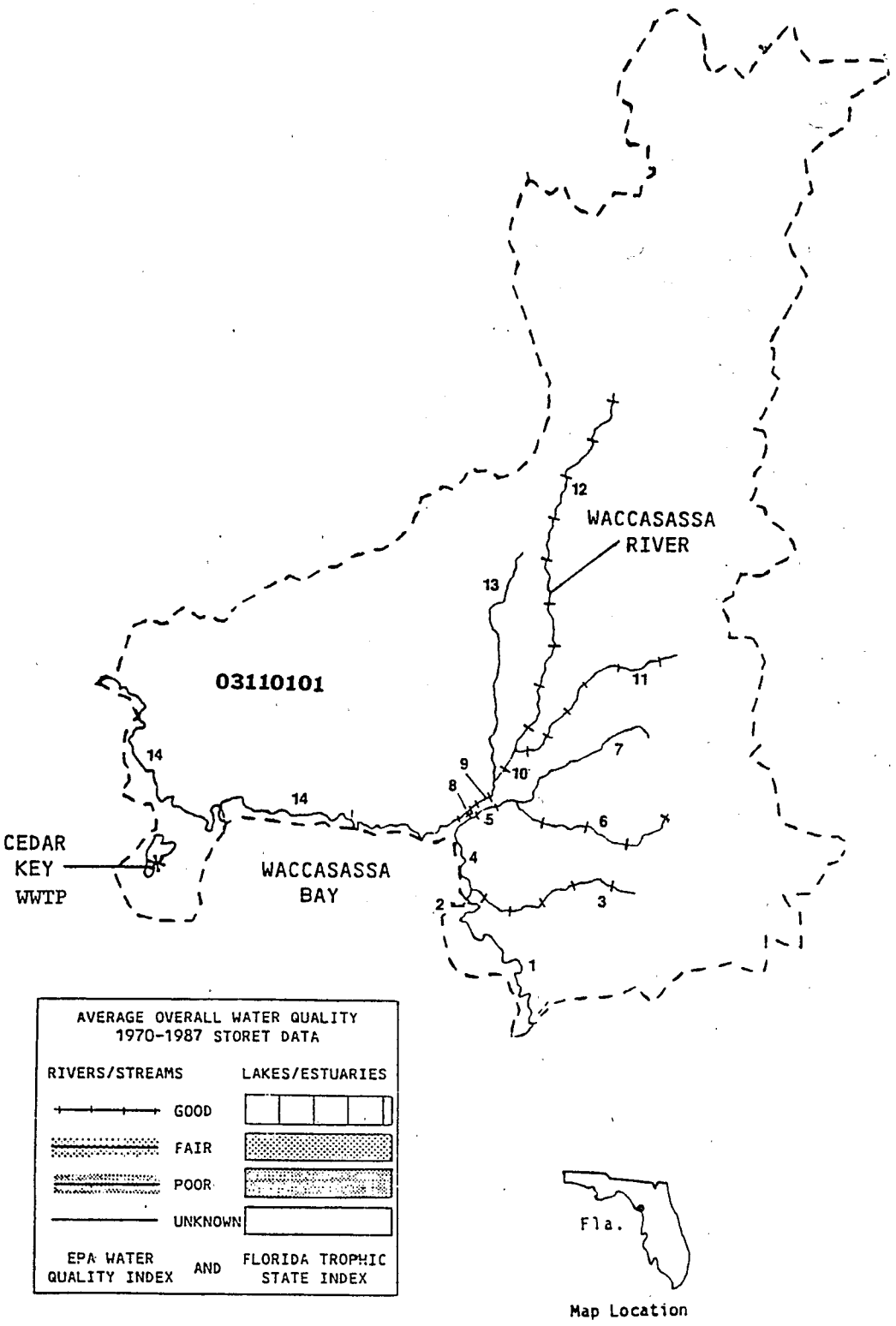


Figure F36. Waccasassa River basin [from 305(b) report of Hand *et al.* (1988n)].

REFERENCES: F-19

Williams *et al.* (1990)

F-20 Deadmans Bay/Steinhatchee River

The Steinhatchee River has two tributaries, Eightmile Creek and Kettle Creek, which drain mostly low wetlands. The river flows directly into the Gulf of Mexico into Deadmans Bay. Spring Warrier Creek (drains forest and wetlands), Fenholloway River (drains mostly wooded land), and Econfina River (drains mostly wooded land) are also located within this basin (Figure F37) (Hand *et al.*, 1988l). The above named rivers and streams, with the exception of the Fenholloway River, are to a large extent not impacted by pollution point sources (Hand *et al.*, 1988l). A large portion of the upper coastal basin has been purchased recently by the State. There is a very small population of 4100 inhabitants within the basin, and no sewage treatment plants discharge effluents to the bay. The Fenholloway River is not typical of streams in this area due to the discharge of a large volume of effluent from a paper mill. This effluent makes up most of the flow of this system during the dryer portions of the year (Hand *et al.*, 1988l).

Most of the streams in this coastal area are meeting the use designations (Figure F37) (Hand *et al.*, 1988l). Low pH and dissolved oxygen concentrations are believed to be due to the sluggish flow of the headwaters of these streams. Bacterial counts are sometimes greater than expected, but these values have not been fully explained. Much of the basin is intensively logged, and the rivers receive periodic impact (mostly turbidity) from both planting and logging operations.

The Econfina River appears to have degraded somewhat since the late 1970s but still meets the use designation (Hand *et al.*, 1988l); no cause for this decline has been determined. The lower portion of Spring Creek has historical bacteria problems, likely due to the City of Perry wastewater treatment plant and a package plant discharge upstream.

The Fenholloway River does not meet the low Class V (industrial use) dissolved oxygen standard below the pulpmill plant, which discharges to the river. Several miles downstream, dissolved oxygen recovers to levels above the 2.0 mg/l required for Class V waters; however, 50 % of the samples do not meet the standards. Improvement in dissolved oxygen levels has been noted during the monitoring period; however, nutrient levels remain high and recent dissolved oxygen violations have been noted (Hand *et al.*, 1988l).

No data were available for the Deadmans Bay portion of the study area.

The shallow, nearshore areas of the Gulf of Mexico adjacent to the polluted Fenholloway River were characterized by elevated levels of color and turbidity compared to the receiving waters of an unpolluted river (Econfina) (Zimmerman and Livingston, 1976). Areas associated with high levels of kraft mill effluents were characterized by severely reduced benthic macrophyte biomass, reduced numbers of species/unit area, and altered species composition when compared to control stations. Areas of chronic impact also had reduced levels of biomass, although the total number of species taken were not significantly different from the controls. There were uniform increases in the total number of species on either side of the affected drainage system. Such areas were considered to be transition zones between the polluted and unpolluted parts of Apalachee Bay (Zimmerman and Livingston, 1976).

Work by Heck (1976, cited in Windsor, 1985) has shown that benthic community structures were exhibiting effects from the discharge of pulp mill effluents in spite of the fact that traditional physico-chemical water quality monitoring parameters showed little difference from background levels. Although sections of the bay tributaries were anoxic, by the time the river waters reached

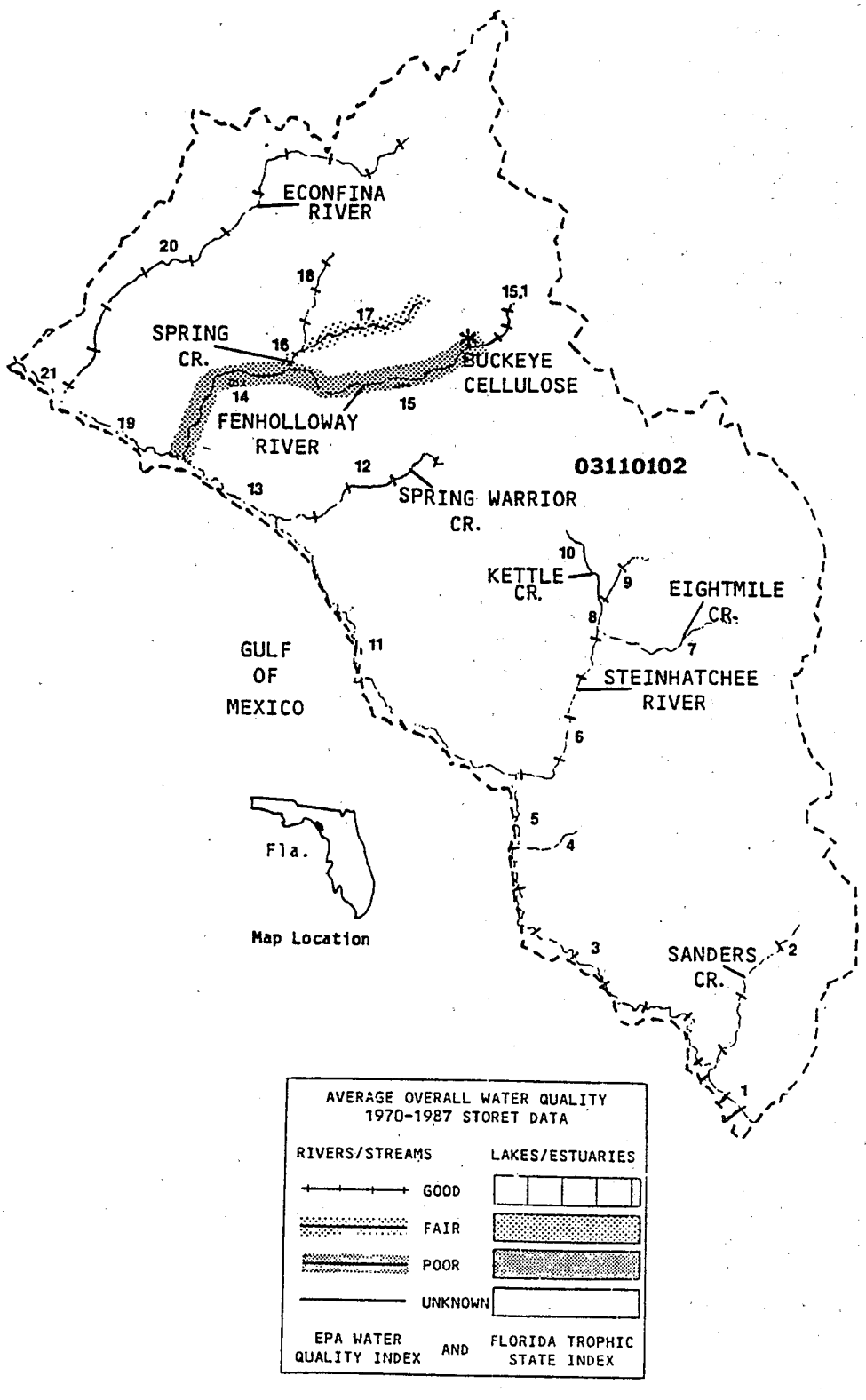


Figure F37. Steinhatchee River Bay basin [from 305(b) report of Hand *et al.* (1988l)].

the well-mixed waters of the Gulf of Mexico, they were apparently no longer a problem (Livingston, 1975; cited in Windsor, 1985).

A 7-yr study of epibenthic macroinvertebrates compared the Gulf of Mexico receiving area for the unpolluted Econfina River with the Gulf adjacent to the polluted area in the Fenholloway River (Dugan and Livingston, 1982). The relative abundance of dominant species and species richness in the two estuaries were similar, although the number of individuals collected in the Econfina area was always at least twice that taken in the Fenholloway. This difference was attributed to the greater seagrass biomass in the Econfina estuary. Comparisons of the constancy of species composition over the study period, as well as changes in species rankings following a pollution abatement program in the Fenholloway River, showed that there was enhanced species persistence in the unpolluted area.

The same stations in the Gulf of Mexico adjacent to the unpolluted Econfina River and polluted Fenholloway River were used in a 9-yr study of the response of fish assemblages to habitat alteration (Livingston, 1984). During the study period, extreme natural habitat changes due to stormwater runoff and low winter temperatures were superimposed over water quality changes (increased color, turbidity, nutrients; reduced dissolved oxygen) associated with release of pulp mill effluents. Various grassbed fishes followed regular seasonal, age-specific feeding patterns, which did not change substantially in terms of qualitative food composition in the unpolluted estuary over a 7-yr period. Anthropogenic habitat alterations were associated with reductions in benthic macrophyte distribution, enhanced phytoplankton productivity, and changes in the relative dominance and numerical abundance of associated fish assemblages. Grassbed species were replaced by planktivorous fishes, and disruption of feeding habits of various species was apparent in the affected area relative to the unpolluted estuary. Those fishes dependent on specific benthic food organisms altered their feeding habits during the years of pollution in the affected estuary. Subsequent water quality improvement was associated with shifts in the age-specific dietary patterns of various species toward those observed in the unaffected estuary. In spite of a highly resilient system, slight water quality changes due to pollution can cause serious disruptions of the basic habitat structure, energy flow, and community composition of the grassbed assemblages at various levels of biological organization (Livingston, 1984).

The results of experiments to determine nutrient limitation in the nearshore northeastern Gulf of Mexico were reported by Myers and Iverson (1979); one station was located in the Gulf of Mexico adjacent to the outflow of Econfina River. The seasonal variability of nutrient and phytoplankton biomass in the Econfina estuary are presented in Figure F38 and details given in Table F5. Nutrient fluctuations of this area were trimodal, with distinct seasonal cycles. Nitrate and phosphate seasonal variability were not closely coupled except during the summer and fall. Phytoplankton chlorophyll *a* concentrations were bimodal with peaks in April-May and September-October. Macrophytes (seagrasses and associated macroalgae) dominate the productivity of this system with peaks in biomass and productivity occurring during the summer (Bittaker, 1975, cited in Myers and Iverson, 1981). The N:P ratios for this area were greater than 10 and suggested a surplus of available nitrogen and possible phosphorus limitation (Myers and Iverson, 1981). Results of both carbon uptake and phosphate nutrient enrichment bioassays indicated that phosphorus was more important than nitrogen in limiting phytoplankton productivity during the summer months in this coastal estuary (Table F6). The authors cautioned that any alterations in land use that increase phosphorus mobility should be discouraged since these activities could lead to eutrophication in the system.

REFERENCES: F-20

Hand *et al.* (1988l)

Myers and Iverson (1981)

Table F5. Summary of environmental, nutrient, and phytoplankton data from northeastern Gulf of Mexico (from Myers and Iverson, 1981).

Station	Temp °C	Salin PPT	Turb FTU	Light ly hr-1	NO_3 µg atomN l-1	NO_2 µg atomN l-1	NH_4 µg atomN l-1	PO_4 µg atomP l-1	Pri Prod µgC l-1 hr-1	Chl-a µg l-1
E-12	28.40	26.20	3.15	26.50	0.32	0.01	0.31	0.04	6.00	0.61
	1.01	2.48	0.35	5.60	0.14	0.03	0.20	0.01	1.25	0.17
M.L.	27.80	29.70	3.15	37.80	0.55	0.02	0.61	0.19	9.20	0.52
	1.78	3.53	0.49	3.73	0.10	0.02	0.49	0.04	0.58	0.21
Ock-1	28.20	4.20	4.97	37.90	1.83	0.05	0.79	0.37	30.80	2.14
	0.90	1.60	0.78	7.22	0.37	0.01	0.44	0.07	2.57	0.41
Ock-2	28.20	10.30	4.93	37.90	2.24	0.12	0.91	0.36	26.40	3.00
	0.80	0.70	0.61	7.22	0.83	0.05	1.04	0.09	4.74	0.51
Apal-1A	27.50	3.74	16.50	33.90	3.08	0.15	0.60	0.34	40.30	5.13
	1.19	2.58	8.96	9.17	2.63	0.16	0.83	0.08	10.70	1.12
Apal-7	27.50	11.70	11.70	36.90	3.55	0.21	0.81	0.40	36.70	4.11
	1.34	8.26	6.88	3.50	3.69	0.16	0.89	0.09	5.81	0.84

[1]Data are from surface samples collected between May and September, 1974-1976. The first value under each factor is the mean value of that factor for a given station and the second value is the standard deviation of the values. *Temp* is temperature, *Salin* is salinity, *Turb* is turbidity, and *Pri Prod* is phytoplankton primary production, and *Chl-a* is chlorophyll-a.

Table F6. Summary of analysis of variance of carbon uptake and phosphate uptake nutrient enrichment bioassay from northeastern Gulf of Mexico (from Myers and Iverson, 1981).

Station	Date	Carbon Uptake NO_3	Phosphate Uptake PO_4
E-12	6/03/75	*	*	N
E-12	7/18/75	-	*	N
E-12	7/12/76	-	*	*
E-12	9/10/76	-	-	-
M.L.	6/13/76	-	*	*
M.L.	7/03/76	-	*	*
M.L.	8/30/76	-	-	-
M.L.	9/22/76	-	*	-
Ock-1	6/17/76	-	-	-
Ock-1	7/28/76	-	*	*
Ock-1	8/30/76	*	-	-
Ock-2	6/17/76	*	-	-
Ock-2	7/28/76	-	*	*
Ock-2	8/30/76	-	-	-
Apal-1A	9/02/74	*	*	N
Apal-1A	5/29/75	-	-	N
Apal-1A	7/11/75	-	*	N
Apal-1A	9/11/75	-	*	*
Apal-1A	9/15/75	-	-	-
Apal-1A	6/10/76	-	*	*
Apal-1A	6/24/76	-	*	*
Apal-1A	7/05/76	-	*	*
Apal-1A	8/15/76	-	*	*
Apal-1A	8/26/76	-	-	-
Apal-7	9/02/74	*	-	N
Apal-7	5/29/75	-	-	N
Apal-7	7/11/75	*	*	N
Apal-7	7/11/75	*	-	-
Apal-7	9/15/77	-	-	-
Apal-7	6/10/76	-	-	-
Apal-7	6/24/76	-	-	-
Apal-7	7/05/76	*	*	*
Apal-7	8/15/76	-	*	*
Apal-7	8/26/76	-	-	-

[1]The symbols under PO_4 and NO_3 indicate the statistical significance (F test) of the effect of that nutrient on either carbon uptake or phosphate uptake. N indicates no data * indicates $\alpha < 0.05$, and - indicates ≥ 0.05. When < 0.05 the effect of the nutrient addition was always stimulatory to the physiological process measured.

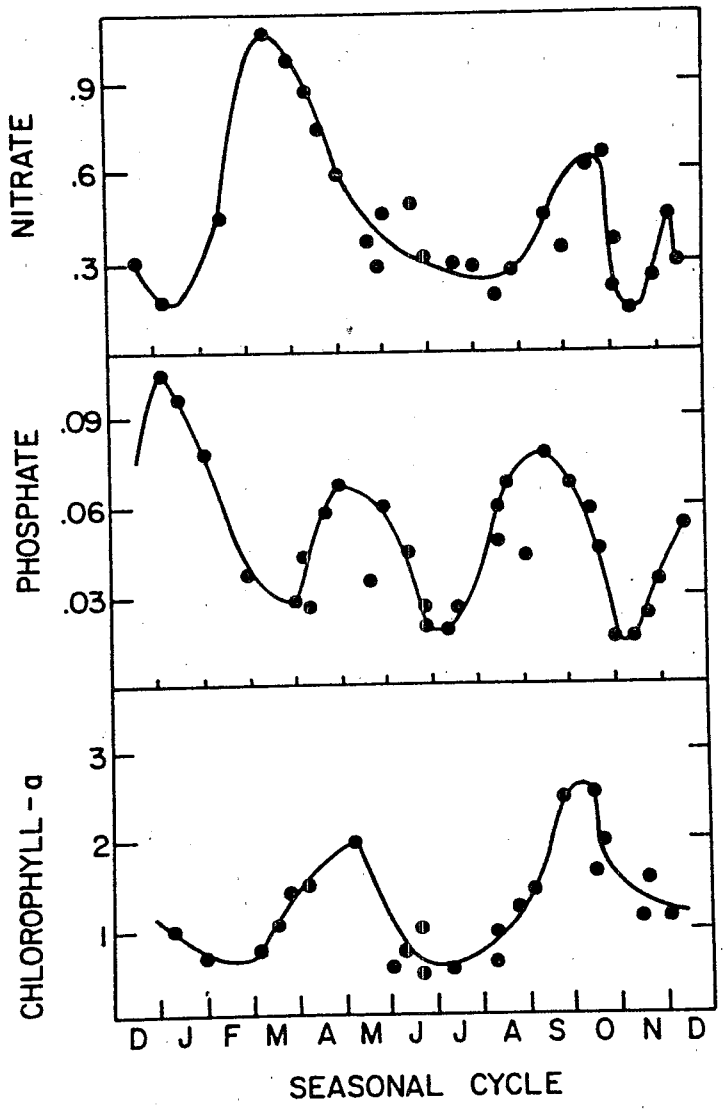


Figure F38. Seasonal cycles in the Econfina estuary of surface dissolved nitrate (μg-at/l), soluble reactive phosphate (μg-at/l), and phytoplankton chlorophyll *a* (μg/l) from 1973 through 1976 (from Myers and Iverson, 1981).

F-21 Aucilla River

The Aucilla River receives the flow of the Little Aucilla and Waccasassa Rivers, and it opens directly into the Gulf of Mexico in Apalachee Bay. No additional information was available since the Windsor (1985) review, parts of which are repeated here.

The land area in the basin is sparsely populated (21,800 inhabitants), and land use is primarily forestry and agriculture. There are no major urban areas within the basin, no sewage treatment plants, and no industries discharging into the river. In general, the water quality is good in this basin. Naturally low pH and dissolved oxygen values result from waters originating in swampy areas (Windsor, 1985).

F-22 Apalachee Bay/St. Marks River

The St. Marks, Aucilla (see Section F-21), Fenholloway (see Section F-20) and Ochlockonee (see Section F-23) Rivers drain into the waters of Apalachee Bay, which is a broad embayment on the easternmost end of the Florida panhandle. The St. Marks River basin drains approximately 1800 mi^2, extends from south Georgia to the Gulf of Mexico, and has an average flow of 700 cfs at a point 11 mi upstream of the confluence of the St. Marks and Wakulla Rivers. The Wakulla River is spring fed and has an average flow of 400 cfs. Land use within the basin is predominantly forestry with about 10 % urban; population within the basin is 180,900 (Windsor, 1985; Hand *et al.*, 1988k). Apalachee Bay has a surface area of 96 mi^2, with an average depth of 1.5 m. There are no sewage treatment plants discharging into the bay. Studies conducted on Apalachee Bay have emphasized the impact of pulp mill effluents on the biota of the bay (Delfino *et al.*, 1984) (see also Section F-20).

Water quality within the basin is excellent, with a few exceptions (Figure F39) (Hand *et al.*, 1988k). Water quality problems in Lake Munson and Munson Slough are related to the city of Tallahassee. The St. Marks River has been declared an Outstanding Florida Water except for the portion downstream of Rattlesnake Branch (the lower 3-4 river miles, which receives the effluent from Seminole Asphalt and Purdom Power Plant. Water quality problems related to toxic effluents are attributed to the Seminole Asphalt plant, which is no longer in operation (Hand *et al.*, 1988k). The Wakulla River is fed by one of Florida's highest discharge springs and has excellent water quality. The upper portion of the river was recently purchased by the State and made into a state park; however, the lower portion of the river is threatened by continued waterfront development with insufficient buffer areas along the water's edge. No routine water quality monitoring for the open Gulf of Mexico were available (2 observations for 1979-1980).

See comparative studies described in Section F-20 on the areas of the Gulf of Mexico adjacent to the Econfina and Fenholloway Rivers. See discussion in Section F-20 concerning nearshore nutrient distributions and nutrient limitations to phytoplankton growth in the Gulf of Mexico waters adjacent to Econfina River, and a similar discussion for Ochlockonee Bay (Section F-23) and Apalachicola Bay (Section F-24).

In July 1964, a *Gymnodinium breve* bloom developed 35 to 140 km offshore in Apalachee Bay and moved into northern Apalachee Bay in September. The area affected was estimated to be approximately 36,000 km^2. Numerous and substantial fish kills were associated with the bloom. (See Section F-24.1.)

REFERENCES: F-22

Dugan and Livingston (1982)
Florida Board of Conservation (1966)
Hand *et al.* (1988k)
Livingston (1984)
Myers (1977)
Stephens and Oppenheimer (1972)
Williams *et al.* (1990)
Zimmerman and Livingston (1976, 1979)

F-23 Ochlockonee Bay

Ochlockonee Bay is located on the panhandle of Florida near the town of Panacea and adjacent to Apalachee Bay. The major tributary of the estuary is the Ochlockonee River, which is 102 mi long, drains 1720 mi^2 of northern Florida and southern Georgia, with a mean flow of 1583 cfs (Windsor, 1985). The bay is about 5 mi long and averages a little more than 1 mi wide. The bay averages 1 m deep, has a tidal range of a little over 0.5 m, and thus is fairly well mixed (Windsor,

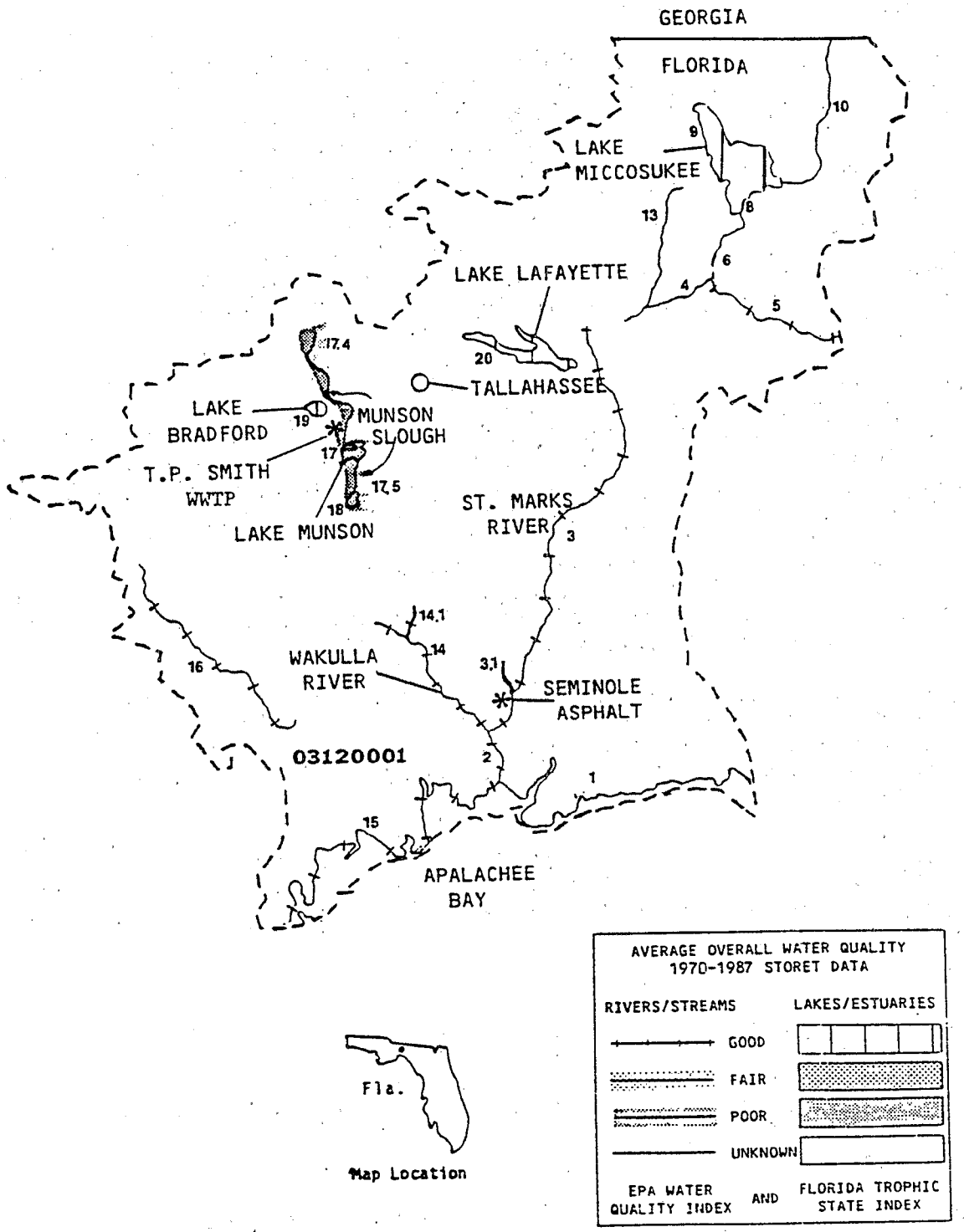


Figure F39. St. Marks River basin [from 305(b) report of Hand *et al.* (1988k)].

1985). The basin is relatively unpopulated (38,900 inhabitants), and land use type is primarily forestry, agriculture and wetlands.

Effects of human activities appear to be minimal within the bay system. No sewage treatment plants are discharging into the estuary. The Ochlockonee Bay system has recently been described as pristine (Kaul and Froehlich, 1984; cited in Windsor, 1985). In the Hand and Jackman 305(b) report cited in Windsor (1985), the water quality for the entire basin was listed as good. There were no data reported for Ochlockonee Bay proper.

The results of experiments to determine nutrient limitation in the nearshore northeastern Gulf of Mexico were reported by Myers and Iverson (1979); two stations were located in Ochlockonee Bay. The values for nutrients and phytoplankton biomass are given in Table F5 (Section F-20). The Ochlockonee and Apalachicola Bay stations exhibited higher nutrient concentrations, phytoplankton productivity, and chlorophyll *a* levels, than the Econfina estuary (see Section F-20). Relatively low mean salinity values and high turbidity were characteristics of the Ochlockonee stations, due probably to watershed runoff and higher river discharge. The higher phytoplankton and nutrient values were considered by the authors to be indicative of productive, but not eutrophic estuarine systems. The N:P ratios for this area were between 5 and 10 and were thus not informative with regards to potential nutrient limitations (Myers and Iverson, 1981). Results of both carbon uptake and phosphate nutrient enrichment bioassays indicated that phosphorus was more important than nitrogen in limiting phytoplankton productivity during the summer months in this coastal estuary (Table F6). The authors cautioned that any alterations in land use that increase phosphorus mobility should be discouraged since these activities could lead to eutrophication in the system.

Work of Wells and Froelich (1982) indicates that the bay is nitrogen limited, that phosphate input occurs in the lower estuary, that intense nitrate and phosphate removal coincides with phytoplankton blooms (high chlorophyll *a* biomass), and that N:P:Si ratios vary seasonally according to river flow, but occur approximately in the Redfield ratios.

REFERENCES: F-23

Florida Board of Conservation (1966)
Myers (1977)
Myers and Iverson (1981)
Pascale and Wagner (1982)
Wells and Froelich (1982)
Wolfe and Reidenauer *et al.* (1988)

F-23.5 St. George Sound

The coastal area between the Ochlockonee and Apalachicola Rivers is poorly drained and consists of two main regions (Wolfe *et al.*, 1988). The eastern portion of the basin is the area drained by the New River and its tributaries, which discharge into St. George Sound at the town of Carabelle. The western portion drains into East Bay of the Apalachicola Bay system (see Section F-24). The major causes of water quality problems in this basin are the discharges to the coast from the sewage treatment plants in Carabelle and Eastpoint, and surface runoff from forest clearcutting. The system at Eastpoint is being upgraded and expanded. The system for the City of Carabelle is the only plant in northwest Florida providing only primary treatment (Wolfe *et al.*, 1988). The highly chlorinated sewage discharge degrades the water in the vicinity of the outfall to St. George Sound and settles to form sludge deposits. Overly-enriched waters produce plankton blooms and excessive growth of filamentous algae, bacteria, virus, and fungi that are pathogenic to the seagrasses of St. George Sound (Wolfe *et al.*, 1988).

REFERENCES: F-23.5

Wolfe *et al.* (1988)

F-24 Apalachicola Bay/River/East Bay

Apalachicola Bay, located in northwest Florida, is the estuarine terminus of the Apalachicola, Chattahoochee, Chipola, and Flint River systems. The Apalachicola River has the largest annual discharge of Florida's rivers (24,000 cfs) with seasonal high flows occasionally exceeding 140,000 cfs (Livingston and Joyce, 1977). The Apalachicola Bay system is composed of six major subdivisions: the Apalachicola River delta, East Bay, Apalachicola Bay, St. Vincent Sound, St. George Sound (see Section 23.5) and Alligator Harbor. Apalachicola Bay is a shallow lagoon-type estuary, bounded by a series of barrier islands, and dominated by the Apalachicola River. In the bay, salinity, nutrient and detritus distribution, primary and secondary productivity, and other factors are dependent on seasonal changes in the drainage characteristics. The bay system is characterized by high levels of primary productivity (phytoplankton) and relatively little development of benthic macrophyte assemblages except in fringing areas. This combination makes the estuary a center of a significant oyster fishery and important habitat for many commercially important crabs, shrimp, and finfish. This section of the Florida panhandle, including Apalachee Bay, is considered by Swanson *et al.* (1972) (cited in Myers and Iverson, 1981), to be one of the least-polluted, least man-influenced subtropical regions in North America. The region, however, is coming under development pressure from residential development on the barrier islands and modifications to the Apalachicola river for navigation and industrialization.

This system is the most comprehensively studied water body in Florida, due primarily to the research efforts of scientists from Florida State University, particularly R. J. Livingston and his colleagues (Livingston, 1991). Continuous water quality monitoring has been performed since 1972. A resource atlas of the estuary (Livingston, 1983) provides a comprehensive data base along with a master bibliography of the technical research that has been performed in the estuary (updated somewhat by this report). The Apalachicola River estuarine system was designated a National Estuarine Sanctuary in 1972, which is now part of the National Estuarine Research Reserve system to be preserved and managed for research and educational purposes. The entire bay as well as the Apalachicola River has been declared an Outstanding Florida Water. In addition, it is an Area of Critical State Concern which requires more intensive regulation of planning and development in the area.

Analysis of long-term scientific data indicate that dominant commercially important estuarine populations are associated with river flow, local salinity characteristics and biological (predation, competition) interactions with the salinity regime, and food web structure (Livingston, 1991). Such complex interactions involve freshwater influxes and biological response in the estuary. Species-specific responses to the principal driving factors further complicate the biological relationships of the Apalachicola system (Livingston, 1991).

According to the most recent 305(b) report (Hand *et al.*, 1988a), the bay has very good water quality (Figure F40). Representative water quality monitoring data are shown in Figure F41. The most serious threats to the water quality in the bay are associated with nonpoint sources from the more urbanized areas in the basin. In the northern part of the bay, untreated stormwater runoff from the City of Apalachicola and nearby fish houses has had a localized impact on the bay. Problems associated with fish houses include BOD from fishing wastes, and pollutants due to boat traffic, docking and fueling.

In the southern bay area, there has been rapid development of St. George Island, and there is concern over septic tank drainage into the bay (Hand *et al.*, 1988a). A recent inspection revealed that 23 % of the 724 septic tanks were failing and that many did not meet State regulations. Finally, on the island, there is a boat basin connected with the bay that receives runoff from a shopping area and wastes associated with the mooring, fueling and offloading activities of oyster boats.

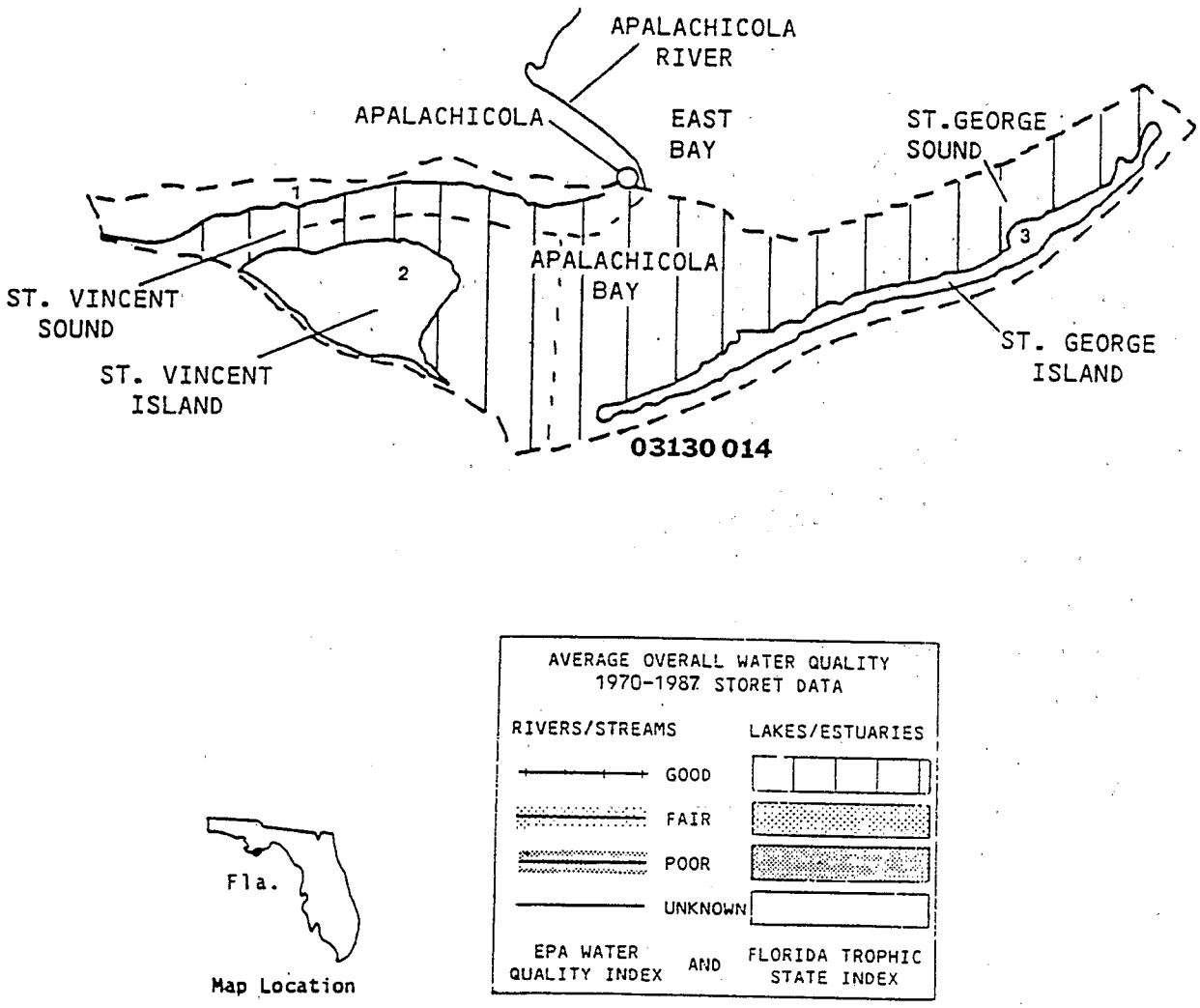


Figure F40. Apalachicola Bay basin [from 305(b) report of Hand *et al.* (1988a)].

The most extensive damage to the bay recently has been through the action of Hurricane Elena and Hurricane Kate in 1985. The entire bay was closed to oystering to allow recovery from damage due to siltation and burial. The impacts on water quality from these hurricanes can be seen in Figure F41. In the early 1980s, the entire bay was closed to oyster harvesting temporarily due to bacterial contamination (Windsor, 1985).

The results of experiments to determine nutrient limitation in the nearshore northeastern Gulf of Mexico were reported by Myers and Iverson (979); two stations were located in Apalachicola Bay and one between it and Apalachee Bay. The seasonal trends in nutrient and chlorophyll *a* values

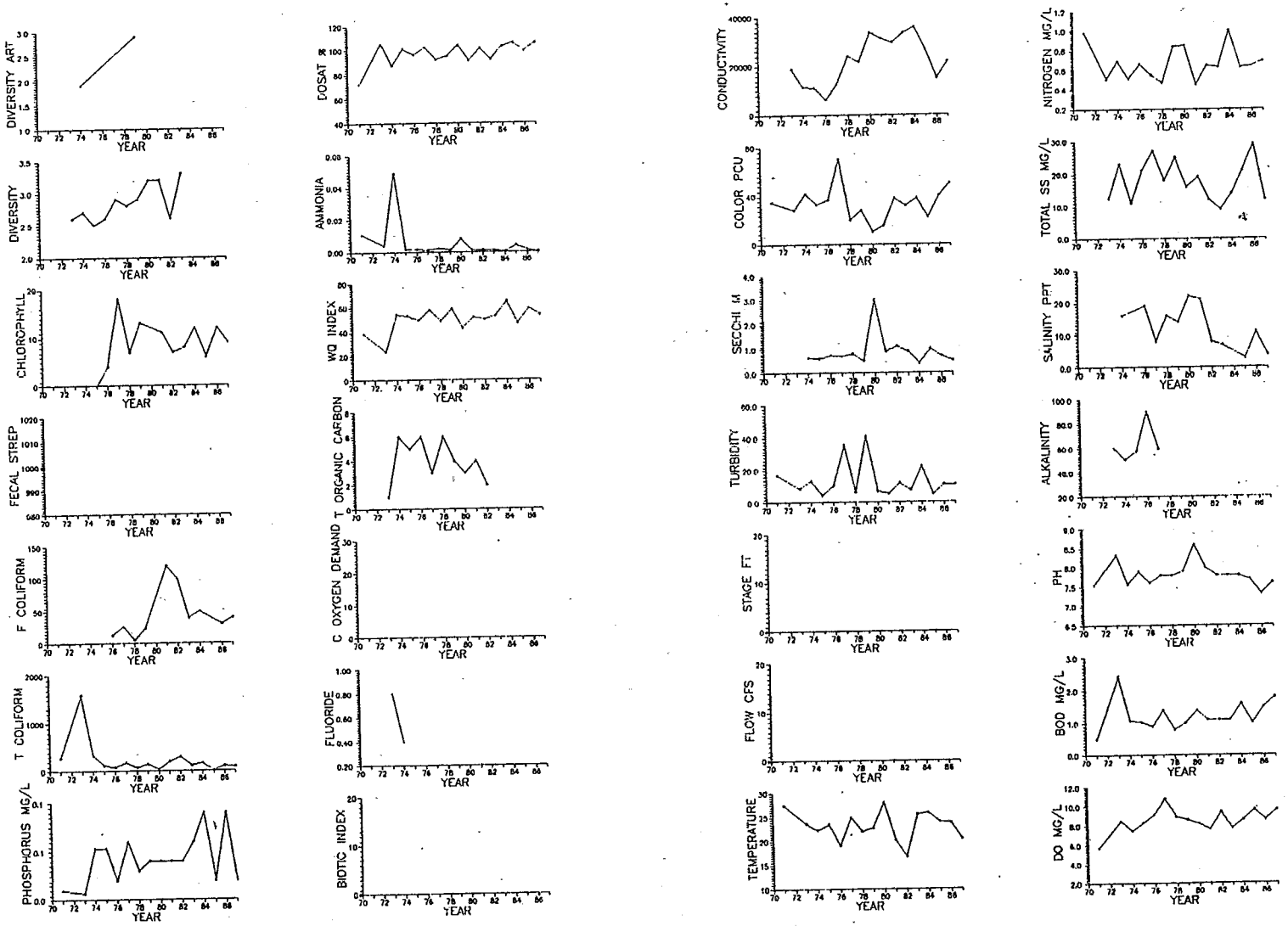


Figure F41. Representative water quality data from Apalachicola Bay above Gulf of Mexico (from Hand *et al.*, 1988a).

are shown in Figure F42 and details are given in Table F5 (Section F-20). The nutrient and phytoplankton levels were an order of magnitude higher in the Apalachicola Bay estuary than in the Econfina estuary (see Section F-20). Maximum nitrate and phosphate concentrations occurred during March-May during the period of maximum river discharge. Phytoplankton chlorophyll *a* levels were maximum during July-October. Relatively low mean salinity values and the highest turbidity values for the entire study area were characteristic of the Apalachicola Bay stations, due probably to watershed runoff and higher river discharge. The higher phytoplankton and nutrient values were considered by the authors to be indicative of productive, but not eutrophic estuarine systems. The N:P ratios for this area were greater than 10 and suggested a surplus of available nitrogen and possible phosphorus limitation (Myers and Iverson, 1981). Results of both carbon uptake and phosphate nutrient enrichment bioassays indicated that phosphorus was more important than nitrogen in limiting phytoplankton productivity during the summer months in this coastal estuary (Table F6). In Apalachicola Bay, where the water column contains high turbidity for several days following periods of high winds, phytoplankton are not phosphate limited but become so after sediments settle to the bottom. The authors cautioned that any alterations in land use that increase phosphorus mobility should be discouraged since these activities could lead to eutrophication in the system.

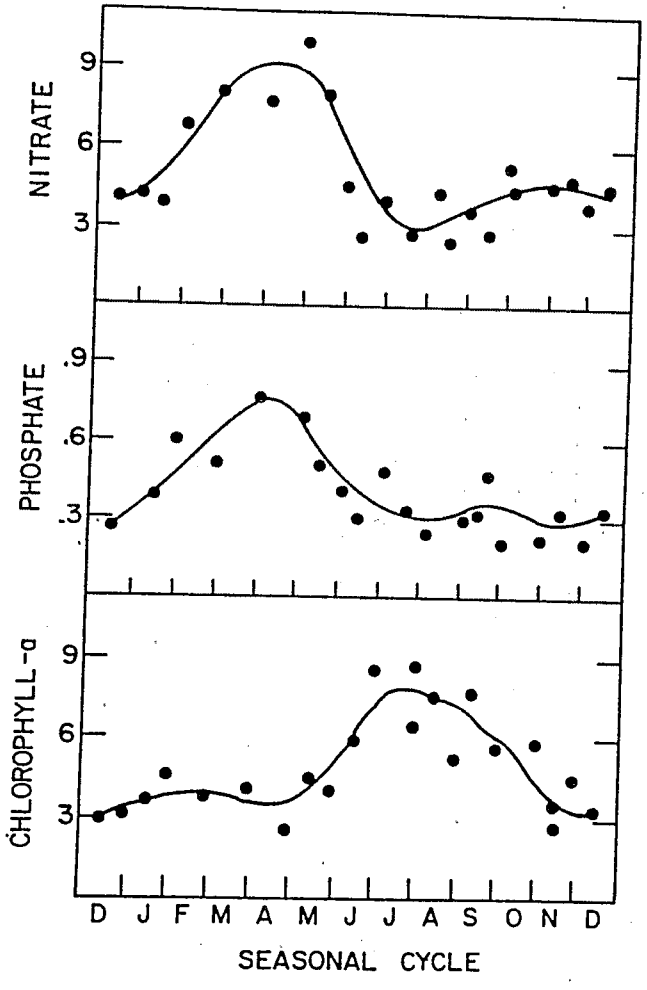


Figure F42. Seasonal cycles in the Apalachicola Bay estuary of surface dissolved nitrate (μg-at/l), soluble reactive phosphate (μg-at/l), and phytoplankton chlorophyll *a* (μg/l) from 1973 through 1976 (from Myers and Iverson, 1981).

Changes in nutrient concentrations in the bay and river were documented by Livingston *et al.* [1974(1975)] for a 12-mo period in 1972-1973 (Figure F43). Nitrate showed the greatest seasonal variation. River nitrate concentration remained relatively stable, however, thus indicating that decreased bay nitrate concentration was not due to decreased river concentrations but to decreased river flow rates and increased summer levels of biological activity. There were no seasonal trends in ammonia values in the bay. The bay sometimes had ammonia concentrations greater than the river, which suggested some other source of ammonia. Orthophosphate had no obvious seasonality. The phosphate concentration in the river was always greater than that of the bay, but when the river flow decreased in summer, the average phosphate concentration did not decline dramatically in the bay. Nutrient enrichment experiments in August 1973 indicated that low concentrations of both nitrate and phosphate were limiting phytoplankton productivity in the bay at the time. These nutrients were usually present in sufficient quantities during most of the year. Silicate concentrations showed a seasonal trend similar to river discharge. Minimal levels of chlorophyll *a* productivity occurred during February and were associated with high river discharge and flushing of the bay. Except for a surface maximum during a calm day in January, productivity was uniform during the remainder of the year [Livingston *et al.*, 1974(1975)].

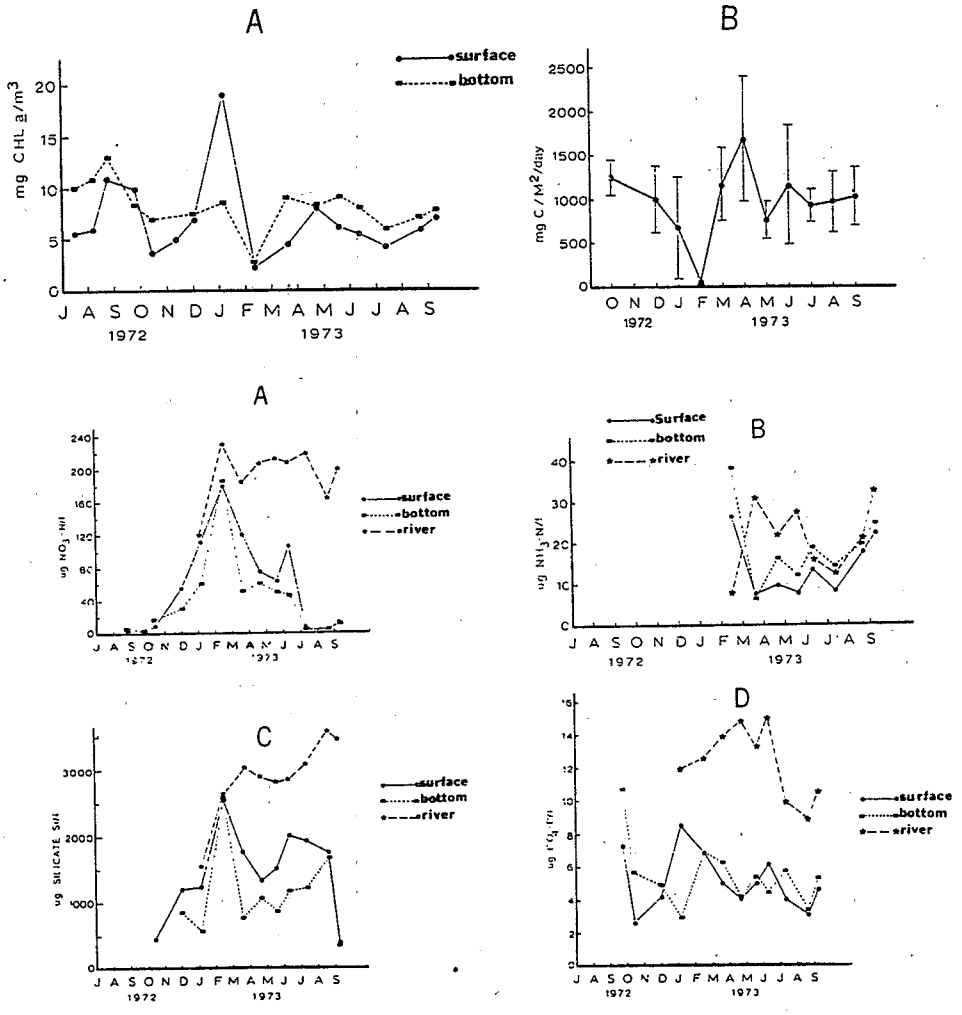


Figure F43. Average seasonal variation in chlorophyll *a* for Apalachicola Bay, average seasonal variation in productivity for Apalachicola Bay, and average seasonal variation for the Apalachicola River-Bay system in nitrate, ammonia, silicate and orthophosphate [from Livingston *et al.*, 1974(1975)].

A survey of 24-h variations in dissolved oxygen at two stations in Apalachicola Bay over a 9-mo period indicated that there was no significant cultural eutrophication in the Apalachicola Bay system (Livingston, 1974; cited in Livingston *et al.*, 1977). Eleven years of monitoring water quality stations monthly in the bay indicated no nutrient enrichment which leads to low dissolved oxygen levels (Livingston, 1983). Overall, the general distribution of water quality parameters (dissolved oxygen, turbidity, water color) during the 11-yr monitoring program indicates that the Apalachicola Bay estuary has not been adversely affected by man's activities in the region except in areas adjacent to population centers (Figure F44) (Livingston, 1983).

A recent evaluation (Livingston, 1991) noted growing evidence of changes in upland characteristics and within-system habitat alterations that are associated with changes in nutrient distributions and salinity relationships and that such changes can have serious impacts on estuarine

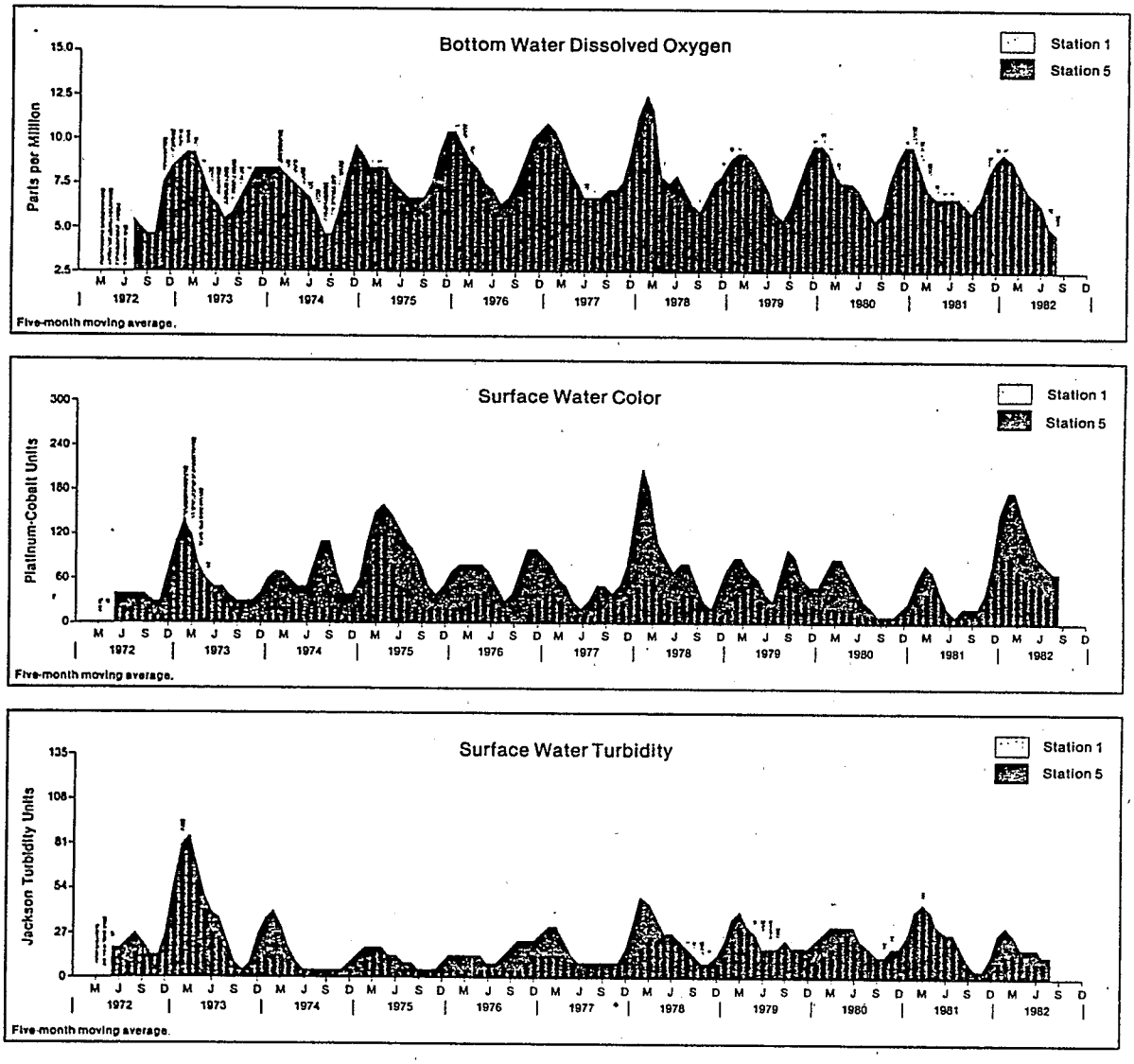


Figure F44. Trends in water quality parameters for Apalachicola Bay (from Livingston, 1983).

systems. In a river-dominated estuary, like the Apalachicola system, management should be based on the control of freshwater sources, nutrients and organic matter with a minimization of physical alterations that lead to increased salinity stratification (Livingston, 1991). Increased land development, waste loads, dredging and channelization of the Apalachicola River, and demands for freshwater sources will likely lead to the alteration of the water quality and productivity of the system (Livingston, 1991).

REFERENCES: F-24

Elder and Mattraw (1982)
Elder *et al.* (1986)
Estabrook (1973)
Florida Board of Conservation (1966)
Haddad and Carder (1979)
Hand *et al.* (1988a)
Isphording *et al.* (1987)
Livingston (1983, 1987))
Livingston and Joyce (1977)
Livingston *et al.* (1974, 1976, 1977, 1991)
Menzel and Cake (1969)
Myers (1977)
Myers and Iverson (1977, 1981)
National Estuary Study (1970a)
Williams *et al.* (1990)
Wolfe *et al.* (1988)

F-24.1 Florida Inner Continental Shelf (Panhandle)

The nearshore environment of the northeastern Gulf of Mexico off the Florida panhandle is characterized by a broad, shallow continental shelf. The region is a low wave energy coast, with maximum tidal amplitudes of 1 m. The area receives discharge from several rivers, the largest of which is the Apalachicola. In a hydrological survey of the northeastern Gulf of Mexico, Curl (1959) noted the influence of the Apalachicola River as far as 160 mi to the south (cited in Livingston and Joyce, 1977).

Large scale water circulation in the northeastern Gulf of Mexico is influenced by the Loop Current and associated eddies. Water from the Loop Current flows north into the Gulf and then veers to the right to form a clockwise gyre which is bounded by two or more smaller counterclockwise gyres off West Florida. Impacts from the Loop Current are more frequent on the eastern end of the Florida panhandle than on the western end; the boundary for many oceanographic processes, geological structures and biological communities is Cape San Blas.

The occurrences of the red tides caused by blooms of the toxic dinoflagellate, *Gymnodinium breve*, were discussed in detail in section F-15.1. While the area between Tarpon Springs and Ten Thousand Island on the Florida west coast experiences the most and most frequently recurring red tides, there have been numerous instances of red tides in the offshore coastal waters of the Florida panhandle (Steidinger, 1973). In July 1964, a *G. breve* developed 35 to 140 km offshore in Apalachee Bay and moved into northern Apalachee Bay in September. The area affected was estimated to be approximately 36,000 km^2. Numerous and substantial fish kills were associated with the bloom. A detailed description of the bloom is available in Florida Board of Conservation (1966). A red tide occurred along the panhandle coast in early September 1974, necessitating the closure of these waters for shellfish harvesting (Keys, 1975). A red tide of an unconfirmed organism was extensive off Pensacola in July 1960 (Florida Board of Conservation, 1966).

A bloom of the toxic dinoflagellate, *Gonyaulax monilata*, occurred in waters adjacent to Pensacola Bay during an extensive bloom within the estuary in August 1979 (Perry *et al.*, 1979). Fish kills were associated with the bloom.

See Sections F-20 and F-23 on nearshore portions of Econfina estuary.

REFERENCES: F-24.1

Atwood (1981)
Churgin and Halminsta (1974)
Cons. Perm. Int. Exp. Mer (1936)
El-Sayed *et al.* (1972)
Florida Board of Conservation (1966)
Freeberg *et al.* (1979)
Haddad and Carder (1979)
Myers and Iverson (1979)
Schroeder *et al.* (1988)
Stuntz *et al.* (N.D.)
Thompson and Bane (1986a,b)
Thompson *et al.* (1988)

F-25 St. Andrews/West/North/East Bays

The St. Andrews Bay system is composed of North, East and West Bays, St. Andrews Bay, Grand Lagoon, St. Andrew sand, and, to the east, St. Joseph Bay. There are no large rivers within the watershed; the largest inflow to the St. Andrews Bay system comes from Econfina Creek, which most of the year is composed predominantly of ground water from springs fed by the Floridan Aquifer. Drainage from the Choctawhatchee and East Rivers flows into the West Bay area. The watershed is primarily forested with an urbanized area concentrated adjacent to St. Andrews Bay at Panama City, Lynn Haven and a narrow strip of development along the Gulf of Mexico. Point sources of pollution in the area include two large paper-pulp processing plants (one in St. Andrews Bay and another in St. Joseph Bay) and several wastewater treatment plants (Figure F45). Little research has been performed in this estuarine system.

The St. Andrews Bay system was studied in 1974 in order to calculate a waste load allocation amount and quality of waste that could be discharges to the system based upon its calculated ability to assimilate that waste without damage to its ecosystem (Johnson *et al.* 1974; cited in Wolfe *et al.*, 1988). During this study, St. Andrew Bay had the poorest water quality of the four bays in this drainage. Some locations, particular Watson Bayou and the International Paper Company outfall, did not meet dissolved oxygen, turbidity, or bacterial standards for Class III standards (*i.e.*, recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife). The other bays met Class II standards (*i.e.*, shellfish propagation or harvesting).

Ten years later, Hand and Jackman (1984; cited in Wolfe *et al.*, 1988) reported that of 400 km^2 of estuary in this basin, all but 14 km^2 has good water quality. The major urban development in the area centers around Panama City. Major point sources of pollution include two large paper-pulp processing plants, one discharge via a regional sewage treatment and one directly to St. Joseph Bay. Historically, problem areas included Watson Bayou, Martin Bayou, and Deeper Point Lake at the head of North Bay.

In the most recent 305(b) report (Hand *et al.*, 1988j) lists the St. Andrews Bay system as generally good water quality. The major river, Econfina Creek, is nearly pristine, and the bay waters are generally well flushed by the Gulf of Mexico. The bay is threatened, however, not only by the growth of nonpoint source pollution, but also by several important domestic and industrial point sources. There are several areas of concern in the Basin: Deer Point Lake and its tributaries, exclusive of Econfina Creek; Beatty Bayou, wastewater treatment plant effluent; Watson Bayou, historical wastewater treatment discharges; West Bay, Panama City waste water treatment plant; St. Andrews Bay, regional wastewater treatment plant discharges. Two of the wastewater treatment plants receive more industrial wastes (paper-pulp mill and chemical company discharges) than domestic sewage. Both of the receiving bays show biological degradation and shifts in sediment composition; however, because of the bays' circulation patterns, the effluent is relatively quickly dispersed (Hand *et al.*, 1988j). Other pollution sources in this basin include many small package plants and septic tanks which discharge poorly treated waste into ditches that empty directly into the bay system, along with significant runoff from highway construction and logging operations. Powell Lake, although relatively pristine, is undergoing rapid development. Localized problems in

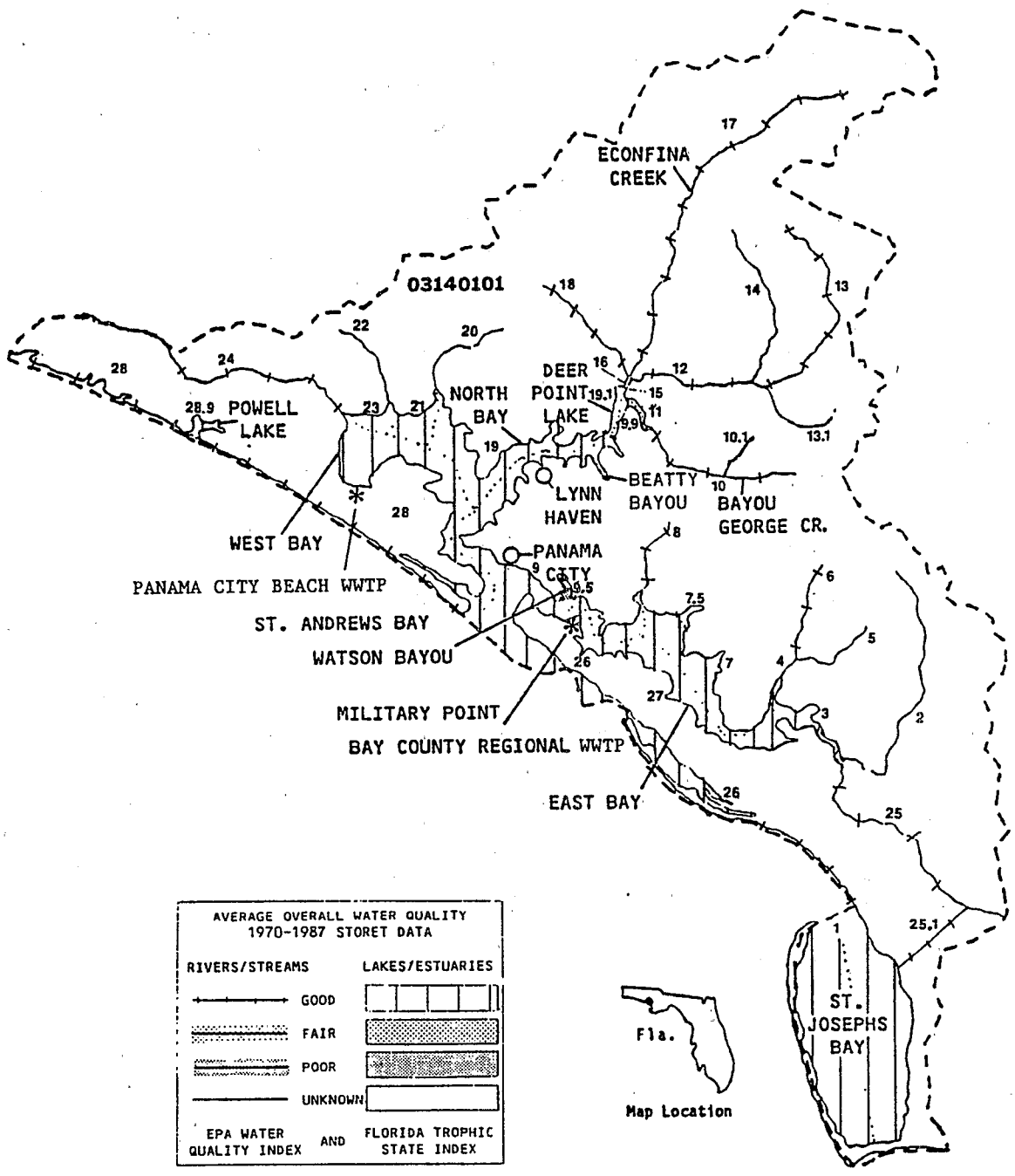


Figure F45. St. Andrews Bay basin [from 305(b) report of Hand *et al.* (1988j)].

within the St. Andrews estuarine area result in high ammonia levels, elevated nutrients, fish kills, increases in aquatic vegetation, reductions in biological richness, decreased dissolved oxygen values, and increased BOD loadings.

REFERENCES: F-25

Hand *et al.* (1988j)
Williams *et al.* (1990)
Wolfe *et al.* (1988)

F-26 Choctawhatchee Bay

Choctawhatchee Bay is a hypopycnal lagoon that is connected to the Gulf of Mexico via East Pass (Delfino *et al.*, 1984). East Pass Lagoon (Destin Harbor) opens into Choctawhatchee Bay just north of East Pass. The highly alluvial Choctawhatchee River drains into the eastern portion of the bay which is separated from the Gulf of Mexico by Santa Rosa Island. Other tributaries to the bay include Lafayette, Magnolia, Alaqua, Rocky, Turkey and Juniper Creeks. The Bay is 40 km long by 5 km wide, averages 3 m in depth at the eastern end, and is 9 m deep in the remainder (Wolfe *et al.*, 1988). The bay is characterized by its minimal connection with the Gulf of Mexico. East Pass, a narrow channel west of Destin and east of Santa Rose Island, is the only connection and is often shoaled to a depth of 2 m (Collard, 1976; cited in Wolfe *et al.*, 1988) requiring maintenance dredging to keep a 4 m channel open. East Pass Lagoon is subject to minimal flushing, resulting in stagnant waters in the eastern area where almost anoxic conditions prevail (Delfino *et al.*, 1984; Windsor, 1985).

The major land uses in the basin are forestry and agriculture, but urban development is occurring rapidly along the coast and in the northwestern bay area. Fort Walton Beach, Destin and Valparaiso are the largest cities in the basin, and the area around these cities along the Gulf coast is undergoing rapid urban development (Wolfe *et al.* 1988). One sewage treatment plant is located in the basin; there is little industrial activity (Windsor, 1985).

Historically, water quality in this basin has been good; however, there have been several problem areas associated with rapid development occurring along the coast (Hand *et al.*, 1988d). In the Hand and Jackman 305(b) report (1984; cited in Windsor, 1985), water quality for most of the bay was listed as good, but fair for localized points in St. Andrews Bay, the eastern end of the bay and several tributaries. The water quality assessment for the area in the most recent 305(b) report (Figure F46) (Hand *et al.*, 1988d) is rated as good. The report, however, notes several fluctuations in the water quality conditions of the St. Andrews Bay system. In the 1970s, treated wastewater effluents caused eutrophication, fish kills, and seagrass bed die-offs in portions of the bay. The wastewater treatment plants have been converted to spray irrigation discharge, and a basin assessment in 1984 indicated that the water quality had improved since this upgrading.

Recently water quality in the bay is again being degraded due to the continued development of the watershed (Hand *et al.*, 1988d). The nonpoint pollution sources are associated with highway runoff, ditching and draining of water-cleansing swampland, and surficial water table seepage from package plant perc-ponds and wastewater treatment plant sprayfields. The poorly circulating Old Pass Lagoon at Destin is experiencing eutrophication and fish kills. Dons Bayou near Ft. Walton has experienced a low grade, chronic fish kill from unknown sources. Recent studies indicate localized metals contamination in sediments near urban areas. Other sources of pollution in the bay include discharge from meat and poultry processing plants and runoff from agricultural areas in the upper basin. Another area of concern is the construction of a proposed bridge across the bay with its associated ecological damage and the eventual further development of Gulf islands.

A State-funded, in-depth ecological baseline study of Choctawhatchee Bay during 1985-1986 was recently completed (Livingston, 1986) and summarized in Wolfe *et al.* (1988). Portions of this summary are presented below. This study was prompted by plans to construct a cross-bay bridge, but much data relevant to the ecological health of the system was presented.

Portions of the bay are much deeper, and vertical stratification of salinity is prevalent with associated stratification of dissolved oxygen and hypoxia at depth during various times of the year (Livingston, 1986; cited in Wolfe *et al.*, 1988). Freshwater input on the eastern end, salt water inflow on the western end, low tidal range (0.2 m within the bay and 0.4 m in the adjacent Gulf of Mexico) results in minimal tidal flushing and poorly mixed bay waters. The resulting stratification (sharp in the western two-thirds of the bay, and weak in the eastern one-third) produces a

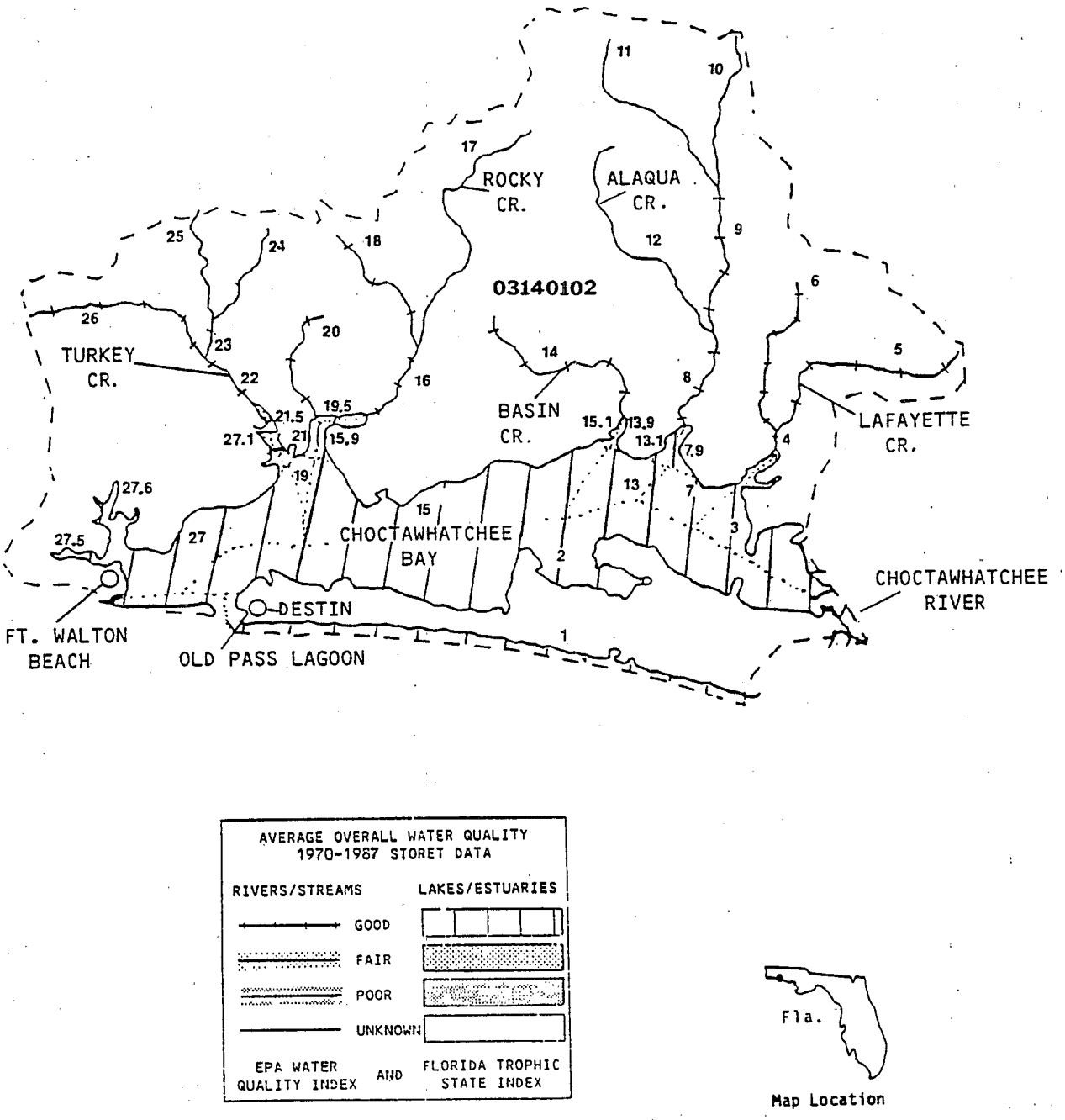


Figure F46. Choctawhatchee Bay basin [from 305(b) report of Hand *et al.* (1988d)].

stagnation of high salinity bottom waters. Collard (1976; cited in Wolfe *et al.*, 1988) found that in summer the bottom of the bay was "biologically barren." Livingston (1986; cited in Wolfe *et al.*, 1988) found that low dissolved oxygen levels associated with the salinity gradients in the deeper portions of the bay were life-limiting to various estuarine forms during certain months of the year. Low dissolved oxygen was most evident during summer months, and by August the entire bay was hypoxic to anoxic at depth.

The baseline study of Livingston (1986) (cited in Wolfe *et al.*, 1988) also found that nitrogen and phosphorus levels were highest in the western sections of the bay. This was attributed to stormwater runoff from the Destin peninsula and adjacent developed areas. A wasteload allocation study was performed on the bay using a water quality model (Johnson *et al.*, 1974; cited in Wolfe *et al.*, 1988). The model determined that water quality was generally good with the exceptions of the Cinco, LaGrange, Boggy and Alaqua Bayous, and that nutrient levels in most of the bay indicated no eutrophication processes. Macroinvertebrate sampling in the basin (Ross and Jones, 1979; cited in Wolfe *et al.*, 1988) indicated areas of healthy benthic populations and others that were impacted.

REFERENCES: F-26

Blaylock (1983)
Hand *et al.* (1988d)
Kaufmann *et al.* (1988)
Livingston (1986)
Sale *et al.* (1988)
Williams *et al.* (1990)
Wolfe *et al.* (1988)

F-27 Pensacola/East/Escambia Bays

The Escambia Bay estuarine system is located in the extreme northwestern section of Florida's panhandle and has a surface area of 159 mi^2. The port city of Pensacola is located on Pensacola Bay. The Yellow, Blackwater and Escambia Rivers drain into the estuarine system which is generally divided into Pensacola, Escambia, East and Blackwater Bays and Santa Rosa Sound. Major flows come from the Escambia River (6500 cfs), the Blackwater River (400 cfs), and the Yellow River (1500 cfs) (Hand *et al.*, 1988g). The bay system is relatively shallow, ranging from less than 1 m to 6 m deep and averages 2.5 m at mean low water. Water depth increases from the north to the south. The system has been described by Ellis (1969; cited in Wolfe *et al.*, 1988) as a low energy estuary. The opening of the bay to the Gulf of Mexico is restricted and shallow, and the bay is generally considered to be vertically homogeneous but does become partially stratified seasonally (Windsor, 1985).

The City of Pensacola, with more than 60,000 inhabitants is located on the estuary (Windsor, 1985). Land use is primarily for forestry, but large acreage is used for agriculture and developed and urban areas. In the estuarine drainage basin there are nine sewage treatment plants, many hazardous waste facilities, two major dredging operations, three pulp and paper plants, one petrochemical plant, one power plant and two steel mills. Historically, this system received national attention as a result of numerous fish kills and the effects of industrial pollution (Windsor, 1985). Years of abuse had severely degraded and damaged the estuarine waters and resulted in poor water quality and the occurrence of extensive fish kills. As a consequence many such areas were closed to commercial fishing and recreational activities. In addition to the growing sewage burden, inadequately treated chemical effluents contributed to high BOD, high nutrients, lowered dissolved oxygen and a what has frequently been described as an advanced state of "eutrophication" (Windsor, 1985). Commercial fisheries harvests dropped or ceased; fish kills were prevalent in the late 1960s and early 1970s. Fish kills were reported in miles of dead fish. Comparative studies suggested that nearly all the seagrass beds in the bay were destroyed (Windsor, 1985).

Significant improvements in water quality, particularly dissolved oxygen, have been noted for the bays as a result of decreasing the discharges from the industrial and municipal effluents by more than 90 %. Fish kills are smaller in size and less frequent (but see below). Water quality for most of the bays was described as good to fair (Hand and Jackman, 1984; cited in Windsor, 1985) with a few notable exceptions of low dissolved oxygen and high bacteria, which were related primarily to point source discharges of sewage treatment plants and some industrial wastes. The figure from

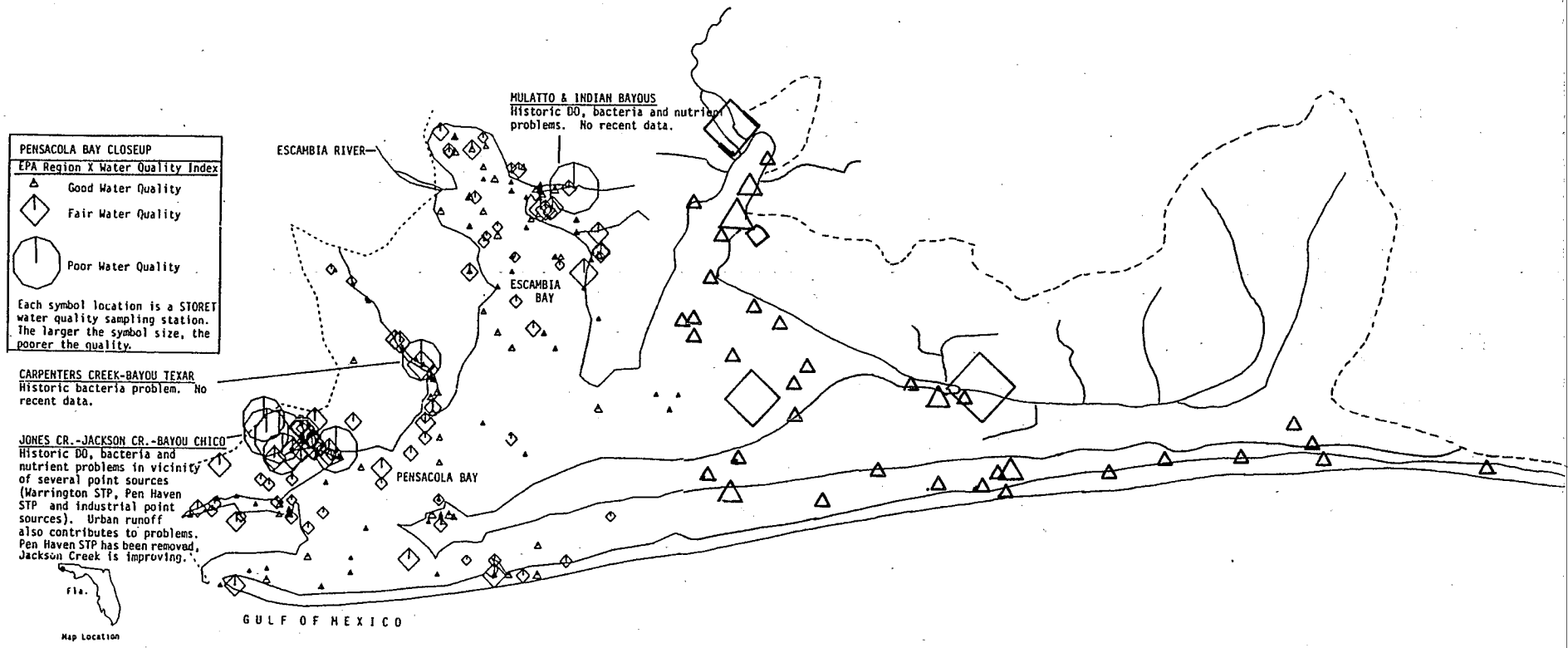


Figure F47. Pensacola Bay basin [from 305(b) report of Hand and Jackman (1984)].

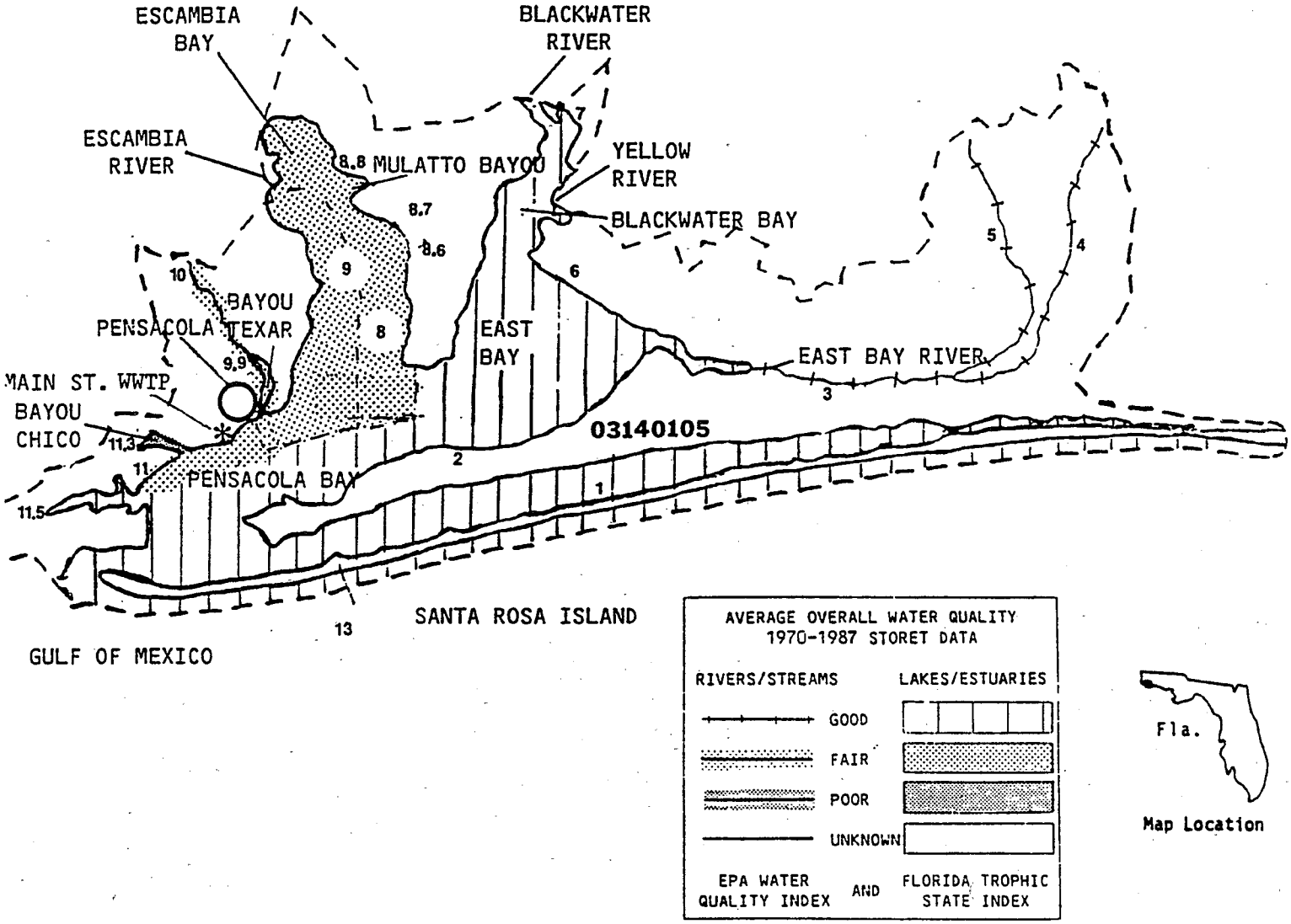


Figure F48. Pensacola Bay basin [from 305(b) report of Hand *et al.* (1988g)].

the 1984 305(b) report (Figure F47) is shown here for comparison with the most recent report (Hand *et al.*, 1988g) (Figure F48). The fair water quality assessment for portions of the East Bay area have been upgraded to good. Tributaries to Blackwater Bay which were listed as fair have been upgraded to good. Problems in Blackwater Bay were attributed to nutrients at the mouth of the Blackwater River (Hand and Jackman, 1984). Pensacola Bay is generally listed as good, but previously had localized fair assessments. Escambia Bay is still listed with fair water quality as it was previously, but poor ratings for several of the tributaries have been changed to fair or good, with the exception of Bayou Chico which is still listed as poor. Representative water quality data from several of these areas are shown in Figures F49-F52.

The Hand *et al.* (1988g) reports cites the main water quality problems in upper Escambia Bay and the two bayous (Bayou Chico and Bayou Texar) which drain the Pensacola urban area. In addition to stormwater runoff, Bayou Chico (rated poor) receives shipyard runoff, historic discharge and runoff from Reichold Chemicals, and a wastewater treatment plant discharge. Historically, it was also impacted by chemical, lumberyard and creosote industries. Sediments are polluted with metals and support almost no macroinvertebrate life. The bayou has bacteria, fish kill and nutrient problems. Two creeks which fed this bayou also exhibit water quality problems. Upgrades to the wastewater treatment plant are scheduled.

Bayou Texar has had increasing fish kill problems in recent years. It receives discharge from 68 storm sewers and heavy suspended solids loads from Carpenters Creek. Modifications to the treatment of stormwater runoff are proposed for this area.

Further up the estuary, water quality problems are evident in the northern portion of Escambia Bay with reduced dissolved oxygen concentrations, fish kills and bacteria problems. A wastewater plant, an industrial discharge and a thermal discharge enter the Escambia River upstream of the mouth at Escambia Bay. Two chemical manufacturing companies discharge into Escambia Bay. Problems in upper Escambia Bay are complicated by poor flushing due to natural circulation patterns and a somewhat restrictive railroad trestle which is scheduled to be replaced. On the eastern side of Escambia Bay is Mulatto Bayou which exhibits dissolved oxygen, nutrient and transparency problems. Indian Bayou, in the southeastern portion of Escambia Bay, still supports a seagrass bed community.

In Pensacola Bay proper, water quality improved and is currently assessed as good (Hand *et al.*, 1988g). A recently completed sampling effort to study the impacts of Pensacola's Main Street wastewater treatment plant showed that the bay was assimilating the current discharge but that loadings should not be increased. Florida Dept. of Environmental Regulation (DER) sampling indicated low diversity and heavy organic sedimentation. Studies are ongoing in Escambia River, Escambia Bay and Pensacola Bay by Florida DER staff.

Santa Rosa Sound is assessed with good water quality, but is threatened by development of the barrier island, dredge and fill operations and stormwater runoff (Hand *et al.*, 1988g). A previous assessment by Moshiri *et al.* (1980) concluded that the Sound exhibited serious degradation of water quality relative to other local estuarine systems and that during warm months red tide outbreaks were possible. Little Sabine Bay at the terminus of the causeway on Santa Rose Island exhibited signs of eutrophication evidenced by high nutrient concentrations, low water transparency, increased algal populations, and low dissolved oxygen concentrations. The study recommended that no further discharges be allowed to Little Sabine Bay.

A variety of studies in this area have focused on water quality, including nutrient levels, chemical pollution and pesticide monitoring. The location of a U.S. EPA laboratory on Sabine Island in Gulf Breeze has facilitated numerous studies of water quality and environmental assessment. Additional research has been conducted by the faculty of the University of West Florida in Pensacola.

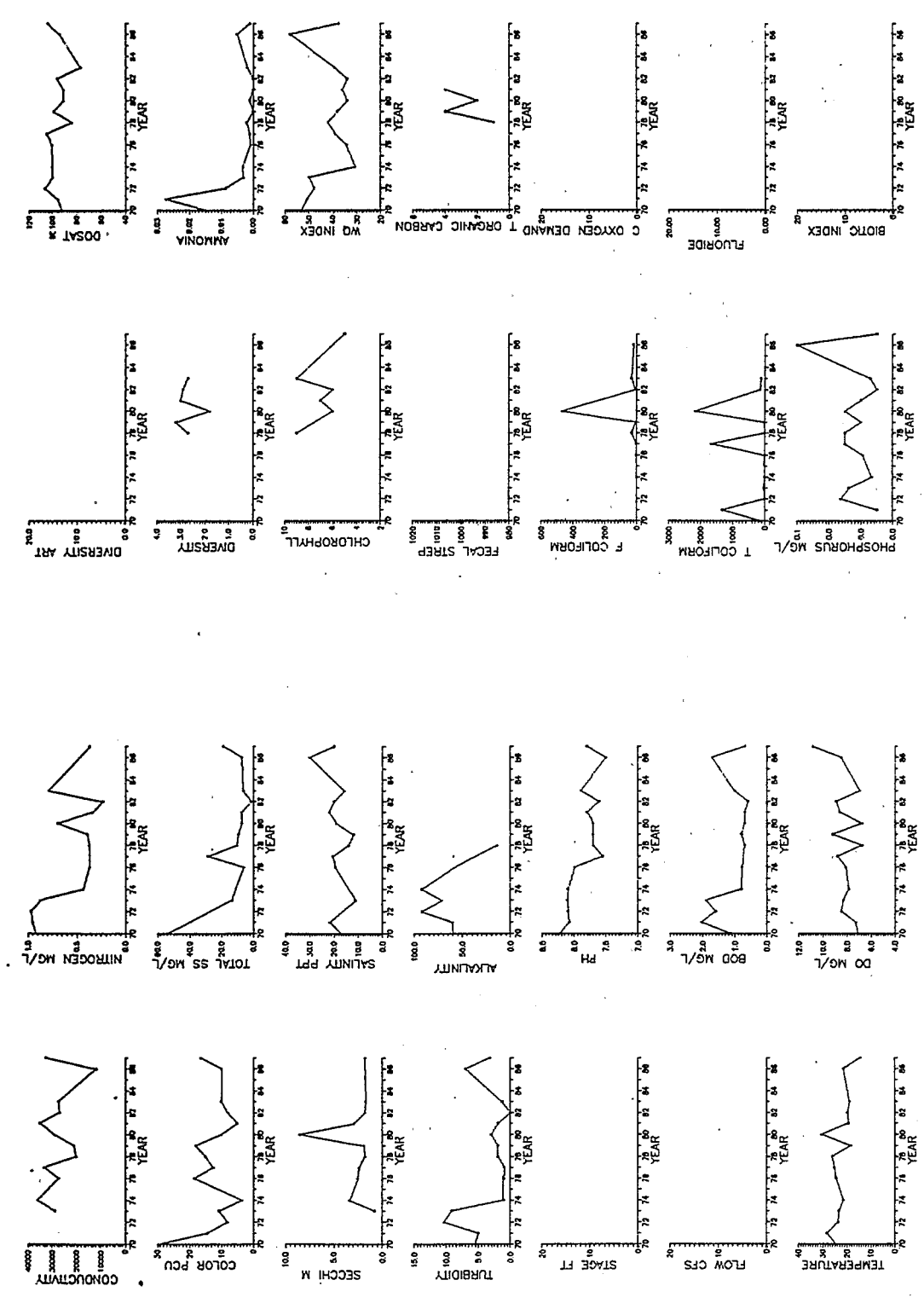


Figure F49. Representative water quality data from Pensacola Bay system in Santa Rosa Sound (from Hand *et al.*, 1988g).

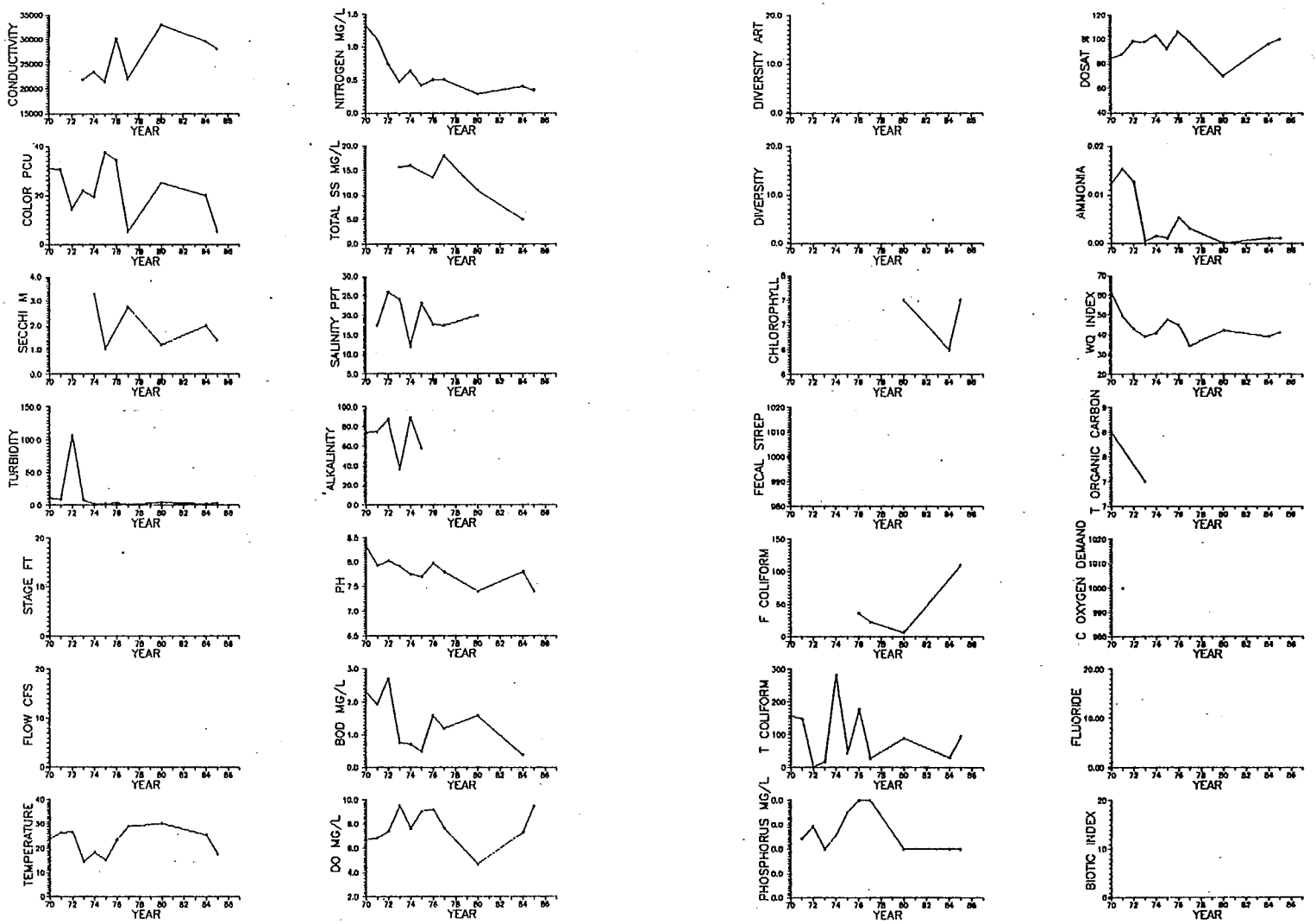


Figure F50. Representative water quality data from Pensacola Bay system above Gulf of Mexico (from Hand *et al.*, 1988g).

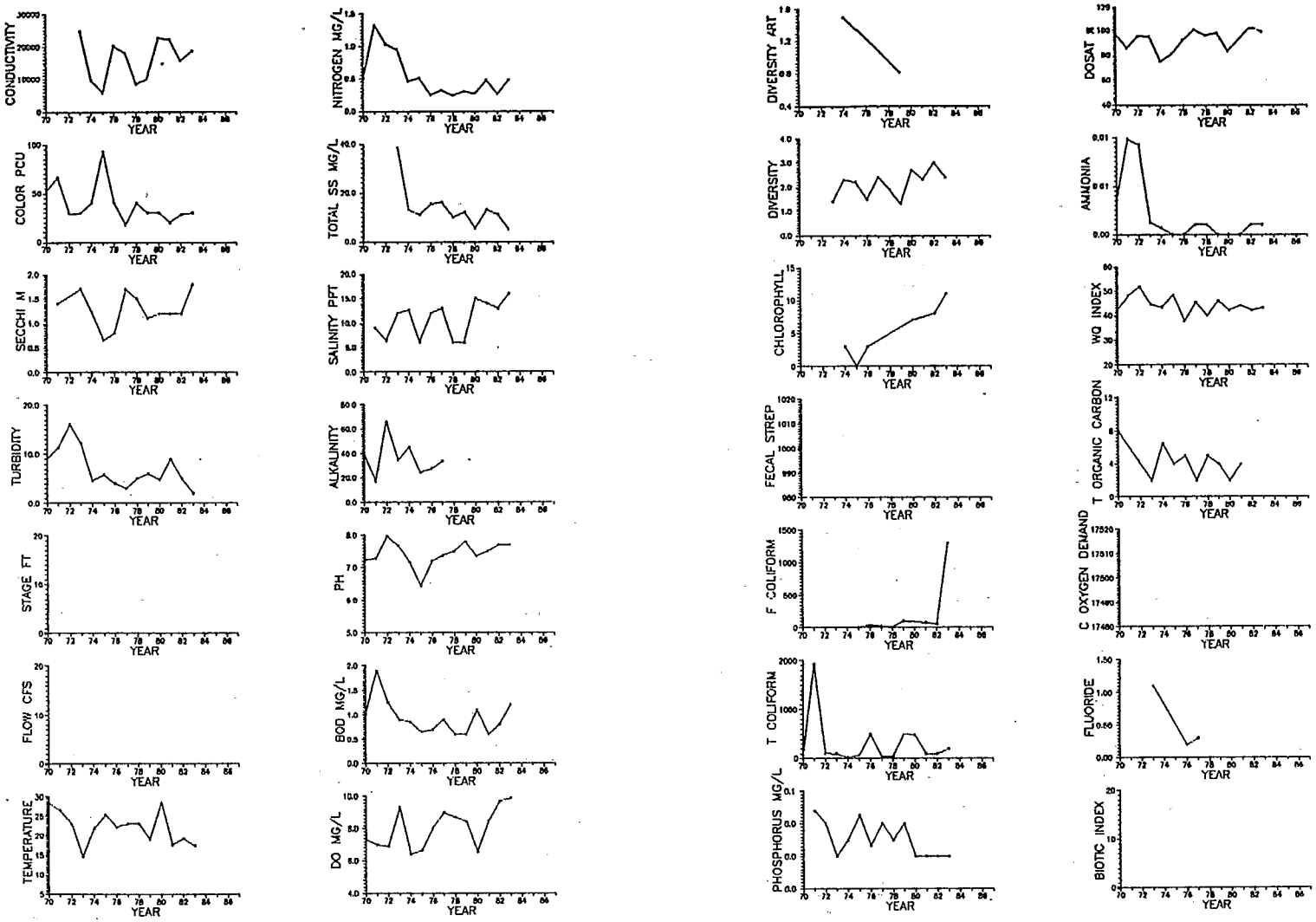


Figure F51. Representative water quality data from Pensacola Bay system in East Bay above the East Bay River (from Hand *et al.*, 1988g).

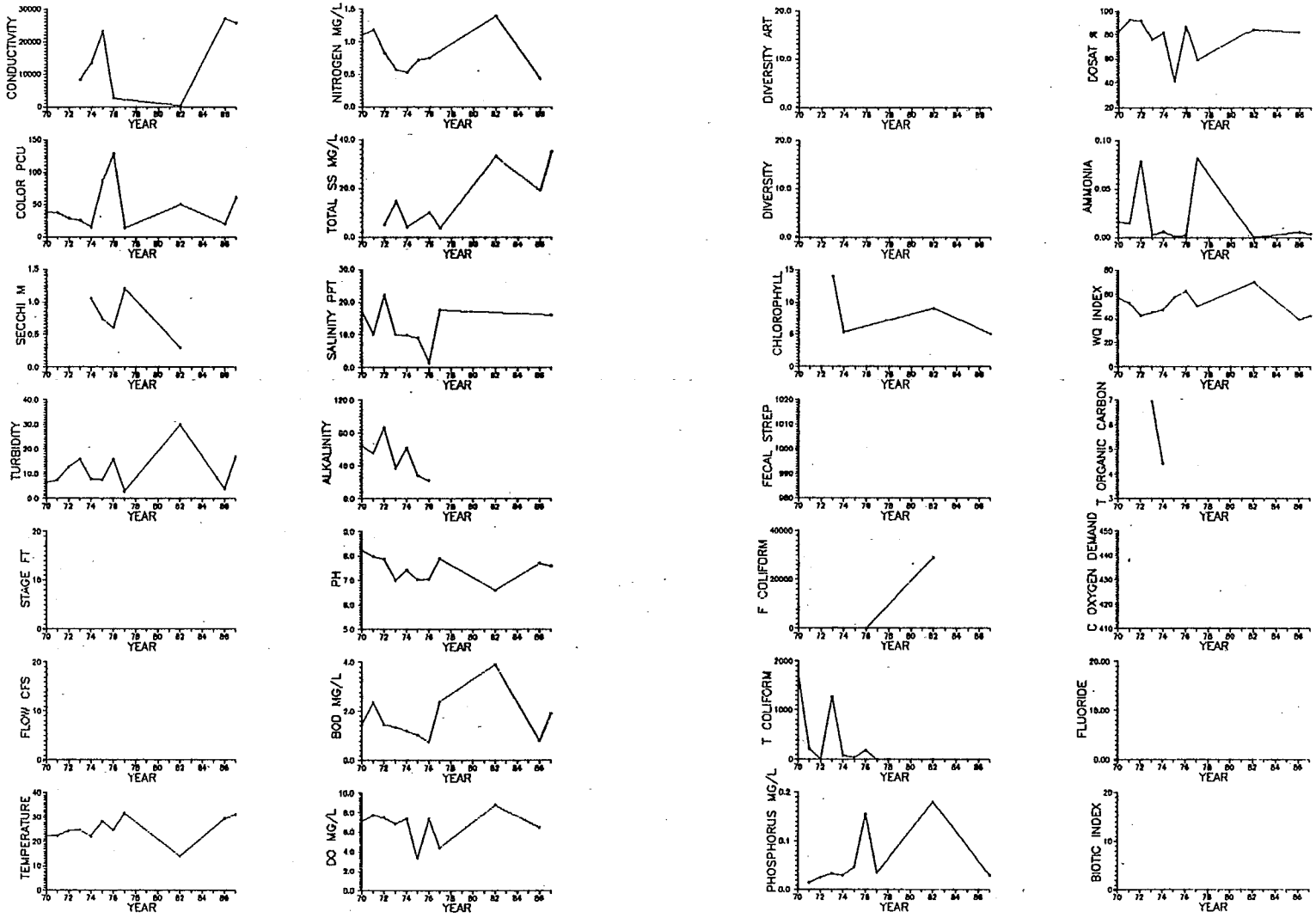


Figure F52. Representative water quality data from Pensacola Bay system in Escambia Bay above the Escambia River (from Hand *et al.*, 1988g).

Moshiri *et al.* (1974, 1978a,b) examined the extent of nitrogen and phosphorus inputs and their effects on algal production in Bayou Texar. Nitrogen and phosphorus concentrations decreased toward the south in the bayou, apparently being related to carbon fixation rates. Ecologically, the Bayou was approaching eutrophication in 1971 as evidenced by highly fluctuating oxygen and primary productivity patterns well correlated with algal cell numbers and distribution. As mentioned earlier in this report, Moshiri *et al.* (1981) reported a reversal of eutrophication following the construction of a retention reservoir and weirs in the upstream channel of Bayou Texar and repair of sewage treatment plants. The authors reported an almost total reduction in fish kills, a 90 % reduction in phytoplankton primary production, a virtual elimination of algal blooms and re-establishment of public use. Fish kills in recent years (1988-1990), however, indicate that the problem has not disappeared (D. A. Flemer, personal communication).

Dissolved oxygen concentrations obtained by continuous monitoring were used to evaluate sampling strategies for water quality conditions based on oxygen levels for several northern Gulf of Mexico estuaries (Summers and Engle, 1992). Dissolved oxygen conditions for estuaries chosen for expected high frequencies of low dissolved oxygen concentrations in near-bottom waters (Bayou Chico, Escambia Bay, lower Perdido Bay, and middle Perdido Bay) based on the assessments of Bault (1972), Rabalais *et al.* (1985) and Windsor (1985) were consistent with the pre-determinations of water quality. Data from Bayou Chico and Perdido Bay are shown in Figure 53. Sites which were expected to be low-frequency hypoxia stations (Upper Perdido Bay and Wolf Bay) rarely encountered low dissolved oxygen, and two sites (Pensacola Bay and Santa Rose Sound) never experienced dissolved concentrations <2 ppm (Figure F53).

Escambia and East Bays have experienced severe vegetation losses since 1949 (Delfino *et al.*, 1984). A comparison of aerial photographs from 1949 and 1974 indicated that all of the seagrass beds were gone except for one bed in East Bay. The loss of seagrasses was ascribed to the synergistic effects of sewage and industrial effluents, dredging and filling activities, beachfront alterations, and changing watershed characteristics (Rogers and Bisterfeld, 1975, cited in Delfino *et al.*, 1984).

Fish kills in warm summer months have plagued portions of the system in 1990 and previous years (*Press Gazette*, August 16, 1990). The kills of 1990 were of menhaden, a species more common in offshore waters than estuarine environments. Algal blooms associated with runoff from nutrient overloading from septic tanks and lawn fertilizers would tend to concentrate these planktivorous fish. High concentrations of the motile, active fish would rapidly deplete the available oxygen content of the waters, especially in the heat of the season.

A bloom of the toxic dinoflagellate, *Gonyaulax monilata*, occurred in the Pensacola Bay estuary during the same time as an extensive bloom in Mississippi Sound in August 1979 (Perry *et al.*, 1979). Large areas of discolored water were reported in the Pensacola Bay estuary and in offshore waters. Fish kills were associated with the bloom.

REFERENCES: F-27

Hand *et al.* (1988g)
Kaufmann *et al.* (1988)
Moshiri *et al.* (1974, 1978, 1979, 1980)
Olinger *et al.* (1975)
Sale *et al.* (1988)
Summers and Engle (1992)
Williams *et al.* (1990)
Wolfe *et al.* (1988)

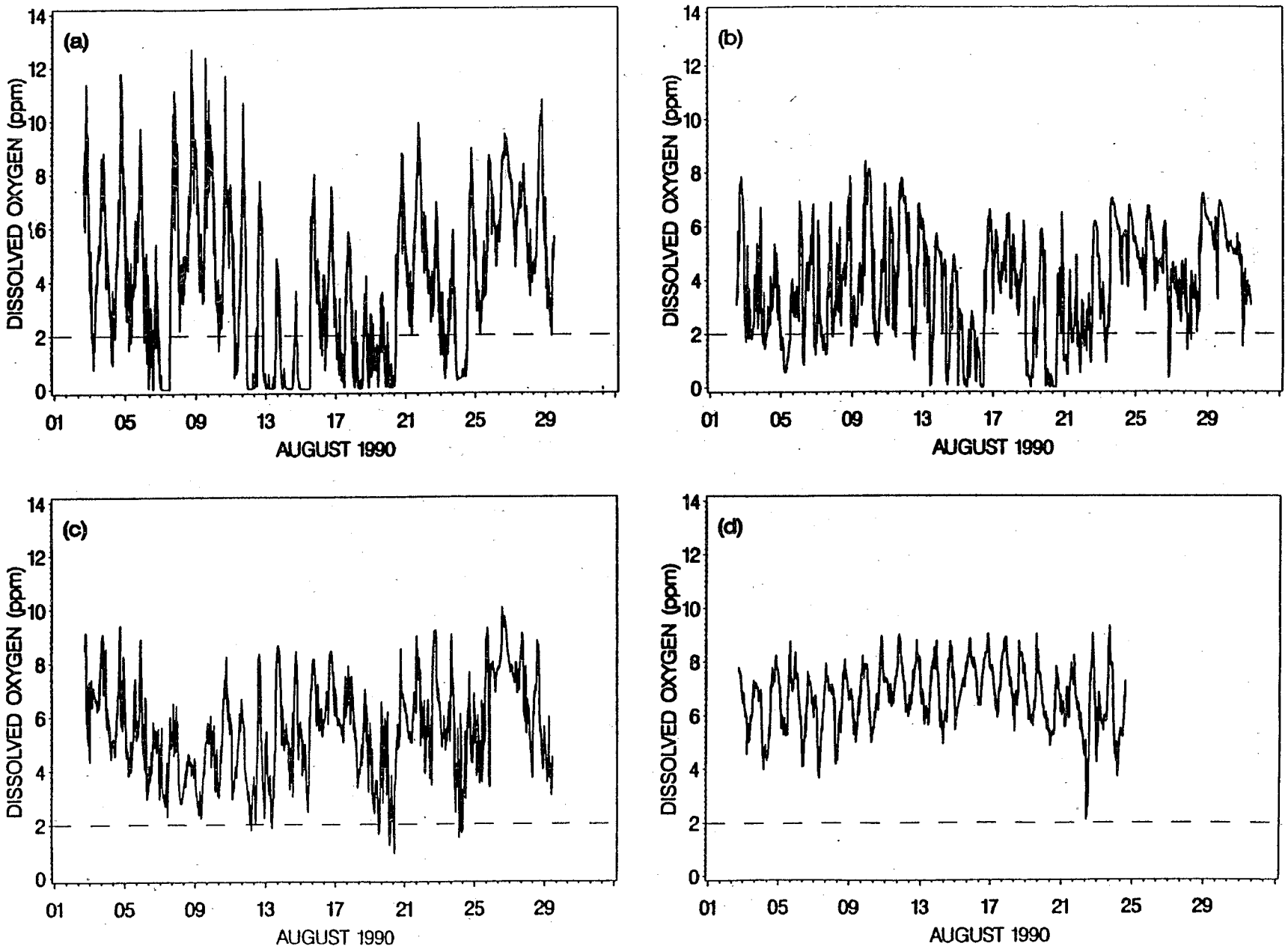


Figure F53. Time series of dissolved oxygen measurements at 15-min intervals during August 1990 at high frequency hypoxia sites: a) Bayou Chico and b) Lower Perdido Bay; and at low frequency hypoxia sites: c) Escambia Bay and d) Santa Rosa Sound (from Summers and Engle, 1992).

ALABAMA

The estuarine systems of Alabama are dominated by the Mobile River delta and Mobile Bay. Other significant water bodies include Mississippi Sound and Perdido Bay. The Mobile Bay system, which supports significant natural resources, is experiencing intensive growth and development of coastal areas, and water quality stress (Horn, 1990). Population growth is evidenced by an upsurge of condominiums in Baldwin County. Waterborne transportation may increase with the completion of the Tennessee-Tombigbee Waterway with Mobile Bay as its southern terminus. Exploitation of mineral resources, particularly natural gas, will increase. There are 106 industrial, 15 sewage and 29 semi-private/small service sources of wastewater discharging into the bay. The major facilities in the National Coastal Pollutant Discharge Study are shown in Figure A1 (Pacheco *et al.* 1989a). Nonpoint source contributions (agriculture, forestry, construction, urban runoff) are not illustrated nor managed to the same degree.

Fish kills and closure of oyster shellfishing grounds, as an obvious indicator of poor water quality, have been prevalent in coastal Alabama for many years (Crance, 1971). The largest fish kill to occur in Alabama was attributed to domestic waste which depleted oxygen in the receiving water body. A summary of the NOAA Fish Kill Inventory Data is given in Table A1.

Much emphasis has been, and is being given, to measuring water quality conditions and trends in the Mobile-Baldwin County area by the Alabama Department of Environmental Management (Trend Stations) with support from EPA and NOAA (Horn, 1990). Although increasing discharges and growth are occurring, water quality measurements over the last two years indicate that water quality standards in Mobile and Baldwin County have been met 86.7 percent of the time (Horn, 1990). Several management plans exist or are in preliminary stages for Mobile Bay and surrounding areas: 1) the South Baldwin County EIS project with EPA to develop and assess various wastewater management alternatives for coastal Baldwin County, 2) water quality modeling for Oyster and Wolf Bays, 3) the establishment of the Weeks Bay National Estuarine Research Reserve, which is managed by the State in a cooperative effort with NOAA, 4) extensive water quality studies of Perdido Bay involving the States of Alabama and Florida, U.S. EPA, NOAA and Champion International, and 5) the plans for submission of a nomination of Mobile Bay as an EPA National Estuary.

The Cooperative Gulf of Mexico Estuarine Inventory (Bault, 1972) covered five areas: East Mississippi Sound, Mobile Bay, Mobile Delta, Little Lagoon, and Perdido Bay. From April 1968 through March 1969, samples were taken monthly at 21 stations located in the five estuarine areas for selected chemical and physical properties. The average concentrations of nitrate-nitrogen, nitrite-nitrogen, and total phosphorus are given in Table A2. During this study, nitrate concentrations indicated low to moderate pollution (1.0 to 7.0 μg-at/l) with the Mobile River delta highest (5.9 μg-at/l) among the five estuarine areas and Perdido Bay the lowest (2.5 μg-at/l). Nitrite values indicated very little pollution, and total phosphorus values indicated moderate to high pollution (0.5 to 1.0 μg-at/l). Progressive dilution of the high nutrients in the Mobile River delta is evident with movement down the axis of Mobile Bay to the Gulf of Mexico.

GENERAL REFERENCES: ALABAMA

ASIWPCA (1984)
Basta and Bower (1985)
Burrage (1989)
Culliton and Blackwell (1989)
Ehler and Basta (1985)
EPA (1974, 1978)
Jones *et al.* (973)
Keys (1975)
Main *et al.* (1987)
NOAA/EPA Team (1990)
Pechmann *et al.* (1986)

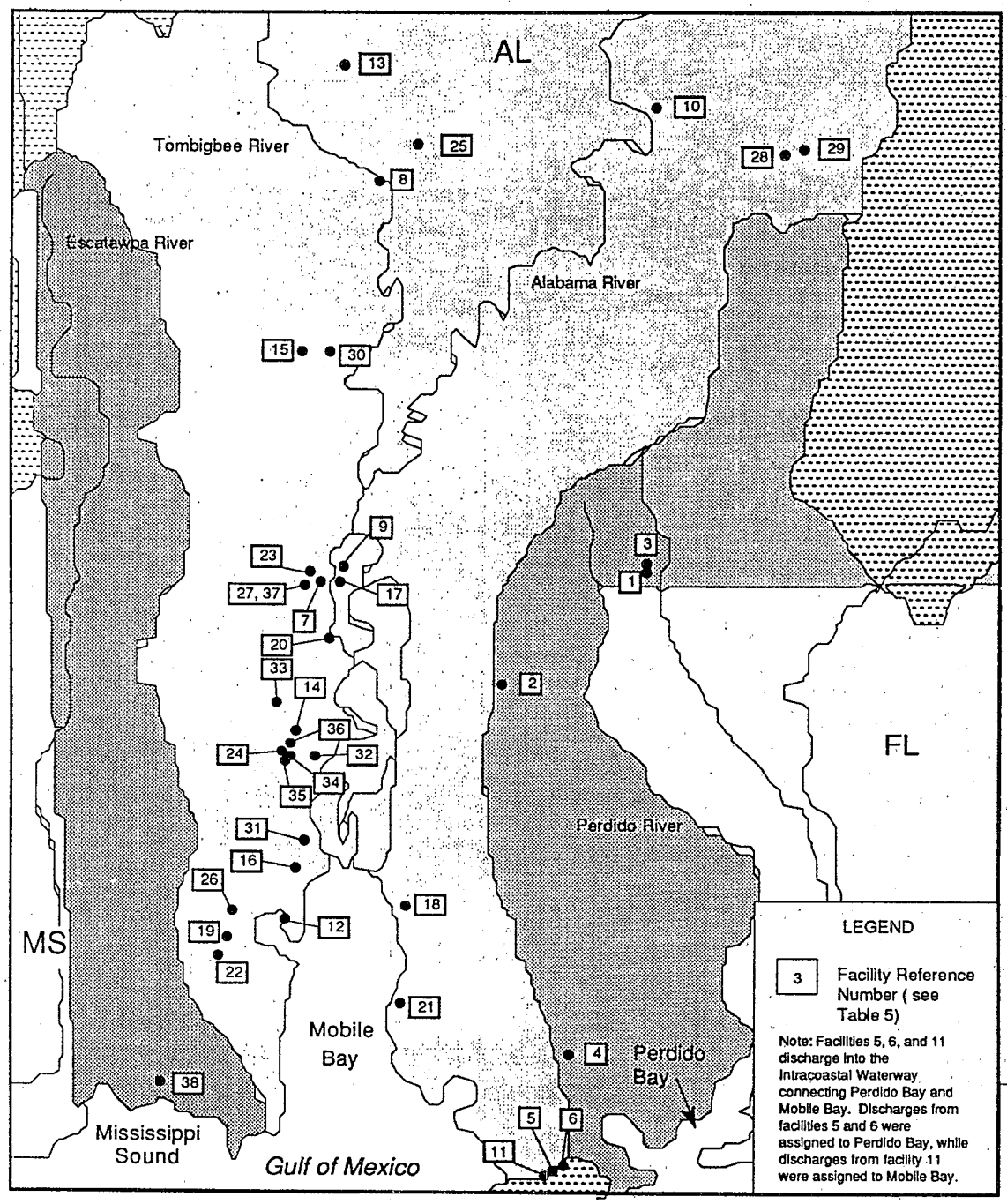


Figure A1. Detailed location of major facilities in the NCPDI study area in Alabama (from Pacheco, 1978a).

Table A1. Summary of NOAA Fish Kill Inventory Data for Alabama (draft data base, 1991; J. A. Lowe, personal communication; see section on Data Sources).

AREA County	Records per County	Cause Low DO	Cause Eutrophication	Cause Red Tide	Cause Nutrient	Cause Unknown or Unspecified
PERDIDO						
Escambia, FL	50	8	2	0	6	4
Baldwin	23	18	0	0	0	0
MOBILE						
Mobile	77	23	1	0	0	7

Table A2. Average concentration of micronutrients in Alabama estuarine study areas from April 1968 through March 1969 (from Bault, 1972).

	Area	Nitrate-nitrogen	Nitrite-nitrogen	Total phosphorus	Fertility index[1]
		Micrograms per liter			
	Averages of all samples				
I	Mississippi Sound	46.3	0.8	63.2	110.3
II	Mobile Bay	67.3	0.7	77.5	145.5
III	Mobile Delta	83.1	0.3	98.8	184.1
IV	Perdido Bay	39.0	0.3	57.9	97.3
V	Little Lagoon[2]	35.0	0.9	57.3	93.2
	Averages of surface and bottom samples				
I	Surface	46.6	0.7	60.1	107.4
	Bottom	45.9	0.9	66.6	113.4
II	Surface	79.8	0.5	63.2	143.5
	Bottom	52.5	0.8	91.4	144.7
III	Surface	103.3	3.3	89.9	196.5
	Bottom	61.3	1.1	107.5	169.9
IV	Surface	38.7	0.2	61.6	100.5
	Bottom	39.3	0.4	53.9	93.6

[1]Fertility index is the total of nitrate-nitrogen, nitrite-nitrogen and total phosphorous concentrations.

[2]Only surface water was sampled in this area.

F-28 and G-1 Perdido Bay/River

The Perdido Bay estuary and River are located along the border of Florida and Alabama and is under the control of environmental departments from both states. This estuary was coded F-28 in the synthesis of Windsor (1985) and G-1 in the synthesis of Rabalais *et al.* (1985). The main tributary to the bay is the Perdido River with an average flow of 700-900 cfs (Hand *et al.*, 1988h), with a total freshwater inflow of 1254 cfs (Windsor, 1985). An unknown quantity of exchange occurs through the Intracoastal Waterway connections with Pensacola Bay and Mobile Bay. The estuary is approximately 17 mi long with an average width of 2 mi covering 40 mi^2 (Windsor, 1985). The bay averages 3 m deep with a 0.2 m average tidal range at the outlet and a calculated residence time of 5 d. Water depths slightly in excess of 4.9 m occur in areas near Perdido Beach

in the western part of the bay (O'Neill and Mettee, 1982). Deeper areas of the lower reaches of Perdido River and Elevenmile Creek range 6-8 m in depth (Flemer, 1989). The only outlet to the Gulf of Mexico is shallow and restrictive. According to Windsor (1985), the bay was considered to be vertically homogeneous for much of the year but occasionally becomes partially stratified. More recent syntheses have determined that the bay is moderately to highly stratified (Flemer, 1989).

Wolf Bay is located entirely within the State of Alabama. The Bay, excluding Bay La Launch, is about 7 km long and the widest point near the southern end is 3.8 km. Water depths in the bay are shallow, and the deepest parts are slightly in excess of 2.7 m (O'Neill and Mettee, 1982). Wolf, Sandy, Miflin and Hammock Creeks flow into Wolf Bay at the northern end. Wolf Bay connects to middle Perdido Bay through Bay La Launch; both then empty to the Gulf of Mexico through Bayou St. John. Tidal flats and marshes border the northern part of the bay and along the western side.

The highly urbanized western edge of the City of Pensacola is located along the system and may contribute significantly to the nonpoint sources of pollutant discharges within the basin. Land use in the basin is primarily forest and urban. The Perdido Bay system has been the subject of several water quality studies with the major focus on water quality problems associated with treated pulp mill effluents which are discharged to Elevenmile Creek and eventually to Perdido Bay. The U.S. EPA Region IV conducted a survey of Elevenmile Creek and Upper Perdido Bay in 1986 (Lord, unpubl.); studies are in progress by the U.S. EPA Gulf Breeze Laboratory (D. Flemer) and Florida State University (R. Livingston).

Historically there has been little research conducted in the Perdido estuary. One of the more notable is that by the U.S. Dept. of Interior (1970) on the effects of water pollution on water quality in Perdido River and Bay. The report concluded that the inadequately treated waste effluent from the paper company on Elevenmile Creek is the major cause of the low dissolved oxygen, unsightly foam, excessive sludge deposits and increased lignin in Perdido Bay and River, as well as degraded water quality in Eleven Mile Creek. Water quality problems in Bayou Marcus were attributed to the collective discharges to the bayou from six small sewage treatment facilities.

More recently, however, there is a flurry of research activity and resource management plans (Flemer, 1989). These include: a 1-yr study of nutrients and hydrography, funded by Coastal Zone Management, NOAA, conducted by Florida Dept. of Environmental Regulation and the Alabama Dept. of Environmental Regulation (Schropp *et al.*, 1990); U.S. EPA provided funds to the U.S. Fish & Wildlife Service and a citizens group for an environmental assessment of the bay and a management plan; Champion International has funded a 2-yr water quality and ecological assessment of the system, conducted by R. Livingston, Florida State University (Livingston, 1989). The bay system is poorly characterized ecologically except for preliminary studies on the benthic macroinvertebrate fauna and a partial, recent inventory of trawl and seine collections of fishes and invertebrates (Flemer, 1989).

An overall degradation of the water quality of the Perdido Bay estuary can be deduced from a comparison of the figures from the Hand and Jackman (1984) 305(b) report (Figure A2) and that of the Hand *et al.* (1988h) report (Figure A3). Elevenmile Creek is still assessed with poor water quality. Bayou Marcus Creek, which was a combination of poor to fair, is now rated fair. Upper Perdido Bay, which was rated generally good previously, is now rated poor; middle Perdido Bay, which was rated generally good, is now rated fair. Representative water quality from middle Perdido Bay and upper Perdido Bay are shown in Figures A4 and A5, respectively.

According to the most recent 305(b) report (Hand *et al.*, 1988h), the most concentrated and voluminous pollution source in the basin is a paper company which discharges 28 mgd of partially treated pulp mill waste into Elevenmile Creek. The historical record shows that the creek has had

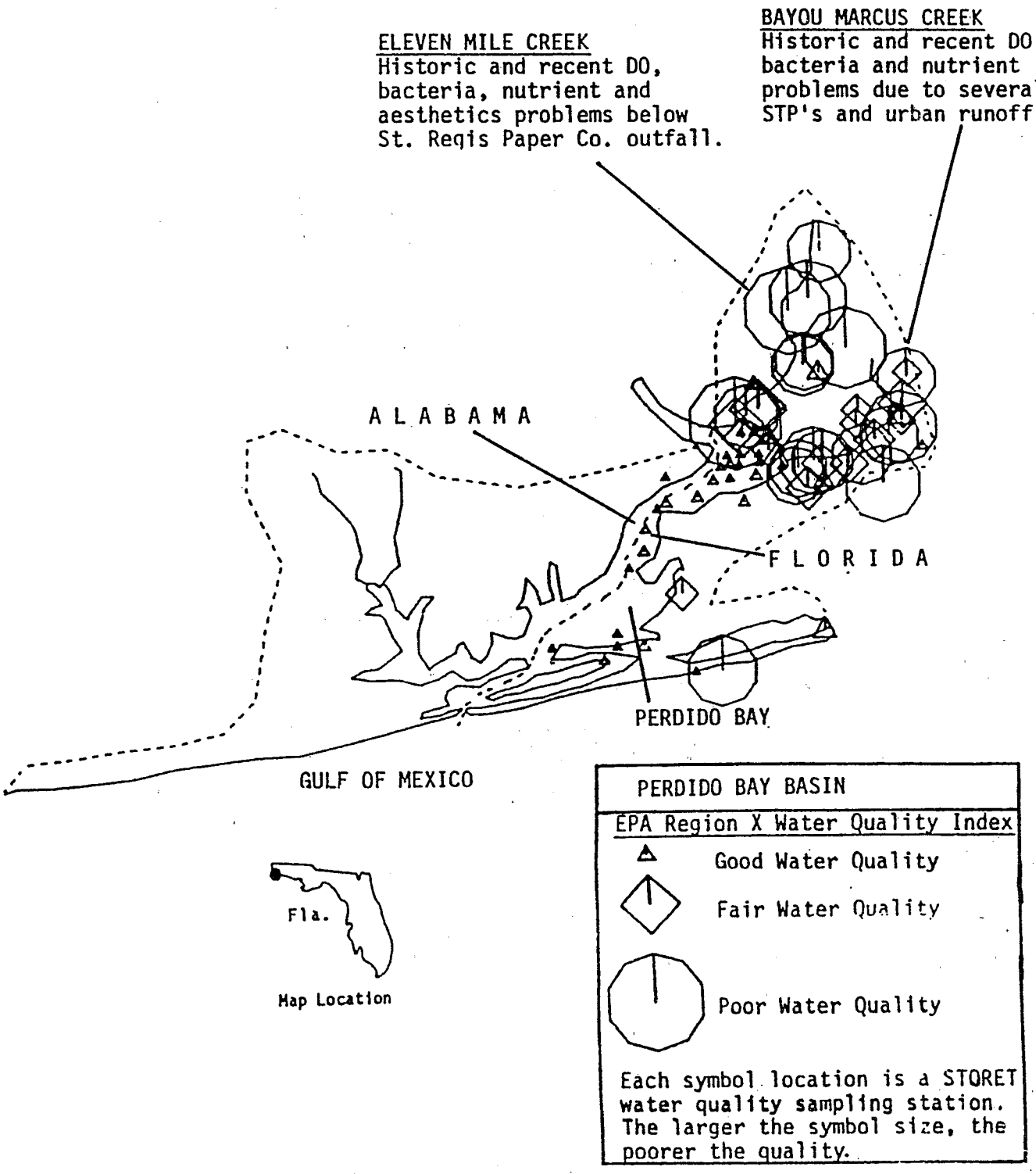


Figure A2. Perdido Bay basin [from 305(b) report of Hand and Jackman (1984)].

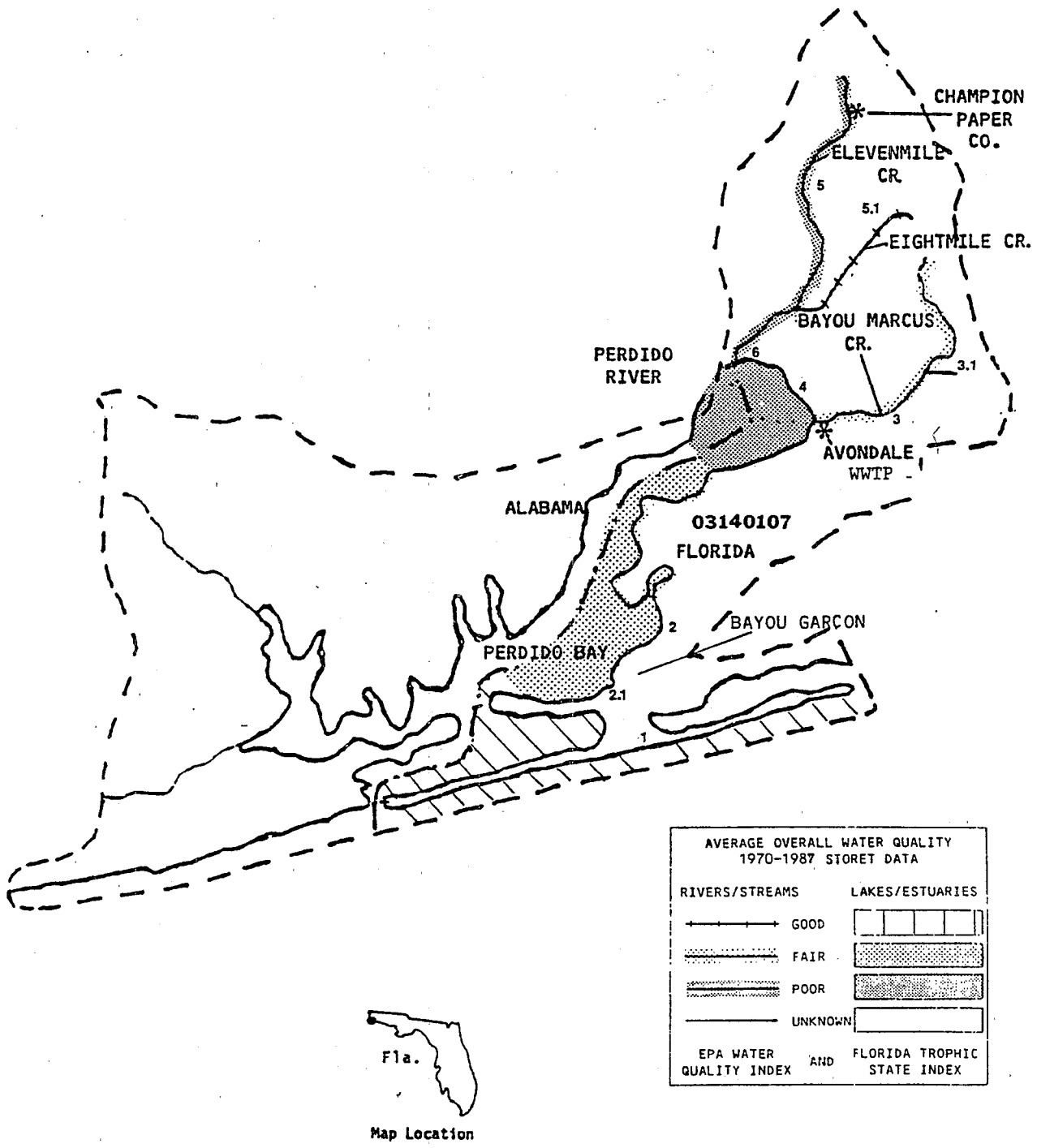


Figure A3. Perdido Bay basin [from 305(b) report of Hand *et al.* (1988h)].

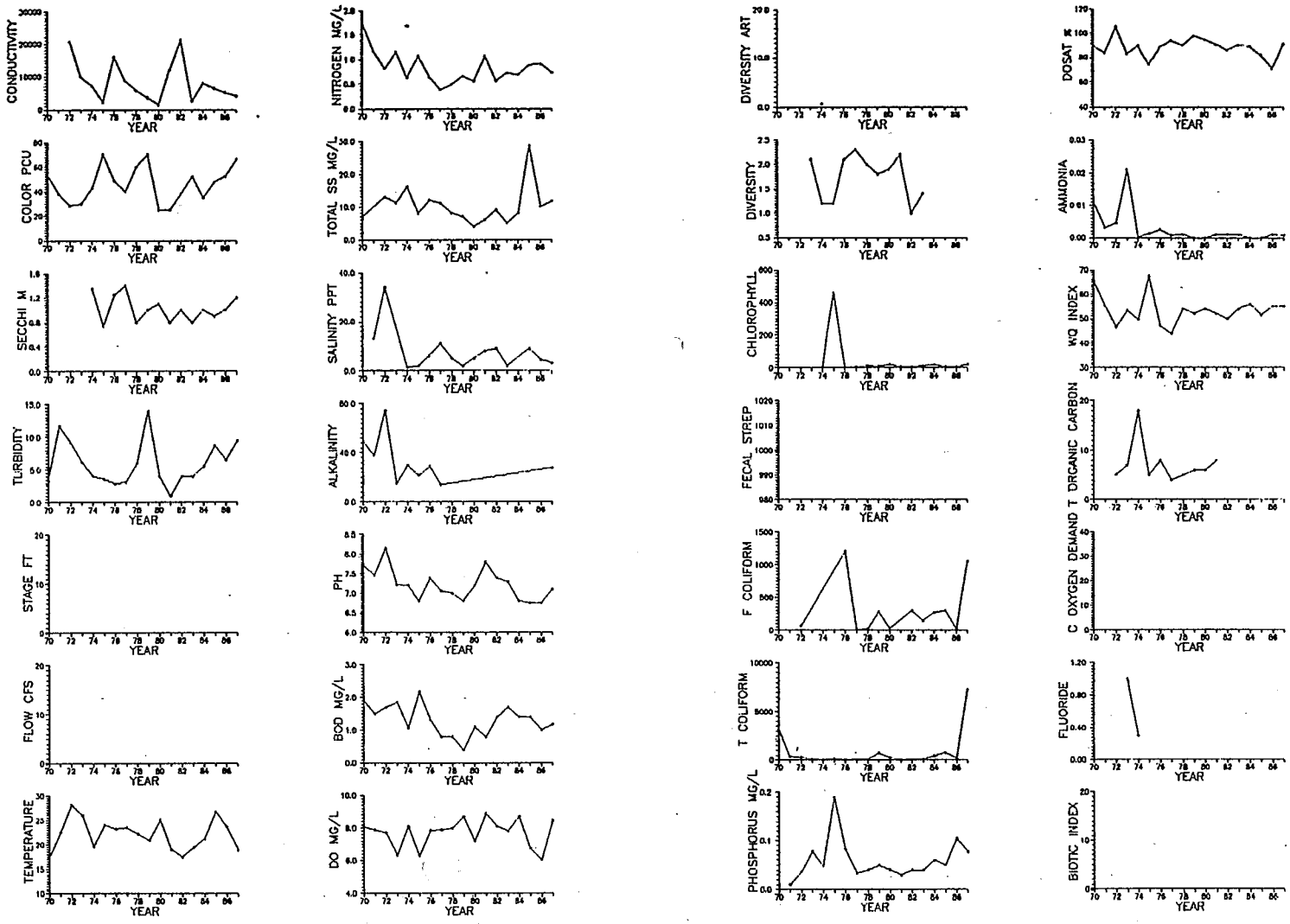


Figure A4. Representative water quality data from Perdido Bay above the Gulf of Mexico (from Hand *et al.*, 1988h).

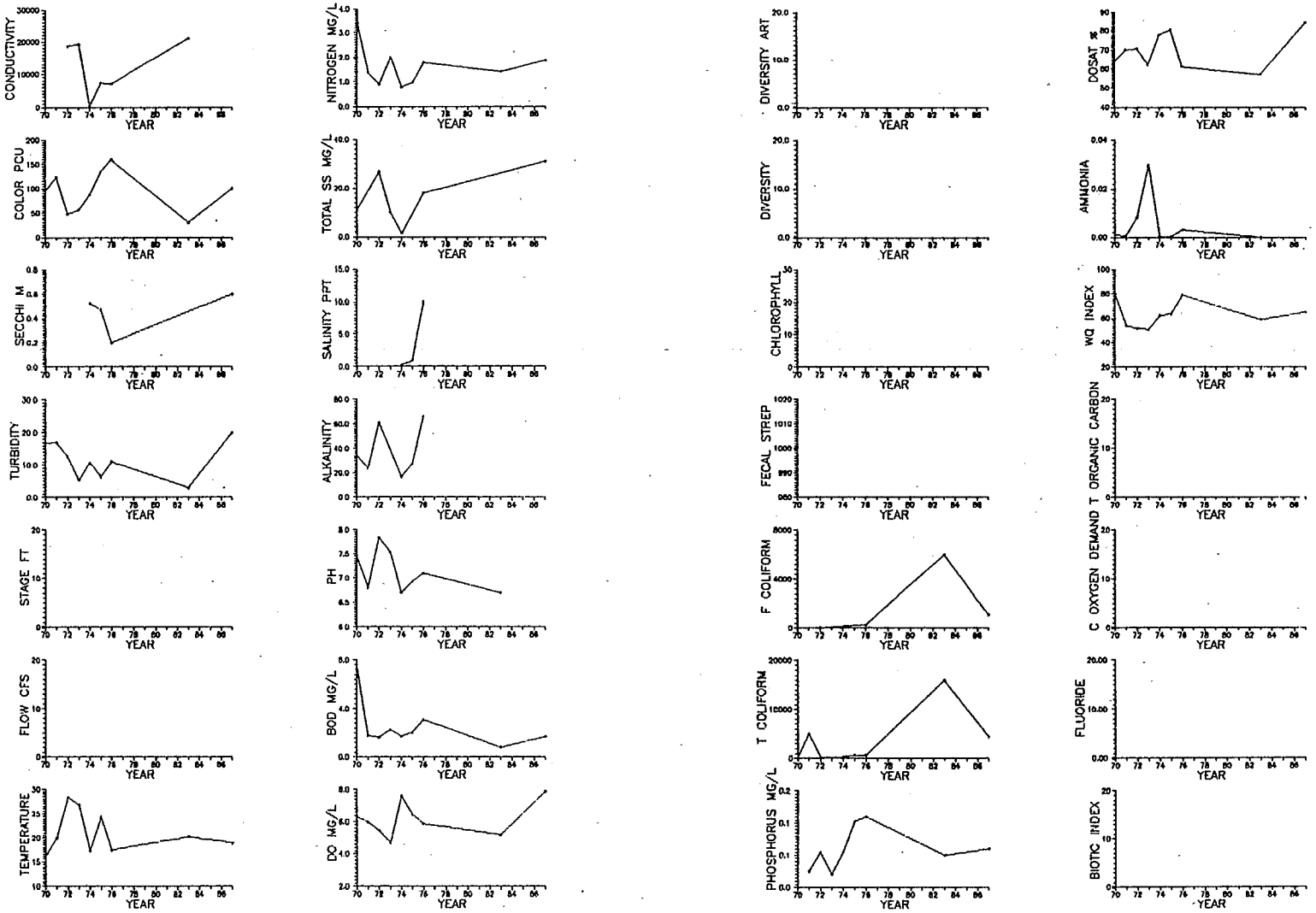


Figure A5. Representative water quality data from Perdido Bay above Bayou Marcus (from Hand *et al.*, 1988g).

major water quality problems since the early 1970s. After the installation of a treatment facility at the paper company, water quality parameters showed some improvement in the mid 1970s; however, in the early 1980s, production and concomitant pollution increased. Proposed changes in processing technology are requiring new permitting standards which is being contested by an environmental group and the State of Alabama. The paper company discharge negatively affects many water quality parameters, particularly color, dissolved oxygen, BOD, nutrients, turbidity and solids. The effects of the creek on color, nutrients and biological parameters are seen to about 12 mi into Perdido Bay (the upper two thirds of the bay).

Upper Perdido Bay is also negatively affected by Eightmile Creek and Bayou Marcus Creek which receive runoff from urbanized areas and have elevated water quality index values. In addition, a wastewater treatment plant with historical spill problems discharges to Bayou Marcus Creek. Increased development pressures have kept the plant in operation; but dissolved oxygen problems below the plant will require higher levels of treatment under a new permit.

Bayou Garcon, which empties into middle Perdido Bay, exhibits transparency and dissolved oxygen problems. In addition, there have been local reports of increased siltation at the mouth of the Bayou which has been attributed to new development in the watershed. Within the last few years, there has been an increase in development in the swampy areas west of Pensacola. During rainy seasons, runoff from these developments can affect much of the eastern portions of the Bay and thus exacerbate the degradation of the Bay caused by Elevenmile Creek.

The results of the interstate study of the physical and chemical processes affecting the management of Perdido Bay are given in Schropp *et al.* (1990). The report concludes that 1) Perdido Bay receives nutrients from anthropogenic sources, dominated during the study by materials delivered by Elevenmile Creek; the Styx and Blackwater Rivers and Bayou Marcus Creek also show evidence of anthropogenic contributions of nutrients; 2) a substantial portion of carbon delivered to the estuary is trapped in the upper Bay; 3) physical conditions resulting from natural forces are such that stratification and hypoxia occur during a major portion of the year, but that oxidation of carbon trapped in the bay can aggravate seasonal hypoxia; 4) there is evidence of some toxic contamination of sediments from urban runoff, although contaminants have not reached levels encountered in other, more developed parts of Alabama and Florida.

The monthly micronutrient data from the Cooperative Gulf of Mexico Estuarine Inventory (Bault, 1972) are shown in Figure A6. Perdido Bay had the lowest concentration of nitrite and next to lowest concentration of nitrate of the five areas. The combined total for the nutrients measured was the next to lowest. Data from a more recent study (Lord, unpubl.) are shown in Figures A7-A10. These results indicate that Perdido Bay proper is characterized by low nutrient concentrations. Dissolved inorganic nitrogen is <1 mg/l orthophosphate is usually <0.02 mg/l, and phosphate levels are low.

Data from the Alabama portion of the Perdido Bay/River area were collected by the Alabama Marine Resources Division at four stations, including two in Wolf Bay (one in the Gulf Intracoastal Waterway), one in Bayou St. John which connects Wolf Bay to Perdido Bay, and one in Perdido Pass which empties into the Gulf of Mexico. The study by Bault (1972) included stations in Wolf Bay and Perdido Pass, as well as a station in Perdido Bay proper.

Bault (1972) reported few records of low dissolved oxygen. On the other hand, the data collected by the Alabama Marine Resources Division show several incidences of oxygen-depleted water in most months at all stations (values mostly between 1 and 2 mg/l). The lowest values are in the Wolf Bay area; at one station over 90 % of the incidences have been since March 1983. Personnel from the agency indicated that Wolf Bay/Perdido Bay are very susceptible to low dissolved oxygen and have been since initiation of hydrographic sampling there in October 1980 (M. Van Hoose, personal communication). Loadings from pulp mill effluents and increased sewage from

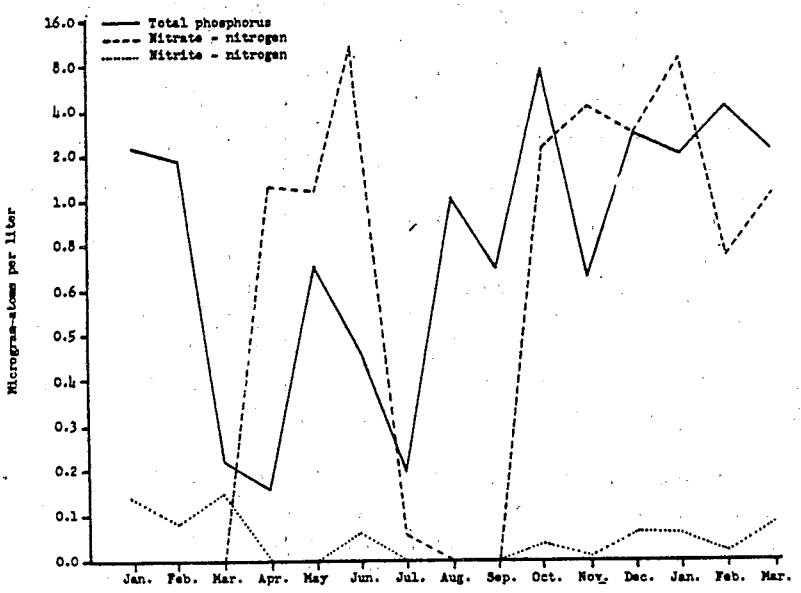


Figure A6. Monthly average concentrations of micronutrients in Perdido Bay from January 1968 through March 1969 (from Bault, 1972).

residential and recreational housing development are credited as probable causes for the increased incidence of low oxygen concentrations. Several instances of dissolved oxygen violations were noted by Windsor (1985) for Perdido Bay, particularly the tributaries, Elevenmile Creek and Bayou Marcus Creek. More recent dissolved oxygen values were collected by Van Hoose (1988) for April 1987 to March 1988 at trawl sampling stations (thus presumably bottom dissolved oxygen levels). In the lower bay oxygen concentrations ranged from 3.2 (June) to 10.4 (April) ppm; in the middle bay, 0.4 ppm in August to 11.4 in April; in the upper bay, 11.0 ppm in April and 0.4 ppm in August. Long-term changes of dissolved oxygen concentrations in Perdido Bay were analyzed by Livingston (1989) who demonstrated no change in the upper river, but a decrease in summer dissolved oxygen levels in the lower river which became progressively lower with time (Figure A11).

See comments in Section F-27 regarding continuous dissolved oxygen measurements in Perdido Bay (upper, mid and lower) and Wolf Bay as well as Figure F53.

The USFWS report (in prep.) on fish and shellfish populations for the period 1975 through 1988, indicates a reduction in certain finfish diversity measures and numbers of trawl-catchable finfish in upper Perdido Bay, and a pronounced masculinization of mosquitofish in Elevenmile Creek. For the lower Bay, a general pattern that seems to emerge is that summertime finfish resources have declined during the period 1983-1988; while wintertime finfish resources have varied considerably during the same period, with a peak in abundance as recently as the winter of 1986-1987. Analysis of trawlable-fish data by Livingston (1989) indicates that during the 1980s there was a serious deterioration of the fish fauna of Perdido Bay. The community indices showed that this trend was based on reduced numbers of species as well as increased dominance. Because of inadequate habitat data, however, no real estimate can be made concerning the reason(s) behind the marked decline of the Perdido Bay fish fauna during the 1980s.

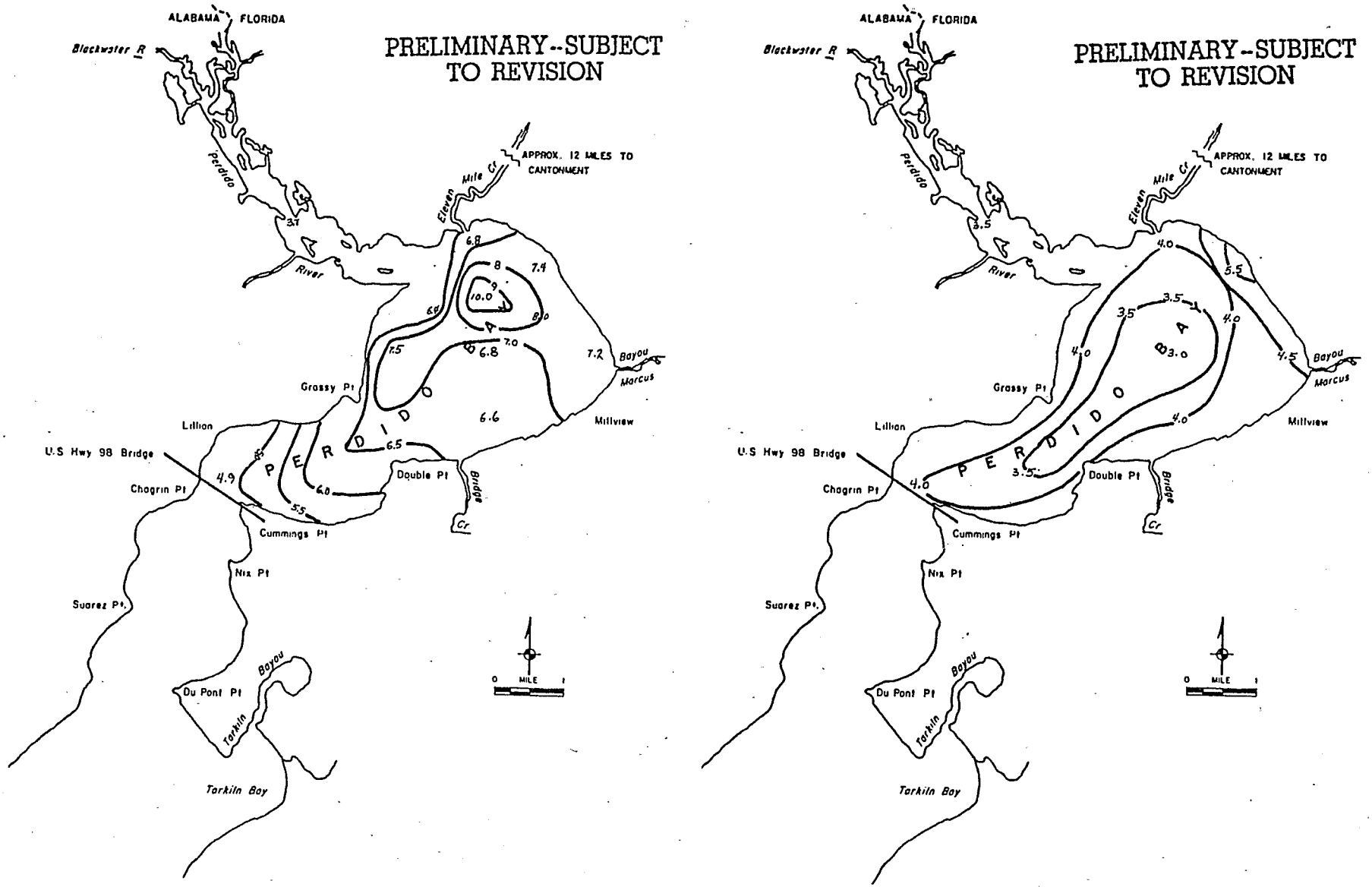
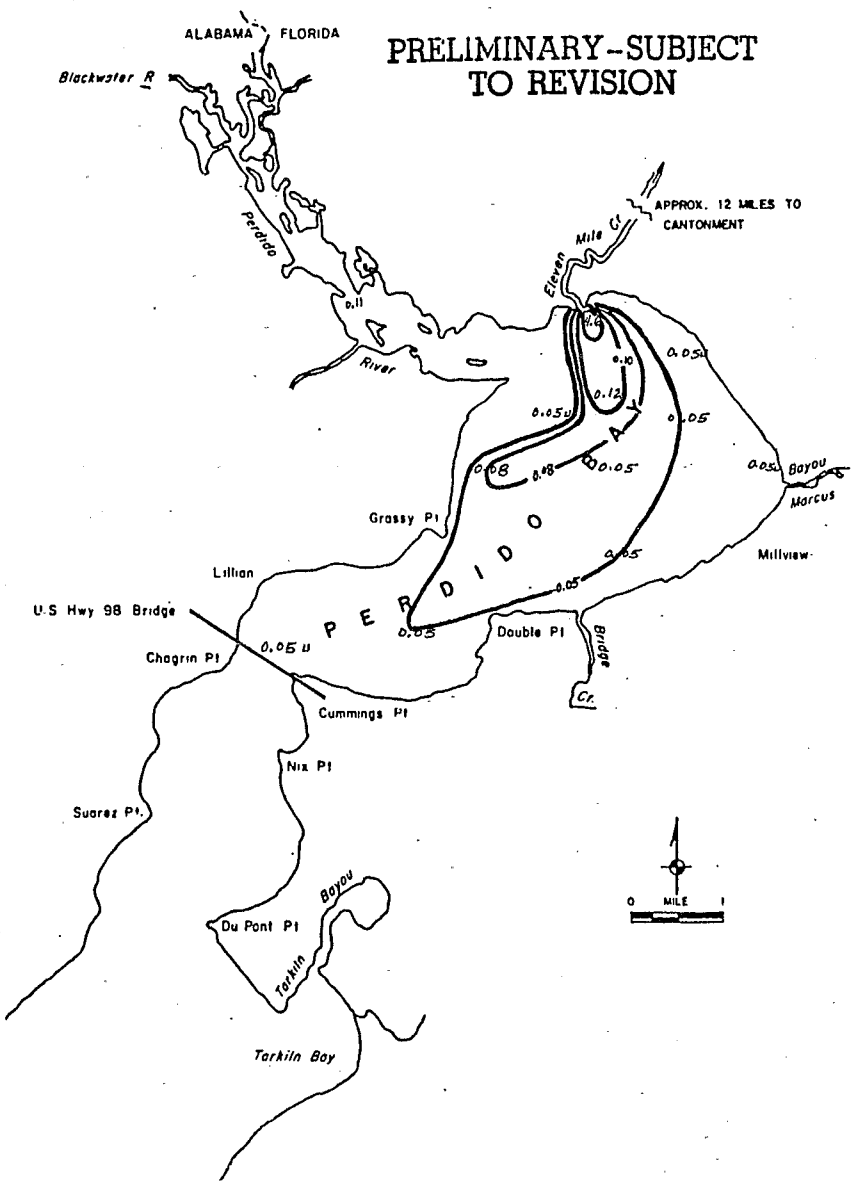


Figure A7. Total organic carbon concentrations (%) (left panel) and total suspended solids concentrations (mg/l) (right panel) at low slack tide, October 4, 1987, Perdido Bay (from Lord, unpubl.).



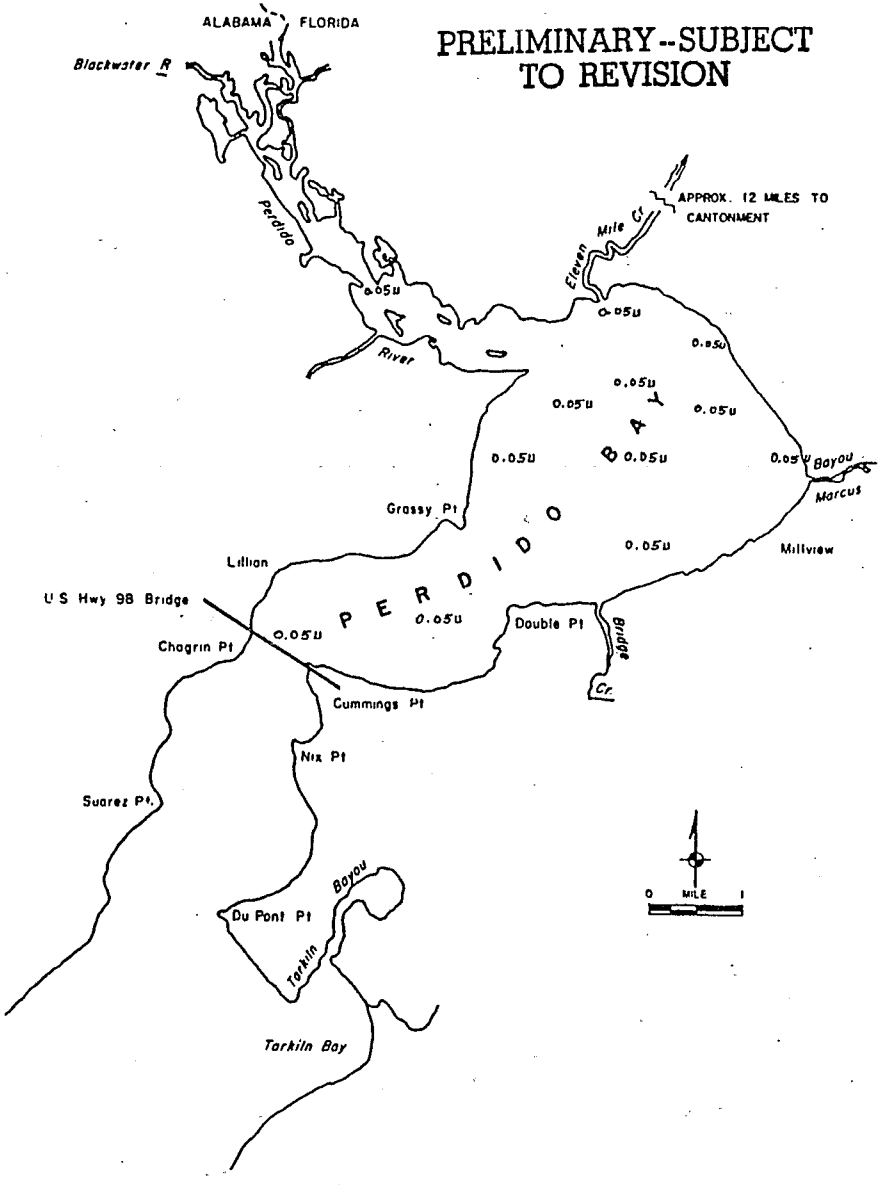


Figure A8. Nitrite-nitrate concentrations (mg/l) (left panel) and ammonia nitrogen concentrations (mg/l) (right panel) at low slack tide, October 4, 1987, Perdido Bay (u=analyzed, but undetected) (from Lord, unpubl.).

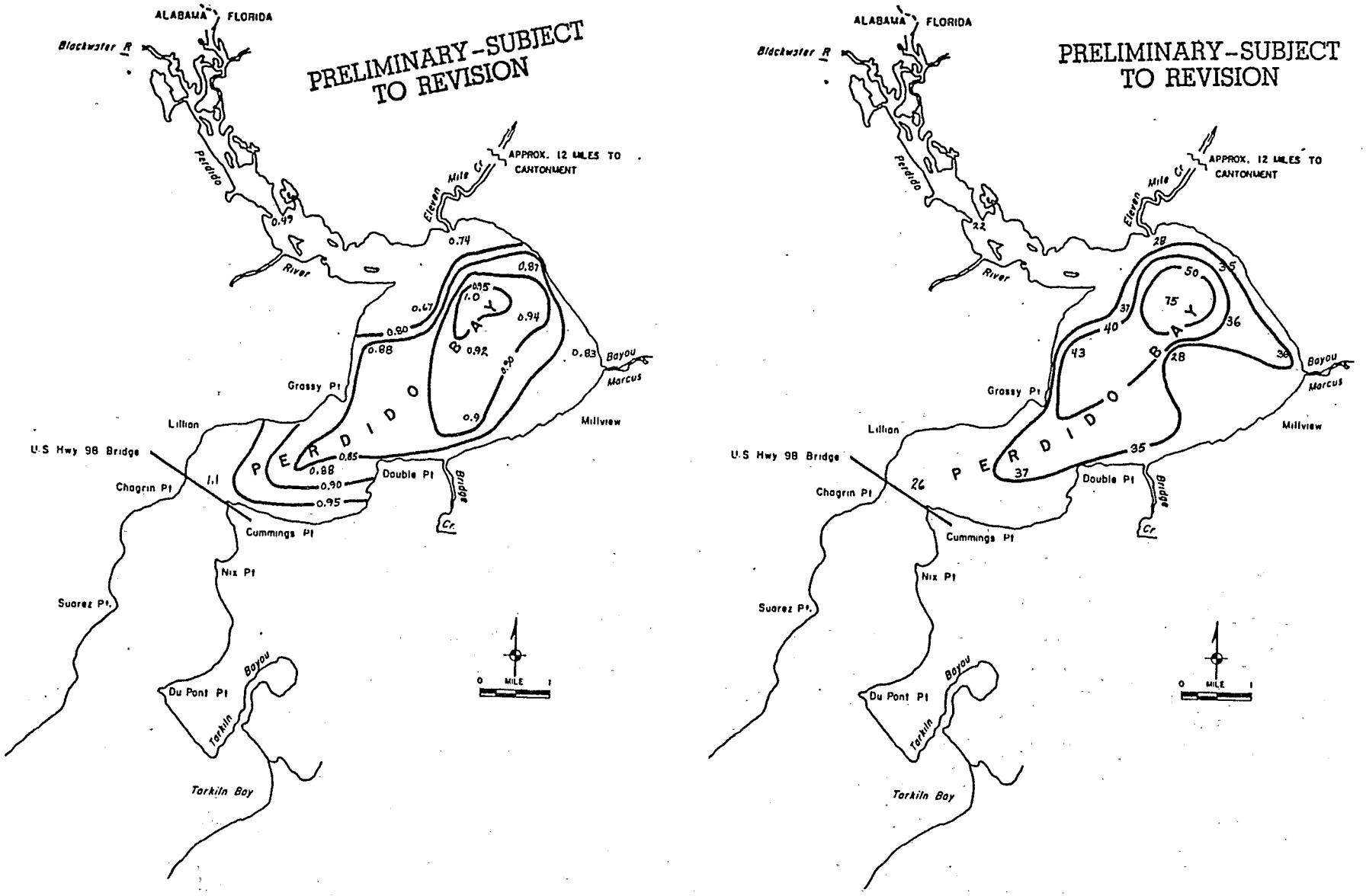
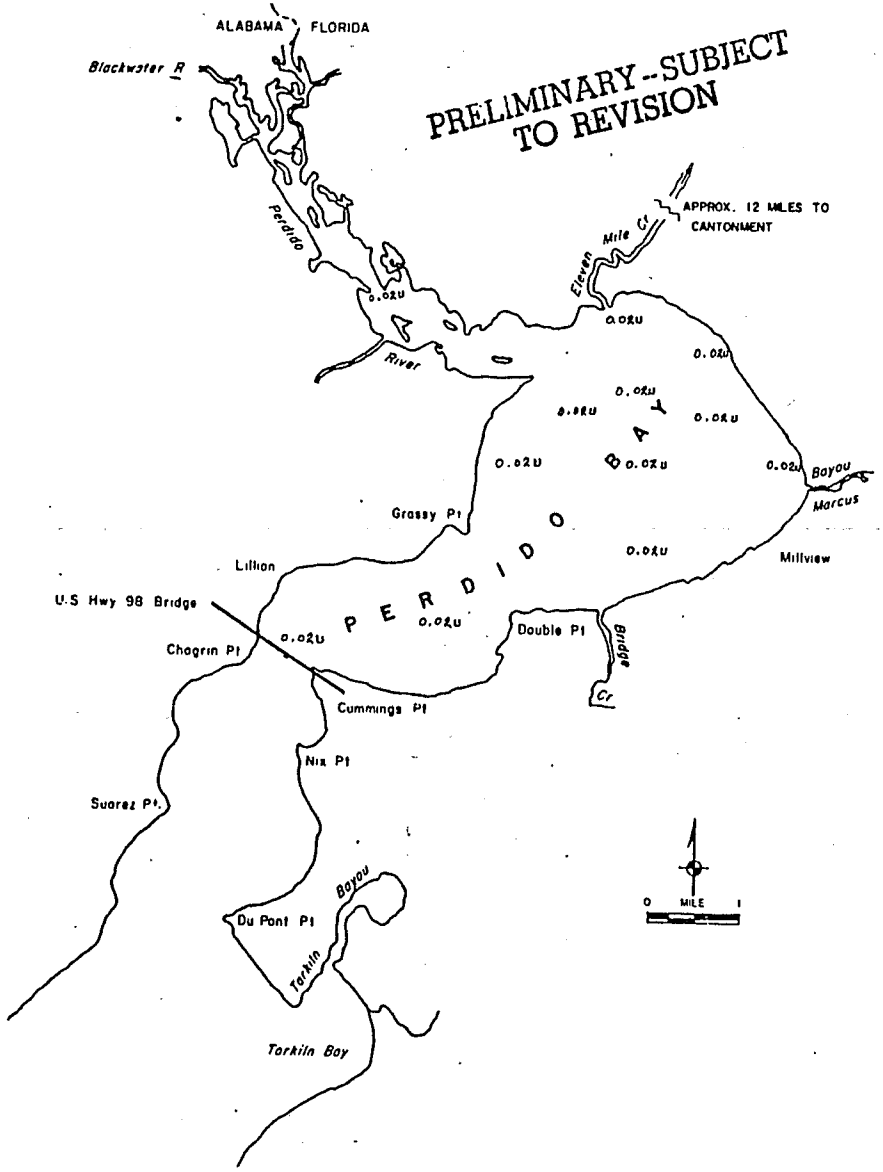


Figure A9. Total Kjeldahl nitrogen concentrations (mg/l) (left panel) and color concentrations (right panel) at low slack tide, October 4, 1987, Perdido Bay (u=analyzed, but undetected) (from Lord, unpubl.).



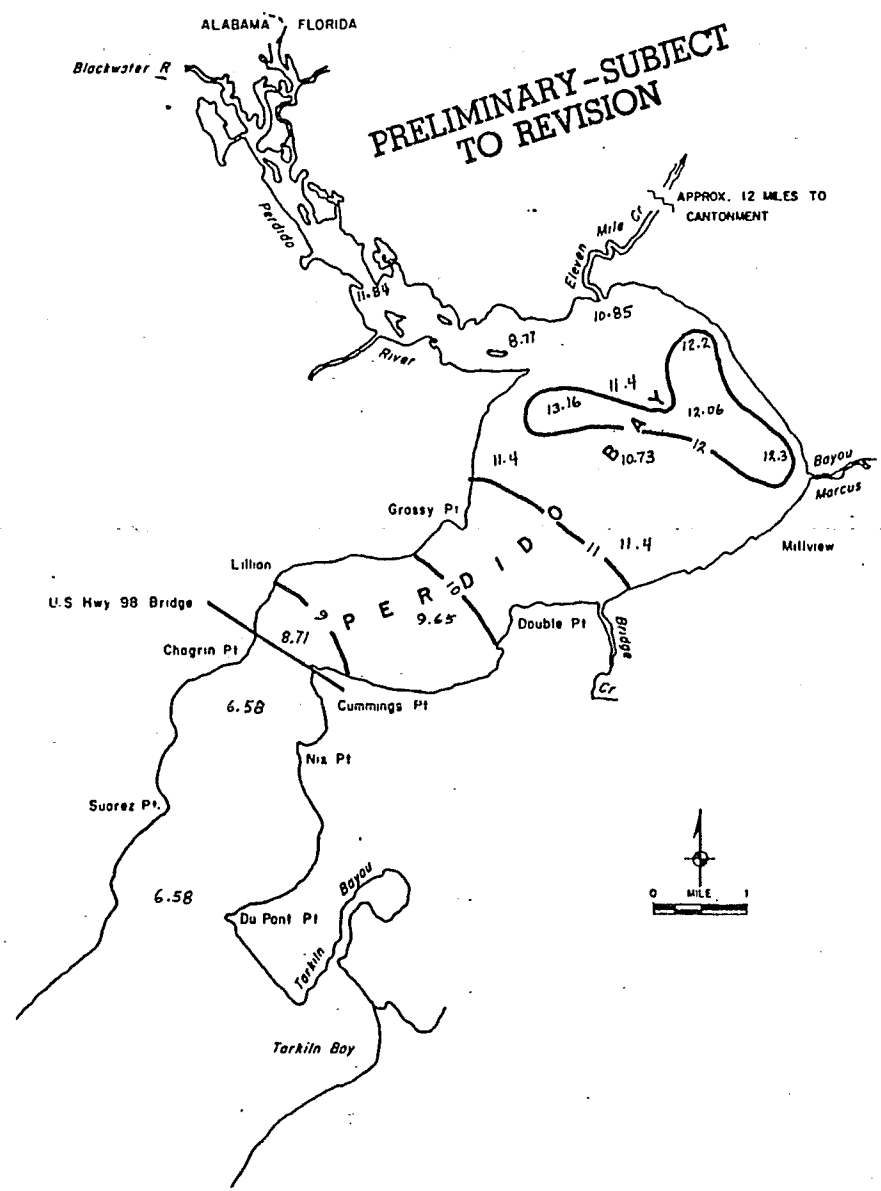


Figure A10. Total phosphorus concentrations (mg/l) (left panel) at low slack tide, October 4, 1987, and chlorophyll *a* concentrations (µg/l) (right panel) at high slack tide, October 3, 1987, Perdido Bay (u=analyzed, but undetected) (from Lord, unpubl.).

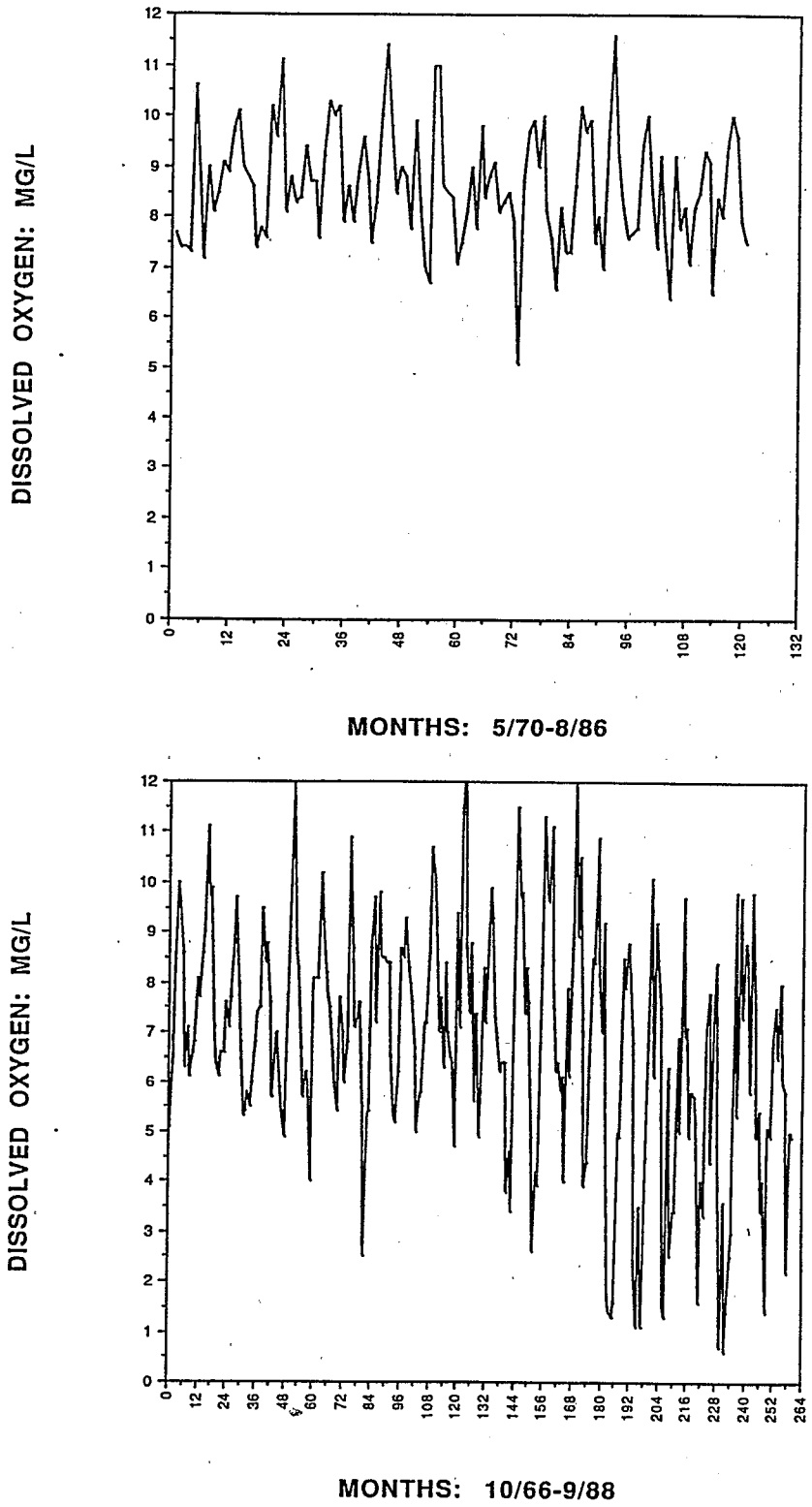


Figure A11. Dissolved oxygen concentrations in the Perdido River at the surface (upper panel) and near the bottom (lower panel) for periods indicated (Livingston, 1989).

REFERENCES: F-28 and G-1

Bault (1972)
Butts (1983)
Crance (1981)
Dardeau (1987)
Flemer (1989)
Flor. Dept. Envir. Reg. (1989)
FWPCA (1970)
Gunning and Suttkus (1986)
Hand *et al.* (1988h)
Heck (1987)
Livingston (1989)
Lord (unpubl.)
O'Neil and Mettee (1982)
Pacheco *et al.* (1989a)
Rabalais *et al.* (1985)
Schroeder (1976)
Schropp *et al.* (1991)
Summers and Engle (submitted)
Swingle (1971)
Swingle and Bland (1974)
U.S. Fish Wild. Serv. (in prep.)
Van Hoose (1988)
Williams *et al.* (1990)

G-2 Mobile Bay/River/Tensaw River

The surface area of Mobile Bay is 984 km^2. The average depth is 3 m and the maximum depth is 20 m off Fort Morgan at the Gulf entrance. Although the bay is a relatively shallow basin, it has a complex bathymetry with topographic lows throughout the northeastern part and a dredged ship channel, 120 m wide and 12 m deep, traversing the length of Mobile Bay and into the Mobile River. There are two natural openings into the Gulf of Mexico at Main Pass and at Pass aux Herons into Mississippi Sound. A dredged channel, the Gulf Intracoastal Waterway crosses the southern end of the Bay, linking Perdido Bay with Mississippi Sound. The entire system of channels in the delta is collectively called the Mobile River, but this name actually refers to the largest and most westerly channel. The delta receives the inflow of the Mobile-Tensaw, Alabama and Tombigbee Rivers. The Mobile River system delivers 95 % of the total freshwater input to the bay (Schroeder, 1978, cited in Turner *et al.*, 1987), with a discharge rate of 60,000 cfs (Isophording and Lamb, 1979). The Mobile and Tensaw River systems receive drainage from over 64 % of the land area of the state of Alabama (Horn, 1990).

The Bon Secour River enters the southeastern corner of Mobile Bay, and flows from Dog River and E. Fowl River enter the western side of the Bay. Weeks Bay is a subestuary on the eastern shore. Little Lagoon (1047 ha) is considered in many treatments of Mobile Bay. Freshwater enters the Lagoon from rainfall, groundwater seepage and a connection with Shelby Lake. A small, shallow pass sometimes connects the Lagoon with the Gulf of Mexico, although most of the time this pass is completely closed (Swingle, 1971).

The monthly micronutrient data from the Cooperative Gulf of Mexico Estuarine Inventory (Bault, 1972) are shown in Figure A12. Mobile Bay had the second highest total concentration of all the areas (highest in the Mobile River delta). The area also ranked second in nitrate-nitrogen and total phosphorus. Mobile Bay receives fresh water from the Mobile River delta. Domestic and industrial effluents from the city of Mobile and other nearby areas contribute to the nutrient loading. Surface values of nitrate were higher than bottom waters, most probably due to stratification of the two water sources--Mobile River delta and Gulf of Mexico. Total phosphorus was low in surface waters and similar to the other areas, with the exception of Perdido Bay which was higher.

Data from the Cooperative Gulf of Mexico Estuarine Inventory (Bault, 1972) for the Mobile River delta are shown in Figure A12. Each of the nutrients measured was highest in this study area. Nutrients from the Alabama-Tombigbee river system and effluents from municipalities and industries above Battleship Parkway contribute significantly to the nutrient loads. Nitrate

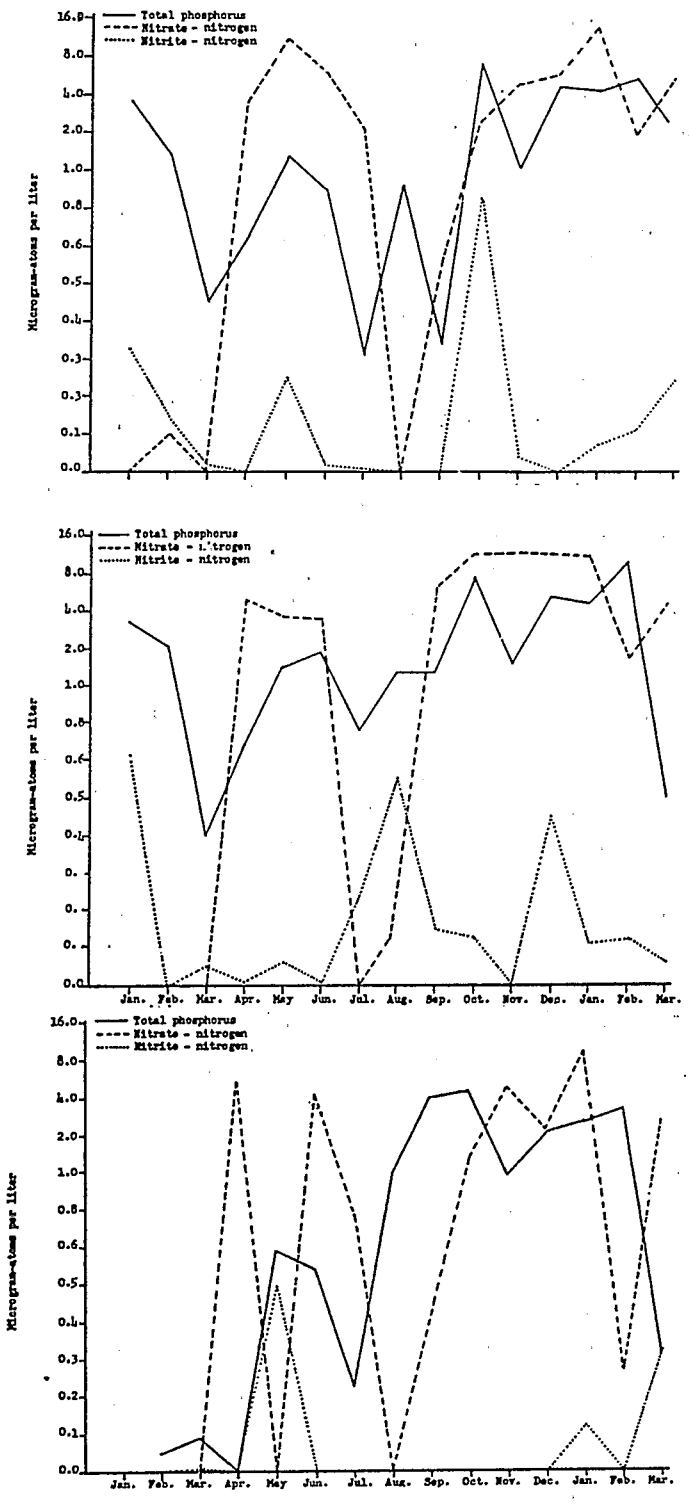


Figure A12. Monthly average concentrations of micronutrients in Mobile Delta (upper panel), Mobile Bay (middle panel), and Little Lagoon (lower panel) from January 1968 through March 1969 (from Bault, 1972).

concentration was much greater than that of any other area. Nitrite nitrogen concentrations were also high. Total phosphorus averaged a significant amount more than in Mobile Bay. Similar values from the Cooperative Gulf of Mexico Estuarine Inventory (Bault, 1972) for Little Lagoon are given in Figure A12.

J. Pennock (personal communication) has been conducting studies of nutrients, nutrient limitation, and features of the physical environment that may be affecting biological processes in Mobile Bay beginning in 1989. The work is in progress, but he has made a preliminary assessment of the nutrient enrichment status of Mobile Bay (abstract in Hinga *et al.*, 1991). Pennock states that Mobile Bay receives moderate loadings of both nitrogen and phosphorus, primarily from upstream nonpoint sources. Despite significant loadings, however, ambient nutrient concentrations at the upper end of the Bay attain concentrations of <20 μM inorganic N and <2 μM inorganic P (10 and five times less than those for the Delaware Bay estuary) as a result of the relatively high flushing rate of the system. Although these nutrient concentrations suggest that Mobile Bay should have a relatively low susceptibility to nutrient enrichment, several responses often associated with eutrophication are evident. For example, chlorophyll *a* concentrations have been observed as high as 100 μg/l during the winter, and recurring hypoxic conditions are seen during summer. While organic loading to Mobile Bay is undoubtedly important to the observed response in chlorophyll *a* and dissolved oxygen (these data are not yet available), it is evident that stratification in Mobile Bay resulting from salinity intrusions through the shipping channel is important in the low oxygen concentrations as well.

Schroeder and Wiseman (1986, cited in Turner *et al.*, 1987) report that strong vertical stratification occurs in Mobile Bay during periods of both 1) high river discharge and weak winds and 2) persistent southward-directed wind stress and low river discharge. Large areas of the bay are affected by hypoxic conditions (Figure A13) (Schroeder and Wiseman, 1988). Strong winds, however, can rapidly dissipate these conditions. Hypoxia quickly redevelops following re-establishment of the stratification after a wind event. Oxygen depletion in the shallow bottom waters of Mobile Bay, and in adjacent nearshore and continental shelf waters, was shown by Turner *et al.* (1987) to be directly related to the intensity of water column stratification (Figure A14). Low wind speeds were coincident with the onset of water column stratification and the occurrence of hypoxic events. Hourly, daily and seasonal changes in the relationship between percent oxygen saturation or oxygen concentration in bottom wasters and surface-to-bottom density differences indicated that the oxidized materials were recently formed and were not relic or overwintering carbon sources.

The deeper areas of Mobile bay experience hypoxic or anoxic bottom waters throughout the year. These include Mobile Ship Channel, Theodore Industrial Canal and Theodore Barge Channel extension (Alabama Marine Resources Division; Marine Environmental Sciences Consortium; Swingle and Bland, 1974). Two deep holes off Brookley Field are subject to low dissolved oxygen values in the colder months; these low values are often associated with speckled trout kills (M. Van Hoose, personal communication).

"Jubilee" is the local name for the shoreward movement of dense concentrations of fish and invertebrates (Loesch, 1960; May, 1973). This phenomenon has been presumed to be associated with the movement of the leading edge of a low oxygen zone. When hypoxic bottom water conditions coincide with a period of light (< 5 m/s) to calm winds followed by a day or two of persistent easterly winds, often associated with a rising tide, the surface waters move away from the eastern shore and the lower hypoxic layers move toward the eastern shore and cause a mass migration of estuarine organisms into shallow waters. This celebratory collection of moribund but often edible seafood has been observed to occur in Mobile Bay since at least 1867 (May, 1973), before significant man-made changes in the estuary that might affect the occurrence of jubilees (Figure A15) (May, 73). Man-made modifications have interacted with the bays geomorphology

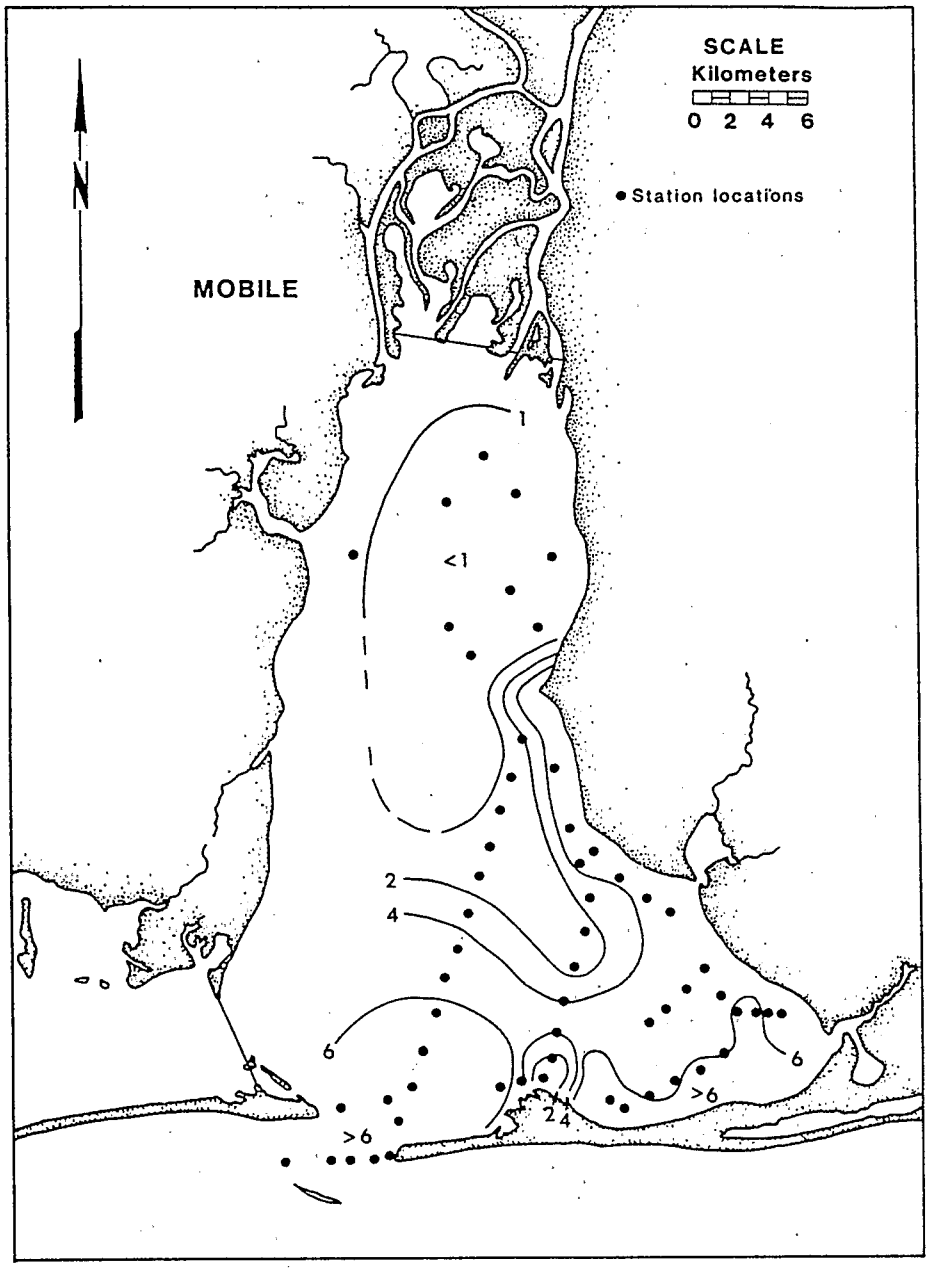


Figure A13. Bottom dissolved oxygen field on July 18, 1978 (concentrations are in ml/l) (from Schroeder and Wiseman, 1988).

and natural hydrology to result in zones of oxygen-depleted bottom waters. Dredged channels complicate the otherwise shallow Mobile Bay. Dredge disposal material island and shoals are located along the ship channel. Deep holes are found in the central area of the northeastern part of the bay. Natural, not man-made factors, are principally involved in jubilee events, although recent anthropogenic activities may have increased their frequency or intensity, according to Turner *et al.* (1987).

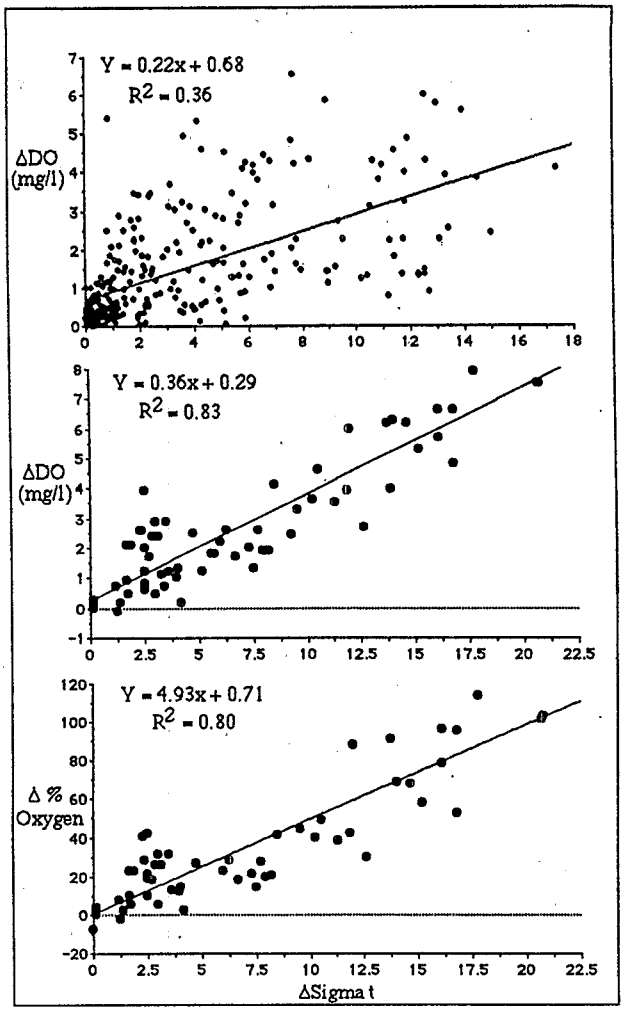


Figure A14. The relationship between surface-to-bottom differences in sigma t and dissolved oxygen for northern Mobile Bay (upper panel) and southern Mobile Bay (middle panel) and the adjacent continental shelf (lower panel) (from Turner *et al.*, 1987).

A bloom of the toxic dinoflagellate, *Gonyaulax monilata*, occurred in lower Mobile Bay during the same time as an extensive bloom in Mississippi Sound in August 1979 (Perry *et al.*, 1979). Fish kills were associated with the bloom. *Dinophysis caudata* has been recognized recently as a toxic dinoflagellate which may contribute to the accumulation of toxins responsible for diarrhetic shellfish poisoning (DSP) in Mobile Bay (R. Hickey, personal communication).

REFERENCES: G-2

Abbott (1975)
Abston *et al.* (1987)
Bault (1972)
Crozier and Heath (1974)
Dauphin Isl. Sea Lab (1983)
Dennis *et al.* (1984)
Donohoe and Calhoun (1982)
McPhearson (1970)
NOAA (1990b)
O'Neil and Mettee (1982)
Pacheco *et al.* (1989a)
Renaud (1985)
Rucker *et al.* (1990)
Schroeder (1976, 1979)

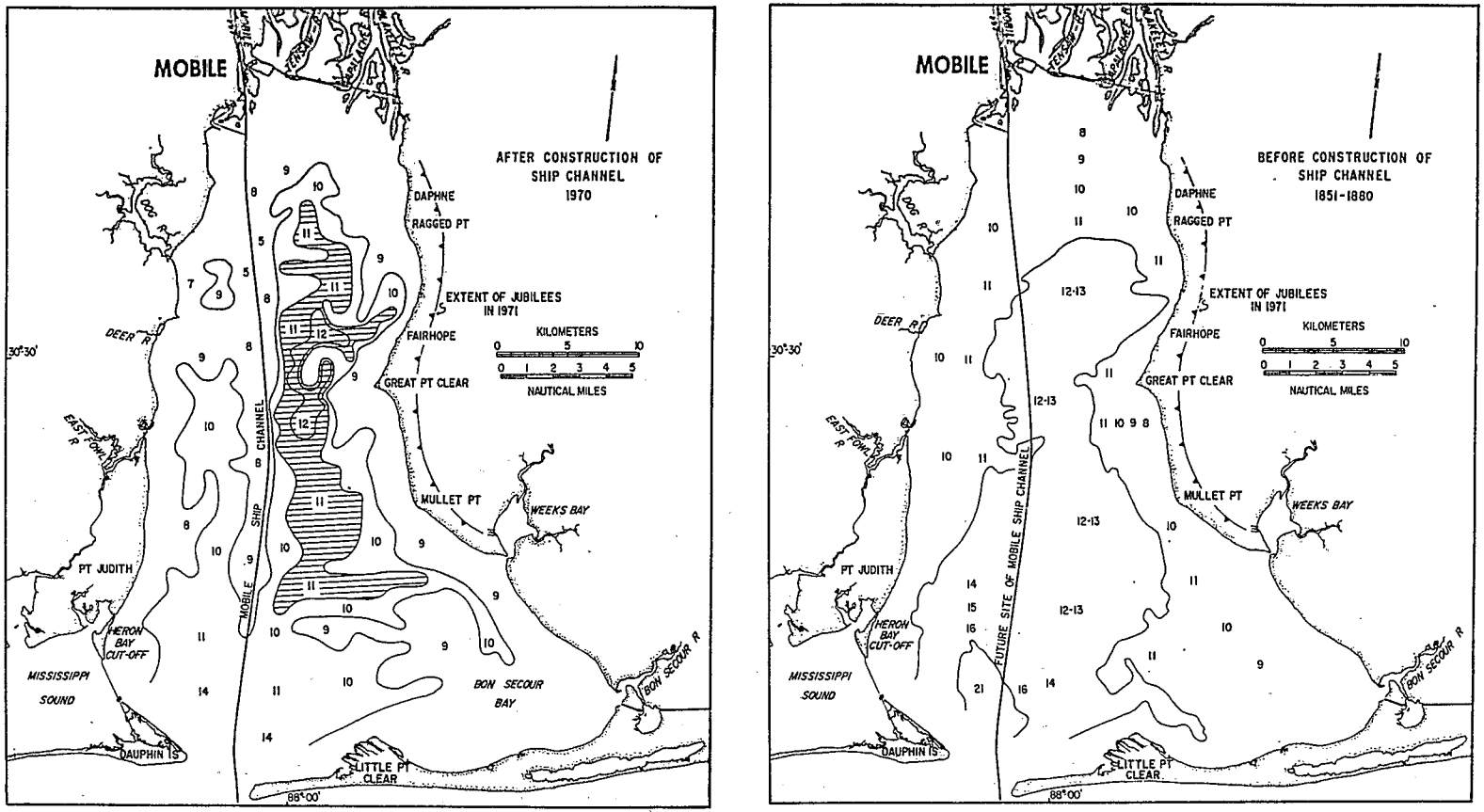


Figure A15. The bathymetry of Mobile Bay before the ship channel was dredged (left panel) and in 1970 showing large sinks created by spoil and shoaling (from May, 1973).

GURC (1979)
Horn (1990)
Ingle *et al.* (1955)
Isphording (1982)
Isphording and Lamb (1979)
Loesch (1960)
Lowery (1987)
Lysinger (1982)
Mar. Envir. Sci. Cons. (1979)
May (1973)
Schroeder and Lysinger (1979)
Schroeder and Wiseman (1988)
Schroeder *et al.* (1990)
Shaw *et al.* (1982)
Skupien (1989)
Swingle (1971)
Swingle and Bland (1974)
Turner *et al.* (1987)
Williams *et al.* (1990)
Wiseman *et al.* (1988)

G-2.1 Alabama inner continental shelf

In a series of five cruises between March 1987 to March 1988 along three north-south transects across the Alabama and Mississippi continental shelf (Darnell, 1991), nitrate concentrations were uniformly low during the summer months but fairly high during the winter especially along the transect closest to the Chandeleur Islands and the outflow of the Mississippi River (Table A3). Phosphate values were uniformly low during both seasons (Table A4).

Low dissolved oxygen values were not found on the Alabama inner continental shelf offshore of Mississippi Sound and Mobile Bay in a benthic survey conducted by Shaw *et al.* (1982); sampling was conducted, however, in spring and fall when hypoxia would be less likely to occur. Oxygen deficient bottom waters have been documented by W. Schroeder and colleagues (personal communication) in bathymetric depressions on the inner continental shelf just offshore of and adjacent to Mobile Bay. In the same series of cruises listed above (Darnell, 1991), bottom water dissolved oxygen concentrations were not reported as hypoxic at three stations along the 20-m isobath (Table A5). In two instances, however, where no data were recorded in the tables of the text of the report, data were recorded in the Appendices (Brooks and Wolff, 1991). These values were 2.48 mg/l (March 1988, station M-1) and 0.00 mg/l (October 1987). The water column was highly stratified near the seabed in both instances, and nutrient concentrations in bottom waters were elevated; these conditions indicate that low oxygen concentrations would not be unusual. Although the Mississippi and Alabama inner shelf has the potential for bottom water hypoxia, such events are not considered frequent nor widespread.

A bloom of the toxic dinoflagellate, *Gonyaulax monilata*, occurred in waters adjacent to Mobile Bay during a bloom within the lower bay in August 1979 (Perry *et al.*, 1979). Fish kills were associated with the bloom.

REFERENCES: G-2.1

Abston *et al.* (1987)
Atwood (1981)
Brooks and Wolff (1991)
Churgin and Halminsta (1974)
Cons. Perm. Int. Exp. Mer (1936)
Darnell (1991)
El-Sayed *et al.* (1972)
Eleuterius and Beaugez (1981)
Eleuterius *et al.* (1981)
Fanning *et al.* (1982)
Kjerfve and Sneed (1984)
O'Neil and Mettee (1982)
Riley (1937)
Russell (1977)
Schroeder (1976)
Schroeder and Crozier (1974)
Schroeder *et al.* (1988)
Shaw *et al.* (1982)
Stuntz *et al.* (N.D.)
Thompson and Bane (1986a,b)
Thompson and Leming (1978)
Thompson *et al.* (1988)
Turner *et al.* (1987)
Wiseman *et al.* (1988)

Table A3. Dissolved oxygen values (mg/l) for bottom waters of Mississippi and Alabama continental shelf. Stations C-1, M-1 and D-1 are on 20-m isobath on north-south transects offshore of Mississippi Sound, Mobile Bay and Perdido Bay, respectively (from Darnell, 1991).

Winter

	C				M				D			
Cruise No.	1	2	3	4	1	2	3	4	1	2	3	4
B-0	5.18	3.98	3.11	2.99	5.30	3.87	3.02	2.93	5.50	3.68	3.17	3.10
B-2	5.08	5.59	---	---	---	5.28	6.43	4.62	8.99	7.78	4.89	4.63
B-4	7.74	7.47	4.85	4.83	8.28	7.94	5.30	4.98	8.24	7.02	7.93	4.22
$\bar{x}$	6.00	5.68	3.98	3.89	6.79	5.70	4.92	4.18	7.56	6.16	5.33	3.98

Summer

B-1	---	4.70	4.62	4.82	---	5.80	4.63	4.70	7.77	---	5.48	4.60
B-3	7.00	6.40	4.78	4.84	5.88	6.13	6.00	5.69	6.05	6.44	5.23	4.26
$\bar{x}$	7.00	5.55	4.70	4.83	5.88	5.97	5.32	5.20	6.91	6.44	5.36	4.43

Table A4. Surface water nitrate values (µM/kg) [sic] of Mississippi and Alabama continental shelf. Stations C-1, M-1 and D-1 are on 20-m isobath on north-south transects offshore of Mississippi Sound, Mobile Bay and Perdido Bay, respectively (from Darnell, 1991).

Winter

	C				M				D			
Cruise No.	1	2	3	4	1	2	3	4	1	2	3	4
B-0	1.32	1.47	0.47	1.59	0.29	0.12	0.26	0.08	0.08	0.19	0.20	0.04
B-4	0.08	1.85	0.28	0.31	0.27	0.10	1.26	0.18	0.16	0.25	---	0.18
$\bar{x}$	0.70	1.66	0.95	0.95	0.28	0.11	0.76	0.13	0.12	0.22	0.20	0.11

Summer

B-1	0.20	0.20	0.20	0.20	0.10	0.10	0.20	0.10	0.20	0.20	0.10	0.10
B-3	0.09	0.06	0.07	0.02	0.07	0.04	0.11	0.10	0.15	0.06	0.06	0.14
$\bar{x}$	0.15	0.13	0.14	0.11	0.09	0.07	0.16	0.10	0.18	0.13	0.08	0.12

Table A5. Surface water phosphate values (µM/kg) [sic] of Mississippi and Alabama continental shelf. Stations C-1, M-1 and D-1 are on 20-m isobath on north-south transects offshore of Mississippi Sound, Mobile Bay and Perdido Bay, respectively (from Darnell, 1991).

Winter

	C				M				D			
Cruise No.	1	2	3	4	1	2	3	4	1	2	3	4
B-0	0.13	0.19	0.10	0.20	0.18	0.17	0.23	0.16	0.17	0.12	0.12	0.09
B-2	0.15	0.32	---	---	0.13	0.17	0.20	0.20	0.09	---	0.15	0.18
B-4	0.02	0.14	0.08	0.12	0.30	0.11	0.14	0.05	0.24	0.16	0.16	0.00
$\bar{x}$	0.10	0.22	0.09	0.16	0.20	0.15	0.19	0.14	0.17	0.14	0.14	0.09

Summer

B-1	0.18	0.27	0.20	0.28	0.15	0.09	0.06	0.03	0.15	0.15	0.05	0.09
B-3	0.15	0.26	0.12	0.37	0.23	0.14	0.13	0.14	0.25	0.14	0.08	0.26
$\bar{x}$	0.17	0.27	0.16	0.33	0.19	0.12	0.10	0.09	0.20	0.15	0.07	0.18

G-2.2 East Mississippi Sound

A general description of Mississippi Sound is given in the introduction to the State of Mississippi. Several studies have been conducted within the Alabama portion of the Sound and are detailed below. The artificial western boundary for East Mississippi Sound is the State border which runs north from Petit Bois Island, on the south, to the Grande Batture Islands on the northern side. The north part of the Sound is typically shallow and bordered by marshes and portions of modified shoreline. The mid Sound is characteristically an area of quiescent waters and slow sedimentation. The barrier islands of Dauphin Island and Petit Bois Island separate the Sound from the open Gulf.

The monthly micronutrient data from the Cooperative Gulf of Mexico Estuarine Inventory (Bault, 1972) are shown in Figure A16. Mississippi Sound ranked third in nitrate-nitrogen, nitrite-nitrogen, total phosphorus and the total of these three (= fertility index). Minimal differences between surface and bottom water samples indicated that the water column was generally well-mixed. The level of nutrients is influenced by waters from the Gulf of Mexico which are relatively low in the nutrients measured. Some nutrient loadings, however, enter from Mobile Bay, Bayou LaBatre, Bayou Coden and Dauphin Island. Pascagoula Bay in Mississippi may also be a significant source of nutrients. The average nitrate concentration for Mississippi Sound was not significantly different from that in Perdido Bay. This similarity may be due to the shallow depths and well-mixed water column. Total phosphorus was low in surface waters and similar to the other areas, with the exception of Perdido Bay which was higher.

Oxygen-depleted bottom waters have been recorded at the stations of Bault (1972) in mid-Sound and those of Swingle and Bland (1974) in tributaries to the Sound. Oxygen-depleted bottom waters have been recorded at these stations, but infrequently (2 out of 20 records at Bayou LaBatre, 3 out of 200 records mid-Sound). Salinity stratification of Gulf waters intruding into the less saline waters of the Sound through the deeper channel of Petit Bois Pass is implicated in oxygen depletion in the latter location (M. Van Hoose, personal communication).

The extensive bloom of *Oscillatoria (Trichodesmium) erythraea*, which occurred in Mississippi Sound in 1974 was also recorded in the eastern end of the Sound within Alabama State waters, but the extent of the distribution was not determined (Housely, 1976 cited in Eleuterius *et al.*, 1981).

REFERENCES: G-2.2

Bault (1972)
Donohoe and Calhoun (1982)
Eleuterius and Beaugez (1981)
Eleuterius *et al.* (1981)
Isphording and Lamb (1980)
Kelly (1981)
Lytle and Lytle (1990)
McPhearson (1970)
O'Neil and Mettee (1982)
Pacheco *et al.* (1989a)
Schroeder (1976)
Shaw *et al.* (1982)
Swingle (1971)
Swingle and Bland (1974)

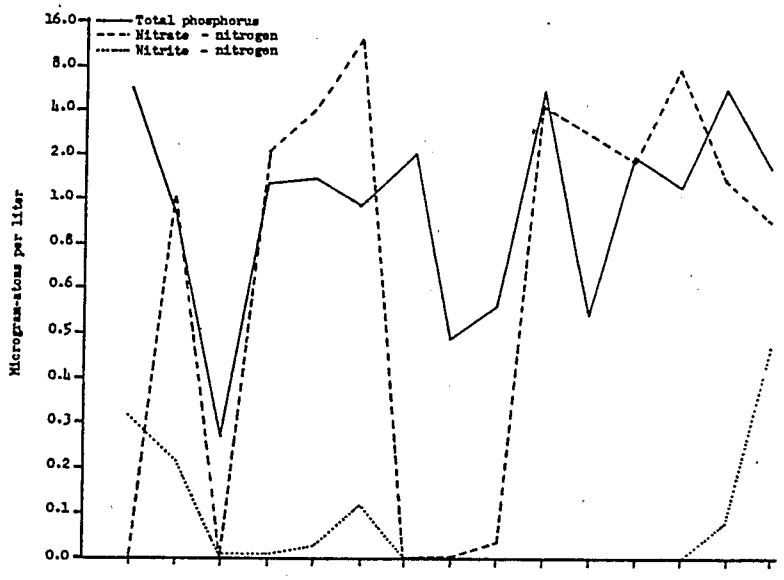


Figure A16. Monthly average concentrations of micronutrients in Mississippi Sound from January 1968 through March 1969 (from Bault, 1972).

MISSISSIPPI

Mississippi Sound dominates the estuarine system of the State. According to many authors, the complex includes the small bays, marshes, bayous, and rivers along the northern shore. Others treat the secondary bays as separate hydrologic units. For this review, we will incorporate data, where available, for the entire complex into a single synthesis. Where data are specific to the Sound, or a bay, they will be identified as such in the appropriate units designated below. The hydrology and physical and biological characteristics of Mississippi Sound cross state borders. The Mississippi-Louisiana state line traverses Mississippi Sound between Cat Island to the Pearl River which forms the landward border. The Alabama-Mississippi state line runs directly north of the most easterly end of Petit Bois Island. Water circulation does not recognize political boundaries. Water quality monitoring programs, however, do. Data for the Sound should include the westerly portions where Lake Borgne and the Pearl River enter and the easterly portion which falls within the state of Alabama. Where systemwide studies have been conducted, the results are more appropriate for comparisons and observations of trends. Political subdivisions, however, dictate much of the data collected, and it is sometimes less informative to compare data of varying temporal and spatial coverage and differing foci or analytical methods.

GENERAL REFERENCES: MISSISSIPPI

ASIWPCA (1984)
Basta and Bower (1985)
Burrage (1989)
Culliton and Blackwell (1989)
Ehler and Basta (1985)
EPA (1974, 1978)
Jones *et al.* (973)
Main *et al.* (1987)
NOAA/EPA Team (1990)
Pechmann *et al.* (1986)
Turner and Rao (1990)

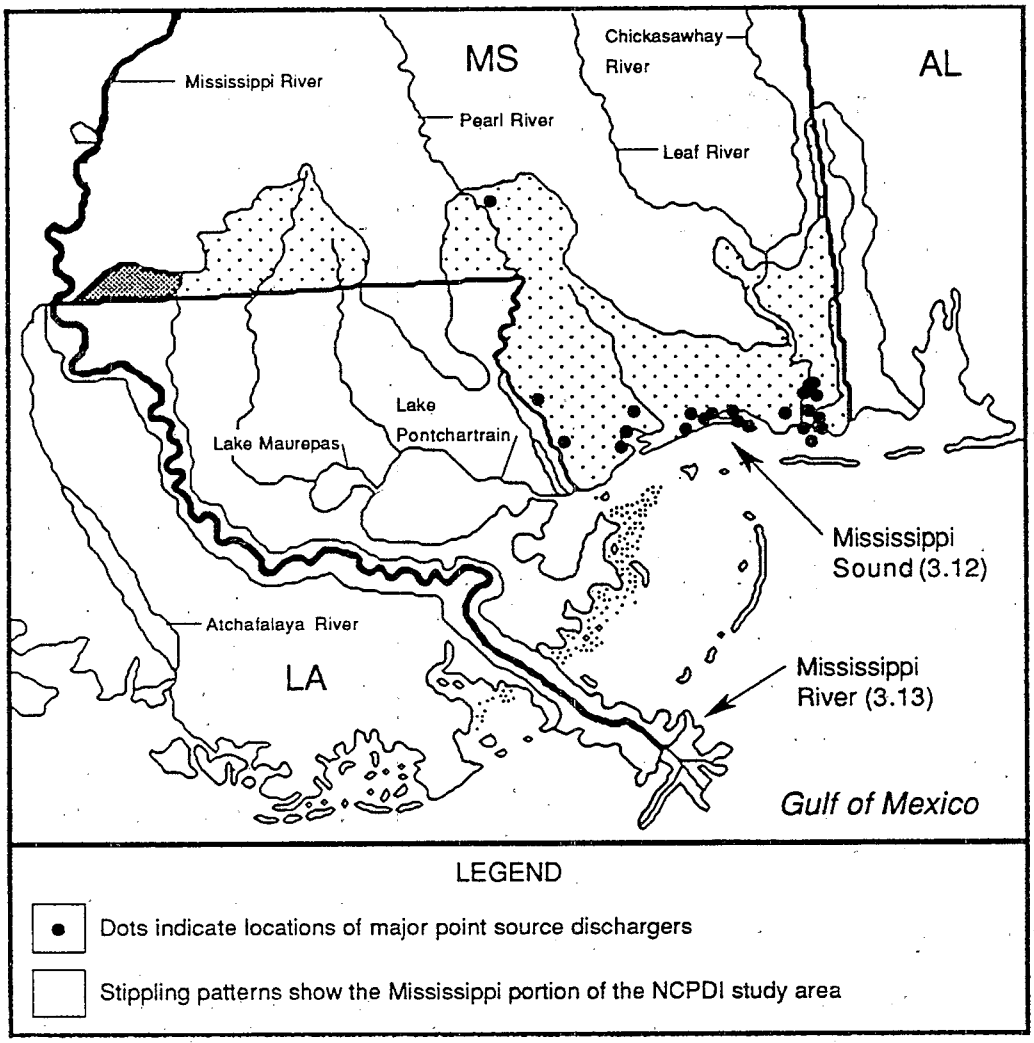


Figure M1. Location of major point source discharges in Mississippi (from Pacheco, 1989b).

Table M1. Pollutant variables in Mississippi Sound surface sediments (from Lytle and Lytle, 1990).

Location	TOC (%)	TKN (mg g^{-1})	Phenols ($\mu g\ g^{-1}$)	Total HC ($\mu g\ g^{-1}$)	Aromatic HC ($\mu g\ g^{-1}$)
Pascagoula River (26 samples)	4.05 ± 3.98 0.145–14.0	1.43 ± 1.21 n.d.–4.24	1.04 ± 0.727 n.d.–2.75	1,800 ± 3,520 0.20–13,300	211 ± 432 n.d.–1,930
Biloxi Bay (19 samples)	1.76 ± 0.832 0.315–3.67	0.88 ± 0.616 0.07–2.59	0.604 ± 0.510 0.254–2.39	686 ± 1,970 1.15–8,600	186 ± 595 0.410–2,610
St. Louis Bay (4 samples)	1.45 ± 0.777 0.328–2.08	1.19 ± 0.200 0.97–1.39	0.543 ± 0.167 0.378–0.773	36.6 ± 21.0 12.8–63.9	7.37 ± 2.82 3.52–9.77
Mississippi Sound (15 samples)	0.869 ± 0.420 0.096–1.36	0.568 ± 0.505 0.0045–1.55	0.647 ± 0.493 0.224–1.77	16.8 ± 12.2 0.986–69.9	3.07 ± 2.96 0.070–11.0
Gulf of Mexico (1 sample)	1.09	0.73	0.285	18.9	3.77

[a] Total Kjeldahl nitrogen, total organic carbon, total hydrocarbons, aromatic hydrocarbons, and phenols. Reported values are mean ± one standard deviation/minimum–maximum values. n.d. is not detected and entered as 0.0 in mean calculations.

Table M2. Summary of NOAA Fish Kill Inventory Data for Mississippi (draft data base, 1991; J.A. Lowe, personal communication; see section on Data Sources).

AREA County	Records per County	Cause Low DO	Cause Eutrophication	Cause Red Tide	Cause Nutrient	Cause Unknown or Unspecified
MISSISSIPPI SOUND						
Hancock	5	0	0	0	0	0
Harrison	3	0	0	0	0	0
Jackson	2	0	0	0	0	1

G-2.3 Mississippi Sound, Gulf Islands area and mid-Sound

A general description of the Mississippi Sound Complex is given by Eleuterius (1976a). Mississippi Sound is an elongate water body which is separated from the open Gulf of Mexico by a series of barrier islands. Narrow peninsulas and shallow shell reefs connecting Dauphin Island to the Alabama mainland separate the Sound from Mobile Bay on the east. Fresh water enters the Sound on this eastern end from Mobile Bay. It is estimated (Austin, 1954; cited in Eleuterius, 1976a) that one-fifth of the discharge from Mobile Bay is diverted into Mississippi Sound mainly via Grants Pass. On the western end, the Sound receives input from Lake Borgne and the Pearl River, and indirectly from Lake Pontchartrain and the Mississippi River, even more infrequently, when the Bonnet Carré spillway is opened. Several other major sources of fresh water enter the Sound directly: The Pearl River on the western end with a flow of 11,580 cfs, and the Pascagoula River with an average flow of 13,369 cfs. The Biloxi and Tchoutacabouffa Rivers (flows of 494 and 437 cfs, respectively) reach the Sound via Biloxi Bay. The Jourdan and Wolf Rivers empty into St. Louis Bay with average flows of 1,535 and 706 cfs, respectively. Tidal bayous contribute lesser amounts of fresh water. Connection through passes and over shoal areas along the barrier island chain permit the intrusion of higher salinity Gulf of Mexico waters.

The Sound is relatively shallow with an average depth of 3 m (Eleuterius, 1976a). The greater depths, caused by tidal scouring action, are located at the immediate western tips of the barrier islands. Three channels traverse Mississippi Sound. The ports at Pascagoula and Gulfport have deep water access with authorized depths of 13 and 11 m, respectively. The third, Biloxi Channel, used primarily by barge, commercial fishing vessels and pleasure craft, has an authorized depth of 4 m. A fourth channel, The Gulf Intracoastal Waterway, spans the east-west axis of the Sound at an authorized depth of 4 m which is exceeded in most parts of the Sound by the natural bathymetry.

Circulation and salinity in the eastern end of Mississippi Sound is controlled by influx of Mobile Bay discharge through Petit Bois Pass and topographic features which direct the outflow of the Pascagoula River (Eleuterius, 1976a). Circulation and salinity in the central portion of Mississippi Sound is largely attributable to tidal flux through Dog Keys and Ship Island passes. Tides entering through the two passes converge approximately along a north-south line bisecting Camille Cut. Since there are no fresh or low salinity water sources between Biloxi Bay and St. Louis Bay, this convergence zone brings higher salinity water closer to the mainland than anywhere else in the Sound. West Mississippi Sound displays an overall consistently lower salinity. The water column is usually well-mixed, but occasionally during periods of moderate freshwater inflow, it displays a pronounced halocline.

The greatest abundance of industrial development has occurred in the Pascagoula River, Escatawpa River and Bayou Casotte (Lytle and Lytle, 1990). Biloxi Bay has a moderate degree of industrialization and St. Louis Bay and Heron Bay have little industrial development. Figure M1 shows the location of the major point source discharges within the estuarine drainage area of Mississippi Sound. Extensive work by Lytle and Lytle (1985, 1990, and references therein) has documented the distribution of organic pollutants. Sediment sampling was conducted over a 3-yr period. TOC values were greatest in the Pascagoula River with Biloxi Bay having considerably lower TOC values, and TOC in St. Louis Bay occurred at levels only slightly higher than the Sound and Gulf samples (Table M1) (Lytle and Lytle, 1990). Using TOC as a gross indicator of pollution, the strongest evidence of pollution exists for discrete sample sites along the Pascagoula River, with some sites in Biloxi Bay also showing unusually high TOC. Ranges of TKN were less dramatic, although there were generally higher values in the bays and rivers compared to the Sound and Gulf with isolated highs near municipal sewage discharges, as expected (Table M1). Phenols were observed at highest levels in the eastern Sound near industrial sources, but at most sampling sites were <1 ppm (Lytle and Lytle, 1985). Hydrocarbons were the most significant of the pollutants found in the sediments of Mississippi Sound. Concentrations were found in Bayou Casotte and other regions in the eastern Sound and were related to petroleum associated with an oil refinery, fuel oil, and sewage. Land runoff apparently also contributed some of the pollutants. Of particular concern was the presence of significant levels of polynuclear aromatic hydrocarbons.

Several freshwater tributaries of the estuarine system in Mississippi have been closed to commercial fishing because of the presence of dioxin in flathead catfish (Houma *Daily Courier*, October 7, 1990). Two of the tributaries enter the Pascagoula River which eventually enters Mississippi Sound. The dioxins are attributed to the operations of the Georgia-Pacific pulp and paper mill.

The general results from the studies of Lytle and Lytle indicate highly localized areas of contamination existing within the rivers and bays of the Mississippi Sound region while there are much larger areas that have relatively little pollution from hydrocarbons. Even in rivers emptying directly into the sound, *e.g.*, the Pascagoula rivers, there is little evidence that riverine pollutants have much impact on Sound sediments (Lytle and Lytle, 1990). The movement of pollutants related to a paper mill revealed that the only sediments which were significantly enriched were in the immediate vicinity of the paper mill (in the Escatawpa River). Tracing hydrocarbon pollutants from Bayou Casotte east of the Pascagoula River also revealed minimal migration of these pollutants from this heavily industrialized bayou into the Sound.

An increase in recurring fish kills of mostly juvenile menhaden was noted in the text supporting the need for the Cooperative Gulf of Mexico Estuarine Inventory and Study within Mississippi (Christmas, 1973). The data for Mississippi in the NOAA Fish Kill Inventory data base were limited, and none indicated aspects of nutrient enrichment and eutrophication as causes (Table M2). However, anecdotal evidence and the Mississippi Dept. of Natural Resources Water Report (1988) points to fish kills as a cause for concern within the Mississippi Sound estuarine complex.

The Cooperative Gulf of Mexico Estuarine Inventory and Study for Mississippi (Christmas, 1973; Christmas and Eleuterius, 1973) documented water quality, including dissolved oxygen and nutrients during 1968-1969 for Mississippi Sound and its sub-basins. Additionally, nutrient samples were taken as part of a hydrography study of Mississippi Sound in 1973-1975 (Eleuterius, 1976b).

The average values for nitrate, nitrite, orthophosphate and total phosphorus for Mississippi Sound are shown in Figures M2 and M3 (Eleuterius, 1976b). Eleuterius documented lower nutrient levels above the Escatawpa River-Pascagoula River confluence than in the lower Pascagoula River. The high levels and variability of phosphorus and nitrogen in the lower Pascagoula River reflect the local introduction of effluents. The apparent inverse relationship between levels of nitrate and

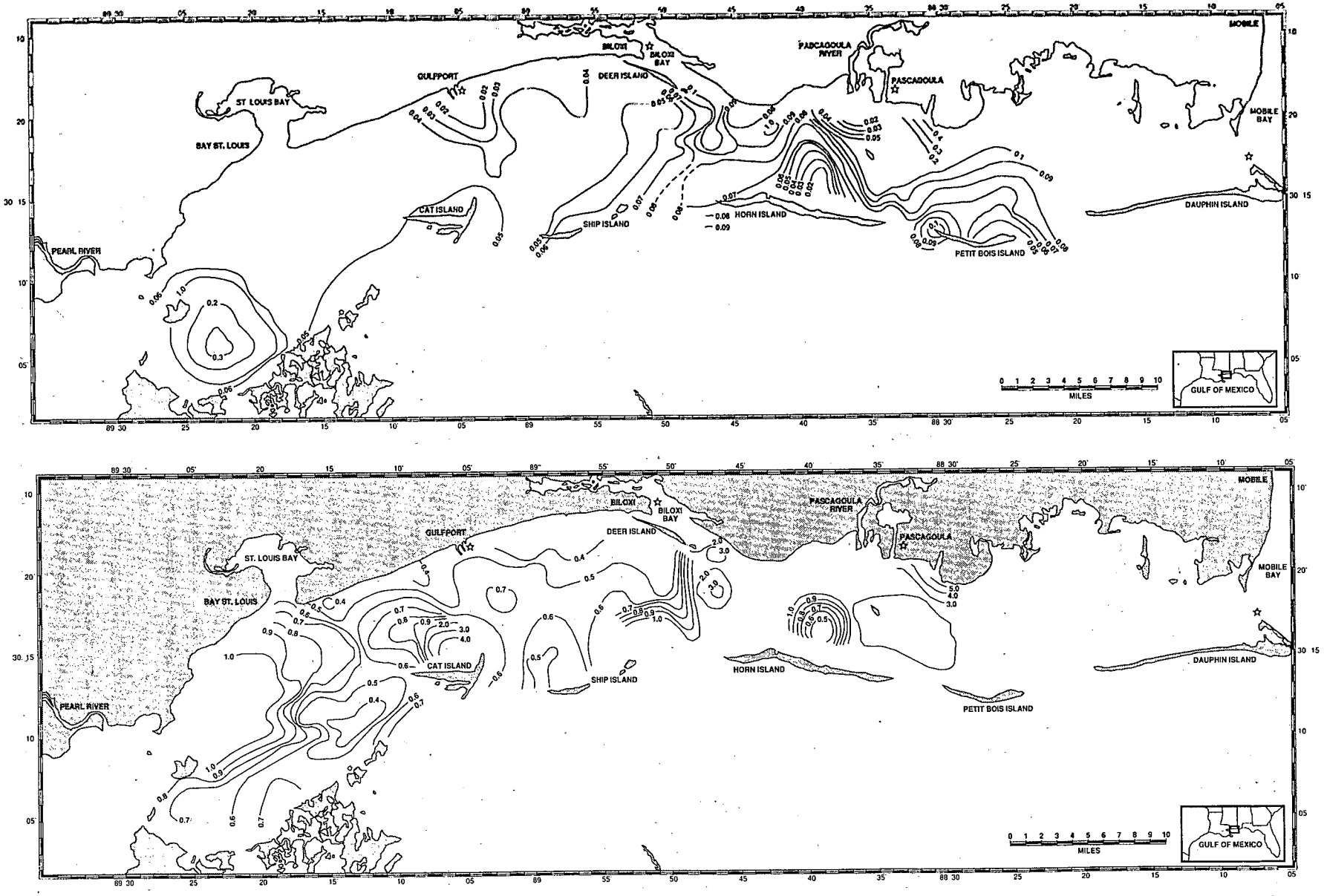


Figure M2. Distribution of average levels of nitrite (µg-at/l) (upper panel) and nitrate (µg-at/l) (lower panel) in Mississippi Sound (adapted from Eleuterius, 1976b).

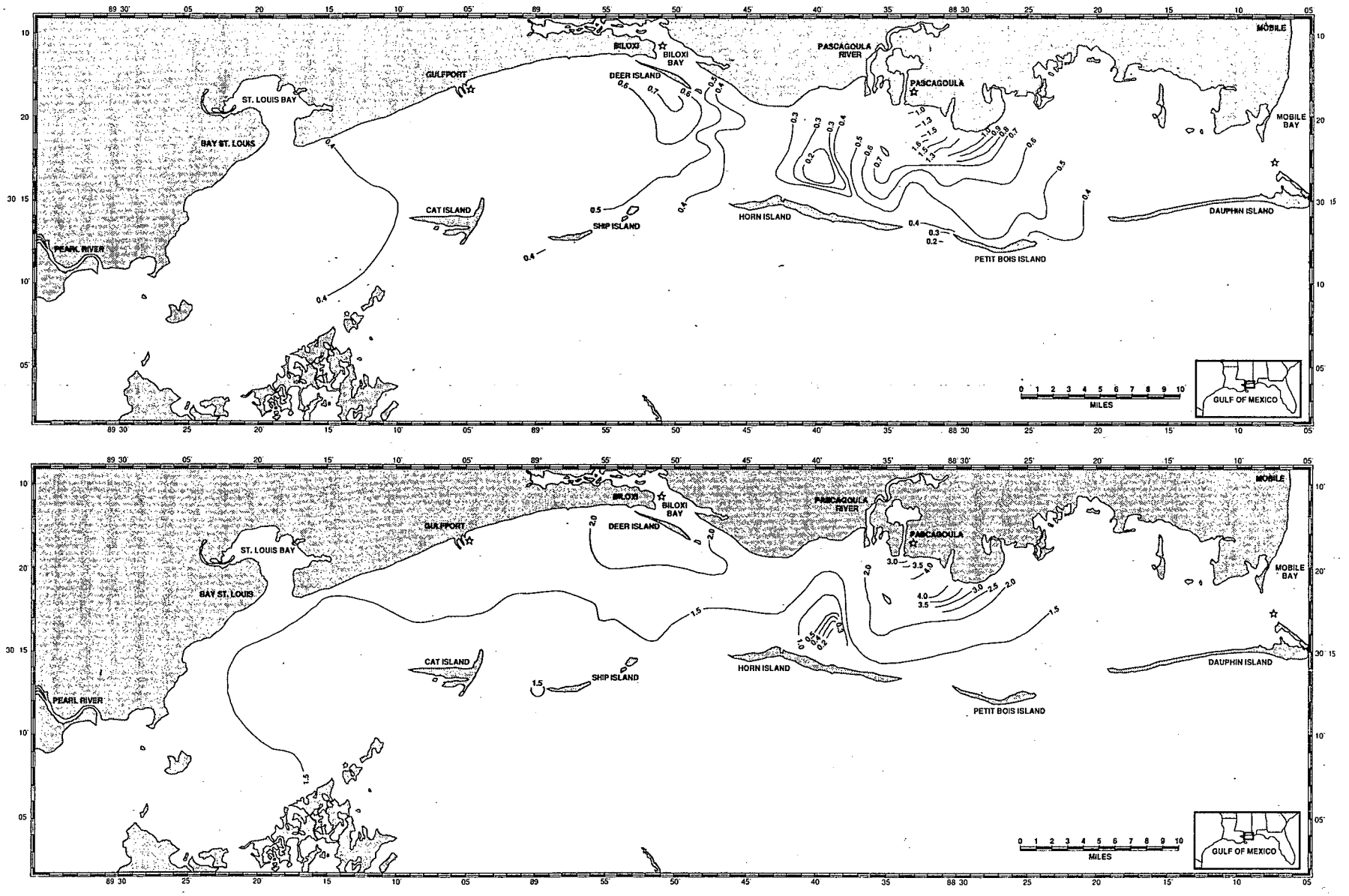


Figure M3. Distribution of average levels of orthophosphate (µg-at/l) (upper panel) and total phosphate (µg-at/l) (lower panel) in Mississippi Sound (adapted from Eleuterius, 1976b).

phosphorus was limited to the lower Pascagoula River and attributed to changes in activities within the drainage basin. In general, levels of all nutrients declined seaward to the barrier island passes. Seaward of the passes, nitrate levels exceeded those of the Sound. General trends for a decrease in nutrients with less variability were seen with distance westward in the Sound. The primary sources of nutrients in the Sound are Pascagoula River, Bayou Casotte, Biloxi Bay and Pearl River (Eleuterius, 1976), but the Pearl River's contribution appears to be low.

The waters within and in the vicinity of Bayou Casotte showed consistently high levels of phosphorus and nitrate (Eleuterius, 1976). The major portion of the phosphorus is inorganic; several chemical plants that manufacture fertilizer are located in an industrial plant next to the bayou.

There are no new data that would indicate a different assessment of Mississippi Sound with regards to dissolved oxygen level; but the general summary is presented again in the context of a 2 mg/l criteria. Low dissolved oxygen levels are infrequently found in Mississippi Sound during the warmer months of April through September. The lowest values are found just inside the passes which cut through the barrier islands (as well as just off the passes). Stations 81 and 84 of the GCRL, FAM data set, are those with the most frequently recorded hypoxia (F. Sutter, personal communication). Suspected mechanisms for the low dissolved oxygen content found in bottom waters just inside and outside of the passes, involve density stratification from higher salinity, lower temperature bottom water intruding onto the inner shelf and into the Sound. The degree of density stratification in the water column would differ depending on the east-west salinity differences present in the Sound. The effects of these oxygen-depleted bottom waters are seen in the death of crabs in traps, occasional jubilees of adult white shrimp (*Penaeus setiferus*) along the Mississippi shore, and a suspected decline in the white shrimp fishery following a summer when low dissolved oxygen levels were present in the Sound (K. Stuck, personal communication). Fisheries yields, however, are dependent on many factors, *e.g.*, climatic factors and suitable nursery habitat. The heavy rains, flooding, and extremely low salinities in Mississippi Sound in the late spring and summer of 1991 have been blamed for a poor shrimp catch (Baton Rouge *Morning Advocate*, June 30, 1991). On the other hand, Russell (1977) attributed an enhanced catch of annual landings of industrial bottom fish following the flooding of the Mississippi River in 1973, the opening of the Bonnet Carre spillway, and concomitant nutrient increases.

Blooms of the toxic dinoflagellate, *Gonyaulax monilata*, occurred in coastal waters of the northern Gulf in August 1979, September 1980 and July 1981 (Perry *et al.*, 1979; Perry and McLelland, 1981a). The blooms were concentrated within Mississippi Sound, but also extended into the nearshore waters of the Gulf of Mexico. No fish kills were associated with these blooms. Concurrent blooms in Florida and Alabama occurred with the extensive bloom in Mississippi Sound in 19790. A red tide attributed to blooms of the dinoflagellate, *Prorocentrum minimum*, occurred in Mississippi Sound and coastal bayous in February 1977 and in January and February 1981. Fish kills were associated with blooms of this dinoflagellate where the outbreaks occurred in enclosed waters (Perry and McLelland, 1981a,b). *P. minimum* appears to be an occasional component of the phytoplankton community in local waters.

A large bloom of *Oscillatoria (Trichodesmium) erythraea* developed *in situ* in Mississippi Sound in August 1974 and extended the length of the sound on the northern edge of the barrier islands to a distance of 10 km and up to 1 km into the adjacent Gulf of Mexico (Eleuterius *et al.*, 1981). No dead fish or other animals were seen during the bloom, either in the Gulf, estuary, or on adjacent beaches. The authors attributed the bloom to high temperature, very high salinity, very transparent water, a slightly alkaline pH, low nutrient concentrations, moderate oxygen concentrations, calm seas (no wind) and brilliant sunlight. *Trichodesmium* blooms have occurred in Mississippi Sound of relatively short duration (2-3 weeks) in 1976, 1978 and 1980 (Eleuterius *et al.*, 1981; Perry and McLelland, 1981).

REFERENCES: G-2.3

Anon. (1981, 1984)
Christmas (1973)
Christmas and Eleuterius (1973)
Donohoe and Calhoun (1982)
Eleuterius (1976a,b, 1978a,b, 1979)
Eleuterius and Beaugez (1981)
Eleuterius *et al.* (1981)
Higgins and Eleuterius (1978)
Kelly (1981)
Lytle and Lytle (1985, 1990)
Miss. Dept. Nat. Res. (1988)
Pacheco *et al.* (1989b)
Perry and McLelland (1981a,b)
Perry *et al.* (1979)
Shaw *et al.* (1982)

G-3 Pascagoula Bay/River/Escatawpa River

The Pascagoula River and its tributaries combine to form one of the largest drainage systems in Mississippi. The Escatawpa River joins the lower Pascagoula River approximately 7 mi upstream of its mouth. The West Pascagoula River diverges from the Pascagoula River 17.7 mi upstream of its mouth; both flow parallel southward. The waters of the lower reaches of the two rivers are interconnected by drainage through swamps, marshes and bayous.

A study of the water quality of the Pascagoula and Escatawpa Rivers was conducted by Bednar (1978c). Concentrations of nitrite, nitrate and ammonia nitrogen at high and low tide are shown in Figure M4. The total phosphorus concentrations in the rivers at sites in this study were comparatively low. Ranges were between 0.01 and 0.16 mg/l.

A similar study was conducted in Bayous Casotte and Chico by Bednar (1979). Concentrations of most nitrogen species were higher in Bayou Casotte at low tide than at high tide and were higher at the most interior station than those closer to Mississippi Sound (Figure M5). The composition and concentration of nitrogen species at high and low tide were more uniform in Bayou Chico than Bayou Casotte. The nitrite plus nitrate concentrations in both estuaries were comparatively low. Variable and high concentrations of organic and inorganic phosphorus were likely the result of industrial wastewaters being released near the upstream sites. The comparatively small difference between the phosphorus concentrations at high and low tide at the mouth of both Bayou Casotte and Bayou Chico is an indication that phosphorus was being transported out of both estuaries in low concentrations during the study.

In its 1988 Water Quality Report (Mississippi Dept. of Natural Resources, 1988), the state identified current water quality and trends in its waters along with causes for nonsupport of designated uses. Two estuarine areas were identified for special study: Bayou Cumbest/Heron Bayou area and Ocean Springs (see Section G-4). A nonpoint source contribution analysis by the Environmental Services Division of EPA Region IV indicated the degradation of shellfish harvesting waters near Pascagoula as a result of domestic wastewater pollution. As a result of these studies, the management guidelines have been set for adequate wastewater treatment and disposal.

Stations in Pascagoula Bay rarely had dissolved oxygen concentrations less than 2 mg/l (GCRL, FAM data set; Christmas and Eleuterius, 1973). Portions of the Pascagoula Bay subestuary are subject to oxygen-depleted bottom waters. This was particularly evident at depth in the Pascagoula and Escatawpa Rivers where there was little circulation and mixing of the more dense salt water (Bednar, 1978b). These values, however, ranged mostly between 2 and 3, with few below 2 mg/l. Stations in the tidal reaches of the West Pascagoula and Pascagoula Rivers and at the mouth of the Pascagoula River are frequently hypoxic or anoxic in the warmer months, March through October (Bednar, 1978b; Bednar, 1979; Christmas and Eleuterius, 1973). Eleuterius and Beaugez (1979) also noted a zone of low dissolved oxygen waters in Mississippi Sound near the mouth of the Pascagoula River. Probable causes of oxygen depleted waters in these areas, besides density

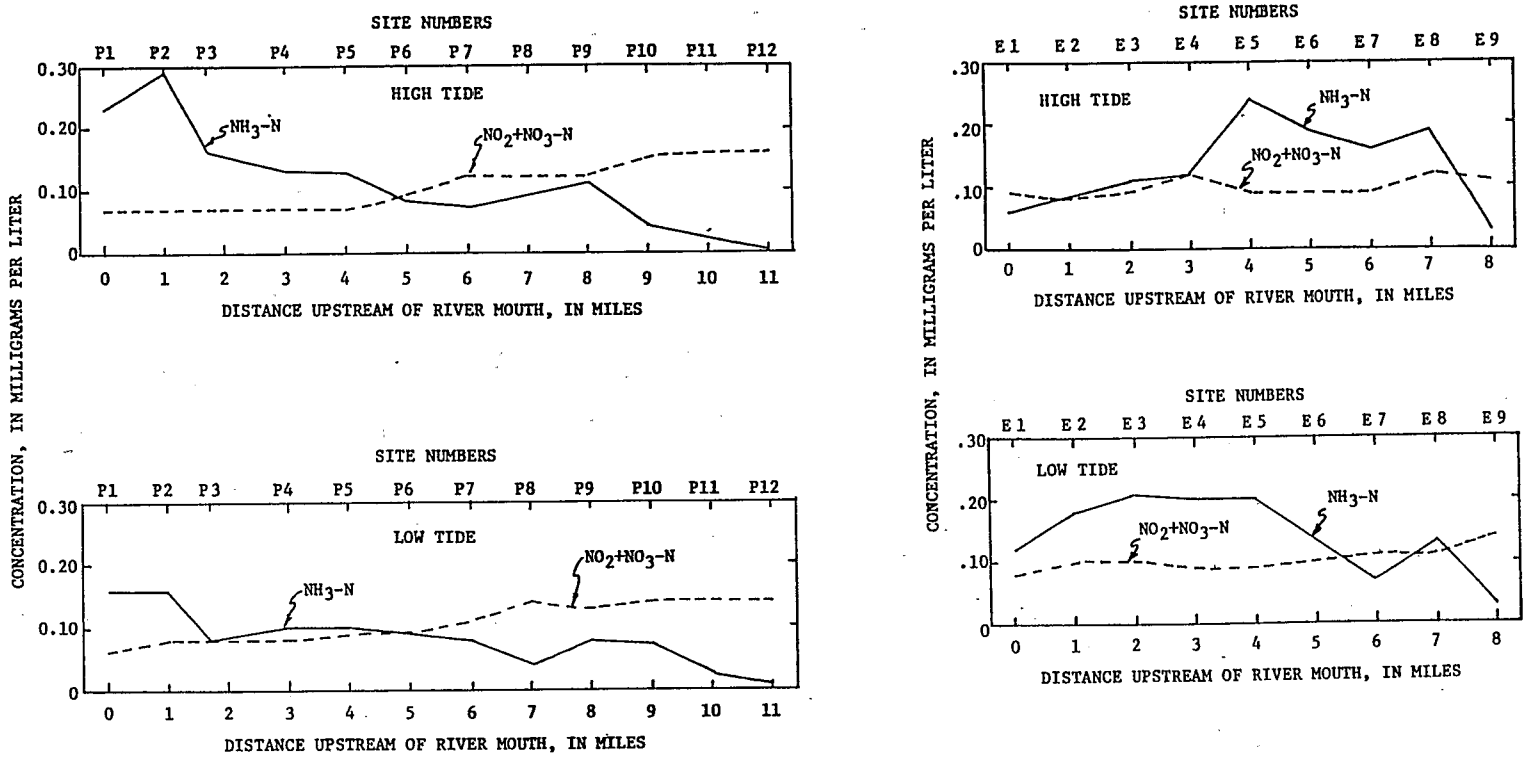


Figure M4. Profiles of nitrite plus nitrate and ammonia nitrogen in Pascagoula River (left panel) and in Escatawpa River (right panel) at high and low tide (from Bednar, 1978c).

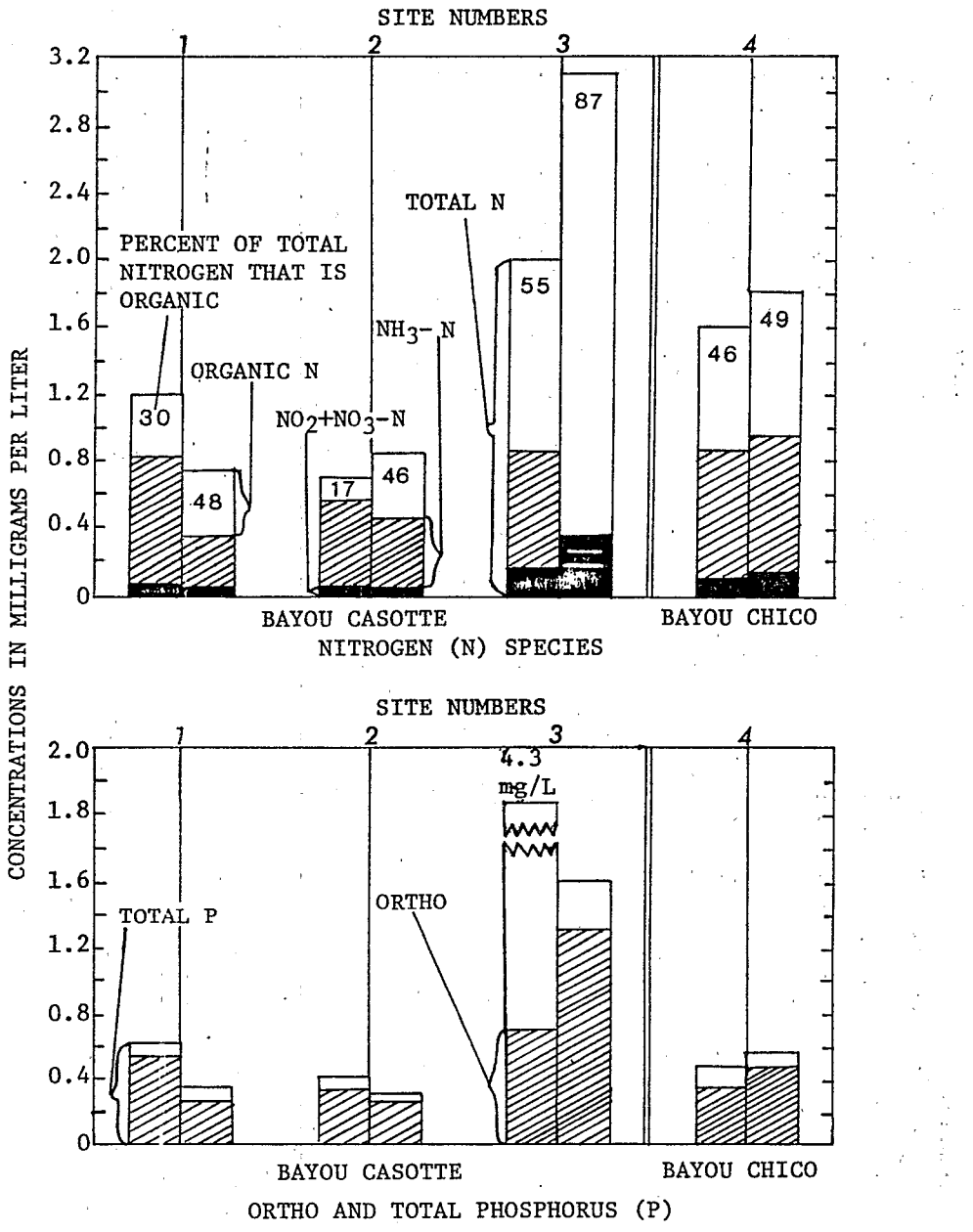


Figure M5. Concentration and composition of nitrogen and the ortho- and total phosphorus species in Bayou Casotte and Bayou Chico at high and low tide on July 25, 1978 (from Bednar, 1979).

stratification (Bednar, 1978b; Eleuterius and Beaugez, 1979) are pollutant loadings from paper mill effluents (F. Sutter, personal communication), menhaden rendering plant effluents (F. Sutter, personal communication), and domestic and industrial effleunts from the city of Pascagoula (see Figure M1). In a 3-day study of Bayous Casotte and Chico in July 1978 (Bednar, 1979), oxygen depleted waters were found in the lower reaches of Bayou Casotte. A ship channel and harbor with industrial activities, including petroleum fuels, petrochemicals, metal processing and fabricating, and nitrogen, potassium and phosphorus fertilizers, characterize the area.

REFERENCES: G-3

Bednar (1978c, 1979)
Christmas (1973)
Christmas and Eleuterius (1973)
Eleuterius (1976a)
Lytle and Lytle (1985, 1990)

G-4 · Biloxi/Bay Bays

In its 1988 Water Quality Report (Mississippi Dept. of Natural Resources, 1988), the state identified current water quality and trends in its waters along with causes for nonsupport of designated uses. Two estuarine areas were identified for special study: Bayou Cumbest/Heron Bayou area (see Section G-3) and Ocean Springs. For a number of years the state has monitored severe water quality problems in Ocean Springs Harbor (Tidewater Bayou). This waterbody flows directly into Biloxi Bay which is classified for shellfish harvesting. A pollution abatement plan for the area included the termination of the discharge from the wastewater treatment plant and the construction of a new land treatment system north of the city. Prior to the abatement period, fecal coliform counts were extremely high, oxygen concentrations were depressed at all stations, concentrations of ammonia, nitrogen and orthophosphorus in harbor waters were greatly elevated, total hydrocarbon concentrations in sediments were high, TOC in sediments were two to five times higher than typically found in Gulf coast estuaries, heavy metals were elevated, and benthic fauna were depressed in abundance and species richness. Following abatement, significant positive changes were seen in the water quality of the harbor in decreased inorganic nutrient concentrations and BOD values, reduced fecal coliform bacteria counts, and increased dissolved oxygen concentrations. The effect of abatement was not as easily seen on other parameters: 1) heavy metals, TOC and total hydrocarbon levels were lower but reductions were attributed to tidal surge and sediment movements as a result of Hurricane Elena in September 1985; 2) phytoplankton populations did not indicate a definite effect; 3) benthic fauna showed only slight change in numbers of individuals and numbers of species. Limitations of abatement were identified as the time required for recovery of the system from chemical pollutants, the physiography of the harbor, and uses of the harbor. The report identified a more far-reaching concern as the failures in the sewage collection system of Ocean Springs which allows raw sewage to enter the harbor.

In a study of the Back Bay of Biloxi, water quality and water flow characteristics were used to determine the residence time of water (Bednar, 1978a) (Figure M6). Nitrite plus nitrate nitrogen concentrations were less than 0.1 mg/l and the concentrations of ammonia, organic and total nitrogen were generally higher at high tide than low tide. The concentrations of ammonia nitrogen ranged from 0.09 to 0.22 mg/l at high tide and 0.06 to 0.16 mg/l at low tide. Organic nitrogen comprised about 85 % of the total nitrogen (Figure M7). The highest concentration of organic nitrogen was 0.97 mg/l and ranged from 0.65 to 1.1 mg/l at high tide and from 0.54 to 1.1 mg/l at low tide. The concentration of total phosphorus leaving the bay at low tide was very low and in about the same concentration as that entering the bay at high tide. Total phosphorus concentrations ranged from 0.1 to 0.24 mg/l at high tide and 0.08 to 0.14 mg/l at low tide (Figure M6).

Within Biloxi Bay, there were few instances of hypoxic bottom waters; these values (1-2 mg/l) occurred in May-September (GCRL, FAM data). Lower oxygen levels were found in waters in the Back Bay during the summer months, but never fell below 2.5 mg/l (Christmas and Eleuterius, 1973: Bednar, 1978a). In the GCRL, FAM data set, two stations in Back Bay were consistently hypoxic in summer. In the stations in Big Lake, *Cladophora* blooms occur in the summer and oxygen is depleted to 1-2.5 mg/l, but this does not occur every year (F. Sutter, personal communication). At another station, midway between Big Lake and Biloxi Bay, hypoxia has been rare since 1979.

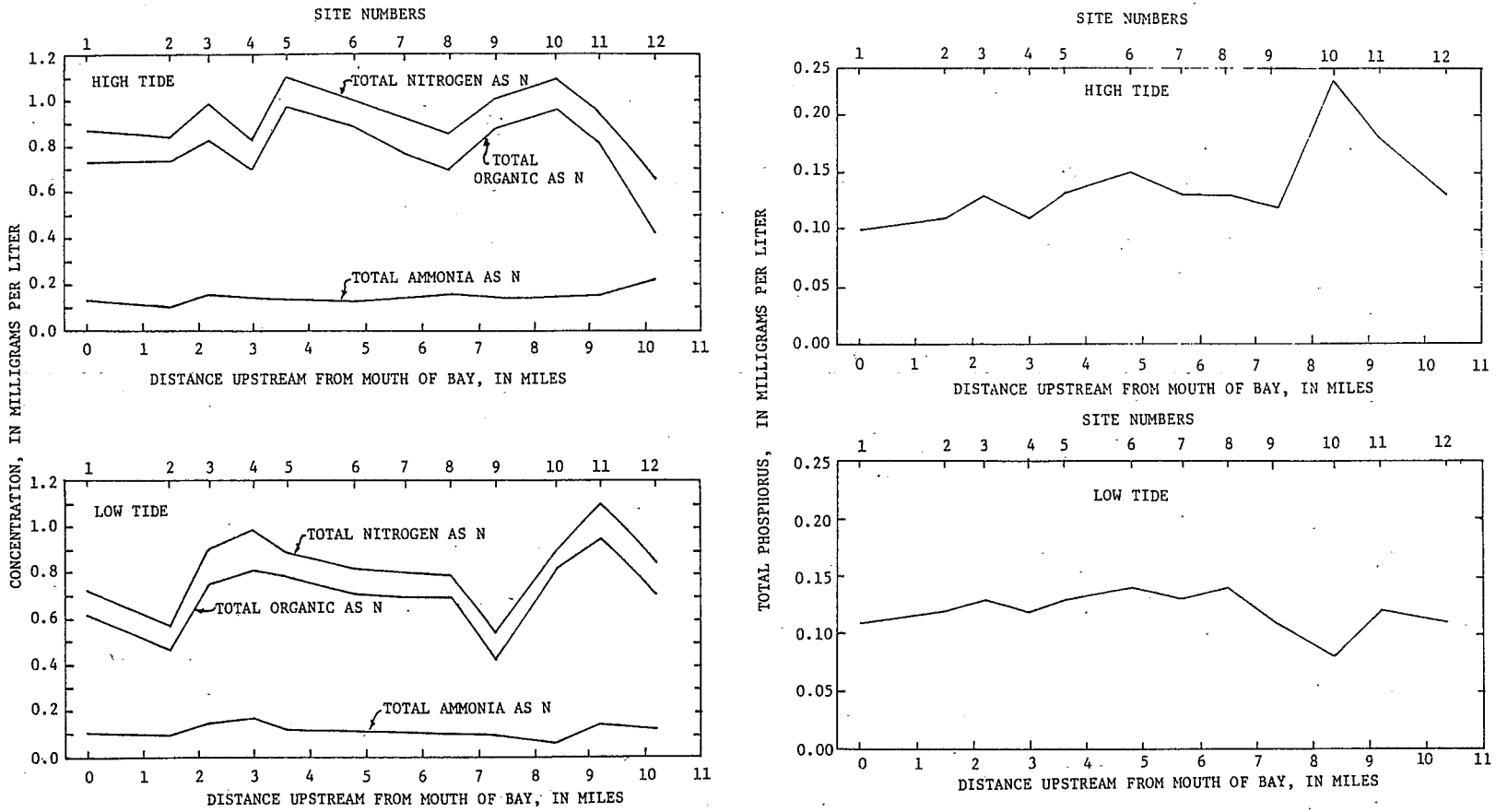


Figure M6. Profiles total nitrogen, organic nitrogen, and ammonia nitrogen in the Back Bay of Biloxi, June 14, 1977 (from Bednar, 1978b).

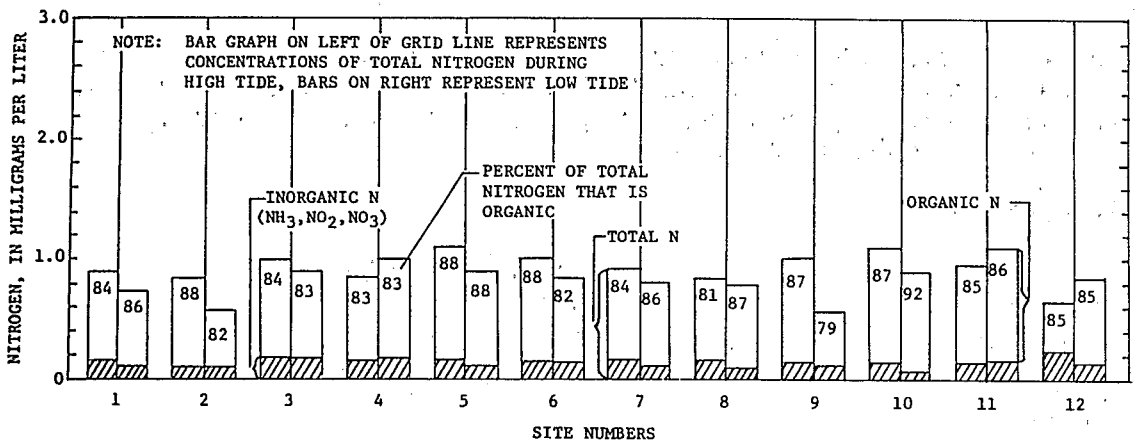


Figure M7. Concentrations and composition of nitrogen species in the Back Bay of Biloxi, June 14, 1977 (from Bednar, 1978b).

The bloom of the dinoflagellate, *Prorocentrum minimum*, which occurred in Mississippi Sound in January and February 1981, extended into the adjacent coastal waters of St. Martin Bayou, an inlet off the Back Bay of Biloxi and at the mouth of Fort Bayou in February 1977 (Perry and McLelland, 1981b). Fish kills were reported coincident with the bloom in St. Martin Bayou in 1981.

REFERENCES: G-4

Bednar (1978b)
Christmas (1973)
Christmas and Eleuterius (1973)
Eleuterius (1976a)
Lytle and Lytle (1985, 1990)
Pacheco *et al.* (1989b)
Perry and McLelland (1981b)

G-5 St. Louis Bay/Wolf/Jourdan Rivers

In a study of the Back Bay of Biloxi, water quality and water flow characteristics were used to determine the residence time of water (Bednar, 1978c). The average total organic nitrogen, ammonia, and total concentrations for sites on Jourdan River and St. Louis Bay during July 1977 are shown in Figure M8. Concentrations of total nitrogen were somewhat higher in the river than the bay. These values are lower than those of Back Bay at Biloxi where a similar study was conducted (Bednar, 1978a). Bednar (1978) suggested that the total nitrogen content of Jourdan River and St. Louis Bay was not abnormally high during the study. Bay waters containing higher concentrations of organic nitrogen were moved upstream by the incoming tides.

In the most comprehensive set of temporal data (GCRL, FAM) there were no dissolved oxygen levels below 4 mg/l in five stations located in St. Louis Bay or just outside the Bay in Mississippi Sound. A few samples between 3 and 4 mg/l were reported in the Jourdan River in July (Bednar, 1978c), but only one value fell below 3 mg/l and none below 2 mg/l. Krutak (1978) who sampled numerous stations but over a limited time found low dissolved oxygen levels at nine of 43 stations; these were mostly in the tributaries, in the bayous or at the mouth of a bayou, but not in the open Bay. The Cooperative Gulf of Mexico Estuarine Inventory (Christmas, 1973) revealed only three values in 27 collected from April 1968-April 1969 below 2 mg/l. Paulson *et al.* (1977), not unexpectedly, found a decrease in dissolved oxygen content (as low as 1 mg/l), along with an increase in coliform bacteria, with distance away from St. Louis Bay and into a dead-end canal system.

Prorocentrum minimum, which caused extensive blooms in Mississippi Sound and the Back Bay of Biloxi Bay in the winters of 1977 and 1981, appears to be an occasional component of the phytoplankton community in local waters of St. Louis Bay, but has not been reported in bloom proportions (Perry and McLelland, 1981).

REFERENCES: G-5

Bednar (1978a)
Christmas (1973)
Christmas and Eleuterius (1973)
Eleuterius (1976a)
Housley (1976)
Krutak (1978)
Lytle and Lytle (1985, 1990)
Pacheco *et al.* (1989b)
Paulson *et al.* (1977)
Perry and McLelland (1981b)
Turner and Rao (1990)

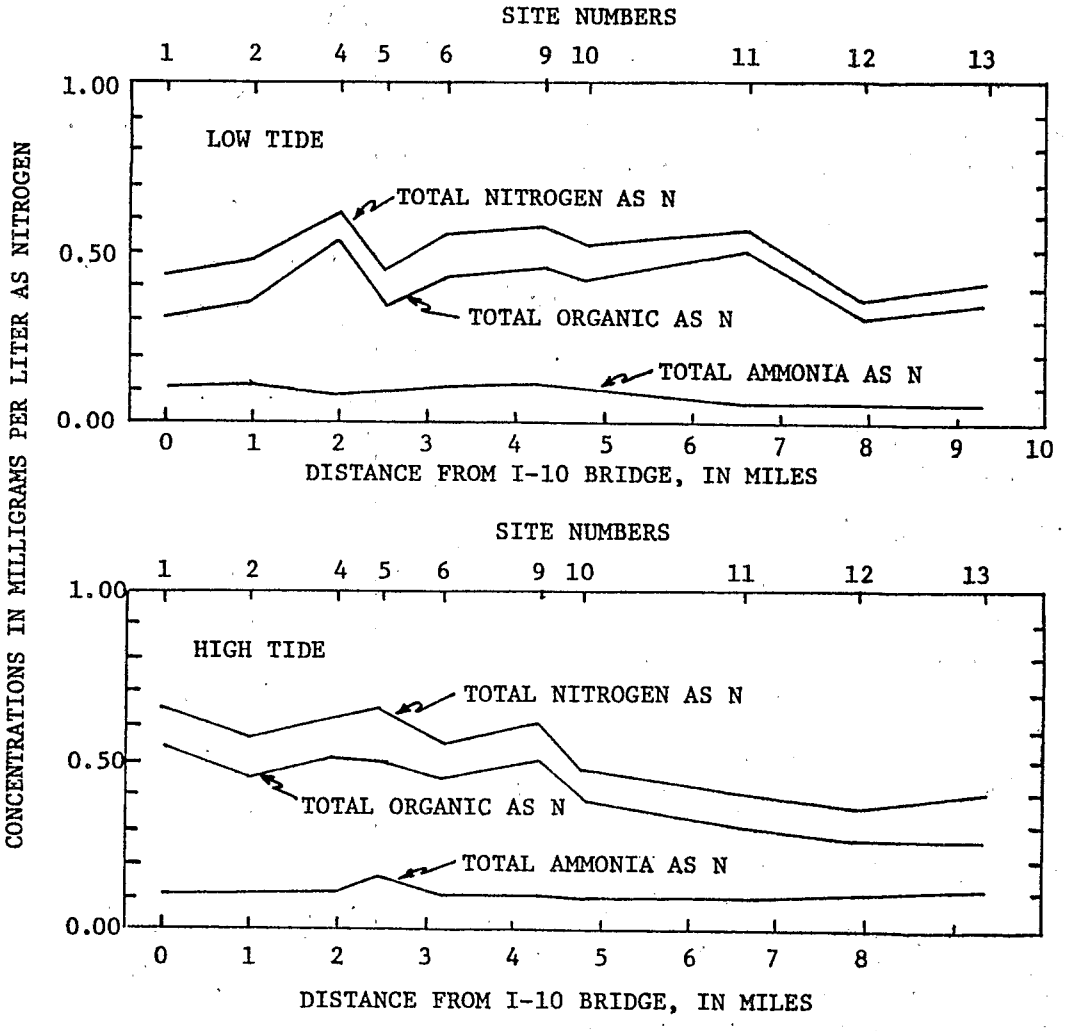


Figure M8. Profiles of total nitrogen, organic nitrogen, and ammonia nitrogen in Jourdan River and St. Louis Bay, July 12-13, 1977 (from Bednar, 1978a).

G-5.1 Mississippi inner continental shelf (outside Gulf Islands)

In a series of five cruises between March 1987 to March 1988 along three north-south transects across the Mississippi and Alabama continental shelf (Darnell, 1991), nitrate concentrations were uniformly low during the summer months but fairly high during the winter especially along the transect closest to the Chandeleur Islands and the outflow of the Mississippi River. Phosphate values were uniformly low during both seasons (see Section G-2.1).

Bottom water oxygen levels are not normally hypoxic along the inner and mid continental shelf off Mississippi, even in mid summer (Schroeder and Crozier, 1974 data for July 1973; SEAMAP data for June 1983 and 1985, Thompson and Bane, 1986a, Thompson *et al.*, 1988). SEAMAP data for the Mississippi inner shelf in the summer of 1984, however, indicated low oxygen bottom waters offshore of Mississippi Sound at Ship Island Pass and Cat Island Pass (*Marine Briefs*, August 1984, GCRL; Thompson and Bane, 1986b;R. Waller, GCRL, personal communication), where low oxygen has been noted in previous years. Trawl catches in the area of bottom water hypoxia were small or contained only catfish. For the station M-1 on the 20-m isobath in the Darnell (1991) study described above, bottom water dissolved oxygen concentration did not fall below 5 mg/l in any season. Based on the limited data set, there appears to be no widespread hypoxia on the Mississippi inner shelf nor any seasonally definable or recurring event.

Blooms of the toxic dinoflagellate, *Gonyaulax monilata*, occurred in coastal waters of the northern Gulf in August 1979, September 1980 and July 1981 (Perry *et al.*, 1979; Perry and McLelland, 1981a). The blooms were concentrated within Mississippi Sound, but also extended into the nearshore waters of the Gulf of Mexico. (See Section G-2.3.) High concentrations of *Trichodesmium erythrem* were found on the eastern side of the Mississippi River delta in the 5-yr study by Housley (1976).

REFERENCES: G-5.1

Anon. (1984)
Atwood (1981)
Brooks and Wolff (1991)
Churgin and Halminsta (1974)
Cons. Perm. Int. Exp. Mer (1936)
Darnell (1991)
El-Sayed *et al.* (1972)
EPA (1990)
Fanning *et al.* (1982)
Perry and McLelland (1981a)
Riley (1937)
Russell (1977)
Schroeder and Crozier (1974)
Schroeder *et al.* (1988)
Shaw *et al.* (1982)
Stuntz *et al.* (N.D.)
Thompson and Bane (1986a,b)
Thompson and Leming (1978)
Thompson *et al.* (1988)
Turner and Rabalais (1991a,b)

LOUISIANA

Louisiana estuaries are experiencing some of the impacts of nutrient enrichment and eutrophication. Some examples are: 1) the Louisiana Depts. of Wildlife and Fisheries and Environmental Quality frequently receive reports of estuarine fish kills that they ascribe to low oxygen conditions that are likely the result of high algal production (see Table L1 below), 2) chlorophyll *a* concentrations in several coastal water bodies frequently exceed 50 µg/l, which is high (R.E. Turner, personal communication), 3) fertilizer use in Louisiana has risen dramatically since the 1940s (Figure L1) and has almost certainly not stayed where applied, and 4) the dissolved silica:nitrate-N atomic ratio fluctuates between 2 and 0.5 in many estuaries, indicating potential chemical control of diatom abundance (R.E. Turner, personal communication).

Although an in-depth analysis of the long-term trends in water quality of the Mississippi River has been completed (Turner and Rabalais, 1991a), data for Louisiana estuaries remain unanalyzed. Data are on file with the U.S. Corps of Engineers (early 1960s), the Louisiana Dept. of Wildlife and Fisheries (part of their estuarine inventories) (Louisiana Wild Life and Fisheries Commission, 1971; Barrett *et al.*, 1978), the U.S. Geological Survey water quality network, and the Louisiana Dept. of Environmental Quality. Larger towns, such as Houma, monitor water quality from their drinking water intake systems. Data for fertilizer consumption is available by parish from records collected by the U.S. Dept. of Agriculture. The water quality in southern Barataria Bay and Terrebonne Bay may be affected by changes in Mississippi River water quality because of its relatively large freshwater inflow and evidence that salinity in Barataria Bay is inversely related to river discharge (Wiseman and Swenson, 1987; Wiseman *et al.*, 1990). However, the upper end of most of Louisiana's estuaries receives a significant source of nutrients from agricultural and urban runoff. There is also sewage discharge from numerous small camps and towns.

GENERAL REFERENCES: LOUISIANA

ASIWPCA (1984)
Basta and Bower (1985)
Burrage (1989)
Culliton and Blackwell (1989)
Day and Culley (1979)
Ehler and Basta (1985)
EPA (1974, 1978)
Jones *et al.* (973)
Louis. Wild Life & Fish. Comm. (1971)
Main *et al.* (1987)
NOAA/EPA Team (1990)
Pechmann *et al.* (1986)
Turner and Rao (1990)
Wiseman and Swenson (1990)

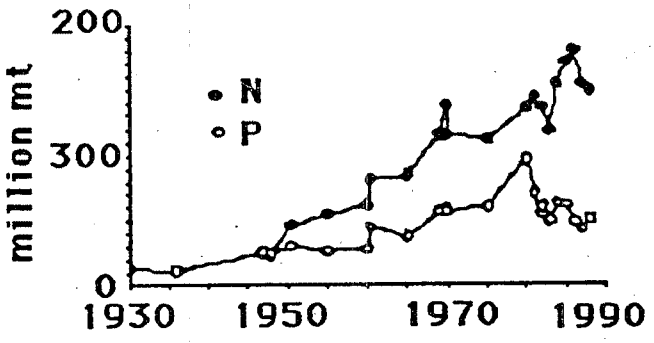


Figure L1. Fertilizer consumption in Louisiana for selected years (R.E. Turner, unpublished data).

G-6 Pearl River

In the Cooperative Gulf of Mexico Estuarine Inventory, limited samples were collected in the Pearl River. Lowest nitrate levels recorded were 0.16 to a high of 2.16 µg-at/l. Lowest nitrate levels occurred in late spring and early summer. Inorganic phosphate levels were lowest in winter and spring (0.5 µg-at/l) with a high of 6.8 µg-at/l recorded at a nearshore station in July (Christmas and Eleuterius, 1973). Mean dissolved oxygen levels were 9.8 and 9.4 mg/l, respectively. The surface and bottom concentrations were usually similar and differences rarely exceeded 1 mg/l. From April 1968 to April 1969 (Christmas, 1973), no dissolved oxygen values below 6 mg/l (three stations sampled monthly for a year) were recorded.

Table L1. Summary of NOAA Fish Kill Inventory Data for Louisiana (draft data base, 1991; J.A. Lowe, personal communication; see section on Data Sources).

AREA County	Records per County	Cause Low DO	Cause Eutrophication	Cause Red Tide	Cause Nutrient	Cause Unknown or Unspecified
PONTCHARTRAIN						
Livingston	5	5	0	0	0	0
Orleans	9	5	1	0	0	2
St. Tammany	64	31	0	0	0	12
Tangipohoa	16	1	0	0	0	4
BRETON/CHANDELEUR						
St. Bernard	24	0	0	0	0	14
MISSISSIPPI RIVER						
Plaquemines	23	6	0	0	2	0
BARATARIA						
Jefferson	29	4	0	0	0	3
Lafourche	36	10	5	0	0	0
St. Charles	20	5	0	0	0	1
TERREBONNE						
Terrebonne	53	19	5	0	1	1
ATCHAFALAYA						
Iberia	40	6	0	0	0	0
St. Mary	18	9	0	0	0	0
Vermilion	0	0	0	0	0	0
CALCASIEU						
Calcasieu	8	3	0	0	0	1
Cameron	3	1	0	0	0	0

REFERENCES: G-6

Christmas (1973)
Christmas and Eleuterius (1973)
Eleuterius (1976a)
Gunning and Suttkus (1986)
Lytle and Lytle (1985)
Pacheco *et al.* (1989b)
Turner and Rao (1990)

G-7 Lakes Pontchartrain/Maurepas

Lake Pontchartrain is a large (1630 km^2), shallow, oligohaline (salinity generally less than 5 ppt) water body located immediately north of New Orleans. Highest salinities (usually 7-11 ppt) occur during dry, late-summer and autumn months in southern and eastern parts of the lake. It is part of an estuarine lake and bay system in which water enters from the Gulf of Mexico via the Rigolets, Chef Menteur Pass, and the Mississippi River Gulf Outlet (MRGO, completed in 1962). The MRGO connects to the open Gulf of Mexico and has facilitated mixing of Gulf water with that of Lake Pontchartrain (Orvos, 1978). Poirrier (1978) documented an increase in the salinity in the eastern section of the estuary. The expected increase in salinity from the construction of the MRGO was 5 ppt, but the actual increase was 2 ppt (Sikora and Kjerfve, 1985); freshwater discharge is the most important factor controlling salinity variations in Lake Pontchartrain. Lake

circulation is wind-driven, the water column is usually well-mixed and the 11 cm tides are primarily diurnal (Chuang and Swenson, 1981). The flushing time is about 60 days (Swenson, 1980). Freshwater enters through several tributaries on the northern shore and through Lake Maurepas on the west where combined annual flow amounts to about 5 % of the volume of the tidal prism entering through tidal passes (Swenson, 1981). The Amite, Blind, Tickfaw and Natalbany Rivers flow into Lake Maurepas. The Bonnet Carré Spillway, located on the western end of the lake debouches Mississippi River water into the lake when opened occasionally to relieve flooding pressure in New Orleans, *e.g.*, in 1937, 1945, 1950, 1973, 1975, 1979 and 1983. (See comments in Section G-10 regarding freshwater diversions from the Mississippi River.) Pass Manchac, rain and northshore rivers account for the bulk of freshwater to Lake Pontchartrain (Table L2).

Table L2. Major freshwater sources of Lake Pontchartrain (taken from Craig and Day, 1977).

Source	10^9 m^3yr^{-1}	% Water Supply
Pass Manchac	5.10	54%
Tangipahoa River	1.53	16%
Rain-Evaporation on Lake	1.42	15%
Tchefuncte River	0.72	7.6%
Bayous Lacombe and Liberty	0.34	3.6%
New Orleans Metropolitan Runoff	0.4	4.2%
TOTAL	9.51	

The Lake Pontchartrain Basin Foundation was established by the State Legislature in July 1989 to "restore and preserve the environmental and ecological balance" of the lake basin. Besides its primary focus, the Foundation has also initiated an Information Resources Project to inventory and catalog the source, location, description, and accessibility of information application to the protection, restoration, and maintenance of the environmental quality of the basin (S. Gorin, personal communication).

Over the past 60 years, human population in this drainage area has risen dramatically. While all sections have shown growth, a large percentage of the residential development incurred by the increase has been located in reclaimed wetlands adjacent to the lake. As a consequence of the rapid development, many of the natural streams and drainage canals which bring fresh water into Lake Pontchartrain now also serve as conduits for domestic wastes and fertilizer residues rich in nitrogen and phosphorus. These inputs have caused a decline in water quality throughout the lake and are responsible for increased incidence of eutrophic conditions (Craig and Day, 1977). A comprehensive study (Stone, 1980) concluded that 1) average turbidity has increased by about 50 % since the early 1950s, 2) nutrients (phosphorus and nitrogen) are significantly higher in areas fringing and surrounding the lake such as in Lake Maurepas, in the marshes and along the southeastern shoreline just off New Orleans, 3) total phosphorus loading to Lake Pontchartrain has increased by about 70 % since the 1950s (Figure L2).

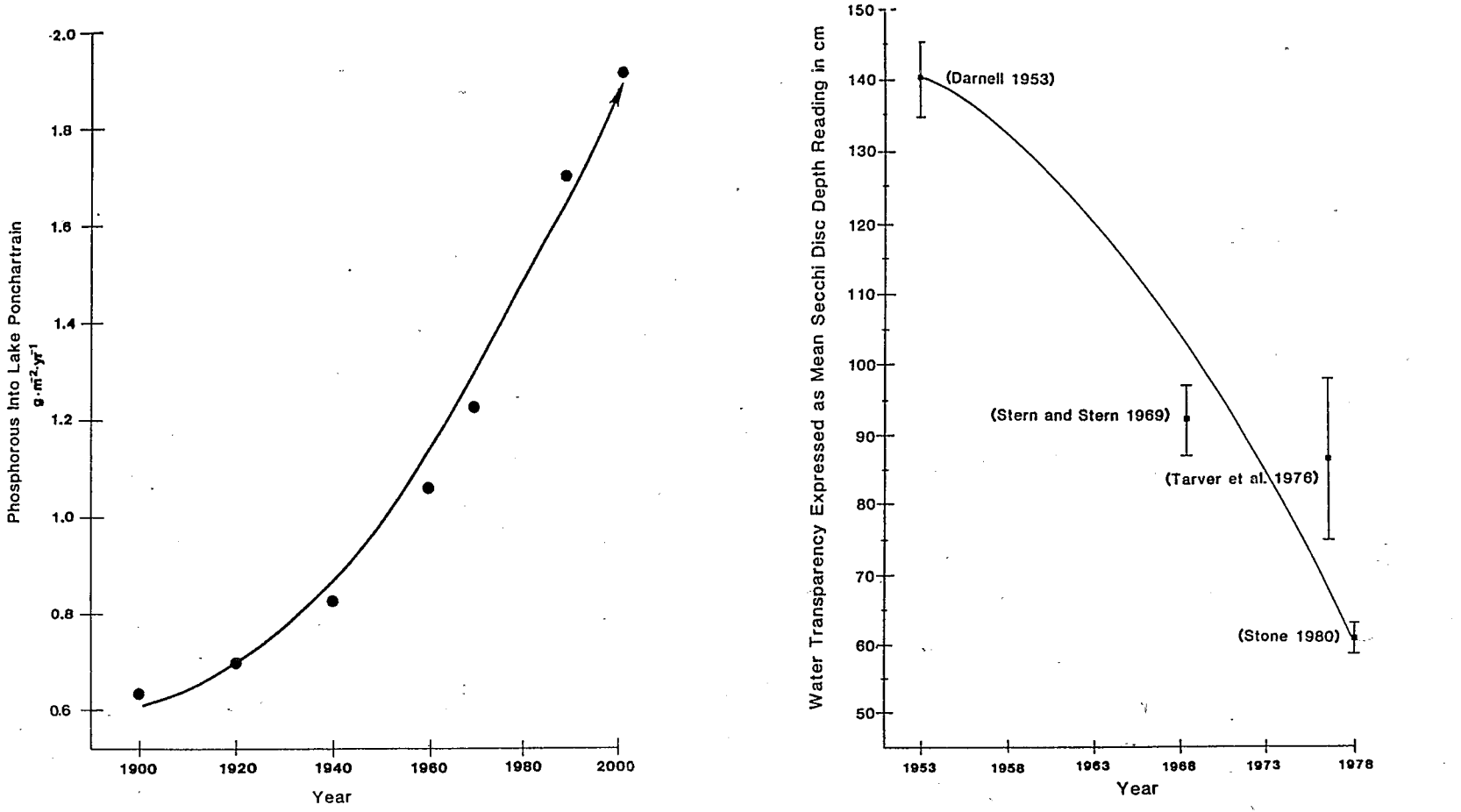


Figure L2. Change in phosphorus loading into Lake Pontchartrain as a function of time (left panel) and water transparency expressed as mean Secchi disk reading in cm as a function of time (right panel) (from Stone, 1980).

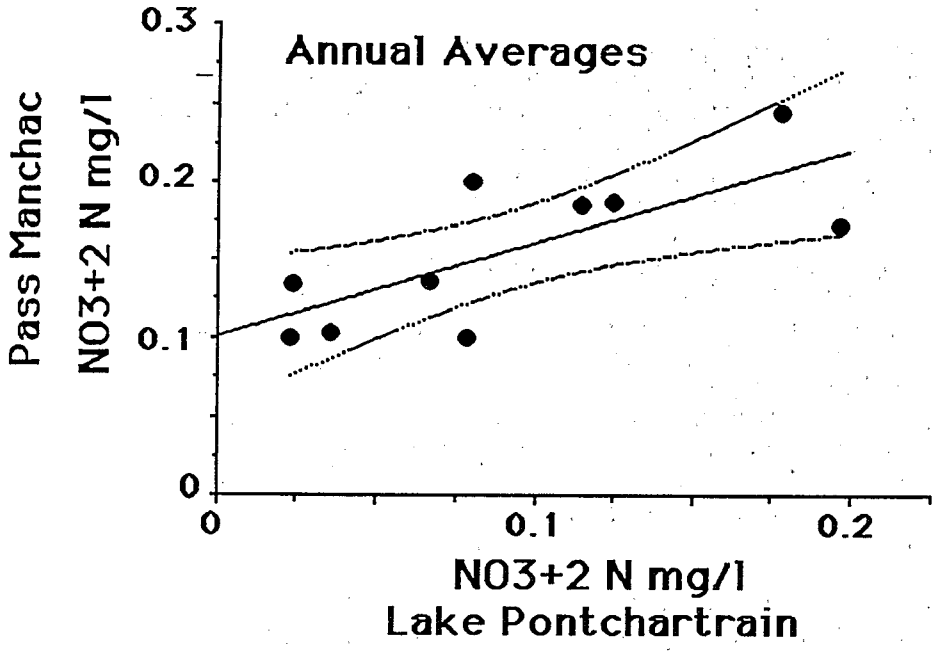
Lake Pontchartrain is not uniformly eutrophic (Craig and Day, 1977; Stone, 1980; and data in Tarver and Dugas, 1973). The most affected area is the south shore adjacent to the metropolitan area. This area is characterized by high nutrient and coliform levels and pollution indicative species. The southwestern part of the lake from Jefferson Parish to Pass Manchac also seems to be eutrophic. The northshore and eastern end of the Lake seem to be fairly clean because of low nutrient input and more rigorous tidal flushing. Thus, there is a gradient in eutrophic conditions from south and west to north and east. This gradient is due to differential inputs of nutrients and rates of flushing. Data for Lake Maurepas (Tarver and Dugas, 1973) show somewhat elevated means for nitrite and nitrate above that of Lake Pontchartrain. Stern and Stern (1968) found that the discharge of storm water into Lake Pontchartrain affects the water quality and increases the coliform count. Phosphates, nitrates, and nitrites brought to the lake from storm runoff increase the phytoplankton and bacterial abundances.

A study of the nutrient and carbon geochemistry in the lake (1977-1979) was conducted by Stoessell (in Stone, 1980). He found that seasonal trends were fairly consistent throughout the lake except for the area bordering the southern shoreline, which was being contaminated by New Orleans' waste waters. Maximum concentrations of inorganic nutrients, organic carbon fractions, and dissolved phosphorus usually occurred during the spring; minimum concentrations occurred in the summer. Levels of inorganic nitrogen fractions and undissolved organic carbon commonly remained low during the fall. Concentrations of phosphate, silicate, dissolved organic carbon and dissolved P tended to increase in the fall. Higher than average concentrations of phosphate and dissolved phosphorus occurred on the south side of the lake. Inorganic carbon content increased spatially from west to east and southeast across the lake. High concentrations in the spring for inorganic nutrients, dissolved phosphorus, and the organic carbon fractions was likely related to maximum river input and to stream flooding through adjacent swamps and marshes into the lake. Assimilation of inorganic nutrients by organisms followed in the summer when concentrations were lower; increased levels of silicate in the fall followed the death and dissolution of diatoms. Higher phosphate and dissolved phosphorus contents in the fall were probably due to nutrient release from suspended sediments. Continued low values of inorganic nitrogen fractions in the fall implies that nitrogen is growth limiting for some lake organisms.

While there is documentation for an increase in phosphorus loading to Lake Pontchartrain, the picture for nitrate is not as clear. Analysis of a long-term data set (R.E. Turner, personal communication) revealed that the nitrate concentrations in Pass Manchac and Lake Pontchartrain were very similar and that the concentrations were on a general decline from 1975 to present (Figure L3).

A study conducted by the Louisiana Dept. of Environmental Quality (Schurtz and St. Pé, 1984) examined the environmental conditions in Lake Pontchartrain with regards to water quality. The study was concerned primarily with the reports of "dead zones" in the lake and the implications of anthropogenic or toxic substances being the cause (see also below). Findings from the study indicated the lake, particularly the southern portion, chronically receives the input of a broad spectrum of anthropogenic contaminants associated with urban, domestic and commercial development. Most significantly impacted are the nearshore areas (within one mile of shore) adjacent to the mouths of major drainage and navigation canals. Inputs of contaminants are primarily through stormwater runoff and sewerage effluents that enter the drainage canals and are subsequently pumped to the lake. Contamination levels are very much higher adjacent to the urbanized southshore in Orleans and Jefferson Parishes, with regard to levels of nutrients and oxygen-demanding wastes from sewage effluents and chemical contaminants from urban runoff and industrial development.

Another environmental factor in Lake Pontchartrain is hydraulic dredging for the clams *Rangia cuneata*. Dredging began around 1933 and increased to 1.5 million cubic yards in 1955 and to 3.8 million cubic yards by 1968. Dredging operations ceased in spring 1990 following extensive legal



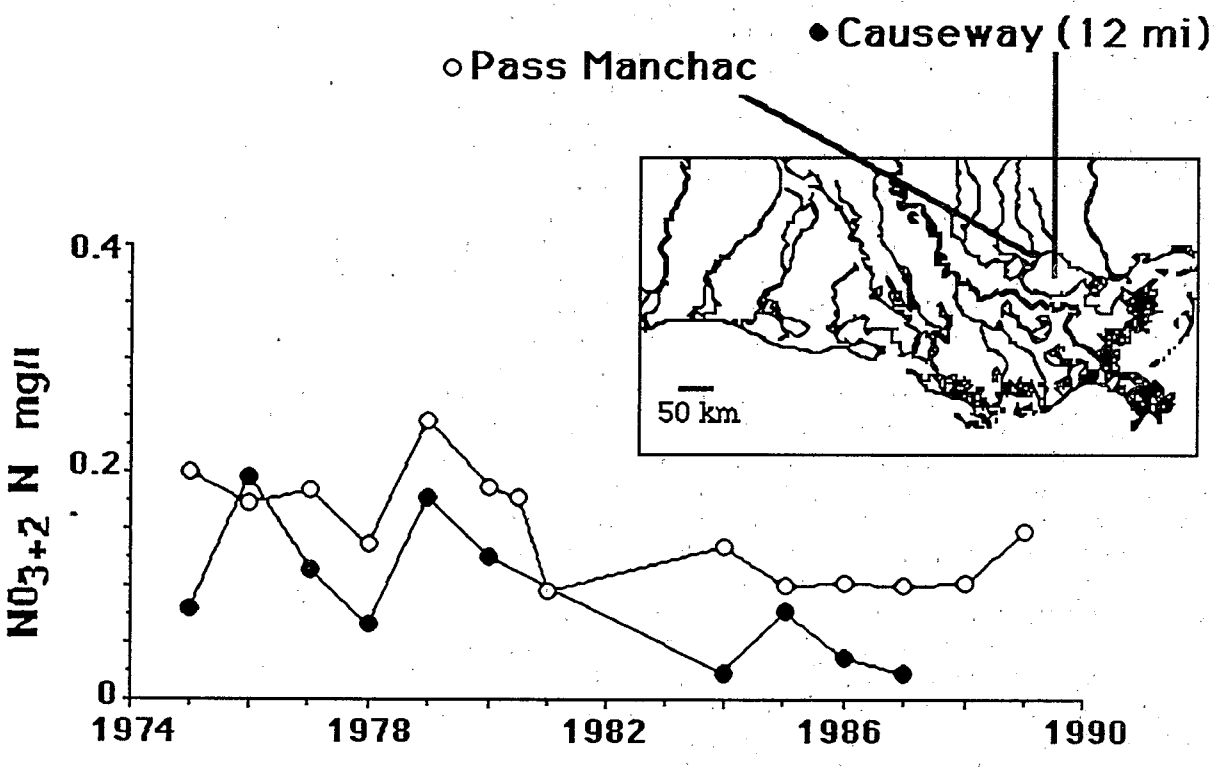


Figure L3. Comparison of nitrate concentrations in Pass Manchac and Lake Pontchartrain (upper panel) and change in nitrate concentration through time at Pass Manchac and at a Causeway station in mid Lake Pontchartrain (R.E. Turner, unpublished data).

proceedings. Before 1990, dredges were restricted to about 44 % of the lake, where they may overturn that area in 1.4 to 2.4 years (Stone, 1980). The apparent effects of this dredging on the benthic fauna, which may be considerable, include the loss of larger size classes of *R. cuneata*, benthic infaunal species and biomass changes, low sediment bulk density, and lower soil carbon content. Of particular importance here is the observation that the average sediment bulk density in surface samples in 1978 approached that of fluid mud (Sikora *et al.*, 1981).

Short-term and long-term changes in estuarine turbidity influence phytoplankton production, pelagic food chain dynamics, and benthic community development, yet continuous long-term data of estuarine light quality are rare. Two common management issues related to estuarine light conditions in Lake Pontchartrain are eutrophication and dredging. The former may reduce light penetration through increased phytoplankton biomass and species shifts; the latter may have the same effect through resuspension of bottom sediments. Either dredging or eutrophication may result in the decline of benthic macrophytes, for example, by reducing light penetration (*e.g.*, Davis and Carey, 1981). There was a net decline in the abundance of two submerged macrophytes (*Ruppia maritima* and *Vallisneria americana*) in Lake Pontchartrain from 1954 to 1973 (Turner *et al.*, 1980).

A long-term data set of Secchi disk depth (SDD) measurements taken between 1953 and 1978 have been analyzed (Turner and Dow, unpubl. data). SDD was significantly lower in 1978 than in the 1953-1955 period. Possible explanations for this change are eutrophication, opening of the Bonnet Carre spillway, dredging and variations in climatic wind patterns. Phytoplankton pigment concentrations were too low to reduce the light penetration and wind speeds were no higher in 1978 than in 1953-1955. The 1979 diversion of Mississippi River water introduced a water volume that was "short-lived and affected about two-thirds of the entire lake area" (Swenson, 1981), and SDD measurements by Tarver and Savoie (1976a,b) during the 1973 diversion did not appear to be significantly higher for the same wind speed immediately after the spillway closed than in the previous or following years. The consequences of dredging remain a probable cause. The benthic biota of the lake clearly changed between the 1950s and 1978 (Sikora *et al.*, 1981) with a reduction in sediment organic content, reduction of larger benthic invertebrates, and changes in sediment bulk density. The types of meiofaunal organisms also reflects the fluid nature of the sediments (Fleeger *et al.*, 1983). These effects are likely agents for allowing the suspended sediments to be scoured into the water column with greater efficiency during normal wind conditions (Turner and Dow, unpubl. data). A prudent test of the hypotheses presented here would be to re-examine the benthic and water column community over the next several years to document if the conditions reverse, and, if so, how quickly.

During some years, when rainfall and Mississippi River flow are low, a more saline bottom water layer occurs offshore from New Orleans, which is related to movement of higher salinity waters from the MRGO. The recurring hypoxic or anoxic bottom waters in Lake Pontchartrain are more likely to be present east of the causeway. The problem is most severe and persistent in the southeastern portion of the lake. On the other hand, those areas closest to canal outlets along the southern shore, both east and west of the causeway also experience problems related to freshwater runoff and pollutant loadings from urban runoff. Outfall canals discharge storm water low in dissolved oxygen and high in organic matter, nutrients, sewage and other pollutants (Poirrier, 1978; Schurtz and St. Pé, 1984). While Stern *et al.* (1968) examined only surface water samples in their study, dissolved oxygen concentrations were very low (near 0.5 mg/l) at stations along the southern shore following heavy rains. Fish kills were associated with these low oxygen values. Heavy rainfall, followed by the admixing of storm and sewer runoff into the lake, contributed to the lowering of the dissolved oxygen content. In years of heavy river flow or rainfall, there is likely more flushing of the system than when outflow is low and the limited tidal mixing does not facilitate breakdown of haloclines developed along the southeastern shore.

In 1982 rainfall and Mississippi River flow were low. Hypoxic and anoxic conditions developed in part of the lake (Figures L4 and L5). In 1983 and 1984, both rainfall and Mississippi River flow were high, and the severely oxygen-depleted waters did not develop in summer. Low oxygen conditions have also been documented in Lake Pontchartrain in the summers of 1976, 1980 (Poirrier, 1978; Windham *et al.*, 1980).

The Schurtz and St. Pé (1984) study concluded that large areas in the southeastern and east central Lake Pontchartrain are subject to severe dissolved oxygen depletions in the lower water column in the warm water months. These depletions dramatically affect the numbers, survival and distribution of organisms confined to the lower water column and bottom sediments. The most noticeable effects are crab kills (*e.g.*, Windham *et al.*, 1980). The anoxic conditions result from non-mixing characteristics brought by pronounced salinity stratification during summer months, particularly in years exhibiting normal or below normal rainfall. The cause of seasonal salinity stratification is the intrusion of highly saline waters from the Gulf of Mexico via the MRGO. Examination of biological samples did not indicate the occurrence of "dead zones" in the Lake, but some areas have been demonstrated to exhibit lower than expected species diversity. The causes for depressed diversity were not attributed to toxic contamination but rather to environmental stresses related to salinity stratification and oxygen depletion.

Many of the studies described above also included the environs of Lake Maurepas, a small (236 km^2), shallow (average 2 m deep) lake that is minimally affected by astronomic tides. There are occasional vertical water quality variations in the lake due primarily to the influx of brackish water from Lake Pontchartrain in contrast to the freshwater inflow from tributary streams on the west and north. Dissolved oxygen values for the entire water column in March and July 1970, however, did not fall below 5 mg/l (Shampine, 1971). On the other hand, G. Childers (personal communication) indicated that there were isolated instances of low oxygen in Lake Maurepas. A study of the microbiological and chemical quality of Lake Maurepas was conducted from July 1986 to June 1987 (Bancroft *et al.*, 1988). They concluded that all concentrations of bacterial indicators of pollution were found to be greater than those observed in 1983-1984 (Childers, 1985; cited in Bancroft *et al.*, 1988), indicating a significant decrease in the water quality of Lake Maurepas.

Two freshwater sources to the Maurepas-Pontchartrain system are listed by the Louis. Dept. of Environmental Quality (1990) as "Waterbodies Under Advisories": 1) Bayou Trepagnier in the southwest corner of Lake Pontchartrain near the Bonnet Carre spillway, which is heavily contaminated with organic compounds, and 2) the Tangipahoa River, which flows into the northwest corner of Lake Pontchartrain, and has high levels of bacterial pollution.

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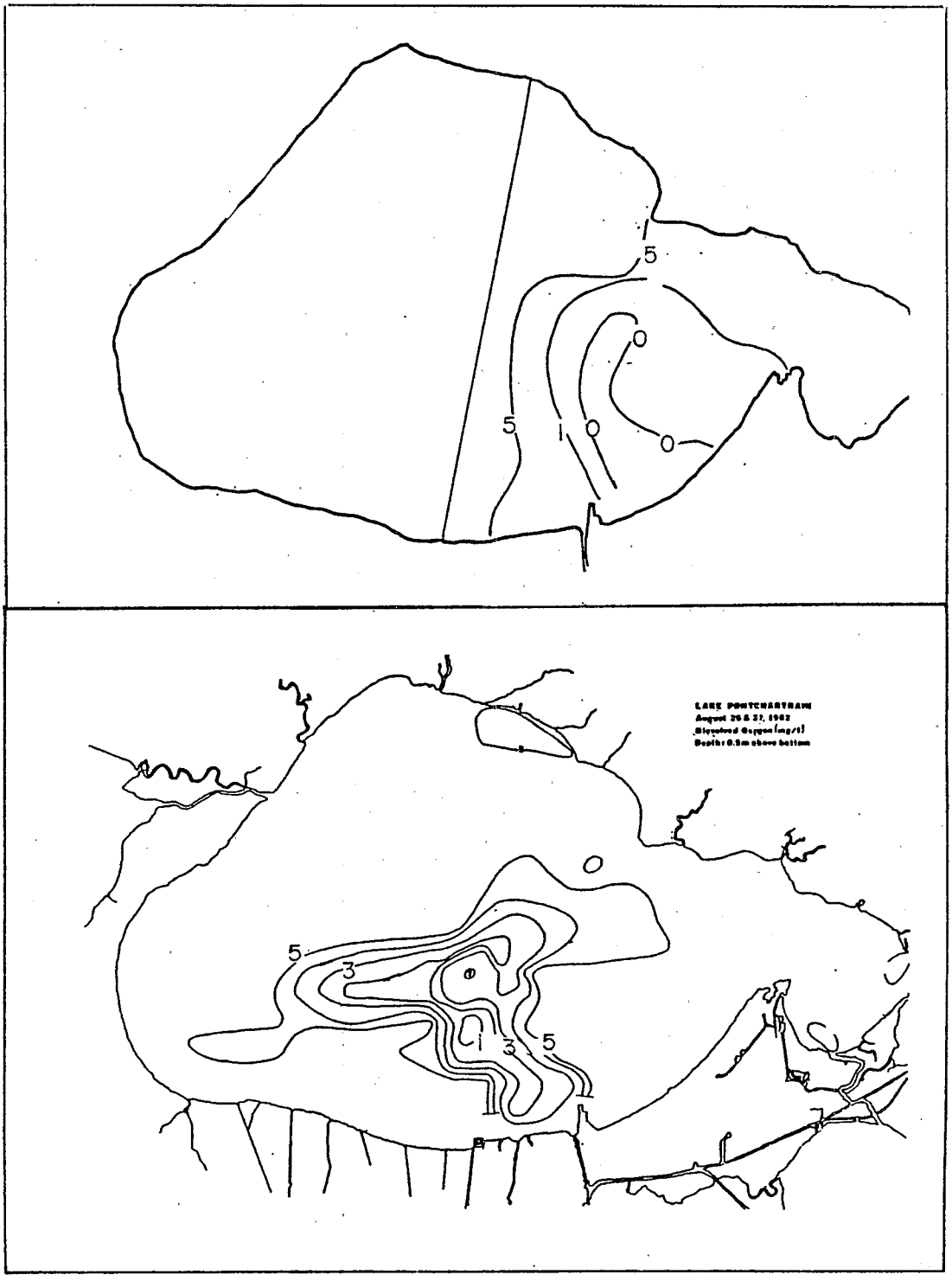

Figure L4. Dissolved oxygen isopleths (mg/l) in lower water column (0.5 m above bottom) for Lake Pontchartrain, August 28-29, 1980 (upper panel) and August 26-27, 1982 (lower panel) (from Schurtz and St. Pé, 1984).

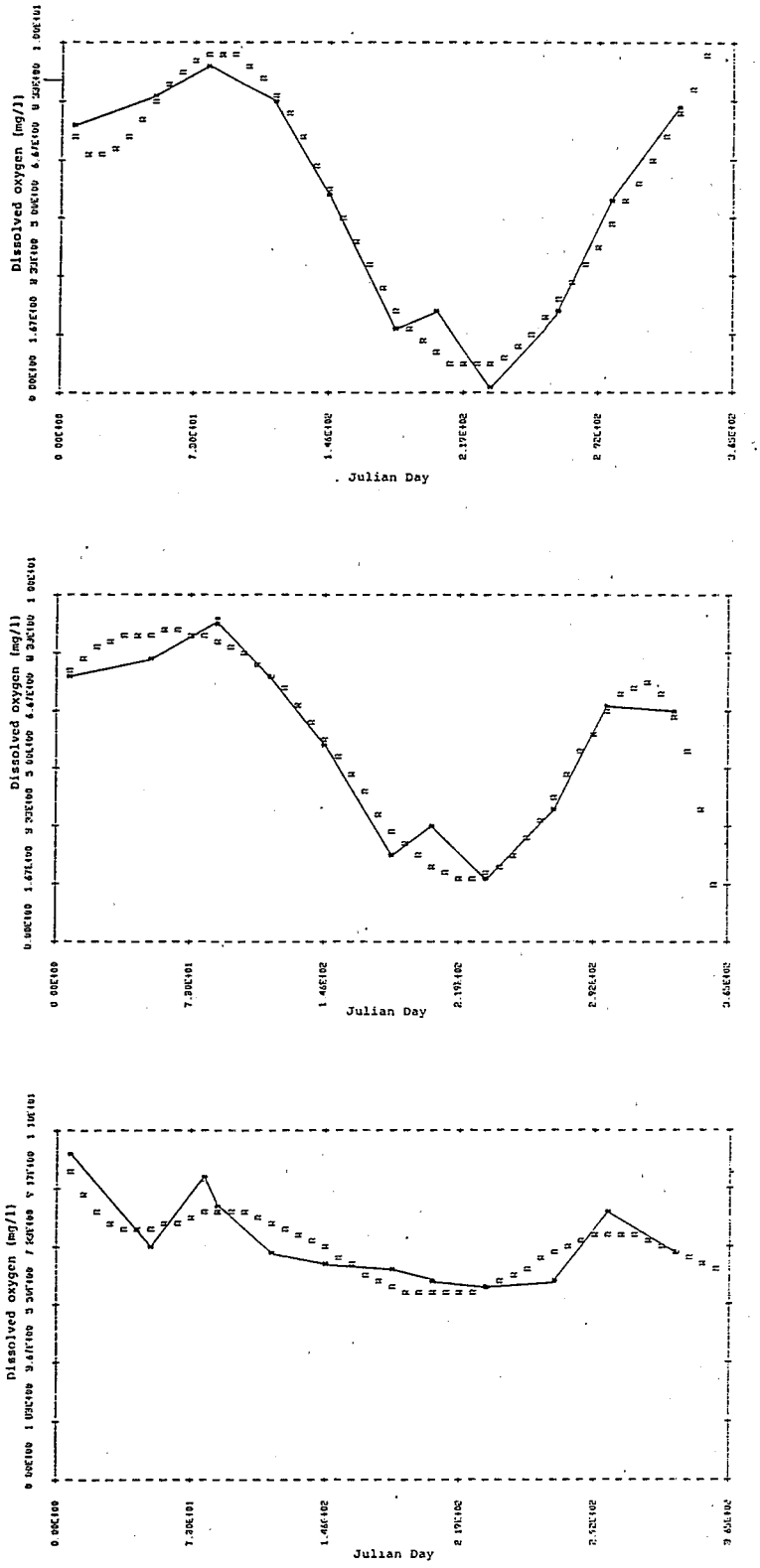

Figure L5. Dissolved oxygen concentration in near-bottom water of Lake Pontchartrain in 1982 at three stations (ordered by decreasing intensity of hypoxia/anoxia) (from Rabalais *et al.*, 1985).

G-7.1 Louisiana inner continental shelf

The largest, most severe, and most persistent zone of hypoxia (operationally defined as oxygen levels of <2 mg/l, based on effects on local biota) in the U.S. coastal waters is found in the northern Gulf of Mexico on the continental shelf off Louisiana (Rabalais *et al.*, 1991a). The zones of hypoxic bottom water in the northern Gulf of Mexico may cover 8000 to 9500 km^2 during mid-summer on the inner continental shelf, from the Mississippi River delta onto the upper Texas coast (see Figure 12). Critically depressed dissolved oxygen conditions may occur in near-bottom waters nearly continuously from April through October on the inner shelf off southeastern (Figure L6) and southwestern Louisiana (Turner and Allen, 1982a; Pokryfki and Randall, 1987). The zones of hypoxia are continuous, widespread, and persistent, and may include up to 40 % of the water column in 10-30 m water depth. In mid-summer 1985, the low oxygen zone was most intense and extensive on the southeastern Louisiana continental shelf and westward to Marsh Island (Figure L7). The band narrowed to the west and was confined to 9 to 12 m water depth. The configuration of the area of hypoxia in mid-summer 1986 differed from that in 1985 in that it was disjunct and larger off southwestern Louisiana and smaller off southeastern Louisiana. The configuration in 1987, 1989, 1990, and 1991 was similar to that of 1986, with disjunct areas on the southeastern and southwestern parts of the coast. Bottom water hypoxia is considered to be more patchy in distribution and ephemeral in duration on the southwestern Louisiana shelf. This is supported by data from the West Hackberry Strategic Petroleum Reserve Program monitoring study (DeRouen *et al.*, 1982, 1983; Hann *et al.*, 1984a,b).

The Mississippi River system discharge creates strongly stratified nearshore waters, which flow westward and southward along the Louisiana and Texas coasts. Mean flow reverses in late spring and the flow actually reverses and flows against the mean wind at some locations along the Louisiana coast (Cochran and Kelly, 1986, cited in Rabalais *et al.*, 1991a). The reversal retains freshwater on the mid to inner shelf. Stratification, as a rule, is strongest in spring, during high runoff, and summer, when wind mixing is weak and solar heating is strong. The salinity of surface waters on the nearshore continental shelf closely tracks the flow of the Mississippi River (Geyer, 1950, 1955). The Mississippi and Atchafalaya River effluents and their influence on the surface salinity distributions can be identified in shelfwide cruises during mid summer and at other times during the year. Oxygen-deficient bottom waters often form beneath a strong salinity-controlled pycnocline at 10 to 15 m water depth. Low oxygen conditions in bottom waters on the Louisiana shelf are coincident with strong density stratification (Figure L8). The implication is that oxygen-depletion is supported and maintained by strong density differences.

The principal source of organic matter in the bottom waters of the northern Gulf of Mexico is probably from phytoplankton production in surface waters. The organic material discharged by the Mississippi River as a source of oxidizable organic material has been largely discounted (Turner and Allen, 1982a). The disjunct zones of hypoxia in 1986, 1987, 1990 and 1991 mirrored the surface salinity field and surface phytoplankton biomass concentrations that resulted from the Mississippi and Atchafalaya River freshwater inputs (Figure L9). Irrespective of the source, the amount of phytoplankton biomass in the bottom waters across the Louisiana inner and mid continental shelf is high, often exceeding 10 µg/l total pigments, and a high percentage is composed of phaeopigments (*i.e.*, degradation products of chlorophyll). There are some indications of the coupling of surface production with the accumulation of organic material in the bottom waters (Figure L10). The amount of material that reaches the bottom should be high for several reasons: 1) primary production in these waters is high (>300 $gC/m^2/yr$, Sklar and Turner, 1981), 2) Suess' (1980) empirically-derived formula relating phytoplankton production in surface waters to the amount of material falling into sediments traps at depths predicts that 50 % or more of the surface production reaches the bottom in depths equal to that in hypoxia occurs.

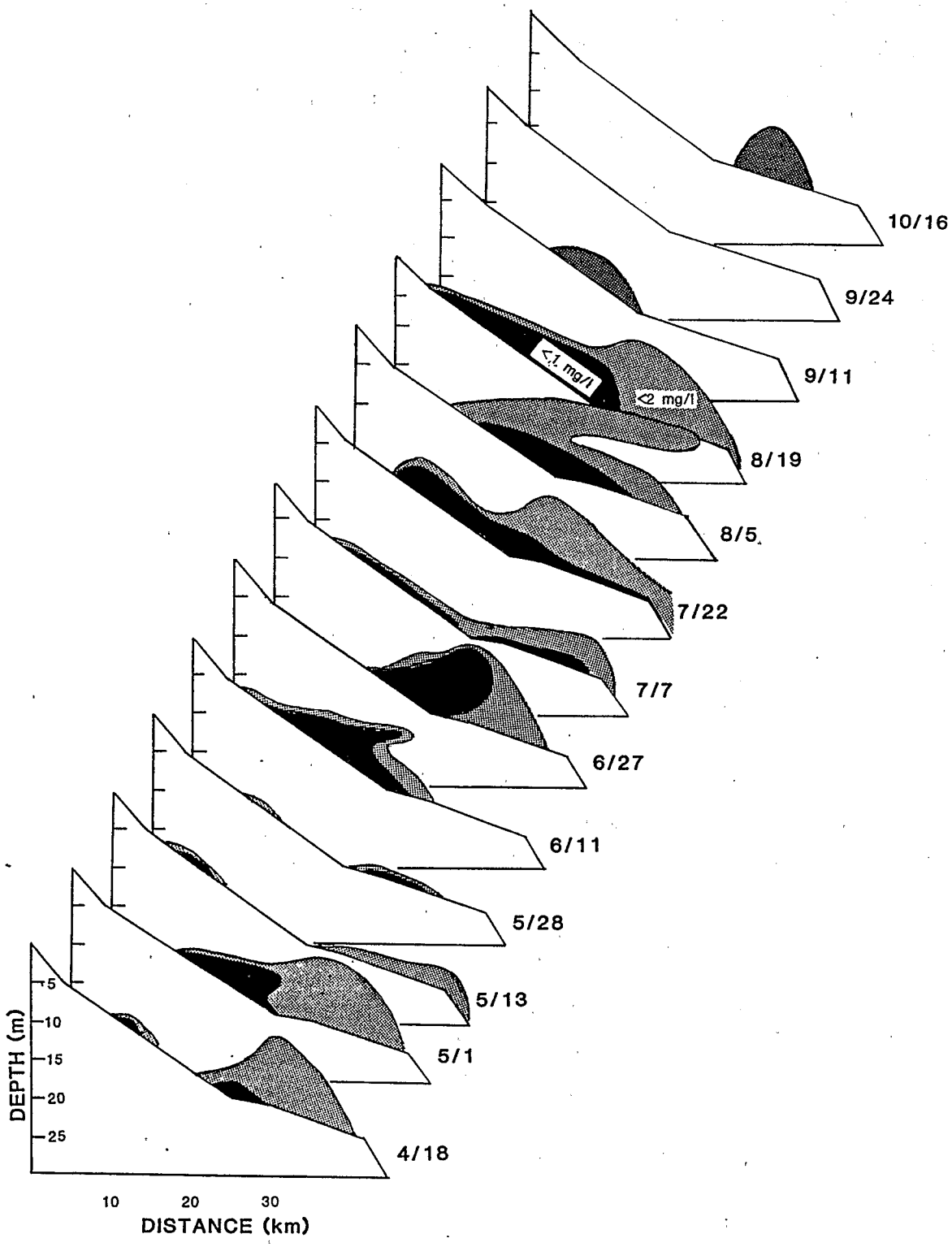

Figure L6. Isopleths for 2 mg/l and 1 mg/l dissolved oxygen along Transect C offshore of Terrebonne Bay for the dates indicated in 1986 (Rabalais *et al.*, unpublished data).

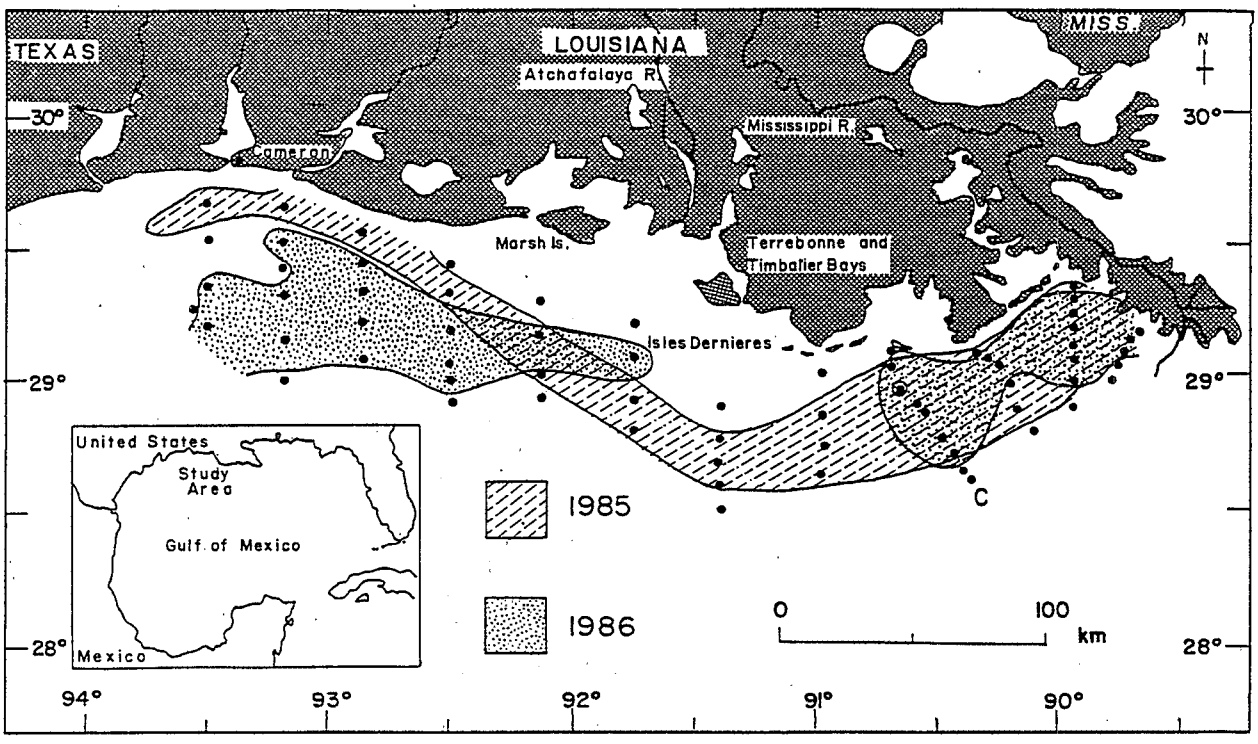

Figure L7. Distribution of hypoxic (<2 mg/l) bottom waters on the Louisiana continental shelf in July of 1985 and 1986 (from Rabalais *et al.*, 1991a).

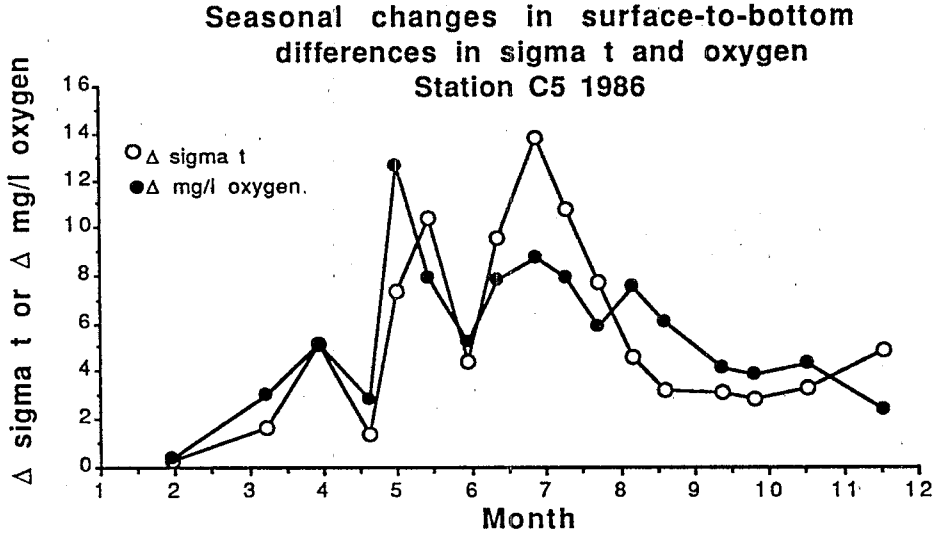

Figure L8. Differences in surface to bottom water values for sigma t and dissolved oxygen concentration by month for Station C5 during 1986 (from Rabalais *et al.*, 1991a).

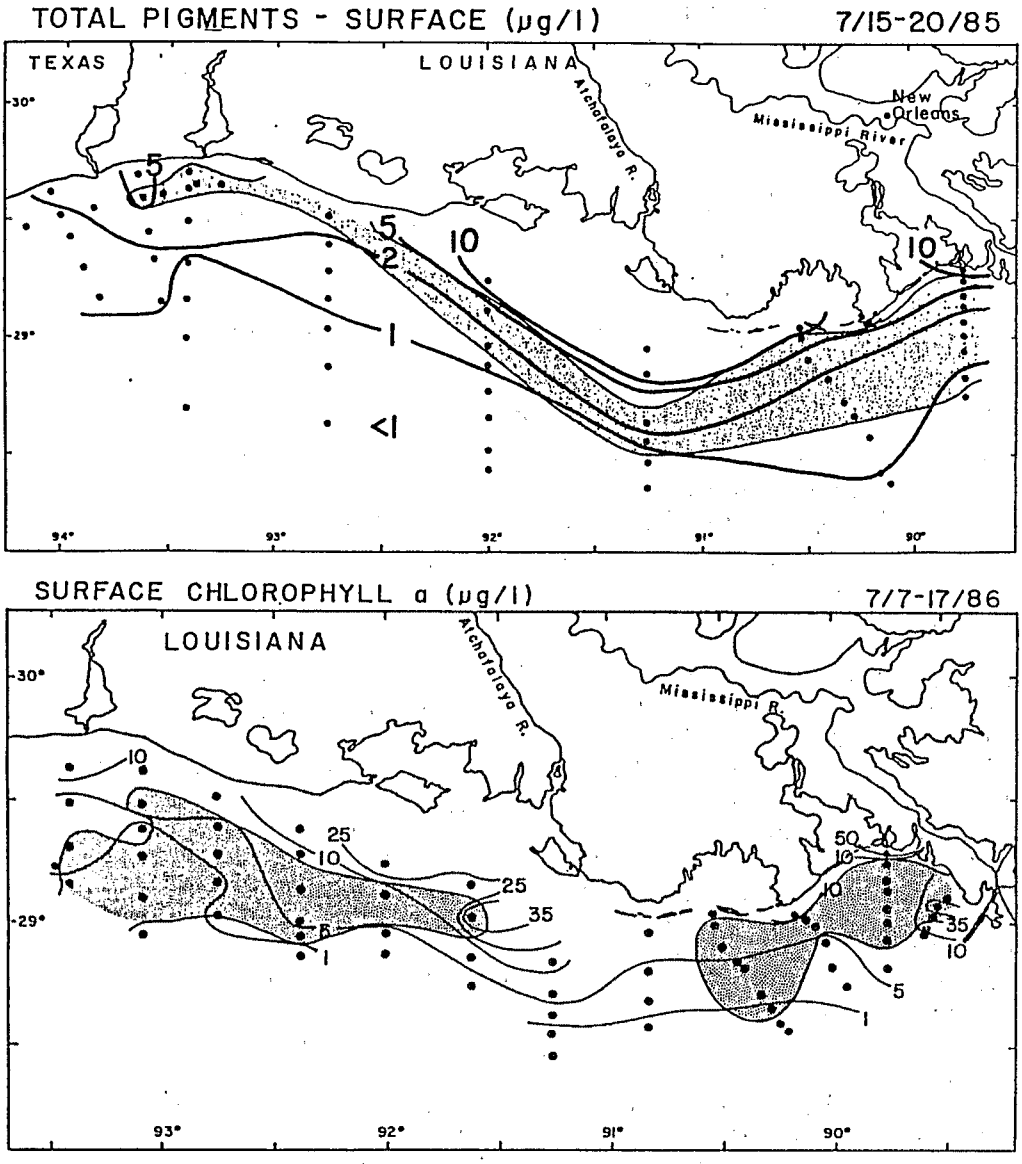

Figure L9. Shelfwide contours of surface water total pigment concentrations (µg/l) across the Louisiana continental shelf in July 1985 (upper panel); similar distributions of surface water chlorophyll *a* concentration (µg/l) in July 1986 (Rabalais *et al.*, 1991a).

The implications of long-term changes in the water quality of the Mississippi River were outlined in Section G-9. Long-term increases in nutrient concentrations in coastal waters have also been documented elsewhere in the world (Rabalais *et al.*, 1991a). Eutrophication in most of these coastal waters has been linked to increased incidences and severity of hypoxia. Thus, changes in nutrient concentrations and nutrient ratios in the Mississippi and Atchafalaya Rivers may have had an impact on the coastal phytoplankton community composition and phytoplankton production. The source of the organic material fueling respiration that depletes oxygen may therefore have changed. It is not known, however, if all these changes have led to an increase or decrease in the size, duration, or severity of hypoxia.

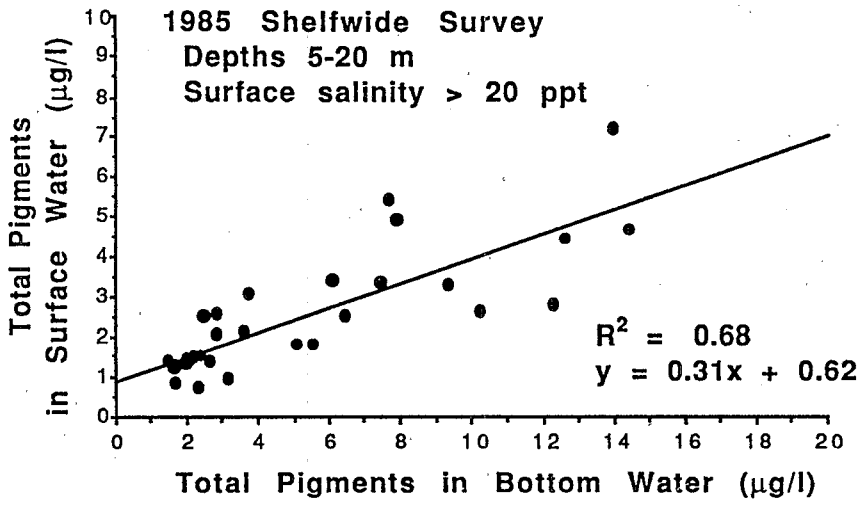

Figure L10. Relationship of total phytoplankton pigments (µg/l) in surface waters to total phytoplankton pigments in the bottom waters for those stations sampled in the 1985 shelfwide cruise that were most likely to have hypoxic bottom waters (depths of 5 to 20 m and surface salinity of >20 ppt) (from Rabalais *et al.*, 1991a).

Low oxygen conditions have been documented every summer since 1972 on the Louisiana continental shelf. Anecdotal data for trawl samples indicate the occurrence of bottom water hypoxia prior to this date (W. W. Forman, personal communication). Inadequate data prevent an analysis of long-term trends in severity, duration or extent. Most of the records prior to 1985 were collected peripherally to other studies. Consistent monitoring of oxygen-deficient bottom waters was not initiated until 1985 (Rabalais *et al.*, 1991a). Current efforts in the examination of eutrophication and/or hypoxia/anoxia indicators in the sedimentary record may shed some light on this mystery (R. E. Turner *et al.*, personal communication). Work on areas of low oxygen on the Louisiana shelf continue [Rabalais *et al.*, under NOAA Nutrient Enhanced Coastal Ocean Productivity (NECOP) funding; Louisiana Dept. of Wildlife and Fisheries in monitoring studies of the West Hackberry Strategic Petroleum Reserve brine disposal site; Southeast Area Monitoring Assessment Program (SEAMAP)].

There is no doubt that oxygen-deficient bottom waters affect demersal finfish and crustacean populations. Trawl catches in areas of hypoxia are minimal or non-existent (see Figure 14) (Pavela *et al.*, 1983; Leming and Stuntz, 1984; Renaud, 1986a). Benthic animal densities are severely depressed in these hypoxic areas or reduced to a few competitively superior species (Harper *et al.*, 1981, 1991; Gaston, 1985; Gaston *et al.*, 1985; Murrell and Fleeger, 1989; Boesch and Rabalais, 1991; Rabalais *et al.*, unpublished data) (Figures 13, L11, and L12). The behavior, if not reproduction, of demersal finfish and crustacean species is affected by the low oxygen. Motile organisms move out of the area, but are often more exposed to predation pressure or the size of suitable habitat is reduced. Fish kills are sometimes the result. A major fish kill off Grande Isle in the Mississippi River Delta bight in 1990 was attributed to the hypoxia/anoxia offshore. Crabs have been killed when caught in traps while a hypoxic water mass excursion moved onto Point au Fer Island. The reproductive cycle of penaeid shrimp may be variously affected during different parts of their life (see Figure 16). Hypoxic bottom waters may also affect the blue crab fishery in that ovigerous females are migrating offshore to spawn during periods when oxygen depleted bottom waters may be present. Dead and decaying adult blue crabs (and other crustaceans) have been observed on the bottom during the severe 1990 hypoxia/anoxia, and crabs and shrimp have been observed to be swimming in the mid-water column or at the surface to avoid hypoxic water masses on several occasions (N. N. Rabalais, personal observations).

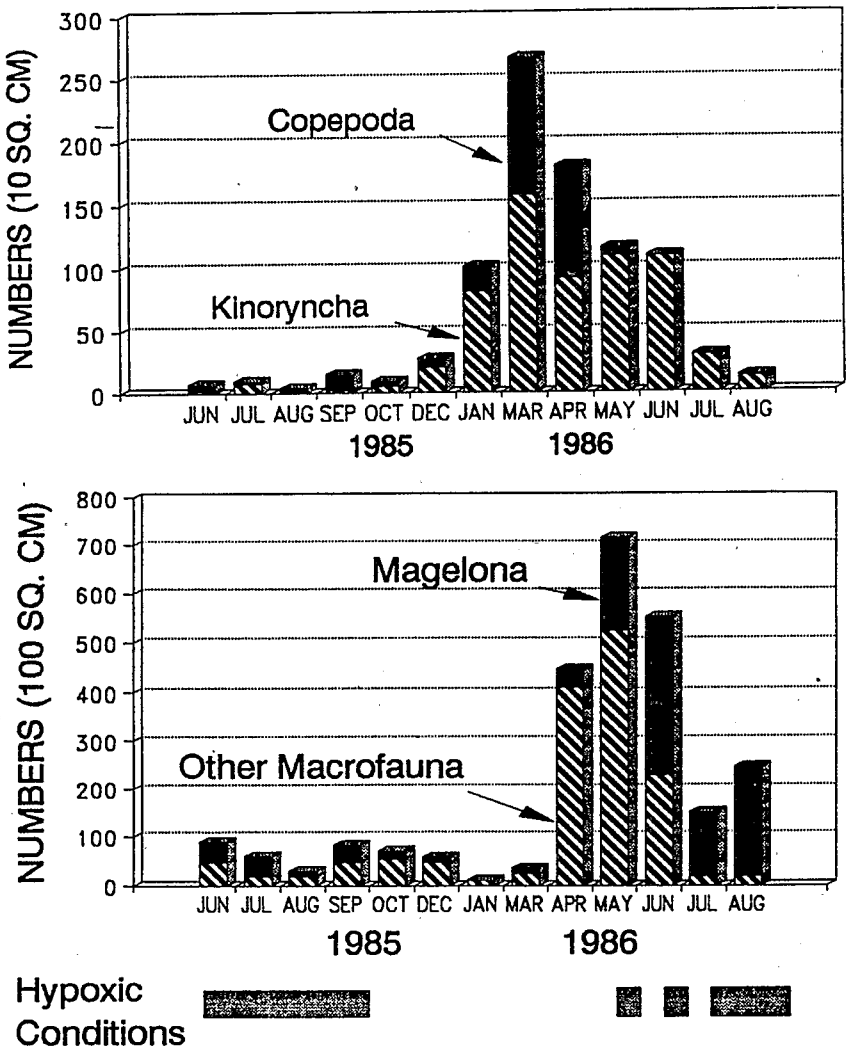

Figure L11. Abundances of meiofauna by taxon (Kinorhyncha and Copepoda) (upper panel) and macroinfauna (grouped by *Magelona* polychaetes and others) from Station C5 off Terrebonne Bay; hypoxic period stippled (from Boesch and Rabalais, 1991).

Q. Dortch *et al.* (personal communication) and research teams at LUMCON are keeping an eye out for high numbers of potentially toxic phytoplankton in samples from the Louisiana coast. *Ceratium tripos* and *C. furca*, which are implicated in low oxygen events elsewhere in U.S. waters, have been documented on the Louisiana shelf (Q. Dortch *et al.*, personal communication). *Gonyaulax monilata* was first recorded in the open waters of the Gulf of Mexico off the southeastern coast near Bayou Lafourche (identification not verified) and west of the Mississippi River in September 1980 (Perry, 1980). Patches of discolored water were also found south of the Grand Terre Islands to Lanaux Island. A similar bloom was found off the eastern part of the Mississippi River delta in 1979 (Perry, 1980). (See also Sections G-8.1 and G-10.) A bloom of *Gonyaulax* cf. *monilata* was documented off Southwest Pass of the Mississippi River delta in September 1990 (Q. Dortch *et al.*, personal communication). The verified occurrence of a red tide followed several reports of "red water" from local fishermen. Red tides of the heterotrophic alga, *Noctiluca* sp., were verified off Terrebonne Bay in March 1992 (Q. Dortch *et al.*, personal communication). *Nitschia pungens*, a pennate diatom, some forms of which produce a powerful neurotoxin, have been identified from Louisiana coastal waters; the morphological form has yet to be be confirmed (Q. Dortch *et al.*, personal communication) (see Section G-17).

Dinophysis sp., most probably *D. caudata*, has been found in high concentrations in shelfwide coastal waters during April and August of 1989 and during a two-week period in July 1990 and along a cross-shelf transect off Terrebonne Bay in March-November 1990 (Q. Dortch *et al.*, personal communication). The organism was present during the late spring and summer months in surface layers at intermediate salinities of 20-30 ppt. *D. caudata* has been recognized recently as a toxic dinoflagellate which may contribute to the accumulation of toxins responsible for diarrhetic shellfish poisoning (DPS) in shellfish in Mobile and Galveston Bays (R. Hickey, personal communication). The *Dinophysis* populations in Louisiana coastal waters have not been implicated in shellfish poisoning (see also sections G-12 and G-15).

Four red tide producing species, *Noctiluca miliaris*, *Oscillatoria (Trichodesmium) erythraea* (bloom proportions), *Gonyaulax monilata* (bloom proportions), and *Prorocentrum minimum*, were recorded in offshore coastal waters of southwestern Louisiana in 1981 (Maples *et al.*, 1983). Occurrences were predominantly in the spring and summer, with the exception of *P. minimum* which was found in all months. No fish kills, jubilees or discolored waters were associated with the presence of *G. monilata*. Some of these organisms were also recorded in the estuarine waters of Calcasieu Pass and Lake Calcasieu (see Section G-15).

See also comments in section G-27 concerning a dinoflagellate bloom (*Gymnodinium splendens*) off Galveston, Texas, that was suggested to originate from the plume of the Atchafalaya River and then transported into nearshore coastal waters of Texas (Harper and Guillen, 1989).

The presence of toxic algae and/or the potential for blooms have clear, negative effects on fishery or shellfish resources. Concern about toxic algal blooms has risen in recent years because of their impact on public health and economics of fisheries. There is evidence that the incidence of blooms as been increasing in recent years (Smayda, 1990). Some attribute the apparent increased incidence to awareness and increased observations, but there seems little doubt that the increase in outbreaks is very real (Shumway, 1990).

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Trask (1953)
Turner and Allen (1982a,b,c)
Turner *et al.* (1987)
Turner and Rabalais (1991a,b)
Wiseman (1982)
Wiseman *et al.* (1986)

G-8 Lake Borgne

No additional information is available for Lake Borgne. Mortalities of blue crabs in traps, resulting from hypoxia, have been assumed in the past (Rabalais *et al.*, 1985). Limited data from Barrett *et al.* (1978) indicate no occurrences of dissolved oxygen less than 2 mg/l (none less than 3 mg/l).

REFERENCES: G-8

Barrett *et al.* (1978)
Cent. Wetland Res. (1970)
Wiseman and Swenson (1987)
Wiseman *et al.* (1990)

G-8.1 Breton/Chandeleur Sounds

No additional data were obtained for Chandeleur or Breton Sounds. Based on very limited data (Barrett *et al.*, 1978) low dissolved oxygen in bottom waters of Breton Sound is not a problem. In monthly samples from October 1974 to September 1976 there were no oxygen values below 2 mg/l. The station on the Breton Sound transect at which the lower dissolved oxygen values were recorded (2.7 and 3.7 mg/l) were located at the most offshore end of the transect. Chandeleur and Breton Sounds are much shallower than Mississippi Sound, are open and exposed to wind mixing, and experience no large freshwater discharges which may induce stratification. There may be a localized influence of the MRGO, because its water column is normally stratified (Fagerburg, 1990).

See comments in Section G-10 regarding freshwater diversions from the Mississippi River.

A study of the phytoplankton production in the Mississippi River delta (Thomas and Simmons, 1959) included a station in Breton Sound. Compared to the remainder of the stations in the river, plume, and open Gulf of Mexico, the station in Breton Sound generally had higher surface phytoplankton production, similar levels of phosphate, and similar levels of soluble Kjeldahl nitrogen. The higher phytoplankton production could be attributed to increased water clarity.

The red tide caused by the dinoflagellate, *Gonyaulax monilata*, documented in Louisiana coastal waters in September 1980 (Perry, 1980) also occurred in the waters of Breton and Chandeleur Sounds.

A major freshwater diversion project has been completed to reroute waters of the Mississippi River into Breton Sound. The intent of the project (Caernarvon Freshwater Diversion) is to lower salinities in the sound by opening the structure when salinities reach a certain level. The structure has been finished and tested, but not yet used. Officials of the Louisiana Dept. of Natural Resources are questioning the usefulness of this project as well as all diversions planned for the Mississippi River (Baton Rouge *Morning Advocate*, May 28, 1991).

REFERENCES: G-8.1

Barrett *et al.* (1978)
Fagerburg (1990)
Lurry (1983)
Perry (1980)
Shirzad *et al.* (1989)
Thomas and Simmons (1960)

G-9 Mississippi River

The Mississippi and Atchafalaya Rivers are the primary source of fresh water to the Louisiana continental shelf (Dinnel and Wiseman, 1986) and to the Gulf of Mexico (90 % of freshwater inflow to Gulf). The Mississippi River watershed is the largest in the U.S. (41 % of the area of the conterminous 48 states). The river ranks third, eighth, and sixth, with respect to length, discharge, and sediment yield (Milliman and Meade, 1983). Approximately 33 % of the flow of the Mississippi River system enters the Gulf of Mexico via the Atchafalaya River (see Figure L16) (Turner and Rabalais, 1991a). Approximately 53 % of the discharge from the Mississippi River delta proper flows westward onto the Louisiana shelf (U. S. Army Corps of Engineers, 1974) Several studies have documented long-term changes in Mississippi River quality. According to Meade and Parker (1985), suspended sediment loadings declined abruptly in the mid 1950s following dam and reservoir construction on major tributaries of the Mississippi River (Figure L12, Turner *et al.*, 1987). Along with the reduction in suspended sediments, there has been a reduction by half the 1950s values, of silicate concentrations, but the decline is less precipitous than that observed for suspended sediments (see Figure 8, Turner and Rabalais, 1991a). A seasonal summer-fall maximum in silicate concentration is no longer evident. The coincidental decline in silicate as phosphorus fertilizer application increased (see Figure 8) is support for the hypothesis of Schelske *et al.* (1983, 1986; cited in Turner and Rabalais, 1991a) that freshwater diatoms growth in the streams and lakes feeding the main river channel is stimulated by phosphorus additions, and that the increased diatom growth leads to a net loss of silicon from the water column, and subsequently in the main Mississippi River channel. This hypothesis is also supported by the small, but significant, increase in silicon from 1986-1988, when phosphorus fertilizer use declined a small amount, but nitrogen fertilizer use stabilized.

Several authors have noted the increase in nitrogen concentrations and loadings and phosphorus concentrations and loadings in the upper Mississippi River, at the terminus of the river, and throughout the Gulf coast (Walsh *et al.*, 1981; Smith and Alexander, 1984; Smith *et al.*, 1987; Turner and Rabalais, 1991a). The mean annual concentration of nitrate in the lower Mississippi River was approximately the same in 1905-1906 and 1933-1934 as in the 1950s, but it has doubled in the last 35 years (see Figure 4) (Turner and Rabalais, 1991a). The mean annual concentration of silicate in the lower Mississippi River was approximately the same in 1905-1906 as in the 1950s, then it declined by 50 %. Although the concentration of total phosphorus appears to have increased since 1972, variations between years are large, and trends, if they exist, are not clear. The seasonal concentrations of nitrogen have also changed; there was no pronounced peak in nitrate concentrations earlier this century whereas there was a spring peak from 1975 to 1985, due most likely to fertilizer application (see Figure 11). Computations of river flow and concentrations of nitrogen and phosphorus have provided long-term data for total loadings of nitrogen and phosphorus into the Gulf of Mexico by the Mississippi and Atchafalaya Rivers combined (see Figure 5). Nitrogen loading doubled from 1954-1959 to 1980-1985; total

phosphorus loading increased in the last 15 years, but there is too much variation to be precise about the percent increase.

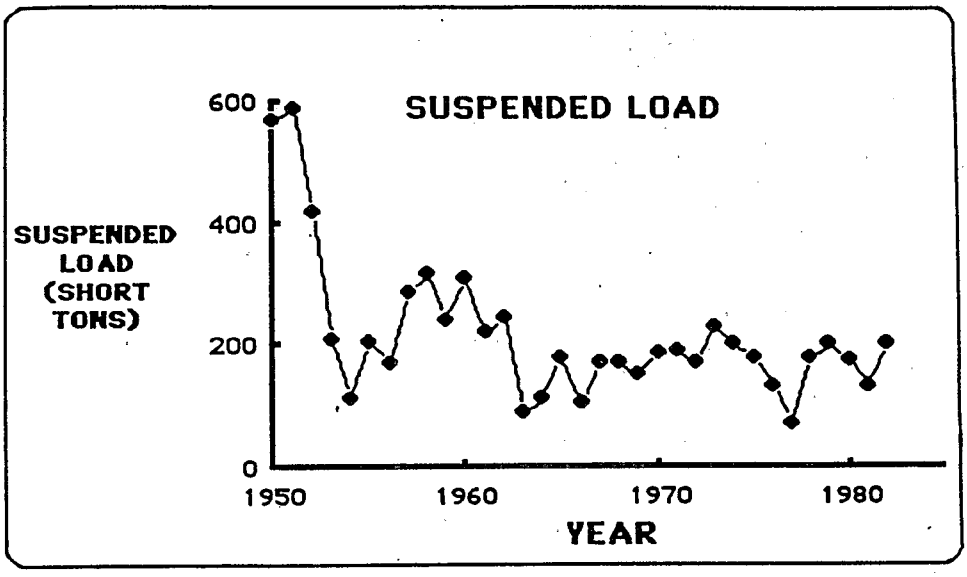

Figure L12. Annual discharge of suspended load in the Mississippi River at Baton Rouge, Louisiana, from 1950 to 1982 (adapted from Meade and Parker, 1984; in Turner *et al.*, 1987). Values in short tons (1 short ton = 2000 pounds, or 907 kilograms).

The silicate:nitrate atomic ratios in the lower Mississippi River for this century have changed as the concentrations varied (see Figure 12a,b). The silicate:nitrate atomic ratio was approximately 4:1 at the beginning of this century, dropped to 3:1 in 1950, and then rose to approximately 4.5:1 during the next ten years, before plummeting to 1:1 in the 1980s. There has been a modest rise in the recent three to five years, as a result of the coincidental concentration increase of silicate and decrease of nitrate.

Water-quality changes in the Mississippi River are coincident with increased nitrogen and phosphorus fertilizer use (see Figure 8). Fertilizer use recently reached a plateau; at the same time, both the rise in river nitrate concentration and the fall in silicate concentration stopped. The rise in nitrate in recent decades is evidence that the ability of watershed land to store the mostly ammonia-based nitrogen fertilizers was exceeded.

The water quality changes documented also suggest that significant reduction of eutrophication is not likely to occur without a reduction in fertilizer use. Limiting the amount of fertilizer used is a more fundamentally sound management approach than is controlling its distribution. Significant amounts of the currently applied nitrogen and phosphorus fertilizer eventually leak into the aquatic environment, as well as possibly into the atmosphere (Turner, 1991). The riverine ecosystem response to higher nutrient loading is consistent with the nitrogen-saturation hypothesis described for northern forests by Aber *et al.* (1989).

The increase in nitrogen (and possibly phosphorus) and the reduction of silicon have profound implications for coastal phytoplankton communities and, therefore, coastal food webs. Increased phytoplankton production is the likely result in an otherwise nitrogen-limited oceanic food web (the current paradigm for many coastal systems; Harris, 1986; Valiela, 1984). Coastal diatom

communities are certainly influenced by silicon supplies, and the Si:N atomic ratio of 1:1 is just below the average for diatoms. Diatoms abundance would have declined, with a decrease in silicate abundance, if all other factors remained constant. Other nutrient concentrations did change, however, and the increased nitrogen and phosphorus should favor flagellates (Office and Ryther, 1980), and this change may have a secondary impact on water column processes on the Louisiana continental shelf. Hypoxic water masses form at the seabed and in overlying waters each spring and summer at the terminus of the both the Mississippi and Atchafalaya Rivers (Rabalais *et al.*, 1991a). The disjunct zones of hypoxia in 1986 and 1987 both mirrored somewhat the surface salinity field and surface phytoplankton biomass concentrations that resulted from the Mississippi and Atchafalaya River freshwater inputs. [The surface water salinity in coastal waters adjacent to the Mississippi River parallels the flow of the river (Geyer, 1950, 1955).] The presence of a normoxic area between the hypoxic zones could be explained by 1) shallower depths, 2) topographic bottom features, and/or 3) less stratified water columns. These explanations are not entirely satisfactory, because the depth and density gradients in the normoxic area were similar to those observed on the western end of the study area where hypoxia was present.

A doubling in riverine nitrogen loading would certainly be expected to increase phytoplankton production, the most probable source of organic matter to fuel the respiration rates that deplete the oxygen from bottom-water masses. However, because diatoms sink more rapidly than most other phytoplankton, reduced diatom populations and/or biomass (through silicon limitation) have compensated for the effects of phytoplankton community production that might have increased through higher nitrogen loading. If flagellated autotroph density increased because of higher nitrogen and phosphorus loading, community oxygen consumption rates may have shifted higher in the water column, simply because diatoms sink much faster. The cumulative result may have actually been no change, or even a decrease in the areal extent or intensity of hypoxia. Those instances of lowered oxygen concentration in the upper water column, however, are consistent through the entire water column (Rabalais *et al.*, unpublished data). As mentioned earlier, the diatom composition of waters adjacent to the Mississippi River may have changed over the period for which there are water quality data (see page 34; Thomas and Simmons, 1959; Q. Dortch, personal communication). Within the Mississippi River delta and its waters, phytoplankton production and biomass is limited by the turbidity of the water, in spite of high nutrient concentrations (R. E. Turner, personal communication).

Water quality data for the Mississippi River is collected by the U. S. Geological Survey in cooperation with state and Federal agencies (*e.g.*, USGS, 1980). Data for selected stations for the Lower Mississippi River Basin and the Mississippi River Delta showed no values of dissolved oxygen below 5 mg/l. The location of the sample in the water column was not indicated clearly but assumed to be mid river, surface, or subsurface.

REFERENCES: G-9

Browder *et al.* (1987)
Cent. Wetland Res. (1970)
Fox *et al.* (1985)
Geyer (1955)
Gunning and Suttkus (1986)
La. Dept. Envir. Qual. (1987-90)
Lurry (1983)
Rabalais *et al.* (1991b)
Shiller (in press)
Shirzad *et al.* (1989)
Trefry *et al.* (1985)
Turner *et al.* (1987)
Turner and Rabalais (1991a,b)
Turner and Rao (1990)
Wiseman and Swenson (1987)
Wright (1970)

G-10 Barataria Bay

Significant sources of information concerning Barataria Basin are Conner and Day (1987), Madden *et al.* (1988), and Boesch *et al.* (1989) and references therein. The Barrataria/Terrebonne Estuarine

Complex has been named as a National Estuary under the U.S. Environmental Protection Agency National Estuary Program. A conference was held in October 1991 for which there will be a published synthesis of existing information on the systems.

The Barataria Basin is bordered by the leveed Mississippi River on the north and east, Bayou Lafourche on the west, and the Gulf of Mexico on the south. The 628,000-ha Barataria Basin is composed of three sub-basins: 1) fresh swamp and forest and a freshwater lake (Lac des Allemands) comprise the upper basin, 2) brackish marsh and several large brackish lakes characterize the middle basin, and 3) the lower basin is composed of two tidal saline bays (Barataria Bay and Caminada Bay), several smaller saline lakes, and *Spartina alterniflora* salt marshes (Madden *et al.* 1988). The Barataria Basin is experiencing a high rate of land loss. With the lack of direct sediment input from the Mississippi River since leveeing in the 1930s, the important long-term mechanisms for sediment deposition in the Barataria Basin wetlands is storm-driven resuspension with redistribution of sediments (Baumann *et al.*, 1984).

Barataria Basin receives nutrient loadings on the same order of magnitude as Fourleague Bay in the influence of the Atchafalaya River (see Section G-12), but the source is different (Madden *et al.*, 1988). Barataria Basin is bordered by agricultural and urban areas, and its chemistry is impacted by high anthropogenic nutrient loadings in runoff. Hopkinson and Day (1979) estimated mean total nitrogen and phosphorus concentrations in runoff water entering the upper Barataria Basin at 279 and 18 μM, respectively. The altered hydrography of the upper Barataria Basin with its extensive channelization has been implicated in the reduction of the ability of the natural wetlands to assimilate high influxes of nutrients (Gael and Hopkinson, 1979). As a result, nutrient concentrations are higher in the water column in channelized areas (Kemp and Day, 1984), and receiving waters that drained the areas of highest canal density were the most eutrophic waters of the basin with chlorophyll *a* levels of 43-59 μg/l (Seaton and Day, 1979). Basinwide averages for chlorophyll *a* were 11 μg/l. Lac des Allemands retains about 55-60 % of the total phosphorus load it receives, thus buffering the impact of phosphorus input downstream in the middle basin (Day *et al.*, 1976; Craig and Day, 1977).

In the lower end of the Barataria estuary, the Gulf of Mexico and the plume of the adjacent Mississippi River become dominant physical and chemical factors (Madden *et al.*, 1988). Ho and Barrett (1975, 1977) measured pulses of freshwater carrying nitrate, phosphate and silicate through the mouth of Barataria Bay during spring flood. The water quality in southern Barataria Bay may be affected by changes in Mississippi River water quality because of its relatively large freshwater inflow and evidence that salinity in Barataria Bay is inversely related to river discharge (Wiseman and Swenson, 1987; Wiseman *et al.*, 1990). There is a slight trend to support this idea in a comparison of lower Barataria nitrate with that of the Mississippi River at St. Francisville, but there is much variability in the limited data available for a preliminary analysis (Figure L13, R.E. Turner, unpublished data).

There is a gradient along the axis of the Barataria estuary of nutrient concentrations, phytoplankton production, chlorophyll biomass and turbidity (Witzig and Day, 1983; Madden *et al.* 1988). The upper end of Barataria Basin is eutrophic. Lac des Allemands has poor water quality and biological oxygen demand is high, from nutrient loading due primarily to agricultural and urban runoff from adjacent uplands. Dense blue-green algal blooms occur in Lac des Allemands and Lake Cataouatche for nine or 10 months of the year (Day *et al.*, 1976; Hopkinson and Day, 1979). The upper Barataria Basin is characterized by frequent blue-green algal blooms, high turbidity, dominance of fish such as gar and shad, and fish kills resulting from low levels of dissolved oxygen. Lake Salvador, further south in the basin, is less productive and less heterotrophic than Lake Cataouatche. From Lake Salvador southward, the waters of Barataria Basin are lower in nutrient concentrations and productivity. While the central basin is far less affected by agricultural runoff than the upper basin, nutrient enrichment is still a problem, stemming from urban runoff

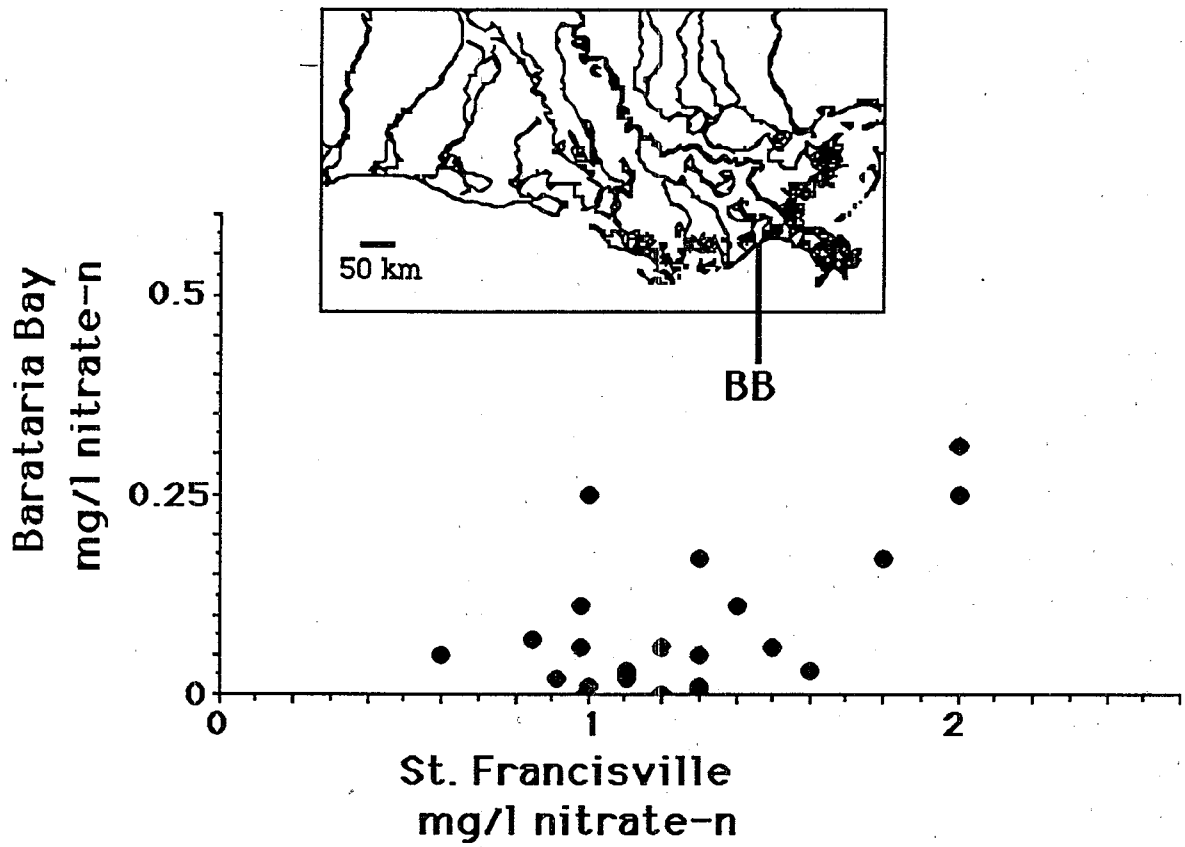

Figure L13. Comparison of nitrate concentrations at the lower end of Barataria Bay to those of the Mississippi River at St. Francisville, Louisiana, for similar time periods (R.E. Turner, unpublished data).

from the New Orleans area. Dissolved organic and inorganic nutrients are largely removed by flocculation in Salvador's brackish waters; waters south of this point in the basin do not receive high anthropogenic nutrient loading. In Little Lake, mid basin, light penetration is greater where depths are also shallower and benthic primary production becomes a dominant feature in the overall productivity of the system. The water quality of Little Lake is good, but the Barataria Waterway allows urban runoff to flow unhindered to the upper part of Barataria Bay. Sewage entering from this route, as well as from fishing and hunting camps located throughout the basin, has resulted in periodic closures of numerous oyster beds due to fecal coliform contamination (Louisiana Dept. of Environmental Quality, 1988). The saline end members have lower nutrient concentrations, water clarity is much greater and benthic photosynthetic production is significant. Witzig and Day (1983) developed a trophic state index (TSI) to classify the water bodies in the Barataria Basin using existing water quality data. Positive TSI scores indicate high nutrient enrichment. Most water bodies in the upper and middle basin were classified with positive values (Table L4).

Barataria Bay is one of the estuarine areas in southeastern Louisiana currently experiencing closure of some of its oyster beds (Louisiana Dept. Environmental Quality, 1990). The oyster growing grounds are impacted by numerous sources of pollution including untreated and partially treated sewage, urban runoff, agricultural runoff, runoff from pasturelands, discharges associated with oil field activities and vessel waste discharges (Louisiana Dept. of Environmental Quality, 1985). Sewage treatment plant by-passes and drainage from non-sewered communities are the main sources of bacterial contamination in the bay.

Table L4. Trophic state index (TSI) of Barataria Basin. O=oligotrophic, M=mesotrophic, E=eutrophic, and H=hypereutrophic (from Boesch *et al.*, 1989, after Witzig and Day, 1983).

Location	Position in Basin	TSI score	Trophic classification
Caminada Pass	lower	-4.8	M-O
Bayou Rigolettes	lower	-4.3	M
Barataria Bay	lower	-3.8	M
Lake Salvador	middle	-3.3	M
Bayou Perot	lower	-2.8	M
Little Lake	lower	-2.7	M
Bayou Barataria	lower	-1.8	M
Barataria Waterway	lower	-1.6	M
Natural swamp stream	upper	-1.4	M
John-the-Fool Bayou	lower	-0.6	M
Little Lake oil and gas field	lower	-0.4	M
Bayou Chevreuil	upper	6.0	E
Lake Cataouatche	upper	0.7	E
Bayou des Allemands	middle	2.6	E
Burtchell Canal	middle	2.7	E
Bayou Citamon	upper	3.7	E-H
Lac des Allemands	upper	3.8	E-H
Bayou Chevreuil	upper	4.0	E-H
St. James Canal	upper	6.4	H

Data on the dissolved oxygen content of the waters of the Barataria estuary are limited. Hewatt (1950) collected data from a total of 60 stations at various times, mostly during April-July from 1945-1947. Out of 95 measurements, only one fell below 2 mg/l. Barrett *et al.* (1978) recorded no instances of dissolved oxygen less than 2 mg/l. Near-bottom water oxygen concentrations substantially below 2 mg/l were found in a canal adjacent to a produced water (oilfield brine) effluent in the Lafitte Oil and Gas Field. The low oxygen was associated with a highly stratified water column and the dense, hydrocarbon-laden effluent which was flowing along the bottom (Boesch and Rabalais, 1989b); dissolved oxygen levels returned to ambient levels at 250 m from the point of lowest oxygen concentrations.

Two of the predominant causes of habitat degradation in the Barataria estuary are believed to be saltwater intrusion and reduced sediment input and retention (EPA, Region VI, 1988). [Yet data from Wiseman *et al.* (1990) indicate no trends in the Barataria Bay stations analyzed with the exception of a decrease in salinity at the station nearest the Gulf of Mexico.] A major strategy to divert a portion of the Mississippi River flow into Barataria Basin has been developed by the New Orleans District of the U.S. Army Corps of Engineers. At least 17 alternative freshwater diversion sites are in the Barataria Basin. The Davis Pond project, near Luling in the uppermost reaches of the basin, is the most imminent. The Caernarvon Diversion Structure, which will drain into Breton Sound, has been completed and had its first test. Proponents and opponents of these diversions have differing views as to the effectiveness in providing sediments to be incorporated in marsh habitats and the ultimate effect of the river's nutrients and chemical constituents upon the receiving systems (see comments in Section G-8.1).

The red tide caused by the dinoflagellate, *Gonyaulax monilata*, documented in Louisiana coastal waters in September 1980 (Perry, 1980) also occurred in the waters of Bayou Lafourche where a fish kill, attributed to this water mass, occurred later in the afternoon.

REFERENCES: G-10

Barrett *et al.* (1978)
Boesch and Rabalais (1989b)
Boesch *et al.* (1989)
Browder *et al.* (1987)
Cent. Wetland Res. (1970)
Childers and Day (1990a,b)
Conner and Day (1987)
Craig *et al.* (1977)
EPA (1988)
Gael and Hopkinson (1979)
Garrison (1982)
Hewatt (1950)
Ho and Barrett (1975, 1977)
Hopkinson and Day (1979, 1980)
Hopkinson *et al.* (1985)
Khalid *et al.* (1978)
La. Dept. Envir. Qual. (1987-90)
Lurry (1983)
Madden *et al.* (1988)
Perry (1980)
Rabalais *et al.* (1991b)
Seaton (1979)
Seaton and Day (1979)
Shirzad *et al.* (1989)
Sklar and Turner (1981)
Smith and DeLaune (1985)
Van Sickle *et al.* (1976)
Waldrop (1983)
Williams (1956)
Wiseman and Swenson (1987)
Witzig and Day (1983)

G-11 Terrebonne/Timbalier Bays

Significant sources of information concerning Barataria Basin are provided in Boesch *et al.* (1989). The Barrataria/Terrebonne Estuarine Complex has been named as a National Estuary under the U.S. Environmental Protection Agency National Estuary Program. A conference was held in October 1991 for which there will be a published synthesis of existing information on the systems.

The northern portion of the Terrebonne/Timbalier drainage system is composed mostly of high land broken by bayous, canals, and swamps which is utilized for agriculture, pastureland, and an ever increasing amount of urban development. Extensive marshes border the southern land extremities and intermingle gradually with an extensive estuarine system, namely Terrebonne and Timbalier Bays and Lake Pelto. These are connected to the Gulf of Mexico through a series of broad passes. The area lies approximately halfway between the Mississippi and Atchafalaya Rivers, but receives no appreciable influence from either; the major factors influencing fluctuations in salinity are rainfall and local drainage (Adkins and Bowman, 1976).

The sources of eutrophication in Terrebonne are similar to other basins. In the upper basin, agricultural runoff is primarily from sugarcane fields. From the available data, industrial waste seems to be the source of extremely high phosphorus inputs, particularly in the Lake Verrett region (Craig and Day, 1977). Municipal sewage from the Houma area is also a source of high nutrient input and is the cause for shellfish bed closures throughout much of the estuary.

Several studies were conducted in the eastern portion of Timbalier Bay from August 1972 to January 1974 in conjunction with an analysis of the effects of oil drilling and production (Offshore Ecology Investigation/Gulf Universities Research Consortium, OEI/GURC) (Ward *et al.*, 1979). These included hydrographic profiles, water column nutrients and sediment nutrients along a transect from the upper bay to the intersection with the Gulf of Mexico (Price, 1979; Burchfield *et al.*, 1979). Mean dissolved oxygen concentrations ranged from slightly less than 6 mg/l to almost 11 mg/l, except for the July 1973 cruise when the mean value was near 3.6 mg/l; these low oxygen levels coincided with the flood of the Mississippi River in 1973 (Figure L15) (Price, 1979). The highest readings, ≥13 mg/l, occurred in the winter months; the lowest was 1.3 mg/l in July 1973.

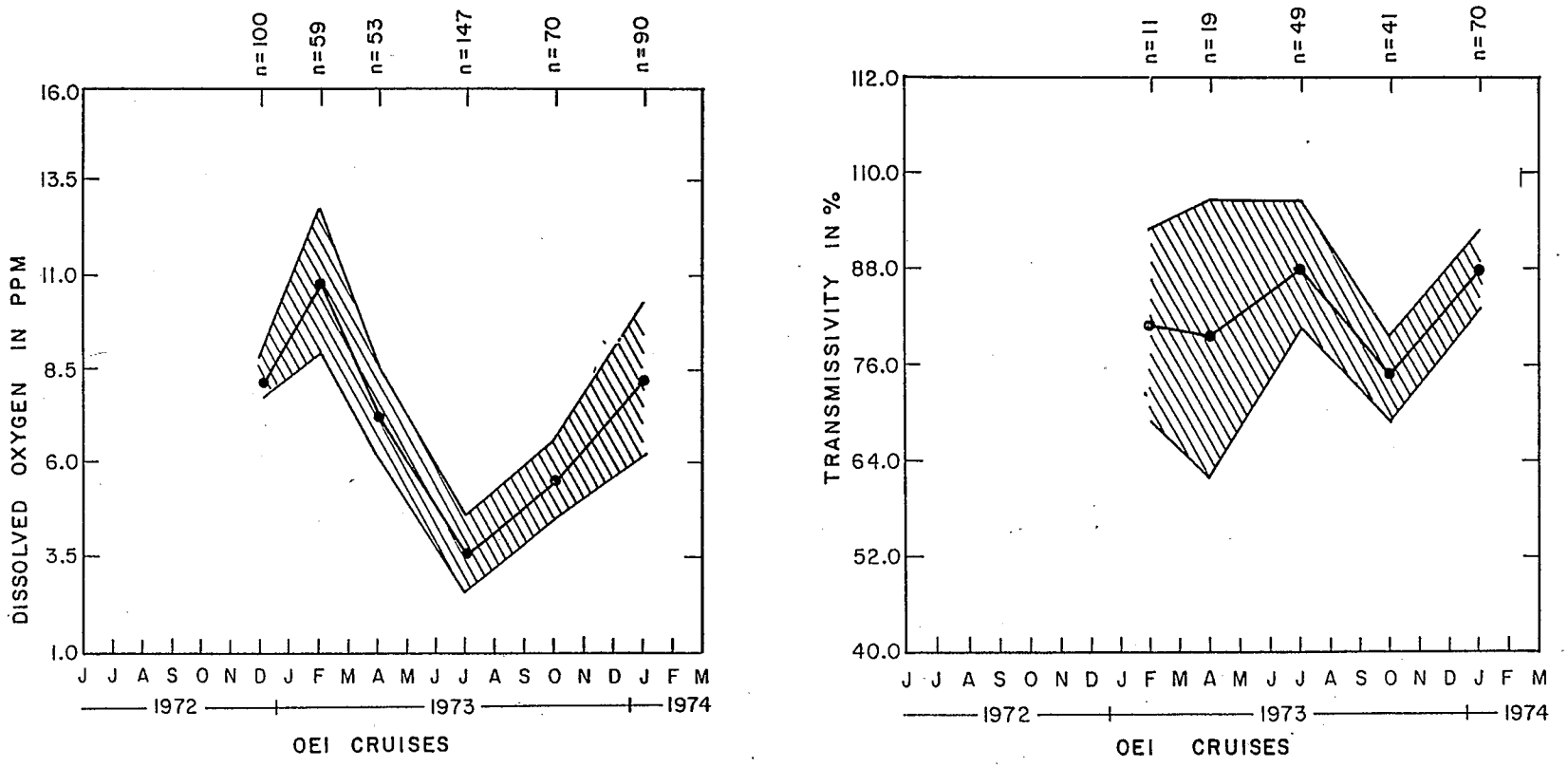

Figure L14. Dissolved oxygen concentrations in means of upper values and lower values for all stations through time (left panel) and similar values for transmissivity for transect from upper Timbalier Bay to the intersection of the Gulf of Mexico (from Price, 1979).

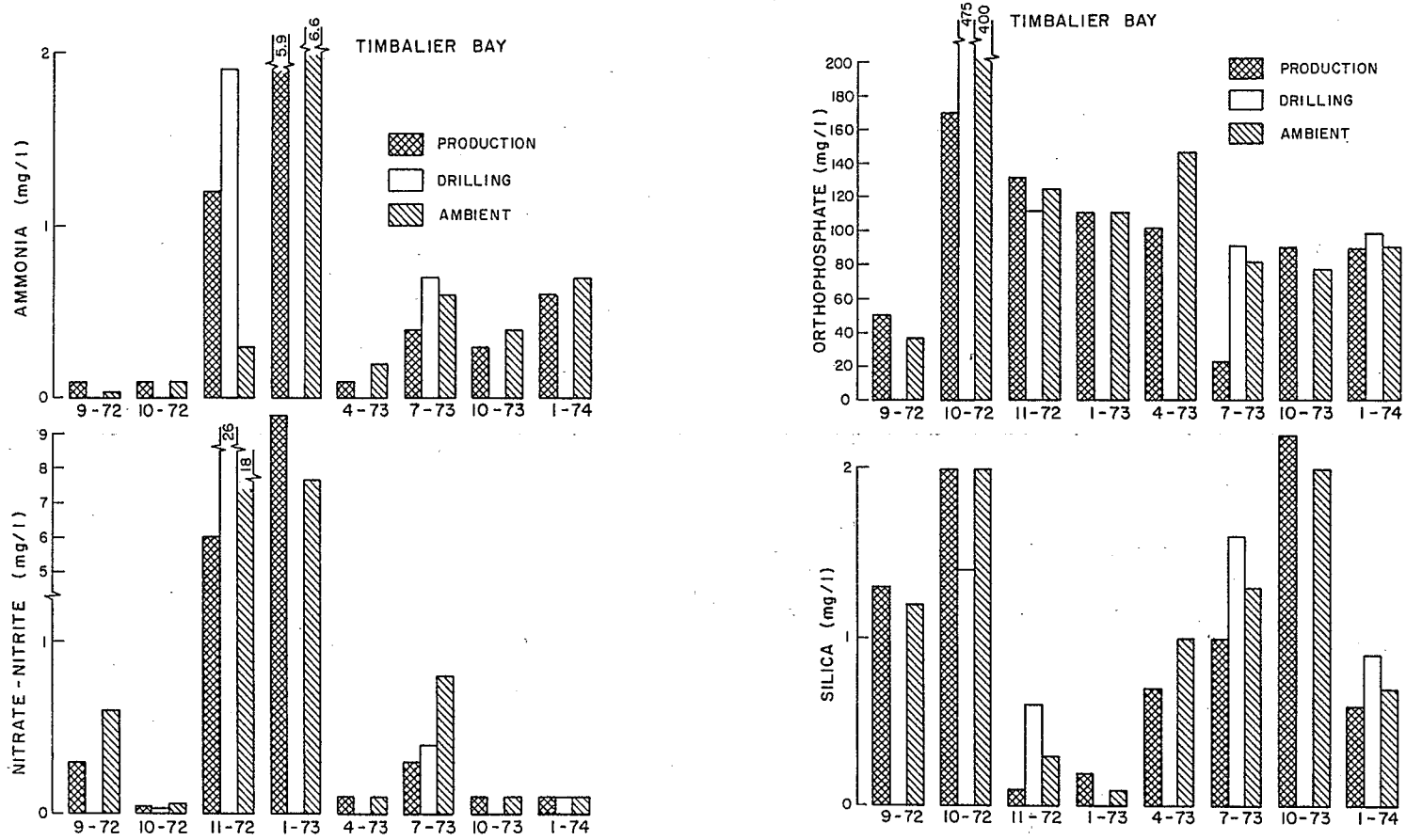

Figure L15. Season variation in water column levels of ammonia, nitrate-nitrite nitrogen, phosphate and silica levels for all stations averaged within Timbalier Bay along a transect from the upper Bay to the intersection of the Gulf of Mexico (from Burchfield *et al.*, 1979).

Transmissivity showed a different seasonal pattern from that exhibited by the other parameters (Figure L14). The maximum (99 %) and the highest mean (88 %) were observed during the July 1973 cruise which occurred during the 1973 flood.

The seasonal variations in nutrient concentrations in the OEI/GURC study (Figure L15) (Burchfield *et al.*, 1979) were generally comparable to data collected by Barrett *et al.* (1978). Nitrogen levels peaked during the winter months, increased in July in response to the heavy summer rainfall, decreased slightly in October and then increased during the following winter. The highest phosphate levels were observed during the fall, then decreased and remained relatively constant throughout the remainder of the study. Silica concentrations were highest during October of both 1972 and 1973 and minimal during the winter months. Price (1979) suggested that there is less seasonal and spatial variability than is typical of many other bays along the central Gulf coast; however, despite the paucity of streams entering the bay and its relative isolation from the Mississippi River, it was responsive to the flooding of the Mississippi River in July 1973.

During the same period of the OEI/GURC investigations in Timbalier Bay, faunal studies of dredged canals were underway in the Terrebonne Bay portion of the estuary (Adkins and Bowman, 1976). No values of dissolved oxygen (1 ft below the surface) less than 2.5 mg/l were recorded; the 2.5 mg/l value was near Terrebonne Bayou in a closed canal. Barrett *et al.* (1978) recorded no dissolved oxygen levels below 3.8 mg/l for three stations in Terrebonne Bay sampled monthly from October 1974 to September 1976. Dissolved oxygen data collected from Lake Boudreaux (upper Terrebonne system) did not fall below 5 mg/l in monthly samples taken in 1968 (Shampine, 1971). A study conducted by Williams (1956) in the Grand Bayou Blue section of the upper Timbalier Bay estuary looked at water quality for the period December 1954 to August 1955. Dissolved oxygen concentrations were taken at approximately 1 m below the water surface; however, several very low readings were obtained in August. All of the stations in the Williams (1956) study were in dredged canals or narrow bayous where flow is expected to be reduced and stagnation may occur during hot weather. Water quality measurements made in similar areas of the Grand Bayou Blue in September 1988 did not reveal any low dissolved oxygen concentrations (Boesch and Rabalais, 1989b). From the limited data available, low dissolved oxygen in bottom waters of the Terrebonne/Timbalier Bay complex cannot be considered a problem. In some areas, such as canals or channels, problems may be encountered in the warmer months.

Adkins and Bowman (1976) also provided nutrient data for their study (see Table L5). Generally, nitrates decreased during cooler months, reaching an average low during December 1972 and during April 1973. During previous studies in coastal Louisiana, Pollard (1973) (cited in Adkins and Bowman, 1976) found much higher average nitrate values, typical of stations further removed from Gulf of Mexico influence. The stations of Adkins and Bowman (1976), however, more closely resembled seaward stations and thus had depressed nitrate levels. Nitrate values in Terrebonne Bay are influenced by freshwater run-off, of which Coastal Study Area IV has very little, which would explain the lower nitrate concentrations. Nitrate, nitrite, and ammonia values did, however, reflect freshwater flooding experienced during the study.

A year-long study (October 1982 - October 1983) of the water column characteristics was conducted along a Terrebonne Bay transect and into adjacent Gulf of Mexico waters (Dagg, N.D.). Chlorophyll *a* levels seldom exceeded 20 μg/l and were more commonly in the range of 10 μg/l. Nutrient concentrations were also generally low as seen by Adkins and Bowman (1976). Secchi disk measurements indicated a normally turbid system.

Table L5. Data from Adkins and Bowman (1976).

Values of selected chemical parameters, surface and bottom water samples, October 1972 through September 1974

	No. of Observations		Range Min — Max		Range Min — Max		Mean		Yearly Average	
	72-73	73-74	72-73		73-74		72-73	73-74	72-73	73-74
Top NO_3 (ug-at/liter)	96	88	0.0	16.5	0.0	26.6	3.2	1.8		
Bottom NO_3	72	88	0.0	25.5	0.0	28.9	4.1	3.0	3.7	2.4
Top NO_2	96	96	0.0	14.0	0.4	3.4	0.9	1.0		
Bottom NO_2	72	96	0.0	5.4	0.4	3.6	1.1	1.0	1.0	1.0
Top NH_4	72	96	0.0	17.0	1.5	10.9	1.8	4.3		
Bottom NH_4	72	96	0.0	20.9	0.0	22.8	1.8	4.6	1.8	4.5
Top PO_4	96	96	0.1	30.0	0.3	12.6	1.9	1.5		
Bottom PO_4	72	95	0.1	28.5	0.3	32.0	2.7	2.1	2.4	1.8
Top Total Phosphorus	96	96	1.2	34.0	0.3	16.6	4.1	3.6		
Bottom Total Phosphorus	72	96	1.4	32.5	1.0	16.0	5.5	4.3	4.8	4.0
Top SO_4	96	96	0.0	1850.0	0.0	1500.0	377.5	325.0		
Bottom SO_4	72	96	0.0	1290.0	0.0	1500.0	337.5	385.0	357.5	355.0
Top Ca (mg/l)	96	96	52.0	312.0	30.0	312.0	148.0	124.0		
Bottom Ca (mg/l)	72	94	52.0	356.0	33.0	332.0	140.0	128.0	144.0	126.0
Top pH	96	95	7.3	8.5	7.1	8.3	7.7	7.6		
Bottom pH	72	95	7.3	8.5	7.3	8.3	7.7	7.6	7.7	7.6
Top Conductivity (25 deg C)	96	96	1.6	36.8	0.8	41.0	12.3	11.3		
Bottom Conductivity (25 deg C)	72	96	1.5	31.2	0.8	41.8	11.7	14.3	12.0	12.8
Top Alkalinity (mg/l)	96	96	56.0	206.0	58.0	146.0	110.0	106.5		
Bottom Alkalinity (mg/l)	72	96	66.0	194.0	62.0	186.0	107.0	109.0	108.5	107.8
Top Turbidity (JC)	96	96	22.0	168.0	20.0	290.0	66.5	61.0		
Bottom Turbidity (JC)	72	96	22.0	211.0	22.0	395.0	76.0	66.5	71.8	63.8
Top Total Solids (mg/l)	96	96	1158.0	26860.0	490.0	20720.0	7544.0	6389.0		
Bottom Total Solids (mg/l)	72	96	1230.0	20130.0	524.0	20420.0	7392.0	7908.5	7468.0	7648.8
Top Dissolved Solids (mg/l)	96	96	1026.0	26800.0	470.0	20630.0	7524.0	6358.0		
Bottom Dissolved Solids (mg/l)	72	96	988.0	20082.0	474.0	20320.0	7347.0	7902.0	7435.5	7130.0
Top Suspended Solids (mg/l)	96	96	0.0	200.0	0.0	196.0	40.0	40.0		
Bottom Suspended Solids (mg/l)	72	96	0.0	328.0	0.0	1074.0	52.0	60.0	46.0	50.0

REFERENCES: G-11

Adkins and Bowman (1976)
Barrett *et al.* (1978)
Boesch and Rabalais (1989b)
Boesch *et al.* (1989)
Browder *et al.* (1987)
Burchfield *et al.* (1974, 1979)
Cahoon and Groat (1991)
Cent. Wetland Res. (1970)
Craig *et al.* (1977)
Dagg (N.D.)
Farrell (1974)
La. Dept. Envir. Qual. (1987-90)
Murrell and Fleeger (1989)
Price (1974, 1979)
Rabalais *et al.* (1991b)
Shampine (1971)
Ward *et al.* (1979)
Wiseman and Swenson (1987)

G-11.1 Caillou Bay

No additional information updates the Rabalais *et al.* (1985) review. No dissolved oxygen values less than 2 mg/l were recorded in a transect from Lake Mechant to Caillou Bay (Barrett *et al.*, 1978) and in limited collections in Lakes DeCade and Mechant (Shampine, 1971).

REFERENCES: G-11.1

Barrett *et al.* (1978)
Shampine (1971)

G-12 Atchafalaya Bay/River

Approximately 33 % of the flow of the Mississippi River system enters the Gulf of Mexico via the Atchafalaya River (Figure L16) (Turner and Rabalais, 1991a). The long-term changes in the Mississippi River were described above in Section G-9. The concentrations of nitrate, silicate, and total phosphorus at Morgan City (0.5 km from the delta of the Atchafalaya River) were 69 %, 94 %, and 130 %, respectively, of that in the Mississippi River at St. Francisville for the combined data for the years 1973-1987 (Table L6; Turner and Rabalais, 1991a). Differences between nutrient concentrations in the Atchafalaya and Mississippi rivers are presumably a consequence of differences in the water quality of the Red River (which mixes with the Mississippi to form the Atchafalaya) compared with that in the Mississippi. These percentages are consistent across the 1973-1987 period, which indicates similar increases in nitrate (but at lower overall concentrations) and similar reductions in silicate (but at lower overall concentrations).

Table L6. The average annual concentration of nitrate, silicate and total P at Morgan City, Louisiana as a percentage of that at St. Francisville, Louisiana (paired samples) (developed from data in Turner and Rabalais, 1991a).

Nutrient	% at St. Francisville	Years
Silicate	69	12
Nitrate-N	94	12
Total P	130	15

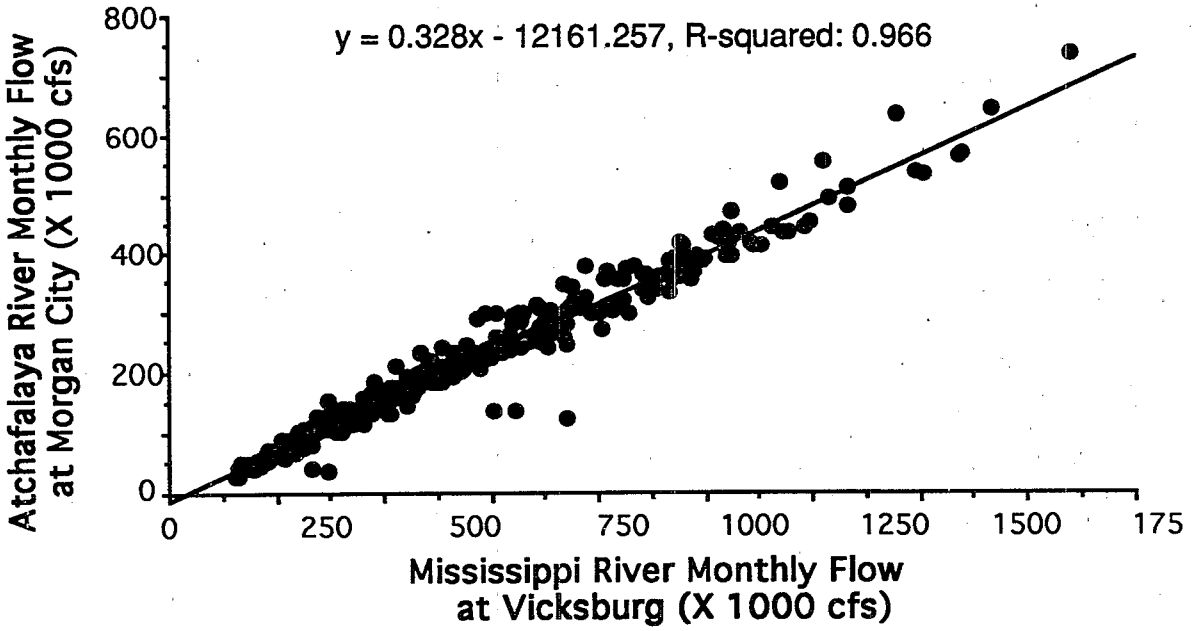

Figure L16. Comparison of annual discharge of the Atchafalaya and Mississippi Rivers (R.E. Turner, unpublished data).

Water quality during a phytoplankton study of the lower Atchafalaya River basin (Sager, 1976) was determined in riverine, lacustrine and swamp habitats. The river stations had high sediment loads, high discharges, stable pH levels, high nutrient levels and high dissolved oxygen percent saturation levels. Swamp stations were characterized by clear waters (low suspended solids) during the low water periods, relatively large variations in pH, low dissolved oxygen saturation percentages, comparatively low nutrient levels, and often humate-rich waters. Lake stations were commonly influenced by swamp waters draining into them but they generally had higher dissolved oxygen concentrations, higher and more stable pH levels and more turbid waters than the swamps during low water periods.

Wells and Demas (1977) and the USGS (1980) both noted that dissolved oxygen concentrations in the main channel and major distributaries of the Atchafalaya River generally exceed 5-6 mg/l. The USGS (1980) water quality data were for stations located in the lower Atchafalaya (Bayou Penchant at Bayou Chene, near Amelia, Louisiana) and in Atchafalaya Bay (at Eugene Island). Neither showed values below 5 mg/l (location of sample in water column not indicated but assumed to be mid river and surface or subsurface).

Several studies have been conducted in Fourleague Bay, a subestuary of Atchafalaya Bay (Caffrey and Day, 1986; Madden, 1986; Randall and Day, 1987; Madden *et al.*, 1988; Teague *et al.*, 1988; Childers and Day, 1990a,b; works in progress of J. Day, R. Shaw, and L. Rouse, LSU; works in progress of R. Twilley, Univ. of Southwestern Louisiana, Lafayette; works in progress of M. Dagg and B. McKee, LUMCON). Flow of the Atchafalaya River strongly influences spatial and seasonal patterns of nutrients, suspended sediments and primary production. The estuary receives most of its sediment input and high loadings of nutrients during spring. During low flow in summer and fall, Gulf of Mexico waters dominate Fourleague Bay and increased water clarity provides an opportunity when riverborne and regenerated nutrients can be exploited maximally by phytoplankton. Even during periods when one would expect the river discharge to dominate, climatic conditions can have a significant effect (Caffrey and Day, 1988).

N:P ratios in Fourleague Bay waters average about 30:1, but upper bay ratios are often >100:1 (Madden *et al.*, 1988), thus indicating a potentially large deficiency of phosphorus relative to nitrogen (Figure L17). The seasonal decline in nitrate input with reduced river discharge is followed by a reduction in the N:P ratio, although it rarely falls to 16:1 in the upper bay. During summer and fall there is a major shift in the ratio of inorganic nitrogen to phosphorus in the lower bay. During the spring flood nitrate concentration in upper Fourleague Bay averages 120 μM; in lower Fourleague Bay, 15 μM (Figure L18, Madden *et al.*, 1988). During low flow nitrate concentration in the upper bay averages 30 μM and in the lower bay is often <1 μM.

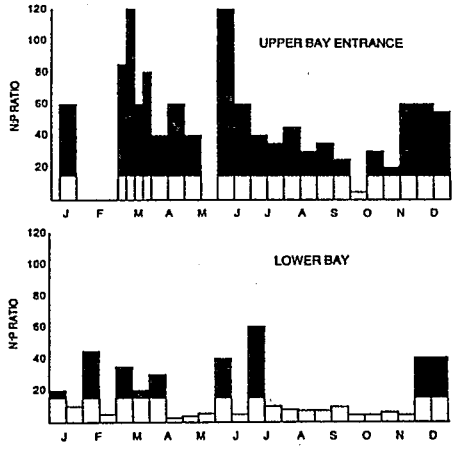

Figure L17. Atomic ratios of inorganic nitrogen to inorganic phosphorus in the Fourleague Bay water column during 1981. Discontinuity at 16:1 Redfield ratio (from Madden *et al.*, 1988).

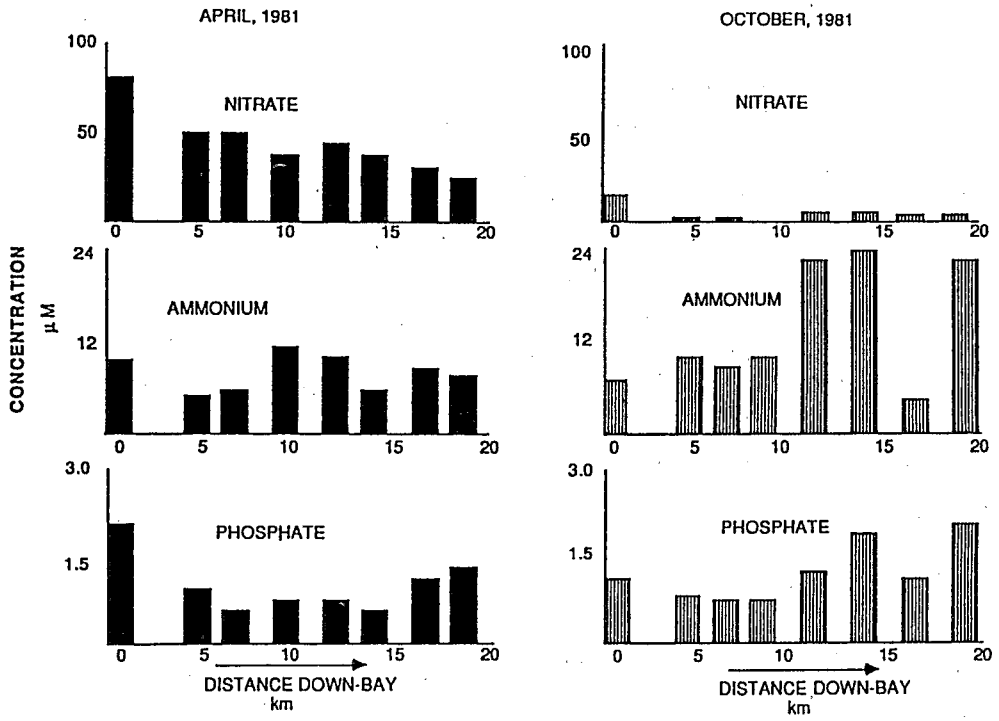

Figure L18. Typical inorganic nutrient concentration gradients in Fourleague Bay along the midbay axis during high and low river flow (from Madden *et al.*, 1988).

Dinophysis sp., probably *Dinophysis caudata*, has been documented recently in an estuary of the Atchafalaya River, Fourleague Bay (Q. Dortch *et al.*, personal communication). *D. caudata* has been recognized recently as a toxic dinoflagellate which may contribute to the accumulation of toxins responsible for diarrhetic shellfish poisoning (DSP) in shellfish in Mobile and Galveston Bays (R. Dickey, personal communication). The population of *Dinophysis* sp. documented in Fourleague Bay was not in bloom proportions and not implicated in shellfish poisoning.

REFERENCES: G-12

Boesch and Rabalais (1989b)
Caffrey and Day (1986)
Cent. Wetland Res. (1970)
Childers and Day (1990a,b)
Craig *et al.* (1977)
Cunningham (1980)
Hern *et al.* (1978)
Juneau (1975)
La. Dept. Envir. Qual. (1987-90)
Lurry (1983)
Madden (1986)
Madden *et al.* (1988)
Rabalais *et al.* (1991b)
Randall and Day (1987)
Sager (1976)
Teague *et al.* (1988)
Turner and Rabalais (1991a)
Wells and Demas (1977)
Wiseman and Swenson (1987)

G-13 Vermilion/West Cote Blanche/East Cote Blanche Bays

Water quality of the Vermilion-Atchafalaya Bay complex is strongly influenced by the discharge from the Atchafalaya River delta and Wax Lake Outlet. There are obvious east-west differences in water temperature and salinity (Juneau, 1975). Water quality data were collected for 17 stations in 1972-1974 in surface and near-bottom waters (Juneau, 1975). Surface and bottom water temperature, salinity and dissolved oxygen levels were similar during the study period, indicating a well-mixed water column. Dissolved oxygen concentrations averaged near 8 mg/l. The highest average nitrate value was at East Bay during April 1972 with a value of 26.73 µg-at/l; the highest single value was 39.90 µg-at/l at Dry Reef-Vermilion Bay. The lowest monthly average nitrate value occurred at Oyster Lake during July 1972 with a value of 0.3 µg-at/l. These differences in nutrients reflect the high and low flow periods of the river, respectively. Similar lows and highs for nitrate, inorganic phosphate and total phosphorus were found seasonally.

Environmental data were collected along with day and night trawls in 1968-1969 (Dugas, 1975). The dissolved oxygen readings, as expected, decreased during the night and gradually increased during the day (not indicated, but assumed to be surface readings); values through all seasons did not fall below approximately 6 mg/l. Turbidity was controlled by wind mixing events in the shallow bay.

Dissolved oxygen values for this system were determined for three stations sampled monthly between October 1974 ad September 1976 (Barrett *et al.*, 1978). In August at each station, dissolved oxygen levels decreased but did not fall below 2.6 mg/l.

REFERENCES: G-13

Barrett *et al.* (1978)
Cahoon and Groat (1991)
Cent. Wetland Res. (1970)
Cunningham (1980)
Dugas (1975)
Juneau (1975)
Wiseman and Swenson (1987)

G-14 Mermentau River/Grand/White Lakes

No update since the Rabalais *et al.* (1985) review. These systems are mostly freshwater marshes and lakes, although they once contained brackish water as a result of saltwater intrusion from the Gulf of Mexico. Control systems to prevent this and create reservoirs suitable for rice irrigation make the lakes freshwater most of the time (Shampine, 1971). No data were available for this area. Data concerning several marsh management areas are given in Cahoon and Groat (1991).

REFERENCES: G-14

Cahoon and Groat (1991)
Cent. Wetland Res. (1970)
La. Dept. Envir. Qual. (1987-90)
Shampine (1971)
Wiseman and Swenson (1987)

G-15 Calcasieu River/Lake/Pass

Calcasieu Lake, with the exception of the 12-m ship channel, is quite shallow, averaging 2 m in depth (Lee *et al.*, 1990). The lake is surrounded by brackish marsh and receives discharge from the Calcasieu River, which enters from the north. The long north-south axis of the lake is approximately 28 km. Calcasieu Pass joins the lake with the Gulf of Mexico. Calcasieu Lake is vertically homogeneous, a reflection of its shallow depth, the tidal and wind energy available for mixing, and the low mean discharge of the Calcasieu River.

The Calcasieu River is heavily industrialized within the city of Lake Charles north of Lake Calcasieu. Land use around Lake Calcasieu is rice farming to the north, particularly north of the Gulf Intracoastal Waterway, and marshland (mostly managed) and wildlife refuges.

The Calcasieu Basin was the focus of a major water quality program by the Water Pollution Control Division of the Louisiana Dept. of Environmental Quality beginning in 1978. These studies were designed to address the sources, fate and effects of point and nonpoint sources of oxygen-consuming materials and toxic substances in order to define water pollution control and best management practices necessary to meet the State's water quality standards for water quality limited segments of the Calcasieu Basin. The Calcasieu Estuary is currently listed (Louisiana Dept. of Environmental Quality, 1990) as a "water body under advisory: toxics related concerns." The Calcasieu Estuary has a history of unpermitted discharges (spills) and discharges exceeding effluent permit limitations. Wastewater discharge permits for the major industrial facilities are being reviewed and revised. The state will continue efforts to monitor and improve water quality in the Calcasieu Estuary.

Several water quality monitoring programs have been conducted in the Calcasieu estuary. Barrett *et al.* (1978) conducted monthly sampling between October 1974 and September 1976 in the Lake and Pass. Additional data were collected during the Dept. of Energy, Strategic Petroleum Reserve Program, monitoring of the West Hackberry brine disposal site. These data (for February 1981 through February 1983) were obtained originally from G. Gaston (Univ. of Mississippi, Oxford, formerly McNeese Stat Univ., Lake Charles) and subsequently published in reports (DeRouen *et al.*, 1982, 1983). Data were obtained from the Louisiana Dept. of Environmental Quality in the form of field reports and some synthesized synoptic surveys of the basin on selected dates in mid summer 1984.

The surveys of Barrett *et al.* (1978) recorded no dissolved oxygen values below 3 mg/l. In general, low dissolved oxygen values are not a problem in Lake Calcasieu where there is little stratification in the shallow, wind-mixed water column. Strong salinity stratification is restricted to the Calcasieu Ship Channel and Calcasieu Pass. Within the ship channel, low oxygen levels (1.4 to 3.0 mg/l) are more prevalent in the area between the Gulf Intracoastal Waterway and the city of

Lake Charles. In Calcasieu Pass, the DEQ data indicated less of a problem than the upper reaches of the channel, because there is better tidal flushing. The data provided by G. Gaston, however, indicated anoxic and hypoxic water in the Pass in June, July, September and October. The Calcasieu River experiences very low oxygen concentrations which are lowest in July-October and frequently reach anoxic levels, 0.0-0.3 mg/l.

A limited set of nutrient data was available from a June 1984 survey of the Calcasieu basin, but provided no insight.

Two red tide producing organisms were documented in water samples taken monthly along a transect through Lake Calcasieu and Calcasieu Pass (Maples *et al.*, 1983)--these were *Prorocentrum minimum* and *Gonyaulax monilata*. No fish kills, jubilees or discolored waters were associated with the presence of these organisms. Another dinoflagellate, *Dinophysis caudata*, was recorded at the opening of Calcasieu Pass to the open Gulf of Mexico. *D. caudata* has been recognized recently as a toxic dinoflagellate which may contribute to the accumulation of toxins responsible for diarrhetic shellfish poisoning (DSP) in shellfish in Mobile and Galveston Bays (R. Dickey, personal communication). The population of *Dinophysis* sp. documented in Calcasieu Pass was not in bloom proportions and not implicated in shellfish poisoning.

REFERENCES: G-15

Barrett *et al.* (1978)
Cent. Wetland Res. (1970)
Craig *et al.* (1977)
Day *et al.* (1979)
Dennis *et al.* (1984)
DeRouen *et al.* (1982, 1983)
Haddad and Carder (1979)
La. Dept. Envir. Qual. (1987-90)
Lee *et al.* (1990)
Lurry (1983)
Maples *et al.* (1983)
Wiseman and Swenson (1987)
Wiseman *et al.* (1990)

TEXAS

Several state agencies collect data on water quality. The primary agencies are the Texas Water Development Board (formerly Texas Department of Water Resources), Texas Water Commission, and Texas Parks and Wildlife Department. Much of the data collected is used in modeling the freshwater inflows to the estuaries for management needs. With the exception of the Sabine and Galveston estuaries, the remaining Texas estuaries fall into a semi-arid habitat classification with rainfall averages of less than 24 in/yr. Freshwater inflow into Texas estuaries is, therefore, disproportionate with dramatic decreases southward (Figures T1 and T2). Much of the rainfall along the Texas coast is aperiodic and extremely variable between years. Prolonged trends of moist periods and droughts last 10 to 25 years. Many streams and rivers in Texas are controlled by dams and reservoirs; the need to manage fresh water is important within the State. In order to provide necessary water planning and management information on the effects of and needs for freshwater inflows to the bays and estuaries of Texas, a Texas Bays and Estuaries Program was established to conduct estuarine-wide studies. The research has been performed in cooperation with the Texas Parks and Wildlife Department, the Texas Water Commission and other interested state agencies and universities, including the Texas Department of Health, The University of Texas, Texas A&M University, and Corpus Christi State University. Many of these research programs will be identified in the following area descriptions.

Parts of the Texas coast are heavily urbanized and industrialized. These centers of point-source discharges are located in the Sabine estuary, the Galveston estuary, and the Corpus Christi estuary (Figure T3).

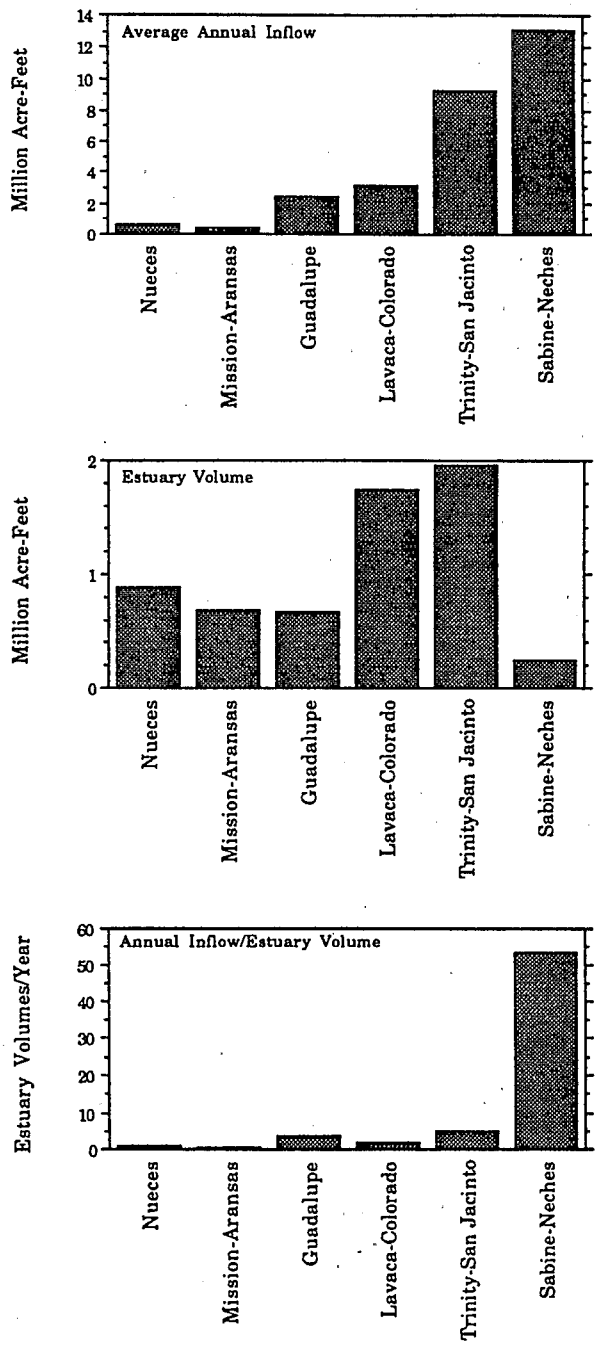

Figure T1. Average annual inflow, estuary volume, and inflow/volume ratio, 1941-1987 (Texas Water Development Board, G. Powell, personal communication).

A synthesis of nutrient loadings into each of the major Texas estuaries was developed by Armstrong (1982) (cited in Armstrong, 1987) (Table T1). The relative proportions of nutrients are influenced by several factors, including the amount of freshwater inflow and the receiving volume. The Sabine estuary receives the highest areal loading, because of its large freshwater inflows. There is a general decrease in areal loading rates with direction southward to the Laguna Madre. Nutrients derived from freshwater inflows dominate the nutrient budgets of all estuaries; marsh contributions and precipitation are minimal. Armstrong (1987) also provides a synthesis of the information concerning phytoplankton assemblages, primary production and zooplankton and nekton population estimates across the major Texas estuaries (Table T2).

The Texas Parks and Wildlife Department collects surface water samples with its monthly gill net and bag seine samples throughout Texas estuaries during spring and fall collection periods. For all the Texas Bay systems sampled (G-16, G-17, G-19, G-21, G-22, G-23, G-24, G-26.1, land G-26.2) between 1975 and 1986, the surface oxygen levels were within the range expected, and there were no obvious trends for an increase in these values (Hegen, 1983; Rice *et al.*, 1988). Surface dissolved oxygen readings are available in previous reports by Martinez (1969-1975). Turbidity readings taken at the same time indicate that concentrations of suspended materials are controlled by meteorological events. Recent trends in increased turbidity within the Laguna Madre system, however, may be related to changes in land use on its periphery, *i.e.*, increased pastureland being converted to cropland.

Fish kill data from the NOAA Fish Kill Inventory are shown in Table T3.

Algal bloom information is routinely collected and synthesized by the Texas Water Commission in Corpus Christi (formerly by D. Jensen, now with Corpus Christi State University, Oil Spill Prevention and Cleanup School, and currently by J. Bowman).

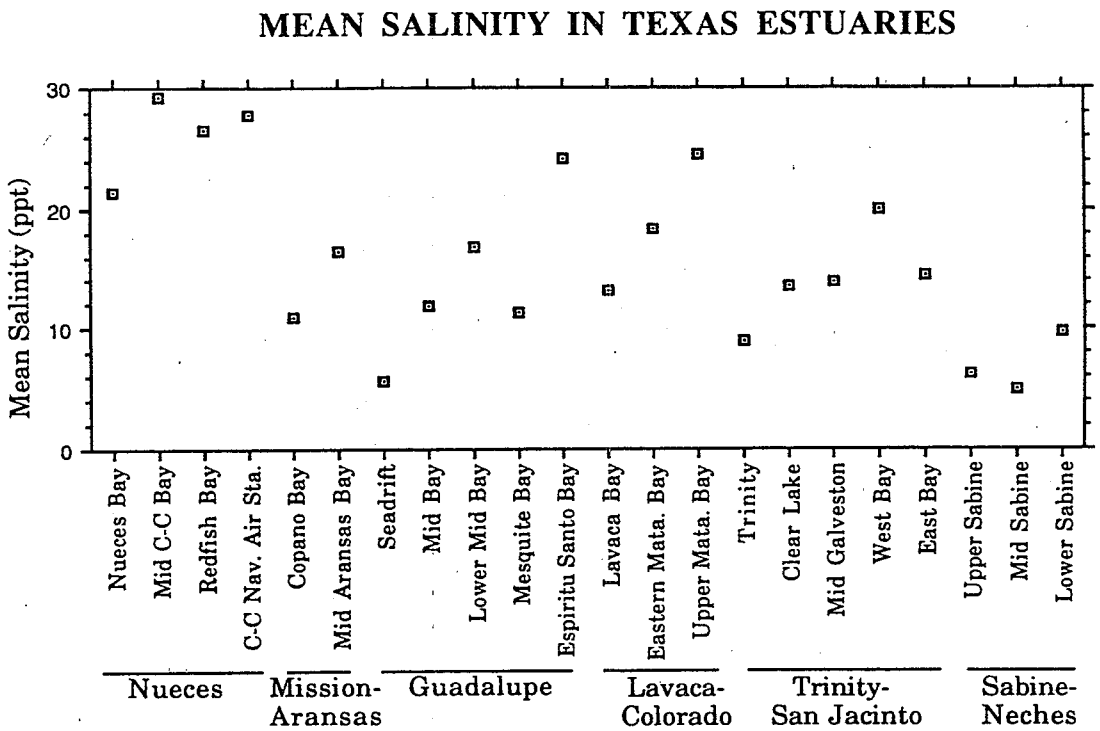

Figure T2. Mean salinity in Texas estuaries (Texas Water Development Board, G. Powell, personal communication).

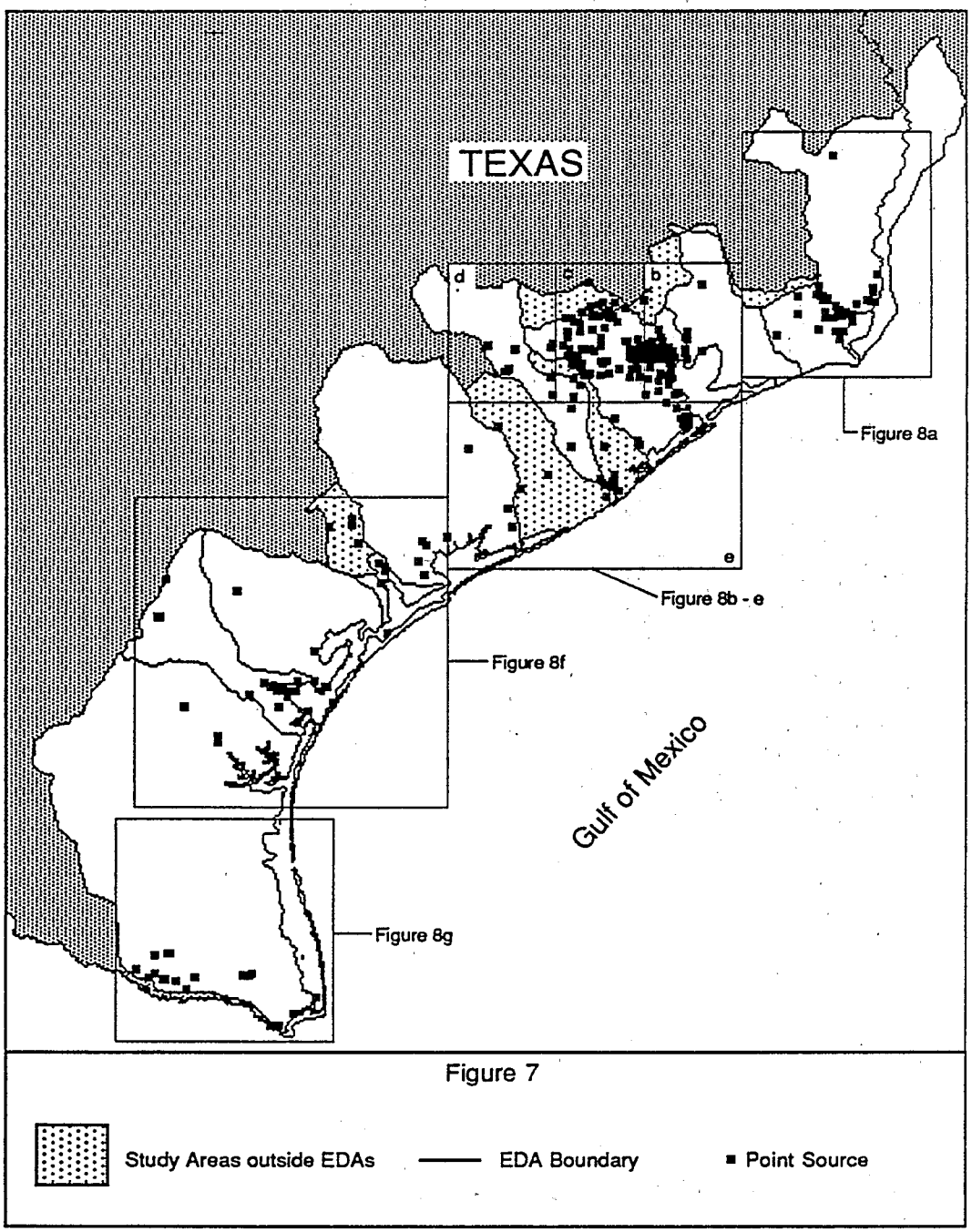

Figure T3. General location of major facilities in the NCPDI study area in Texas (from Pacheco *et al.*, 1989c).

Table T1. Carbon, nitrogen, and phosphorus loading budgets for Texas estuaries (from Armstrong, 1987).

Nutrient	Estuary	Freshwater inflows (10^6kg/yr)	Marshes		Precipitation (10^6kg/yr)	Total (10^6kg/yr)	Areal loading (g/m^2/yr)
			Tidal (10^6kg/yr)	Flood (10^6kg/yr)			
Carbon	Sabine Lake	115.70	2.50	1.44		119.64	672.20
	Galveston Bay	103.44	4.02	0.14		107.60	75.20
	Matagorda Bay	75.75	5.35	0.14		81.62	80.50
	San Antonio Bay	17.95	0.88	0.30		19.13	34.10
	Copano-Aransas Bays	5.98				5.98	12.90
	Corpus Christi Bay	8.21	9.11	0.42		17.74	39.90
	Laguna Madre	6.00				6.00	2.90
Nitrogen	Sabine Lake	9.32	0.02	0.36	0.04	9.75	54.80
	Galveston Bay	11.58	0.12	0.04	0.34	12.08	8.40
	Matagorda Bay	3.58	0.05	0.04	0.51	4.33	4.30
	San Antonio Bay	5.80	0.01	0.08	0.14	6.02	10.70
	Copano-Aransas Bays	0.44			0.11	0.55	2.00
	Corpus Christi Bay	0.55	0.02	0.01	0.11	0.68	1.52
	Laguna Madre	0.61				0.61	.28
Phosphorus	Sabine Lake	0.74	0.50	0.41	0.01	1.21	6.82
	Galveston Bay	3.63	0.09	0.04	0.04	3.81	2.66
	Matagorda Bay	1.31	0.11	0.04	0.04	1.54	1.52
	San Antonio Bay	1.00	0.02	0.09	0.02	1.12	2.00
	Copano-Aransas Bays	0.07			0.01	0.08	0.18
	Corpus Christi Bay	0.22	0.18	0.12	0.01	0.53	1.20
	Laguna Madre	0.72				0.72	0.34

GENERAL REFERENCES: TEXAS

ASIWPCA (1984)
Basta and Bower (1985)
Burrage (1989)
Culliton and Blackwell (1989)
Diener (1975)
Ehler and Basta (1985)
EPA (1974, 1978)
Hackney (1978)
Longley (1992)
Main *et al.* (1987)
Martinez (1969-1975)
Orlando *et al.* (1991)
Pechmann *et al.* (1986)
NOAA/EPA Team (1990)
Shew *et al.* (1981)
Texas Water Dvlt. Bd. (1973)
Trebatowski (1988)

Table T2. Summary of the major characteristics of phytoplankton assemblages in the open-bay bottom biotopes of Texas estuaries (from Armstrong, 1987).

Estuary	Seasonal phytoplankton abundance (cells/ml)[a] Minimum	Maximum	Dominant groups (by % of)	Primary production estimate (g C/m^2/day)[b]
Sabine Lake	70 (W)	200 (S)	Diatoms (45%) Green algae (36%)	ND
Galveston Bay (Trinity Bay)	50 (F)	400 (W-Sp)	Diatoms (41%) Green algae (25%) Blue-green algae (23%)	5.87
Lavaca Bay	150 (S)	4,500 (W)	Diatoms	
San Antonio Bay	549 (F)	19,000 (W)	Dinoflagellates	1.0
Aransas Bay	6 (S)	381 (W)	Diatoms	
Corpus Christi Bay	50 (S-F)	900 (W-Sp)	Diatoms Blue-green algae	2.52 (0.91)[c]
Nueces Bay	7 (S-F)	300 (W-Sp)	Diatoms Blue-green algae	0.52
Oso Bay and Upper Laguna Madre	ND (S)	1,600 (W)	Diatoms	2.75
Lower Laguna Madre	ND	ND	Diatoms	1.79

[a]Seasons are: S = summer, F = fall, W = winter, Sp = spring.
[b]Carbon fixation based on oxygen method of measurement.
[c]Carbon fixation based upon ^{14}C method of measurement and converted to gross production.

G-16 Sabine Lake/Pass (Sabine-Neches Estuary, includes Sabine Lake, Sabine Pass)

The Sabin estuary lies along the Texas-Louisiana border, has a surface area of 17,798 ha, and receives inflow from the Sabine and Neches Rivers (Armstrong, 1987). Water depths at mean low water vary from about 3 m or less in Sabine Lake to greater than 12 m in dredged areas; the average depth is about 1.8 m. Much of the area around Sabin Lake is in urban and industrial land use in the "Golden Triangle" area of Beaumont, Port Arthur and Orange (see Figure T3 for the relative proportion of point source discharges in the estuarine drainage basin.). Marsh land comprises a sizable percentage of lands near the estuary with urban populations centered on the south and west of Sabine Lake, while the balance parallels the Sabin and Neches Rivers at the head of the estuary.

Table T3. Summary of NOAA Fish Kill Inventory Data for Texas (draft data base, 1991; J.A. Lowe, personal communication; see section on Data Sources).

AREA County	Records per County	Cause Low DO	Cause Eutrophication	Cause Red Tide	Cause Nutrient	Cause Unknown or Unspecified
SABINE						
Jefferson	60	6	0	0	1	9
Orange	50	8	0	0	0	5
GALVESTON						
Chambers	45	16	0	0	0	12
Galveston	176	100	0	0	0	8
Harris	100	34	1	0	0	16
BRAZOS						
Brazoria	78	19	0	0	0	9
MATAGORDA						
Matagorda	68	16	2	6	1	8
SAN ANTONIO						
Calhoun	23	16	2	0	0	4
ARANSAS						
Aransas	25	1	0	1	0	3
Refugio	3	0	0	0	0	1
San Patricio	11	4	0	0	0	0
CORPUS CHRISTI						
Nueces	24	6	1	1	0	3
UPPER LAGUNA MADRE						
Kenedy	1	0	0	0	0	1
Klegerg	4	2	0	0	0	0
LOWER LAGUNA MADRE						
Cameron	14	4	0	0	0	1
Willacy	0	0	0	0	0	0

Little new environmental data were available for this estuary. A reassessment of bottom water dissolved oxygen values from the Texas Department of Water Resources, Coastal Data System, indicated that most of the low dissolved oxygen values occur in the deeper channels and tidal rivers. Many values in the Sabine and Neches Rivers fell below 1 mg/l or were anoxic. There were fewer low oxygen values (<2 mg/l) in Sabine Pass than in the Sabine-Neches Canal and the Port Arthur Canal because of increased tidal flux at the former. A few values at the opening of Sabine Pass approached anoxia. In Sabine Lake, of many values for the open water environments, only one fell below 2 mg/l.

REFERENCES: G-16

Armstrong (1987)
Dennis *et al.* (1984)
DeRouen *et al.* (1982)
Hahl and Ratzlaff (1970, 1972, 1975)
Lind (1983)
Monaco *et al.* (1989)
Pacheco *et al.* (1989)
Rice *et al.* (1988)
TDWR (1981b)
Turner and Rao (1990)

G-17 Galveston/East/West Bays (Trinity-San Jacinto Estuary, includes Galveston, East, West, and Trinity Bays, Bolivar Pass, GIWW)

The Galveston Bay estuary is the second largest on the Texas coast with a surface area of 143,153 ha (Armstrong, 1987). It has an average depth of 2.1 m, although it is traversed by a major navigation channel, the Houston Ship Channel, which extends from the mouth of the estuary through Galveston Bay and into the San Jacinto River Channel, turns west into Buffalo Bayou and ends on the east side of Houston. Most of the industrial complex in the Houston area borders this navigation channel. The major freshwater inflows to Galveston Bay come from the Trinity and San Jacinto Rivers.

The Galveston Bay complex is heavily industrialized (see relative proportion of point-source discharges in Figure T3). Major chemical and petrochemical plants line the estuary and extend far inland along the Houston Ship Channel and other dredged canals. Unpermitted discharges (spills), inadequate waste treatment and stormwater runoff are mechanisms by which chemical pollutants enter the Galveston Bay system. Evidence for the potential impacts that toxics carried into the system may have is a recent report of the occurrence of the solvent, 2-butoxy ethanol, in Gulf of Mexico waters adjacent to Galveston Bay (Baton Rouge *Morning Advocate*, July 6, 1991). The compound was isolated from Gulf waters which were used in laboratory toxicity tests and found to be toxic to larval shrimp. The report indicated that heavy rains in the Galveston Bay complex during the spring and early summer flushed the toxic chemical into the nearshore waters of the Gulf. Other contaminants affect fisheries resources. During the last 30 years, large portions of the bay, usually around the shoreline, have remained closed to shellfishing, primarily as a result of high levels of coliform bacteria introduced by runoff from surrounding lands.

Galveston Bay was designated an estuary in the EPA National Estuary Program because of its significant natural resources and the threats impinging upon those resources from pollution, development or overuse. The EPA Galveston Bay National Estuary Program has established a Galveston Bay Information Center which will 1) conduct a Galveston Bay literature survey and 2) develop a reference collection of the identified literature. This work is in progress (F. Shipley, personal communication). A workshop to characterize problems in Galveston Bay as part of the EPA National Estuary Program was held in February 1991 (Shipley and Kiesling, 1991). The purpose of the meeting was to synthesize information prior to the development of a Comprehensive Conservation and Management Plan.

A NOAA-funded study was conducted in the Galveston Bay estuarine complex to determine long-term trends in water quality and their relationships to the living resources (Stanley, 1989); similar studies were conducted in Narragansett Bay, Delaware Bay, and the Pamlico River estuary. Data for the Houston Ship Channel, open Galveston Bay and the Trinity River were targeted for analysis. The Houston Ship Channel is heavily populated and industrialized. The analysis of the long-term data set indicated that low dissolved oxygen levels in bottom waters have been alleviated during the last 20 years (Figure T4) and that BOD loading to the system has gone down (Figure T5). Data from 1968-1988 in the ship channel indicated that surface water dissolved oxygen content has gone up, bottom water oxygen levels no longer fall below 1.5 mg/l, ammonia has decreased, nitrate has increased, and overall DIN has decreased but not as dramatically (Figure T6) (Stanley, 1989). Phosphorus concentrations in the ship channel have shown about the same temporal spatial trends as those for nitrogen.

Analyses of nekton populations in the upper portions of the Houston Ship Channel indicate an increase in abundance and diversity with concomitant improvement in water quality since the mid 1970s (Seiler *et al.*, 1991). Dissolved oxygen data compiled for 1988-1989 by Seiler *et al.* (1991) in their nekton studies indicated extended periods in mid summer of both years where bottom waters in Segment 1007 (uppermost Houston Ship Channel near turning basin) were hypoxic or near-anoxic (Figure T7). Bottom water dissolved oxygen concentrations in Segment 1006 (lower

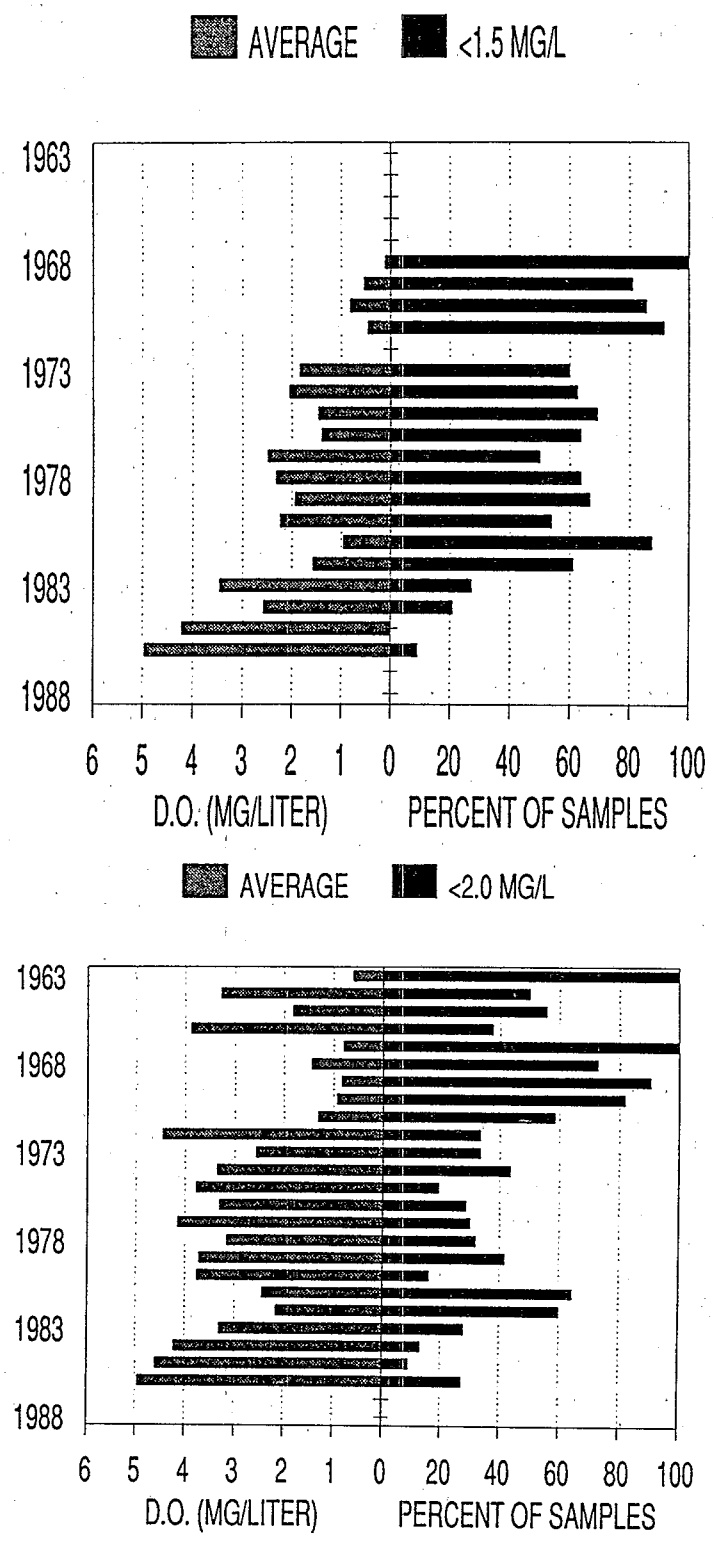

Figure T4. Trends in annual mean surface dissolved oxygen in Houston Ship Channel Segment 1007 (Turning Basin) (upper panel) and Channel Segment 1006 (Greens Bayou to San Jacinto River) (lower panel) (from Stanley, 1992).

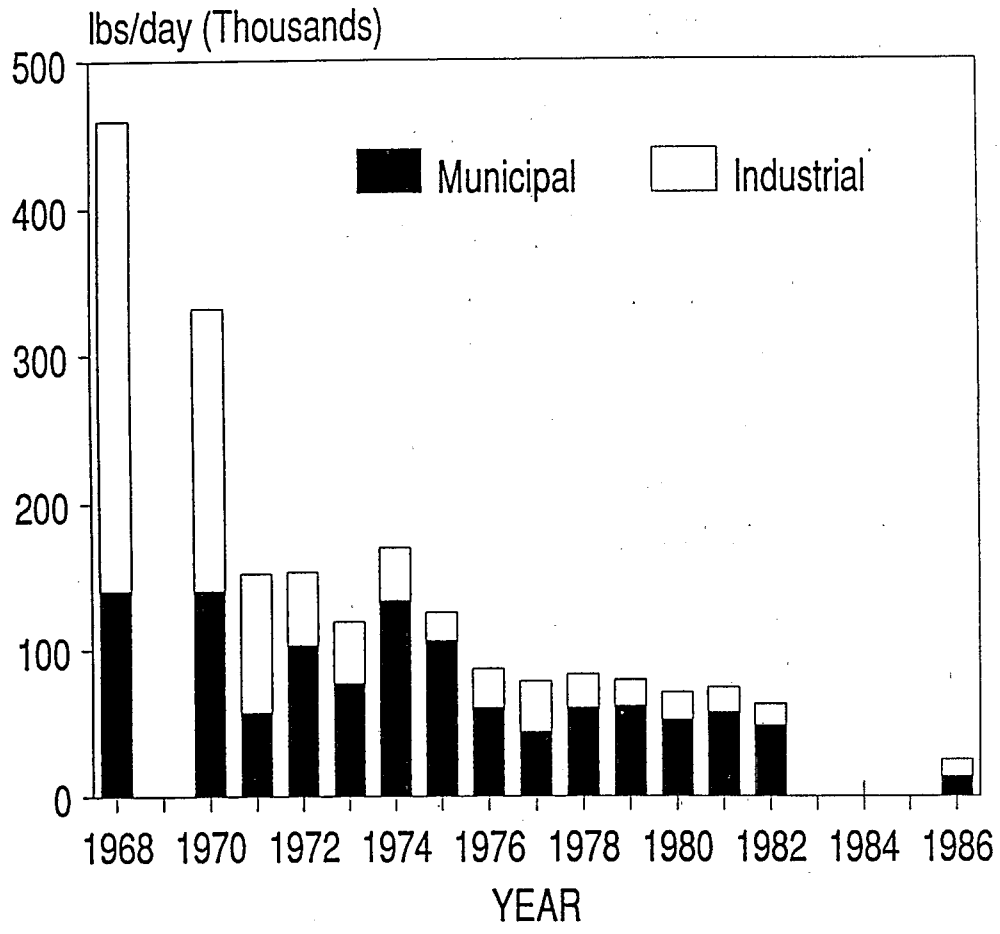

Figure T5. Trends in BOD loading to the Houston Ship Channel between 1968 and 1986 (from Stanley, 1992).

Houston Ship Channel near Tabbs Bay confluence) were consistently higher for the same timer period, in spite of an apparent lack of stratification (Figure T7).

In open Galveston Bay, analysis of trends was more difficult given the paucity of bottom water oxygen data; however, surface water data did not show any obvious trends (Figure T8) (Stanley, 1992). High BOD or low dissolved oxygen have never been found to be problems in the open waters of Galveston Bay (Rabalais, *et al.*, 1985; Stanley, 1992). The average concentration of surface water dissolved oxygen concentrations would be expected to increase as a result of nutrient enrichment and eutrophication (see section on Altered Habitats).

The long-term data for nitrogen and phosphorus were also examined by Stanley (1992). He found that nitrate concentrations appear to have declined after 1972, but that this may be an artifact of the data sets (Figure T9). There was a trend of decreasing nitrate along the increasing salinity gradient from Trinity Bay toward the Gulf of Mexico. Nitrate levels in this system do not seem abnormally high in comparison to other Gulf coast or Atlantic coast estuaries. There have been no obvious trends in the ammonia concentration data (Figure T10). Other than an apparent decrease in total phosphorus in Trinity Bay, there have been no obvious trends in phosphorus concentrations in the

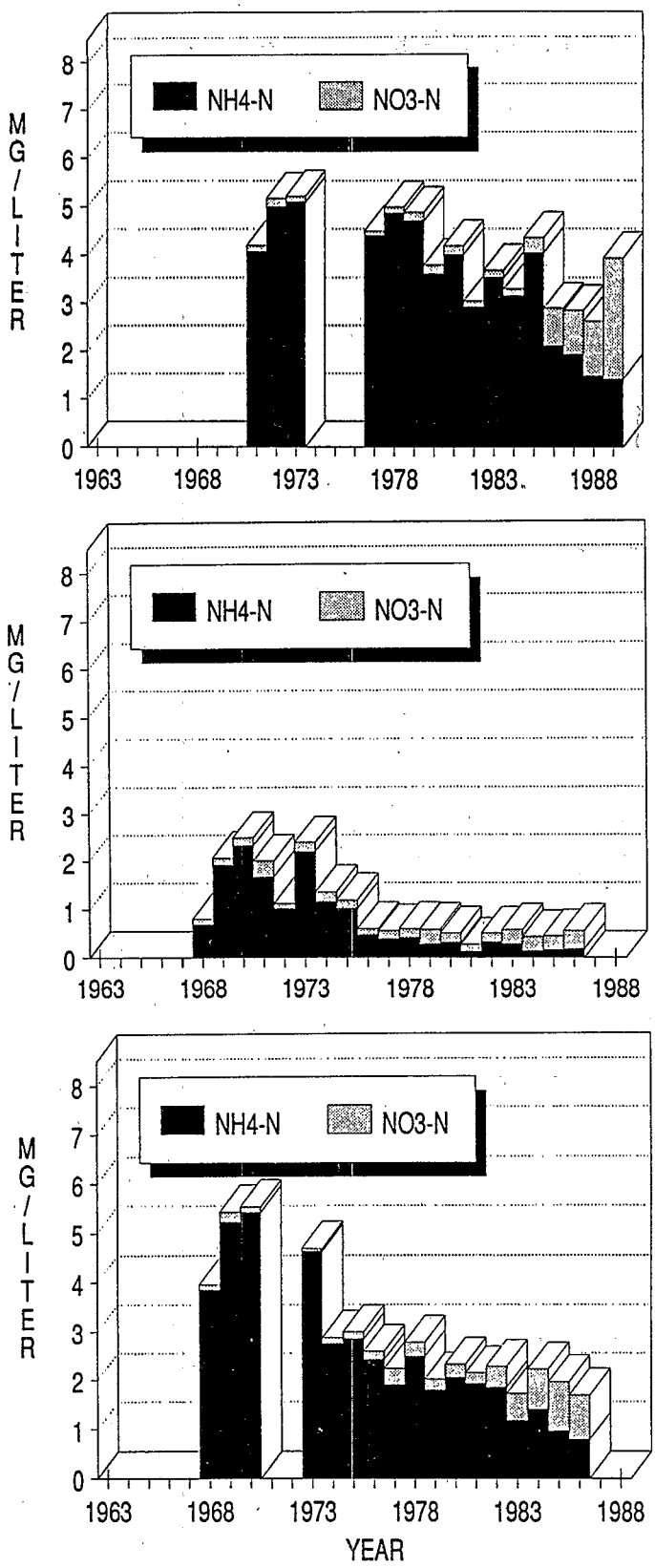

Figure T6. Trends in ammonia and nitrate concentrations in Houston Ship Channel Segment 1007 (Turning Basin) (upper panel), Segment 1005 (San Jacinto River to Morgan's Point) (middle panel), and Segment 1006 (Greens Bayou to San Jacinto River (lower panel) (from Stanley, 1992).

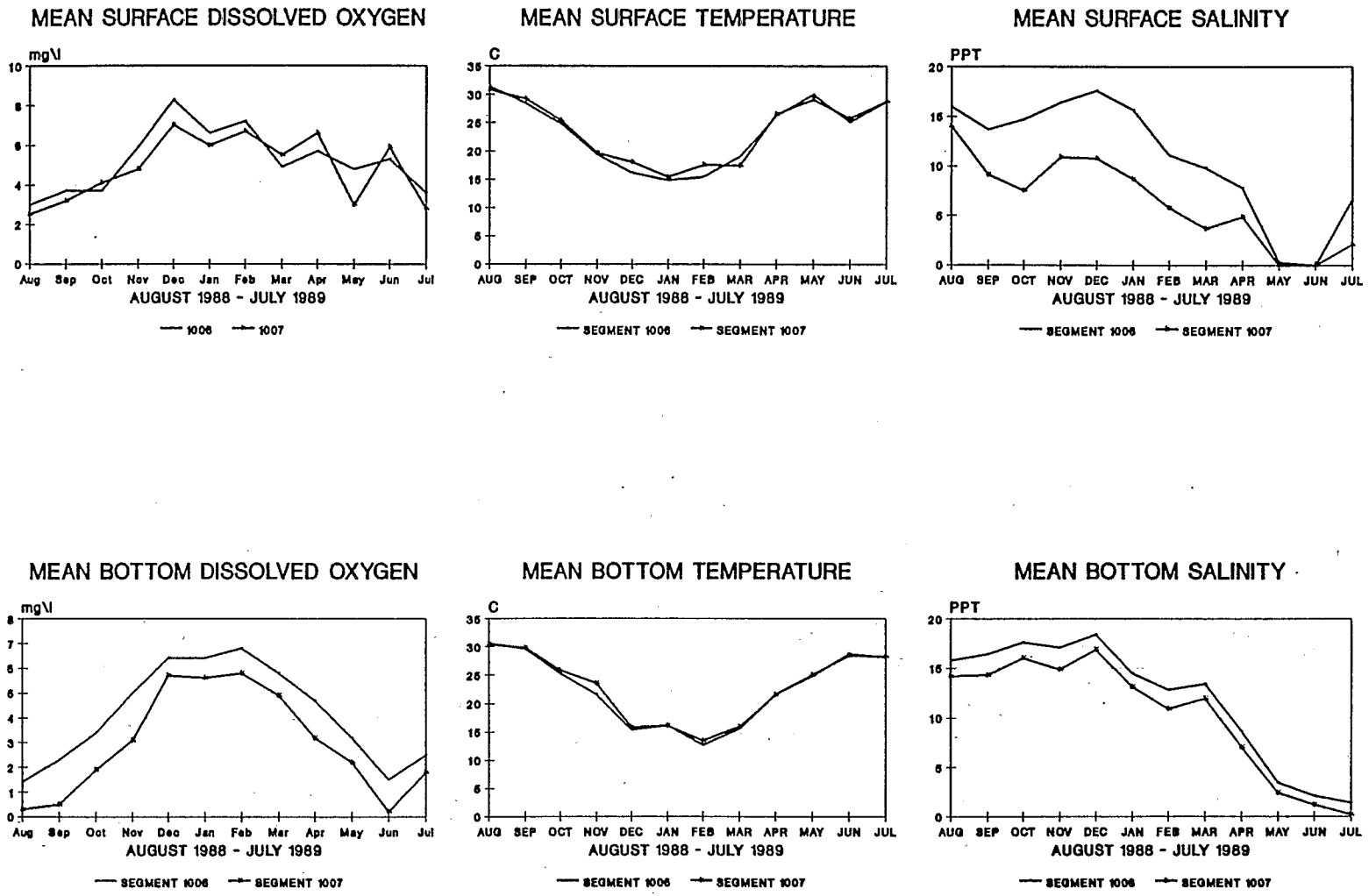

Figure T7. Mean surface and bottom dissolved oxygen, temperature and salinity in Segments 1006 and 1007 of the Houston Ship Channel (from Seiler *et al.*, 1991).

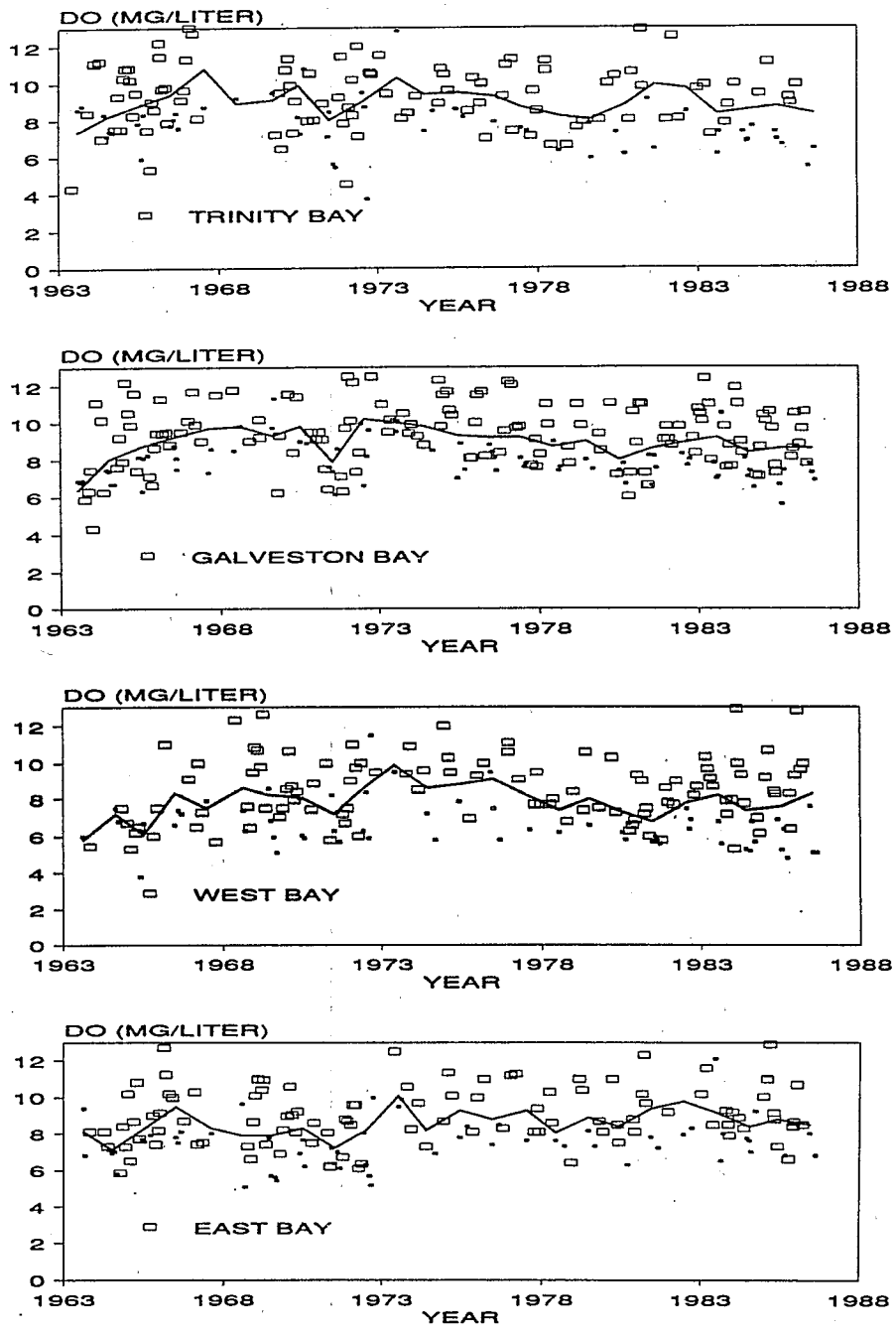

Figure T8. Dissolved oxygen trends in four areas of the Galveston Bay system, 1963-1986 (from Stanley, 1992).

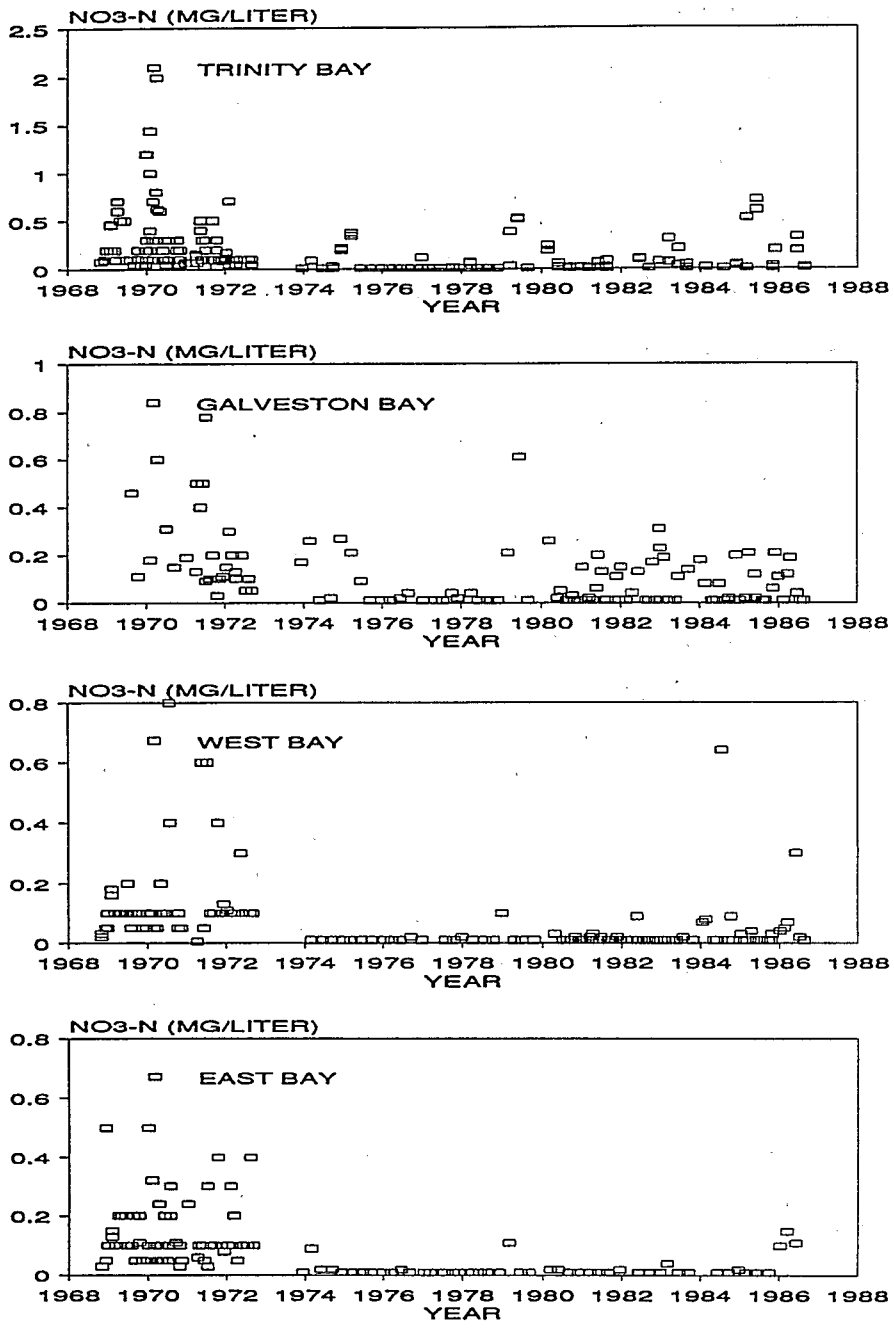

Figure T9. Nitrate nitrogen concentration trends in four areas of the Galveston Bay system, 1968-1986 (from Stanley, 1992).

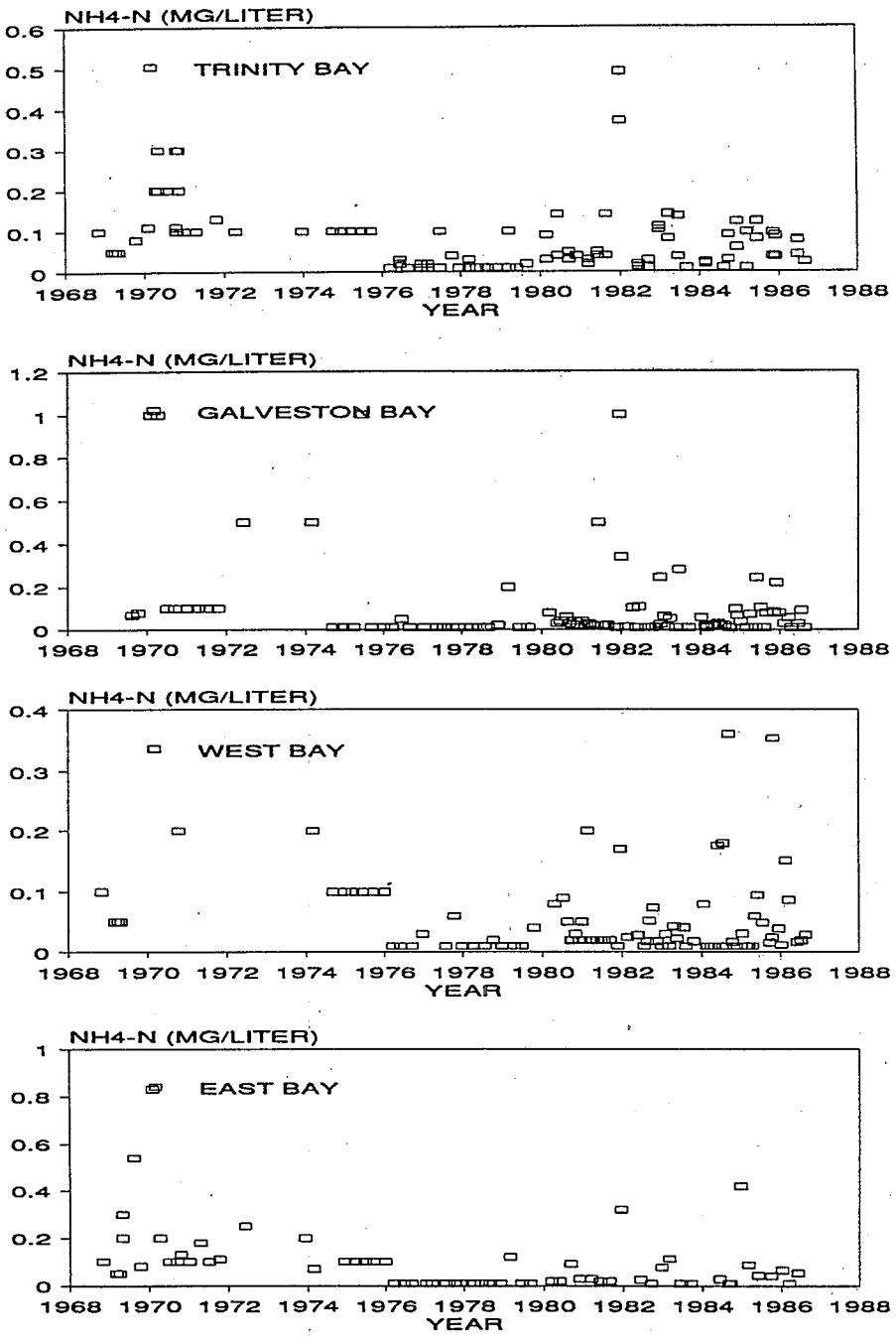

Figure T10. Ammonia nitrogen concentration trends in four areas of the Galveston Bay system, 1968-1986 (from Stanley, 1992).

bay system over the past 20 years (Figure T11). Preliminary results from a similar analysis of Galveston Bay nutrient data (1980-1989) (Santschi and Samuell, 1991) indicated strong seasonal- and salinity-related patterns to the distribution of phosphate, nitrate and total inorganic nitrogen concentrations.

Very few low dissolved oxygen values are found in the bottom waters of the shallow open bays. There were area-wide low dissolved oxygen values (but only a few <2 mg/l) in July 1976 in Galveston Bay and those stations in East Bay closest to Galveston Bay, but this did not occur in other years (Rabalais *et al.*, 1985). Limited low oxygen values have been recorded in Trinity Bay and East Bay in the hottest months when wind mixing of the water column does not occur. In the East Bay area, dissolved oxygen concentrations fluctuated between 0 and 4 mg/l in July and August 1982 (Figure T12) (Ambler, 1982).

In the upper parts of Trinity Bay, there are more problems year-round with low dissolved oxygen concentrations in bottom waters because of reduced mixing and the heavy industrialization of the area. Historically, the lowest oxygen levels are in the channels, particularly the Houston Ship Channel, but the trend in the Houston Ship Channel has reversed over the last 20 years. Low values, below 2 mg/l and often below 1 mg/l, have been recorded in Barbour's Cut, Texas City Ship Channel, Bayport Channel, Galveston Channel and Dickinson Bayou. Among the channels, those closer to the Gulf of Mexico with increased tidal exchange have less frequent occurrences of low dissolved oxygen.

The Texas Water Development Board has conducted many long-term deployments of water quality instrumentation in selected Texas estuaries to follow continuous variations in near-bottom water salinity, temperature and dissolved oxygen (Longley, 1992). Results from these deployments have been provided by the Texas Water Development Board (Longley, 1992). The results for dissolved oxygen concentrations must be reviewed in the context of the instrumentation and the environments in which deployed. The instruments become fouled with algae and bryozoans and the oxygen probe fails at the end of the record (G. Powell, personal communication). Weekly changes in the instrumentation across a series of sites is prohibitively expensive and logistically difficult; still, pilot studies have been conducted in a few estuaries.

Deployments were made in Galveston Bay, off Dollar Point for most of 1988. While the data from the deployment in October 1988 (Figure T13) show no dissolved oxygen levels below 2 mg/l, the data are displayed to show the decay in the oxygen probe with time and the recovery of the signal when exchanged with a new instrument with a freshly installed and calibrated oxygen probe. During 1988 no values from February-June or August-December fell below 2 mg/l. [This analysis is based on the first seven days of the instrument deployment.] During January, many values were below this level and registered zero; however, changing of the instrumentation in February alleviated this problem. The data from January are assumed to be inaccurate, especially since the water temperatures should have been conducive to high dissolved oxygen content.

Stanley (1989) presented data summarized by Johnson (1975) on Galveston Bay fish kills for the period 1962-1974. Most kills occurred during the summer; many were located in the semi-enclosed harbor at Texas City; few were in open water; most of the kills in the ship channel were attributed to oxygen depletion or sewerage operations; open bay kills were attributed to oxygen depletion, pesticides, petrochemicals, bacterial infections and unknown causes. Although there is an increase in the number of fish killed in the system since 1975, this has been attributed to increased monitoring and reporting (Stanley, 1989). Fish kills in Dickinson Bayou in 1972 were directly related to sewage outfall, increased and dense algal blooms, and subsequent oxygen depletion (Knudson and Belaire, 1975). According to the NOAA Fish Kill Data Inventory (Lowe *et al.*, 1991), the Galveston Bay estuary drainage area had the highest number of fish killed of all counties in the entire Gulf of Mexico study area. Half of these kills were attributed to low-dissolved oxygen levels that were not associated with a land-use cause. This drainage area also

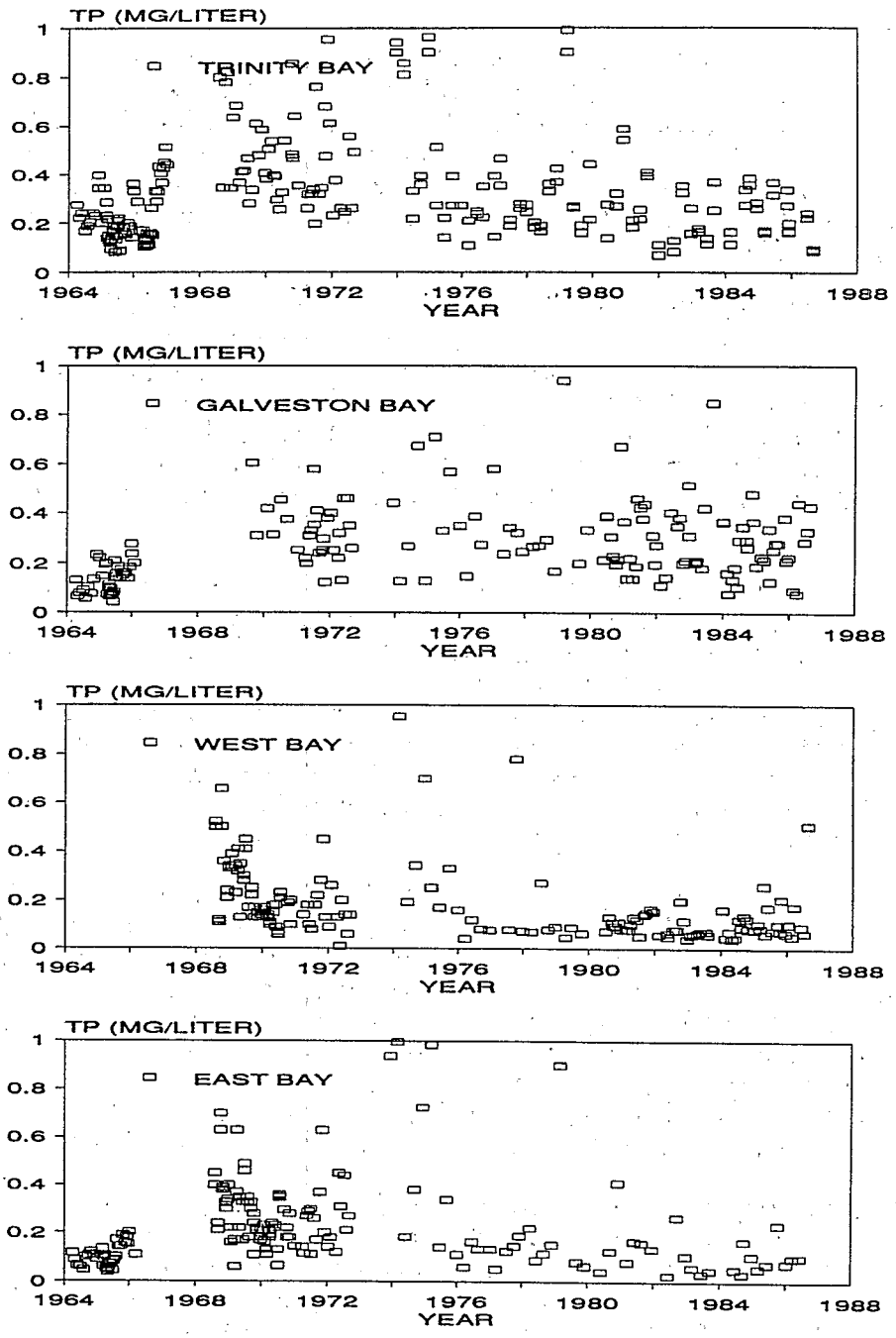

Figure T11. Trends in total phosphorus concentrations in four areas of the Galveston Bay system, 1963-1986 (from Stanley, 1992).

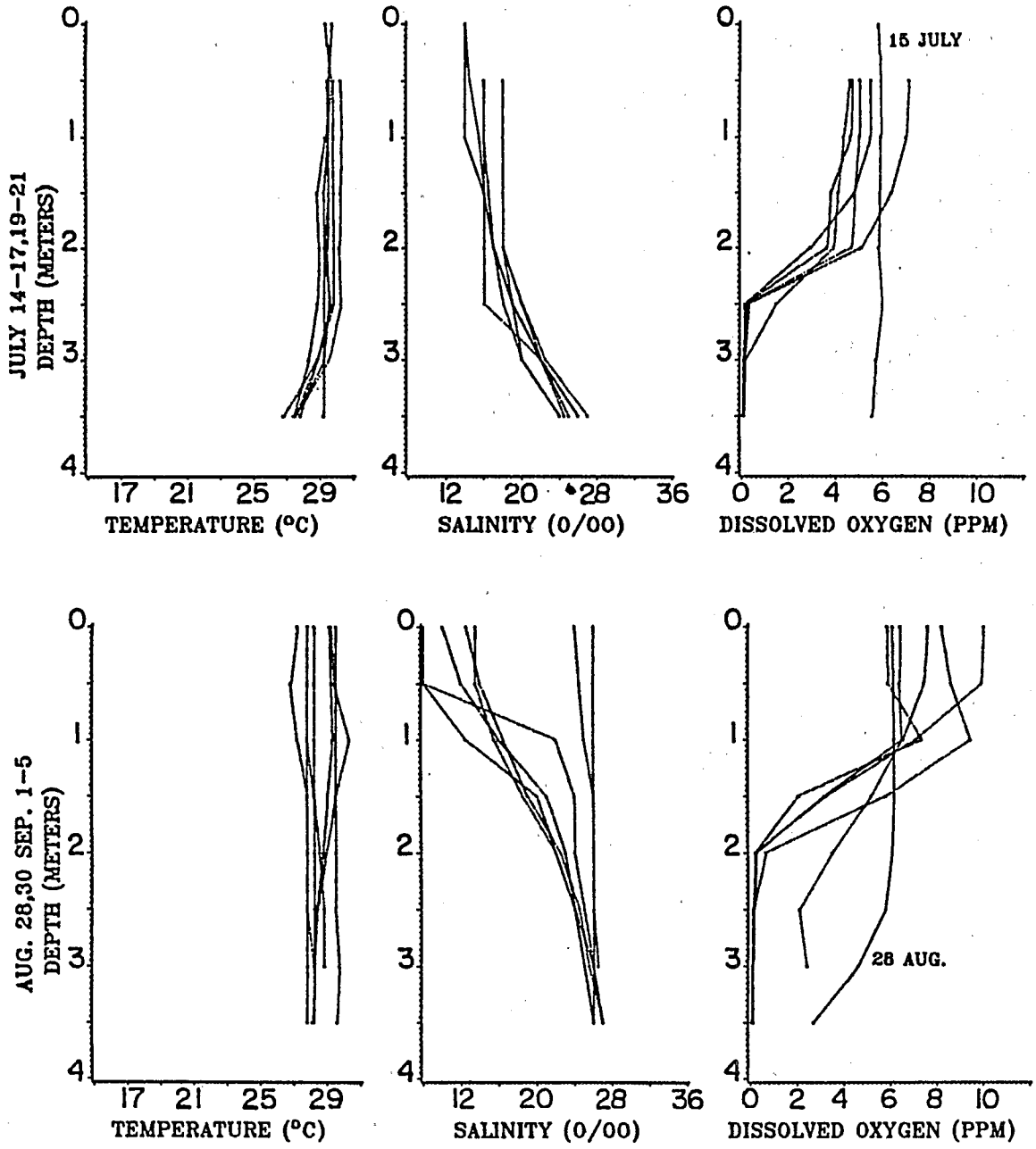

Figure T12. Vertical profiles at 0.5 m intervals of temperature, salinity, and dissolved oxygen at the East Lagoon sampling station on several consecutive days during two sample periods (from Ambler, 1982).

contains the highest concentration of point sources in the U.S. coastal area (Lowe *et al.*, 1991; see also Figure T3).

Studies of benthic and nektonic communities in Galveston Bay have generally concluded that the community structure is controlled primarily by salinity, but that some areas of the bay have a preponderance of organisms that indicate some level of environmental pollution (Chambers and Sparks, 1959; Bechtel and Copeland, 1970; Holland *et al.*, 1973).

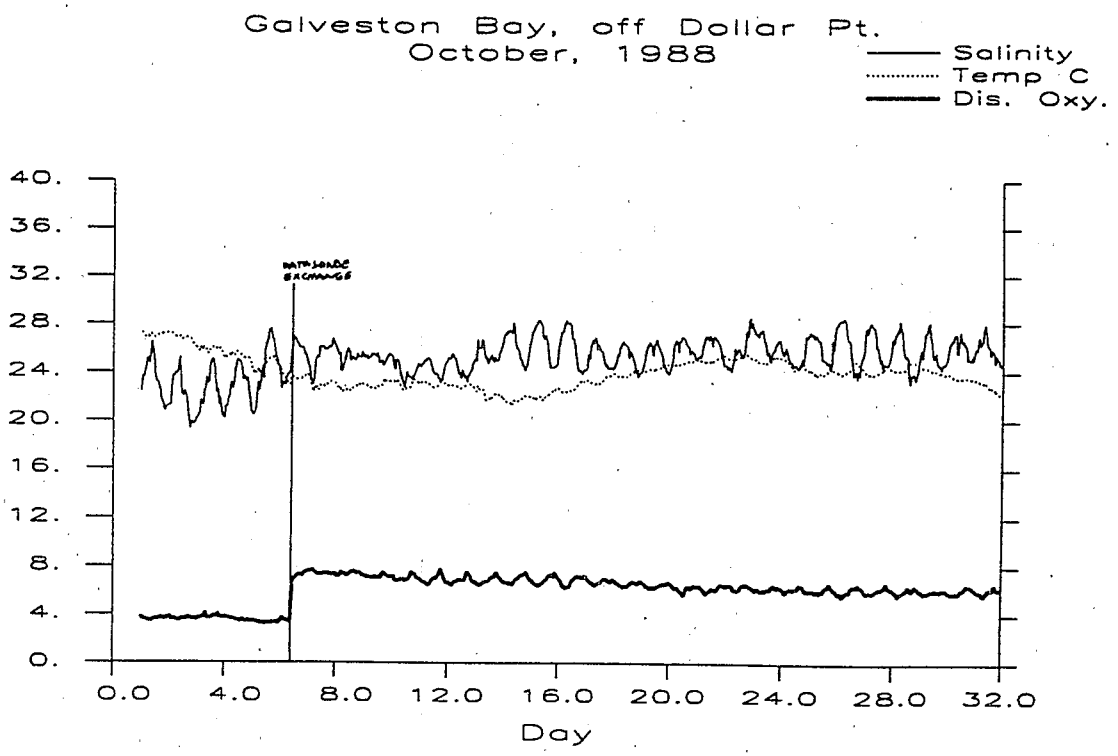

Figure T13. Oxygen meter deployment data (Longley, 1992).

Pulich and White (1991) have documented the decline of submerged vegetation in the Galveston Bay system and attributed these losses to critical physical alterations, including shoreline erosion and dredging and development activities, and to water quality degradation related to Galveston Island development projects (secondary treatment plants), noxious chemical effluents and chemical spills (Pulich *et al.* (1991). Loss of SAV in West Bay is likely related to differences in chlorophyll *a* levels in West Bay compared to Christmas Bay between 1972 and 1980 (Pulich *et al.*, 1991). Resultant reduction in light availability and anoxic conditions may have ultimately decimated many of the West Bay seagrass beds.

Historically, excessive growth of phytoplankton has not occurred with any regularity in the open waters of the Galveston Bay system (Stanley, 1989); however, the few reports are worth noting. Red tides associated with the dinoflagellate, *Gonyaulax*, have been reported from locations within Galveston Bay. The notable example is the 1949 summer episode in Offatts Bayou (Connell and Cross, 1950). The organism was tentatively identified as *G. catenella* by Connell and Cross (1950), but subsequently confirmed by Howell (1953) as *G. monilata*. Few fish were killed and no oysters were contaminated during the peak of the "red water," but fish died quickly when the bloom settled out of the surface waters and the water became "white" or "milky." Similar red tide incidences had been reported by residents and fishermen for the previous 15-20 years (circa 1930). Gunter (1942) attributed the mass mortality of fish in Offatts Bayou, during years previous to the massive red tide, to the stagnation of the inner portions of the bayou plus the accumulation and anaerobic decomposition of organic matter during the summer months. Several other authors (cited in Wardle *et al.*, 1975) have noted common inshore summer blooms of *G. monilata* in the Galveston area.

High cell concentrations of the dinoflagellate, *Exuviella baltica*, were recorded in three areas of the Galveston Bay system, including portions of Trinity Bay (Zotter, 1979). The bloom persisted during the winter of 1976-1977 and was similar to the bloom of winter 1972-1973 that persisted two to three months in the western half of Galveston Bay. In addition to the high cell concentrations of the dinoflagellate, there were high numbers of the blue-green alga, *Schizothrix calcicola*, and the green alga, *Chlorella* sp.

Nitzchia pungens f. multiseries has been identified from Galveston Bay samples (1989) and archived East Lagoon samples (1974) (Fryxell *et al.*, 1991). This morphological form of the pennate diatom *N. pungens*, produces a powerful neurotoxin domoic acid that is responsible for amnesiac shellfish poisoning (ASP). While not encountered in bloom conditions in Galveston Bay, *N. pungens f. multiseries* is presumed to become toxic during senescent blooms. Systematic surveys and laboratory experiments with the diatom are underway (Fryxell *et al.*, 1991).

Dinophysis caudata has been recognized recently as a toxic dinoflagellate which may contribute to the accumulation of toxins responsible for diarrhetic shellfish poisoning (DSP) in shellfish in Galveston Bay (R. Hickey, personal communication).

REFERENCES: G-17

Ambler (1982)
Armstrong (1987)
Baldauf *et al.* (1970)
Bechtel and Copeland (1970)
Benefield *et al.* (1983)
Chambers and Sparks (1959)
Connell and Cross (1950)
Dennis *et al.* (1984)
Fryxell (1990)
Fryxell *et al.* (1991)
Gillard (1974)
Gunter (1942)
Harper and Guillen (1989)
Hegen (1983)
Holland *et al.* (1973)
Johnson (1974)
Knudson and Belaire (1975)
Lind (1983)
Monaco *et al.* (1989)
NOAA (1989)
Pacheco *et al.* (1989)
Pulich and White (1991)
Pulich *et al.* (1991)
Pullen *et al.* (1971)
Renaud (1985)
Rice *et al.* (1988)
Santschi and Samuell (1991)
Seiler *et al.* (1991)
Shepard and Rusnak (1957)
Shipley and Kiesling (1991)
Stanley (1989)
TDWR (1981c)
Zotter (1979)

G-18 Brazos River (Brazos River Estuary, includes Brazos River, San Bernard River, Freeport Ship Channel)

The Brazos River is the longest and largest in basin area of eight Texas river basins (Johnson, 1977). It empties directly into the Gulf of Mexico near Freeport. The lower 9.6 km were dredged to form the "new river" or Brazos River Diversion Channel when the original river mouth was made into the Freeport Harbor. The Freeport Ship Channel empties directly, into the Gulf of Mexico. The San Bernard River enters the Gulf 6.4 km southwest from the Brazos River mouth.

No new data concerning oxygen depletion or nutrient concentrations are available for this area. Most low dissolved oxygen values (well below 2 mg/l and near anoxic) were found in the upper reaches of the San Bernard and Brazos Rivers where there is infrequent flushing of the rivers. Johnson (1977) discussed additional factors of chemical plant discharge, waste treatment outfall and salinity stratification compounded by a drought in 1974. The Freeport Ship Channel does not experience the low dissolved oxygen values observed in man-made channels in other areas (G-16, G-17, G-26.2). It is not as deep (18-20 ft) and the distance between Freeport Harbor and the Gulf

of Mexico is much less, than for example, the Houston Ship Channel or the Corpus Christi Chip Channel.

The red tide of 1986 which occurred along the length of the Texas coast from near Galveston to Port Isabel did not enter the waters of the Brazos River or the Freeport Ship Channel (Trebatowski, 1988).

REFERENCES: G-18

Armstrong and Goldstein (1975)
Hahl and Ratzlaff (1972, 1975)
Johnson (1977)
Lind (1983)
Monaco *et al.* (1989)
Pacheco *et al.* (1989)
Seadock (1974)
Steidinger (1973)

G-19 East Matagorda Bay

Portions of the flow of the Colorado River reach East Matagorda Bay, but the majority of its flow goes directly into the Gulf of Mexico through a dredged channel (Armstrong, 1987).

No new data concerning oxygen depletion or nutrient concentrations are available for this area. No low dissolved oxygen levels below 2 mg/l were found for this bay in the Texas Department of Water Resources, Coastal Data System.

The red tide of 1986 which occurred along the length of the Texas coast from near Galveston to Port Isabel did not enter the waters of East Matagorda Bay (Trebatowski, 1988).

REFERENCES: G-19

Hahl and Ratzlaff (1972, 1975)
Hegen (1983)
Lind (1983)
Pacheco *et al.* (1989)
Rice *et al.* (1988)

G-20 Colorado River (Colorado Estuary)

Portions of the Colorado River flow into the northeast arm of Matagorda Bay and adjacent parts of East Matagorda Bay to its north. Because of the configuration of the Colorado River delta, the proportion of the river flow that actually reaches the adjacent estuaries is largely unknown (Armstrong, 1987). A dredged channel through the river delta permits most of the discharge to flow directly to the Gulf of Mexico, but there are points of access between the river channel and the estuaries.

No new data concerning oxygen depletion or nutrient concentrations are available for this area. The lowest dissolved oxygen values (1.8 and 0.3 mg/l out of 76 records) were found in the upper reaches of the estuary in deep channels (11-15 m). No stations located below the Gulf Intracoastal Waterway had dissolved oxygen levels less than 3 mg/l. These stations were shallower (3-4.5 m), closer to the Gulf of Mexico and more subject to tidal exchange and flushing.

The red tide of 1986 which occurred along the length of the Texas coast from near Galveston to Port Isabel did not enter the waters of the Colorado River (Trebatowski, 1988).

REFERENCES: G-20

Groover and Sharik (1974)
Hahl and Ratzlaff (1970, 1972, 1975)
Lind (1983)

G-21 Matagorda/Lavaca Bays (Lavaca-Tres Palacios Estuary, includes Lavaca, Matagorda and Tres Palacios Bays)

The Matagorda Bay system is the third largest estuary on the Texas coast with a surface area of 101,368 ha (Armstrong, 1987). Its average depth is 2.3 m. Like Galveston Bay, Matagorda Bay is traversed by a navigation channel that extends from a cut through the barrier island up to Lavaca Bay in the northwest corner of the estuary. Major freshwater sources include the Lavaca River, flowing into Lavaca Bay, and the Colorado River, which flows into the northeast arm of Matagorda Bay. Because of the configuration of the Colorado River delta, the proportion of the river flow that actually reaches the estuary is largely unknown (Armstrong, 1987). A dredged channel through the river delta permits most of the discharge to flow directly to the Gulf of Mexico, but there are points of access between the river channel and the bay. Matagorda Bay has relatively little urban development around its periphery. Small cities are scattered along its western and northern boundaries, and some major industry is located on the shores of Lavaca Bay. The Matagorda estuarine drainage areas is one of three drainage areas in the Gulf of Mexico (others are Galveston Bay and Lower Laguna Madre) which received the highest applications of fertilizer to adjacent agricultural lands (NOAA, 1990a).

Two studies update the previous review by Rabalais *et al.* (1985). These are 1) a synthesis on Matagorda Bay by Ward and Armstrong (1980), and 2) the comprehensive studies funded by the Texas Water Development Board and conducted by The University of Texas at Austin, Marine Science Institute, on the freshwater inflow effects on the Lavaca River delta and Lavaca Bay (Jones *et al.*, 1986).

The average concentrations of several nutrients and forms of carbon were synthesized by Ward and Armstrong (1980) and are shown in Table T4. In general, the average concentrations at these stations, which give representative spatial coverage of the entire system, indicate relatively uniform nutrient levels throughout the system. Nearly two-thirds of the inorganic nitrogen is in the form of nitrate with the remainder as ammonia and nitrite. Since Matagorda Bay is lightly impacted by the activities of man in comparison to other Texas Bays (*e.g.*, Galveston Bay, Sabine Lake, and Corpus Christi Bay), numerous nutrient point-source loadings from municipal and industrial discharges do not currently exist, as reflected in the measured nutrient levels (Ward and Armstrong, 1980).

On the other hand, strong patterns in the distribution of nutrients were demonstrated in the Jones *et al.* (1986) study and were often related to the influence of fresh water. High concentrations of nitrate were associated with low salinities in the first study year (1984-1985) which was relatively wet, and concentrations were very low in the following dry year (1985-1986). Pigment concentrations were significantly higher in the first year, consistent with, but not demonstrating higher primary production. Total phosphorus was also higher in fresh water. Total Kjeldahl nitrogen (TKN) concentrations were higher in the dry second year. Total nitrogen, defined as TKN + nitrate + nitrite, was not significantly different between years. The ratio of phosphorus to nitrogen in the water column declined as a function of salinity, and it appeared that phosphorus declined more sharply than would be predicted from mixing of different water types (*i.e.*, P was removed from the water column, either physically, chemically or biologically). Even though inorganic nitrogen levels were often very low and the potential for phytoplankton growth may have been limited by the supply of nitrogen, it was possible that the supply of phosphorus could ultimately exert an important control on productivity of the system.

Data from the Texas Department of Water Resources, Coastal Data System, were re-examined for values less than 2 mg/l. There was only one occurrence of oxygen deficiency in the open, shallow bay system (in Tres Palacios Bay). The Jones *et al.* (1980) study, reported that fresh water introduced to a rather salty bay system formed a lens over the river in June 1986, vertical mixing was restricted, and anoxia (0.3 mg/l) formed below the surface at two river stations. Another

Table T4. Matagorda Bay system average nutrient concentrations from TWQB data (from Ward and Armstrong, 1980).

Sta. No.	Location	Ammonia (mg/l as N)	Nitrite (mg/l as N)	Nitrate (mg/l as N)	Total Phosphorus (mg/l as P)	Ortho-Phosphate (mg/l as P)	Total Organic Carbon (mg/l)
2441.01	East Matagorda Bay	0.156	0.028	0.20	0.074	0.047	9.2
2451.01	Matagorda Bay (Mid-bay)	0.152	0.027	0.13	0.036	0.016	7.2
2451.02	Matagorda Bay (near Powderhorn Lake)	0.165	0.028	0.52	0.041	0.015	9.3
2451.03	Matagorda Bay (near Pass Cavallo)	0.102	0.021	0.29	0.025	0.020	7.3
2452.01	Tres Palacios Bay (Mid-bay)	0.120	0.027	0.15	0.041	0.018	8.7
2452.02	Tres Palacios Bay (Upper-bay)	0.102	0.027	0.24	0.065	0.028	9.9
2453.01	Lavaca Bay (near Port Lavaca)	0.156	0.030	0.16	0.080	0.030	10.7
2453.02	Lavaca Bay (Mid-bay)	0.169	0.033	0.16	0.047	0.022	9.1
2453.03	Lavaca Bay (near Alcoa facility)	0.121	0.031	0.22	0.048	0.016	9.8
2454.01	Cox Bay	0.168	0.027	0.21	0.044	0.020	8.9
2455.01	Keller Bay	0.152	0.027	0.22	0.040	0.015	8.1
2456.01	Karankawa Bay (Upper-bay)	0.108	0.036	0.32	0.127	0.051	14.1
Average	(Average of 12 monitored stations)	0.139	0.029	0.24	0.056	0.025	9.4

instance of hypoxia (1.4 mg/l) was recorded at a river station in October 1985. Similar low values (0.3 and 0.4 mg/l) were documented in Rabalais *et al.* (1985) for the Lavaca River and Navidad Rivers in 3 m water depth. In the relatively shallow bays, strong wind-induced mixing results in generally uniform dissolved oxygen concentrations vertically (Ward and Armstrong, 1980). Low dissolved oxygen values occurred in deep channels (approximately 9 m) where slight stratification occurs (Ward and Armstrong, 1980). Some of the most frequent occurrences of low dissolved oxygen (<2 mg/l) were in the Palacios Channel (two of 58 records) and the Alcoa Ship Channel at its terminus (10 of 37 records).

The Texas Water Development Board has conducted many long-term deployments of water quality instrumentation in selected Texas estuaries to follow continuous variations in near-bottom water salinity, temperature and dissolved oxygen. Preliminary results from these deployments have been provided by G. Powell (Texas Water Development Board, personal communication) (see Section G-17 for details). A deployment was made in Lavaca Bay, off the Highway 35 causeway in October 1990. The data indicated no dissolved oxygen levels below 2 mg/l based on the first seven days of the instrument deployment.

The extensive 1986 red tide (*Gymnodinium breve*) which affected most of the Texas coast spread throughout the Matagorda-Lavaca Bay system, entering via the Matagorda Bay Ship Channel and Cavallo Pass, and extending up into Lavaca, Cox and Keller Bays. The organism existed in the Matagorda-Lavaca Bay system throughout September (Trebatowski, 1988).

REFERENCES: G-21

Armstrong (1987)
Benefield *et al.* (1983)
Blanton *et al.* (1971)
Cullen and Jones (1986)
Cullen and Lane (1986)
Gilmore *et al.* (1976)
Groover and Sharik (1974)
Hahl and Ratzlaff (1970, 1972, 1975)
Hegen 1983)
Jones *et al.* (1986)
Kalke (1986)
Kalke and Montagna (1989, 1991)
Lind (1983)
Maurer and Parker (1972)
Monaco *et al.* (1989)
Montagna and Kalke (1989b)
Rice *et al.* (1988)
Seadock (1974)
Shepard and Rusnak (1957)
TDWR (1980b)
Ward *et al.* (1980)

G-22 San Antonio/Espiritu Santo Bays (Guadalupe Estuary, includes San Antonio, Espiritu Santo and Mesquite Bays)

The San Antonio Bay complex has a total surface area of 56,162 ha (Armstrong, 1987). Freshwater inflow is from the Guadalupe River, which has built a large delta at the upper end of the estuary. This estuary is connected with Matagorda Bay to the northeast and the Aransas Bay complex to the southwest. The average depth of the estuary is 1.4 m. Land use in surrounding areas is primarily agriculture (irrigated rice crops) and ranching.

Two studies supplement the review of Rabalais *et al.* (1985): 1) a study of the effects of freshwater inflow on hydrological and biological parameters (Childress *et al.*, 1975) and 2) the comprehensive studies funded by the Texas Water Development Board and conducted by The University of Texas at Austin, Marine Science Institute, on the freshwater inflow effects on the San Antonio Bay system (Kalke and Montagna, 1989; Montagna and Kalke, 1989; and Whitledge, 1989).

Freshwater inflow into San Antonio Bay introduced nitrate concentrations of 68-120 μg-at/l into the upper bay with the highest concentration in November and the lowest in July 1987 (Figure T14) (Whitledge, 1989). The range of observed nitrate concentrations in surface waters was 0.1 to 120 μg-at/l. In all samples the surface nitrate was reduced to less than 1.0 μM in lower San Antonio Bay. Surface chlorophyll *a* distributions throughout the sampling period had maximum concentrations in the middle or lower bay regions due to the combination of rather large nutrient concentrations and increased light penetration with distance from the river source. The concentration of chlorophyll *a* in the river source ranged from 0.6 to 13.5 μg/l and in the open bay water reached as high as 50 μg/l (Figure T15) (Whitledge, 1987). Ammonia concentrations were highest on the west side of San Antonio Bay suggesting an apparent link in space of the inflow of nutrients, production of organic matter and decomposition into recycled nutrients (Whitledge, 1989).

Out of 58 stations throughout the system, with hydrographic data from 1972-1984 (Texas Department of Water Resources, Coastal Data System), no bottom water dissolved oxygen values fell below 2 mg/l, and only two values were <3 mg/l. Of the Texas estuaries, this area had the lowest frequency with the least intensity of oxygen-depleted waters. Although Whitledge (1989) indicated an area of depressed oxygen concentrations in the west and central regions of San Antonio Bay in April 1987, only one of these values fell below 4 mg/l and all others were greater. Although low dissolved oxygen values were indicated for the lower bay station in the Montagna and Kalke (1989) portion of the 1986-1988 San Antonio Bay program (R. Kalke, personal communication), these data were not included in the report.

The Texas Water Development Board has conducted many long-term deployments of water quality instrumentation in selected Texas estuaries to follow continuous variations in near-bottom water salinity, temperature and dissolved oxygen (Longley, 1992). Results from these deployments have been provided by the Texas Water Development Board (Longley, 1992) (see Section G-17 for details). Deployments were made in San Antonio Bay near Seadrift in December 1986, January 1987, January-July 1989 and September 1990. The data indicated no dissolved oxygen levels below 2 mg/l based on the first seven days of the instrument deployments; data for March-April 1989 are displayed in Figure T16). [*N. B.*, the decay in the oxygen readings with time.] The record for October 1990 picked up the extreme daily fluctuations in dissolved oxygen concentrations associated with the bloom of a blue-green alga (G. Powell, personal communication).

The extensive 1986 red tide (*Gymnodinium breve*) which affected most of the Texas coast was spread throughout the Espiritu Santo Bay through Saluria Bayou and by the end of September all of Espiritu Santo Bay contained red tide and resultant fish kills (Trebatowski, 1988).

REFERENCES: G-22

Armstrong (1987)
Benefield *et al.* (1983)
Childress (1966)
Childress *et al.* (1975)
Hahl and Ratzlaff (1970, 1972, 1975)
Hegen (1983)
Kalke and Montagna (1989)
Lind (1983)
Maurer and Parker (1972)
McIntyre and Cullen (1988)
Monaco *et al.* (1989)
Montagna and Kalke (1989a,b)
Montagna and Yoon (1989)
Montagna *et al.* (1989)
Pacheco *et al.* (1989)
Rice *et al.* (1988)
Shepard and Rusnak (1957)
TDWR (1980a)
Whitledge (1989)

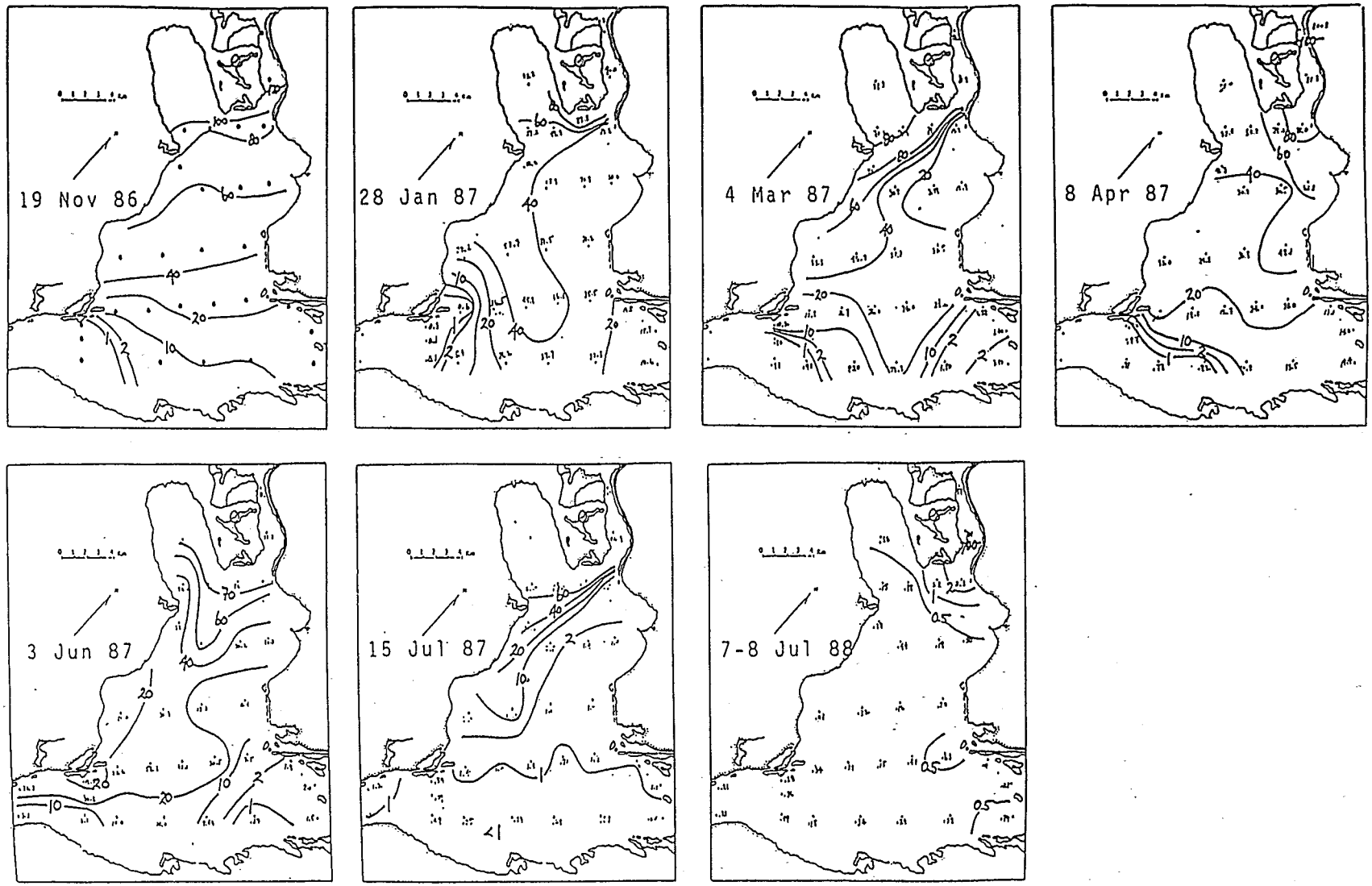

Figure T14. Surface nitrate concentrations (μM) in San Antonio Bay (from Whitledge, 1989).

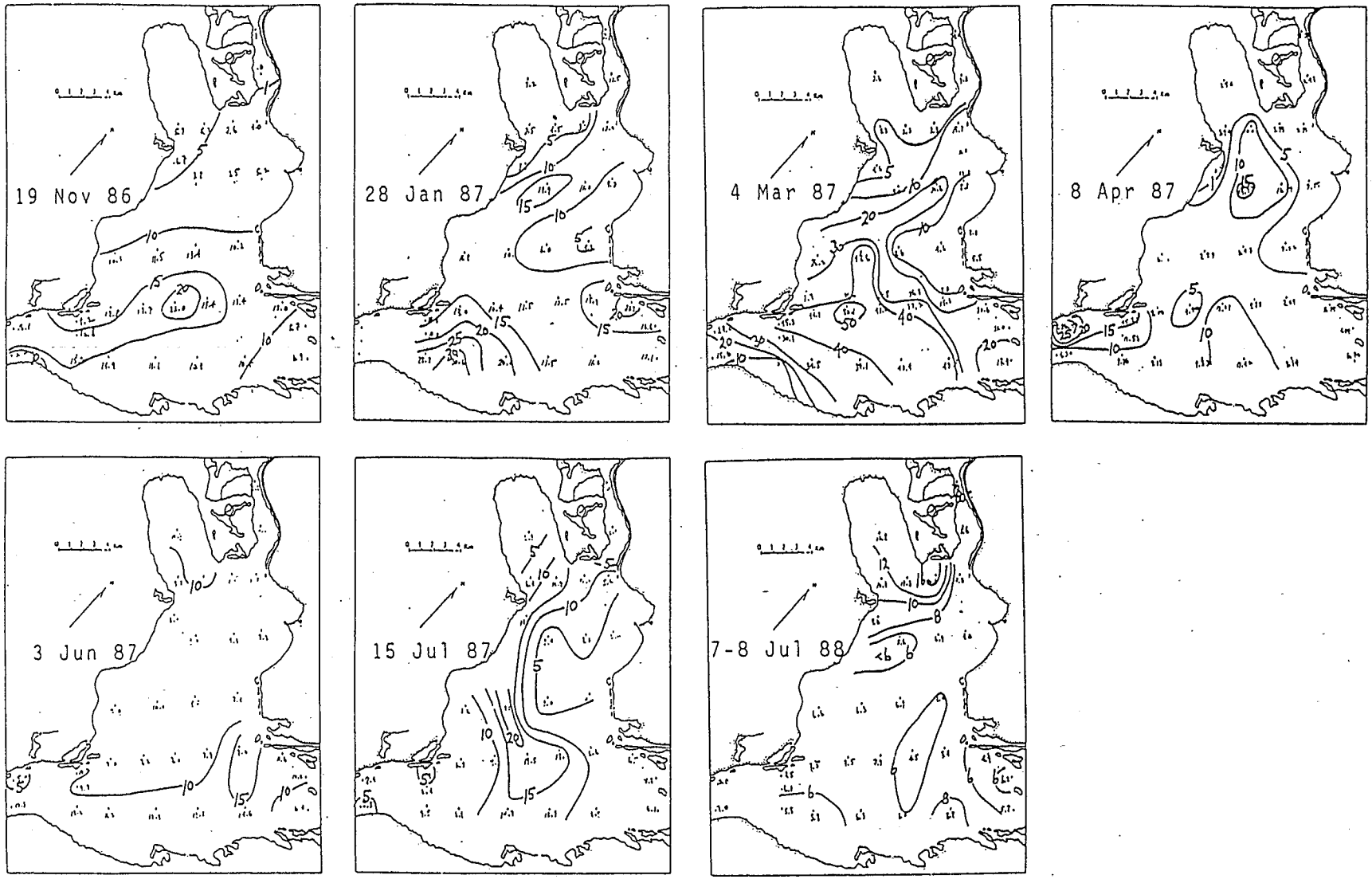

Figure T15. Surface chlorophyll *a* (µg/l) in San Antonio Bay (from Whitledge, 1989).

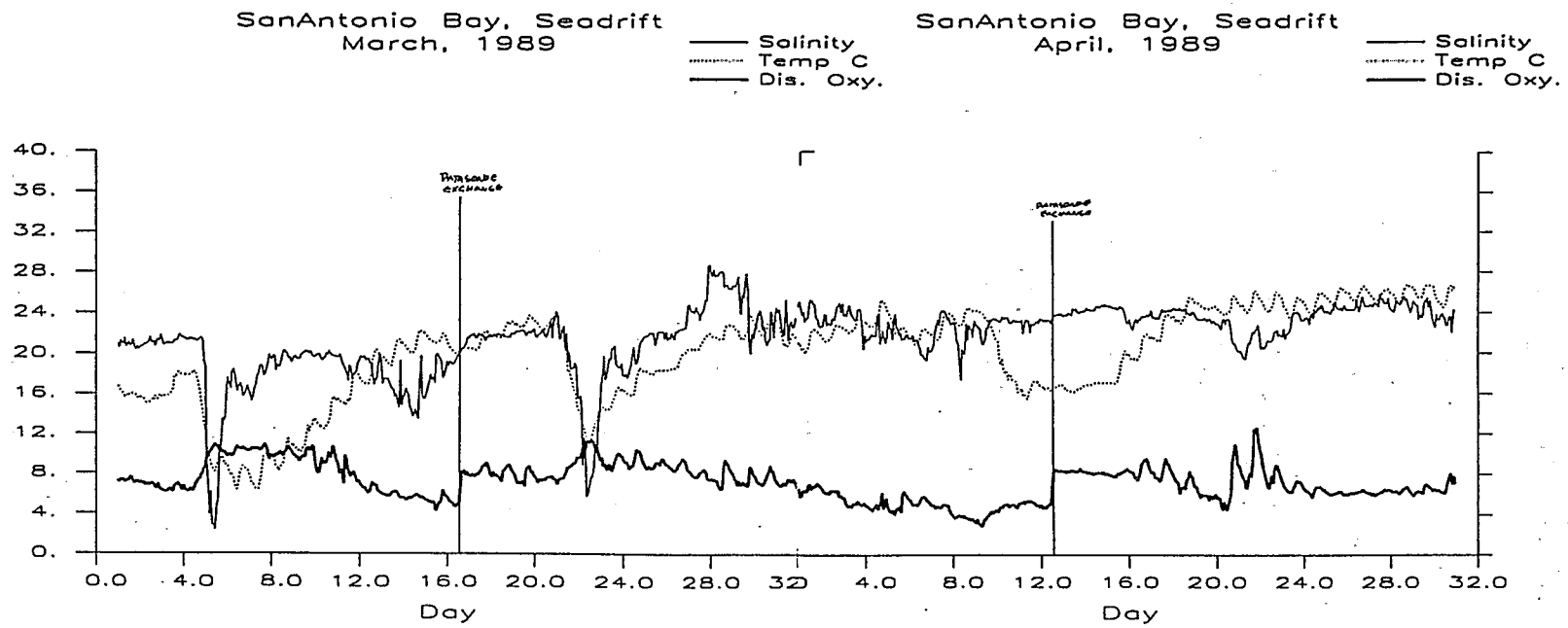

Figure T16. Oxygen meter deployment data (Longley, 1992).

G-23 Aransas/Copano Bays [Mission-Aransas Estuary, includes Mission, Aransas, Copano and Redfish (part) Bays and Aransas Pass]

The Aransas Bay complex is made up primarily of Copano and Aransas Bays, with a very small area immediately northwest of Copano Bay in Mission Bay and part of Redfish Bay, for a total surface area of 46,279 ha (Armstrong, 1987). Major freshwater inflows are from the Mission and Aransas Rivers, although these inputs are relatively small. Land use in the estuary is dominated by agricultural and ranching activities with only minor areas of irrigated crops. Population density is low.

The studies of Holland *et al.* (1973, 1974, 1975) documented the nutrient and hydrographic characteristics of Copano, Redfish and Aransas Bays. Means of data from transects across these three areas are given in Tables T5-T7). Additional values are given by Henley and Rauschuber (1981) for Redfish Bay (Table T8).

There are few occurrences of low dissolved oxygen values in the shallow, open bay waters. Of these, only two fell below 2 mg/l (out of 500^{+} samples). Most of the low dissolved oxygen values, often anoxic, were associated with tidal rivers and creeks (*e.g.*, Heffernan, 1969-1970, 1972); some of the anoxic waters may be related to oilfield brine discharges (Heffernan, 1972). The Mission-Aransas estuary occurs in an area of the Texas coast in a transition to semi-arid climatic conditions. Rainfall averages 35 in/yr but is coupled with a subtropical temperature regime and persistent southeasterly winds. The annual precipitation deficit is 12 to 16 inches (Brown *et al.*, 1976). Thus, reduced freshwater inflows in the peripheral tidal creeks and rivers of this estuary coupled with climatic factors, contribute to the occurrence of low oxygen values.

The extensive 1986 red tide (*Gymnodinium breve*) which affected most of the Texas coast entered Aransas Bay through Aransas Pass and quickly spread into Aransas, Corpus Christi, and Redfish Bays (Trebatowski, 1988).

Table T8. Statistical summary of water quality data for the Redfish Bay portion of the Nueces-Corpus Christi Bay System for 1972-1976 (from Henley and Rauschuber, 1981).

Parameter	Mean	Median	Variance	Standard deviation
		Redfish Bay		
Water temperature (°C)	21.35	22.05	46.54	6.82
Dissolved oxygen (mg/l)	7.90	7.40	2.35	1.53
Salinity (ppt)	24.74	25.25	18.04	4.24
Organic nitrogen (mg/l)	0.387	0.350	0.020	0.142
Nitrite (mg/l)	0.013	0.005	0.0002	0.016
Nitrate (mg/l)	0.028	0.030	0.00002	0.005
Ammonia nitrogen (mg/l)	0.100	0.100	0.00	0.00
Orthophosphate (mg/l)	0.014	0.010	0.00003	0.0057
Total phosphate (mg/l)	0.0315	0.030	0.00015	0.0121
Inorganic carbon (mg/l)	19.28	16.75	59.16	7.69
Organic carbon (mg/l)	16.95	17.50	123.47	11.11
Turbidity (JTU)	23.58	16.25	396.70	19.92
pH	8.52	8.40	0.062	0.249

Table T5. Minima, maxima and averages of selected hydrographic parameters (from Holland *et al.*, 1973, 1974, 1975).

COPANO BAY (LINES 44–77)

	WATER TEMP. °C			DISSOLVED O_2 MG/L			SALINITY °/oo			ORGANIC N_2 MG/L			NO_2 MG/L			NO_3 MG/L			NH_4 MG/L			TOTAL PO_4 MG/L			INORGANIC C MG/L			ORGANIC C MG/L		
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
OCTOBER, '72	26.5	27.5	26.9	5.7	6.8	6.4	6.2	15.2	9.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NOVEMBER, '72	20.1	21.0	20.8	7.2	10.1	8.6	9.4	13.9	10.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DECEMBER, '72	7.0	8.5	7.6	11.2	19.8	14.9	10.5	14.1	12.3	0.20	0.70	0.45	0.005	0.005	0.005	0.03	0.26	0.09	0.10	0.20	0.15	0.06	0.16	0.09	18.0	18.0	18.0	23.0	23.0	23.0
JANUARY, '73	4.0	6.8	5.3	13.3	16.3	14.0	11.9	17.7	14.1	0.10	1.4	0.5	0.005	0.005	0.005	0.03	0.04	0.03	0.20	0.40	0.28	0.04	0.09	0.06	--	--	--	--	--	--
FEBRUARY, '73	12.0	15.0	13.4	9.5	11.1	10.2	13.6	21.7	16.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.0	24.0	20.8	15.0	21.0	18.5
MARCH, '73	20.5	22.8	21.5	6.6	7.5	7.0	15.7	20.3	17.0	0.20	0.40	0.32	0.005	0.03	.011	0.03	0.03	0.03	0.10	0.80	0.28	0.03	0.04	0.04	18.0	22.0	19.5	8.0	13.0	10.0
APRIL, '73	17.0	17.5	17.2	7.3	8.8	8.3	16.6	19.6	17.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	15.0	27.0	18.2	7.0	14.0	11.5
MAY, '73	25.1	25.3	25.2	6.2	7.4	7.0	15.7	18.3	17.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	24.0	29.0	25.5	10.0	14.0	11.8
JUNE, '73	25.5	27.5	26.6	3.1	6.8	5.5	0.0	17.0	8.4	0.40	1.40	0.78	0.005	0.015	0.010	0.03	0.16	0.08	0.10	0.10	0.10	0.05	0.39	0.18	10.0	17.0	14.5	15.0	35.0	25.2

REDFISH BAY (LINES 151 and 152)

OCTOBER, '72	28.0	29.0	28.4	6.2	7.0	6.6	25.9	28.2	27.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NOVEMBER, '72	14.5	14.9	14.7	7.2	8.4	7.8	22.1	25.2	23.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DECEMBER, '72	7.5	13.0	10.2	9.3	16.6	11.2	21.0	26.7	23.9	0.40	0.60	0.50	0.005	0.014	0.009	0.03	0.04	0.04	0.10	0.10	0.10	0.04	0.05	0.04	15.0	15.0	15.0	26.0	26.0	26.0
JANUARY, '73	8.7	10.7	9.6	10.1	12.9	11.6	25.2	27.2	26.1	0.30	0.30	0.30	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.02	0.10	0.06	--	--	--	--	--	--
FEBRUARY, '73	8.0	11.0	9.5	8.5	10.3	9.5	28.4	30.0	29.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	21.0	23.0	22.0	17.0	19.0	18.0
MARCH, '73	21.5	22.8	22.4	7.3	7.8	7.4	23.4	25.5	24.3	0.10	0.20	0.15	0.003	0.005	0.004	0.03	0.03	0.03	0.10	0.10	0.10	0.01	0.01	0.01	15.0	22.0	18.5	4.0	11.0	7.5
APRIL, '73	19.5	20.0	19.8	6.2	7.5	7.1	25.2	26.2	25.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.2	2.2	2.2	7.0	7.0	7.0
MAY, '73	20.2	22.5	20.8	4.9	6.7	6.1	19.2	23.9	20.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	23.0	23.0	23.0	10.0	10.0	10.0
JUNE, '73	28.0	29.5	29.0	6.8	7.0	6.9	25.0	27.1	26.0	0.30	0.40	0.35	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.03	0.03	0.03	8.0	16.0	12.0	15.0	25.0	20.0

ARANSAS BAY (LINES 100 through 141)

	WATER TEMP. °C			DISSOLVED O_2 MG/L			SALINITY °/oo			ORGANIC N_2 MG/L			NO_2 MG/L			NO_3 MG/L			NH_4 MG/L			TOTAL PO_4 MG/L			INORGANIC C MG/L			ORGANIC C MG/L		
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
OCTOBER, '72	27.0	29.2	28.0	6.4	7.6	6.9	11.9	23.5	15.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NOVEMBER, '72	14.9	21.0	17.3	7.7	9.8	8.9	14.0	19.2	17.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DECEMBER, '72	6.8	9.0	8.0	10.4	20.0	14.6	14.2	19.6	17.4	0.20	0.90	0.47	0.005	0.009	0.006	0.03	0.06	0.04	0.10	0.20	0.12	0.05	0.10	0.07	14.0	20.0	16.7	18.0	24.0	21.3
JANUARY, '73	4.7	7.2	5.9	12.9	17.9	14.2	16.4	22.5	19.8	0.10	0.50	0.23	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.30	0.18	0.04	0.07	0.06	--	--	--	--	--	--
FEBRUARY, '73	7.5	17.0	13.8	8.8	11.4	10.1	19.1	24.9	22.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.0	29.0	24.7	10.0	23.0	14.5
MARCH, '73	21.0	23.5	22.7	8.2	8.7	8.4	21.1	23.9	22.5	0.10	0.40	0.22	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.01	0.30	0.08	19.0	23.0	22.0	7.0	11.0	8.7
APRIL, '73	17.8	18.5	18.1	8.1	8.9	8.5	19.8	22.4	21.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20.0	28.0	24.8	3.0	11.0	6.8
MAY, '73	26.0	26.9	26.5	6.5	7.7	7.1	11.5	18.8	15.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	25.0	28.0	26.3	8.0	15.0	11.2
JUNE, '73	27.5	28.5	28.2	5.9	7.5	6.6	15.2	22.9	20.1	0.40	0.80	0.52	0.005	0.014	0.008	0.03	0.07	0.04	0.10	0.20	0.12	0.03	0.10	0.06	14.0	20.0	17.5	15.0	28.0	20.2

.. oxygen meter not functioning
-- no samples taken

Table T6. Minima, maxima and averages of selected hydrographic parameters (from Holland *et al.*, 1973, 1974, 1975).

COPANO BAY (LINES 44-77)

	NO_2 MG/L			NO_3 MG/L			NH_4 MG/L			ORGANIC N_2 MG/L			ORTHO PO_4 MG/L			TOTAL PO_4 MG/L			ORGANIC C MG/L			INORGANIC C MG/L		
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
JULY 1973	0.005	0.014	0.007	0.03	0.03	0.03	0.10	0.10	0.10	0.70	0.90	0.78	0.04	0.06	0.05	0.09	0.11	0.10	41.0	49.0	45.8	7.0	17.0	12.5
AUGUST 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.50	1.00	0.80	0.04	0.06	0.05	0.08	0.15	0.10	33.0	57.0	45.2	8.0	17.0	11.2
SEPTEMBER 1973	0.005	0.050	0.018	0.03	0.18	0.06	0.10	0.10	0.10	0.50	1.40	0.83	0.04	0.30	0.11	0.06	0.43	0.17	—	—	—	—	—	—
OCTOBER 1973	0.005	0.007	0.005	0.06	0.13	0.09	0.10	0.10	0.10	0.40	0.50	0.43	0.03	0.16	0.08	0.06	0.20	0.11	21.0	31.0	26.2	4.0	10.0	7.5
NOVEMBER 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.20	0.70	0.50	0.06	0.08	0.07	0.10	0.12	0.11	27.0	27.0	27.0	10.0	10.0	10.0
DECEMBER 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.40	0.38	0.05	0.07	0.06	0.08	0.12	0.10	22.0	34.0	30.0	7.0	19.0	13.0
JANUARY 1974	0.005	0.008	0.006	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.70	0.50	0.06	0.07	0.06	0.07	0.10	0.09	31.0	36.0	34.0	15.0	20.0	17.0
FEBRUARY 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.50	0.70	0.57	0.02	0.07	0.04	0.05	0.07	0.06	27.0	36.0	31.7	15.0	20.0	18.0
MARCH 1974	0.005	0.005	0.005	0.03	0.05	0.04	0.10	0.10	0.10	0.40	0.50	0.45	0.05	0.05	0.05	0.06	0.09	0.07	32.0	62.0	47.8	21.0	32.0	28.2
APRIL 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.50	0.43	0.04	0.05	0.04	0.06	0.08	0.07	27.0	46.0	36.2	13.0	15.0	13.5
ARANSAS BAY (LINES 100-141)																								
JULY 1973	0.005	0.008	0.006	0.03	0.03	0.03	0.10	0.10	0.10	0.50	0.90	0.65	0.03	0.06	0.05	0.06	0.10	0.08	39.0	51.0	42.5	13.0	16.0	14.0
AUGUST 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.70	0.45	0.02	0.07	0.05	0.03	0.11	0.07	25.0	68.0	36.5	6.0	16.0	12.7
SEPTEMBER 1973	0.005	0.008	0.006	0.03	0.06	0.04	0.10	0.10	0.10	0.50	1.10	0.65	0.04	0.07	0.05	0.05	0.10	0.08	—	—	—	—	—	—
OCTOBER 1973	0.005	0.014	0.008	0.12	0.33	0.25	0.10	0.10	0.10	0.40	0.70	0.53	0.07	0.20	0.13	0.08	0.24	0.14	19.0	37.0	29.0	13.0	25.0	17.8
NOVEMBER 1973	0.005	0.005	0.005	0.03	0.09	0.05	0.10	0.10	0.10	0.30	0.70	0.50	0.04	0.12	0.09	0.05	0.16	0.12	19.0	33.0	26.3	10.0	19.0	16.2
DECEMBER 1973	0.005	0.011	0.006	0.03	0.04	0.03	0.10	0.10	0.10	0.20	0.50	0.27	0.04	0.07	0.06	0.07	0.10	0.08	17.0	52.0	34.3	10.0	25.0	17.0
JANUARY 1974	0.005	0.006	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.80	0.52	0.02	0.07	0.04	0.05	0.14	0.09	21.0	53.0	31.8	16.0	25.0	20.8
FEBRUARY 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.60	0.48	0.03	0.03	0.03	0.04	0.09	0.06	29.0	42.0	33.5	15.0	19.0	17.2
MARCH 1974	0.005	0.005	0.005	0.03	0.04	0.03	0.10	0.10	0.10	0.30	0.50	0.37	0.03	0.06	0.04	0.05	0.09	0.06	18.0	54.0	32.3	15.0	32.0	26.5
APRIL 1974	0.005	0.050	0.020	0.03	0.05	0.03	0.10	0.10	0.10	0.00	0.60	0.32	0.03	0.04	0.04	0.05	0.07	0.06	25.0	152.0	82.3	11.0	20.0	15.5

— no sample taken

REDFISH BAY (LINES 151-152)

JULY 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.50	0.70	0.60	0.01	0.01	0.01	0.02	0.03	0.02	48.0	48.0	48.0	14.0	14.0	14.0
AUGUST 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.20	0.20	0.20	0.01	0.01	0.01	0.02	0.04	0.03	21.0	26.0	23.5	13.0	14.0	13.5
SEPTEMBER 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.20	0.50	0.35	0.01	0.01	0.01	0.02	0.02	0.02	—	—	—	—	—	—
OCTOBER 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.60	0.70	0.65	0.02	0.04	0.03	0.03	0.06	0.04	22.0	27.0	24.5	16.0	19.0	17.5
NOVEMBER 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	1.00	0.65	0.01	0.02	0.02	0.03	0.04	0.04	20.0	21.0	20.5	13.0	15.0	14.0
DECEMBER 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.20	0.20	0.20	0.01	0.02	0.02	0.04	0.04	0.04	28.0	44.0	36.0	12.0	20.0	16.0
JANUARY 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.60	0.45	0.02	0.02	0.02	0.03	0.03	0.03	24.0	30.0	27.0	15.0	16.0	15.5
FEBRUARY 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.40	0.35	0.01	0.02	0.02	0.03	0.03	0.03	29.0	41.0	35.0	14.0	16.0	15.0
MARCH 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.30	0.30	0.01	0.01	0.01	0.01	0.02	0.02	19.0	20.0	19.5	13.0	14.0	13.5
APRIL 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.40	0.40	0.01	0.02	0.02	0.03	0.04	0.04	23.0	23.0	23.0	10.0	12.0	11.0

Table T7. Minima, maxima and averages of selected hydrographic parameters (from Holland *et al.*, 1973, 1974, 1975).

	NO_2 (MG/L)			NO_3 (MG/L)			NH_4 (MG/L)			ORGANIC N_2 (MG/L)			ORTHO PO_4 (MG/L)			TOTAL PO_4 (MG/L)			ORGANIC C (MG/L)			INORGANIC C (MG/L)		
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
COPANO BAY (LINES 44-77)																								
May 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.50	0.80	0.68	0.04	0.08	0.05	0.05	0.13	0.09	28	32	30	10	13	11
June 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.80	0.60	0.04	0.12	0.06	0.07	0.21	0.12	20	38	27	17	23	20
July 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.90	0.55	0.04	0.05	0.04	0.06	0.10	0.08	29	41	33	12	15	14
August 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.70	0.52	0.03	0.04	0.03	0.03	0.08	0.06	11	20	16	25	28	26
September 1974	0.050	0.050	0.050	0.03	0.05	0.04	0.10	0.10	0.10	0.30	0.70	0.55	0.05	0.21	0.10	0.08	0.25	0.13	9	20	14	9	17	12
October 1974	0.050	0.050	0.050	0.03	0.04	0.03	0.10	0.10	0.10	0.30	0.90	0.50	0.02	0.05	0.04	0.05	0.11	0.07	7	14	9	20	34	25
November 1974	0.010	0.010	0.010	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.60	0.48	0.01	0.02	0.02	0.03	0.05	0.04	4	6	5	19	26	22
December 1974	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.40	0.38	0.03	0.06	0.04	0.04	0.09	0.06	10	19	13	22	32	25
January 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.60	0.38	0.03	0.05	0.04	0.05	0.08	0.06	11	14	12	23	28	26
February 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.60	0.40	0.04	0.06	0.05	0.05	0.08	0.06	2	6	4	30	35	32
March 1975	0.010	0.010	0.010	0.02	0.03	0.02	0.10	0.10	0.10	0.40	0.50	0.46	0.05	0.07	0.05	0.06	0.10	0.08	5	7	6	27	37	32
April 1975	0.010	0.010	0.010	0.02	0.10	0.04	0.10	0.10	0.10	0.20	0.50	0.38	0.03	0.08	0.06	0.07	0.13	0.09	1	4	3	31	35	33
May 1975	0.020	0.020	0.020	0.02	0.02	0.02	0.10	0.10	0.10	0.40	0.80	0.55	0.03	0.07	0.05	0.07	0.09	0.08	5	12	7	27	37	30
ARANSAS BAY (LINES 100-141)																								
May 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.40	0.37	0.04	0.06	0.05	0.05	0.07	0.06	6	10	7	24	28	26
June 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	1.40	0.60	0.02	0.06	0.03	0.04	0.14	0.07	19	23	20	18	20	18
July 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.60	0.42	0.01	0.03	0.03	0.04	0.07	0.06	20	31	26	11	14	12
August 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.40	0.38	0.01	0.04	0.03	0.04	0.07	0.06	12	14	13	25	28	27
September 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.60	0.50	0.01	0.09	0.04	0.04	0.11	0.07	11	16	13	16	25	20
October 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.40	0.37	0.04	0.06	0.05	0.05	0.07	0.06	6	10	7	24	28	26
November 1974	0.010	0.010	0.010	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.60	0.42	0.02	0.03	0.03	0.04	0.06	0.05	1	5	3	25	29	26
December 1974	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.20	0.70	0.38	0.02	0.05	0.04	0.04	0.06	0.05	9	12	11	27	32	29
January 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.40	0.32	0.03	0.05	0.04	0.05	0.08	0.06	5	11	9	27	32	29
February 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.40	0.35	0.03	0.06	0.05	0.03	0.07	0.05	3	7	5	34	43	38
March 1975	0.010	0.020	0.012	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.80	0.56	0.01	0.05	0.03	0.03	0.14	0.10	4	7	6	29	37	35
April 1975	0.010	0.020	0.012	0.02	0.07	0.03	0.10	0.10	0.10	0.10	0.30	0.23	0.02	0.06	0.04	0.04	0.10	0.07	1	4	2	34	39	37
May 1975	0.020	0.020	0.020	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.40	0.37	0.02	0.05	0.04	0.04	0.07	0.06	3	6	4	26	31	28
REDFISH BAY (LINES 151-152)																								
May 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.20	0.30	0.25	0.01	0.01	0.01	0.02	0.02	0.02	18	24	21	8	9	8
June 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.30	0.30	0.01	0.01	0.01	0.02	0.03	0.02	16	18	17	15	16	16
July 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.60	0.45	0.01	0.01	0.01	0.04	0.04	0.04	21	22	21	11	12	12
August 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.40	0.40	0.01	0.01	0.01	0.01	0.03	0.02	4	7	6	26	27	26
September 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.40	0.50	0.45	0.01	0.03	0.02	0.03	0.03	0.03	13	17	15	22	22	22
October 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.60	0.45	0.01	0.03	0.02	0.04	0.07	0.06	7	10	8	28	28	28
November 1974	0.010	0.010	0.010	0.03	0.03	0.03	0.10	0.10	0.10	0.60	0.80	0.70	0.01	0.01	0.01	0.04	0.05	0.04	6	10	8	27	28	28
December 1974	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.20	0.20	0.20	0.01	0.01	0.01	0.03	0.04	0.04	13	14	14	27	28	28
January 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.40	0.35	0.01	0.01	0.01	0.03	0.04	0.04	5	10	8	27	28	28
February 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.40	0.35	0.01	0.01	0.01	0.01	0.02	0.02	1	3	2	31	34	32
March 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.60	0.45	0.01	0.01	0.01	0.02	0.02	0.02	4	5	4	29	29	29
April 1975	0.010	0.010	0.010	0.02	0.02	0.02	0.10	0.10	0.10	0.20	0.30	0.25	0.01	0.01	0.01	0.02	0.02	0.02	1	1	1	30	31	30
May 1975	0.020	0.020	0.020	0.02	0.02	0.02	0.10	0.10	0.10	0.40	0.40	0.40	0.01	0.01	0.01	0.03	0.03	0.03	2	6	4	29	31	30

REFERENCES: G-23

Armstrong (1987)
Brown *et al.* (1976)
Hahl and Ratzlaff (1970, 1972, 1975)
Heffernan (1970. 19071, 1972)
Hegen (1983)
Henley and Rauschuber (1981)
Holland *et al.* (1973, 1974, 1975)
Lind (1983)
Maurer and Parker (1972)
Monaco *et al.* (1989)
National Estuary Study (1970b)
Pacheco *et al.* (1989)
Rice *et al.* (1988)
Riley *et al.* (1989)
Shepard and Rusnak (1957)
TDWR (1981a)

G-24 Corpus Christi/Nueces Bays (Nueces Estuary, includes Nueces, Corpus Christi and Redfish (part) Bays and Aransas Pass)

The Corpus Christi Bay estuarine system is made up of Nueces Bay, Oso Bay, Corpus Christi Bay and the southern end of Redfish Bay for a total surface area of 44,451 ha (Armstrong, 1987). The average depth is 2.4 m and, like many other Texas bays, is traversed by a major navigation channel that begins in the Aransas Pass Inlet and ends in the port of Corpus Christi. Land use around the estuary is dominated by agriculture and ranching. The City of Corpus Christi, with its associated port and industrial complex is located on the west side of the estuary and dominates land use in that area. An increasing number of additional industrial complexes are located on the north shore of Corpus Christi Bay in Ingleside. Suburban sprawl affects much of the land adjacent to the bay.

Table T9. Statistical summary of water quality data for the Nueces-Corpus Christi Bay System for 1972-1976 (from Henley and Rauschuber, 1981).

Parameter	Mean	Median	Variance	Standard deviation
		Nueces Bay		
Water temperature (°C)	21.05	22.50	51.90	7.20
Dissolved oxygen (mg/l)	8.10	8.20	2.45	1.56
Salinity (ppt)	20.34	22.10	53.70	7.32
Organic nitrogen (mg/l)	0.641	0.620	0.025	0.158
Nitrite (mg/l)	0.091	0.010	0.029	0.171
Nitrate (mg/l)	0.038	0.030	0.0002	0.0145
Ammonia nitrogen (mg/l)	0.125	0.100	0.003	0.054
Orthophosphate (mg/l)	0.057	0.040	0.001	0.036
Total phosphate (mg/l)	0.117	0.110	0.002	0.043
Inorganic carbon (mg/l)	21.84	21.60	52.47	
Organic carbon (mg/l)	23.32	23.00	412.54	
Turbidity (JTU)	67.34	62.50	2,001.80	
pH	8.35	8.30	0.047	
		Corpus Christi Bay		
Water temperature (°C)	21.15	22.70	45.47	
Dissolved oxygen (mg/l)	7.59	7.10	2.17	
Salinity (ppt)	26.16	26.70	19.66	
Organic nitrogen (mg/l)	0.444	0.430	0.009	0.095
Nitrite (mg/l)	0.017	0.006	0.0003	0.016
Nitrate (mg/l)	0.053	0.030	0.006	0.079
Ammonia nitrogen (mg/l)	0.124	0.100	0.002	0.039
Orthophosphate (mg/l)	0.032	0.030	0.0002	0.014
Total phosphate (mg/l)	0.059	0.050	0.0006	0.024
Inorganic carbon (mg/l)	20.19	17.55	43.86	6.62
Organic carbon (mg/l)	17.64	17.65	109.31	10.45
Turbidity (JTU)	19.03	17.45	110.05	10.49
pH	8.42	8.40	0.051	0.226

The studies of Holland *et al.* (1973, 1974, 1975) and Henley and Rauschuber (1981) documented the nutrient and hydrographic characteristics of Corpus Christi and Nueces Bays. Means of data from transects across these three areas are given in Tables T9-T12. The work of Flint (1983) and Flint *et al.* (1986) documents the importance of freshwater inflow into this system with its accompaniment of nutrients. Primary production is positively related to the amount of ammonia in the water column which is inversely related to the salinity (Figure T17).

There were no occurrences of low dissolved oxygen values (<2 mg/l) in the open, shallow bay waters. Most low values were found in the deeper channels, e.g., Corpus Christi Chip Channel and associated turning basins, 12-15 m; LaQuinta Channel, 12 m. Fewer and less intense low dissolved oxygen values were found in other channels, less deep, *e.g.*, Aransas Shrimp Channel, 4.6 m; Redfish Bay, Conn Brown Harbor, 4.6 m. A few other low values (2-4 mg/l) were reported in the tidal reaches of the Nueces River. These values were probably present when there was reduced flow in the river. This estuary is situated in an area of semi-arid climatic conditions. Yearly rainfall averages 28.5 inches and is coupled with a subtropical temperature regime and persistent southeasterly winds. The annual precipitation deficit is 16 inches (Brown *et al.*, 1976). Reduced freshwater inflows, coupled with climatic factors, is aggravated by a series of dams and reservoirs along the course of the Nueces River.

The Texas Water Development Board has conducted long-term deployments of water quality instrumentation in selected Texas estuaries to follow continuous variations in near-bottom water salinity, temperature and dissolved oxygen. Preliminary results from these deployments have been provided by G. Powell (Texas Water Development Board, personal communication) (see Section G-17 for details). Deployments were made in mid Nueces Bay in May-June 1987. The data indicated no dissolved oxygen levels below 2 mg/l based on the first seven days of the instrument deployments.

The extensive 1986 red tide (*Gymnodinium breve*) which affected most of the Texas coast entered Aransas Bay through Aransas Pass and quickly spread into Corpus Christi Bay (Trebatowski, 1988). The bloom of *Gymnodinium breve* which extended along most of the Texas coast in 1986-1987 was monitored at two sites near Port Aransas (Riley *et al.*, 1989). High cell densities of 10 to 50 X 10^6 cells/l were commonly found during October 1986. Densities of red drum larvae were substantially lower following the onset of the red tide bloom than prior to the bloom. Hatch rates of laboratory-spawned red drum eggs were unaffected by various concentrations of the red tide organisms; however, once hatched, larvae were negatively affected by all concentrations >40 cells/ml (Riley *et al.*, 1989). See additional comments in Section G-26.

REFERENCES: G-24

Armstrong (1987)
Benefield *et al.* (1983)
Brown *et al.* (1976)
Flint (1983, 1984)
Flint and Kalke (1985, 1986)
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Flint et al. (1986)
Hahl and Ratzlaff (1970, 1972, 1975)
Hegen (1983)
Holland *et al.* (1973, 1974, 1975)
Kalke and Montagna (1989)
Kalke and Montagna (1989)
Lind (1983)
Maurer and Parker (1972)
Monaco *et al.* (1989)
Montagna and Kalke (1989a)
Montagna *et al.* (1989)
Pacheco *et al.* (1989)
Rice *et al.* (1988)
Steidinger (1973)
TDWR (1981a)
Whitledge and Pulich (1991)

Table T10. Minima, maxima and averages of selected hydrographic parameters (from Holland *et al.*, 1973, 1974, 1975).

NUECES BAY (LINES 25-64)

	WATER TEMP. °C			DISSOLVED O_2 MG/L			SALINITY °/oo			ORGANIC N_2 MG/L			NO_2 MG/L			NO_3 MG/L			NH_4 MG/L			TOTAL PO_4 MG/L			INORGANIC C MG/L			ORGANIC C MG/L		
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
OCTOBER, '72	27.5	29.0	28.4	6.4	7.1	6.6	15.4	25.1	22.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NOVEMBER, '72	13.0	15.0	13.9	7.4	10.3	8.7	19.4	30.6	27.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DECEMBER, '72	7.0	11.0	9.3	7.5	18.8	11.1	22.3	27.2	24.9	0.30	0.40	0.37	0.005	.027	.018	0.04	0.08	0.05	0.20	0.20	0.20	0.05	0.09	0.07	19.0	22.0	20.5	23.0	29.0	26.0
JANUARY, '73	1.0	18.0	6.5	8.5	12.0	10.8	21.0	31.1	25.1	0.20	1.0	0.48	0.005	.010	.008	0.03	0.10	0.05	0.20	0.40	0.28	0.04	0.19	0.10	--	--	--	--	--	--
FEBRUARY, '73	11.5	13.0	12.4	9.0	10.1	9.4	23.4	28.4	26.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.0	29.0	22.0	7.0	42.0	26.7
MARCH, '73	22.0	23.0	22.8	..	..	..	24.5	27.9	27.2	0.30	0.40	0.38	0.003	0.005	0.004	0.03	0.03	0.03	0.10	0.10	0.10	0.01	0.11	0.05	12.0	24.0	16.5	6.0	17.0	10.2
APRIL, '73	15.5	16.5	15.9	6.8	7.5	7.2	27.6	29.3	28.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.0	24.0	21.2	5.0	25.0	12.8
MAY, '73	25.2	27.6	26.4	3.5	7.2	6.3	27.6	31.6	30.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	23.0	26.0	24.2	7.0	10.0	8.5
JUNE, '73	29.0	30.0	29.5	5.7	6.4	6.1	3.6	26.5	19.3	0.50	0.80	0.68	0.20	0.04	0.03	0.05	0.09	0.07	0.10	0.20	0.15	0.10	0.22	0.14	8.0	24.0	15.8	18.0	25.0	21.0

CORPUS CHRISTI BAY (LINES 122-200)

OCTOBER, '72	27.0	30.0	28.1	4.4	10.8	6.8	26.8	31.6	29.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NOVEMBER, '72	14.5	18.0	16.5	7.3	8.2	7.8	27.5	30.9	29.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DECEMBER, '72	8.5	13.0	10.2	9.0	12.5	10.9	27.2	29.2	28.2	0.10	3.00	0.54	0.005	0.017	0.006	0.03	0.08	0.35	0.10	1.00	0.19	0.02	0.07	0.04	15.0	16.0	15.2	15.0	26.0	19.8
JANUARY, '73	5.0	11.5	6.9	8.5	12.0	10.9	21.0	31.1	25.1	0.20	1.00	0.48	0.005	0.10	0.008	0.03	0.10	0.05	0.20	0.40	0.28	0.04	0.19	0.10	--	--	--	--	--	--
FEBRUARY, '73	11.5	13.0	12.4	9.0	10.1	9.4	23.4	28.4	26.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.0	29.0	22.0	7.0	42.0	26.8
MARCH, '73	22.0	23.0	22.8	..	..	..	24.5	27.9	27.2	0.30	0.40	0.38	0.003	0.005	0.004	0.03	0.03	0.03	0.10	0.10	0.10	0.01	0.11	0.05	12.0	24.0	16.5	6.0	17.0	10.2
APRIL, '73	15.5	16.5	15.9	6.8	7.5	7.2	27.6	29.3	28.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	19.0	24.0	21.2	5.0	25.0	12.8
MAY, '73	25.2	27.6	26.4	3.5	7.2	6.3	27.6	31.6	30.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	23.0	26.0	24.2	7.0	10.0	8.5
JUNE, '73	29.0	30.0	29.5	5.7	6.4	6.1	3.6	26.5	19.3	0.50	0.80	0.68	0.02	0.04	0.03	0.05	0.09	0.07	0.10	0.20	0.15	0.10	0.22	0.14	8.0	24.0	15.8	18.0	25.0	21.0

Table T11. Minima, maxima and averages of selected hydrographic parameters (from Holland *et al.*, 1973, 1974, 1975).

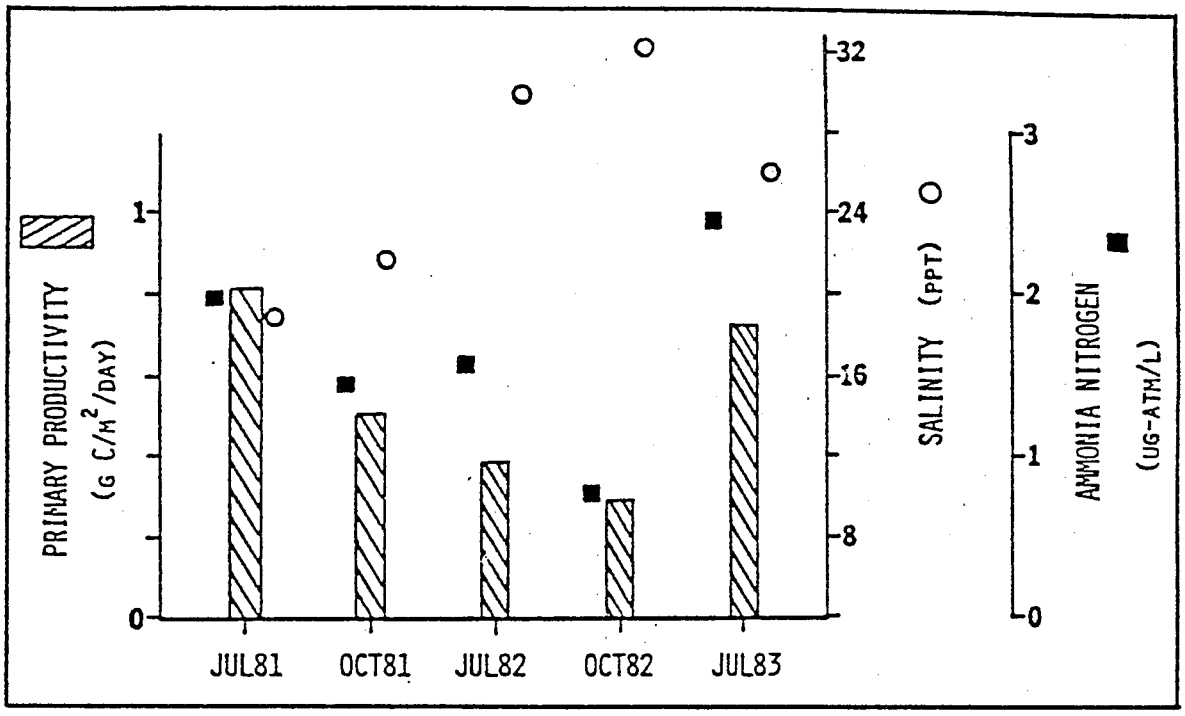
NUECES BAY (LINES 38-64)

	NO_2 MG/L			NO_3 MG/L			NH_4 MG/L			ORGANIC N_2 MG/L			ORTHO PO_4 MG/L			TOTAL PO_4 MG/L			ORGANIC C MG/L			INORGANIC C MG/L		
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
JULY 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.70	0.80	0.73	0.06	0.11	0.09	0.12	0.17	0.15	34.0	52.0	45.5	18.0	19.0	18.3
AUGUST 1973	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.50	0.80	0.62	0.03	0.13	0.08	0.08	0.22	0.13	27.0	34.0	29.5	10.0	17.0	14.0
SEPTEMBER 1973	0.005	0.010	0.006	0.03	0.12	0.05	0.10	0.10	0.10	0.50	0.70	0.60	0.01	0.22	0.07	0.05	0.34	0.13	—	—	—	—	—	—
OCTOBER 1973	0.005	0.008	0.006	0.03	0.11	0.08	0.10	0.20	0.12	0.40	0.70	0.52	0.09	0.20	0.16	0.09	0.28	0.19	18.0	56.0	32:5	11.0	19.0	15.0
NOVEMBER 1973	0.005	0.005	0.005	0.03	0.04	0.04	0.10	0.10	0.10	0.50	1.10	0.75	0.07	0.18	0.12	0.14	0.26	0.18	22.0	20.0	28.0	7.0	12.0	9.2
DECEMBER 1973	0.005	0.005	0.005	0.03	0.14	0.06	0.10	0.10	0.10	0.30	0.50	0.42	0.06	0.13	0.08	0.07	0.18	0.11	30.0	35.0	32.7	10.0	19.0	15.0
JANUARY 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.60	1.10	0.78	0.02	0.03	0.02	0.11	0.13	0.12	26.0	40.0	32.2	12.0	20.0	16.8
FEBRUARY 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.60	1.30	0.92	0.03	0.06	0.04	0.12	0.29	0.19	7.0	42.0	26.8	19.0	29.0	22.0
MARCH 1974	0.023	0.035	0.029	0.03	0.06	0.04	0.10	0.20	0.15	0.50	0.70	0.60	0.03	0.06	0.04	0.08	0.19	0.13	16.0	30.0	25.0	26.0	31.0	28.0
APRIL 1974	0.005	0.580	0.028	0.03	0.09	0.05	0.10	0.10	0.10	0.50	1.10	0.85	0.10	0.04	0.03	0.07	0.14	0.09	22.0	55.0	34.5	9.0	19.0	13.0
CORPUS CHRISTI BAY (LINES 122-200)																								
JULY 1973	0.005	0.008	0.005	0.03	0.04	0.03	0.01	0.10	0.10	0.20	0.90	0.60	0.01	0.05	0.02	0.02	0.14	0.06	40.0	63.0	45.0	10.0	18.0	16.0
AUGUST 1973	0.005	0.005	0.005	0.03	0.04	0.31	0.10	0.10	0.10	0.20	0.60	0.38	0.01	0.03	0.02	0.02	0.08	0.04	21.0	47.0	27.3	10.0	15.0	13.2
SEPTEMBER 1973	0.005	0.026	0.006	0.03	0.10	0.03	0.10	0.10	0.10	0.20	1.00	0.43	0.01	0.34	0.04	0.02	0.48	0.06	—	—	—	—	—	—
OCTOBER 1973	0.005	0.014	0.006	0.03	0.03	0.03	0.10	0.20	0.11	0.20	1.20	0.53	0.02	0.11	0.05	0.03	0.30	0.07	20.0	52.0	29.3	8.0	19.0	13.0
NOVEMBER 1973	0.005	0.027	0.006	0.03	0.03	0.03	0.10	1.00	0.16	0.30	1.00	0.62	0.01	0.33	0.06	0.03	0.40	0.09	13.0	34.0	21.7	5.0	18.0	13.3
DECEMBER 1973	0.005	0.008	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.20	1.00	0.36	0.01	0.28	0.05	0.03	0.43	0.08	23.0	46.0	30.5	8.0	20.0	15.2
JANUARY 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.04	1.00	0.15	0.10	0.70	0.43	0.02	0.10	0.03	0.03	0.20	0.05	22.0	32.0	26.3	8.0	18.0	15.2
FEBRUARY 1974	0.005	0.014	0.006	0.03	0.03	0.03	0.10	0.40	0.12	0.30	0.80	0.44	0.01	0.37	0.04	0.02	0.40	0.06	22.0	51.0	32.9	12.0	17.0	14.4
MARCH 1974	0.005	0.005	0.005	0.03	0.05	0.03	0.10	0.10	0.10	0.30	0.40	0.34	0.01	0.03	0.02	0.01	0.03	0.03	9.0	28.0	19.3	13.0	23.0	18.1
APRIL 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.20	1.30	0.46	0.01	0.23	0.03	0.02	0.44	0.06	15.0	36.0	25.6	9.0	23.0	12.0

Table T12. Minima, maxima and averages of selected hydrographic parameters (from Holland *et al.*, 1973, 1974, 1975).

	NO_2 (MG/L)			NO_3 (MG/L)			NH_4 (MG/L)			ORGANIC N_2 (MG/L)			ORTHO PO_4 (MG/L)			TOTAL PO_4 (MG/L)			ORGANIC C (MG/L)			INORGANIC C (MG/L)		
	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
NUECES BAY (LINES 38-64)																								
May 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.60	0.90	0.70	0.04	0.05	0.04	0.11	0.16	0.12	27	34	30	10	12	11
June 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.60	0.90	0.70	0.02	0.05	0.03	0.07	0.13	0.09	22	357	112	15	22	18
July 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.40	1.00	0.68	0.02	0.06	0.04	0.06	0.18	0.10	24	28	25	12	14	13
August 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.60	0.90	0.70	0.03	0.11	0.05	0.06	0.28	0.14	16	30	20	29	37	32
September 1974	0.050	0.050	0.050	0.03	0.04	0.03	0.10	0.10	0.10	0.70	1.10	0.80	0.07	0.16	0.12	0.10	0.31	0.19	13	19	17	20	27	24
October 1974	0.030	0.050	0.045	0.03	0.03	0.03	0.10	0.10	0.10	0.50	1.00	0.70	0.04	0.09	0.06	0.06	0.14	0.10	8	10	9	30	36	32
November 1974	0.010	0.890	0.237	0.03	0.10	0.05	0.10	0.50	0.30	0.50	1.40	1.02	0.01	0.08	0.04	0.04	0.17	0.08	7	10	9	29	32	30
December 1974	0.010	0.010	0.010	0.02	0.04	0.02	0.10	0.10	0.10	0.30	0.50	0.45	0.03	0.05	0.04	0.06	0.06	0.06	5	9	7	30	33	32
January 1975	0.010	0.020	0.012	0.02	0.10	0.04	0.10	0.50	0.20	0.50	0.80	0.70	0.01	0.05	0.03	0.06	0.10	0.08	5	9	6	26	30	28
February 1975	0.010	0.030	0.017	0.02	0.06	0.03	0.10	0.10	0.10	0.06	0.70	0.52	0.02	0.04	0.03	0.03	0.09	0.06	3	8	6	33	35	34
March 1975	0.010	0.030	0.015	0.02	0.02	0.02	0.10	0.10	0.10	0.50	0.70	0.62	0.02	0.06	0.03	0.05	0.17	0.11	7	10	8	28	32	30
April 1975	0.020	0.040	0.030	0.02	0.06	0.04	0.10	0.10	0.10	0.30	0.50	0.45	0.02	0.05	0.04	0.04	0.11	0.08	4	5	4	29	31	30
May 1975	0.020	0.020	0.020	0.02	0.02	0.02	0.10	0.10	0.10	0.40	0.80	0.58	0.01	0.04	0.02	0.03	0.16	0.07	5	12	8	24	29	26
CORPUS CHRISTI BAY (LINES 122-200)																								
May 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.10	0.60	0.35	0.01	0.07	0.02	0.01	0.09	0.03	15	36	25	8	18	11
June 1974	0.005	0.005	0.005	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.70	0.44	0.01	0.04	0.02	0.01	0.09	0.04	15	27	20	15	21	17
July 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.10	0.10	0.30	0.70	0.49	0.01	0.05	0.02	0.02	0.09	0.04	21	30	26	11	14	12
August 1974	0.050	0.050	0.050	0.03	0.03	0.03	0.10	0.20	0.11	0.20	1.30	0.44	0.01	0.19	0.03	0.03	0.51	0.08	7	36	15	25	35	28
September 1974	0.050	0.050	0.050	0.03	0.09	0.03	0.10	0.30	0.11	0.30	1.40	0.51	0.01	0.40	0.06	0.03	0.47	0.08	11	20	16	22	25	23
October 1974	0.050	0.050	0.050	0.03	0.40	0.06	0.10	0.20	0.11	0.30	0.80	0.46	0.01	0.30	0.04	0.03	0.31	0.06	6	10	8	27	32	28
November 1974	0.010	0.470	0.040	0.03	0.04	0.03	0.10	0.40	0.12	0.30	1.10	0.51	0.01	0.27	0.03	0.01	0.33	0.05	4	8	6	26	32	27
December 1974	0.010	0.060	0.014	0.02	0.02	0.02	0.10	0.40	0.12	0.20	0.40	0.32	0.01	0.25	0.03	0.02	0.25	0.05	5	19	10	27	33	29
January 1975	0.010	0.080	0.015	0.02	0.02	0.02	0.10	0.80	0.15	0.30	0.70	0.41	0.01	0.31	0.04	0.03	0.34	0.06	2	11	4	24	33	27
February 1975	0.010	0.180	0.020	0.02	0.02	0.02	0.10	0.90	0.16	0.30	0.50	0.36	0.01	0.39	0.04	0.02	0.41	0.05	2	7	4	31	37	33
March 1975	0.010	0.070	0.019	0.02	0.02	0.02	0.10	0.10	0.10	0.30	0.80	0.39	0.01	0.16	0.02	0.02	0.21	0.05	4	7	5	27	31	28
April 1975	0.010	0.020	0.013	0.02	0.02	0.02	0.10	0.10	0.10	0.20	0.50	0.28	0.01	0.02	0.01	0.02	0.08	0.03	1	5	3	27	31	30
May 1975	0.020	0.020	0.020	0.02	0.06	0.02	0.10	0.10	0.10	0.30	0.60	0.38	0.01	0.04	0.01	0.02	0.10	0.04	3	8	5	25	29	27

Figure T17. Phytoplankton primary productivity, salinity, and ammonia concentrations in Corpus Christi Bay during July and October, 1981-1983 (from Flint, 1983).



G-25 Baffin Bay

Baffin Bay is an extension of the Upper Laguna Madre. Depth in the central part of the Bay ranges from 1.8 to 3.6 m but much of the Bay and its arms (Laguna Salada, Cayo del Grullo and Alazan Bay) range in depth from 0.9 to 1.8 m (Brown *et al.*, 1977) The Bay is subject to hypersalinity as a result of low rainfall, high evaporation rates and isolation from tidal passes to the Gulf of Mexico.

Only one bit of additional data was available for an update on this area; however, extensive studies are in progress by researchers from The University of Texas, Marine Science Institute, funded by the Texas Water Development Board.

Data for Baffin Bay are limited but there were a few values of low dissolved oxygen in bottom waters. One record in 33 fell below 2 mg/l (1.8 mg/l in 2 m of water). Russell and Baskin (1989) reported that runoff from heavy rains associated with the passage of Hurricane Allen in 1980 subsequently entered the bay over the more dense saline water of the bay (50 ppt) and formed a stagnant layer extending 1 m above the bottom of the main stem of Baffin Bay. The dissolved oxygen content of this layer declined to zero, until mixing destroyed the identity of the stagnant water mass approximately two months after passage of the hurricane.

See comments in section G-26 concerning a brown tide in 1990-1991.

REFERENCES: G-25

Breuer (1957)
Maurer and Parker (1972)
Monaco *et al.* (1989)
Russell and Baskin (1989)
TDWR (1983)

G-26 Laguna Madre

The Laguna Madre estuary consists of Upper and Lower Laguna Madre, Baffin Bay and part of Arroyo Colorado for a total surface area of 214,545 ha (Armstrong, 1987). The estuary is shallow (1.2 m), has extensive seagrass meadows and is traversed along its length by the Gulf Coast Intracoastal Waterway. A landmass separates the Upper and Lower Lagunas and is dissected by the waterway. The South Bay system south of the causeway connecting Port Isabel to the southern tip of Padre Island exchanges waters with the Lower Laguna Madre. Rio Grande tidal water does not interchange directly with the Lower Laguna Madre.

The nutrient concentrations of Laguna Madre are generally low, with low nutrient loading, high water clarity, and hypersaline conditions preventing species succession of primary producers. Simmons (1957) pointed out that dissolved nutrient concentrations in the Laguna Madre are usually low, which he attributed to the lack of an adequate watershed for the area. Pulich (1980) compiled nutrient data from the Laguna Madre, which are presented in Table T13. These data show that concentrations of nitrate, ammonia and phosphate are usually higher at the mouth of Arroyo Colorado in the Lower Laguna and at the north end at the Kennedy Causeway near Corpus Christi Bay and points of inflow to the system than they are in the central parts of the Laguna. Pulich (1980) further outlined the implications of nutrient enrichment to the enhancement of periphytic algae on seagrass stems which would cause an overall decline in macrophyte populations.

Table T13. Nutrient concentrations at Texas Department of Water Resources Monitoring stations in Laguna Madre during 1978 (from Pulich, 1980).

Site	NO_3	NH_4	PO_4
Kennedy Causeway	0.09	ND[a]	0.320
Marker 59	0.05	ND	0.160
Mouth of Baffin Bay	0.03	ND	0.122
Marker 225A	0.02	ND	0.140
Port Mansfield	0.02	ND	0.150
Arroyo Colorado Mouth	0.30	0.10	0.550
Port Isabel	0.02	ND	0.120

[a]Not detectable; less than 0.5 mg/ℓ

The comprehensive survey by Merkord (1978) as reported in Pulich (1980) provides evidence of the changes in seagrass populations, particularly in the Lower Laguna Madre since the work of Simmons (1957) and McMahan (1968). Seagrass abundance has increased in the Upper Laguna, with *Halodule* and *Halophila* expanding their ranges since 1966. A dramatic shift in species distribution has occurred in the Lower Laguna Madre as evidence by the spread of manateegrass (*Syringodium*) northward from the Arroyo Colorado and a decline in *Halodule* to the south of Port Mansfield along the eastern half of the Lower Laguna Madre. This range expansion may be the result of a general increase in turbidity noted in the Lower Laguna Madre (G. Merkord, personal communication; cited by Pulich, 1980), although it has not been quantified. It is also possible that runoff from the Arroyo Colorado which included nutrients, pesticides, herbicides and silt (Warshaw, 1974; cited in Pulich, 1980) has allowed *Syringodium* to grow relatively unchecked. If *Halodule* is inefficient at using blue light, which would predominate in turbid water, then growth of *Syringodium* could be favored.

A recent algal bloom attributed to an undescribed chrysophyte has persisted in the Upper Laguna Madre, Baffin Bay, Corpus Christi Bay and Redfish Bay (part) since since June 1990 (D. Stockwell *et al.*, personal communication). The so-called "brown tide" was still present as recently as April 1992 (T.E. Whitledge, personal communication), but the extent and population levels have declined. A conference, sponsored by the Texas Parks and Wildlife Department and the U.S. EPA Gulf of Mexico Program, was held in July 1991 at The University of Texas Marine Science Institute in Port Aransas to synthesize knowledge about the bloom (Whitledge and Pulich, 1991).

A brown tide bloom began in the hypersaline waters of Baffin Bay and the Upper Laguna Madre in June 1990 and has persisted into 1992. The extensive bloom is composed of a 5 µm-diameter, non-motile, autotrophic chrysophyte in average concentrations of 1.9 X 10^9 cells/l, with maximum values of 4.9 X 10^9 cells/l. Chlorophyll *a* concentrations increased to 30-80 µg/l from typical values of 1-3 µg/l. The bloom has caused increased turbidity in the usually fairly clear waters of the Laguna Madre, Baffin Bay and Corpus Christi Bay. Indirect impacts of the bloom may be shading of the extensive submerged aquatic vegetation beds of the Laguna Madre and a decrease in seagrass coverage. Another indirect impact of the bloom has been the decline in populations of the bivalve, *Mulinia lateralis*, which is a major food organism for black drum and some overwintering waterfowl.

Researchers note that the brown tide is coincident with an extremely hard freeze during the winter of 1989-1990 and elevated salinities within the Laguna Madre system in 1990. These conditions, however, are not unusual for the Laguna Madre. It was also noted, however, by Hildebrand and King (1978) (cited in Armstrong, 1987) that salinity was the controlling factor of phytoplankton dynamics in the Upper Laguna Madre, that blooms generally occurred following salinity changes and that blooms were never found in salinities >40 ppt. Simmons (1957) also noted that phytoplankton were nonexistent in the Upper Laguna Madre in the higher saline areas (>60 ppt) but that "red water," or "bad water," was often present in the Upper Laguna Madre, commonly associated with high salinity, but not necessarily so. Other potential factors which may have lead to the formation of the bloom include major changes in land use in the watershed of the Laguna Madre as more land is converted from pastureland into cropland and fertilizer use increases. The Lower Laguna Madre is one of three drainage areas in the Gulf of Mexico (others are Galveston Bay and Matagorda Bay) which received the highest applications of fertilizer to adjacent agricultural lands (NOAA, 1990a).

Brown tides, documented in Long Island Sound from 1985-1987 (several authors cited in Cosper *et al.*, 1989), were responsible for the reduction in extent and biomass of eelgrass beds and caused starvation and recruitment failure of commercially important bay scallop populations. Brown tides were also responsible for the near-elimination of mussel populations in areas of Narragansett Bay [Olsen, 1986; Seiburth *et al.*, 1986; as cited in Shumway, 1990]. Shellfish resources in most of Laguna Madre are limited to scallops, which are not commercially harvested. Apparently, in the Laguna Madre, the extensive seagrass beds have not been impacted by the reduced light penetration from the highly concentrated populations of the chrysophyte (R. Kalke, personal communication).

REFERENCES: G-26

Armstrong (1987)
Brown *et al.* (1977, 1980)
Hahl and Ratzlaff (1972, 1975)
Lind (1983)
Maurer and Parker (1972)
Monaco *et al.* (1989)
Pacheco *et al.* (1989)
Pulich (1980)
Shepard and Rusnak (1957)
Smith (1988)
TDWR (1983, 1984)
Whitledge and Pulich (1991)

G-26.1 Upper Laguna Madre

No additional data were available for an assessment of low dissolved oxygen concentrations. Most of the low dissolved oxygen values recorded in the area were in deeper channels, particularly the Gulf Intracoastal Waterway. No occurrences were recorded in the shallower margins of the lagoon. A series of low values in August 1980 can be attributed to stratification following heavy rains and freshwater runoff following Hurricane Allen (see Section G-25). Some of the low values in the deeper channels may be related to a high BOD from decomposing seagrasses which may be moved with water currents into these areas. Seagrasses form extensive meadows in the Upper Laguna Madre and undergo a general senescence and die off in late summer/fall.

The extensive 1986 red tide (*Gymnodinium breve*) which affected most of the Texas coast had a limited impact on the Laguna Madre. In spite of the extensive and heavy densities of *G. breve* in Corpus Christi Bay, impact in Laguna Madre was limited to the northern end at passes connecting to Corpus Christi Bay (Trebatowski, 1988).

See comments in section G-26 concerning a brown tide in 1990-1991.

REFERENCES: G-26.1

Benefield *et al.* (1983)
Hegen (1983)
Rice *et al.* (1988)
Simmons (1957)
TDWR (1983)

G-26.2 Lower Laguna Madre (includes Arroyo Colorado, South Bay, Brownsville Ship Channel and Brazos Santiago Pass)

No additional data are available for an assessment of the dissolved oxygen concentrations of this area. In the Lower Laguna Madre, proper, no low dissolved oxygen values occurred in the open shallow waters. Low values were in deeper channels, particularly in the Gulf Coast Intracoastal Waterway, where many of the samples were taken. Low values in a series of stations in August 1980 may be related to stratification following heavy rains and freshwater runoff following Hurricane Allen (see Section G-25). Some of the lower values in the deeper channels may be related to the decay of senescent seagrass populations. There were no oxygen-depleted waters recorded in the few samples from South Bay. Arroyo Colorado is often hypoxic or anoxic. Flow is low in the Arroyo and oxygen depletion is most severe in the summer when there are strong vertical gradients associated with a high salinity salt wedge (Bryan, 1971). Hypoxia and anoxia occur year-round in this natural drainage channel which has been dredged to 3 to 3.6 m. Oxygen-depleted waters (often anoxic) occur in the Brownsville Ship Channel (12 m) in April-October. There is little tidal mixing in the upper reaches of the channel. Those parts of the channel closest to the Gulf of Mexico and Brazos Santiago Pass have fewer or no low dissolved oxygen values. None of the few samples taken in Brazos Santiago Pass were below 4 mg/l.

A research program was conducted in the Rio Grande River, Arroyo Colorado and lower Laguna Madre to provide information to regulatory agencies concerning the potential impacts of constructing another dam across the Rio Grande. This work, funded by the Public Utilities Board of Brownsville, included surveys of nekton and benthos (D. Harper, personal communication).

The extensive 1986 red tide (*Gymnodinium breve*) which affected most of the Texas coast, including waters in and near Mansfield Channel, did not impact the Lower Laguna Madre (Trebatowski, 1988).

See comments in section G-26 concerning a brown tide in 1990-1991 which extended into the Lower Laguna Madre. At the same time that a brown tide was affecting the Upper Laguna Madre

in 1990, a red tide was occurring in the Lower Laguna Madre (J. Bowman, personal communication).

REFERENCES: G-26.2

Benefield *et al.* (1983)
Breuer (1962, 1972)
Brown *et al.* (1980)
Bryan (1971)
Hegen (1983)
Rice *et al.* (1988)
TDWR (1983)

G-26.3 Rio Grande Tidal

No additional data are available for the assessment of dissolved oxygen concentrations. Limited data (Breuer, 1969-1970) indicated oxygen-depleted waters in the warmer months. Stations at mile 0, 4, 8 and 12 are tidally influenced. There was no discussion of causes other than noting that flow in the lower Rio Grande has been reduced considerably from upstream damming and removal of river water for agriculture, industry and municipalities.

A research program was conducted in the Rio Grande River, Arroyo Colorado and lower Laguna Madre to provide information to regulatory agencies concerning the potential impacts of constructing another dam across the Rio Grande. This work, funded by the Public Utilities Board of Brownsville, included surveys of nekton and benthos (D. Harper, personal communication).

REFERENCES: G-26.3

Breuer (1969-70)
Hackney (1978)

G-27 Texas inner continental shelf

The water quality of the Texas inner shelf can be typified by several data bases along an Aransas Pass Inlet transect off Port Aransas (Flint and Rabalais, 1981a; Dagg and Checkley, unpublished data). The dominant source of fresh water is discharge from Texas rivers. The effect of the Mississippi River is evident along the upper coast but is minimized in the vicinity of Port Aransas, although salinities at mid shelf in the spring are lower and thus reflect the influence of the Mississippi River. In general, nutrients and chlorophyll biomass are much lower in mid shelf waters of Texas than compared to the continental shelf of Louisiana (Figure T18). There are distinct water masses along the lower Texas shelf which are typified by fresh water from rivers (Texas), a mixing zone of Texas freshwater sources as well as the Mississippi River influence, and an offshore zone where Mississippi River discharge dominates the shelf (however, variations in salinity are minimal) (Figure T19).

Conditions of strong salinity stratification and high nutrient input are therefore limited to the upper Texas coast. This is also the area to which conditions of oxygen-deficient bottom waters are confined. Through three years of continental shelf baseline studies on the south Texas coast between Port O'Connor and the Rio Grande (57 samples), the lowest dissolved oxygen concentration found was 3.2 mg/l in 18 m water depth in June (Sackett and Brooks, 1976; Sackett *et al.* (1977, 1979). On the inner shelf between Galveston Bay and Matagorda Bay, seasonal sampling (four times per year) revealed scattered low oxygen concentrations in July 1973 (Seadock, Inc., 1974), with one value of 0.2 mg/l in 15.5 m water depth and another of 2.0 mg/l in 21 m water depth. Shallower stations and deeper stations did not experience low oxygen.

Oxygen conditions off Galveston and Freeport, Texas, however, are considerably different. While the Louisiana continental shelf experiences hypoxia almost annually over a broad area (Rabalais *et al.*, 1991), the upper Texas coast is affected infrequently. Monitoring of a brine disposal site off

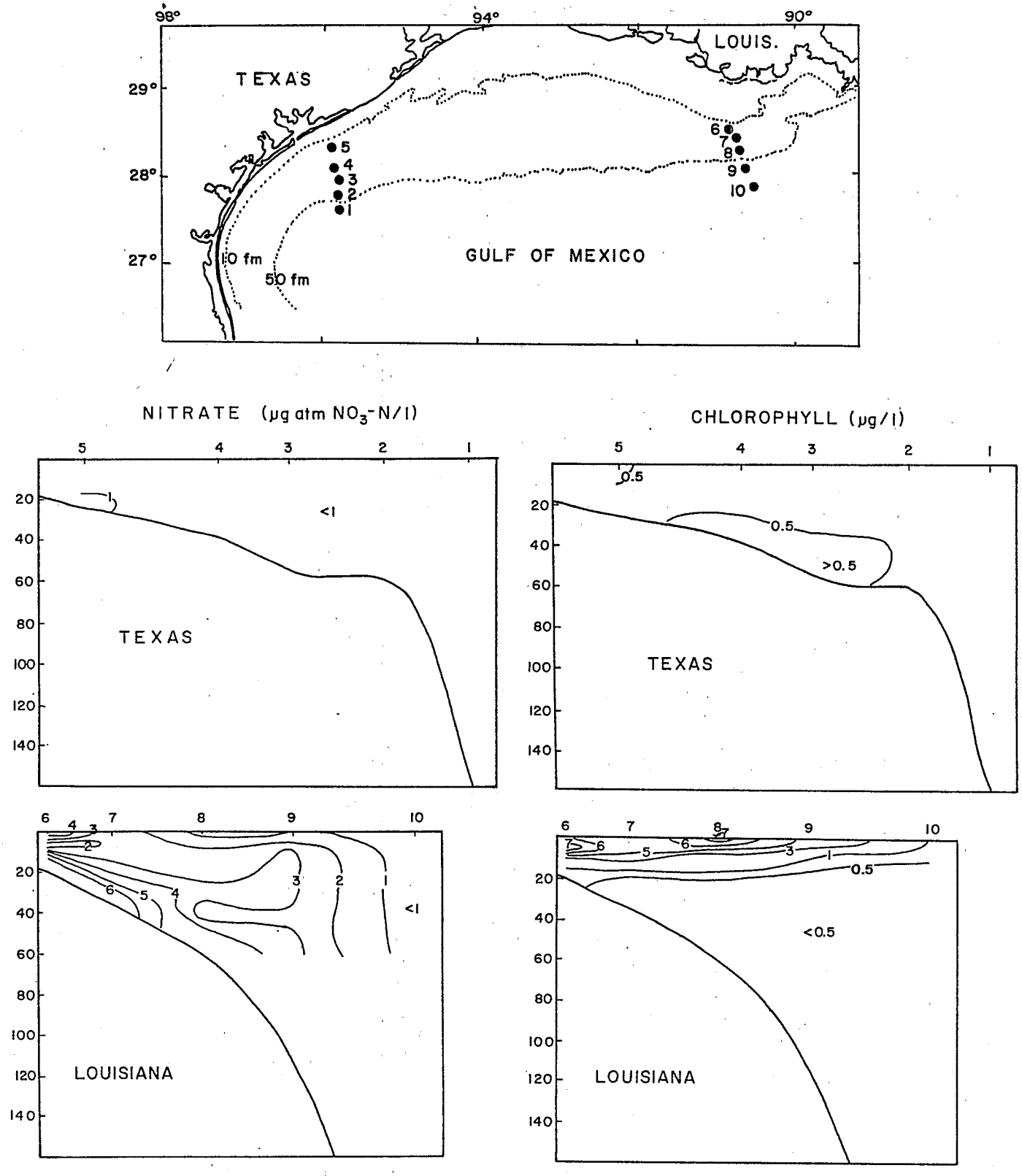


Figure T18. Isopleths of nitrate and chlorophyll for comparative areas of the Texas and Louisiana continental shelves (Dagg and Checkley, unpublished data).

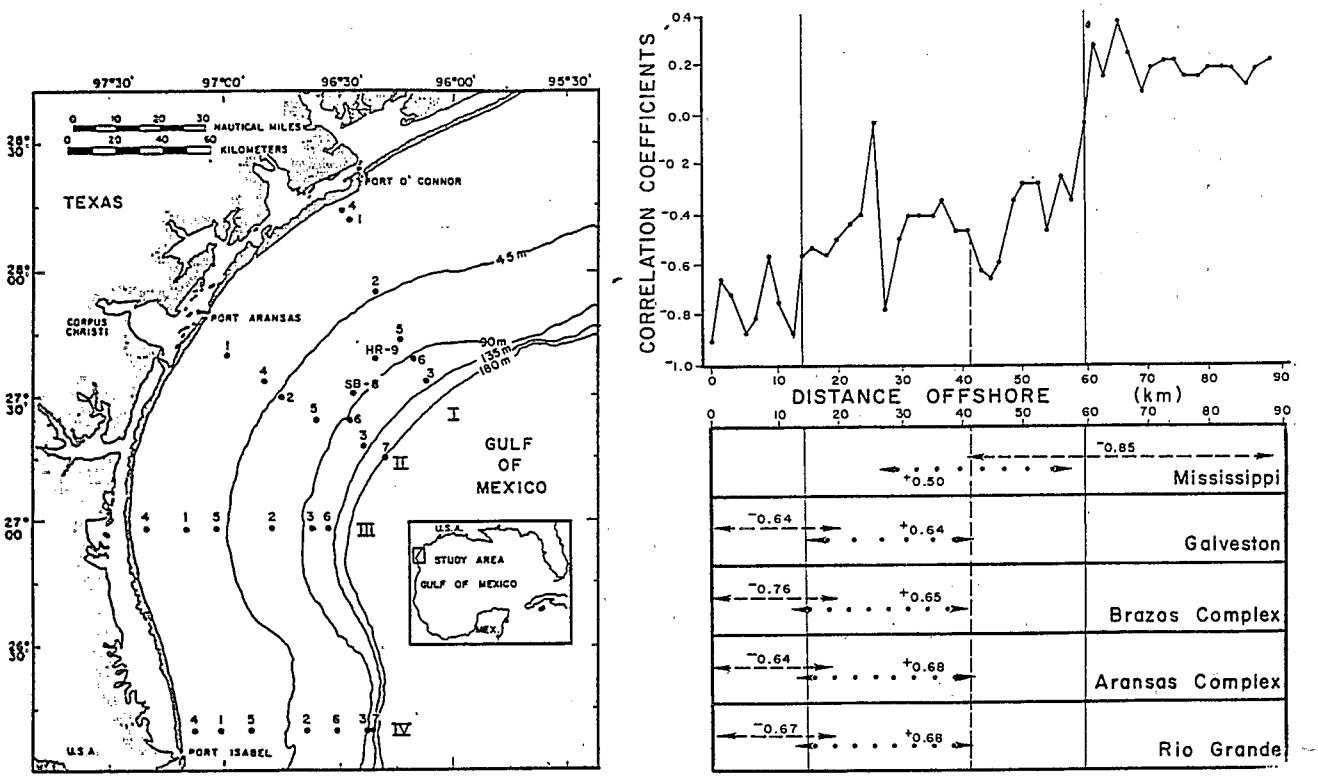


Figure T19. Map of study area of south Texas outer continental shelf and correlation analysis between chlorophyll *a*, salinity and freshwater sources (from Flint and Rabalais, 1981a).

Freeport revealed a hypoxic event between May and July 1979 in 15- and 20-m water depths (Figure T20) (Harper *et al.*, 1981, 1991). Macroinfaunal sampling at the sites showed that abundances of benthic organisms declined precipitously during the event. Divers inspecting the study areas during the hypoxia observed mats of sulfur-oxidizing bacteria covering large areas of the bottom and numerous bodies of dead benthic invertebrates. This hypoxic event was also responsible for sharply reduced abundance and elimination of both fishes and shrimps in trawl catches (Pavela *et al.*, 1983). Hypoxia was also recorded at this site in June 1983, and possibly occurred in June 1982 and 1984 (Harper *et al.*, 1991). Harper and Guillen (1989) suggest that the high runoff of the Atchafalaya River, reduced salinities, transported nutrients and associated phytoplankton blooms together with the appropriate meteorological conditions cause hypoxia along the upper Texas coast. These events, however, are infrequent, short-lived and limited in extent.

Two blooms of the toxic dinoflagellate, *Gonyaulax monilata*, occurred in the offshore coastal waters of Texas at Galveston in August 1971 and August 1972 (Wardle *et al.*, 1975). Similar numbers of dead and moribund marine organisms were collected from the beachfront on days following peak cell counts of 1.2 to 1.8 X 10^6 cells/l. The organisms consisted of coelenterates, annelids, molluscs, crustaceans, echinoderms and fishes, all of which were either sessile, sedentary or weakly motile, suggesting that the more mobile species were able to avoid the area of the bloom before accumulating lethal amounts of the toxin. Despite extensive monitoring in late July and August of 1973, no *G. monilata* cells were noted in the offshore area of Galveston Island. Wardle *et al.* (1975) suggested that the absence of red tides during 1973 was related to relatively low salinities and temperatures in the Galveston Bay drainage area during the month of August.

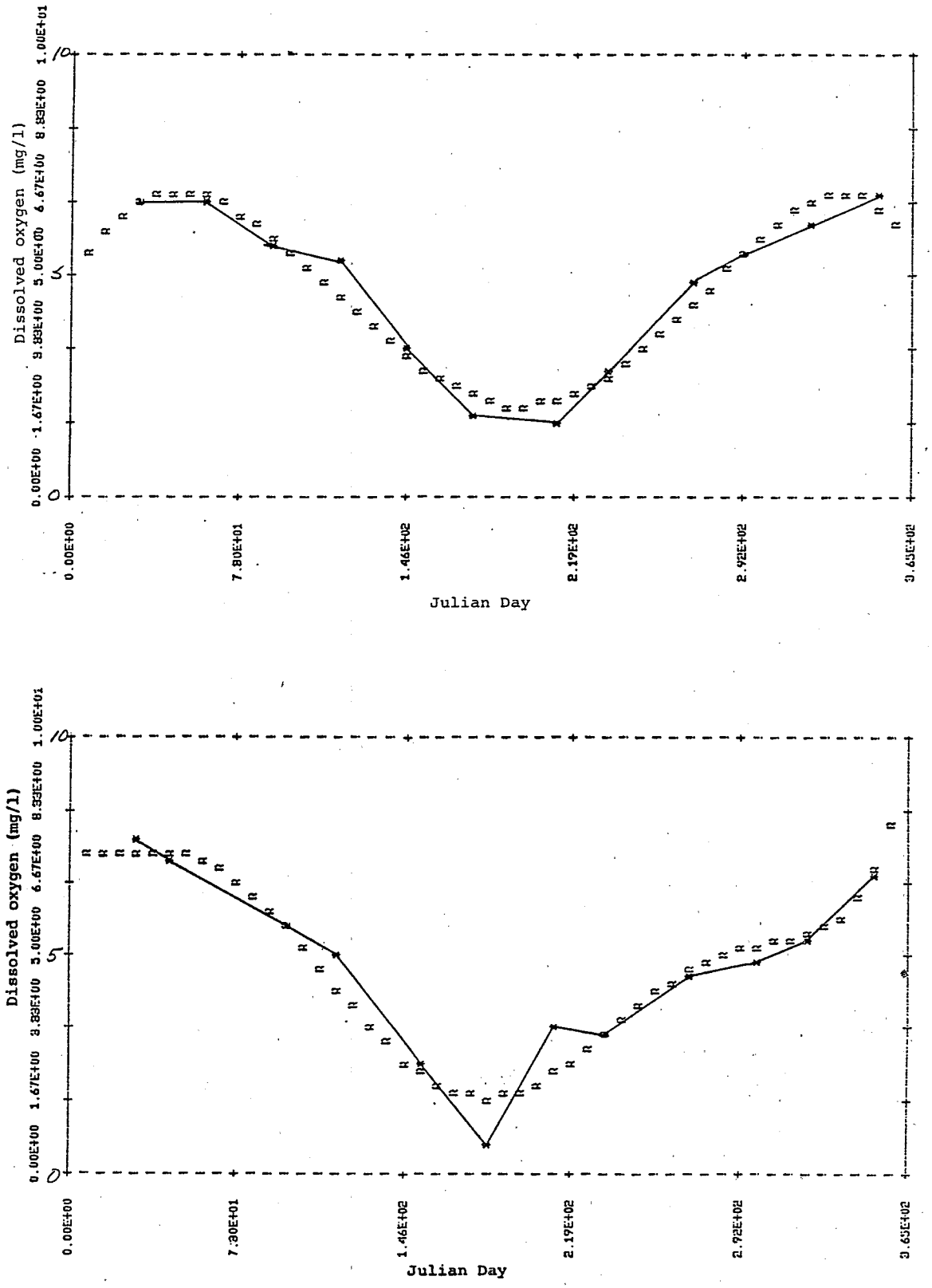


Figure T20. Dissolved oxygen levels in bottom waters at the Bryan Mound 10-mile (upper panel) and 5-mile (lower panel) site in 1979 (from Rabalais *et al.*, 1985).

A bloom of the dinoflagellate, *Exuviella baltica*, which was extensive in the Galveston Bay system during the winters of 1972-1973 and 1976-1977 also occurred along the Galveston beachfront in offshore coastal waters (Zotter, 1979).

Another dinoflagellate, *Gymnodinium splendens*, was implicated in extensive mortalities of demersal fish and benthic invertebrates during the summer of 1984 off Galveston in nearshore coastal waters (Harper and Guillen, 1989). The authors suggested that the high runoff of the Atchafalaya River, reduced salinities, transported nutrients and associated blooms were concentrated along the Louisiana shore by winds and then driven alongshore into Texas by the strong alongshore wind component in May. The decomposition of the phytoplankton that had settled to the bottom, reduction in oxygen concentrations, and the production of hydrogen sulfide were the causes of the mortalities of organisms.

Blooms of the dinoflagellate, *Gymnodinium breve*, were implicated in fish kills in the nearshore coastal waters of the lower Texas coast off Port Isabel and the Rio Grande in 1955; these fish kills extended along the coast of the Mexican State of Tamaulipas for at least 120 miles below the Rio Grande. Other infrequent occurrences of this dinoflagellate have been reported in Texas waters (Lund, 1935; Wilson and Ray, 1956; cited in Trebatowski, 1988).

The report by Trebatowski (1988) documents an extensive, long-lived and highly toxic bloom of *G. breve* which occurred in Texas waters in 1986. Similar to the outbreaks of red tide on the southwestern Florida coast (see Section F-15.1), the red tide bloom originated in offshore waters then moved inshore. The bloom was first reported on 27 August 1986 in Gulf of Mexico waters near Galveston Island. In subsequent weeks the bloom progressed southward along the coastline and into Matagorda Bay. By mid-September, virtually all of Matagorda Bay and parts of Lavaca Bay and Espiritu Santo Bay contained red tide. While the red tide continued to impact the Matagorda Bay area, it also progressed slowly southward until October. During October, the red tide came ashore as far south as Port Isabel, and into Mexico waters of the State of Tamaulipas, and also became established in Aransas Bay, Redfish Bay, Corpus Christi Bay and parts of Laguna Madre (northern end) and Copano Bay. Although the bloom had virtually abated by late October; localized, and at times dense, concentrations were encountered through January 1987 (Trebatowski, 1988). Nutrient analyses conducted on red tide water did not reveal a strong nitrogen and phosphorus correlation with cell count and supports the view that *G. breve* is not nutrient limited. The Texas Parks and Wildlife Department estimated 126 species of fish reported killed by red tide and 22.2 million vertebrates and invertebrates killed during the red tide. These estimates were considered conservative by Trebatowski (1988). (See also sections G-21, G-22, G-23, G-24, G-25, G-26.1).

The diatom, *Nitzchia pungens f. multiseries*, has been found recently in the Galveston, Texas area of the Gulf of Mexico (Fryxell, 1990). This diatom is responsible for a 1987 outbreak of neurotoxic domoic acid in an area of maricultured blue mussels in Prince Edward Island, Canada, which resulted in several human deaths and disabilities.

Other algal blooms have been documented for the lower Texas coast: *Chaetoceros* sp., a diatom (Gunter and Lyles, 1979), and *Trichodesmium* sp., a blue-green alga (Van Baalen and Brown, 1969; work of C. Van Baalen, University of Texas Marine Science Institute, deceased).

REFERENCES: G-27

Atwood (1981)
Benefield *et al.* (1983)
Boesch and Rabalais (1991a)
Casserly *et al.* (1982)
Churgin and Halminsta (1974)
Parker and Bailey (1979)
Parker *et al.* (1979)
Pavela *et al.* (1983)
Pokryfki (1985)
Pokryfki and Randall (1987)

Cons. Perm. Int. Exp. Mer (1936)
Dennis *et al.* (1984)
Dinnel (1984)
Dinnel and Wiseman (1986)
El-Sayed *et al.* (1972)
Flint and Kamykowski (1984)
Flint and Rabalais (1981a,b)
Gazey *et al.* (1982)
Gunter (1979)
Gunter and Lyles (1979)
Hann *et al.* (1984)
Hann and Randall (1980-1983)
Harper and Guillen (1989)
Harper and McKinney (1982a,b)
Harper *et al.* (1981, 1991)
Leming and Stuntz (1984)
Mauer and Parker (1972)
Rabalais *et al.* (1991a)
Ray (1981)
Renaud (1985, 1986b)
Richards and Redfield (1954)
Sackett and Brooks (1976)
Sackett *et al.* (1977, 1979)
Seadock (1974)
Shaw *et al.* (1988)
Stetson (1953)
Stuntz *et al.* (N.D.)
Temple *et al.* (1977)
Thompson and Bane (1986a,b)
Thompson et al. (1988)
Trask (1953)
Wardle *et al.* (1975)
Wilson and Ray (1956)
Zein-Eldin and Renaud (1986)

Appendix A. Terms and Conversions

Table A1. Definitions of terms.

Alkalinity - acid-neutralizing capacity of water measured as calcium carbonate equivalent.

Biochemical Oxygen Demand (BOD) - measure of the quantity of dissolved oxygen, in mg/l, necessary for the decomposition of organic matter by micro-organisms, such as bacteria.

Chemical Oxygen Demand (COD) - measure of chemically oxidizable material in water and furnishes an approximation of the amount of organic and reducing material present.

Color Unit - produced by 1 mg/l of platinum in the form of chloroplatinate ion. Color is expressed in units of the platinum-cobalt scale. In surface waters and effluents, the most important materials that contribute color are humic acids and tannic acids. These substances are typically from the microbiological breakdown of plant and/or animal material.

Conductance (also Specific Conductance) - measure of the ability of a water to conduct an electrical current and depends on the presence of ions, their total concentration, mobility, valence, and relative concentration, and on the temperature of the measurement. Expressed in microhmos/cm at 25°C; used to estimate the dissolved solids concentration of a water sample.

Cubic feet per second (cfs) - rate of discharge; equivalent to 7.48 gal/sec or 646.3 gal/d, or 0.02832 m^3/s.

Dissolved Inorganic Nitrogen (DIN) - usually refers to nitrate + nitrite + ammonia.

Dissolved Oxygen (DO) - amount of oxygen dissolved in water; concentrations expressed in mg/l.

Dissolved Oxygen Percent Saturation - ratio of the measured dissolved oxygen to the solubility in water at the temperature, pressure and salinity at the time of the measurement.

EPA - U.S. Environmental Protection Agency

Fecal coliform bacteria - gram-negative, nonspore-forming, rod shaped bacteria found in the intestinal tract of warm-blooded animals. Concentrations are reported as the Most Probable Number (MPN) per 100 ml of sample. Total coliform bacteria are characterized as aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 h at 35°C; also reported as MPN.

GCRL, FAM - Gulf Coast Research Laboratory, Fisheries Assessment Monitoring program, Ocean Springs, Mississippi.

Hardness - of water is a physical-chemical characteristic that is commonly recognized by the increased quantity of soap required to produce lather. It is due primarily to the presence of calcium and magnesium. Concentrations reported as mg/l $CaCO_3$.

MMS - U.S. Minerals Management Service.

MRGO - Mississippi River Gulf Outlet, dredged channel through Breton Sound that links the inner harber of New Orleans East to the Gulf of Mexico.

NOAA - National Oceanic and Atmospheric Administration.

pH - negative base-10 logarithm of the hydrogen ion activity in M/l. pH is a measure of whether a solution is acidic or basic and can range from near 0 (acidic) up to 14 (basic) with normal measurements ranging from 6 to 9 standard units (SU).

Salinity - concentration of dissolved solids in a kg of water; units are ppt (parts per thousand).

SAV - submerged aquatic vegetation

Secchi Disk - disk, 20-cm in diameter, painted black and white in alternate quadrants, used to measure, semi-quantitatively, the passage of light through water. Secchi Disk Depth (SDD) values usually given in m.

STORET - computerized data base utility maintained by EPA for the STOrage and RETrieval of parametric data pertaining to the quality of the waterways within and contiguous to the United States. The data are collected by a variety of federal, state, interstate, and local government agencies. The STORET system contains:

- geographical, political, and descriptive information concerning sites where data have been collected.

- measurements of the physical characteristics and chemical composition of water, fish tissue, or sediment sampled at these sites, *i.e.* the Water Quality System.

- counts and descriptions of living organisms found at these sites, *i.e.* the Biological Field Surveys.

- stream flow data, obtained from the U.S. Geological Survey, *i.e.* the "daily values" system.

TDWR - Texas Department of Water Resources (was Texas Water Development Board).

TKN - Total Kjeldahl Nitrogen, forms of nitrogen quantified in a Kjeldahl test, usually the sum of total ammonia-N and organic N, excludes nitrate-N and nitrite-N.

Total Dissolved Solids (TDS) - amount of solid material dissolved in water, commonly expressed as mg/l.

Total N - usually refers to TKN + nitrate + nitrite

Total Organic Carbon (TOC) - indication of the relative amount of organic material dissolved and suspended in water, expressed in mg/l.

Total Suspended Solids (TSS) - amount of solid material suspended in water, expressed in mg/l.

Turbidity - optical property of a suspension with reference to the extend to which the penetration of light is inhibited by the presence of insoluble material and is a function of both the concentration and particle size of the suspended material. Turbidity is reported in nephelometric turbidity units (NTU).

USFWS - U.S. Fish and Wildlife Service

USGS - U.S. Geological Survey.

Table A2. Conversions.

M = mole	gram molecular weight per liter (or molar concentration)	Area Equivalents	Oxygen (O*2) Equivalents
µg-atoms/l	mg-atoms/m*3	1 km*2 = 0.386 mi*2	1 mg/l = 0.70 ml/l = ppm
	µM (note: a mole is a concentration)	1 km*2 = 247.1 acres	1 ml/l = 1.43 mg/l
µg/l	mg/m*3	1 hectare = 2.471 acres	
ppm	mg/l		Flow Equivalents
ppb	µg/l		
µg/l div. by atomic weight	µg-atoms/l		1 cfs = 7.8 gal/s
µg/l div. by mol. weight	µM = µmol		1 cfs = 0.02832 m*3/s

mole=molecular weight = sum of atomic weight of elements in molecule
atomic weight=the average weight of an element; see atomic chart for weights

nitrate=NO*3
Nitrogen=14.0067
Oxygen=15.994
NO*3=14.0067+(3*15.994)

molecular weight		atomic weight	
61.9887	nitrate NO*3	14.0067	Nitrogen
45.9947	nitrite NO*2	30.9738	Phosphorus
14.0067	nitrogen	28.086	Silicon
17.0307	NH*4 ammonium	12.011	Carbon
18.0387	NH*3 ammonia	15.9994	Oxygen
94.9714	phosphate PO*4		
92.0836	silicate SiO*4		

Examples

to convert :	**to**	**then**	**by**
mg Kjeldahl N	mg N	multiply	1
mg Kjeldahl N/l	mmol N	divide by atomic weight of N	14.01
mg nitrate/l	mg nitrate-N/l	multiply by: (mol. wt N/mol. wt NO*3)	0.23
mg nitrate N/l	mg-at N-nitrate/l	divide by atomic weight	14.01
mg nitrate N/l	mmol nitrate (moles are a conc.)	divide by molecular weight	61.99
µmol nitrate	µg-at/l nitrate	multiply by mol. wt NO*3 to get µg nitrate/l	
		divide the above by mol. wt NO*3	1.00
µmol nitrate	µg-at/l nitrate-N	multiply by atomic weight of N	14.01
µmol silicate	µg-at Silicate-Si	mult. by mol. wt SiO*4 to get wt per vol. SiO*4	
		mult. above by (at. wt Si/mol. wt SiO*4)	28.09

Any others are on the same principles.

Appendix B. Data Bases

FLORIDA

Florida's literature base
1988 reports of ALL Florida estuaries. Trend Reports only have what STORET has in them and are an indication of the lack of long term available data in many of the bays.

Mark Freidmann
Florida Dept. of Environmental Regulation
2600 Blair Stone Rd
Twin Towers Office Bldg.
Tallahassee, FL 32399-2400
904-487-0505

Tampa Bay
1974-1990
ASCI files
1974-86 can be used in SAS
1986-1990 need to be reformatted for use with SAS

Richard Boler
Melvin T. Geloneck
Hillsborough County
Environmental Protection Commission
1900 9th Ave.
Tampa, FL 33605
813-272-5960

Perdido Bay
dBase files, vertical profiles of temperature, salinity, DO, nutrients; worked with ADEM for this project
1988

Steve Schropp
State of Florida
Department of Environmental Regulation
2600 Blair Stone Road
Twin Towers Office Bld
Tallahassee, FL 32399-2400
904-488-6221

Hydrographic data, seston, chl a. Unpublished data.

David A. Flemer
EPA
Environmental Research Laboratory
Sabine Island
Gulf Breeze, FL 32561-5299

Perdido hydrological data
paper copy

Robert J. Lord
EPA Region IV
Water Quality Management Branch
345 Courtland St., NE
Atlanta, GA 30365
404-347-2126

ALABAMA

Monitoring data collection, submission to data management group at Gulf Shores, AL

Steve Heath
Alabama Dept. Conservation and Natural Resources
Dauphin Island, AL 36528
205-861-2882

Temperature, Salinity, DO
1983 - 1989
bottom measurments
ASCI files, clearly marked

Dr. Henry G. "Skip" Lazauski
Alabama Dept. Conservation and Natural Resources
Alabama Marine Resources Division
P.O. Drawer 458
Gulf Shores, AL 36542

Water column monitoring
In Symphony, need to convert Lotus to move into ASCI or dBase
Paper copy of various parts

Gary Halcomb, Brad Gane, John Carlton
Alabama Dept. Environmental Management (ADEM)
2204 Perimeter Road
Mobile, AL 36615
205-479-2336

Mobile Bay
1989 cruises, nutrient and hydrological data;
paper copy

Dr. John Pennock
Dauphin Island Sea Lab
Marine Environmental Sciences Consortium
Dauphin Island, AL 36528
205-861-2141

MISSISSIPPI

Estuarine Inventory
Stations 1973 - 1986
dBase files;
maps of stations

James "Tut" Warren, Dick Waller, Harriet Perry
Gulf Coast Research Laboratory
Ocean Springs, MS 39564
601-875-2244

Ambient water quality data submitted to STORET
305(b) reports

Mr. Robert Seyfarth
Mississippi Bureau of Pollution Control
P. O. Box 10385
Jackson, MS 39209

Pascagoula Bay
Dredging report;
Information on streamflow project in the Gulf

Dr. Susan Ivyster-Rees
205-690-2724
Larry Land
USGS
8011 Cameron Rd.
Austin, TX 78753
512-832-5791

LOUISIANA

Louisiana Dept. of Environmental Quality data, along with other agencies, entry to the STORET system

Stephanie Braden
Louisiana Dept. of Environmental Quality
Office of Water Resources
Water Pollution Control Division
P. O. Box 82215
Baton Rouge, LA 70884-2215
504-295-0547

Lake Pontchartrain
the LPBF is relatively new
and has no data per se but
is setting up an Information Resources
Project

Michael Conroy
Steve Gorin
Lake Pontchartrain Basin Foundation
Lakeway I, 3900 N. Causeway Blvd., Suite 621
P. O. Box 6965
New Orleans, LA 70009-6965
504-836-2215

TEXAS

hydrological/meteorological
data from resource monitoring
programs, 1976 - 1990;
ancillary data for Coastal Fisheries
Surveys

Charles D. Travis, Executive Director
Maury Osborn
Texas Parks and Wildlife Department
4200 Smith School Road
Austin, TX 78744
512-389-4647

Water quality monitoring and freshwater
inflow assessment studies
only monitors every six months

Gary Powell
Texas Water Development Board
Austin, TX 78711-3231
512-463-7979

availability of Texas data provided
to STORET for Texas; contains Coastal
Data System of Texas Water Development
Board; USGS data

Charlotte Schwartz
Texas Natural Resources Information System
P. O. Box 13231
Austin, TX 78711-3231
512-463-8337

Red tide data base

Jim Bowman
(previously Dave Jensen)
Texas Water Commission
Corpus Christi, TX

INNER CONTINENTAL SHELF

SEAMAP
From cruises 1982-1988
inside 200 meters;
ASCI files

Rick Minkler
Ken Savastano
NOAA/NMFS
Southeast Fisheries Center
Mississippi Laboratories
Pascagoula Facility
P. O. Drawer 1207
Pascagoula, MS 39568-1207
601-762-4591

Appendix C. Information Resources

NATIONAL and/or GULF OF MEXICO REGIONAL

Dr. Robert Dickey
U.S. Food and Drug Administration
P. O. Box 158
Dauphin Island, AL 36528
Public health issues in the Gulf of Mexico, toxic or noxious algal blooms

Dr. Bernard L. Griswold, Co-Chair
NOAA COP/RID
c/o Marine Advisory Service
National Sea Grant College Program
Office of Oceanic and Atmospheric Research, NOAA
Silver Spring Metro Center Bldg. 1, Room 5216
1335 East-West Highway
Silver Spring, MD 20910
301-427-2431, -2799 (Fax)

Kenneth R. Hinga
University of Rhode Island
Graduate School of Oceanography
Narragansett, RI 02882
401-792-6851
Principal Investigator, NOAA's
National Estuarine Eutrophication Project

Mr. Larry Land
U.S. Geological Survey
8011 Cameron Road
Austin, TX 78753
STORET data

Dr. Donald Stanley
Institute for Coastal and Marine Resources
East Carolina University
Greenville, NC 27858
analysis of long-term data sets, Pamlico River, Houston Ship Channel, Galveston Bay

Strategic Assessment Branch
Ocean Assessments Division
Office of Oceanography and Marine Assessment
National Ocean Service, NOAA
11400 Rockville Pike
Rockville, MD 20852
301-443-0453
Daniel T. Basta
Dan Farrow
Charles John Klein
Ms. Jamison A. Lowe, NOAA's Fish Kill Inventory
Danielle T. Lucid, National Estuarine Eutrophication Project

EMAP State Contacts

Alabama	Mr. John Carlton Alabama Dept. of Environmental Management Field Operations Div. - Mobile Branch 2204 Perimeter Road Mobile, AL 33615 205-479-2336
Florida	Mr. Tom Swihart Florida Dept. of Environmental Regulation Standards and Monitorint Section Twin Towers Office Bldg. 2600 Blair Stone Road Tallahassee, FL 32399-2400 904-487-0505
Louisiana	Ms. Emelise Cormier Louisiana Dept. of Environmental Quality Office of Water Resources P. O. Box 82215 Baton Rouge, LA 70884-2215 504-765-0634
Mississippi	Mr. Jeff Thomas Mississippi Office of Pollution Control Surface Water Division Water Quality Monitoring Branch P. O. Box 10385 Jackson, MS 39287-0385 601-961-5157
Texas	Mr. Bruce Smith Texas General Land Office State/Federal Project Coordinator Stephen F. Austin Bldg., Room 730 1700 North Congress Austin, TX 78701-1495 512-463-5055

FLORIDA

Apalachicola River National Estuarine Research Reserve
Woodard Miley II, Mgr.
261 7th Street
Apalachicola, FL 32320
904-653-8063

Center for Marine Science
University of South Florida
140 7th Ave. S
St. Petersburg, FL 33701
813-893-9512
Dr. Gabriel A. Vargo, 813-893-9130, nutrient studies of Little Manatee, Tampa Bay

Sid Flannery
Southwest Florida Water Management District
2379 Broad Street
Brooksville, FL 34609-6899
904-796-7211

Dr. Robert J. "Skip" Livingston
Center for Aquatic Research and Resource Management
Department of Biological Sciences
Florida State University
Tallahassee, FL 32306-2043
904-644-1466
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Mr. Gary Powell
Texas Water Development Board
Austin, TX
Oxygen criteria for Texas estuaries, salinity, freshwater inflow needs

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Dr. Donald E. Harper, Jr., hypoxia on the inner Texas continental shelf; estuarine-level studies in several Texas bays
Dr. Peter H. Santschi and colleagues, nutrient cycling studies in Trinity River estuary and Galveston Bay, trace metal studies
Dr. Frederick C. Schlemmer II, hydrographic data analysis for Galveston Bay

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noxious or toxic algal bloom inventory

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Appendix D. Bibliographies

Compiled by

Nancy N. Rabalais
R. V. Bates
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Organization

Bibliography I includes those references that were used for the identification of eutrophication indicators; it is named GOMBIB.DAT in the ProCite software. Annotations to this bibliography are a short description of the manuscript and codes that identify the estuary or coastal area of concern. Details of the manuscript, especially where relevant to the identification of eutrophication indicators, are included in the text of the report. A list of the estuarine codes and maps that identify the coastal areas of the five Gulf of Mexico states are provided in Table 8 and Figures 19-23.

Bibliography II lists useful references; it is named PROBIB.DAT in the ProCite software.

Use of Bibliographies with ProCite Software

Diskette copies of both bibliographies in ProCite software have been submitted to the EPA Gulf of Mexico Program Office for inclusion on the Gulf of Mexico Program Data Base. Details of using ProCite are given in the manual for the software (ProCite, Version 1.4. 1988. Personal Bibliographic Software, Inc., Ann Arbor, Michigan); however, a few useful hints can make use of the bibliographies easier.

Searching

- Simple searches using single term or phrase in full-text or selected fields.
- Complex searches using Boolean logic in full-text or selected fields.
- Search Only software offered by ProCite that enables the user to search databases and print bibliographies.

Creating Bibliographies

- Choice of several punctuation styles, including user-defined. (The NNR.PCT specific style for production of manuscript word document was used for the bibliographies and is part of database submitted.)
- Create subject bibliographies using index terms.

Other Features

- Preview citations before sending to diskette or printer.
- Sort records in variety of ways.
- Import and export capabilities.
- Merge with other ProCite databases.

BIBLIOGRAPHY I.

FOR
IDENTIFICATION OF EUTROPHICATION INDICATORS

Abbott, B. C. 1975. Marine Pollution Hazards. Final Report, Contract No. N00014-67-A-0269-0017. UCLA Allan Hancock Foundation, Los Angeles, California, 24 p. (not in hand)
G-2

Red tides around our coastline are due mainly to blooms of dinoflagellates. Those in colder northern waters are due mainly to *Gonyaulax* sp. which produces the paralytic shellfish poison saxitoxin, a neurotoxin. In the Gulf of Mexico off Florida, red tides, due to *Gymnodinium breve*, kill millions of fish during a bloom.

Abston, J. R., S. P. Dinnel, W. W. Schroeder, A. W. Shultz and W. J. Wiseman, Jr. 1987. Coastal sediment plume morphology and its relationship to environmental forcing: Main Pass, Mobile Bay, Alabama. Pages 1989-2005 in Coastal Sediments '87. Vol. II. Proceedings of a Conference, May 12-14, 1987, New Orleans, Louisiana. WW Div./ASCE, New York.
G-2, G-2.1

Landsat multispectral scanner imagery has been used to determine the variability of the surface morphology of Mobile Bay effluent plumes. The plume characteristics derived from the imagery are area, orientation and rate of spreading. These characteristics are in turn related to external environmental forces. The observed relationships between the environmental parameters and the plume morphology are discussed. Estimates of suspended sediment transport based on limited field data of plume hydrography and total suspended solid loads are offered. Finally, the authors speculate on the role the plume plays in dispersal of Mobile Bay sediments on the adjacent continental shelf.

Adkins, G. and P. Bowman. 1976. A Study of the Fauna in Dredged Canals of Coastal Louisiana. Tech. Bull. No. 18, Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana, 72 p.
G-11

In attempts to investigate biological and hydrological parameters now associated with artificial wetland features, samples were made in four environment types: 1) open, unaltered areas, 2) open canals, 3) semi-open canals, 4) closed canals. Sampling was accomplished by using various gear over a 2-yr period. Water chemistry reflected a trend of fluctuation dependent upon freshwater and saltwater intrusion. Peak levels of most nutrients were recorded following freshwater flooding conditions or storm surges caused by the passage of hurricanes.

Ambler, J. W. 1982. Influence of Natural Particle Diets on Egg Laying and Hatching Success of *Acartia tonsa* in East Lagoon, Galveston, Texas. Ph.D. Dissertation, Texas A&M University, College Station, Texas.
G-17

Experiments were conducted on copepod (*Acartia tonsa*) egg hatching at low oxygen concentrations. Although oxygen concentrations had to fall below 0.4 ppm to affect hatching success, reduced oxygen concentrations well above this level probably affected the metabolism of the *A. tonsa* females. Oxygen profiles for East Lagoon, Galveston Bay, are presented for April, May, July, August and November 1982. In East Lagoon, the metabolism of *A. tonsa* would probably be decreased if they resided in the poorly oxygenated deeper waters, which were present especially during the summer. If the duration of the hypoxic events is not too long, egg viability should not be greatly affected. The frequency and duration of hypoxic events are unknown for East Lagoon, but probably occur during the summer when winds are low.

Anon. 1984. Low bottom oxygen observed offshore. Marine Briefs 13(8):1/3.
G-2.3, G-5.1

Personnel of the Laboratory fisheries monitoring and assessment project report that average water temperature in Mississippi Sound increased in July. Average salinity increased over the last month and was considerably greater than that recorded last year at this time. Hydrological data from the western-most stations showed low oxygen levels and cooler temperatures near the bottom. Hypoxic, or low-oxygen, conditions have been reported for this area in past years.

Anon. 1981. Shrimp postlarvae taken in samples. Marine Briefs 10(3):1.
G-2.3

The first brown shrimp postlarvae of the year were noted in the Biloxi estuary, indicating that the offshore spawning of this species had begun. Inshore samples were dominated by catches of young-of-the-year menhaden. Average temperature was within the seasonal norm. Salinities at monitored stations were high initially but decreased sharply with increased rainfall during the latter part of the month. Areas of discolored water have been investigated. Samples of the water contained large numbers of a dinoflagellate tentatively identified as *Prorocentrum minimum.*

Armstrong, N. E. 1987. The Ecology of Open-Bay Bottoms of Texas: A Community Profile. Biological Report No. 85(7.12), U.S. Dept. of the Interior, Fish and Wildlife Service, Research and Development, National Wetlands Research Center, Washington, D.C., 104 p.
G-16, G-17, G-21, G-22, G-23, G-24, G-26

Open-bay bottoms represent one of the most extensive habitats in any estuarine system, especially in the northwestern Gulf of Mexico estuaries of Texas. The structure and function of the benthic communities in these Texas estuaries are examined by reviewing and integrating data from a number of past and ongoing studies. The key functions of the benthic system are production of biomass as food resources for higher trophic levels; bioturbation, which enhances nutrient regeneration; and nutrient regeneration itself. Benthic nutrient regeneration in the shallow water of Texas estuaries may play a key role in regulating primary production in the estuaries.

Armstrong, N. E. and A. Goldstein. 1975. Determination of Effects of Dow Chemical Company Discharge on Organisms of the Lower Brazos River. Final Report to the Dow Chemical Co., Texas Division, Freeport, Texas. Center for Research in Water Resources, University of Texas, Austin, Texas. (not in hand)
G-18

Association of State and Interstate Water Pollution Control Administrators. 1984. America's Clean Water: The States' Evaluation of Progress, 1972-1982. Appendix. Association of State and Interstate Water Pollution Control Administrators, Washington, D.C.
F-9 through G-27

The information in this report was drawn from 56 reports submitted by State, interstate and territorial water pollution control agencies. Respondents used a standardized format and instructions to compile and display their findings about water quality. These submittals were prepared between June and October 1983. The last section of this appendix is the instruction package used by the States in completing their reports; it includes the definitions specifically developed for this effort to promote national consistency.

Atwood, D. K. 1981. Environmental Research Needs in the Gulf of Mexico (GOMEX). Vol. I: Executive Summary and Panel Reports. Vol. IIA: Summary Papers. Vol. IIB: Summary Papers. Vol. IIC: Summary Papers. Proceedings of a Symposium, September 30 - October 5, 1979, Key Biscayne, Florida. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories. Atlantic Oceanographic

and Meteorological Laboratories, Miami, Florida, 769 p.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

From September 30 to October 5, 1979, a group of U.S. and Mexican economists, marine scientists, and environmental managers met at Key Biscayne, Florida to discuss the needs for marine-related environmental research in the Gulf of Mexico during the next decade. As working papers for this workshop, the participants had at their disposal a series of NOAA contracted summary documents on the status of our present knowledge of the physics, chemistry, geology, and biology of the Gulf and the socioeconomic pressures on the Gulf. All indications are that uses of the Gulf of Mexico and its coastline will continue and increase. Unless these uses are adequately managed, severe aesthetic and economic loses could result. Several research objectives and tasks were specified as the result of workshop deliberations.

Baldauf, R. J., J. Van Conner, H. W. Holcombe and F. M. Truesdale. 1970. A Study of Selected Chemical and Biological Conditions of the Lower Trinity River and Upper Trinity Bay. Research Project Completion Report. Project No. A-007-TEX. February 1, 1966 - June 30, 1969. Tech. Rept. No. 26, Water Resources Institute, Texas A&M University, College Station, Texas, 168 p.
G-17

Hydrographic samples and nekton from trawls, marsh nets, and seines for semimonthly samples from March 1966 through May 1968. Water samples were for temperature, salinity, dissolved oxygen, total dissolved Kjeldahl nitrogen and total phosphorus.

Bancroft, K., E. T. Nelson and G. W. Childers. 1988. The microbiological and chemical quality of Lake Maurepas. The La. Environmental Professional 5(1):53-66.
G-7

The water quality of Lake Maurepas was monitored from July 1986 to June 1987. Seventeen physical and chemical parameters and four microbiological parameters were monitored monthly. Seasonal trends in physical and chemical parameters were found for all locations. The highest values for turbidity, suspended solids, dissolved organic carbon, dissolved oxygen, nitrate and nitrite were recorded in the winter. Dissolved solids, total solids, ammonia, conductivity and salinity were highest in the summer. Seasonal trends were also found for bacteria with densities highest in the winter. All concentrations of bacterial indicators of pollution were found to be greater than those observed during 1983-1984, indicating a significant decrease in the water quality of Lake Maurepas. Based on fecal coliform and fecal streptococci ratios, the pollution appeared to be primarily of human origin.

Barrett, B. B., J. O. Merrell, T. P. Morrison, M. C. Gillespie, E. J. Ralph and J. F. Burdon. 1978. A Study of Louisiana's Major Estuaries and Adjacent Offshore Waters. Tech. Bull. No. 27, Louisiana Dept. of Wildlife and Fisheries, New Orleans, Louisiana, 197 p.
G-8, G-8.1, G-10, G-11, G-11.1, G-13, G-15

Seven of Louisiana's major estuaries and adjacent offshore waters were sampled monthly from October 1974 through September 1976. In each of these seven areas, four stations yielded samples that were analyzed in terms of physical properties, water chemistry, nekton, zooplankton, and chlorophyll *a*. When evident, correlations and interrelationships among the various parameters are presented along with tabular information on all measurements made during the study. Variability of the parameters sampled were primarily the result of one or more of the following factors: amount of freshwater introduction, season, and proximity to oceanic waters.

Barrett, B. B. and E. J. Ralph. 1976. 1976 Environmental Conditions Relative to Shrimp Production in Coastal Louisiana. Tech. Bull. No. 21, Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana, 20 p.
G-7.1

Shrimp catch data are presented along with environmental factors which influence Louisiana's shrimp harvest. Environmental data for the first four months of 1976, particularly in the Barataria-Caminada Bay area, are compared with previous years. Relationships between shrimp harvest and river discharge, rainfall, salinity, water temperatures and the available amount of nursery area are presented.

Basta, D. J., B. T. Bower, C. N. Ehler, F. D. Arnold, B. P. Chambers and D. R. G. Farrow. 1985. The National Coastal Pollutant Discharge Inventory. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, Rockville, Maryland, 18 p.
F-9 through G-27

The National Coastal Pollutant Discharge Inventory is a database and computational framework being developed by the Strategic Assessment Branch of the Ocean Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration. When completed, the NCPDI will include all point, nonpoint, and riverine sources of pollutant discharges into estuarine, coastal, and oceanic waters of the contiguous U.S. (excluding the Great Lakes), extending landward to the head of estuaries and seaward to the boundary of the Exclusive Economic Zone.

Bault, E. I. 1972. Hydrology of Alabama Estuarine Areas - Cooperative Gulf of Mexico Estuarine Inventory. Ala. Mar. Resour. Bull. 7:1-36.
G-1, G-2, G-2.2

Twenty-one hydrological stations in five Alabama estuarine areas were sampled monthly from January 1968 through March 1969. Nitrite-nitrogen, nitrate-nitrogen, orthophosphate-phosphorus, total phosphorus, pH, dissolved oxygen, temperature, turbidity and salinity were determined for each station. Bimonthly isohalines and isotherms and graphical representations of micronutrients and chemophysical parameters are presented. All data are presented in tables or graphs and comparisons are made among the estuarine areas.

Bechtel, T. J. and B. J. Copeland. 1970. Fish species diversity indices as indicators of pollution in Galveston Bay, Texas. Contrib. Mar. Sci. 15:103-132.
G-17

Fish species diversity indices (natural bels/individual) calculated for both fish weights and numbers from trawl collections were found to be useful indicators of environmental and pollution stress in Galveston Bay, Texas. Sampling throughout the system indicated that the fish populations could be divided into somewhat separate communities, each structured as a response to environmental and pollution stress.

Bedinger, Jr., C. A., R. E. Childers, J. W. Cooper, K. T. Kimball and A. Kwok. 1981. Part 1 - Background, program organization and study plan. In C. A. Bedinger, Jr. (ed.), Ecological Investigations of Petroleum Production Platforms in the Central Gulf of Mexico. Vol. 1 - Pollutant Fate and Effects Studies. Report to Bureau of Land Management, New Orleans OCS, Contract AA551-CT8-17. SwRI Project No. 01-5245, Southwest Research Institute, San Antonio, Texas, 53 p.
G-7.1

Twenty-four sites on the continental shelf of the Louisiana coast have been studied for long-term cumulative effects of petroleum production in the region of offshore platforms. Sampling and analysis included hydrography and hydrocarbons of the water column; sediment physical characterization, hydrocarbons, trace metals, and contamination with depth; and population of the meiofauna, macroinfauna, macroepifauna, demersal fishes and species associated with the "artificial reef" brought about by the platform. Bottom studies extended from 100 to 2000 m away from platforms and were therefore indicative of regional as opposed to localized contamination. Results confirm widespread, chronic contamination with hydrocarbons and metals with some apparent incorporation of pollutants into biota found at platforms. Over the entire study area

absolute amounts of contaminants vary widely showing a general concentration in the nearshore and eastern portions where the Mississippi River apparently contributes more contaminants than petroleum production platforms.

Bednar, G. A. 1978a. Quality of Water and Dye Dispersion Characteristics in Jourdan River and St. Louis Bay, Hancock and Harrison Counties, Mississippi. Open-File Report No. 78-584, U.S. Dept. of the Interior, Geological Survey, and Mississippi Air and Water Pollution Control Commission, Jackson, Mississippi, 63 p.
G-5

Jourdan River is one of two major streams supplying fresh water to St. Louis Bay. As this fresh water moves through the bay into the Mississippi Sound it mixes with and measurably dilutes the very saline waters entering the bay from the Gulf of Mexico. The concentrations of dissolved oxygen, nutrients, and the biochemical oxygen demand, as well as the other water quality parameters examined, were within limits that might be expected under the hydrologic conditions that existed during this study. However, fecal coliform and fecal streptococci bacteria were excessive and in proportions indicative of human enteric wastes. The movement of dye from Jourdan River through St. Louis Bay was traced during a 50-hr time-of-travel study. It was determined from this study that a soluble pollutant discharged into St. Louis Bay or into the tidal reach of Jourdan River would likely remain in the Bay for many days before being diluted and dispersed by inflow to the Bay.

Bednar, G. A. 1978b. Quality of Water and Dye Dispersion Characteristics in the Back Bay of Biloxi, Harrison County, Mississippi. Open-File Report No. 78-908, U.S. Dept. of the Interior, Geological Survey, and Mississippi Air and Water Pollution Control Commission, Jackson, Mississippi, 62 p.
G-4

The quality of water characteristics of the estuarine system is complex, and is, to a large extent, dominated by the interactions of opposing tides. The Biloxi and Tchoutacabouffa Rivers contribute the majority of freshwater inflow. As the fresh water moves through the Bay it mixes with and dilutes the saline water of Gulf tides. During this study, the Gulf waters penetrated the entire length (about 10 miles) of the study area and freshwater inflow was low. The dissolved oxygen content of the water in the bay was generally at concentrations that would support aquatic life, and at some sites the water was supersaturated with dissolved oxygen at low tide. Dissolved oxygen concentrations were highest near the surface and the mean dissolved oxygen concentration of the water at each sampling site was greater than 7.0 mg/l at low tide and decreased to less than 7.0 mg/l at high tide as the Gulf waters moved through the Bay.

Bednar, G. A. 1978c. Quality of Water in Pascagoula and Escatawpa Rivers, Jackson County, Mississippi. Open-File Report No. 78-913, U.S. Dept. of the Interior, Geological Survey, and Mississippi Air and Water Pollution Control Commission, Jackson, Mississippi, 91 p.
G-3

The chemical and physical properties and the range of concentrations of most constituents in water in these rivers during the period May 17-19, 1977, varied rapidly between high and low tides, primarily as the result of interactions of freshwater inflow with highly mineralized Gulf waters. There was evidence of oxygen deficiency (less than 3.0 mg/l) at many sites in deep pools where there is little circulation and mixing of the more dense saltwater. Dissolved oxygen concentrations ranged from 2.1 to 8.2 mg/l.

Bednar, G. A. 1979. Quality of Water in Bayou Casotte and Bayou Chico, Jackson County, Mississippi. Open-File Report No. 79-1059, U.S. Dept. of the Interior, Geological Survey, and Dept. of Natural Resources, Bureau of Pollution Control, Jackson, Mississippi, 36 p.
G-3

A short-term water quality study was conducted on July 25-27, 1978. The results of the study indicated that the chemical and physical properties and range of concentrations of several dissolved constituents in both estuaries varied during a tide cycle primarily as the result of the interaction of freshwater and wastewater inflow with the saline Gulf waters. The water quality condition of both estuaries generally was good and the low 5-d biochemical oxygen demand in the estuaries indicated that excessive oxygen demand was not exerted during the study. The 5-d biochemical oxygen demand generally was less than 3.5 mg/l. Dissolved oxygen concentrations decreased with depths and the lowest concentrations occurred below 30-ft depths in Bayou Casotte. Oxygen levels at shallow depths generally were less in Bayou Chico than in Bayou Casotte. Dissolved oxygen concentrations in Bayou Casotte ranged from 0.7 to 7.7 mg/l at high tide and from 2.5 to 8.2 mg/l at low tide.

Benefield, R. L., T. J. Cody, B. E. Fuls and P. C. Hammerschmidt. 1983. Monitoring of Coastal Shellfish Resources, January - December 1982. Management Data Series No. 55, Texas Parks and Wildlife Dept., Coastal Fisheries Branch, Austin, Texas, 75 p.
G-17, G-21, G-22, G-24, G-26.1, G-26.2

Trends in relative abundance and size of brown shrimp (*Penaeus aztecus*), white shrimp (*P. setiferus*), pink shrimp (*P. duorarum*) and blue crabs (*Callinectes sapidus*) in Texas bay systems and the Gulf of Mexico (shrimp only) were monitored from January-December 1982. Shorelines and deeper portions of bays were sampled in Galveston, Matagorda, San Antonio, Aransas and Corpus Christi Bays and upper and lower Laguna Madre. Passes were sampled in Galveston, Matagorda, Aransas and Corpus Christi Bays and the lower Laguna Madre and Gulf samples were collected along the central coast. Data summarized in this report represent the initiation of a program that will yield long-term trends in abundance and stability of shellfish in Texas waters. Improved information on trends will result as the peaks of seasonal abundance are identified through time in the different areas sampled.

Bien, G. S., D. E. Contois and W. H. Thomas. 1958. The removal of soluble silica from fresh water entering the sea. Geochim. Cosmochim. Acta 14:35-54.
G-7.1

Determinations of soluble silica and chlorosity of water samples collected in and around the east Mississippi Delta showed that most of the soluble silica was removed from river water by some process other than dilution with seawater. While biological uptake by diatoms can account for part of this removal, it is more likely that a major portion is removed by inorganic precipitation. Laboratory experiments with river water and sea water showed that both suspended matter from the river and electrolytes in sea-water are necessary for maximum inorganic precipitation. It is concluded that this process is an adsorption of soluble silica on suspended matter as it comes in contact with electrolytes, rather than a simple formation of salts with electrolytes. The inorganic removal can increase by a maximum of 4-5 % the weight of sediment in the water that may be expected to reach the bottom.

Blanton, W. G., T. J. Culpepper, H. W. Bischoff, A. L. Smith and C. J. Blanton. 1971. A Study of the Total Ecology of a Secondary Bay (Lavaca Bay). Final Report. Texas Wesleyan College, Fort Worth, Texas, 306 p.
G-21

A large-scale multidisciplinary ecological study of the bay systems has been initiated as follows: 1) Chemical and physical parameters were monitored throughout the Lavaca Bay system. 2) Biological parameters were compiled with regard to: a) species survey of phytoplankton, zooplankton, and nekton; b) population dynamics; c) species diversity. 3) Surface sediments with their corresponding water columns were analyzed with regard to: a) microbiological studies (bacterial count and diversity); b) benthonic studies (benthos count and diversity); c) sediment type. 4) Laboratory studies of the effects of various concentrations of fluoride on a variety of organisms. 5) Toxicity of fluoride on fish and phytoplankton.

Blaylock, D. A. 1983. Choctawhatchee Bay: Analysis and Interpretation of Baseline Environmental Data. Technical Paper No. 26, University of West Florida, Pensacola, Florida. (not in hand)
F-26

Boenig, D. L. 1990. Hypoxia and Its Effect on Bottom-Dwelling Macrofauna Distribution. Student Report, Louisiana Universities Marine Consortium, Chauvin, Louisiana, 10 p.
G-7.1

It has been established that the largest, most severe, and most persistent zone of hypoxia (defined by oxygen levels of <2 mg/l) in the United States is found in the northern Gulf of Mexico on the continental shelf off of Louisiana. Numerous theories have been presented as to the cause of hypoxia. The purpose of this paper is to show the changes in bottom-dwelling macrofauna distribution as it is affected by the depleted oxygen abundance during the summer months (April through July) off the coast of Cocodrie, Louisiana.

Boesch, D. F. 1982. Causes and effects of shelf oxygen depletion: Lessons from the 1976 New York Bight episode. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, Louisiana.
G-7.1

Severe depletion of dissolved oxygen in open continental shelf waters is known from only very few areas in the world, mostly regions of pronounced coastal upwelling. Hypoxic or anoxic bottom water on the inner shelf of the north-central Gulf of Mexico is apparently a regular occurrence, although it is scarcely reported in the formal literature and has been little studied. Unusual and widespread oxygen depletion of bottom waters in the New York Bight occurred during the summer of 1976 and was relatively well studied because of the substantial ongoing research programs in the area. The findings of these studies are reviewed with regard to the environmental conditions and biological phenomena that caused oxygen depletion and resulting effects on benthic organisms. Development of hypoxia in continental shelf waters depends on 1) intense stratification which reduces eddy diffusivity and, consequently, oxygenation of bottom waters, and 2) an ample supply of labile organic material resulting from ungrazed phytoplankton production, rather than from inputs of fluvial organic material.

Boesch, D. F. 1983. Implications of oxygen depletion on the continental shelf of the northern Gulf of Mexico. Coastal Ocean Pollution Assessment News 2(3):25-28.
G-7.1

The brief review describes what is known about the spatial and temporal extent of the bottom-water oxygen depletion phenomenon in the Gulf, considers whether the phenomenon has recently increased in extent or severity, evaluates the potential causes and whether they are related to human activities, and considers consequences of the phenomenon.

Boesch, D. F., J. W. Day, Jr. and W. H. Conner. 1989. Barataria-Terrebonne Estuarine Complex. Governor's Nomination and Request for a Management Conference under the National Estuary Program. Office of the Governor, State of Louisiana, Baton Rouge, Louisiana, 109 p.
G-10, G-11

The Barataria-Terrebonne Estuarine Complex consists of an extensive array of estuarine wetlands and waterbodies filling the basins between the two active distributary systems of the Mississippi River, the lower Mississippi River proper and the Atchafalaya River. The principal environmental problems faced by the Barataria-Terrebonne Estuarine Complex are hydrological modification, habitat loss and modification, eutrophication, changes in living resources, toxic substances, and pathogen contamination. The environmental quality problems center more around physical deterioration of habitats and non-point or diffuse sources of

pathogens, nutrients and toxicants than large discharges of toxic materials and biostimulants. In addition, the pervasive influence of oil and gas production activities, both in terms of hydrologic and habitat alterations resulting from associated dredging and operational discharges which affect water quality, presents a unique management challenge.

Boesch, D. F. and N. N. Rabalais (eds.). 1989a. Produced Waters in Sensitive Coastal Habitats: An Analysis of Impacts, Central Coastal Gulf of Mexico. OCS Report/MMS 89-0031, U.S. Dept. of Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana, 157 p.
G-10, G-11

The objectives of this study were to 1) quantify the location and characteristics of outer continental shelf (OCS) produced waters discharged into coastal environments of the Gulf of Mexico and 2) provide an assessment of the environmental fate and effects of selected discharges. An inventory of produced water discharges based on records of regulatory agencies in Texas and Louisiana was compiled. The other Gulf states (Mississippi, Alabama and Florida) do not permit the discharge of produced water into surface waters. A field assessment provided a general delimitation of the scope and nature of the impacts.

Boesch, D. F. and N. N. Rabalais (eds.). 1989b. Environmental Impact of Produced Water Discharges in Coastal Louisiana. Proceedings of Report prepared for The Louisiana Division of the Mid-Continent Oil and Gas Association. Louisiana Universities Marine Consortium, Chauvin, Louisiana, 287 p.
G-10, G-12

In response to concerns about the effects of the discharge of produced waters (oilfield brines) in estuarine and wetland environments of coastal Louisiana, a three-part study was conducted to 1) determine the potential that the numerous brine discharges in the coastal zone may have on the salinity regime, 2) assess the effects of produced water discharges on wetlands based on analysis of aerial photographs, 3) assess the hydrological, chemical, and biological effects in field studies. The field studies documented the effects of the brine discharge in near-bottom waters with regards to elevated salinities to some distance from the discharge, depending on the volume discharged and the characteristics of the receiving environment. In two locations, low dissolved oxygen concentrations were documented in near-bottom waters where there was a strong salinity stratification of the overlying water column.

Boesch, D. F. and N. N. Rabalais. 1991. Effects of hypoxia on continental shelf benthos: Comparisons between the New York Bight and the Northern Gulf of Mexico. Pages 27-34 in R. V. Tyson and T. H. Pearson (eds.), Modern and Ancient Continental Shelf Anoxia. Geological Society Special Publication No. 58, The Geological Society, London, 470 p.
G-7.1, G-27

Depletion of dissolved oxygen to a point inducing mortality of bottom-dwelling organisms (hypoxia) occurs in several continental shelf environments in Europe and North America and may have increased as a result of nutrient overenrichment from human activities. Hypoxia in coastal waters develops as a result of decomposing plankton and density stratification of the water column, which hinders the oxygenation of bottom waters. Mass mortalities of benthic organisms have occurred as a result of extensive hypoxia on the inner continental shelves of the New York Bight and the northern Gulf of Mexico off Louisiana and Texas. In the New York Bight, extensive hypoxia is rare and recovery of the benthic communities from the catastrophic 1976 hypoxia to previous conditions was not complete over 2 yr later. On the Louisiana-Texas shelf, large-scale hypoxia occurs virtually very year, and recovery from this disturbance is rapid, because the community is kept in an early successional state by the annually recurring hypoxia.

Boler, R. (ed.). 1987. Water Quality 1986-1987, Hillsborough County, Florida. Hillsborough County Environmental Protection Commission, Tampa, Florida, 207 p.
F-15

Sampling has been conducted routinely by the Environmental Protection Commission of Hillsborough County in Tampa Bay since 1972, when only mid-depth samples were collected. Starting in 1975, samples for selected parameters have been collected at surface, mid-depth, and bottom. Fresh waters have been sampled routinely since 1973. These data, obtained during 1972-1987, may provide useful background for eventual development, revision and enforcement of regulations, standard effluent limitation plans, or programs established under the Federal Water Pollution Control Act of 1972.

Brent, C. R. N.D. Effect of Mississippi River flood plume on dissolved oxygen, April - July, 1973. Memorandum, University of Southern Mississippi, Hattiesburg, Mississippi, 4 p.
G-7.1

Salinity measurements during April 1973 indicate a surface layer of fresher water having a salinity depression of some 33% from waters below it extending to a depth of about 10 m. The salinity gradient in April was rather uniform from the surface to a depth of 10 m, indicating uniform mixing to that depth. The isolation of waters deeper than 7 m by an extensive, low density Mississippi River plume allowed oxygen demand from a variety of natural, manmade and unseasonable sources to overtake oxygen resupply mechanisms on the continental shelf off Timbalier Bay. No one factor seems to dominate the causes of this phenomenon except the presence of Mississippi plume overlying and isolating the water below it.

Breuer, J. P. 1969-70. A biological survey of the tidewater areas of the Rio Grande. Project CF-2-1 (Job No. 2). Pages 127-136 in Coastal Fisheries Project Reports 1969-1970. Texas Parks and Wildlife Dept., Austin, Texas.
G-26.3

Hydrographic and biological sampling stations were established on the Lower Rio Grande every 4 mi from the mouth upstream to Mile 28. These were sampled 15 times in 1969 and 1970. Hydrographic samples included water temperatures, pH, turbidity, surface and bottom salinities, and surface and bottom dissolved oxygen. Biological samples were taken principally with a 12-ft otter trawl. Results of sampling were tabulated and analyzed.

Breuer, J. P. 1957. An ecological survey of Baffin and Alazan Bays, Texas. Publ. Inst. Mar. Sci. Univ. of Texas 4(2):134-155.
G-25

In the summer of 1950, the Texas Game and Fish Commission began an extensive long-term ecological study of the Laguna Madre of Texas, a 130-mi long hypersaline bay on the South Texas coast. One of the three areas of study was the Baffin-Alazan Bay area. Field work in this area was started in June 1951 and was continued until May 1953. This paper is a portion of a final report to the Texas Game and Fish Commission on this study.

Breuer, J. P. 1962. An ecological survey of the Lower Laguna Madre of Texas, 1953-1959. Publ. Inst. Mar. Sci. Univ. of Texas 8:153-183.
G-26.2

Hydrographic data and annotated comments on the distribution and habits of species are presented for the Lower Laguna Madre of Texas, a shallow, hypersaline marine bay extending 76 miles north of the Rio Grande delta. In summer, waters of the Gulf move northward through the lagoon with increasing salinity due to evaporation. The variety of species in the plankton and bottom communities diminish with distance from the pass. In winter, flow is southward. Some ecological effects of manmade changes are described, including the effects of opening Port Mansfield Pass, the isolation and silting of South Bay due to spoil, and the management of the Rio Grande River during floods. Movements of year classes of game fishes are described.

Breuer, J. P. 1972. Ecological survey of the Brownsville ship channel - 1971-1972. Pages 93-131 in Coastal Fisheries Project Reports. Texas Parks and Wildlife Dept., Austin, Texas.
G-26.2

The objective of the ecological survey was to determine the value of the Brownsville ship channel to the area marine fishery. Monthly biological samples were taken by trawl and water chemistry was analyzed at 14 stations in the Brownsville ship channel and surrounding areas from August 1971 to December 1972. Monthly rainfall varied from 0.74 in in August 1971 and December 1972 to 10.78 in in September 1972. Surface and bottom temperatures ranged from 12 °C to 30 °C during the study, and no significant difference was found between surface and bottom temperatures. Overall salinities ranged from 0.5 ppt to 33.9 ppt. Bottom dissolved oxygen ranged from 1.8 to 9.0 ppm. pH ranged from 6.8 to 8.7.

Brooks, J. M. 1980. Vol. III - Determine Seasonal Variations in Inorganic Nutrients Composition and Concentration in the Water Column. In W. B. Jackson and G. M. Faw (eds.), Biological/Chemical Survey of Texoma and Capline Sector Salt Dome Brine Disposal Sites off Louisiana, 1978-1979. NOAA Tech. Memo. NMFS-SEFC-32, NOAA/NMFS Final Report to DOE. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Galveston, Texas, 31 p.
G-7.1

Seawater samples were analyzed for ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, phosphate phosphorus, and dissolved silicate at the West Hackberry (Texoma) and Weeks Island (Capline) Strategic Petroleum Reserve brine disposal sites. The nutrient concentrations were typical of the nearshore environment from which the samples were taken. High ammonia, phosphate, and silicate concentrations were observed in some near-bottom samples correlating with low oxygen concentrations. Nitrate showed a negative correlation with salinity suggesting freshwater inputs as a source of this nutrient.

Brooks, J. M. and G. A. Wolff (eds.) 1991. Mississippi-Alabama Continental Shelf Ecosystem Study Data Summary and Synthesis. Vol. III: Appendices, Part 1 (Appendices A-D). OCS Study MMS 91-0064. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana, 1001 p.
G-2.1, G-5.1, G-7.1

Browder, J. A., L. N. May, Jr., A. Rosenthal, R. H. Baumann and J. G. Gosselink. 1987. Utilizing Remote Sensing of Thematic Mapper Data To Improve Our Understanding of Estuarine Processes and Their Influence on the Productivity of Estuarine-Dependent Fisheries. Fourth Semiannual Progress Report to the National Aeronautics and Space Administration on the TM Project. Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana.
G-9, G-10, G-11

A stochastic spatial computer model addressing coastal resource problems in Louisiana is being refined and validated using thematic mapper imagery. This research consists of two major activities: 1) Measuring land (or emergent vegetation) and water and the length of the interface between land and water in thematic mapper imagery of selected coastal wetlands (sample marshes); 2) Comparing spatial patterns of land and water in the sample marshes of the imagery to those in marshes simulated by the computer model. This report discusses the accomplishments in modeling by the NMFS group and in digital processing of thematic mapper data by the LSU group. Planned future work is briefly discussed in a final section.

Brown, Jr., L. F., L. L. Brewton, J. H. McGowan, T. J. Evans, W. L. Fisher and C. G. Groat. 1976. Environmental Geologic Atlas of the Texas Coastal Zone - Corpus Christi Area. Bureau of Economic Geology, University of Texas, Austin, Texas, 123 p.
G-23, G-24

A series of maps presents data on land and water. The basic environmental geology map delineates and depicts in detail resource units of first-order environmental significance. The accompanying series of eight special-use maps outline physical properties and land use suitability, current land use, active physical processes, mineral and energy resources, topographic and bathymetric configurations, natural and artificial water systems, and climate. A descriptive text explains the data presented, their utility, and means of extrapolating for other special uses.

Brown, Jr., L. F., L. L. Brewton, J. H. McGowan, T. J. Evans, C. G. Groat and W. L. Fisher. 1980. Environmental Geologic Atlas of the Texas Coastal Zone - Brownsville-Harlingen Area. Bureau of Economic Geology, University of Texas, Austin, Texas, 140 p.
G-26, G-26.2

See Brown *et al.* (1976).

Brown, Jr., L. F., J. H. McGowan, T. J. Evans, C. G. Groat and W. L. Fisher. 1977. Environmental Geologic Atlas of the Texas Coastal Zone - Kingsville Area. Bureau of Economic Geology, University of Texas, Austin, Texas, 131 p.
G-26

See Brown *et al.* (1976).

Bryan, C. E. 1971. An ecological survey of the Arroyo Colorado, Texas, 1966-1969. Texas Parks and Wildlife Dept. Tech. Ser. 10:1-28.
G-26.2

The lower portion of the Arroyo Colorado is one of very few brackish water areas in the Lower Laguna Madre of Texas and provides a nursery ground for marine species of the region. Data on biological and hydrographic conditions prior to and following a major flood were obtained. Salt water reached Mile 25 before the flood and the entire area was fresh following it. It took one year for hydrographic conditions to approximate pre-flood status. During a major portion of the year, there was little or no oxygen on the bottom from Mile 7 to Mile 25. There was an inverse relationship between encroaching high salinity water and low dissolved oxygen readings, indicating high organic content and poor water circulation.

Buck, J. D. and R. H. Pierce. 1989. Bacteriological aspects of Florida red tides: A revisit and newer observations. Estuarine Coastal Shelf Sci. 29(4):317-326.
F-14

A brief review is presented of the literature involving the occurrence of bacteria in red tides caused by the dinoflagellate Ptychodiscus brevis. Both quantitative and qualitative studies were made on outbreaks along the Florida Gulf coast in 1982 and 1987 and a bloom along the North Carolina coast in 1987. Non-bloom waters in both areas were sampled in 1988. Members of the genera *Aeromonas*, *Alteromonas/Pseudomonas* and *Vibrio* were frequently isolated from the three blooms studied as well as from non-bloom waters.

Burchfield, H. P., R. J. Wheeler and W. Subra. 1974. Nutrient analysis of water and sediment in Timbalier Bay, Louisiana (August 1973 - January 1974). Pages 54-57 in Abstracts, Summaries, and Conclusions from the Offshore Ecology Investigation, 1972-74. Gulf Universities Research Consortium (GURC), Galveston, Texas.
G-11

Seasonal variations were apparent for the nutrients within the study area. Nutrient values were highest in October 1972 for total alkalinity, dissolved silica and orthophosphate and sediment total alkalinity, dissolved silica and total phosphate. Elevated values occurred in October 1973 but were not comparable with the October 1972 values. The ammonia nitrogen and nitrite plus nitrate nitrogen contents of waters and the Kjeldahl nitrogen contents of sediments were elevated during the winter months and lowest from early spring

to late fall. The values for the winter of 1972-1973 were much greater than the values for the 1973-1974 winter. Variations around oil company structures were observed and attributed to effects of the physical structure.

Burchfield, H. P., R. J. Wheeler and W. Subra. 1979. Nutrient concentrations in Timbalier Bay and the Louisiana oil patch. Pages 223-233 in C. H. Ward, M. E. Bender and D. J. Reish (eds.), The Offshore Ecology Investigation. The Effects of Oil Drilling and Production in a Coastal Environment. Rice University Studies 65(4&5).
G-11

Water samples along a transect in eastern Timbalier Bay were taken in August 1972 through January 1974 and analyzed for total alkalinity, dissolved silica, orthophosphate, ammonia nitrogen, and nitrate and nitrite nitrogen. Sediments were analyzed for total alkalinity an dissolved silica of the interstitial water and for total Kjeldahl nitrogen and total phosphate in bulk sediments. Seasonal variations were shown for all of the nutrients studied. During any collection period, no significant differences were shown among study areas.

Burrage, D. (ed.). 1989. Public Health Issues in the Gulf of Mexico. Proceedings of a Mississippi Sea Grant Advisory Service Workshop, November 14-15, 1989. Publ. No. MASGP-90-002, Mississippi-Alabama Sea Grant Consortium, Ocean Springs, Mississippi, 29 p.
F-9 through G-27

Sections of this report include an Introduction, Pathogen Exposure via Molluscan Shellfish, Human Exposure to Pathogens in Seawater, Marine Biotoxins and Associated Public Health Risks in the Gulf of Mexico, Summary and Recommendations, and a List of Participants.

Butts, G. L. 1983. Dissolved Oxygen Survey of Upper Perdido Bay. Memorandum, State of Florida, Dept. of Environmental Regulation, Pensacola, Florida, 4 p.
F-28, G-1

On July 14, 1983, L. W. Doneland and G. L. Butts sampled Perdido Bay utilizing a model 6D Hydrolab. The data recorded are included in the memorandum.

Caffrey, J. M. and J. W. Day, Jr. 1986. Control of the variability of nutrients and suspended sediments in a Gulf coast estuary by climatic forcing and spring discharge of the Atchafalaya River. Estuaries 9(4A):295-300.
G-12

Water column nutrients (nitrate, ammonium, soluble reactive phosphate, total Kjeldahl nitrogen, and total phosphorus) and suspended sediments were measured during one 44-h and two 28-h periods in March 1982 at two stations in Fourleague Bay, Louisiana, which is located at the mouth of the Atchafalaya River, a distributary of the Mississippi River. River water (a source of nitrate, total Kjeldahl nitrogen, total phosphorus, and suspended sediments to Fourleague Bay) flows into the upper reaches of the Bay during high tide and frontal overrunning conditions with northerly and westerly winds. During one sampling period, decreasing wind speed and the rising tide resulted in Atchafalaya River water inundating the Bay and nitrate concentrations in the upper Bay increasing from 30-70 μM to 90-118 μM. Significant variations in nutrients associated with the movement of water masses from the river, marshes, and Gulf of Mexico occurred over several different time scales. Tidal transport occurred over 25-h periods, while frontal passages occurred at 3-d to 5-d intervals. Variability in nutrient and suspended sediment concentrations over these relatively short time scales can be as great as seasonal variability in the bay.

Cahoon, D. R. and C. G. Groat (eds.). 1990. A Study of Marsh Management Practice in Coastal Louisiana. Vol. I. Executive Summary, Vol. II. Technical Description, Vol. III. Ecological Evaluations. Final Report to U.S. Dept. of Interior, Minerals Management Service, New

Orleans, Louisiana. Contract No. 14-12-0001-30410. OCS Study/MMS 90-0073, 90-0074, 90-0075, 36 p, 309 p., 423 p.
G-11, G-13, G-14

Cardinale, T. and R. Boler. 1984. Environmental Quality: 1982-1983, Hillsborough County, Florida. Hillsborough County Environmental Protection Commission, Tampa, Florida, 242 p. (not in hand)
F-15

Casserly, D. M., M. Vecchione, R. S. Maples, R. Ilg, G. R. Gaston, D. Weston, J. Beck and J. Lascara. 1982. Biological attributes of the West Hackberry brine disposal site. Abstr. for Oceans '82 Conference Record: Industry, Government, Education - Partners in Progress, September 20-22, 1982. Washington, D.C.
G-27

A Strategic Petroleum Reserve brine disposal site is located 11.4 km off the southwest coast of Louisiana. A grid of stations centered at the brine diffuser was monitored monthly for biological attributes during a 12-mo period. Temporal and spatial distributions in species abundances and diversity were measured for: 1) macrobenthic invertebrates, 2) fishes and nektonic macrocrustaceans, 3) plytoplankton, and 4) zooplankton. These assemblages were studied relative to physical and chemical variations occurring in the study area. The marine fauna and flora of the diffuser area are characteristic of coastal assemblages of the northwestern Gulf coast. Population fluctuations were attributed to seasonal and hypoxic conditions. The macrobenthic community was dominated by polychaetes and phoronids; the nekters were typical of the white shrimp community; the phytoplankton community was dominated by estuarine and neritic species; and the zooplankton community was dominated by copepods with *Penaeus* spp. and *Brevoortia* spp. common in the area.

Center for Wetland Resources. 1970. Louisiana Wild Life and Fisheries Commission, Water Chemistry Survey Data, Louisiana Estuaries, 1968-1969. Report to Dept. of the Army, New Orleans District, Corps of Engineers. Hydrologic and Geologic Studies of Coastal Louisiana Report No. 7, Coastal Resources Unit, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana, 91 p.
G-7, G-8, G-9, G-10, G-11, G-12, G-13, G-14, G-15

This report contains a summary of chemical and physical parameters of mainly the saline waters of coastal Louisiana. Data were collected by the Louisiana Wild Life and Fisheries Commission at stations located throughout the coastal wetlands during the period December 1967 through June 1969. At most of the stations water samples were taken once every month. Recorded parameters are: temperature, salinity, oxygen, turbidity, nitrate, nitrite, reactive phosphorus, total phosphorus. For each parameter, the mean, maximum, and minimum value for the year 1968 are given. In addition, seasonal means are presented for those parameters for which monthly values were available for more than 4 months during winter-spring and/or summer-autumn of 1968 and/or winter-spring of 1969.

Chambers, G. V. and A. K. Sparks. 1959. An ecological survey of the Houston Ship Channel and adjacent bays. Publ. Inst. Mar. Sci. Univ. of Texas 6:213-250.
G-17

An ecological survey of the Houston Ship Channel and adjacent bays was initiated in the summer of 1957 with data collected at frequent regular intervals. This report includes the comparison of data on temperature, chlorinity, dissolved oxygen, and related quantities with data on fish, shrimp, and crabs caught in trawls. Data are also given on currents, bottom cores, and organic content of sediments. In the ship channel, a dissolved oxygen gradient existed from a low dissolved oxygen concentration in the upper channel to near normal concentrations at the lower boundary of the survey area. The dissolved oxygen in the ship channel below the

mouth of the San Jacinto River is greatly influenced by the flow rate of the river which is, in turn, controlled largely by rainfall.

Childers, D. L. and J. W. Day, Jr. 1990a. Marsh-water column interactions in two Louisiana estuaries. I. Sediment dynamics. Estuaries 13(4):393-403.
G-10, G-12

Throughflow marsh flumes were used to measure total sediment exchanges between the marshes and water column of two Louisiana estuaries. Comparisons were made between the Barataria Basin estuary which is isolated from significant riverine sediment input and the Fourleague Bay estuary which receives large sediment inputs from the Atchafalaya River.

Childers, D. L. and J. W. Day, Jr. 1990b. Marsh-water column interactions in two Louisiana estuaries. II. Nutrient dynamics. Estuaries 13(4):404-417.
G-10, G-12

The exchange of dissolved nutrients between marshes and the inundating water column was measured using throughflow marsh flumes built in two microtidal Louisiana estuaries: the Barataria Basin estuary and Fourleague Bay. Comparisons were made between the two systems in relation to the deltaic successional stage of the estuary.

Childers, R. E. 1981. Part 8 - Summary data set. In C. A. Bedinger, Jr. (ed.), Ecological Investigations of Petroleum Production Platforms in the Central Gulf of Mexico. Vol. 1 - Pollutant Fate and Effects Studies. Report to Bureau of Land Management, New Orleans OCS, Contract AA551-CT8-17. SwRI Project No. 01-5245, Southwest Research Institute, San Antonio, Texas, 794 p.
G-7.1

See Bedinger *et al.* (1981).

Childress, U. R. 1966. Hydrographic and Meteorological Study of the San Antonio Bay System. Pages 447-475 in Coastal Fisheries Project Reports 1964. Texas Parks and Wildlife Dept., Austin, Texas. (not in hand)
G-22

Childress, U. R., E. Bradley, E. Hagen and S. Williamson. 1975. The Effects of Freshwater Inflows on Hydrological and Biological Parameters in the San Antonio Bay System, Texas. Texas Parks and Wildlife Dept., Coastal Fisheries Branch, Austin, Texas, 190 p.
G-22

The San Antonio Bay system is an oligohaline system that supports substantial populations of economically important fish and shellfish. The anticipated construction of flow-control structures such as dams and diversion canals on the Guadalupe and San Antonio Rivers, as well as on other rivers that drain into Texas' coastal waters, prompted a study of the composition and extent of freshwater flow into and the corresponding effects on the San Antonio Bay system. This system was chosen for the study because it was an area of high volume river inflow having little industrialization and few restrictions on the flow of incoming fresh water.

Christmas, J. Y. (ed.). 1973. Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi. Phase I: Area Description. Phase II: Hydrology. Phase III: Sedimentology. Phase IV: Biology. Mississippi Marine Conservation Commission, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, 434 p.
G-2.3, G-3, G-4, G-5, G-6

The Mississippi portion of the Gulf of Mexico Estuarine Inventory and Study with attention primarily to the physical and environmental properties of estuaries, but also economic, developmental, and political factors associated with them. The major goal of the inventory is related to management of coastal resources.

Christmas, J. Y. and C. K. Eleuterius. 1973. Phase II: Hydrology. Pages 75-121 in J. Y. Christmas (ed.), Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi. Mississippi Marine Conservation Commission, Gulf Coast Research Laboratory, Ocean Springs, Mississippi.
G-2.3, G-3, G-4, G-5, G-6

Salinity, temperature, pH and dissolved oxygen concentration were measured at 5-ft intervals through the water column at 51 stations in Mississippi inshore estuarine waters. Micronutrient concentrations were determined from surface and bottom water samples. Monthly stream flow was documented. Sampling was accomplished monthly or oftener. Salinity was closely correlated with stream flow, providing drastic seasonal and areal variations. Temperature followed a seasonal pattern with spring and fall reversal of offshore clines. Saltwater wedges were described. Average isohalines and isotherms for Mississippi Sound were constructed. General micronutrient levels in the study area were established. Concentrations were closely related to adjacent human population density.

Chuang, W.-S. and E. M. Swenson. 1981. Subtidal water variations in Lake Pontchartrain, Louisiana. J. Geophys. Res 86:4198-4204. (not in hand)
G-7

Churgin, J. and S. J. Halminsta. 1974. Key to Oceanographic Records Documentation No. 2. Temperature, Salinity, Oxygen, and Phosphate in Waters off United States. Vol. II. Gulf of Mexico. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Washington, D.C., 117 p.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

Comiskey, C. E. and T. A. Farmer (eds.). 1981. Characterization of Baseline Oceanography for the Texoma Region Brine Disposal Sites. Vol. I. Contract No. DEAC01-77US08788. Final Report to DOE, Strategic Petroleum Reserve Office, Washington, D.C., 130 p. (not in hand)
G-7.1

Committee on Merchant Marine and Fisheries. 1988. Coastal Waters in Jeopardy: Reversing the Decline and Protecting America's Coastal Resources. Oversight Report. Serial No. 100-E, Committee on Merchant Marine and Fisheries, Washington, D.C., 47 p.

This report culminates the efforts of the Committee, through the course of nine oversight hearings, to amass a comprehensive record covering every major aspect of the coastal pollution problem, from direct discharges of pollutants into coastal waters to surface runoff to atmospheric deposition to sediment leaching. The heart of the report is the recommendations section.

Connell, C. H. and J. B. Cross. 1950. Mass mortality of fish associated with the protozoan *Gonyaulax* in the Gulf of Mexico. Science 112(2908):359-363.
G-17

This is the first reported observation of the concurrent appearance of a red tide, luminescent water, and immense numbers of the dinoflagellate protozoan, *Gonyaulax*, with mass mortality of fish on the eastern coast of North America. The episode occurred in the summer of 1949 in a saltwater lagoon known as Offatts Bayou along Galveston Island.

Conner, W. H. and J. W. Day, Jr. (eds.). 1987. The Ecology of Barataria Basin, Louisiana: An Estuarine Profile. Biological Report No. 85(7.13), U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C., 165 p.
G-10

This estuarine profile is one of a series of publications concerning estuarine areas of the U.S. Its purpose is to synthesize existing information on the basin. It is one the interdistributary sub-estuaries of the Mississippi deltaic plain. Habitats in the basin vary from swamp forest to marine open water. Chapters are entitled: Description of the Basin; Physical Variables; Chemistry and Nutrient Dynamics; Vegetation: Composition and Production; Zooplankton; Benthos; Nekton; Wildlife; Review of Modeling Studies in the Barataria Basin; Management Issues; Synthesis.

Conseil Permanent International pour l'Exploration de la Mer. 1936. Bulletin hydrographique pour l'année 1935 (Séries B1), 105 p.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

Provides oxygen, phosphate, and nitrate profiles at numerous locations in the Gulf of Mexico during 1935.

Craig, N. J., J. W. Day, Jr., A. M. Seaton, P. Kemp and W. G. Smith. 1977. Part 1 - Eutrophication. In N. J. Craig and J. W. Day, Jr. (eds.), Cumulative Impact Studies in the Louisiana Coastal Zone. Final Report to Louisiana State Planning Office. Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana.
G-7, G-10, G-11, G-12, G-15

This publication consists of two parts. Part 1 recognizes that eutrophication is a widespread problem throughout the coastal zone of Louisiana. It leads to poor water quality, development of nuisance algal blooms, decline in desirable commercial and sports fishery species, and diminished recreational usefulness of water bodies. The major cultural sources of nutrients leading to eutrophication are urban runoff, domestic sewage, and agricultural runoff.

Crance, J. H. 1971. Description of Alabama estuarine areas - cooperative Gulf of Mexico estuarine inventory. Ala. Mar. Resour. Bull. 6:1-85.
G-1, G-2, G-2.2

The physical characteristics of Alabama estuarine areas are presented as part of a cooperative Gulf of Mexico estuarine inventory. The importance of estuaries as nursery areas for marine species and for other uses is discussed, and the early history of the exploration and development of the Gulf of Mexico and the coastal area of Alabama is reviewed. Maps are presented to show the Alabama estuarine study area and the surface sediment types, pollution sources, oyster beds, isotherms, isohaline and certain economic characteristics of the area. Data on climate, tides, open water surface area and average depth, tidal marsh, stream discharge, domestic and industrial wastes, navigation channels, commercial fisheries, and other characteristics of the study area are presented in tables.

Crozier, G. F. and S. R. Heath. 1974. Mobile Bay Plume Study Cruise Report: A-74-45. NASA Contract No. NAS8-30810, Marine Environmental Sciences Consortium, Dauphin Island, Alabama, 10 p.
G-2

In an effort to define the boundaries and provide some quantitative data for the Mobile Bay "plume" of turbidity and its effect on the inner continental shelf, an east-west cruise track was utilized, October 9, 1974. NASA has conducted several types of remote sensing studies which clearly demonstrate the occurrence of the offshore surface turbid water, but found truth turbidity quantitation has not been available for this particular feature. The intent of this study was to compare visual observations to optical measurements while providing needed

ground truth for satellite photography. In addition, nutrient transfer, usually associated with Bay waters, was determined.

Cullen, J. J. and R. S. Jones. 1986. Executive summary. In R. S. Jones *et al.*, Studies of Freshwater Inflow Effects on the Lavaca River Delta and Lavaca Bay, Texas. Final Report to the Texas Water Development Board, Contract No. 55-61011. Tech. Rept. No. TR/86-006, University of Texas Marine Science Institute, Port Aransas, Texas, 17 p.
G-21

The primary goals of this study were to obtain an environmental assessment of the upper Lavaca Bay after completion of the Palmetto Bend reservoir project on the Navidad River, and to document the use of the lower river delta as a nursery area for finfish and shellfish. Systematic sampling provided good records of a large number of variables over limited temporal (1984-1986) and spatial scales. Individual components of the project were Nutrients, Hydrographic Parameters and Phytoplankton; Benthic Respiration Rate and Ammonium Flux; Zooplankton; Benthos; Finfish and Shellfish; and Stable Isotopes.

Cullen, J. J. and R. G. Lane. 1986. Nutrients, hydrographic parameters and phytoplankton, 1984 - 1986. Chapter 2 in R. S. Jones *et al.*, Studies of Freshwater Inflow Effects on the Lavaca River Delta and Lavaca Bay, Texas. Final Report to the Texas Water Development Board, Contract No. 55-61011. Tech. Rept. No. TR/86-006, University of Texas Marine Science Institute, Port Aransas, Texas, 106 p.
G-21

This component of the study was designed to observe spatial and temporal patterns of nutrients and phytoplankton in the Lavaca Bay estuary and to interpret the observations with respect to the influence of freshwater input on primary production. Strong patterns were found, and these could often be related to the influence of freshwater. Sampling was inadequate to examine properly some relationships such as interannual correlations of nutrients and salinity. The data allow instructive comparisons between a wet year and a dry year and between sites along a salinity gradient. See also Cullen and Jones (1986).

Culliton, T. J., C. M. Blackwell, D. G. Remer, T. R. Goodspeed and M. A. Warren. 1989. Selected Characteristics in Coastal States, 1980 - 2000. NOAA's Coastal Trends Series: Report 1. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C., 15 p.
F-9 through G-27

This report describes some of the activities and resource uses in coastal states that affect the environmental quality of our coasts, and provides an overview of conditions existing during the 1980s and that may exist in the year 2000. Information is presented for land, population, housing, transportation, employment and business establishments, water withdrawals, energy production and consumption, solid waste, wastewater treatment plants, and hazardous waste sites.

Cunningham, R. 1980. Report on Atchafalaya-Vermilion Estuarine Complex Studies. Hydraulic Branch, U.S. Army Corps of Engineers District, New Orleans, Louisiana. (not in hand)
G-12, G-13

Dagg, M. J. 1988. Physical and biological responses to the passage of a winter storm in the coastal and inner shelf waters of the northern Gulf of Mexico. Continental Shelf Res. 8(2):167-178.
G-7.1

Hydrographic and biological properties in coastal and inner shelf waters of the northern Gulf of Mexico were monitored daily over 3 days in February 1984, immediately after the passage of a meteorological front. Strong northerly and westerly components of the wind resulted in upwelling of high salinity inner shelf water

containing low nitrate and chlorophyll concentrations. Low salinity coastal water, with associated high concentrations of chlorophyll and nitrate, was transported offshore at the surface. The passage of such winter storms at 3- to 8-d intervals could result in a periodic offshore transport of nutrient- and phytoplankton-rich water from the coastal boundary layer to the inner shelf regions. Laboratory experiments with the neritic copepods, *Acartia tonsa* and *Centropages furcatus*, showed that egg production increases dramatically within a few hours after an increase in food availability such as might occur in inner shelf waters during upwelling events. It is possible that winter storms and the associated redistribution of nutrients and phytoplankton have significant direct biological consequences in the inner shelf waters of the northern Gulf of Mexico.

Dagg, M. J. N.D. Temperature, Salinity, Chlorophyll, and Nutrient Concentrations in Terrebonne Bay, Louisiana from October 1982 to October 1983. Data Report No. 1, Louisiana Universities Marine Consortium, Chauvin, Louisiana.
G-7.1, G-11

Coastal and inshore continental shelf waters of Louisiana are influenced by marsh run-off, the Mississippi River, and the open Gulf of Mexico. The interactions between freshwater run-off and oceanographic processes, coupled with meteorological conditions that vary widely over short periods as well as seasonally, result in a complex hydrography and therefore in a complex biological system. As the preliminary portion of a long-term program designed to analyze and understand these processes, a survey of basic hydrographic, chemical, and biological parameters was made at monthly intervals over a l-yr period from October 1982 to October 1983. Nine stations were occupied, transecting Terrebonne Bay and extending into the Gulf of Mexico. The purpose of this report is to present the data from this survey.

Dagg, M. J. and T. E. Whitledge. 1991. Concentrations of copepod nauplii associated with the nutrient-rich plume of the Mississippi River. Continental Shelf Res. 11(11):1400-1423.
G-7.1

During spring and summer, discharge plumes of the Mississippi River were located visually by water color. Temperature, salinity, nutrients, chlorophyll *a* and copepod nauplii were sampled coincidentally in a cross-plume direction. Plume waters contained high concentrations of nitrate, silicate and chlorophyll during both spring and summer. Nitrate was depleted before silicate during summer but not during spring. During spring, concentrations of copepod nauplii (50-1000/l) were similar to those reported in an earlier wintertime study in this region. Summertime concentrations of nauplii were much higher, sometimes >1000/l. Nauplii were associated with plume waters.

Danek, L. J. and G. S. Lewbel (eds.). 1986. Southwest Florida Shelf Benthic Communities Study Year 5 Annual Report. Vol. I - Executive Summary. Vol. II - Technical Discussion. Vol. III - Appendices. Contract No. 14-12-0001-30211, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana.
F-15.1

The objectives of this study were to determine the potential impact of outer continental shelf oil and gas offshore activities on live-bottom habitats and communities, which are integral components of the southwest Florida shelf ecosystem; to produce habitat maps that show the location and distribution of various bottom substrates; to classify broadly the biological zonation across and along the shelf, projecting the amount covered by live/reef bottoms and the amount covered by each type of live/reef bottom; to investigate the biological process of the southwest shelf that would provide the information needed to better assess potential impacts of offshore development, to develop a conceptual model and impact assessment of offshore oil development. This was a 6-yr study with the results of the first five years included in this report series.

Dardeau, M. R. 1987. Structure of Soft Bottom Benthic Assemblages in Middle Perdido Bay. Report to Alabama Dept. of Economic and Community Affairs, Contract No. ADECA-MESC-CXM-87-5. Marine Environmental Sciences Consortium, Dauphin Island, Alabama.
G-1, F-28

The data presented here offer a preliminary examination of community structure of macroinfaunal invertebrates at four stations in middle Perdido Bay. The patterns of species diversity, dominance and abundance are examined for evidence of stress and disturbance. Species composition and animal densities are compared to those of other southeastern estuaries, the effect of benthic community structure on estuarine ecosystem function is discussed and directions for future research are outlined. The water column in the Bay may be strongly stratified with the potential for hypoxic events in late summer and early fall.

Darnell, R. M. 1991. Summary and Synthesis. Chapter 15 in J. M. Brooks (ed.), Mississippi-Alabama Continental Shelf Ecosystem Study Data Summary and Synthesis. Vol. II: Technical Narrative. OCS Study MMS 91-0063. U.S. Dept. of Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana, 862 p.
G-2.1, G-5.1, G-7.1

Includes a synthesis of the physical environment of the Mississippi and Alabama continental shelf, including water masses and circulation, standard CTD profiles, bottom water dissolved oxygen, and water column dissolved nutrient concentrations.

Dauer, D. M. 1984. High resilience to disturbance of an estuarine polychaete community. Bull. Mar. Sci. 34(1):170-174.
F-15

Massive reductions in the population densities of the polychaetous annelids of an estuarine, intertidal habitat were quantified. Anaerobic conditions as a result of the deposition of large volumes of the green alga, *Ulva lactuca* L., resulted in an 89 % decrease in the density of the 10 most common polychaete species, while only two of the 10 species became locally extinct. One month after the peak reduction in total density, all 10 species were present, and the total polychaete community density reached the second highest value for the study. The high resilience of the polychaete community was explained by 1) the presence of numerous opportunistic species, 2) the possibility of adult immigration, 3) the spatial extent of the disturbance and 4) the intensity of the disturbance.

Dauer, D. M. and J. L. Simon. 1976. Repopulation of the polychaete fauna of an intertidal habitat following natural defaunation: Species equilibrium. Oecologia(Berl.) 22:99-117.
F-15

During summer 1971, a massive outbreak of red tide resulted in defaunation of a previously characterized sandy, intertidal habitat in upper Old Tampa Bay, Tampa, Florida. Repopulation of the polychaete fauna was studied from August 1971 to July 1973. A transect composed of four stations running from just below mean high water to just below mean low water was quantitatively sampled each month for species composition, densities of individual population, biomass, and distribution of age classes. The community is viewed as a system in which species composition is determined primarily by the physical attributes of the area, and the density dominance of any species is dampened by the vagaries of adult dispersal and larval settlement. Such a system could be used to explain the relatively large number of species that belong to the same trophic type and yet occupy the same habitat.

Dauphin Island Sea Lab. 1983. Analysis of an Environmental Monitoring Program, Theodore Ship Channel and Barge Channel Extension, Mobile Bay, Alabama. Vol. I and II. Prepared for Mobile District Corps of Engineers, Contract No. DACW01-80-C-0264. Technical Report No. 83-003, Dauphin Island Sea Lab, Dauphin Island, Alabama.
G-2

Environmental assessment for the impacts from spoil island construction west of the Mobile Ship Channel and south of Hollingers Island Channel to provide access to the Theodore Industrial Park.

Day, Jr., J. W., D. D. Culley, Jr., R. E. Turner and A. J. Mumphrey, Jr. (eds.). 1979. Environmental Conditions in the Louisiana Coastal Zone. Proceedings of the Third Coastal Marsh and Estuary Management Symposium, March 6-7, 1978, Baton Rouge, Louisiana. Division of Continuing Education, Louisiana State University, Baton Rouge, Louisiana, 511 p.
G-7 through G-15

This volume is the third in a series concerned with marsh and estuary management. The impression that one gets from this volume is that there are serious environmental problems in coastal Louisiana. Further, it seems that these problems are not isolated from each other. Most of them are connected in indirect and cumulative ways. What are isolated and fragmented are the causes of these problems as well as many of the attempts to address them. We must realize that man and estuary in South Louisiana are part of a single unified system. Unless environmental problems are addressed within this context, it seems likely that we will achieve, at best, partial solutions. The most important changes that must take place are social, ethical and philosophical changes.

Degrove, B. D. 1980. Caloosahatchee River Intensive Survey Documentation. Water Quality Technical Series Vol. 1, No. 32, Southwest Florida Regional Planning Council, Ft. Myers, Florida. (not in hand)
F-12

Delfino, J. J., D. L. Frazier and J. L. Nepshinsky. 1984. Contaminants in Florida's Coastal Zone: A Review of Present Knowledge and Proposed Research Strategies. A Summary of a Workshop held April 5-6, 1984 in Gainesville, Florida and a Literature Review. Rept. No. 62, Sea Grant Project No. IR-83-13, Florida Sea Grant College, University of Florida, Gainesville, Florida, 176 p.
F-9 through F-28

The objectives of this project were two-fold: to hold a workshop to discuss research issues and priorities with representatives from Florida's scientific, regulatory and private organizations; and to conduct a literature review for research related to the topic of contaminants in Florida's coastal zone. Both of these objectives were met, and the results of the efforts expended in meeting them appear in this report. A list of recommendations are included.

Dennis, G. D., T. J. Bright and C. A. Shalan. 1984. Offshore Oceanographic and Environmental Monitoring Services for the Strategic Petroleum Reserve. Annotated Bibliography of Hypoxia and Other Oxygen-Depleted Literature on the Marine Environment. Final Report to DOE, Strategic Petroleum Reserve Project Management Office, Contract No. DOE-AC96-83PO10850. Texas A&M University, Texas A&M Research Foundation, College Station, Texas, 46 p.
F-15, G-2, G-7.1, G-15, G-16, G-17, G-27

The references compiled herein were acquired principally through Automated Information Retrieval Service (AIRS) at the Sterling C. Evans Library of Texas A&M University, College Station, Texas. All references were reviewed for their content pertaining to the subject of hypoxia. Most annotations are the journal abstract of the paper with additional information pertinent to hypoxia. Papers without abstracts are summarized with special reference to their hypoxia information content.

DeRouen, L. R., R. W. Hann, Jr., D. M. Casserly and C. P. Giammona. 1982. West Hackberry Brine Disposal Project Pre-Discharge Characterization. Final Report to DOE, Strategic Petroleum Reserve Project Management Office, Contract No. DOE-AC96-80P01288. McNeese State University, Lake Charles, Louisiana. Texas A&M University, Texas A&M Research Foundation, College Station, Texas.
G-7.1, G-15, G-16

Environmental baseline monitoring of the southwestern Louisiana continental shelf off Holly Beach in the vicinity of the proposed brine discharge for the West Hackberry site of the Dept. of Energy Strategic Petroleum Reserve. Data are for February, March and April 1981.

DeRouen, L. R., R. W. Hann, Jr., D. M. Casserly, C. P. Giammona and V. J. Lascara (eds.). 1983. West Hackberry Strategic Petroleum Reserve Site Brine Disposal Monitoring. Vol. I: Executive Summary. Vol. II: Physical and Chemical Oceanography. Year 1 Report. Final Report to DOE, Strategic Petroleum Reserve Project Management Office, Contract No. DOE-AC96-80P010288. McNeese State University, Lake Charles, Louisiana. Texas A&M University, Texas A&M Research Foundation, College Station, Texas.
G-7.1

Data from monthly hydrographic surveys of the coastal waters off Holly Beach, Louisiana in conjunction with monitoring of the Dept. of Energy Strategic Petroleum Reserve brine disposal from West Hackberry. Field data cover January 1981 through April 1982.

Diener, R. A. 1975. Cooperative Gulf of Mexico Estuarine Inventory and Study - Texas: Area Description. NOAA Technical Report NMFS CIRC-393, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, 128 p.
G-16 through G-26

Seven Texas estuarine areas are described in terms of their dimensions; major vegetation types; geology and geological history; drainage basins and stream discharge records; hydrological, biological and benthic properties; populations and economic development; pollution; and navigation projects. These areas include the Sabine Lake, Galveston Bay, Matagorda Bay-Brazos River Delta, San Antonio Bay, Copano-Aransas Bay, Corpus Christi Bay, and the Laguna Madre. A list of pertinent literature is also presented.

Dinnel, S. P. 1984. Distribution and Residence Time of Freshwater on the West Louisiana and Texas Continental Shelves. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana, 89 p.
G-7.1, G-27

Hydrographic data collected on monthly cruises over the West Louisiana and Texas Shelves during 1963-1965 were analyzed, and the volume of fresh water relative to a reference salinity computed for each cruise. The freshwater volume on this shelf system exhibits an annual cycle that is dominated and initiated by the spring floods of the Mississippi and Atchafalaya Rivers. The shelf freshwater volume is largest one to two months after peak spring discharge and gradually decreases throughout the rest of the year to the annual low freshwater volume just prior to the next spring flood. The distribution of fresh water on the shelf is described in a series of maps made for individual cruises. Distribution patterns are present in each of the study years, but the magnitude of the spring flood discharge determines the strength of the distribution patterns.

Dinnel, S. P. and W. J. Wiseman, Jr. 1986. Fresh water on the Louisiana and Texas shelf. Continental Shelf Res. 6(6):765-784.
G-7.1, G-27

Hydrographic data collected on monthly cruises over the West Louisiana and Texas shelf from 1963 to 1965 were analyzed and the volume of fresh water on the shelf was estimated for each data set. The freshwater volume exhibits an annual cycle that is dominated by the spring flood of the Mississippi and Atchafalaya Rivers. During the winter, shelf freshwater content is low, with the highest content appearing as a discontinuous band along the inner shelf. In summer an isolated high-content region is present in the center of the shelf. This high-content region dissipates and the pattern migrates toward the southeast in the late summer. By late fall the winter distribution is again present.

Donohoe, R. and W. Calhoun. 1982. Synopsis of the Mobile Bay - Mississippi Sound Research Review. Proceedings of a Conference, February 4-5, 1982, Mobile, Alabama. Publ. No. MASPG-81-026, Mississippi-Alabama Sea Grant Consortium, Ocean Springs, Mississippi, 19 p.
G-2, G-2.2, G-2.3

To open avenues of communication between researchers, the Mississippi-Alabama Sea Grant Consortium, in conjuction with the Alabama Sea Grant Advisory Service, sponsored a workshop for researchers of the Mobile Bay Mississippi Sound Region. Investigators had the opportunity to review the current status of other projects, to determine what data were presently available from other researchers, and to discuss areas in which work still is needed to be done. This review is a significant effort to define status of knowledge in selected disciplines and geographic areas of this dynamically developing resource.

Dooris, P. M. and G. M. Dooris. 1985. Surface flows to Tampa Bay: Quantity and quality aspects. Pages 88-106 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

The streams discharging to the Bay are discussed with respect to their flow characteristics and chemical quality. Emphasis is placed on well-defined surface water bodies, leaving undiscussed other flows such as sewage plant effluent and stormwater runoff. There are 20 named rivers and streams with discharge to Tampa Bay. Long-term data on discharge and chemical quality are available for some, such as the Hillsborough, Alafia, and Little Manatee Rivers. Other streams, particularly those entering the Bay from Pinellas County have scanty or non-existent data.

Doyle, L. J. 1985. A short summary of the geology of Tampa Bay. Pages 27-32 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

From the body of data, the refereed literature (where there is surprisingly sparse representation), the grey literature, and from a series of seismic lines and vibracores that have been obtained, the author has distilled this summary of the geology of Tampa Bay.

Dragovich, A., J. H. Finucane and B. Z. May. 1961. Counts of red tide organisms, *Gymnodinium breve*, and associated oceanographic data from Florida west coast, 1957-59. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 369. U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D. C., 175 p.
F-9, F-10, F-10.1, F-11, F-12, F-13, F-14, F-15, F-15.1

During the period this report covers, two outbreaks of red tide occurred. The first, from the end of September through December 1957, occurred chiefly in coastal waters and bays from Anclote Key south to the Shark River in the Florida Everglades. The second outbreak occurred September through December 1959 in the coastal area between St. Petersburg Beach and Cape Romano. Both outbreaks caused heavy fish mortalities.

Dragovich, A., J. H. Finucane, J. A. Kelly, Jr. and B. Z. May. 1963. Counts of Red-Tide Organisms, *Gymnodinium breve*, and Associated Oceanographic Data from Florida West Coast, 1960-61. U.S. Fish and Wildlife Service Special Scientific Report--Fisheries No. 455. U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D. C.
F-15, F-15.1

This report presents counts of the red-tide organism, *Gymnodium breve*, and associated oceanographic data for the period January 1960 to August 1961. During this period two minor outbreaks of red tide occurred. The first was in March 1960 and the second during July and August of the same year. Both of these outbreaks were confined mainly to an area from the mouth of Tampa Bay to 35 miles offshore, and no fish mortality was observed.

Dragovich, A., J. A. Kelly, Jr. and J. H. Finucane. 1966. Hydrographic Observations of Tampa Bay, Charlotte Harbor, Pine Island Sound, Florida, and Adjacent Waters of the Gulf of Mexico, February 1964 through February 1965. Data Report No. 13, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C., 72 p.
F-13, F-15, F-15.1

See Saloman (1974).

Drake, T. 1982. Oxygen depletion as influenced by the Mississippi River outflow. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, Louisiana.
G-7.1

This paper characterizes the lower Mississippi River with respect to oxygenation and reoxygenation, reviews historical and future trends, describes effects of dredging, and outlines the U.S. Army Corps of Engineers project to deepen and make other navigational improvements to the river. Conclusions as to the possible effects of this project and conclusive chemical/biochemical analysis of the water cannot be made until further information on the interaction of physical and chemical forces is gathered. Samples are chiefly from the Venice, Louisiana gauging station.

Drew, R. D., N. S. Schomer and S. H. Wolfe. (in review). An Ecological Characterization of the Tampa Watershed. Biological Report No. 87, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C. (not in hand)
F-15

Dugan, P. J. and R. J. Livingston. 1982. Long-term variation of macroinvertebrate assemblages in Apalachee Bay, Florida. Estuarine Coastal Shelf Sci. 14(4):391-403.
F-22

Trawlable epibenthic macroinvertebrates were sampled monthly from June 1972 to May 1979 to compare invertebrate assemblages in polluted (Fenholloway drainage) and unpolluted (Econfina drainage) portions of Apalachee Bay. Decapod crustaceans comprised 95 % of the total number of individuals collected. The relative abundance of dominant species and species richness in the two estuaries were similar, although the number of individuals collected in the Econfina area was always at least twice that taken in the Fenholloway. This difference was attributed to the greater seagrass biomass in the Econfina estuary. Comparisons of the constancy of species composition over the 7-year period and species rank changes following a pollution abatement program in the Fenholloway system indicated enhanced species persistence in the unpolluted area. Overall, despite considerable seasonal variability of physico-chemical and biological characteristics, there was long-term stability of key invertebrate populations in the unpolluted estuarine system.

Dugas, R. J. 1975. Variation in Day-Night Trawl Catches in Vermilion Bay, Louisiana. Tech. Bull. No. 14, Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana, 13 p.
G-13

A total of 1733 organisms, representing 22 species, was taken in trawl samples collected periodically over a 24-h period, on five different occasions near the State Wildlife Refuge on Fearman Bayou, Vermilion Bay, Louisiana. Simultaneously, the environmental factors of dissolved oxygen, surface temperature, salinity, light

intensity, turbidity and pH were recorded; tank observations were conducted on several of the captured animals. Differences between day-night ratios for several species are presented.

Dugas, R. J., J. W. Tarver and L. S. Nutwell. 1974. The Mollusk Communities of Lakes Pontchartrain and Maurepas, Louisiana. Tech. Bull. No. 10, Louisiana Wild Life and Fisheries Commission, New Orleans, Louisiana, 13 p.
G-7

Densities and distribution of the brackish-water mollusk communities of Lake Pontchartrain and Lake Maurepas, Louisiana, are outlined. Lakes Pontchartrain and Maurepas were divided into 99 3-mi^2 grids with two Peterson grab samples taken in each grid. The results of these 198 samples, including 10 molluscan species, are reported, as well as some apparent trends in the two lakes.

Ehler, C. N., D. J. Basta and T. F. LaPointe. 1985. Gulf of Mexico Coastal and Ocean Zones Strategic Assessment: Data Atlas. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Washington, D.C.
F-9 through G-27

El-Sayed, S. Z., W. M. Sackett, L. M. Jeffrey, A. D. Fredericks, R. P. Saunders, P. S. Conger, G. A. Fryxell, K. A. Steidinger and S. A. Earle. 1972. Folio 22. Chemistry, primary productivity, and benthic algae of the Gulf of Mexico. Pages 1-29 in V. C. Bushnell (ed.), Serial Atlas of the Marine Environment. American Geographical Society, New York.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

This folio summarizes the knowledge of the chemistry of seawater, its primary production, and the pelagic and benthic flora of the Gulf of Mexico based on various programs of the Dept. of Oceanography of Texas A&M Univ. The sections summarize the physical and chemical constituents of the Gulf, the primary production and standing crop of phytoplankton, and the species composition of two of the main primary producers (the diatoms and dinoflagellates). Checklists of all species known to occur in the Gulf are given in appendices. A final section summarizes benthic algae.

Elder, J. F. and H. C. Mattraw, Jr. 1982. Riverine transport of nutrients and detritus to the Apalachicola Bay estuary, Florida. Water Resour. Bull. 18(5):849-856.
F-24

Fifteen percent of the area is a dense bottom-land hardwood forest that is periodically flooded. The annual leaf-litter fall from the flood-plain trees is a potential source of nutrients and detritus that eventually can flow into the Bay. Transport of such material is dependent on the periodic inundation of the flood plain. Flood characteristics, such as prior hydrologic conditions, extent, and timing, are important in determining the amount and forms of materials transported. Nutrient concentration varied little with discharge in the 1980 spring flood, but it accounted for 53, 60, 48, and 56 % of the annual flux of total organic carbon, particulate organic carbon, total nitrogen, and total phosphorus, respectively. In 1980, the flood peaks, rather than the rise or recession, accounted for maximum nutrient and detritus transport.

Elder, J. F., S. D. Flagg and H. C. Mattraw, Jr. 1986. Hydrology and Ecology of the Apalachicola River, Florida: A Summary of the River Quality Assessment. Water-Supply Paper No. 2196-D, U.S. Dept. of the Interior, Geological Survey, Tallahassee, Florida, 46 p.
F-24

During 1979-1981, The U.S. Geological Survey conducted a large-scale study of this river, which emphasized interrelations among hydrodynamics, the flood-plain forest, and the nutrient-detritus flow through the river system to the estuary. This report summarizes major findings of the study. Data on accumulation of toxic substances in sediments and benthic organisms in the river were also collected. Water and nutrient budgets

based on data collected during the river assessment study indicate the relative importance of various inputs and outputs in the system. Whatever management decisions are made, they should take into account the impact on the natural flooding cycle. Permanent, substantial changes in the natural flooding cycle would likely induce concomitant changes in the flood-plain environment and in the nutrient and detritus yield to the estuary.

Eleuterius, C. K. 1976a. Mississippi Sound. Salinity Distribution and Indicated Flow Patterns. Sea Grant Publ. No. MASGP-76-023, Mississippi-Alabama Sea Grant Consortium, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, 128 p.
G-2.3, G-3, G-4, G-5, G-6

This study of the circulation and salinity regime of Mississippi Sound describes the general patterns of flow indicated by the horizontal distribution of salinity at selected depth levels and the variability of salinity through the year. An appendix containing tables of salinity is included. Particular attention was given to certain areas or situations that the author felt warranted it in view of various activities planned or ongoing in the Sound, including those associated with disposal of domestic waste, dredging, fisheries, heavy industry and biological studies.

Eleuterius, C. K. 1976b. Mississippi Sound. Temporal and Spatial Distribution of Nutrients. Sea Grant Publ. No. MASGP-76-024, Mississippi-Alabama Sea Grant Consortium, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, 48 p.
G-2.3

In a general manner, the levels of nutrients declined and became less erratic westward through Mississippi Sound. In addition, with one exception, there was a seaward decline in the nutrient levels. The primary sources of nutrients in the Sound are Pascagoula River, Bayou Casotte, Biloxi Bay and Pearl River. To properly monitor and manage the estuarine waters of Mississippi Sound, a comprehensive study of the Sound's chemistry is necessary. The emphasis in such a study should be on those parameters that are known to have a sizable effect on the biota.

Eleuterius, C. K. 1978a. Classification of Mississippi Sound as to estuary type by vertical salinity structure. J. Miss. Acad. Sci. 23:23-32.
G-2.3

To classify Mississippi Sound as to estuarine type based on vertical salinity structure, 2421 surface-bottom pairs of salinity measurements made at 90 stations within the Sound during 4 April 1973 through 12 April 1977 were used. Ratios were obtained for surface to bottom salinity for all paired-observations at all stations. The station data were then sorted by depths at mean low water into four groups: < 5 ft; 5 ft $<$ depth $<$ 10 ft; 10 ft $<$ depth $<$ 15 ft; $>$ 15 ft. The first group of stations showed considerable variability during the period January through June. From July through December, the range in ratios became much smaller, and the values approached 1 reflecting a more uniform water column with decreasing river flow. A greater variability was noted in the second, third and fourth groups than in the first; however, the same trend was present. Although the data verified that the Sound does become locally stratified, the preponderance of observations showed that it generally fluctuates between a partially mixed and well-mixed estuary.

Eleuterius, C. K. 1978b. Geographical Definition of Mississippi Sound. Gulf Res. Rep. 6(2):179-181.
G-2.3

Boundaries for Mississippi Sound are determined by application of definitions, established surveying practices and observations of the physical processes of the area. U.S. Coast and Geodetic charts 1266 (1972 edition), 1267 (1972 edition) and 1268 (1974 edition) were used in ascertaining the boundaries. These boundaries provide a formal geographical definition for Mississippi Sound.

Eleuterius, C. K. 1979. Hydrology of Mississippi Sound North of Petit Bois Pass. Prepared for Mississippi Marine Resources Council. Project No. CO-ST-78-016, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, 54 p.
G-2.3

The objective of this study was to determine the seasonal norms and variations in levels of several parameters for the period of sampling. The parameters measured were water temperature, salinity, pH, dissolved oxygen, nitrite-nitrogen, nitrate-nitrogen, orthophosphate and total phosphate. The hydrology of the area is highly variable. Water temperatures approach uniformity areally and throughout the water column during summer. In late summer and fall, salinity reaches maximum levels with minimum variation. Mean levels of pH were found highest in winter and lowest in late summer and early fall. Dissolved oxygen was highest in winter and lowest in summer. Nitrite-nitrogen was at lowest levels during winter and summer with the maximum occurring in the spring. Nitrate-nitrogen was highest in winter and spring with summer and fall levels being much lower. Orthophosphate was highest during spring and summer. Total phosphate reached maximum levels in summer with fall and winter showing the lowest levels.

Eleuterius, C. K. and S. L. Beaugez. 1981. Mississippi Sound: A Hydrographic and Climatic Atlas. Publ. No. MASGP-79-009, Mississippi-Alabama Sea Grant Consortium, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, 135 p.
G-2.1, G-2.2, G-2.3

Eleuterius, L. H., H. M. Perry, C. K. Eleuterius, J. Warren and J. Caldwell. 1981. Causative analysis on a nearshore bloom of *Oscillatoria erythraea* (*Trichodesmium*) in the northern Gulf of Mexico. Northeast Gulf Sci. 5(1):1-11.
G-2.1, G-2.2, G-2.3

Physical, chemical, and biological characteristics that preceded and caused a bloom of *Oscillatoria erythraea* (commonly known as trichodesmium) in coastal waters of Mississippi and adjacent waters of the Gulf of Mexico are described. This is the first report of the blue-green alga occurring in high density near the mainland and in a predominantly estuarine area of the northern Gulf of Mexico. The alga occurred in patches with the greatest concentration near the surface. Some entrapment of zooplankton in the dense algal mass was observed, but most of the zooplankton was diverse and unharmed. Harmful effects of the algal bloom on larger animals were not observed nor believed to have occurred.

Environmental Protection Agency. 1978. National Water Quality Inventory. 1977 Report to Congress. Publ. No. EPA-440/4-78-001, U.S. Environmental Protection Agency, Office of Water Planning and Standards, Washington, D.C.
F-9 through G-27

A national overview of water quality as reported by the individual State reports for Section 305(b) of PL 92-500.

Environmental Protection Agency. 1984. National Water Quality Inventory. 1982 Report to Congress. Publ. No. EPA-440/2-84-006, U.S. Environmental Protection Agency, Office of Water Planning and Standards, Washington, D.C.
F-9 through G-27

A national overview of water quality as reported by the individual State reports for Section 305(b) of PL 92-500.

Environmental Protection Agency. 1988. Sediment Deficit and Saltwater Intrusion in Barataria Basin, Louisiana. Draft Report to Office of Marine and Estuarine Protection. EPA, Region VI, Dallas, Texas.
G-10

Coastal Louisiana wetlands are vanishing at a rate of 40-60 mi^2 each year. The losses arise from a combination of natural processes and human activities that include flood control practices, impoundment, dredging, channelization, subsidence, erosion, and sea level rise. The end result of these compounding influences has been a tremendous reduction of sediment and freshwater allocations into Barataria Basin. The fresh water is being channeled largely out the Mississippi River passes and the river's heavy load of sediments is being funneled into deep waters in the Gulf of Mexico. As a result, the swamps and marshes in the delta plain are experiencing a sediment deficit and pathways are opened for the inland advance of saline waters. As the substrate subsides and the vegetation is stressed, the wetlands are converted to open water. Management strategies are being developed to restore these wetlands by altering the flow of the water and sediments that feed and fuel the estuary.

Environmental Protection Agency. 1990. Draft Environmental Impact Statement for the Designation of an Ocean Dredged Material Disposal Site Located Offshore Pascagoula, Mississippi. EPA, Region IV, Atlanta, Georgia, 464 p.
G-5.1

The proposed Ocean Dredged Material Disposal Site (ODMDS) will encompass part or all of the former interim disposal site and an adjacent charted former disposal site. The need for this ocean disposal is primarily based on the lack of economically, engineeringly, and environmentally feasible alternatives for the disposal of the projected quantities of dredged material. The Pascagoula ODMDS is restricted to the disposal of dredged material from the Mississippi Sound area that meets the Ocean Dumping Criteria. No grain size restrictions have been applied to the proposed ODMDS.

Estabrook, R. H. 1973. Phytoplankton Ecology and Hydrography of Apalachicola Bay. M.S. Thesis, Florida State University, Tallahassee, Florida, 163 p.
F-24

A year-long study of phytoplankton was conducted from October 1972 to September 1973, with preliminary studies beginning in July 1972. Productivity, yielding 371 $gC/m^2/yr$, generally followed water temperature, although peaks occurred in the late spring and fall. Average chlorophyll *a* was about 7 mg Chl a/m^3. Nitrate values varied greatly over the year. Ammonia concentrations were fairly constant. Orthophosphate values were generally low. Silicate values ranged from 400 to 2500 µg/1 in response to seasonal salinity changes. Diatoms were generally dominant throughout the year in the netplankton. Bioassays indicated that nutrients were generally in sufficient quantities for most of the year, but during times of quiescent water in the late summer, phosphate could be limiting.

Estevez, E. D. (ed.). 1989. Tampa and Sarasota Bays: Issues, Resources, Status, and Management. Proceedings of a Seminar, December 10, 1987, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 11, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C., 215 p.
F-14, F-15

A series of seminars presented as part of the Estuarine Programs Office of the National Oceanic and Atmospheric Administration as part of the continuing series held with the objective of bring to public attention the important research and management issues of the Nation's estuaries. Participants presented historical and scientific overviews of the study area, followed by an examination of management issues.

Estevez, E. D. and J. Merriam. 1989. Resource status and management issues of Sarasota Bay, Florida. Pages 186-206 in E. D. Estevez (ed.), Tampa and Sarasota Bays: Issues, Resources, Status, and Management. Proceedings of a Seminar, December 10, 1987, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 11, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C.

F-15

The Sarasota Bay area is experiencing rapid population growth, although most of its development having adverse environmental impact has occurred in the last 50 years. Barrier islands are completely developed as residential, light commercial, and tourist areas. Nearly the entire upland watershed of Sarasota Bay is also developed, mostly as suburban residential and commercial areas. There are no heavy industries in the watershed, and the amount of agricultural land is low and decreasing due to urbanization. The Bay supports an extensive recreational industry and is showing signs of overuse.

Estevez, E. D., J. Miller and J. Morris. 1984. Charlotte Harbor Estuarine Ecosystem Complex and The Peace River. Vol. I. A Review of Scientific Information. Southwest Florida Regional Planning Council, Ft. Meyers, Florida, 370 p.
F-13

The purposes of this review are to: 1) compile information on these areas as a ready reference for local, regional and state governments; 2) develop the first composite description of the Peace River and the Charlotte Harbor complex of estuaries; and 3) identify information needs useful in resource management and provide recommendations for future study.

Fagerburg, T. L. 1990. Mississippi River - Gulf Outlet, Louisiana. Field Data Report. Final Report. Tech. Rept. No. HL-90-7, U.S. Army Engineers District, New Orleans, Louisiana, 172 p.
G-8.1

Water levels, current speeds and directions, salinities, and suspended sediment concentrations were measured in the Mississippi River-Gulf Outlet Canal, New Orleans, Louisiana, in October and November 1988. The prototype data were collected as part of a study to incorporate these data in a numerical model for determination of shoaling rates. This report describes the equipment and procedures used in the data acquisition and presents tables, plots, and summaries of all the data collected. Attempts to correlate ground truth suspended sediment data with satellite data were unsuccessful due to cloud cover during the periods data were obtained.

Fanning, K. A. and L. M. Bell. 1985. Nutrients in Tampa Bay. Pages 109-129 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

Several nutrients are considered in this review. They were chosen because they are necessary for growth of most autotrophs or heterotrophs and because they might occasionally be in short supply. Members of the nitrogen system are the most interesting in the Bay, particularly ammonia. Also considered are nitrate and nitrite. Phosphate must be discussed because of its abundance in the Bay. Dissolved silica is found in the Bay, as in many estuaries, although there is little evidence that it is ever limiting. However, diatoms are significant components of the Bay phytoplankton.

Fanning, K. A., K. L. Carder and P. R. Betzer. 1982. Sediment resuspension by coastal waters: A potential mechanism for nutrient re-cycling on the ocean's margins. Deep Sea Res. 29(8A):953-965.
G-2.1, G-5.1, G-7.1, F-15.1

Nutrient profiles from the continental shelf of the northeastern Gulf of Mexico indicated considerable near-bottom enrichment in silica and nitrate above coarse sediments east of the Mississippi delta. In contrast, near-bottom waters of the carbonate-rich West Florida shelf showed no such enrichments. Most of the nutrient increase appeared to come from previously deposited sediments in the early stages of resuspension. Using the

ratios of nutrients released to sediments resuspended, calculations indicate that resuspension of as little as 1 mm of shelf sediment could intermittently augment overlying productivity by as much as 100 to 200 %. Thus, resuspension may accelerate nutrient recycling on continental margins.

Farrell, D. H. 1974. Benthic Ecology of Timbalier Bay, Louisiana, and Adjacent Offshore Areas in Relation to Oil Production. Ph.D. Dissertation, Florida State University, Tallahassee, Florida, 164 p.
G-7.1, G-11

This investigation examines species diversity, faunal similarities, and biomass relations of benthic communities in Timbalier Bay and offshore Louisiana. A marked oxygen diminuation occurred in the offshore region during July 1973 and was apparently limiting to most benthic species. The low dissolved oxygen levels apparently resulted from natural causes and probably were caused by the unusually high Mississippi River flood during the previous spring. Sampling was designed to examine possible long-term deleterious effects of oil platforms on the benthic environment, and no abnormal environmental stress could be attributed to the petroleum structures.

Federal Water Pollution Control Administration. 1970. Effects of Pollution on Water Quality, Perdido River and Bay, Alabama and Florida. U.S. Dept. of the Interior, Federal Water Pollution Control Administration, Southeast Water Laboratory, Technical Services Program, Athens, Georgia, 33 p.
G-1, F-28

An investigation of waste sources and a detailed study of the Bay and its major tributaries were conducted during September 9-17, 1969. This report presents an evaluation of the data collected during this study. The inadequately treated waste effluent from the St. Regis Paper Company at Cantonment, Florida is the major cause of the low dissolved oxygen, unsightly foam, excessive sludge deposits, and increased lignin in Perdido Bay and River, as well as degraded water quality in Eleven Mile Creek. Water quality problems in the mouth of Bayou Marcus are caused by the collective discharges to the Bayou from six small treatment facilities, the most significant of which are the Mayfair, Montclair, and Avondale plants.

Fehring, W. K. 1985. History of the port of Tampa. Pages 512-524 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

The Port of Tampa has served as a vital transportation link for the west central Florida region since the early 19th century. It evolved initially as a gateway for agricultural products flowing to and from Cuba. Improvements to the natural harbor began with the discovery of phosphate in the region and the first Congressional authorization in the 1880s. During the past 100 years, channel dimensions have repeatedly been enlarged, the size of ships calling on the port has increased, and the annual tonnage transiting the Port has increased from 1 million tons in 1920 to 50 million tons in 1980. The several separate private and public improvement projects which have culminated in the current 43-ft project are traced, including some analysis of disposal strategies.

Fernald, E. A. (ed.). 1981. Atlas of Florida. Florida State University Foundation, Tallahassee, Florida, 276 p.
F-9 through F-28

Fernald, E. A. and D. J. Patton (eds.). 1984. Water Resources Atlas of Florida. Institute of Science and Public Affairs, Florida State University, Tallahassee, Florida, 291 p.
F-9 through F-28

Finucane, J. H. 1964. Distribution and Seasonal Occurrence of *Gymnodium breve* on the West Coast of Florida, 1954-57. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 487. U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D. C.
F-9, F-10, F-10.1, F-11, F-12, F-13, F-14, F-15, F-15.1

The distribution and seasonal occurrence of *Gymnodinium breve* was recorded for a 4-yr period in estuarine and neritic waters along the Florida west coast. *G. breve* was found throughout the year in the area from Tarpon Springs south to the Florida Everglades. Blooms of this dinoflagellate occurred mainly from September through December in 1954 and 1957. Essentially, both 1955 and 1956 were not red-tide years.

Finucane, J. H. and A. Dragovich. 1966. Hydrographic Observations in Tampa Bay, Florida, and the Adjacent Gulf of Mexico - 1963. Data Report No. 14, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C., 80 p.
F-15, F-15.1

See Saloman (1974).

Fitzhugh, J. K. 1983. Factors Determining the Distribution and Abundance of Polychaetous Annelids on the Central North Gulf of Mexico Continental Shelf. M.S. Thesis, Texas A&M University, Galveston, Texas, 286 p.
G-7.1

Polychaete samples (830 total) collected on the Louisiana continental shelf during the Central Gulf Outer Continental Shelf study were reanalyzed. Stations were located around four primary platforms, 16 secondary platforms and four control sites. The objectives of this study were to determine factors regulating polychaete distribution and if effects from petroleum-related activities were present. No indication was seen of polychaete distribution being determined by production platform presence. The major trophic group on the shelf are motile deposit-feeders. The lack of a more diverse trophic structure is probably due to the fine nature of sediments and their unstable nature.

Flannery, M. S. 1989. Tampa and Sarasota Bays' watersheds and tributaries. Pages 18-48 in E. D. Estevez (ed.), Tampa and Sarasota Bays: Issues, Resources, Status, and Management. Proceedings of a Seminar, December 10, 1987, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 11, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C.
F-14, F-15

In this paper, the status of tributaries to Tampa and Sarasota Bays is reviewed. Emphasis is placed on water quality and seasonal quantities of flow and how these characteristics are related to land use and other human impacts on the watersheds. A brief synopsis of regional meteorological conditions affecting runoff is also presented.

Fleeger, J. W., W. B. Sikora and J. P. Sikora. 1983. Spatial and long-term temporal variation of meiobenthic-hyperbenthic copepods in Lake Pontchartrain, Louisiana. Estuarine Coastal Shelf Sci. 16(4):441-453.
G-7

The distribution and abundance of the meiobenthic-hyperbenthic copepods of Lake Pontchartrain were characterized monthly from August 1978 to August 1979. Ten stations, all with water depth >2 m, were established and sampled quantitatively by removing four benthic subsamples (containing as much as 25 cm overlying water) from replicated box cores. Averaged across stations over time, total copepod densities ranged from 31-89 X 10 cm^{-2}. Only 15 copepod species were identified from benthic samples. The copepod assemblage in Pontchartrain differs from all other known benthic assemblages in that the species composition

is dominated by species that are often associated with the water column; true infaunal species are rare or found in reduced abundance. Four species comprised 90 % of all individuals collected. Cluster analysis reveals diffuse seasonal grouping of stations for all seasons except fall, with spatial groupings from the central and western sides. Physical processes appear to dictate the community structure of benthic-hyperbenthic copepods in the lake.

Flemer, D. A. 1989. Perdido Bay as a Long-Term Gulf Estuarine Ecosystem Verification Template. Publ. No. EPA/600/X-89/162, U.S. Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development, Gulf Breeze, Florida, 72 p.
G-1, F-28

Functional integration of monitoring and research is described for Perdido Bay, a representative northern Gulf of Mexico bayou-type estuary. The research strategy is tiered. Tier 1 includes base-line monitoring in a long-term time series (e.g., monthly) for hydrographic, climatic and ecological variables. Tier 2 provides special field studies that require a sampling regime incompatible with a monthly sampling frequency. Emphasis is placed on analysis of factors such as storms or extreme tides that control the strength of the pycnocline, hypoxic events, and larval and postlarval recruitment. Tier 3 focuses on laboratory and field experiments and field manipulation. Tier 4 includes conceptual, statistical, and process mathematical modeling.

Flint, R. W. 1983. Freshwater inflow and estuarine dynamics as characterized by benthic processes. Pages 3-20 in R. J. Varnell (ed.), Water Quality Wetland Management. Proceedings of a Conference, August 4-5, 1983, New Orleans, Louisiana.
G-24

Using a south Texas estuary, an attempt was made to identify environmental changes that affect an estuary, isolate specific processes for measurement that lead to a holistic view of ecosystem function, and develop a simple predictive model of ecosystem dynamics that can serve as a basic tool in decision-making processes. The results suggested a new perception of the function of south Texas estuaries, relative to freshwater input. Furthermore, with a holistic approach to understand ecosystem function, sound environmental management balancing ecosystem preservation with societal needs can be performed.

Flint, R. W. 1984. Phytoplankton production in the Corpus Christi Bay estuary. Contrib. Mar. Sci. 27:65-83.
G-24

The Texas Gulf coast is characterized by a number of subtropical estuaries that have great economic and ecologic value in that they support important regional fisheries through production of new organic matter by phytoplankton photosynthesis. One of these estuaries, the Corpus Christi Bay ecosystem, was studied for a 3-yr period to define temporal and spatial variability in its primary production and to elucidate environmental factors important in regulating production. It was concluded from the study results that long-term maintenance of primary production in this estuary is accomplished through nutrient recycling while acute changes from both meteorologic and hydrologic forcing cause short-term increases in production that sustain steady-state and replenish lost materials to the system.

Flint, R. W. and R. D. Kalke. 1985. Benthos structure and function in a south Texas estuary. Contrib. Mar. Sci. 28:33-53.
G-24

The Corpus Christi Bay estuary in the northwestern Gulf of Mexico was investigated for spatial and temporal variation of benthos community structure and function. Four stations were sampled quarterly for 2.5 years to investigate for macroinfaunal species assemblage changes as well as changes in benthic metabolism and nutrient regeneration. Cluster analysis of species assemblages illustrated that community structure changed for the riverine-influenced end of the estuary to the oceanic-influenced end.

Flint, R. W. and R. D. Kalke. 1986. Biological enhancement of estuarine benthic community structure. Mar. Ecol. Prog. Ser. 31(1):23-33.
G-24

Benthos in south Texas estuaries are normally concentrated in the top 3 to 4 cm where the sediment is well-oxygenated and less compact. Where larger infauna such as enteropneusts, ophiuroids, or echiurans occur in the sediments bioturbation by these infauna oxygenates and redistributes normally uninhabited deeper sediments. A natural disturbance to Corpus Christi Bay benthos by these larger infauna could increase density and expansion of infaunal populations into deeper regions of the sediments, as well as enhance colonization by new infaunal species.

Flint, R. W. and D. Kamykowski. 1984. Benthic nutrient regeneration in south Texas coastal waters. Estuarine Coastal Shelf Sci. 18(2):221-230.
G-27

Because of the variable, unpredictable nature of many potential nutrient sources for coastal phytoplankton primary production needs in the northwestern Gulf of Mexico, benthic regeneration was investigated as a more constant source of nutrients to this ecosystem. Water column ammonia profiles taken at several locations on the south Texas inner-shelf in the past 7 years showed peak concentration in bottom waters. Benthic chamber measurements verified the presence of ammonia fluxes at the mud-water interface in south Texas coastal waters. These fluxes were related to benthic faunal activity as measured by sediment metabolism. Laboratory experiments, designed to test the effect of benthic faunal removal on nutrient regeneration, suggested that the fauna play a role in regulating this process. How this regulation may occur is discussed.

Flint, R. W., G. L. Powell and R. D. Kalke. 1986. Ecological effects from the balance between new and recycled nitrogen in Texas coastal waters. Estuaries 9(4A):284-294.
G-24

Benthic nutrient recycling is a significant source of dissolved nitrogen for south Texas coastal waters in the region of the Corpus Christi Bay estuary. Studies indicate that 90% of the dissolved nitrogen supply for phytoplankton production is derived from sediments in the upper-estuary, whereas benthic regeneration supplies only 33 % of the dissolved nitrogen required for primary production outside the barrier island in coastal waters (15 m depth). It is suggested that combined effects from new and recycled nutrient sources buffer south Texas coastal productivity against long periods of low nutrient input from fluvial flow. The comparison of biological responses at several trophic levels to temporal variability in nitrogen recycling and fluvial flow indicated the importance of freshwater nitrogen input in stimulating primary production. Freshwater nitrogen input also appeared to sustain long-term productivity by replacing nutrients lost from the system by extended reliance upon recycling.

Flint, R. W. and N. N. Rabalais. 1981a. Environmental Studies of a Marine Ecosystem. South Texas Outer Continental shelf. University of Texas Press, Austin, Texas, 240 p.
G-27

This study of the south Texas outer continental shelf was conducted on behalf of the Bureau of Land Management (now Minerals Management Service) of the U.S. Dept. of the Interior. The overall program included information on: 1) geology and geophysics by the U.S. Geological Survey, 2) fisheries resources and ichthyoplankton populations by the National Marine Fisheries Service, and 3) biological and chemical characteristics of selected topographic features in the northern Gulf of Mexico by Texas A&M university. The data resulting from this investigation represent the environmental background existing before major petroleum exploration and development commence in the area. The central goal of these and other environmental quality surveys of continental shelf areas is the characterization and protection of the living marine resources.

Flint, R. W. and N. N. Rabalais. 1981b. Gulf of Mexico shrimp production: A food web hypothesis. Fish. Bull. 79(4):737-748.
G-27

The desire to better understand the dynamics of commercial shrimp populations which support an important regional fishery on the south Texas outer continental shelf stimulated us to investigate an extensive data base for links in the various ecosystem components that related to these dynamics. A correlational model was developed that suggested relationships between pelagic and benthic components of the south Texas marine ecosystem. Utilizing tracers, such as nickel concentrations in biota, sediment, and water, we identified pathways of natural transfer between zooplankton, the benthos, and coastal shrimp populations. These results stimulated us to develop a theoretical food web for the shrimp populations, focusing on transfer of carbon. The results of this exercise indicated that the majority of the primary production (approximately 80 %) is diverted to the benthos. Furthermore, it appeared that the secondary production of benthic infauna was not sufficient to alone support the coastal shrimp populations. We concluded that at at least part of their nutrition was derived from the detritus pool which was maintained by the excessive amount of primary production diverted to the benthos.

Flint, R. W. and J. A. Younk. 1983. Estuarine benthos: Long-term community structure variations, Corpus Christi Bay, Texas. Estuaries 6(2):126-141.
G-24

A study of the benthic communities in Corpus Christi Bay was carried out between 1974 and 1979 to identify both natural and human-induced variations in community dynamics of the benthos over a long period of monthly sample collection. General results of the investigation were comparable to previous shorter-term studies of this estuary in respect to species list of dominant fauna, total densities and species diversity measures. The results of this long-term study illustrated the resilience of benthic communities to disturbance. They also provided supportive evidence to hypotheses concerning the high resistance of communities to disturbance in inconstant environments and the source of colonists in these environments after a major disturbance to the bottom.

Florida Board of Conservation. 1966. Observations of an Unusual Red Tide. A Symposium. Florida Board of Conservation, Professional Papers Series, No. 8. Florida Board of Conservation, Marine Laboratory, St. Petersburg, Florida, 84 p.
F-22, F-23, F-24, F-24.1

Results from studies initiated during a red tide in the general vicinity of Apalachee Bay from July 29 through August 15, 1964.

Florida Department of Natural Resources. 1975. Proceedings of the Florida Red Tide Conference, 10-12 October 1974, Sarasota, Florida. Florida Marine Research Publications, Number 8. Florida Dept. of Natural Resources, Marine Research Laboratory, St. Petersburg, Florida.
F-9 through F15.1

Florida Department of Environmental Regulation. 1989. Perdido Bay Interstate Study. A Report on Physical and Chemical Processes Affecting the Management of Perdido Bay. Provisional Results from March 1988 - February 1989. Florida Department of Environmental Regulation, Pensacola, Florida, 125 p. (not in hand)
F-28, G-1

Foote, K. 1982. Observations of oxygen depletion in Louisiana offshore waters. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of the Interior, Minerals Management

Service, Outer Continental Shelf Office, New Orleans, Louisiana.
G-7.1

Low dissolved oxygen concentrations were found yearly in Louisiana offshore waters from 1978 through 1982. Samples were taken from the coastline to 20 fathoms between Grand Terre Island and Timbalier Island. Concentrations of dissolved oxygen were found in July and September 1978; June, July, August and November 1979; June, July and August 1980; May through October 1981; and May through August 1982. Catches of demersal nekton, near-bottom zooplankton and benthos, were significantly lower during periods of low bottom dissolved oxygen. The relationships of seasonality and salinity stratification to bottom dissolved oxygen concentration were shown in an empirical model developed by stepwise multiple regression with log-log transformed water chemistry and temperature data. Bottom, dissolved oxygen concentration was inversely related to water temperature, conductivity, the difference between bottom and surface salinities, and concentrations of ammonium, orthophosphate, and silicates.

Fotheringham, N. and G. Weissberg. 1979. Some causes, consequences and potential impacts of oxygen depletion in the northern Gulf of Mexico. Proceedings, 11th Annual Offshore Tech. Conf. OTC 4(3611):2205-2208.
G-7.1

Biological and water quality changes in the Gulf of Mexico off the central Louisiana coast have been examined during a seasonal period of stratification and oxygen depletion in the water column. Probable cause, observed effects, and potential impacts on the timing of ocean discharges and dumping and onsite selection for offshore industries are described. Apparently an annual phenomenon of variable intensity resulting from a large discharge of low salinity, organic-laden water from the Mississippi and Atchafalaya Rivers at a time of minimal vertical mixing, the midsummer event may be intensified and prolonged by the intrusion of high salinity bottom water from a Loop Current eddy. The temporal and geographic distribution of this condition and its environmental consequences should be recognized by industries engaged in fishing, offshore petroleum production, and offshore dumping and by government agencies providing leases and permits for these activities.

Fox, L. E., F. Lipschultz, L. Kerkhof and S. C. Wofsy. 1987. A chemical survey of the Mississippi estuary. Estuaries 10(1):1-12.
G-7.1

A "snapshot" survey of the Mississippi estuary was made during a period of low river discharge, when the estuarine mixing zone was within the deltaic channels. Concentrations of H^+, Ca_2^+, inorganic phosphorus and inorganic carbon suggest that the waters of the river and the low salinity portion of the estuary are near saturation with respect to calcite and sedimentary calcium phosphate. The concentrations of dissolved NH_4^+ and O_2, over most of the estuary, appeared to be influenced by decomposition of terrestrial organic matter in bottom sediments.

Fox, L. E., S. L. Sager and S. C. Wofsy. 1985. Factors controlling the concentrations of soluble phosphorus in the Mississippi estuary. Limnol. Oceanogr. 30(4):826-832.
G-9

Sediments from the Mississippi River estuary were suspended in solutions with a range of salinities and various initial concentrations of phosphate. After 42 days, the suspensions had nearly uniform values for the ion activity product of calcium times biphosphate, $[Ca_2^+]$ $[HPO_4^{2-}]$ approx. 10^{-9} M^2. Similar values were observed for this ion product in the Mississippi River and in the upper estuary, suggesting that the concentration of soluble phosphorus may be controlled by an equilibrium with sedimentary material. Phosphorus levels in the lower estuary are controlled primarily by dilution with low-nutrient waters from the Gulf of Mexico.

Fraser, T. H. 1985. Long-Term Water-Quality Characteristics of Charlotte Harbor, Florida. U.S. Geological Survey Water-Resources Investigations Report No. 86-4180, U.S. Dept. of the Interior, Geological Survey, Tallahassee, Florida, 43 p.
F-13

Water-quality data for nine constituents collected from January 1976 through March 1984 in upper Charlotte Harbor were examined for evidence of trend (change) with time. Average seasonal patterns and moving averages were described to aid initial descriptions of variation. Evidence suggested an increasing trend for temperature and orthophosphate and decreasing trend for near-surface dissolved oxygen. The temperature trend was related to low winter temperatures early in the period. The orthophosphate trend was related to a major source, the Peace River. The source of the dissolved oxygen trend was not identified, but a relation with primary producers (phytoplankton) was likely.

Freeberg, L. R., A. Marshall and M. Heyl. 1979. Interrelationships of *Gymnodinium breve* (Florida red tide) within the phytoplankton community. Pages 139-144 in D. L. Taylor and H. H. Seliger (eds.), Toxic Dinoflagellate Blooms. Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, October 31 - November 5, 1978, Key Biscayne, Florida. Developments in Marine Biology - Vol. 1, Elsevier North Holland, New York.
F-15.1, F-24.1

Medium, preconditioned by prior growth of *G. breve*, has been bioassayed with 28 species of phytoplankters recently isolated in axenic cultures. Growth in 18 of the 28 species tested was significantly inhibited in the preconditioned medium. Sensitivity to the apparent growth inhibitor is species-specific and variable within those species affected. The population levels, as indicated by *in vivo* chlorophyll *a* for four diatom, one flagellate, and four dinoflagellate species, only slightly exceeded the inoculum levels, while the inocula of two dinoflagellate species lysed. Crude extracts of *G. breve* toxin(s) tested for growth inhibition with 12 algal species resulted in the total arrest of growth for four diatom and four dinoflagellate species. Partial purification of the toxin extract employing column chromatography techniques did not appear to separate properties of the algal inhibition from the ichthyotoxicity.

Frey, H. R., M. W. Szabados and L. E. Hickman. 1981. National Ocean Survey Strategic Petroleum Reserve Support Project: Final Report. Vol. I - Oceanography on the Louisiana Inner Continental Shelf. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Washington, D.C.
G-7.1

The Dept. of Energy proposes to store crude oil for the National Strategic Petroleum Reserve in subterranean storage caverns that are produced by solution-mining salt deposits. This NOS project is directed toward characterizing the physical oceanography of two proposed brine disposal sites along the coast of Louisiana. Planning for the project began in August 1977, and the mobilization for the field effort began in November 1977. Time series data being obtained with fixed recording instruments include current, speed and direction, water temperature and conductivity, water levels, waves, air speed and direction, barometric pressure and air temperature. Conductivity/temperature/depth, vertical profiles and water samples are obtained on a monthly basis. The water samples are analyzed for salinity and dissolved oxygen. Registered hydrographic surveys have been conducted at each site on a cooperative basis. A rigorous data quality assurance task is being carried out. Data quality acceptance and rejection levels have been established for each sensor, and a field check system has been installed on the NOAA Ship Ferrel to monitor instrument performance.

Friedemann, M. and J. Hand. 1989. Typical Water Quality Values for Florida's Lakes, Streams and Estuaries. Standards and Monitoring Section, Florida Bureau of Surface Water Management, Dept. of Environmental Regulation, Tallahassee, Florida, 23 p.
F-9 through F-28

Over the last 20 years, approximately five million water quality measurements have been taken in Florida waters. Information has been collected from all of Florida's major lakes, streams, and estuaries and the data have been placed in "STORET", EPA's water quality database. This document presents the range of typical values that have been sampled. Values are shown for the conventional water quality constituents, including water temperature, nutrients, bacteria, oxygen, oxygen demanding substances, water clarity, pH, and biological diversity indices.

Fryxell, G. A., M. E. Reap, D. L. Roelke, L. A. Cifuentes and D. L. Valencic. 1991. Confirmed presence of neurotoxin-producing diatom around Galveston, Texas. Pages 153-154 in F. S. Shipley and R. W. Kiesling (eds.), Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6, 220 p.
G-17

See Shipley and Kiesling (1991).

Fryxell, G. A. 1990. More on *Nitzschia pungens*. Phycological Newsletter 26(1):1.
G-17

In 1987, an outbreak of neurotoxic domoic acid, observed after an extended diatom bloom in an area of a mariculture shellfish project on Prince Edward Island, Canada, resulted in several human deaths and disabilities; this event is the first time that a diatom has been documented as the source of a neurotoxin. This same diatom, *Nitzschia pungens f. multiseries* Hasle, has just been found in the Galveston, Texas area of the Gulf of Mexico, and Jinhae Bay, Korea. It is difficult to distinguish from the common coastal diatom, *Nitzschia pungens* Grunow, and thus is little known and rarely recorded anywhere, although indications now are that it is widespread.

Fuller, D. A., R. E. Condrey, J. P. Geaghan and B. B. Barrett. 1990. An analysis of long-term salinity patterns in the Louisiana coastal zone. Northeast Gulf Sci. 11(1):11-17.
G-7.1

Saltwater intrusion is believed to be one of the greatest threats to Louisiana's fishery and wildlife resources. The Louisiana Department of Wildlife and Fisheries has maintained salinity recording stations throughout the State's coastal marshes since the 1960s. We applied several different analytical approaches to the salinity data from 17 stations to determine whether this database could be used to detect and quantify long-term salinity trends in coastal Louisiana. We did not detect a large-scale, consistent trend over time in coastal salinities across the State. For the data to be useful in monitoring salinity trends in coastal marshes, especially with respect to saltwater intrusion, stations should be added in fresh and intermediate marshes. In addition, the relationships our study revealed between short- and long-term data indicate that records covering less than a decade are insufficient to denote long-term salinity changes, barring some major modification of the hydrologic regime.

Gael, B. T. and C. S. Hopkinson, Jr. 1979. Drainage density, land-use and eutrophication in Barataria Basin, Louisiana. Pages 147-163 in J. W. Day, Jr., D. D. Culley, Jr., R. E. Turner and A. J. Mumphrey, Jr. (eds.), Environmental Conditions in the Louisiana Coastal Zone. Proceedings of the Third Coastal Marsh and Estuary Management Symposium, March 6-7, 1978, Baton Rouge, Louisiana. Division of Continuing Education, Louisiana State University, Baton Rouge, Louisiana.
G-10

A multiparametered index has been used to describe the trophic state of water bodies in the Barataria Basin Hydrologic Unit in Louisiana. Drainage density is significantly correlated with the trophic state index. High drainage densities serve to move water directly and rapidly from high nutrient loading areas such as urban and agricultural areas to lakes, effectively preventing overland flow through wetlands in the process. Highest

drainage densities were found along upland areas and had concomitantly highest trophic state indexes. Further increases in drainage density and upland development are projected to further exacerbate the eutrophication problem in coastal Louisiana.

Gallaway, B. J. 1982. Defining and obtaining management information related to oxygen depletion. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, Louisiana, 4 p.
G-7.1

Development of hypoxic conditions off the Louisiana coast, together with some major biological changes in the northwestern Gulf, suggest the need to quantitatively define the oxygen dynamics of the shelf for the purpose of assessing impacts and planning management strategies. This paper surveys the historical data associated with changes in the Mississippi River waters, summarizes reports of hypoxia and major biological changes in Gulf water, and suggests development of an assimilative capacity model for the Texas-Louisiana shelf ecosystem through a series of modeling workshops.

Gallaway, B. J. 1981. An Ecosystem Analysis of Oil and Gas Development on the Texas-Louisiana Continental Shelf. Biological Services Program Publ. FWS/OBS-81/27, U.S. Dept. of the Interior, Bureau of Land Management, Fish and Wildlife Service, Washington, D.C., 89 p.
G-7.1

Observed effects of oil and gas development activities and effluents are described. Data from most field studies indicate that direct effects are limited in space, but the effects over time are unknown. One of the major problems has been separating effects of oil and gas development-related activities and other man-induced variations from natural changes. Particular concern is expressed relative to increased organic loading of the system and the apparently related low dissolved oxygen levels characteristic of some parts of the system during warm seasons.

Garrison, C. R. 1982. Water-Quality of the Barataria Unit, Jean Lafitte National Historical Park, Louisiana (April 1981 - March 1982. Open-File Report No. 82-691, U.S. Dept. of the Interior, Geological Survey, Baton Rouge, Louisiana.
G-10

Surface-water samples were collected monthly for April 1981-March 1982 from six sites within the Barataria Unit of the Jean Lafitte National Historical Park, Louisiana. The sites were located on Bayou Segnette, Kenta Canal, and Millaudon Canal. Biological, chemical, and physical analyses were performed. Three of the sites were sampled quarterly for additional parameters including pesticides, metals, algal growth potential, phytoplankton, benthic macroinvertebrates, and grain size of bed material. The results of the analyses are presented without interpretation.

Gaston, G. R. 1985. Effects of hypoxia on macrobenthos of the inner shelf off Cameron, Louisiana. Estuarine Coastal Shelf Sci. 20(5):603-613.
G-7.1

The effects of hypoxic bottom water, an annual event, were documented on the inner shelf off Cameron, Louisiana during the summer of 1981. Populations of most species of macrobenthos were dramatically reduced. In an area of fine sediment that was numerically dominated by polychaetous annelids, the most severely affected populations were those of tube-dwelling and surface-feeding species. Burrowing species were less influenced by the hypoxia.

Gaston, G. R., Rutledge. Philip A. and M. L. Walther. 1985. The effects of hypoxia and brine on recolonization by macrobenthos off Cameron, Louisiana. Contrib. Mar. Sci. 28:79-93.
G-7.1

Screened defaunated sediment containers were placed on racks 100 m downcurrent and 10 km upcurrent of a Dept. of Energy brine diffuser located in the nearshore Gulf of Mexico 20 km southwest of Cameron, Louisiana. Samples were periodically collected from both racks over a period of 14 weeks to assess recolonization by the macrobenthos. A disparity in dissolved oxygen levels of the two sites led to a disruption of recolonization at one site, and a subsequent dissimilar temporal pattern there. This difference in recolonization of the two sites was apparent in analyses of numerically dominant species and feeding groups until the tenth week of the study. By the end of the study, however, differences between diffuser and control sites were limited to earliest colonizers (surface deposit feeders and suspension feeders) and carnivores, and did not occur in the subsurface deposit feeders that colonized after the severe hypoxia.

Gazey, W. J., B. J. Gallaway, R. C. Fechelm, L. R. Martin, L. A. Reitsema, K. F. Bennry, R. Schroeder and D. Chester. 1982. Shrimp mark release and port interview sampling survey of shrimp catch and effort with recovery of captured tagged shrimp. In W. B. Jackson (ed.), Shrimp Population Studies: West Hackberry and Big Hill Brine Disposal Sites off Southwest Louisiana and Upper Texas Coasts, 1980-1982. Vol. II. Final Report to DOE. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D.C., 306 p. (not in hand)
G-7.1, G-27

Geyer, R. A. 1955. Effect of the Gulf of Mexico and the Mississippi River on hydrography of Redfish Bay and Blind Bay. Publ. Inst. Mar. Sci. Univ. of Texas 4(1):154-168.
G-9

A hydrographic survey was conducted in Redfish and Blind Bays, on the southern edge of the Mississippi Delta, and in the adjoining areas in the Gulf of Mexico. Almost 1100 observations were made at 49 locations during an 8-wk period in the spring of 1953. Information was obtained on salinity, temperature, and current conditions. These data are summarized and evaluated with emphasis on the effect of the Mississippi River and the Gulf of Mexico on the hydrography of Redfish and Blind Bays. A correlation exists between the stage of the Mississippi River and the salinity and temperature characteristics of these bays and their adjoining Gulf areas. Similarly, the diluting effect during high stages of the Mississippi River is evident over an area extending several miles into the Gulf. It was noted that islands in Redfish Bay are wasting away.

Geyer, R. A. 1950. The occurrence of pronounced salinity variations in Louisiana coastal waters. J. Mar. Res. 9(2):100-110.
G-7.1

The chloride-ion contents of more than 700 sea water samples from the coastal waters of western Louisiana were converted to salinity values and were used in a study of the salinity characteristics. These data were gathered from seven drilling platforms during a period of 14 months in a zone paralleling the coast for about 60 miles, approximately 6 to 8 miles offshore and in depths varying between 40 and 50 ft. The chloride-ion content was determined by the standard chemical titration method in connection with quality control of salt water drilling mud used in the drilling of offshore oil wells. The analysis of the chloride-ion concentration data clearly demonstrates the existence of a wide salinity variation in any one area. The variations may be classified into long seasonal and shorter daily and even hourly types. A well defined correlation exists between the seasonal variations in salinity and the variations in the amount of water discharged by the Mississippi River. These data demonstrate that this is the major factor in determining the long-term salinity characteristics of this area. However, available information also indicates that salinity variations in a given area are affected as well by local drainage patterns and current characteristics.

Gillard, R. M. 1974. Distribution, Abundance, and Species Diversity of Macrobenthic and Meiobenthic Invertebrates in Relation to Houston Ship Channel Pollution in Upper Galveston Bay and Tabbs Bay, Texas. M.S. Thesis, Texas A&M University, College Station, Texas, 174 p.
G-17

Benthic collections were made with a modified Ekman dredge over a period of 18 months from August 1970 through January 1972 at 17 stations in Tabbs Bay and upper Galveston Bay, Texas. A total of 87 species, including 24 polychaete worms, 10 gastropod snails, 11 pelecypod clams, and 26 crustaceans, were collected. The total number of species, number of individuals, and the Shannon and Weaver species diversity index were used as benthic community parameters in relation to the environmental parameters of sediment composition, temperature, salinity, dissolved oxygen, seasonal, areal, and pollution effects.

Gilmore, G., J. Dailey, M. Garcia, N. Hannebaum and J. Means. 1976. A Study of the Effects of Fresh Water on the Plankton, Benthos, and Nekton Assemblages of the Lavaca Bay System, Texas. Tech. Rept. to the Texas Water Development Board, January, 1973 - June, 1975. Texas Parks and Wildlife Dept., Coastal Fisheries Branch, Austin, Texas, 113 p.
G-21

This study was typified by above normal freshwater inflow. The average inflow into the Lavaca Bay system during this 30-mo study was about 59 % above normal. A total of 156 phytoplankton taxa representing six divisions were identified. Phytoplankton taxa diversities generally declined with increased freshwater inflow. A total of 201 zooplankton taxa representing 14 phyla were identified. No significant correlations were found between zooplankton standing crops or taxa diversity and freshwater inflow. A total of 169 benthos taxa representing nine phyla were identified. Benthos taxa diversity was positively related to bottom salinity and negatively related to bottom turbidity and nutrients. A total of 70 nekton taxa representing three phyla were identified from trawl samples. Nekton populations appeared to be affected more by water temperature than by freshwater inflow.

Gosselink, J. G., R. R. Miller, M. Hood and L. M. Bahr, Jr. (eds.). 1975. Environmental Assessment of a Louisiana Offshore Oil Port and Appertinent Storage and Pipeline Facilities. Vol. II - Technical Appendices. Appendix V - The Offshore Ecology Study. Prepared for Louisiana Offshore Oil Port, Inc., New Orleans, Louisiana.
G-7.1

As part of the LOOP, Inc. environmental assessment, an offshore study was carried out to describe the marine chemistry and biology in the vicinity of the proposed single-point mooring terminal and offshore pipeline. The study was accomplished through both a literature search and a field study of 1-yr duration. Contents include the following sections: 1) Geological and Geographical Description of Louisiana Coast; 2) Hydrology; 3) Offshore Physical Oceanography; 4) Nearshore Oceanography; 5) Marine Biology; 6) Onshore Ecology Study; 7) Economic Impact of Superport in Lafourche and Terrebonne Parishes, Louisiana; 8) Archeology.

Graham, H. W., J. M. Amison and K. T. Marvin. 1954. Phosphorus Content of Waters along the West Coast of Florida. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 122. U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D. C., 43 p.
F-12, F-13, F-14, F-15.1

The high values of total phosphorus found in the bloom of *Gymnodinium breve* in 1947 have yet to be satisfactorily explained. Nowhere in the Gulf of Mexico or in Charlotte Harbor at any time during this investigation were phosphorus concentrations found corresponding to high values which occurred in the red tide of 1947 except in a bloom of *Trichodesmium*.

Griffin, G. M. and B. J. Ripy. 1974a. Horizontal and vertical distribution of turbidity on the Louisiana shelf south of Timbalier Bay--August 1972-July 1973. In Offshore Ecology Investigation, 1974. #3453, C.I.R. files, Gulf Universities Research Consortium (GURC), Galveston, Texas.
G-7.1

The study was designed to determine whether or not the intensive petroleum exploration activities on the continental shelf off Timbalier Bay have significantly affected the turbidity of surrounding waters. The report concluded no increase in surface turbidity over the ambient background level of the region could be detected around any of the production platforms examined.

Griffin, G. M. and B. J. Ripy. 1974b. Turbidity, suspended sediment concentrations, clay mineralogy of suspended sediments, and the origin of the turbid near-bottom water layer--Louisiana shelf south of Timbalier Bay--August 1972-January 1974--with comments on a process model for turbid layer transport. Pages 75-79 in Abstracts, Summaries and Conclusions from the Offshore Ecology Investigation, 1972-74. Gulf Universities Research Consortium (GURC), Galveston, Texas.
G-7.1

See Griffin and Ripy (1974a).

Groover, R. D. and T. S. Sharik. 1974. A Report on the Ecology of the Lower Colorado River - Matagorda Bay Area of Texas: June 1973 through July 1974. Docket No. STN 50-498, STN 50-499, U.S. Atomic Energy Commission, Washington, D.C. (not in hand)
G-20, G-21

Gulf Universities Research Consortium. 1979. The Alabama Coastal Zone Ecology and Water Quality Data Information Sources Existing Benthic Data Evaluation. Final Report to the Marine Environmental Sciences Consortium, Dauphin Island, Alabama, Agreement MESC-9-90060. GURC Report No. 170, Gulf Universities Research Consortium, Galveston, Texas, 21 p. (not in hand)
G-2

Gunning, G. E. and R. D. Suttkus. 1986. A comparative study of pH levels in the Sabine, Red, Mississippi, Pearl, Alabama and Perdido Rivers of the southern United States. The La. Environmental Professional 3(1):4-20.
F-28 and G-1, G-6, G-9

Six rivers of the southern United States exhibited the following pH ranges: 6.1-7.7, Sabine; 6.8-8.6, Red; 6.7-8.7, Mississippi; 5.6-7.7, Pearl; 6.3-9.0, Alabama; and 4.8-8.5, Perdido. Of the six rivers, the Sabine showed the least variation, the Red and Mississippi showed similar pH ranges, the Pearl was properly characterized as an acid stream, and the Alabama and Perdido showed the greatest range of variation in pH, the former due to influence of a dam upstream, and the latter due to effects of Perdido Bay. Levels of pH were generally within the 5.0-9.0 range recommended by biologists for fully developed freshwater fisheries.

Gunter, G. 1979. Notes on sea beach ecology. Food sources on sandy beaches and localized diatom blooms bordering Gulf beaches. Gulf Res. Rep. 6(3):305-307.
G-27

Of relevance is the description of a type of plankton bloom that occurs along the Texas coast composed of the diatom *Chaetoceros* sp. Blooms of 16 miles extend from the water's edge along Mustang Island for 15 or 20 yards. The parallel coincidence of blooms following rains and calm weather is suggested.

Gunter, G. 1942. Offatts Bayou, a locality with recurrent summer mortality of marine organisms. Am. Midl. Nat. 28(3):631-633.
G-17

Discussion of mortalities of marine organisms in Offatts Bayou which opens to West Galveston Bay. Events occur primarily in the summer and are related to decomposition of organic materials of anthropogenic origin.

Gunter, G. and G. E. Hall. 1965. A biological investigation of the Caloosahatchee estuary of Florida. Gulf Res. Rep. 2(1):1-72.
F-12

The scope and purpose of this work was to: a) review the history of the Caloosahatchee River and analyze the problems concerned with discharges into the estuary; 2) present biological data from investigations of the estuary made at different times during the years 1957 to 1960, inclusive; 3) determine the biological effects of operation of Moore Haven and Ortona Locks, and the planned lock and dam at Olga with reference to important indicator species within the lower river and estuary; and 4) determine operation procedures, practicable within specific operational requirements of the project, which would be either beneficial or of least damage to estuarine fishes and fishing.

Gunter, G. and C. H. Lyles. 1979. Localized plankton blooms and jubilees on the Gulf coast. Gulf Res. Rep. 6(3):297-299.
G-27

The writers describe various small types of plankton blooms such as those occurring in boat slips, the head of a large bayou and a strip-type bloom of Chaetoceros on the Gulf beach. Oyster kills from "poison water" draining off of marshes are said to be caused by plankton bloom. Small "jubilees" are said to be caused by localized blooms, and one of these is described as it occurred.

Hackney, C. T. 1978. Summary of Information: Relationship of Freshwater Inflow to Estuarine Productivity along the Texas Coast. Publ. FWS/OBS-78/73, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C. (not in hand)
G-16 through G-26.3

Haddad, K. D. and K. L. Carder. 1979. Oceanic intrusion: One possible initiation mechanism of red tide blooms on the west coast of Florida. Pages 269-274 in D. L. Taylor and H. H. Seliger (eds.), Toxic Dinoflagellate Blooms. Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, October 31 - November 5, 1978, Key Biscayne, Florida. Developments in Marine Biology - Vol. 1, Elsevier North Holland, New York.
F-24.1

Upwelling and intrusion of Loop Current water onto the west Florida shelf is suggested as a mechanism that resuspends *Gymnodinium breve* resting cysts and provides conditions for excystment and growth.

Hahl, D. C. and K. W. Ratzlaff. 1970. Chemical and Physical Characteristics of Water in Estuaries of Texas, September 1967 - September 1968. Prepared by the U.S. Geological Survey. Rept. No. 117, Texas Water Development Board, Austin, Texas, 91 p.
G-16, G-20, G-21, G-22, G-23, G-24

In September 1967, the USGS and the TWDB began a water-resources investigation of the principal estuaries along the Texas coast except Galveston Bay and the Rio Grande. The objectives of the investigation are to determine: 1) the occurrence, source, and distribution of nutrients; 2) current patterns, directions, and rates of movement; 3) physical, organic, and inorganic water quality and its variations; 4) the occurrence, quantity and dispersion of land drainage entering the estuarine systems; and 5) the chemical and physical characteristics of Gulf water that enters the estuaries.

Hahl, D. C. and K. W. Ratzlaff. 1972. Chemical and Physical Characteristics of Water in Estuaries of Texas, October 1968 - September 1969. Prepared by the U.S. Geological Survey. Rept. No. 144, Texas Water Development Board, Austin, Texas, 161 p.
G-16, G-18, G-19, G-20, G-21, G-22, G-23, G-24, G-26

See Hahl and Ratzlaff (1970).

Hahl, D. C. and K. W. Ratzlaff. 1975. Chemical and Physical Characteristics of Water in Estuaries of Texas, October 1970 - September 1971. Prepared by the U.S. Geological Survey. Rept. No. 191, Texas Water Development Board, Austin, Texas, 153 p.
G-16, G-18, G-19, G-20, G-21, G-22, G-23, G-24, G-26

See Hahl and Ratzlaff (1970). This report represents data collected during the 1971 water year and is the fourth in an annual series.

Hand, J. and J. Jackman. 1984. Water Quality Inventory for the State of Florida. Florida Department of Environmental Regulation, Bureau of Water Analysis, Tallahassee, Florida, 235 p. (not in hand)

Hand, J., V. Tauxe and M. Friedemann. 1988a. Apalachicola Bay Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 102, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-24

To assess Florida stream water quality, a Florida stream Water Quality Index (WQI) was developed. It is based on the quality of water as measured by six water quality categories (water clarity, dissolved oxygen, oxygen demanding substances, bacteria, nutrients and biological diversity). Each category may have more than one parameter. Raw (annual average) data are converted into index values that range from 0 to 90 for the six categories. Index values correspond to the percentile distribution of stream water quality data in Florida. The overall WQI is the arithmetic average of the six water quality index categories. The index for each category is determined by averaging its component parameter index values. Missing water quality parameters and missing water quality categories are ignored in the final calculation. Therefore, the final WQI is based on an average of anywhere from 1 to 6 water quality index categories.

Hand, J., V. Tauxe and M. Friedemann. 1988b. Caloosahatchee River Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 106, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-12

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988c. Charlotte Harbor Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 107, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-13

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988d. Choctawhatchee Bay Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 110, Bureau of Surface Water Management, Div. of Water

Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-26

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988e. Crystal River to St. Petersburg Beach Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 112, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-16

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988f. Everglades West Coast Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 116, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-10.1

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988g. Pensacola Bay Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 131, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-27

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988h. Perdido Bay Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 132, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-28

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988i. Sarasota Bay Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 135, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-14

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988j. St. Andrews Bay Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 137, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-25

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988k. St. Marks River Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 140, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-22

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988l. Steinhatchee River Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 142, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-20

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988m. Tampa Bay Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 145, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-15

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988n. Waccasassa River Basin Technical Report. An Appendix of the 305(b) Water Quality Assessment for the State of Florida. Standards and Monitoring Technical Rept. No. 147, Bureau of Surface Water Management, Div. of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida.
F-18

See Hand *et al.* (1988a).

Hand, J., V. Tauxe and M. Friedemann. 1988o. Water Quality Assessment for the State of Florida. Submitted in Accordance with the Federal Clean Water Act, Section 305(b). Standards and Monitoring Section, Bureau of Surface Water Management, Division of Water Management, Dept. of Environmental Regulation, Tallahassee, Florida, 105 p.
F-9 through F-15, F-16 through F-24, F-25 through F-28

See Hand *et al.* (1988a).

Hann, Jr., R. W., C. P. Giommona and R. E. Randall (eds.). 1984a. Offshore Oceanographic and Environmental Monitoring Services for the Strategic Petroleum Reserve Program. Vol. I, II and III. Annual Report for the Bryan Mound Site, September 1982 - August 1983. Dept. of Energy Contract No. DE-AC96-83P010850, Texas A&M University, Texas A&M Foundation, College Station, Texas.
G-27

The DOE's Strategic Petroleum Reserve Program began leaching the Bryan Mound salt dome and discharging brine into the coastal waters offshore of Freeport, Texas on March 10, 1980. This report describes the findings of a team of Texas A&M University scientists and engineers who have conducted a study to evaluate the effects of the Bryan Mound brine discharge on the marine environment. The study addresses the areas of physical oceanography, analysis of the discharge plume, water and sediment quality, nekton, benthos and data management. It focuses on the period from September 1982 through August 1983. Vol. II consists of supporting data in the form of figures and tables, and Vol. III is the Executive Summary.

Hann, Jr., R. W. C. P. Giommona and R. E. Randall (eds.). 1984b. Offshore Oceanographic and Environmental Monitoring Services for the Strategic Petroleum Reserve Program. Vol. I, II and III. 18-Month report for the West Hackberry Site from May 1982 through November 1983. Dept. of Energy Contract No. DE-AC96-83P010850, Texas A&M University, Texas A&M Foundation, College Station, Texas.
G-7.1

The purpose of this report is to describe the findings of the project team during the 18 months of postdisposal study conducted from May 1, 1982 through November 14, 1983. The areas of investigation are benthos, brine plume, data management, nekton, physical oceanography, phytoplankton, water and sediment quality and zooplankton. Vol. II consists of supporting data in the form of figures and tables, and Vol. III is the Executive Summary.

Hann, Jr., R. W. and R. E. Randall (eds.). 1980. Evaluation of Brine Disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program. Vol. I and II. Final Report of Predisposal Studies. Dept. of Energy Contract No. DE-FC96-79P010114, Texas A&M University, Texas A&M Foundation, College Station, Texas.
G-27

The purpose of this report is to describe the environmental conditions found by the principal investigators during the predisposal study conducted from September 1977 through February 1980 prior to the start of brine discharge in March 1980. The major areas of investigation are physical oceanography, analysis of the discharge plume, water and sediment quality, nekton, benthos, phytoplankton, zooplankton, and data management. Vol. II consists of appendices which contain additional supporting data in the form of figures and tables.

Hann, Jr., R. W. and R. E. Randall (eds.). 1981. Evaluation of Brine Disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program. Vol. I and II. Final Report of Twelve-Month Postdisposal Studies. Dept. of Energy Contract No. DE-FC96-79P010114, Texas A&M University, Texas A&M Foundation, College Station, Texas.
G-27

From March 1980 through February 1981, a team of scientists and engineers at Texas A&M University conducted a 12-mo environmental study to evaluate the effects of discharging brine into the coastal waters off Freeport, Texas. The brine discharge is the result of leaching large storage caverns in an underground salt dome that is being used for the storage of petroleum products. The study addresses the area of physical oceanography, analysis of the discharge plume, water and sediment quality, nekton, benthos, phytoplankton, zooplankton, and data management. Vol. II consists of supporting data in the form of figures and tables.

Hann, Jr., R. W. and R. E. Randall (eds.). 1982. Evaluation of Brine Disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program. Vol. I and II. Final Report of Eighteen-Month Postdisposal Studies. Dept. of Energy Contract No. DE-FC96-79P010114, Texas A&M University, Texas A&M Foundation, College Station, Texas. (not in hand)
G-27

Hann, Jr., R. W. and R. E. Randall (eds.). 1983. Evaluation of Brine Disposal from the Bryan Mound Site of the Strategic Petroleum Reserve Program for September 1981 - August 1982. Vol. I, II and III. Dept. of Energy Contract No. DE-FC96-79P010114, Texas A&M University, Texas A&M Foundation, College Station, Texas.
G-27

See Hann *et al.* (1984).

Harper, Jr., D. E. and G. Guillen. 1989. Occurrence of dinoflagellate bloom associated with an influx of low salinity water at Galveston, Texas, and coincident mortalities of demersal fish and benthic invertebrates. Contrib. Mar. Sci. 31:147-161.
G-17, G-27

Low salinity water and an associated dinoflagellate bloom appeared suddenly off Galveston, Texas, in early June 1984. An aerial survey showed the bloom extended east at least as far as Cameron, Louisiana. High discharge from the Mississippi-Atchafalaya Rivers between March and late May, and a strong, wind-driven downcoast current preceded the appearance of low salinity water and its associated bloom. Within a week of the first appearance of the bloom, demersal fish, numerically dominated by Atlantic threadfin began dying early in the morning and washing ashore. It is believed the kill was caused by hypoxia and/or hydrogen sulfide production resulting from nocturnal metabolism of the bloom and anaerobic decay of dead dinoflagellate cells.

Harper, Jr., D. E. and L. D. McKinney. 1982a. Causes and effects of oxygen depletion on the benthic biota of the upper Texas coast. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, Louisiana.
G-27

Hypoxia occurring in June 1979 at two sites off Freeport, Texas caused extensive mortalities of soft-bottom and hard-bottom organisms. Events of this kind, which appear to occur nearly annually off the Louisiana coast, indicate a need for monitoring leading to predictive modeling. After data have been collected for several years, it should be possible to define the variable causing hypoxia. From this information, a model could be constructed. Thereafter, routine monitoring of important variables would provide data to be plugged into the model, which would estimate both the probability of occurrence and areal extent of hypoxia.

Harper, Jr., D. E. and L. D. McKinney. 1982b. Effect of brine disposal on benthic communities off Freeport, Texas. Abstr. for Oceans '82 Conference Record: Industry, Government, Education - Partners in Progress, September 20-22, 1982. Washington, D.C.
G-27

Brine (250 ppt) derived from solution mining the Bryan Mound salt dome located near Freeport, Texas, was discharged into the Gulf of Mexico through a series of vertical pipes collectively called the "diffuser." Disposal of brine had no apparent effect on either bottom-water temperature of dissolved oxygen. However, salinity of the bottom water and pore water in the vicinity of the diffuser was increased above ambient levels as much as 3 ppt. The brine did not appear to effect a change in numbers of species collected near the diffuser, nor did the amphipod populations (which are relatively sensitive to pollution) appear to be affected. However, abundances of organisms may have been altered.

Harper, Jr., D. E., L. D. McKinney, R. R. Salzer and R. J. Case. 1981. The occurrence of hypoxic bottom water off the upper Texas coast and its effects on the benthic biota. Contrib. Mar. Sci. 24:53-79.
G-27

Hypoxic bottom water occurred off the upper Texas coast in May-July 1979 after heavy spring runoff and a diatom bloom. Benthic assemblages at two study sites off Freeport, Texas decreased from spring densities of 3000-4000 individuals per m^2 to 300-600 individuals per m^2 by late July. Species diversity also decreased and perturbations occurred in the Shannon-Weiner diversity indices. Of the dominant taxa, polychaetes were least affected by hypoxia and amphipods and echinoderms the most affected. Storm-caused waves in late July initiated the breakup of hypoxic conditions; these conditions had completely abated by late September. A short-lived irruption occurred immediately afterward as depopulated bottoms were reinvaded. Diversity and abundances appeared to be returning to more normal conditions by early 1980.

Harper, Jr., D. E., L. D. McKinney, J. M. Nance and R. R. Salzer. 1991. Recovery responses of two benthic assemblages following an acute hypoxic event on the Texas continental shelf, northwestern Gulf of Mexico. Pages 49-64 in R. V. Tyson and T. H. Pearson (eds.), Modern and Ancient Continental Shelf Anoxia. Geological Society Special Publication No. 58, The Geological Society, London, 470 p.
G-27

A hypoxic/anoxic event occurred in the northwestern Gulf of Mexico between May and July 1979. This event, associated with warm water temperatures, water column stratification and the decay of a phytoplankton bloom, led to the production of hydrogen sulfide that moved above the sediment-water interface and into the lower 2 m of the water column. Regular monthly sampling at two sites off Freeport, Texas showed that abundances of benthic organisms declined precipitously during the event. The assemblage in deeper water apparently stabilized within 1 yr. The shallower water assemblage, however, underwent a very different recovery process. Each of the species underwent a "bloom" and constituted the numerical dominant for 1 to 3 mos, and then declined and was replaced by another species "bloom." This sequential dominance pattern persisted until about May 1981, 2 yrs after the hypoxic event, at which time polychaetes again became numerically dominant.

Harris, A. H., J. G. Ragan and R. Kilgen. 1976. Oxygen Depletion in Coastal Waters. Final Report. Project No. R/BOD-1., Office of Sea Grant, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C., 45 p.
G-7.1

Baseline studies were conducted on the southeastern Louisiana continental shelf as part of the environmental data requirements for the proposed superport. Hypoxic waters were found throughout several hundred square miles of normally highly productive shrimping grounds in the Gulf of Mexico where there were significantly less fish, crabs, shrimp, and other motile benthic organisms within this area. Hypoxia was found from May 1973 through September 1975 in varying degrees of magnitude, except following hurricanes that affected the area. Results from nekton, zooplankton and benthic macroinfauna samples are given.

Hausknecht, K. A. 1980. Vol. V - Describe Surficial Sediments and Suspended Particulate Matter. In W. B. Jackson and G. M. Faw (eds.), Biological/Chemical Survey of Texoma and Capline Sector Salt Dome Brine Disposal Sites off Louisiana, 1978-1979. NOAA Tech. Memo NMFS-SEFC-29, NOAA/NMFS Final Report to DOE. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Galveston, Texas, 56 p.
G-7.1

This report summarizes measurements of surficial and suspended sediment characteristics which were made during four cruises to the West Hackberry and Weeks Island brine disposal sites in June and October 1978 and January and May 1979. The sites showed significant differences in sedimentology, with the West Hackberry site being composed predominantly of fine-grained silt and clay (<40 % sand) with characteristically high levels of total organic carbon averaging 12-15 mg/g. Conversely, sediments at Weeks Island were primarily silty sand (> 70 % sand) with low levels of organic carbon (5-8 mg/g). Total organic carbon showed a significant inverse correlation with grain size (total organic carbon increased with decreasing grain size).

Heck, K. L. 1987. The Common Rangia (*Rangia cuneata*) in Perdido Bay: An Investigation of Mass Mortality in October 1986. Report to Alabama Dept. of Economic and Community Affairs, Contract No. ADECA-MESC-CZM-87-5. Marine Environmental Sciences Consortium, Dauphin Island, Alabama.
G-1, F-28

The data presented here were gathered to shed light on the circumstances involved in a large mortality of *Rangia* observed in the nearshore zone of upper Perdido Bay in early October 1986. At this time large numbers of adult rangia, but few if any juveniles, were observed to be experiencing mortality by residents of

communities along the Perdido Bay shoreline. The aims of the study were to: 1) determine the sizes, and age and growth rates of clams involved in the October mortality; 2) use this information to assess whether affected clams grew normally throughout their life, thereby indicating a single catastrophic event as a cause of mortality, or whether clams had a record of depressed growth up to the time of their death, suggesting a lifetime of poor conditions for growth in Upper Perdido Bay; and 3) suggest the most plausible hypotheses to explain the observed mortality.

Heffernan, T. L. 1970. An ecological evaluation of some tributaries of the Aransas Bay area. Project No. CE-1-1. Pages 23-125 in Coastal Fisheries Project Reports 1969-1970. Texas Parks and Wildlife Dept., Austin, Texas.
G-23

Environmental conditions were surveyed in the Copano and St. Charles Bay tributary areas in 1969 and 1970. The white shrimp (*Penaeus setiferus*) and blue crab (*Callinectes sapidus*) habitat in the vicinity of Chiltipin Creek and Mission River was found to be adversely affected by oilfield brine. Production of commercial crustaceans in the Aransas River was found to be severely retarded by abnormal salinity and water quality conditions attributed to oilfield brine from Chiltipin Creek. Tributaries of St. Charles Bay had water of very high quality and were normally very productive. The entire St. Charles Bay system appeared to be prime habitat for adult and juvenile food and game species. Heavy rainfall alleviated poor conditions in Chiltipin Creek, the Aransas River and the Mission River, but this relief was short-lived.

Heffernan, T. L. 1972. The effect of oilfield brine on the Mission River, Aransas Bay area. Pages 37-76 in Coastal Fisheries Project Reports 1972. Texas Parks and Wildlife Dept., Austin, Texas.
G-23

A daily discharge of 1.5 mil gallons of oilfield brine (containing approximately 36 gal of crude oil) into the Mission River has retarded utilization of the stream by marine organisms and has eliminated the freshwater fishery in the river below the city of Refugio. Hydrological samples collected from December 1971 to November 1972 indicated conditions were within the tolerance limits of the marine organisms inhabiting tertiary environments in the local area and the loss of Mission River as a nursery system was attributed primarily to oil pollution.

Heffernan, T. L. 1971. Port Bay - An evaluation of the marine habitat. Project No. CE-1-2. Pages 63-80 in Coastal Fisheries Project Reports 1971. Texas Parks and Wildlife Dept., Austin, Texas.
G-23

Trawl samples taken at weekly intervals from December 1970 through July 1971 in Port Bay, a tertiary bay of the Aransas Bay system, produced 38 species of fin fish and nine species of Crustacea. A 9-mo period of below normal rainfall from November 1970 through July 1971 influenced white shrimp, Penaeus setiferus, and blue crab, Callinectes sapidus, populations by raising salinities above optimum ranges during juvenile migration periods. In September 1971, rainfall associated with tropical storm "Fern" dropped salinities from above 30.0 to 0.0 ppt. Eight hundred ninety six hydrographic samples collected during the survey were correlated with population densities to establish the salinity influence on individual species. The parameters determined for each sample were salinity, temperature, turbidity, pH, dissolved oxygen, calcium, total hardness and magnesium.

Hegen, H. E. 1983. Monitoring of Coastal Finfish Resources for Sport Fish Management, October 1981 - September 1982. Management Data Series No. 49, Texas Parks and Wildlife Dept., Coastal Fisheries Branch, Austin, Texas, 157 p.
G-17, G-19, G-21, G-22, G-23, G-24, G-26.1, G-26.2

Trends in relative abundance and size of six economically important saltwater fishes (red drum, spotted seatrout, black drum, sheepshead, southern flounder and Atlantic croaker) were monitored with gill nets and bag seines in eight Texas bay systems. Catch-rates and mean total lengths of each type are discussed.

Henley, D. E. and D. G. Rauschuber. 1981. Freshwater Needs of Fish and Wildlife Resources in the Nueces-Corpus Christi Bay Area, Texas: A Literature Synthesis. Biological Services Program Publ. FWS/OBS-80/10, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C., 410 p.
G-23

The highly variable environment of the Nueces-Corpus Christi Bay system is subject to many extremes, including the effects of freshwater runoff from rural and urban areas; creeks and rivers; rainfall directly on the Bay surface; and effluent return flows from various industrial, domestic, and agricultural users. Saline Gulf water flows into the Bay primarily by way of the Corpus Christi Ship Channel at Port Aransas. Variability of freshwater inflows results from numerous factors, such as hurricanes, droughts, channelization, and dredge and fill activities. The objectives of this study were to relate the proposed construction of Choke Canyon Reservoir and Harbor Island Deep-Water Port on resultant hydrologic effects that these structural features may have on the biological productivity of the estuarine system.

Hern, S. C., W. D. Taylor, L. R. Williams, V. W. Lambou, M. K. Morris, F. A. Morris and J. W. Hilgert. 1978. Distribution and Importance of Phytoplankton in the Atchafalaya Basin. Publ. No. 277544, U.S. Environmental Protection Agency, Environ. Monitor. Support Lab, Las Vegas, Nevada. (not in hand)
G-12

Hewatt, W. G. 1950. Studies on Dissolved Oxygen Content and Hydrogen Ion Concentration in the Waters of Barataria Bay, Louisiana, 1945-1947. Project 9. Texas A&M University, Texas A&M Research Foundation, College Station, Texas, 11 p.
G-10

Barataria Bay is a relatively shallow embayment on the Gulf coast of Louisiana, west of the mouth of the Mississippi River. The surface of the Bay and its contiguous waters which are considered in this report is about 400 square miles. The Bay is the center of a large shrimp and oyster fishing industry. Thirty-eight sampling stations were selected in the Bay and the adjoining bodies of water. Only the dissolved oxygen and the hydrogen ion concentration data are considered in the report.

Higgins, G. G. and C. K. Eleuterius. 1978. Mississippi Sound: Volume, surface area and bathymetric statistics. J. Miss. Acad. Sci. 23:39-45.
G-2.3

Area measurements were made of the bathymetry of Mississippi Sound contoured at 1-ft depth intervals using a Leitz (TM) planimeter. Assuming a level surface, the measurement of surface area at mean low water for the Sound was 22,915,708,304 ft^2 (2,128,869,301 m^2). Excluding the Intracoastal Waterway, the Biloxi approach channels and that portion of the Gulfport and Pascagoula ship channels below the contiguous natural Sound bottoms, a volume of 223,333,594,368 ft^3 (63,248,073,920 m^3) was obtained at mean low water, with an average depth of 9.76 ft (2.97 m). Considering the Gulfport and Pascagoula ship channels, the volume is 224,079,602,627 ft^3 (63,459,343,424 m^3), with an average depth of 9.77 ft (2.98 m) at mean low water. The distribution of depths is skewed positively but 99 % of the total area has a depth of 20 ft (6.10 m) or less.

Ho, C. L. and B. B. Barrett. 1975. Distribution of Nutrients in Louisiana's Coastal Waters Influenced by the Mississippi River. Tech. Bull. No. 17, Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana, 39 p.
G-10

The volume of freshwater introduced into Louisiana's coastal zone during 1973, both by rainfall and river discharge, was the highest recorded since 1940. Selected nutrients (ammonium-N, [nitrate + nitrite]-N, phosphate-P, and dissolved silicate), organic-N, and salinity were measured in Louisiana coastal waters from the mouth of the Mississippi River to Caminada Bay during four sampling trips in 1973. Three of these sampling trips coincided with high river discharge, and the last sampling effort occurred during low river discharge. Resultant data showed the tremendous influence of the Mississippi River on nutrient concentrations in the coastal waters adjacent to the river mouth. Nutrient contribution by the Mississippi River undoubtedly accounts for the high production of fisheries in this region of the Gulf.

Ho, C. L. and B. B. Barrett. 1977. Distribution of nutrients in Louisiana coastal waters influenced by the Mississippi River. Estuarine Coastal Mar. Sci. 5:173-195.
G-10

The volume of freshwater introduced into Louisiana's coastal zone during 1973, by rainfall and river discharge, was the highest in the past 35 years. Water samples were taken from inshore estuarine areas as well as in the open Gulf of Mexico during 1973. Three of these sampling trips coincided with high river discharge and the last trip was made during low river discharge. Analysis of the water samples showed that the nutrient content of the water within the zone of the Mississippi River influence is directly related to the volume of water discharged to the Gulf by the river. The high fishery productivity of the water adjacent to the river mouth is a result of nutrient contribution by the Mississippi River. However, marshes play a key role in providing organic matter and nutrients to the estuaries which serve as nursery grounds for many marine species.

Holland, J. S., N. J. Maciolek, R. D. Kalke and C. H. Oppenheimer. 1973. A Benthos and Plankton Study of the Corpus Christi, Copano and Aransas Bay Systems. I. Report on the Methods Used and Data Collected During the Period September, 1972 - June, 1973. First Annual Report to the Texas Water Development Board. University of Texas Marine Science Institute, Port Aransas, Texas.
G-23, G-24

Certain physical and chemical parameters of the water column were investigated in this study. Physical parameters included air temperature, total depth, water temperature and conductivity. Chemical parameters investigated included dissolved oxygen, organic nitrogen, nitrate, nitrite, ammonia, total phosphate, orthophosphate, inorganic carbon and organic carbon. It is quite apparent that these are two very hydrographically dissimilar estuarine systems. The Copano-Aransas system had, over the period reported, a classic positive estuary salinity regime. In Corpus Christi Bay the salinity regimes were very confused.

Holland, J. S., N. J. Maciolek, R. D. Kalke and C. H. Oppenheimer. 1974. A Benthos and Plankton Study of the Corpus Christi, Copano and Aransas Bay Systems. II. Report on Data Collected During the Period July, 1973 - April, 1974. Second Annual Report to the Texas Water Development Board. University of Texas Marine Science Institute, Port Aransas, Texas.
G-23, G-24

See Holland *et al.* (1973). Added to the 1973 study were the hydrographic parameter measurement of turbidity and pH. Dissolved oxygen values followed essentially the same pattern during this study as was initially observed.

Holland, J. S., N. J. Maciolek, R. D. Kalke, L. Mullins and C. H. Oppenheimer. 1975. A Benthos and Plankton Study of the Corpus Christi, Copano and Aransas Bay Systems. III. Report on Data Collected During the Period July 1974 - May 1975. Final Report to the Texas Water Development Board. University of Texas Marine Science Institute, Port Aransas, Texas.
G-23, G-24

Study an extension of that presented in Holland *et al.* (1974). Low dissolved oxygen concentrations were found in bottom waters of the Reynolds Metals Co. turning basin near the La Quinta Channel. Otherwise, oxygen concentrations were high enough at most sites to not be a limiting factor.

Holland, J. S., N. J. Maciolek and C. H. Oppenheimer. 1973. Galveston Bay benthic community structure as an indicator of water quality. Contrib. Mar. Sci. 17:169-188.
G-17

The objective of this study was to ascertain water quality through investigation of benthic community structure. Various methods of community structure analysis including several species diversity indices, rarefaction curves and a probability of interspecific encounter index were applied to data collected from selected sites in Galveston Bay, Texas. Hydrographic data and sediment analysis were used in interpreting the results of the various methods of investigating community structure. The different methods of analysis used in this study showed very close agreement. It is suggested that three of the five investigation sites in Galveston Bay showed normal estuarine water quality. Two other stations showed evidence of large amounts of stress probably due to water quality. One of the two was probably stressed due to natural causes, primarily salinity fluctuations. The other, a channel site near a huge industrial complex, showed intermittent stress possibly due to manmade pollution.

Hopkinson, Jr., C. S. and J. W. Day, Jr. 1979. Aquatic productivity and water quality at the upland-estuary interface in Barataria Basin, Louisiana. Pages 291-314 in R. J. Livingston (ed.), Ecological Processes in Coastal and Marine Systems. Proceedings of a Conference, April 13-15, 1978, Florida State University, Tallahassee, Florida. Marine Science, Vol. 10, Plenum Press, New York.
G-10

Three fresh- to brackish-water coastal lakes and streams at the upland-estuary interface of Barataria Basin were studied for a 1-yr period. Measurements of community production and metabolism, chlorophyll *a*, and water column nitrogen and phosphorus were used to assess the functional relationship the upland connection has with the estuary. Spatial distribution of selected water chemistry parameters indicates that artificial drainage and navigation canals in the estuarine and upland area have changed the hydrologic regime. Nutrient loading rates and high production values indicate that the area immediately adjacent to the upland is currently hypereutrophic. Its potential to absorb increasing nutrient loads is in doubt.

Hopkinson, Jr., C. S. and J. W. Day, Jr. 1980. Modeling the relationship between development and storm water and nutrient runoff. Environ. Manage. 4(4):315-324.
G-10

The EPA Storm Water Management Model was used to model the effects of urban and agricultural development on storm water runoff from uplands bordering a Louisiana swamp forest. Using this model, we examined the effects of changing land use patterns. By 1995, it is projected that urban land on the uplands bordering the swamp will increase by 321 %, primarily at the expense of land currently in agriculture. Simulation results indicate that urbanization will cause storm water runoff rates to be up to 4.2 times greater in 1995 than in 1975. Nutrient runoff will increase 28 % for nitrogen and 16 percent for phosphorus during the same period. The environmental effects of these changes in the receiving swamp forest are examined.

Hopkinson, Jr., C. S., J. W. Day, Jr. and B. J. Kjerfve. 1985. Ecological significance of summer storms in shallow water estuarine systems. Contrib. Mar. Sci. 28:69-77.
G-10

Dissolved oxygen, an integrative community metabolic parameter, was monitored in a shallow, coastal, estuarine water body in Louisiana on days with and without thunderstorms to ascertain the ecological importance of periodic meteorological mixing events. A thunderstorm caused complete overturn of stratified water masses and substantially increased oxygen exchange across the air-water interface. Analysis of storm

data for coastal Louisiana indicates a high frequency of occurrence of summer storms of sufficient magnitude to completely mix shallow estuarine water bodies. Periodic mixing and reaeration of bottom waters may be an important mechanism that increases the habitat value of shallow water bodies to commercially important fishery species.

Horn, C. R. 1990. Water quality. Pages 53-62 in Mobile Bay: Issues, Resources, Status, and Management. Proceedings of a Seminar, November 17, 1988, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 15, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C.
G-2

Mobile Bay, located at the southern extremity of Alabama, receives drainage through the Mobile and Tensaw River Systems from over 64 % of the land area of the State. The water use classifications of the bay and tributary streams are high compared to the average of the remainder of the State due to the coastal nature of the area and to widespread usage for human contact activities and for shellfish growth and harvesting. The water quality environment is experiencing considerable stress. The Alabama Dept. of Environmental Management maintains an ambient water quality monitoring capability at 26 locations in the two-county (Mobile-Baldwin) area, representing 38 % of the total statewide capability, which is indicative of the high priority and value assigned to coastal Alabama. Though generally good throughout this area, existing water quality does not meet the higher standards in certain areas. Recent data suggests strongly, however, that standards are not met in much of the coastal area due to natural causes.

Housley, H. L. 1976. Distribution, Periodicity, and Identification of the Phytoplankton in the Bay of St. Louis, Mississippi and the Northeastern Gulf of Mexico. Ph.D. Dissertation, University of Southern Mississippi, Hattiesburg, Mississippi, 206 p.
G-5

The initial objective of this research was to photograph and describe the commonly occurring species and construct a dichotomous key using the photographs as illustrations. The study area included the Bay of St. Louis, Mississippi, and areas east and west of the Mississippi River Delta. The area included a shallow estuarine bay and extended offshore to the 50-fm isobath. The study was later structured to include the seasonal periodicity of the planktonic algae in the Bay of St. Louis and the distribution of the plankton in the northeastern Gulf of Mexico. To achieve these objectives, commonly occurring species of the Bay were identified and their periodicity and distribution were correlated with chemical and physical parameters.

Huang, T.-C. and H. G. Goodell. 1967. Sediments of Charlotte Harbor, southwestern Florida. J. Sediment. Petrol. 37(2):449-474.
F-13

Bottom grab samples and shallow cores from the Charlotte Harbor system have been studied to show the distribution of its sediments textural and compositional properties. The sediments are relatively uniform in character throughout the harbor system. The distribution of the sediment properties shows that the sediments are shifted by the two major tidal circulations of the harbor proper and of San Carlos Bay. Multivariate nonlinear regression is used to relate the sediment characteristics to their provenance, transportation, and depositional environments.

Ingham, M. 1982. Distress signals from inner space? Coastal Oceanography and Climatology News 4(4):47.
G-7.1

The regularity of reports of dinoflagellate blooms, red tide conditions, or critically low oxygen concentrations in bottom water masses ("dead areas") in the northwestern Gulf of Mexico leads one to wonder if these episodes are signals of degrading environmental conditions in recent years or if observers are just paying closer attention

to normal circumstances. Parallels are drawn with the areas of hypoxic or anoxic bottom waters off New Jersey in the summer of 1976.

Ingle, R. M., A. R. Ceurvels and R. Leinecker. 1955. Chemical and Biological Studies of the Muds of Mobile Bay. Report to the Division of Seafoods, Alabama Dept. of Conservation. Wetumpka Printing Co., Wetumpka, Alabama, 14 p.
G-2

This study concerns the inorganic and organic nutrients, carbohydrates, fats, and proteins contained in the muds of Mobile Bay. Presumably, these compounds can appear in the muds either adsorbed on the surface of individual particles or dissolved or particulate in the interstitial water. An attempt was also made to determine if any of the above substances contained toxic components, or if the muds, in suspension, were harmful to fish life. This report covers studies carried out during the spring and summer of 1954. All sample were obtained from dredges, or from water, in Mobile Bay. The activity of the dredges was centered about 2 to 3 miles west of Great Point Clear, Alabama.

Isphording, W. C. 1982. Mis-interpretation of environmental monitoring data--a plague on mankind! Trans. Gulf Coast Assoc. Geol. Soc. 32:399-411.
G-2

All too often, data collected as part of environmental monitoring programs are subjected to interpretation by those unqualified to do so. A recent example involved a study carried out in Mobile Bay where geochemical data were used to "identify" bottom sediments contaminated by the drilling of an exploratory well. Elevated barium contents of up to several hundred ppm near the mouth of the Bay were attributed to the spillage of drilling mud, although all drill cuttings, mud, and effluent from the rig had been pumped directly onto barges for disposal at sites onshore. Partitioning of the barium in the Mobile Bay sediments disclosed that most was associated with the various clay mineral phases and substitutional impurities in shell material. Thus, the barium observed was not the direct result of the drilling operation but rather reflected its common association with disseminated oxides in the bottom muds, as a chelated form adhering to the clay platelets and as replacement ions in the lattice of carbonate minerals.

Isphording, W. C., D. Imsand and G. C. Flowers. 1987. Storm-related rejuvenation of a northern Gulf of Mexico estuary. Trans. Gulf Coast Assoc. Geol. Soc. 37:357-370.
F-24

The massive influx of sediment from the Apalachicola River system has built an extensive delta system at the river's mouth. In the vicinity of the delta, sedimentation rates up to 10 mm/yr have been measured. Analysis of bathymetric data dating back to the mid-1880s disclosed that Apalachicola Bay has been undergoing exceptionally rapid infilling which persists. The passage of two hurricanes near the Bay in 1985, however, generated high-velocity currents that scoured some 3.6 billion cubic feet of sediment from the bottom of the Bay, completely changing the character of the texture, mineralogy, and heavy metal chemistry of the bottom sediments. Even more remarkable, perhaps, is the fact that over 83 mil tons of sediment was carried by the currents out through one of the passes into the Gulf of Mexico. The removal of this quantity of sediment has thus returned the Bay to bathymetric conditions existing in the early 1800s and significantly extended the life of the Bay.

Isphording, W. C. and G. M. Lamb. 1979. The Sediments of Mobile Bay. Report to. Rept. No. 80-003 for the Alabama Coastal Area Board, Dauphin Island Sea Lab, Dauphin Island, Alabama, 24 p.
G-2

Mobile Bay constitutes the primary depositional basin for the sixth largest river system in the U.S., in terms of area. The mean discharge of the river system through a 25-yr period is over 60,000 ft^3/s. This large

volume is funneled into a relatively small estuary, creating a unique site for the study of the interactions of a fluvial-estuarine system. Although new data are constantly being accumulated concerning conditions within the Bay, there is still a dearth of knowledge. The purpose of this study is to map the sediment distribution within the bay at the present time. This includes both the distribution of sediments by size, and the distribution of the various clay minerals included in the sediments. This study is meant to provide a basis for monitoring future change, and a better understanding of the processes that are taking place within the Bay, so that more intelligent decisions can be made regarding the management of this environment.

Isphording, W. C. and G. M. Lamb. 1980. The Sediments of Eastern Mississippi Sound. Rept. No. 80-003 for the Alabama Coastal Area Board, Dauphin Island Sea Lab, Dauphin Island, Alabama, 17 p.
G-2.2

This study deals with the eastern portion of the Sound, lying largely within Alabama, and an adjacent portion in Mississippi. The western boundary of the study area is generally from Petit Bois Island, on the south, to the Grande Batture Islands on the northern side. The purpose of the study is to map the sediment distribution in the eastern portion of Mississippi Sound. This includes both the distribution of the sediments by size, and the distribution of the various clay minerals included in the sediments. This study is meant to provide the basis for monitoring future change, and a better understanding of the processes that are taking place within the Sound, so that more intelligent decisions can be made regarding the management of this environment.

Johansson, J. O. R. and R. R. Lewis, III. 1991. Recent Improvements of Water Quality and Biological Indicators in Hillsborough Bay, a Highly Impacted Subdivision of Tampa Bay, Florida, U.S.A. A manuscript submitted to the International Conference on Marine Coastal Eutrophication, March 21-24, 1990., Bologna, Italy, 16 p. (in press)
F-15

Hillsborough Bay water quality has recently improved in response to reduced nitrogen loading caused primarily by the conversion of Hooker's Point Wastewater Facility from primary to advanced treatment. Less nitrogen is now available for phytoplankton growth, and the reduced biomass has apparently allowed for improved water column light penetration. Evidently, seagrasses and the attached macroalgae *Caulerpa* have responded to the increased light penetration by colonizing shallow areas. Although this trend is encouraging, most shallow areas in Hillsborough Bay still lack macrophyte vegetation.

Johansson, J. O. R., K. A. Steidinger and D. C. Carpenter. 1985. Primary production in Tampa Bay, Florida: A review. Pages 279-344 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

A review of historical primary production data; discussion of methodologies and shortcomings; outline of future research needs for understanding the carbon cycle of the Tampa Bay system; and discussion of the carbon cycle in relation to trophic dynamics.

Johnson, Jr., R. B. 1974. Ecological changes associated with the industrialization of Cedar Bayou and Trinity Bay, Texas. Texas Parks and Wildlife Dept. Tech. Ser. 16:1-79.
G-17

Cedar Bayou (a tributary of Galveston Bay) and Trinity Bay were studied before and after construction and operation of two industries. Cedar Bayou is the discharge site for U.S. Steel Co., and the intake site for Houston Lighting and Power Co.'s Cedar Bayou Generating Station. Trinity Bay, near Point Barrow, is the discharge site for thermal effluents from the power plant. Ninety percent of dissolved oxygen values in Trinity Bay were above 6.0 ppm, reflecting unpolluted conditions. Turbidity values were highest during heavy river

discharge. Compared to values in the Trinity Bay, the power plant discharge into Trinity Bay had higher salinity, higher temperature and lower turbidity. Temperature and dissolved oxygen content of the effluent decreased after the effluent was diverted through the cooling pond.

Johnson, Jr., R. B. 1977. Fishery survey of Cedar Lakes and the Brazos and San Bernard River Estuaries. Texas Parks and Wildlife Dept. Tech. Ser. 23:1-65.
G-18

A fishery study of Cedar Lakes and the lower parts of the Brazos and San Bernard Rivers, Brazoria County, Texas, was conducted during February 1973 to January 1975. Samples were collected at 17 stations each month to determine hydrological conditions and occurrence of estuarine organisms. Salinity, temperature, dissolved oxygen values, pH values and turbidity were determined in surface- and bottom-water samples. An otter trawl was used to sample nekton. Benthos was sampled quarterly at the 17 stations with an Ekman dredge. Samples were collected at four stations monthly after December 1973 with a minnow seine. Area and station descriptions are presented. Dissolved oxygen values were highest in winter and lowest in summer. Values less than 3.0 ppm were recorded in the Brazos and San Bernard Rivers. Effects of pollution are discussed.

Jones, J. I., R. E. Ring, M. O. Rinkel and R. E. Smith (eds.). 1973. A Summary of Knowledge of the Eastern Gulf of Mexico, 1973. Publ. No. IIE-1 - IIE-50, State University System of Florida, Institute of Oceanography, St. Petersburg, Florida, 590 p.
F-9 through G-9

This report represents a compilation and evaluation of selected studies of the significant natural and artificial environmental characteristics of the eastern Gulf of Mexico. It has been prepared by a group of qualified scientists collectively conversant with the major environmental aspects of the subject region. The purpose of this report is to provide an overview of the current status of knowledge and information on past and ongoing studies which are significant for a more complete understanding of the environment and ecology of this area. Selected investigations have been utilized by the respective authors, and there has been no attempt to list or discuss all studies within the area.

Jones, R. S., J. J. Cullen, R. G. Lane, W. Yoon, R. A. Rosson, R. D. Kalke, S. A. Holt, C. R. Arnold, P. L. Parker, W. M. Pulich and R. S. Scalan. 1986. Studies of Freshwater Inflow Effects on the Lavaca River Delta and Lavaca Bay, Texas. Final Report to Texas Water Development Board, Austin, Texas, by The University of Texas at Austin, Marine Science Institute, Port Aransas, Texas.
G-21.

See Cullen and Jones (1986).

Juneau, Jr., C. L. 1975. An Inventory and Study of Vermilion Bay - Atchafalaya Bay Complex. Phase I, Area Description. Phase II, Biology. Phase III, Hydrology and Water Chemistry. Tech. Bull. No. 13, Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana, 153 p.
G-12, G-13

The Vermilion-Atchafalaya Bay estuarine complex is a vast open water brackish system whose primary sources of fresh water are the Atchafalaya and Vermilion Rivers. There are approximately 475,000 surface acres within the system. Vegetation in the complex varies from fresh to brackish, depending on nearness to the mouth of the Atchafalaya River. Biological sampling was conducted from April 1972 through March 1974 at 12 trawl, two seine, and four plankton stations in the complex. A total of 63 species of fishes and nine species of invertebrates were collected. The areal and seasonal distribution of the species are discussed. In the two years of field sampling, hydrological conditions varied considerably, due to flooding conditions on the river systems.

Trends and seasonal changes regarding water temperature, salinity, and various chemical parameters are discussed; tables and graphs supplement the discussion.

Junot, J. A., M. A. Poirrier and T. M. Soniat. 1983. Effects of saltwater intrusion from the Inner Harbor Navigational Canal on the benthos of Lake Pontchartrain, Louisiana. Gulf Res. Rep. 7(3):247-254.
G-7

A study of the benthos of southern Lake Pontchartrain, Louisiana, was conducted from July 1976 to July 1978. Seven offshore stations and three stations in the New Orleans Marina complex were sampled seasonally. Offshore stations formed a transect from the Lake Pontchartrain Causeway to the Inner Harbor Navigation Canal (IHNC). A west-to-east gradient of increasing salinity and salinity stratification was evident. Faunal differences among stations were assessed using indices of diversity, biological dominance, pollution, and station homogeneity. The fauna of the marina stations had a low species diversity and was dominated by annelids indicative of a stressed environment. The fauna of stations near the IHNC were similar to the marina stations. Moving westward from the IHNC, species diversity increased and the fauna became dominated by mollusks. Stressful conditions associated with the intrusion of water from the IHNC into Lake Pontchartrain appeared to be responsible for the faunal differences observed.

Kalke, R. D. 1986. Zooplankton. Chapter 4 in R. S. Jones *et al.*, Studies of Freshwater Inflow Effects on the Lavaca River Delta and Lavaca Bay, Texas. Final Report to the Texas Water Development Board, Contract No. 55-61011. Tech. Rept. No. TR/86-006, University of Texas Marine Science Institute, Port Aransas, Texas, 14 p.
G-21

Zooplankton sampling was conducted to monitor the effects of freshwater inflow on the spatial and temporal distribution of zooplankton at seven stations in upper Lavaca Bay from November 1984 through August 1985 (Year 1) and October 1985 through August 1986 (Year 2). In Year 2, sampling effort was increased to cover marine input from the lower bay by adding six stations along a transect from state highway 35 causeway south along the Matagorda Ship Channel to marker 35 and 36. Historical and concurrent stream flow data indicate that Year 1 was a wet year and Year 2 was a drier year. Zooplankton data reflect these differences. See also Cullen and Jones (1986).

Kalke, R. D. and P. A. Montagna. 1989. A review: The effect of freshwater inflow on the benthos of three Texas estuaries. Pages 185-234 in P. A. Montagna (ed.), Nitrogen Process Studies (NIPS): The Effect of Freshwater Inflow on Benthos Communities and Dynamics. Final Report to the Texas Water Development Board. Tech. Rept. No. TR/89-011, University of Texas Marine Science Institute, Port Aransas, Texas.
G-21, G-22, G-24

The effect of freshwater inflow on benthic community structure in three Texas estuaries is the subject of a literature review. All three estuaries can be divided into marine, estuarine, and freshwater zoogeographic zones. But the boundaries of the zones are regulated by three factors: 1) location of the estuary, 2) whether the bay has a direct opening to the Gulf of Mexico, and 3) the interannual variability in rainfall and freshwater inflow. In an open system, such like the Lavaca-Tres Palacios and Nueces estuaries, biomass and abundance typically increase near the opening to the Gulf, but in a closed system, such as the Guadalupe Estuary, abundance and biomass usually decrease toward the marine influenced zone. This indicates that the estuaries must be treated independently when making management decisions, but that we can develop a generic model which describes the effect of freshwater inflow on estuarine benthic dynamics.

Kalke, R. D. and P. A. Montagna. 1991. The effect of freshwater inflow on macrobenthos in the Lavaca River delta and upper Lavaca Bay, Texas. Contrib. Mar. Sci. 32:49-71.
G-21

A two year study on the effect of freshwater inflow on macrobenthos at selected sites in the upper portion of the Lavaca River and Bay was conducted from November 1984 through August 1986. Lowest densities occurred in lakes, and highest densities occurred in creek deltas. Sediment grain size did not have a significant effect on spatial distribution. Temporal changes of inflow had a large effect on spatial variability, because freshwater species had extended ranges during the high-flow year. Temporal variation in the benthic community during the study was associated with high inflow rates during the first year. Freshwater inflow is apparently necessary to induce the recruitment of low salinity species in the upper bay.

Kaufmann, P. R., A. T. Herlihy, J. W. Elwood, M. E. Mitch, W. S. Overton, M. J. Sale, J. J. Messer, K. A. Cougan, D. V. Peck, K. H. Reckhow, A. J. Kinney, S. J. Christie, D. D. Brown, C. A. Hagley and H. I. Jager. 1988. Chemical Characteristics of Streams in the Mid-Atlantic and Southeastern United States (National Stream Survey-Phase I). Vol. I: Population Descriptions and Physico-Chemical Relationships. Publ. No. EPA/600/3-88/021a, U.S. Environmental Protection Agency, Washington, D.C., 397 p.
F-26, F-27

The objectives of the National Stream Survey-Phase I (NSS-I) were to: 1) determine the percentage, extent (number, length, and drainage area, location, and chemical characteristics of streams in the Mid-Atlantic and Southeast that are presently acidic, or that have low ANC and thus might become acidic in the future; 2) identify streams representative of important classes in each region that might be selected for more intensive study or long-term monitoring. The basic results of the NSS-I are population descriptions of the location, number, length, and percentage of streams within referenced ranges of chemical concentrations. The most important of these descriptions are those concerning ANC and pH. Further data interpretation includes an examination of regional patterns in the relationships among the chemical constituents within stream waters in an effort to infer the possible geochemical factors and anthropogenic impacts controlling stream chemistry. Lastly, a high-interest segment of the stream population with low ANC was examined and classified according to probable sources of acidity.

Kelly, J. R. (ed.). 1981. Symposium on Mississippi Sound. Proceedings of a Conference, June 25-26, 1981, Biloxi, Mississippi. Publ. No. MASGP-81-007, Mississippi-Alabama Sea Grant Consortium, Ocean Springs, Mississippi, 152 p.
G-2.2, G-2.3

A series of publications on the Mississippi Sound estuary, covering flora, fauna, pollutants in coastal waters, resource management, hydrology, socioeconomics, and geology.

Kennedy, V. S. (ed.). 1982. Estuarine Comparisons. Proceedings of the Sixth Biennial International Estuarine Research Conference, November 1-6, 1981, Gleneden Beach, Oregon. Academic Press, New York, 709 p.

This book represents a first in the efforts of the Estuarine Research Federation to compare the knowledge that they have gained about many of the world's estuaries. It is the first real effort to compare different estuaries. Such estuarine comparisons are vital to the future of estuaries. All future research, as well as management concepts, must consider the diversity of estuaries in the world, the various management options available, and the wealth of information gained by comparing estuaries, to make environmentally effective and economically workable management decisions.

Keys, V. E. 1975. Management of Florida red tides regarding shellfish harvesting. Pages 483-488 in V. R. LoCicero (ed.), Proceedings of the First International Conference on Toxic Dinoflagellate Blooms. The Massachusetts Science and Technology Foundation, Wakefield, Massachusetts, 541 p.
F-9 through F-27

Historically, red tides have occurred along the Florida west coast from Tarpon Springs to the Everglades. Since 1963, red tides of public health significance have occurred in areas outside the historical zone. The northwest coast (Panhandle) of Florida experienced a red tide bloom in the early part of September 1974, necessitating the closure of these waters for shellfish harvesting.

Khalid, R. A., W. H. Patrick, Jr. and R. P. Gambrell. 1978. Effect of dissolved oxygen on chemical transformations of heavy metals, phosphorus, and nitrogen in an estuarine sediment. Estuarine Coastal Mar. Sci. 6(1):21-35.
G-10

The effect of dissolved oxygen on the chemical transformations of Fe, Mn, Zn, Cu, Pb, Cd, NH_4^+-N and P in an estuarine sediment suspension was investigated under laboratory conditions. The data indicate that increasing oxygen concentrations in the gas mixture resulted in lower sediment pH and higher oxidation-reduction potential with time. Changes in redox potential and pH strongly modified the distribution of trace metals in various chemical fractions. Phosphorus and NH_4^+-N concentrations decreased sharply with time as a result of increased redox potential levels in the 2.1 % and 21 % oxygen levels. This indicates that oxidized sediment conditions may be an important factor in regulating eutrophication by reducing levels of P and N available for biota.

Kjerfve, B. J. (ed.). 1988. Hydrodynamics of Estuaries. Vol. 1. Estuarine Physics. CRC Press, Boca Raton, Florida, 165 p.

This volume summarizes many of the prevalent concepts and approaches in the investigation in hydrodynamics and physical processes of estuaries. Leading scientists in the field were asked to contribute chapters, which are broadly summarizing in nature. It is intended to be useful to oceanography students, research workers in the field, and persons charged with the management of our estuarine resource. This volume focuses on estuarine physics and physical processes and interpretations.

Kjerfve, B. J. and J. E. Sneed. 1984. Analysis and Synthesis of Oceanographic Conditions in the Mississippi Sound Offshore Region. Vol. I and II. Final Report, Contract DACW 01-83-R-0014. U.S. Army Corps of Engineers District, Mobile, Alabama, 253 p. (not in hand)
G-2.1

Knudson, K. and C. E. Belaire. 1975. Causes and probable correctives for oxygen depletion fish kills in the Dickinson Bayou estuary: A field study and simplified algal assay. Contrib. Mar. Sci. 19:37-48.
G-17

Frequent oxygen depletion fish kills, caused by dense algal blooms, have occurred during summers in the 6-km portion of Dickinson Bayou directly upstream from two sewage treatment plants. These plants are the major contributors of wastes to the bayou. During summer periods of low freshwater inflow, the treatment plant effluents are carried upstream by tidal action, causing dense algal blooms; algal density is much less above tidal influence and downstream from the plant outfalls. Algal assays demonstrated that if the plants employed chemical coagulation to remove phosphorus, the summer algal densities in the critical 6-km portion of the bayou would be reduced to concentrations corresponding to, or less than, the levels found in the rest of the bayou. Such treatment would thereby reduce the probability of summer fish kills.

Krutak, P. R. 1978. Holocene Ostracoda of Bay St. Louis, Mississippi, U.S.A. Micropaleontology 24(3):225-250.
G-5

Forty-three quantitative (100 cm^3) bottom samples from Bay St. Louis, on the coast of Mississippi, have yielded 1623 ostracods. Sixteen species of podocopid ostracods occur in these samples, in four discrete

sedimentary biotopes of the Bay area: estuaries, marshes, bay, and sound. Comparison of the thanatocoenosis (total population - live + dead) and biocoenosis (live only) of the 16 species reveals significantly different map distributions in each of the four sedimentary facies; of the 16 species of the thanatocoenosis only 10 are present in the biocoenosis. Total ostracod populations (live + dead) vary from none in 17 samples to a maximum of 464 individuals per 199 cm^3 in one. Total populations and relative abundance of individuals is higher in estuaries and marshes, lower in the Bay and sound. The proportion of living ostracods is higher in the Bay, marshes, and estuaries than in the sound biotope.

Landry, A. M. and H. W. Armstrong. 1980. Vol. IV - Determine Seasonal Abundance, Distribution and Composition of Zooplankton. In W. B. Jackson and G. M. Faw (eds.), Biological/Chemical Survey of Texoma and Capline Sector Salt Dome Brine Disposal Sites off Louisiana, 1978-1979. NOAA Tech. Memo NMFS-SEFC-29, NOAA/NMFS Final Report to DOE. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Galveston, Texas, 179 p.
G-7.1

Demersal finfishes and macro-crustaceans were trawled from proposed West Hackberry and Weeks Island brine disposal sites off Louisiana during summer and fall 1978 and winter and spring 1979. Results indicated that 74 taxa of finfish comprising 41,369 individuals and 25 species of macrocrustaceans representing 31,120 specimens were taken. Overall mean catch at West Hackberry stations exceeded that for Weeks Island by more than double.

LaRose, H. R. and B. F. McPherson. 1983. Chemical and Hydrologic Assessment of the Caloosahatchee River Basin, Lake Okeechobee to Franklin Lock, Florida. U.S. Geological Survey, Water-Resources Investigations Report 83-4126. Dept. of the Interior, U.S. Geological Survey, Denver, Colorado, 63 p.
F-12

This report is restricted to the freshwater reaches of the system, but identifies the sources of nutrients. Contributions of nitrite plus nitrate, orthophosphate and total phosphorus from the basin and the river substantially exceeded input from Lake Okeechobee, while concentrations of ammonia from the river and basin were quite small compared to the input from the lake. In most tributaries, concentrations of nitrogen and phosphorus compounds were lower than those in river.

Lee, J. M., W. J. Wiseman, Jr. and F. J. Kelly. 1990. Barotropic, subtidal exchange between Calcasieu Lake and the Gulf of Mexico. Estuaries 13(3):258-264.
G-15

Long-term measurements of flow through Calcasieu Pass, Louisiana, are compared to water level variations within Calcasieu Lake, Louisiana. Except during periods of freshets driven by local rainfall, the exchange is shown to be predominantly barotropic. A simple wind-driven model accounts for the observed phase relations between wind, current, and water level.

Leming, T. D. and W. E. Stuntz. 1984. Zones of coastal hypoxia revealed by satellite scanning have implications for strategic fishing. Nature 310(5973):136-138.
G-7.1, G-27

Hypoxic and occasionally anoxic bottom waters occur along the inner continental shelf of Texas and Louisiana. Little is known, however, about the spatial and temporal scales of these hypoxic areas. Because hypoxia appears to be related to surface chlorophyll and temperature, which can both be measured with the Coastal Zone Color Scanner on board the Nimbus 7 spacecraft, we have tried to determine if conditions favorable for formation of hypoxia could be detected and monitored from space. A linear discriminant function successfully identified areas of bottom-water hypoxia detected by research vessels for as many as 10 d after

satellite overpass. The discriminant function also successfully predicted hypoxic areas in June 1983 without resort to research vessel data. Shrimp and finfish were absent in the hypoxic zones; hence, the mapping from space of conditions favorable for hypoxia development may have significant marine resource implications for both strategic fishing and management.

Lewis, R. R., III. 1989. Biology and eutrophication of Tampa Bay. Pages 89-112 in E. D. Estevez (ed.), Tampa and Sarasota Bays: Issues, Resources, Status, and Management. Proceedings of a Seminar, December 10, 1987, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 11, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C.
F-14, F-15

Studies were initiated in response to the problem of blooms of toxic dinoflagellates known as "red tides," particularly the massive blooms of 1946-1947. The findings of all studies to date have revealed: 1) a north-to-south, or head-to-mouth, gradient exists in phytoplankton species numbers; 2) nannoplankton generally are the dominant size class of the phytoplankton; 3) at least 272 species of phytoplankton occur in the bay; 4) short-term fluctuations in species composition and standing crop are common; 5) the majority of the bloom species are resident in the bay but significant blooms occasionally occur due to species which invade from the Gulf of Mexico; and 6) many of the previous studies utilized analytical procedures which limit the quantitative comparison of all data; some uniform sampling strategy and analytical procedures are needed to make future data more usable.

Lewis, R. R., III and E. D. Estevez. 1988. The Ecology of Tampa Bay, Florida: An Estuarine Profile. Biological Report No. 85(7.18), U.S. Dept. of the Interior, Fish and Wildlife Service, National Wetlands Research Center, Washington, D.C., 132 p.
F-15

Tampa Bay is Florida's largest open-water estuary and one of the most highly urbanized. This report summarizes and synthesizes many years of scientific investigation into Tampa Bay's geology, hydrology and hydrography, water chemistry, and biotic components. Significant changes occurring as a result of urbanization and industrialization include significant declines in intertidal wetlands and seagrass meadows, changes in circulation and flushing, and degradation of water quality. Important management issues include dredge and fill operations, restoration of fisheries, increasing freshwater flow to the Bay, and eutrophication.

Lind, W. B. 1983. Chemical and Physical Characteristics of Water in Estuaries of Texas, October 1975 - September 1976. Prepared by the U.S. Geological Survey. Rept. No. 275, Texas Department of Water Resources, Austin, Texas, 203 p.
G-16, G-17, G-18, G-19, G-20, G-21, G-22, G-23, G-24, G-26

In September 1967 the USGS and TWDB began a cooperative water-resources investigation of the principal estuaries along the Texas coast except the Rio Grande estuary. The objectives are to define 1) the occurrence, source, and distribution of nutrients; 2) the physical, organic, and inorganic water-quality constituents and their areal distribution and time variations; 3) the chemico-physical characteristics of Gulf water that enters the estuaries, 4) the occurrence, quality, quantity, and dispersion of drainage entering the estuarine systems, and 5) the current patterns, directions, and rates of water movement. This report presents data collected during water year 1976 and is one of a series of annual data reports.

Lindall, Jr., W. N., W. A. Fable, Jr. and L. A. Collins. 1974. Additional studies of the fishes, macroinvertebrates, and hydrological conditions of upland canals in Tampa Bay, Florida. Fish. Bull. 73(1):81-85.
F-15

Hydrological and biological data from a concluding study of upland canals in Tampa Bay, Florida are presented and compared with those collected the previous year. Critically low levels of dissolved oxygen occurred more

frequently and over a longer period in the second year. Most affected were the inland portions of the canal system where the number of species declined markedly over the previous year. Impoverishment of fauna on or near the bottom is expected to recur during summer months because of oxygen depletion resulting from a combination of continuing accumulation of decomposing organic sediment, warm water, and little circulation in the dead-end canals.

Livingston, R. J. 1986. The Choctawhatchee River-Bay System. Center for Aquatic Research and Resource Management, Florida State University, Tallahassee, Florida, 1,075 p. (not in hand)
F-26

Livingston, R. J. 1987. Field sampling in estuaries: The relationship of scale to variability. Estuaries 10(3):194-207.
F-24

The spatial/temporal scaling problem (i.e., fitting a given research question to the dimensions of variability of the study area) is particularly pronounced in highly variable systems such as estuaries. Long-term, multidisciplinary studies in this system were used to evaluate variation of different physical, chemical, and biological factors. Specific limitation of weekly, monthly, and quarterly sampling intervals were directly related to the efficiency of the sampling gear, the range of variation in the study parameters, and specific biological features (motility, recruitment, natural history) of infaunal macroinvertebrates and epibenthic organisms. Unless experimental studies and field sampling programs are scaled to the dimensions of the research problem and the study area in question there will be a continued proliferation of trivial studies at one end of the continuum and the progressive deterioration of estuarine resources at the other.

Livingston, R. J. 1989. Historical Overview and Data Review, Perdido River Complex, Elevenmile Creek, Bayou Marcus and the Perdido Bay System. Environmental Planning and Analysis, Inc., Tallahassee, Florida, 68 p.
F-28, G-1

A review was conducted concerning the historical changes that have taken place in the Perdido Drainage System. According to various sources, serious changes associated with human activities have taken place in the basin in recent times. Causative factors are postulated including dredging, timbering activities, agricultural practices, paper manufacturing processes, municipal development (sewage/septic waste releases and stormwater runoff), and sports/commercial fishing. Definitive cause-and-effect relationships have not been established by the existing, somewhat inconsistent scientific data base. Various studies of Elevenmile Creek and the Perdido estuary are currently being carried out by a variety of private and public agencies and groups. These studies will address system-wide environmental questions in the Perdido Drainage System. Such data will be used in the long-term planning and resource management in the region. An appendix consisting of maps, charts, interview questions, and data is included.

Livingston, R. J. 1991. Historical relationships between research and resource management in the Apalachicola River estuary. Ecological Applications 1(4):361-382.
F-24

A continuous field research effort has been carried out in the Apalachicola River estuary since March 1972. The information generated from this interdisciplinary study has been directly applied to the management of the Apalachicola resource by means of closs associations among local, state, and federal officials and university scientists. During 1972-1983, scientific data were instrumental in the prevention of the impoundment of the Apalachicola River. Other initiatives were carried out that were designed to protect the naturally high productivity of the river estuary. Since 1983, there has been a gradual reduction in the importance of research as an integral part of the planning and management process in the Apalachicola system. The author sees this regional trend as also a national pattern.

Livingston, R. J. 1983. Resource Atlas of the Apalachicola Estuary. Grant No. NA80AA-D-00038. Rept. No. 55, Sea Grant Project No. T/P-1, Florida Sea Grant College Program, University of Florida, Gainesville, Florida, 64 p.
F-24

The Apalachicola Valley has been part of a major experiment to determine if scientific information can indeed be used to develop a resource management program to meet those needs. The central question remains how to broaden the existing, relatively narrow economic base while continuing to maintain one of the last naturally functional big river basins in the country. It is with these challenges in mind that this atlas has been written.

Livingston, R. J. 1984. Trophic response of fishes to habitat variability in coastal seagrass systems. Ecology 65(4):1258-1275.
F-22

Shallow coastal areas of the northeast Gulf of Mexico are physically unstable in terms of short-term, seasonal, and year-to-year changes in temperature, salinity, nutrient concentration, and other water quality features. A 9-yr comparison was made of two estuaries, one polluted and one in the natural state, to determine the response of fish assemblages to habitat alteration in space and time. Apparently slight water quality changes due to pollution, which are outside the evolutionary experience of the biotic components, can cause serious disruptions of the basic habitat structure, energy flow, and community composition of the grassbed assemblages at various levels of biological organization.

Livingston, R. J., R. L. Iverson, R. H. Estabrook, V. E. Keys and J. Taylor, Jr. 1974. Major features of the Apalachicola Bay system: Physiography, biota, and resource management. Fla. Sci. 37(4):245-271.
F-24

A review was made of various features of the Apalachicola Bay System. Unique physical, chemical, and biological features of this system combine to make it one of the most productive estuarine areas in the State of Florida. Primary productivity and secondary productivity are discussed in relation to various forcing functions (natural and man-induced). Problems associated with development include dredging, sewage effluents, pesticides and a number of up-river activities such as industrialization, cattle ranching, channelization, and damming. The Apalachicola Drainage System is viewed as one of the largest relatively unpolluted areas in the country. However, it is a neglected resource with little management or control; as such it is presently endangered by a number of activities. It is suggested that critical information necessary for the management and protection of this system be obtained, and that the impact of watershed alterations be viewed on a regional basis with coordinated participation of the involved states (Florida, Georgia, and Alabama).

Livingston, R. J., and E. A. Joyce, Jr. (eds.). 1977. Proceedings of the Conference on the Apalachicola Drainage System, 23-24 April 1976, Gainesville, Florida. Florida Marine Research Publications, Number 26. Florida Department of Natural Resources, Marine Research Laboratory, St. Petersburg, Florida, 177 p.
F-24

A compendium of information concerning the intrinsic and extrinsic values of the Apalachicola Drainage System. The various topics covered are the legal, economic, managerial, and environmental aspects of the Apalachicola basin with contributions from two state university systems, three departments of state government, the Florida Bar, one private Florida research facility, and one out-of-state university system. Papers are presented on geobotany, terrestrial and aquatic fauna, and natural history of the Apalachicola River and Bay systems. The Apalachicola Valley is shown to be a center of endemism in the southeastern U.S. and critical to the environmental and economic considerations of a three-state area (Florida, Georgia and Alabama).

Livingston, R. J., G. J. Kobylinski, F. G. Lewis, III and P. F. Sheridan. 1976. Long-term fluctuations of epibenthic fish and invertebrate populations in Apalachicola Bay, Florida. Fish. Bull. 74(2):311-321.
F-24

A 3-yr study was made concerning seasonal changes in the biota of Apalachicola Bay. The Apalachicola River causes a temporal progression of changes of various environmental parameters in the bay such as salinity, turbidity, nutrients, and detritus levels. Fishes were more widespread in their distribution throughout the bay than invertebrates. This was thought to be related to trophic response and habitat preference. High levels of relative dominance prevailed for both groups with the top three species of each group accounting for more than 80 % of the total number of individuals taken. The temporal and spatial distribution of estuarine fishes and invertebrates was associated with species-specific reproductive cycles, trophic relationships, and habitat preferences. The Apalachicola estuary was viewed as a seasonally stable system, with regular temporal fluctuations of the biota through each annual cycle.

Livingston, R. J., P. S. Sheridan, B. G. McLane, F. G. Lewis, III and G. G. Kobylinski. 1977. Pages 75-100 in R. J. Livingston, E. A. Joyce, Jr. (eds.), Proceedings of the Conference on the Apalachicola Drainage System, 23-24 April 1976, Gainesville, Florida. Florida Marine Research Publications, Number 26. Florida Department of Natural Resources, Marine Research Laboratory, St. Petersburg, Florida, 177 p.
F-24

Initiated in 1972, this study is one of a series of publications concerning the long-term fluctuations of the biota in the Apalachicola Bay system. Previous studies have confirmed that the Apalachicola Bay system has a relatively high level of primary and secondary production, and that such production depends, to a large degree, on the Apalachicola River system, the largest of its kind in Florida. This unpolluted shallow coastal estuary is a river-forced, barrier island system that serves as a major source of sports and commercial fisheries in Florida.

Loesch, H. 1960. Sporadic mass shoreward migrations of demersal fish and crustaceans in Mobile Bay, Alabama. Ecology 41(2):292-298.
G-2

At infrequent intervals in Mobile Bay, crabs, shrimp, and several species of fish crowd to the shallow water where they may be easily taken by anyone on the beach at the time. This phenomenon, locally termed "Jubilee," has heretofore been unreported in literature. In Mobile Bay, mortalities seldom occur. The theory has been advanced that these shoreward migrations occur when certain meteorological and oceanographic factors are in coincidence. These jubilees occur in Mobile Bay most frequently during the dark hours on a rising tide following a day of east wind. The coincidence of these climatological conditions results in an inshore movement of water which is low in oxygen because of the rotting of wood debris accumulated from the Tensaw River runoff from a deep pocket near the eastern shore of the bay. Demersal animals especially move inshore ahead of this water mass. Changes in tide, wind, or other meteorological conditions result in water aeration and terminate the jubilee.

Lohrenz, S. E., M. J. Dagg and T. E. Whitledge. 1990. Enhanced primary production at the plume/oceanic interface of the Mississippi River. Continental Shelf Res. 10(7):639-664.
G-7.1

Mechanistic and empirical models were used to examine relationships between primary production and environmental variables along the Mississippi River plume/oceanic gradient off Southwest Pass, Louisiana. Comparison of observed chlorophyll concentrations with those predicted using a steady-state light limitation model suggested factors in addition to light availability constrained maximum biomass levels in the plume. Factors which may have contributed to low observed biomass included growth limitation or inhibition by substances not measured, losses due to grazing and sinking, and a short residence time for plume water, which

may have prevented populations from reaching steady state. Nutrient-salinity distribution, in conjunction with approximate calculations of primary consumption of riverine nutrient sources by phytoplankton, led to the conclusion that biomass and production were controlled by nutrient supply at salinities above 30.

Longley, W.L. (ed.). 1992. Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationship and Methods for Determination of Needs. Report of the Texas Water Development Board and the Texas Parks and Wildlife Department, Austin, Texas, 400 p. (Not in hand).
G-16 through G-26.3

Lopez, M. A. and R. F. Giovannelli. 1984. Water-Quality Characteristics of Urban Runoff and Estimates of Annual Loads in the Tampa Bay Area, Florida, 1975-1980. U.S. Geological Survey Water Resources Investigations Rept. No. 83-4181, U.S. Dept. of the Interior, Geological Survey, Tallahassee, Florida, 76 p.
F-15

Rainfall, runoff, and water-quality data were collected at nine urban watersheds in the Tampa Bay area of west-central Florida from 1975 to 1980. Watershed drainage ranged from 0.34 to 3.45 mi^2. Land use was mixed. Development ranged from a mostly residential watershed with 19 % impervious surface to a commercial-residential watershed with 61 % impervious surface. The flow regression equations of this report were used to compute 1979 water-year loads of biochemical oxygen demand, chemical oxygen demand, total nitrogen, total organic nitrogen, total phosphorus, and total lead for the nine Tampa Bay area urban watersheds.

Lord, R. J. (in prep.). Perdido Bay, Florida-Alabama Preliminary Analytical and Field Data, July 1986 through October 1987. Draft Report. U.S. Environmental Protection Agency, Region IV, Atlanta and Athens, Georgia.
F-28, G-1

Lord, R. J. 1989. Perdido Bay. A coordinated approach to an environmental problem. Gulfwatch 1(5):3/7.
G-1, F-28

In many ways, Perdido Bay's physical characteristics and environmental problems reflect many of the concerns about the Gulf coast and its estuaries. Because of this, it was selected as the site of a pilot project under the EPA Near Coastal Waters Program. This report describes the background, details and hoped-for results of this project.

Louisiana Continental Shelf System Working Group. 1982. Evaluation of the Brine Disposal from the West Hackberry Site: The Regional Impact on Menhaden Resources. Vol. I and II. Final Report to the U.S. Dept. of Energy Strategic Petroleum Reserve Project Management Office, New Orleans, Louisiana. Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana.
G-7.1

The commercial fishery for the Gulf menhaden is the largest (by weight) in the U.S. Given the value of the menhaden resource, the history of exploitation of related species, and the general lack of an understanding of the offshore marine ecosystem of the Louisiana shelf, a study was conducted to assess the impacts of brine discharge on the spawning of menhaden and shrimp and the possible significance to commercial Louisiana landings; and assess the impact of brine discharge on the food web, with emphasis on those species critical to menhaden and shrimp. A summary of the relationships within the shelf ecosystem observed during the year's study stresses cross-shelf gradients, the importance of the coastal boundary layer, trends in phytoplankton specific growth rates, trends in phytoplankton and zooplankton biomass, location of fish and, specifically menhaden, larval densities, and location of menhaden spawning.

Louisiana Department of Environmental Quality. 1984. Crab Kill in Gulf of Mexico off Point au Fer Island. Memorandum, Louisiana Department of Environmental Quality, Baton Rouge, Louisiana, 6 p.
G-7.1

On August 24, 1984 an investigation was made of a reported crab kill in the Gulf of Mexico just off Point au Fer Island between the mouth of Oyster Bayou and Point au Fer. It was believed that the problem was due to an offshore rig dumping brine into the Gulf and resulted in crabs dying in traps. Water quality readings were taken at six locations within the area. Measurements were made at 1-m intervals to a depth of 0.3 m above the bottom. The readings indicated that high salinities were present. Also, it was seen that nearer to the mouth of the Atchafalaya, salinity stratification was present and resulted in depressed dissolved oxygen levels at or near the bottom. It was confirmed that low oxygen levels and not the brine discharge was the cause of the crab mortalities. Future trips are planned to gain a more complete understanding of the areal extent and magnitude of the stratification and low dissolved oxygen levels.

Louisiana Department of Environmental Quality. 1987. Water Quality Management Plan. Vol. 4 - Basin/Segment Boundaries and Inventories. Vol. 5 - Water Quality Assessment. B. Water Quality Data Summary. Louisiana Department of Environmental Quality, Office of Water Resources, Water Pollution Control Division, Baton Rouge, Louisiana.
G-7, G-9, G-10, G-11, G-12, G-14, G-15

This volume of the Louisiana Water Quality Management Plan includes descriptions of each water quality management basin and all segments within each basin. It includes descriptions of the geology, geography, climatology, and hydrology of the basins. Much of the information was extracted from the 1980 Phase II Basin Plans. Some of the descriptions identify Major Land Resource Areas included within a basin.

Louisiana Department of Environmental Quality. 1988. Water Quality Management Plan. Vol. 5, Part A - Water Quality Inventory, 1988. Part B. Water Quality Data Summary. Vol. 6, Part A - Nonpoint Source Pollution Assessment Report. Louisiana Department of Environmental Quality, Office of Water Resources, Water Pollution Control Division, Baton Rouge, Louisiana.
G-7, G-9, G-10, G-11, G-12, G-14, G-15

The 1988 Water Quality Inventory assesses water quality data and pollution activities for the years 1986 and 1987. The assessment has two phases involving two categories of information: ambient monitoring data and evaluative data, which includes pollution sources, citizen complaints, fish kills, and general observations. For this report, 419 water bodies were assessed. Based upon this assessment, water quality in Louisiana is good; better than 60 % of the assessed waterbodies are considered to be fully supporting their designated uses. Among the various pollutants identified as causes for non-support of designated uses, the most frequently cited pollutants are fecal coliform bacteria, oxygen-demanding substances, nutrients, oil and inorganics, specifically chlorides and brine. The most commonly cited sources of pollutants impacting the assessed waterbodies are runoff from unsewered communities, inadequately treated sewage discharges from municipalities, discharges and spills from petroleum activities, agricultural runoff, and urban runoff. At this time, nonpoint sources appear to be the predominant sources contributing to water quality problems in the state.

Louisiana Department of Environmental Quality. 1989. Water Quality Management Plan. Vol. 5, Part B - Water Quality Data Summary, 1980-81. Louisiana Department of Environmental Quality, Office of Water Resources, Water Pollution Control Division, Baton Rouge, Louisiana.
G-7, G-9, G-10, G-11, G-12, G-14, G-15

Data report for water quality stations for 1980-1981.

Louisiana Department of Environmental Quality. 1990. Water Quality Management Plan. Vol. 5 - Water Quality Data Summary, 1988-89. Vol. 5 - Water Quality Inventory, 1990. Louisiana Department of Environmental Quality, Office of Water Resources, Water Pollution Control Division, Baton Rouge, Louisiana.
G-7, G-9, G-10, G-11, G-12, G-14, G-15

Data report for water quality stations for 1988-1989. The Water Quality Inventory assesses water quality data and pollution control activities for the same years. The assessment has two phases involving two categories of information: ambient monitoring data and evaluative data. The latter includes pollution sources, citizen complaints, fish kills, and general observations. For this report, 443 waterbodies were assessed, including 8665 miles of rivers, 5,602,758 acres of lakes, and 4212 miles of estuaries. Based upon this water quality assessment, covering the years of 1988 and 1989, it is concluded that the overall quality of Louisiana's surface waters is fair to good, with scattered incidences of toxic contamination in certain areas and widespread incidence of bacterial contamination in populated areas. Nearly 60% of the assessed waterbodies are considered to be fully supporting their designated uses, and about 30% of the assessed waters are suffering some degree of impairment. The remaining 10 % are unclassified due to lack of information. It should be noted that the assessed waters represent only a fraction of the total waters of the State.

Louisiana Wild Life and Fisheries Commission. 1971. Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana. Phase I, Area Description. Phase II, Hydrology. Phase III, Sedimentology. Phase IV, Biology. Louisiana Wild Life and Fisheries Commission, New Orleans, Louisiana, 366 p.
G-7 through G-16

Tabular data are presented on water volume, vegetation, stream discharge, commercial fishery operations, coastal populations, pollution, filled areas, drained areas and navigation channels in Louisiana's estuarine zone. Comparisons are made between past years' data and recent information.

Lowery, T. A. (ed.). 1987. Symposium on the Natural Resources of the Mobile Bay Estuary. Publ. No. MASGP-87-007, Alabama Sea Grant Extension Service, Alabama Cooperative Extension Service, Auburn University, Mobile, Alabama, 208 p.
G-2

Series of extended abstracts from the symposium covering topics of resources; fisheries research and management; amphibian, reptilian and avian populations; benthic and wetland resources; habitat preservation, restoration and mitigation, educational efforts; and hydrography, circulation, water quality and pollutants.

Lurry, D. L. 1983. Analysis of Native Water, Bottom Material, Elutriate Samples, and Dredged Material from Selected Southern Louisiana Waterways and Selected Areas in the Gulf of Mexico, 1979-81. Open-File Report No. 82-690, U.S. Dept. of the Interior, Geological Survey, Baton Rouge, Louisiana, 114 p.
G-8.1, G-9, G-10, G-12, G-15

Series of chemical samples on water samples, bottom sediments, elutriate samples and dredged materials from 10 locations in coastal Louisiana. Chemical analyses included sodium, potassium, bicarbonate, carbonate, alkalinity, sulfate, chloride, various solids, various nitrogen, various phosphorus, various trace metals, oil and grease, cyanide, chemical oxygen demand, PCBs and related chemicals, DDT and related chemicals, and other toxic chemicals.

Lysinger, W. R. 1982. An Analysis of the Hydrographic Conditions Found in the Main Pass of Mobile Bay, Alabama. M.S. Thesis, University of Alabama, University, Alabama, 139 p.
G-2

Water quality surveys (temperature, salinity, dissolved oxygen) were made in Main Pass from September 1975 through November 1977. This report summarizes the predominant wind conditions, tidal ranges and mean river flows associated with each survey. Dissolved oxygen mean saturation levels for the surveys ranged from 56.6 to 127.1 %. In June and July, isolated water parcels with values less than 20 % were observed in bottom waters greater than 9 m. These low values occurred only on falling tides, suggesting that their origins were in the Bay.

Lytle, T. F. and J. S. Lytle. 1990. Contaminants in sediments from the central Gulf of Mexico. Estuaries 13(1):98-111.
G-2.2, G-2.3, G-3, G-4, G-5

Surface sediment samples at 89 locations and 300-cm cores from 43 sites in the Mississippi Sound were examined for evidence of pollutant impact upon this coastal environment. Chemical variables determined were total organic carbon, Kjeldahl nitrogen, phenols, and hydrocarbons. Values of these pollutant indicators were about the same or lower in Gulf of Mexico samples compared to Mississippi Sound sediments and considerably lower than those from rivers and bays emptying into the sound, indicating limited impact from sites of pollutant sources into the sound. Concentrations of sedimentary pollutants peaked in the Pascagoula River where levels of total organic carbon, Kjeldahl nitrogen, phenols, and hydrocarbons exceeded sound values by one to three orders of magnitude. Analysis of cores shows pollutant intrusion to sediment strata predating industrial development. The level of pollution varies from site to site but fortunately is serious only at localized sites within the sound.

Lytle, T. F. and J. S. Lytle. 1985. Pollutant Transport in Mississippi Sound. Sea Grant Publ. No. MASGC-82-038, Mississippi-Alabama Sea Grant Consortium, Gulf Coast Research Laboratory, Ocean Springs, Mississippi, 124 p.
G-2.3, G-3, G-4, G-5, G-6

Because pollution can have a widespread and longlasting effect on the aquatic environment, areas of concern that must emerge in a scientific investigation of pollution are: 1) the types of pollutants present in the system; 2) where pollutants are found: in water, sediments or biota; 3) current state of pollution in the Sound; 4) migration or transport of pollutants throughout the Sound; 5) environmental significance of pollution; and 6) use of scientific data to constructively ameliorate the problem of pollution. The principal investigators began this study in 1979, cognizant of these concerns, and with overall objectives to characterize pollutants in Mississippi Sound, clarify those processes responsible for pollutant movement and develop criteria essential for coastal management based upon sound scientific information.

Madden, C. J. 1986. Distribution and Loading of Nutrients in Fourleague Bay, a Shallow Louisiana Estuary. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana, 143 p.
G-12

Synoptic transects in Fourleague Bay showed nitrate and salinity regimes strongly tied to the hydrologic cycle of the Atchafalaya River. Nitrate peaked in June; lower Bay nitrate profiles followed the upper Bay pattern but at a 40-90 % lower concentration. Phosphate concentrations decreased away from the river to the lower Bay. The primary source of nitrate was the Atchafalaya River and strong non-conservative declines in concentration caused a spatial shift from N:P ratios of over 100:1 in the upper bay to as low as 8:1 in the lower Bay. Retention of water in the bay was highly dependent on the wind regime.

Madden, C. J., J. W. Day, Jr. and J. M. Randall. 1988. Freshwater and marine coupling in estuaries of the Mississippi River deltaic plain. Limnol. Oceanogr. 33(4, part 2):982-1004.
G-10, G-12

The estuaries of Louisiana's Mississippi River deltaic plain exhibit sharp physical and biological contrast due to their different successional stages in delta development. A comparison of the Atchafalaya-Fourleague Bay

complex and the Barataria Basin estuary offers an excellent opportunity to observe coupling of freshwater and marine environments at the extremes of their scale of interaction. Despite being at opposite ends of the delta life cycle, both estuaries are highly productive and perform similar functions as important nursery grounds for juvenile marine and estuarine fishes.

Mahadevan, S., J. Sprinkel, D. Heatwole and D. H. Wooding. 1984. A Review and Annotated Bibliography of Benthic Studies in the Coastal and Estuarine Areas of Florida. With a Selected Compilation of Worldwide Benthic Methodological References and Southeastern United States Benthic Taxonomic References. Project No. IR-79-10. Grant No. NA80AA-D-00038. SGR Report No. 66, Florida Sea Grant College Program, University of Florida, Gainesville, Florida, 576 p.
F-9 through F-28

Over 70 % of benthic information from Florida is in the form of technical reports and unpublished material. While published information could be easily obtained through library searches, unpublished information is often difficult to obtain. As a result, a reasonable compilation of the majority of benthic studies conducted in Florida's waters has not been available to date; this report is an attempt to do so, at least for the coastal and estuarine areas of Florida. The finished project is a compilation of over 1500 benthic studies.

Main, M. B., D. R. G. Farrow and F. D. Arnold. 1987. The National Coastal Pollutant Discharge Inventory. Publicly Owned Treatment Works in Coastal Areas of the USA. Draft Report. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Survey, Rockville, Maryland, 42 p.
F-9 through G-27

In addressing the question regarding publicly owned treatment works' (POTW) relative importance as a source of the pollutants that contribute to water quality problems in estuarine and coastal areas, this report presents estimates of existing and projected wastewater flows, conventional pollutant loadings, and sludge production from POTWs in the nation's coastal areas. A comparison is made to the volume of wastewater discharged from industrial facilities, and the levels of wastewater treatment practiced by POTWs are examined. The information presented provides insights into the relative importance of POTWs as dischargers to the nation's estuarine and coastal waters and to the regional differences that must be considered in the further development and implementation of national pollution control policies.

Maples, R. S., M. D. Cruze and R. Donahoe. 1983. Observations on "red tide" organisms in coastal waters of southwestern Louisiana. Northeast Gulf Sci. 6(2):157-160.
G-7.1, G-15

This paper reports the common occurrence of four species of red tide producing organisms in the estuarine waters of Lake Calcasieu and Calcasieu Pass and offshore locations within 15 km of the pass. Bloom proportions were recorded for *Gonyaulax monilata*.

Marine Environmental Sciences Consortium. 1979. Baseline Data Collection Experimental Monitoring Program, Theodore Ship Channel and Barge Channel Extension, Mobile Bay, Alabama. October, 1977 - October, 1978. Vol. I. Report to Mobile District Corps of Engineers, Contract No. DACW01-78-C-0010. Marine Environmental Sciences Consortium, Dauphin Island, Alabama.
G-2

There is a paucity of coherent field data for the wetlands and Bay area involved with the new ship channels and disposal island. This created the need for a baseline characterization which may be used in conjuction with a monitoring program to ascertain the actual environmental impact of the proposed construction. The majority of samples were taken on a quarterly/seasonal basis with the intention of describing the area's sedimentology,

benthic biology and hydrography including estimates of "turbidity." The adjacent marshes and submersed flora were monitored on the same basis. Hydrographic data (temperature and salinity) were also taken on a continuous basis with recording units while monthly benthic/hydrography sampling was initiated in the spring of 1978. An intensive investigation of dissolved oxygen levels in Deer River was also pursued. General categories of the report are: hydrography, turbidity/suspended solids, bay bottom, monthly samples, grass beds, and Deer River dissolved oxygen.

Martinez, A. R. 1969-1970, 1971, 1972, 1973, 1974, 1975. Coastal hydrographic and meteorological study. In Coastal Fisheries Project Reports for years stated. Texas Parks and Wildlife Dept., Austin, Texas.
G-16 through G-26.2

Hydrographic and meteorological data collected in the field and taken from publications are presented in these reports. Included are yearly reports on the following subjects: rainfall, hurricane damage, tides, water temperature, salinity patterns, dissolved oxygen, hydrogen ion determinations, turbidity readings, river flow measurements, commercial landings, habitat modifications, and fish kills.

Mauer, L. G. and P. L. Parker. 1972. The distribution of dissolved organic matter in the near-shore waters of the Texas coast. Contrib. Mar. Sci. 16:109-124.
G-21, G-22, G-23, G-24, G-25, G-26, G-27

The concentration of dissolved organic matter in the coastal waters of south Texas, estuaries and shelf, was measured. Zones of high and low concentration were found on the shelf. The concentrations in the estuaries (2-5.3 mg/l) were higher than those for shelf waters (1-3.7 mg/l). A new analytical method based on persulfate oxidation and gas chromatographic detection was developed.

May, E. B. 1973. Extensive oxygen depletion in Mobile Bay, Alabama. Limnol. Oceanogr. 18(3):353-366.
G-2

Extensive areas of bottom water in Mobile Bay, Alabama, one of the largest estuaries on the Gulf of Mexico, suffer oxygen depletion in summer because of salinity stratification in sinks created by shoals in the lower bay and by spoil from construction of the Mobile Ship Channel. When these water masses low in dissolved oxygen are occasionally forced against the beach, demersal fishes and crustaceans migrate shoreward in a depressed or moribund state. In the absence of technical, data these popular occurrences, called "jubilees," provide over a century of historical evidence of oxygen depletion. Oxygen depletion and jubilees occurred in the Bay before man physically modified the basin but the conditions responsible for oxygen depletion are worse than in the past. Because of bathymetric changes and modifications that have restricted water circulation, Mobile Bay has exceeded its capacity to assimilate its oxygen demand in summer, which has severely affected the biota of the estuary.

McCoy, E. D. and S. S. Bell. 1985. Tampa Bay: The end of the line? Pages 460-473 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

Vertebrate and invertebrate species composition of the Tampa Bay area were examined to determine the zoogeographical affinities. The authors found little evidence that Tampa Bay serves as a boundary for tropical species of fishes, decapods, polychaetes, gastropods, or bivalves. However, better data, as well as data from other locations, may indicate a pattern different from the one found.

McIntyre, H. L. and J. J. Cullen. 1988. Primary Production in San Antonio Bay, Texas: Contribution by Phytoplankton and Microphytobenthos. Vol. 30. Report to the Texas Water Development Board. University of Texas Marine Science Institute, Port Aransas, Texas. (not in hand)
G-22

McNulty, J. K., W. N. Lindall, Jr. and J. E. Sykes. 1972. Cooperative Gulf of Mexico Estuarine Inventory and Study, Florida: Phase I, Area Description. NOAA Technical Report NMFS CIRC-368, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, 126 p.
F-9 through F-28

Newly developed tables and maps depict the dimensions, submerged vegetation, tidal marshes, mangrove swamps, commercial oyster beds, leased oyster-rearing areas, sources of pollution, drained tidal marshes, and filled areas of Florida's west coast estuaries. Published and unpublished information on temperature, salinity, geology, artificial fishing reefs, stream discharge, human population, commercial fishing, and economic development is presented in new form.

McPhearson, Jr., R. M. 1970. The hydrography of Mobile Bay and Mississippi Sound, Alabama. J. Mar. Sci. Alabama 1(2):1-83.
G-2, G-2.2

Forty-nine hydrographic stations were sampled at least bimonthly in Mobile Bay and Mississippi Sound, Alabama from May 1963 through April 1964. An additional 27 stations were sampled monthly from November 1965 through October 1966. At 671 sites, temperature and salinity (surface and bottom) and turbidity data were taken. Data on mean low water levels, tidal range and flushing, currents, and river discharge are presented and discussed.

McPherson, B. J. and H. R. LaRose. 1982. Algal Conditions in the Caloosahatchee River (1975-1979), Lake Okeechobee to Franklin Lock, Florida. USGS WRI/81-81, U.S. Geological Survey, Water Resource Investigations, Tallahassee, Florida, 28 p.
F-12

Melancon, E. and R. Kilgen. 1991. Nicholls State University Trawl Data on Shrimp and Bottomfish Samples Collected on the Louisiana Continental Shelf from 1975-78. Abstr. for Proceedings of a Meeting of the Louisiana Chapter of the American Fisheries Society, March 1, 1991, Covington, Louisiana.
G-7.1

During the first year of the study, 1975-1976, eight transects spanning the width of Louisiana's continental shelf were sampled. Each transect was divided into 10 sampling stations by depth and ranged from 6 to 110 m. The number of transects was reduced to six in the following year, 1976-1978. All stations were sampled with a 12-m four-seam semi-balloon trawl with a 4.1-cm stretch mesh. All species of shrimp were collected from the trawl samples and a random sample of bycatch taken at each station. Temperature, salinity, pH, and dissolved oxygen were measured at each station. BOD, COD, volatile solids, and some metals were also examined at selected sites.

Menzel, R. W. and E. W. Cake, Jr. 1969. Identification and Analysis of the Biological Value of Apalachicola Bay, Florida. Contract No. 14-12-191, Florida Water Pollution Control Agency, Tallahassee, Florida. (not in hand)
F-24

Miller, R. L. 1980. Phytoplankton Production within the Grass Beds off Goose Point, Lake Pontchartrain, Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana, 138 p.
G-7

Phytoplankton particulate and dissolved production were measured within the grass beds off Goose Point, Lake Pontchartrain, Louisiana. Considerable variation was observed; however, all measures of phytoplankton biomass and production followed the same general seasonal pattern with maximum values occurring during the winter. Particulate production rates ranged from 20.93 to 133.59 $mgC/m^3/h$. Chlorophyll *a* concentrations ranged from 4.6 to 133.59 g/l. Nannoplankton (<53 µm) were the most important component of the phytoplankton and accounted for 90.9 % of production and 91.7 % of biomass. Estimates of phytoplankton production and biomass were negatively related to the presence of the grasses.

Miller, R. L., T. F. Kraemer and B. F. McPherson. 1990. Radium and radon in Charlotte Harbor Estuary, Florida. Estuarine Coastal Shelf Sci. 31(4):439-457.
F-13

Radium-226 and ^{222}Rn activities are greater in the estuarine waters of northern Charlotte Harbor and the lower tidal Peace and Myakka Rivers, Florida, than in either the freshwater reaches of the rivers or waters of the lower estuary and the Gulf of Mexico. The source of the high activity of ^{226}Ra and ^{222}Rn is predominantly ground water inflow. Because of the large ground water input, the contribution of ^{226}Ra from suspended and bottom sediments is a smaller fraction of the total ^{226}Ra input than in many other estuaries.

Mississippi Department of Natural Resources. 1988. Mississippi Water Quality Report, 1988. Pursuant to Section 305(b) of the Clean Water Act. Mississippi Department of Natural Resources, Bureau of Pollution Control, Jackson, Mississippi, 148 p.
G-2.3

The purpose of the 1988 Mississippi Water Quality Report is to identify the status and recent trends of the quality of the State's waters. The state is divided into nine major stream basins with a total length of streams in excess of 15,600 miles. It has been estimated that marsh or wetlands cover an area of 642,000 acres (1003 mi^2). The southern edge of Mississippi borders Mississippi Sound with 81 total coastal miles. The total area of estuarine waters is estimated to cover an area of 133 mi2. Surface water quality in Mississippi is generally good. Most water bodies either meet all applicable water quality standards or fully support their designated uses.

Monaco, M. E., T. E. Czapla, D. M. Nelson and M. E. Pattillo. 1989. Distribution and Abundance of Fishes and Invertebrates in Texas Estuaries. NOAA's Estuarine Living Marine Resources Project, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Rockville, Maryland, 107 p.
G-16, G-17, G-18, G-21, G-22, G-23, G-24, G-25, G-26

This report presents information synthesized on the spatial and temporal distribution, relative abundance, and life history characteristics of 40 fish and invertebrate species in nine estuaries along the Texas coast. The presence, distribution and relative abundance of each species' life history stage, and the time period that it utilizes each estuary, are shown.

Montagna, P. A. and R. D. Kalke. 1989a. The effect of freshwater inflow on meiofaunal and macrofaunal populations in San Antonio, Nueces and Corpus Christi Bays, Texas. Pages 97-148 in P. A. Montagna (ed.), Nitrogen Process Studies (NIPS): The Effect of Freshwater Inflow on Benthos Communities and Dynamics. Final Report to Texas Water Development Board. Technical Report No. TR/89-011, University of Texas Marine Science Institute, Port Aransas, Texas.

G-22, G-24

Two estuaries with very different inflow characteristics were compared to test the hypothesis that benthic productivity is enhanced by freshwater inflow. The Guadalupe estuary had 79 times more freshwater inflow than the Nueces estuary, and a third of the salt content. The Guadalupe had higher macrofaunal densities and biomass than the Nueces, and both parameters increase along a decreasing salinity gradient within the Guadalupe Estuary. Macrofauna density increased with increasing salinity in the Nueces Estuary. Meiofaunal densities were higher in the Nueces estuary, and decreased along increasing salinity gradients in both estuaries. These results indicate that macrofauna may be responding to freshwater inflow with increased productivity. Increased macrofaunal densities appear to be associated with decreasing meiofaunal densities.

Montagna, P. A. and R. D. Kalke. 1989b. A synoptic comparison of benthic communities and processes in the Guadalupe and Lavaca-Tres Palacios estuaries, Texas. Pages 149-183 in P. A. Montagna (ed.), Nitrogen Process Studies (NIPS): The Effect of Freshwater Inflow on Benthos Communities and Dynamics. Final Report to Texas Water Development Board. Technical Report No. TR/89-011, University of Texas Marine Science Institute, Port Aransas, Texas.
G-21, G-22

Water use planning and management in Texas requires that we understand the effect of freshwater inflow on ecological processes that control and maintain productivity in our bays and estuaries. However, there is a large gap in our knowledge. We do not know if generalizations gathered in one estuary are applicable to another. This is true not only in Texas but in the Nation as a whole. We in Texas are fortunate because, within short distances we have access to bays that are very different in the amount of freshwater input and salinity. We can compare parameters across different systems synoptically. Sediment oxygen uptake and nutrient regeneration are good general measures of benthic community metabolism. An important distinction between these two particular estuaries is that the Lavaca has direct exchange with the Gulf of Mexico, and the Guadalupe does not.

Montagna, P. A. and W. B. Yoon. 1989. The effect of freshwater inflow on meiofaunal consumption of sediment bacteria and microphytobenthos in San Antonio Bay, Texas. Pages 1-28 in P. A. Montagna (ed.), Nitrogen Process Studies (NIPS): The Effect of Freshwater Inflow on Benthos Communities and Dynamics. Final Report to Texas Water Development Board. Technical Report No. TR/89-011, University of Texas Marine Science Institute, Port Aransas, Texas.
G-22

Edaphic bacteria and microphytobenthos are known to be food resources for meiobenthic organisms. River inflow is a source of nutrients in estuaries. If inflow results in concomitant primary and secondary production, then meiofauna grazing rates should be higher in the freshwater influenced part of the estuary. Meiofauna grazing rates in San Antonio Bay were 3.5 times greater in the freshwater-influenced zone than in the marine-influenced zone. However, this was due to a predominance of juvenile molluscs in the freshwater zone. Permanent meiofauna all had higher grazing rates in the marine influenced zone. Production of bacteria and microalgae in the head of the estuary was advected, resulting in higher biomass in the lower end of the estuary. Therefore, advection of microbial production from the river is very important in maintaining standing stocks of benthic meiofauna throughout the estuary.

Montagna, P. A., W. B. Yoon and T. E. Whitledge. 1989. The effect of freshwater inflow and sediment resuspension on benthic metabolism and nutrient regeneration in the Guadalupe and Nueces estuaries, Texas. Pages 29-96 in P. A. Montagna (ed.), Nitrogen Process Studies (NIPS): The Effect of Freshwater Inflow on Benthos Communities and Dynamics. Final Report to Texas Water Development Board. Technical Report No. TR/89-011, University of Texas Marine Science Institute, Port Aransas, Texas.
G-22, G-24

Current flow has the potential to increase photosynthesis by resuspending large quantities of chlorophyll, and limiting nutrients into the water column. Resuspension can also enhance the decomposition of sediment organic matter by making buried organic matter available to aerobes and increasing rates of diffusion of metabolites, thus "stirring the pot." Increased flow rates do increase flux of sediment, chlorophyll, ammonia, nitrite, phosphate, and silicate to the water column, but decrease nitrate flux. The nitrate uptake and chlorophyll resuspension indicate that photosynthesis is probably enhanced by resuspension. However, increased photosynthesis is mitigated by increased turbidity and because resuspended pigment has low chlorophyll to phaeophytin ratios. The net effect is that increased current flow does not always result in increased oxygen consumption, since photosynthesis may be stimulated, but this is counter balanced by chemical oxidation of reduced ions released from the sediment.

Moon, R. E. 1985. Point source discharge in the Tampa Bay area. Pages 551-556 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

A point source inventory was performed describing municipalities, industries and commercial businesses which discharge effluent into surface waters of the State and the Tampa Bay areas. Data for the inventory were retrieved from 1980 monthly operating reports required by the State and Federal National Pollutant Discharge System permits. The reports revealed 59 sources along rivers and sites that discharge into the Bay. In 1980, these sources contributed 190 billion gallons of water carrying 2.35 and 3.58 million pounds of phosphorus and nitrogen, respectively, to Tampa Bay. Since 1980, significant reductions in nutrient discharge to the Bay have resulted from alternative sewage disposal methods including spray irrigation, water reuse, land reclamation projects and limited Federal funds.

Moshiri, G. A., N. G. Aumen and W. G. Crumpton. 1981. Reversal of the eutrophication process: A case study. Pages 373-390 in B. J. Neilson and L. E. Cronin (eds.), Estuaries and Nutrients. Proceedings of an International Symposium on the Effects of Nutrient Enrichment in Estuaries, May 29-31, 1979, Williamsburg, Virginia. Contemporary Issues in Science and Society, Humana Press, Clifton, New Jersey.
F-27

Bayou Texar, Pensacola, Florida, is a bayou estuary that was advancing toward eutrophy, due to nutrient loadings from various sources. The occurrence of characteristic symptoms of eutrophication, coupled with the closing of the bayou for water contact recreation, led to the initiation of an intensive 7-yr study. Initial results indicated that Carpenter's Creek is a prime source of most nitrogen species and that an exchange exists between dissolved phosphates and those adsorbed onto sediments. A final study suggested among other things that the importance of toxins from algal blooms to fish kills may be greater than previously indicated. Specific recommendations made after the fourth year of the study were implemented in most part and led to a substantial improvement of water quality and the subsequent opening of the bayou to the public for recreational use.

Moshiri, G. A., N. G. Aumen and W. G. Swann, III. 1980. Water Quality Studies in Santa Rosa Sound, Pensacola, Florida. Grant No. R-803566, U.S. Environmental Protection Agency, Research and Development, Environmental Research Laboratory, Gulf Breeze, Florida, 71 p.
F-27

Water samples were collected from six stations in Santa Rosa Sound and Little Sabine Bay, Florida, every 2 wk between October 1977 and June 1979. The samples, taken at the surface, mid-depth, and bottom of each station, were analyzed for temperature, salinity, pH, transparency, inorganic carbon, 5-d biochemical oxygen demand, dissolved oxygen, orthophosphate, poly-phosphate, ammonia, nitrate, and nonvolatile grease and oil; bacteria were enumerated; phytoplankton were identified and enumerated; and the water column primary

productivity was measured. Although there were seasonal changes, there were few intra- or inter-station differences on each sampling day. However, Little Sabine Bay exhibited lower water transparency, higher BOD, higher rates of primary production, higher concentrations of nonvolatile grease and oil, and larger numbers of bacteria and phytoplankton than Santa Rosa Sound.

Moshiri, G. A., D. Brown, P. Conklin, D. Gilbert, M. Hughes, M. Moore, D. Ray and L. Robinson. 1974. Determination of a Nitrogen-Phosphorus Budget for Bayou Texar, Pensacola, Florida. Research Project Technical Completion Report. Publication No. 29, Florida Water Resources Research Center, University of Florida, Gainesville, Florida, 82 p.
F-27

To date, results indicate that there are numerous sources of nutrients into the Bayou, of which Carpenter's Creek and stormwater runoff are the major contributors. Other sources are runoff from fertilizers applied to lawns, overflow of inadequate sewer lines, and, to a much lesser extent, from sources such as rainwater and encroaching Pensacola Bay waters. Ecologically, the Bayou is approaching eutrophication as is evidenced by highly fluctuating oxygen and primary productivity patterns well correlated with algal cell numbers and distribution. Recommendations made for the improvement of water quality in the Bayou include 1) improvement of circulation by the construction of a new channel, 2) improvement of storm water and sewage facilities, 3) improvement in the Carpenter's Creek channel to alleviate erosion, and 4) selected dredging in areas of heavy siltation in the Bayou in order to improve flushing and circulation.

Moshiri, G. A., W. G. Crumpton and D. A. Blaylock. 1978. Algal metabolites and fish kills in a bayou estuary: An alternative explanation to the low dissolved oxygen controversy. J. Water Pollut. Control Fed. 50:2043-2046.
F-27

Bayou Texar is a shallow bayou estuary that has sustained considerable water quality degradation in recent years as a result of the growing urban development within its drainage basin. Frequent raw wastewater leaks were followed by massive algal blooms and extensive fish kills. Fish kills of this nature have usually been attributed to low concentration of dissolved oxygen in the water, primarily because little information is available on the biotic aspects of the system at the time of the kill. Consequently, these events presented a unique opportunity to observe the possible presence of other less obvious causative factors, particularly those involving certain aspects of physiological changes in the phytoplankton population in respect to specific physicochemical parameters.

Moshiri, G. A., W. G. Crumpton, N. G. Aumen, C. T. Gaetz, J. E. Allen and D. A. Blaylock. 1978. Water-Column and Benthic Invertebrate and Plant Associations as Affected by the Physico-Chemical Aspects in a Mesotrophic Bayou Estuary, Pensacola, Florida. Research Project Technical Completion Report. Publication No. 41, Florida Water Resources Research Center, University of Florida, Gainesville, Florida, 160 p.
F-27

Water column samples were collected every 2 wk over a 1-yr period from three stations in mesotrophic Bayou Texar, Pensacola, Florida. The samples were analyzed for -NO_3, -NH_3, -PO_4, and total organic carbon (TOC) against a background of physical parameters. Phytoplankton and zooplankton populations present during the study period were identified and enumerated. Benthic core samples were collected to assess the macroinvertebrate populations; however, analysis indicated a paucity of organisms in general. Data was subjected to appropriate statistical analysis to indicate possible relationships among aspects studied. Negative correlations appeared between salinity and nitrates, between ammonia and dissolved oxygen (at some stations), between *Brachionus plicatilus* and dissolved oxygen, and between Cryptophytes and dissolved oxygen. Positive correlations were indicated between TOC and ammonia, between *Brachionus* and Cryptophytes, and between *Brachionus* and *Oithona colcarva.*

Murrell, M. C. 1987. Spatial and Temporal Abundance of Meiofauna on a Gulf of Mexico Continental Shelf Affected by Hypoxia. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana, 54 p.
G-7.1

Meiofauna were sampled in shallow (8-13 m) continental shelf waters off the coast of Louisiana at three stations on 13 dates from June 1985 through August 1986. Total meiofauna abundances ranged from 525 to 3406 individuals per 10 cm^2 with a mean of 1810 individuals per 10 cm^2. Peak abundances occurred in late spring and early summer whereas seasonal lows occurred during late summer and winter. Hypoxic waters (dissolved oxygen <2 mg/l) develop seasonally on this shelf as a result of water column density stratification and eutrophication during late spring and summer. Abundances of all taxa declined during the summers of both years apparently in response to hypoxic conditions. Density declines were seasonally correlated with the onset of hypoxia, as inshore stations developed hypoxia later and underwent declines later.

Murrell, M. C. and J. W. Fleeger. 1989. Meiofauna abundance on the Gulf of Mexico continental shelf affected by hypoxia. Continental Shelf Res. 9(12):1049-1062.
G-7.1, G-11

Meiofauna were sampled in shallow (8-13 m) continental shelf waters off the coast of Louisiana at three stations on 13 dates from June 1985 to August 1986. Total meiofauna abundances ranged from 525 to 3406 individuals per 10 cm^2 with a mean of 1810 individuals per 10 cm^2. Peak abundances occurred in late spring and early summer while seasonal lows occurred during late summer and winter. Hypoxic conditions developed seasonally on this shelf as a result of water column density stratification and eutrophication during late spring and summer. Abundances of all taxa declined during the summers of both years apparently in response to hypoxic conditions. A single collection of meiofauna from July 1983 in nearby normoxic Terrebonne Bay at similar water depths reveals a high density and diversity of copepods, further suggesting the sensitivity of copepods to hypoxia.

Myers, V. B. 1977. Nutrient Limitation of Phytoplankton Productivity in North Florida Coastal Systems: Technical Considerations, Spatial Patterns, and Wind Mixing Effects. Ph.D. Dissertation, Florida State University, Tallahassee, Florida, 61 p.
F-22, F-23, F-24

A reliable short-term nutrient enrichment method was developed for the determination of phytoplankton nutrient limitation. Nutrient enrichment experiments conducted in nearshore waters of the northeastern Gulf of Mexico indicated that phytoplankton productivity in these waters was phosphorus-limited. A multiple linear regression model, with phytoplankton productivity regressed against several nutrient and environmental factors, emphasized the importance of phosphorus for phytoplankton productivity. These data suggest that the hypothesis that nitrogen limits phytoplankton productivity in coastal waters is not universally true. Therefore, water quality planning for the coastal zone is best done on a regional basis.

Myers, V. B. and R. L. Iverson. 1981. Aspects of nutrient limitation of the phytoplankton productivity in the Apalachicola Bay system. Pages 68-74 in R. J. Livingston and E. A. Joyce, Jr. (eds.), Proceedings of the Conference on the Apalachicola Drainage System, April 23-24, 1976, Gainesville, Florida. Florida Marine Research Publications No. 26, Florida Dept. of Natural Resources, Marine Research Laboratory, St. Petersburg, Florida.
F-20, F-23, F-24

The quantification of the extent of nutrient limitation in a marine ecosystem is critical for the prediction of the response of the system to various nutrient related stresses. To make sound environmental policy, the critical nutrients and the relationships between these nutrients and plant productivity must be known. The nutrient enrichment and phosphorus uptake experiments presented in this paper suggest that phosphorus is the most

critical limiting nutrient in this estuarine system and that a reduction in phosphate level during summer months could reduce phytoplankton productivity.

Myers, V. B. and R. L. Iverson. 1979. Phosphorus and nitrogen limited phytoplankton productivity in northeastern Gulf of Mexico coastal estuaries. Pages 569-582 in B. J. Neilson and L. E. Cronin (eds.), Estuaries and Nutrients. Proceedings of an International Symposium on the Effects of Nutrient Enrichment in Estuaries, May 29-31, 1979, Williamsburg, Virginia. Contemporary Issues in Science and Society, Humana Press, Clifton, New Jersey.
F-24.1

An understanding of nutrient limitation of estuarine phytoplankton growth is important in making environmentally sound decisions concerning watershed development and the use of aquatic environments for waste disposal. Experiments to determine nutrient limitation of phytoplankton productivity were conducted monthly during the summers of 1975 and 1976 in several shallow north Florida coastal and estuarine systems by inorganic carbon-14 uptake and phosphorus-32 bioassays. The results of these nutrient enrichment experiments suggest that phosphorus is frequently more important than nitrogen in limiting phytoplankton productivity in nearshore northeastern Gulf of Mexico. Nitrogen has been identified as the primary limiting nutrient for phytoplankton in coastal waters, and it has been proposed that the removal of phosphorus from marine waste discharges will have little impact on the control of eutrophication. The observation that phosphorus is important in limiting phytoplankton productivity in these coastal and estuarine areas suggest that water quality planning for the coastal zone is best done on a regional basis, with consideration given to local nutrient cycling processes.

National Estuary Study. 1970a. Apalachicola Bay, Florida. Pages 145-186 in Vol. III, Appendix B - Management Studies in Specific Estuaries. U.S. Dept. of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife and Bureau of Commercial Fisheries, Washington, D.C.
F-24

The Apalachicola Bay system is a complex of lagoons and an estuary located behind a line of barrier islands fronting the prominent cusp of Apalachicola Delta on the northeastern Gulf Coast of the Florida Panhandle. The Bay system is important oceanographically because it is the only Florida Bay into which a large river system drains. It is important biologically and ecologically for several reasons. This report describes the magnitude of commercial and sport fisheries and the uncommon recreational advantages of the Bay. These values are relatively great because the surrounding area is not heavily populated, the few pollution sources have low volumes of discharge, and the coastline has not suffered significant damage from hydraulic engineering projects or other forms of modification. Fish and wildlife values are pronounced in that the economy of all the area surrounding Apalachicola Bay is closely related to the Bay and is fishery oriented.

National Estuary Study. 1970b. Aransas Bay, Texas. Pages 147-214 in Vol. III, Appendix B - Management Studies in Specific Estuaries. U.S. Dept. of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife and Bureau of Commercial Fisheries, Washington, D.C.
G-23

Aransas Estuary, located in Aransas and Refugio Counties, Texas comprises about 111,500 surface acres of land and water. About 28,700 acres of the estuary are salt flats and marshes. The estuary is connected to the Gulf of Mexico by Aransas Pass. Most of the saline waters enter from the east through the Gulf Intracoastal Waterway. The estuary has a well distributed shallow-deep water relationship. Ecological modifications have occurred in the estuary from reduced freshwater inflows and man-made developments and contributions. The habitat in the estuary is of great importance.

National Oceanic and Atmospheric Administration. 1987. National Estuarine Inventory. Data Atlas. Vol. 2: Land Use Characteristics. Strategic Assessment Branch, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, Maryland.
F-9 through G-27

This volume presents area estimates for seven categories and 24 subcategories of land use based on data from the "Land Use and Land Cover Program" of the U.S. Geological Survey (1971-1984).

National Oceanic and Atmospheric Administration. 1989. Galveston Bay: Issues, Resources, Status, and Management. Proceedings of a Seminar, March 14, 1988, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 13, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C., 114 p.
G-17

This seminar was held with the objective of bringing to public attention important research and management issues of our Nation's estuaries. To this end, participants first presented historical and scientific overviews of the Bay area, followed by an examination of management issues by scientists and research managers involved in Galveston Bay.

National Oceanic and Atmospheric Administration. 1990b. Mobile Bay: Issues, Resources, Status, and Management. Proceedings of a Seminar, November 17, 1988, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 15, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C., 147 p.
G-2

The articles in this volume closely correspond to the presentations that were given at this seminar. The contents are: Introduction, Overview, Geological and Geochemical Characterization, Climate and Oceanography, Water Quality, Estuarine Habitats, Faunal Components, Natural Resource Conservation, Economic Aspects, and Coastal Resource Management in Alabama: Past Efforts and Future Needs.

NOAA/EPA Team on Near Coastal Waters. 1990. Susceptibility and Status of Gulf of Mexico Estuaries to Nutrient Discharges. Draft Report. College of Marine Studies, University of Delaware, Newark, Delaware and Strategic Assessment Branch, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, Maryland.
F-9 through G-27

This draft report summarizes the estimated relative susceptibility and estimated status of 23 estuaries in the Gulf of Mexico with respect to nutrient-related pollution. The assessments are based on estimated estuarine characteristics and nutrient loadings and do not reflect actual estuarine measurements of nutrient concentration or documented symptoms of eutrophication.

Oetking, P., R. Back, R. Watson and C. Merks. 1974. Hydrography on the Nearshore Continental Shelf of South Central Louisiana. Final Report of Offshore Ecology Investigation for Gulf Universities Research Consortium, Galveston, Texas. SwRI Proj. No. 03-3720, Southwest Research Institute, Corpus Christi, Texas.
G-7.1

A measure of the salinity, temperature, dissolved oxygen, transmissivity and currents was made on the nearshore continental shelf of south central Louisiana to develop baseline data and to determine whether offshore production platforms affect the water column. Data from 10 Offshore Ecology Investigation cruises,

between August 1972 and January 1974, were used to determine daily, seasonal and areal trends for each of the parameters. Graphic sections of each day's findings were constructed to reflect the changes in the water column caused by geographic position, depth, time, air/sea conditions and offshore production platforms. These profiles and the season average displays showed large variations in dissolved oxygen, zones of highly turbid water, multiple layers of current, lenses of brackish water offshore and a few temporary changes in the water column near offshore structures. Current data included in the daily profile displays are discussed on a seasonal basis in an accompanying OEI paper.

Olinger, L. W., R. G. Rogers, P. L. Fore, R. L. Todd, B. L. Mullins, F. T. Bisterfeld and L. A. Wise II. 1975. Environmental and Recovery Studies of Escambia Bay and the Pensacola Bay System, Florida. Publ. No. EPA 904/9-76-016, U.S. Environmental Protection Agency, Region IV, Atlanta, Georgia.
F-27

The Escambia Bay Recovery Study (EBRS) was established when public concern over the degradation of the waters of Escambia Bay, Florida prompted a multidisciplinary team of EPA scientists to determine methods of accelerating the recovery of Escambia Bay over and above reducing waste reductions into the Bay. Goals were to document conditions in the Pensacola Bay system under various environmental situations, determine the significant mechanisms causing degradation to the ecosystem of Escambia Bay, determine the feasibility of restoration schemes. The report documents pollution sources, hydrodynamics, sediments, water quality and natural history aspects.

O'Neil, P. E. and M. F. Mettee (eds.). 1982. Alabama Coastal Region Ecological Characterization: 2. A Synthesis of Environmental Data. Report to U.S. Dept. of the Interior, Fish and Wildlife Service, National Coastal Ecosystems Team. Information Series No. 61, Geological Survey of Alabama, University, Alabama, 346 p.
G-1, G-2, G-2.1, G-2.2

The purpose of this report is to summarize all available information on the natural resources of coastal Alabama. Data included will be used by the U.S. Fish and Wildlife Service and Bureau of Land Management, Outer Continental Shelf office to plan for the development of outer continental shelf oil and gas reserves offshore of Alabama. The report is divided into two sections. The first section contains a detailed description of the geology and geography, hydrology, climate, plant and animal life, and threatened and endangered species of coastal Alabama. The second section of the report (not cited) presents a conceptual model and supporting text on four natural and two manipulated systems.

Orlando, Jr., S. P., L. P. Rozas, G. H. Ward and C. J. Klein. 1991. Analysis of Salinity Structure and Stability of Texas Estuaries. Strategic Assessment Branch, NOS/NOAA, Rockville, Maryland, 97 p.
G-116, G-17, G-18, G-21, G-22, G-23, G-24, G-26

The report for this project refines both the temporal and spatial aspects of salinity as depicted in the original National Estuarine Inventory, Volume 1, by characterizing both its "structure" and "stability." Salinity structure refers to its spatial distribution at a given time. The current effort improves over the three previously established zones by defining salinities at 5-ppt increments for both the surface and bottom layers of the water column for two seasonal periods reflective of representative high and low salinity conditions. Salinity stability addresses the temporal variability and characterizes the dominant time scales over which the salinity structure exhibits its greatest differences due to the frequency, magnitude and duration of events that may potentially alter this structure.

Otvos, Jr., E. G. 1978. Calcareous benthic foraminiferal fauna in a very low salinity setting, Lake Pontchartrain, Louisiana. J. Foraminiferal Res. 8(3):262-269.
G-7

Lake Pontchartrain is a large, semi-enclosed, shallow, coastal embayment, with bottom salinities commonly in the 1-5 % range, at certain locations infrequently reaching values of 12-19 %. In addition to the exclusively agglutinated, brackish fauna, calcareous forms dominate large areas. Indications are strong that the calcareous forms originated in the Gulf of Mexico and, helped by tidal currents, most of them reached the lake through the Gulf Outlet Canal. This is confirmed by the absence of calcareous forms in the most saline eastern section of the lake which is separated from the open Gulf by the brackish waters of Lake Borgne and the western Mississippi Sound. The patchy distribution of sediments with high percentages of calcareous foraminifera may be related to a number of factors such as bottom currents and nutrient distribution in the sediment and water.

Pacheco, P. A., D. R. G. Farrow, T. Manuelides and S. O. Rohmann. 1989a. Point Source Discharges in Coastal Areas of Alabama. A Summary by Estuarine Watershed for 1987. Draft. The National Coastal Pollution Discharge Inventory Program. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Rockville, Maryland, 34 p.
G-1, G-2, G-2.2

This report presents an inventory of the 38 major and 153 minor direct discharging point sources located in the National Coastal Pollutant Discharge Inventory (NCPDI) study area in Alabama. It also summarizes estimates of annual wastewater and pollutant discharges from these facilities for 16 pollutants. The estimates reflect discharges for the period December 1986 through November 1987 (base year 1987), and are organized by the five estuarine drainage areas in the study area. This report is the first in a series that is being compiled for each state bordering the Gulf of Mexico, as part of an effort to update and improve the estimates in the NCPDI.

Pacheco, P. A., D. R. G. Farrow, T. Manuelides and S. O. Rohmann. 1989b. Point Source Discharges in Coastal Areas of Mississippi. A Summary by Estuarine Watershed for 1987. Draft. The National Coastal Pollution Discharge Inventory Program. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Rockville, Maryland, 32 p.
G-2.3, G-4, G-5, G-6

This report presents an inventory of the 24 major and 217 minor direct discharging point sources located in the National Coastal Pollutant Discharge Inventory study area in Mississippi. It also summarizes estimates of annual wastewater and pollutant discharges from these facilities for 16 pollutants. The estimates reflect discharges for the period December 1986 through November 1987 (base year 1987), and are organized by the two estuarine drainage areas in the study area. This report is the second in a series that is being compiled for each state bordering the Gulf of Mexico, as part of an effort to update and improve the estimates in the NCPDI.

Pacheco, P. A., D. R. G. Farrow, T. Manuelides, S. O. Rohmann, M. J. Katz and J. McLeod. 1989c. Point Source Discharges in Coastal Areas of Texas. A Summary by Estuarine Watershed for 1987. Draft. The National Coastal Pollution Discharge Inventory Program. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Rockville, Maryland, 71 p.
G-16, G-17, G-18, G-19, G-22, G-23, G-24, G-26

This report summarizes annual wastewater and pollutant discharge estimates for 15 pollutants for 306 major and 1116 minor direct discharging point sources in the National Coastal Pollutant Discharge Inventory study area in Texas. The estimates reflect discharges between December 1986 and November 1987 (base year 1987), and are organized by the eight estuarine drainage areas in the study area . This report is the third in a series for states bordering the Gulf of Mexico, and is part of an effort to update and improve NCPDI discharge estimates.

Parker, Jr., F. R. and C. M. Bailey. 1979. Massive aggregations of elasmobranchs near Mustang and Padre Islands, Texas. Tex. J. Sci. 31(3):255-266.
G-27

From June 1 to June 4, 1977, large aggregations of elasmobranchs were observed along Gulf of Mexico beaches in the vicinity of Padre and Mustang Island, Texas. Climatological conditions produced unusually transparent water allowing observation of the aggregation. Resulting hydrological conditions favored concentration of prey species in the shallow surf zone. Feeding was observed, evidence of recent birth recorded, and mating behavior indicated in several species of elasmobranch. All of the species identified have been previously reported to occur in the Gulf of Mexico.

Parker, R. H., A. L. Crowe and L. S. Bohme. 1980. Vol. I - Describe Living and Dead Benthic (Macro-Meio-) Communities. In W. B. Jackson and G. M. Faw (eds.), Biological/Chemical Survey of Texoma and Capline Sector Salt Dome Brine Disposal Sites off Louisiana, 1978-1979. NOAA Tech. Memo NMFS-SEFC-29, NOAA/NMFS Final Report to DOE. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Galveston, Texas, 103 p.
G-7.1

A baseline survey of megabenthic and meiobenthic assemblages near two proposed brine disposal areas was conducted from June 1978 through May 1979. Temporal changes occurred in species composition and abundance at both sites. Both sites were characterized by low dissolved oxygen values during the summer cruise. Little correlation between faunal abundance or diversity and sediment type or bacteria counts was found at the station, site, or seasonal level, although community composition differed considerably between the two sites. The inference suggested is that abundance and diversity are random but unique for each overall site, suggesting sampling pattern or frequency is relatively unimportant in determining average production for the region only.

Pascale, C. A. and J. R. Wagner. 1982. Water Resources of the Ochlockonee River Area, Northwest Florida. Water-Resources Investigations Open-File Report No. 81-1121, U.S. Dept. of the Interior, Geological Survey, Tallahassee, Florida, 114 p.
F-23

The Ochlockonee River area comprises about 1420 square miles in the panhandle of northwest Florida. In 1975, the population of the area was about 48,000. Water use averaged 11.4 mil gal per day; about half was pumped from wells and half from streams. The area receives 57 in/yr of precipitation on the average. Much of this water enters the surficial sand aquifer, seeps to streams, or enters the underlying water-bearing zone of the upper confining unit and the Floridan aquifer. The water-bearing zone of the upper confining unit is used for rural domestic supplies and is also important because the water it stores is a source of recharge to the underlying Floridan aquifer.

Paulson, Jr., O. L., G. F. Pessoney, H. Battalora, R. Williams, J. Eastman and G. Pruitt. 1977. Flushing characteristics of a Mississippi dead-end canal system. Water Resour. Bull. 13(2):341-348.
G-5

A study of a residential canal system on the Mississippi Gulf Coast and adjacent natural water bodies was conducted to determine the relationship in flushing characteristics between manmade and natural systems. The comparison was based on measurements of temperature, salinity, conductivity, coliform, pH, transparency, biological oxidation demand, dissolved oxygen, bathymetry, tides, water velocity, and Rhodamine dye concentrations. The results indicate that coliform bacteria increase with increasing distance of stations from St. Louis Bay and dissolved oxygen decreases in a similar manner. Biological oxidation demand was low at all stations, showing no differences between natural and manmade systems. The other parameters measured showed little or no differences between natural and manmade systems, but reflect overall seasonal changes.

Pavela, J. S., J. L. Ross and M. E. Chittenden, Jr. 1983. Sharp reductions in abundance of fishes and benthic macroinvertebrates in the Gulf of Mexico. Northeast Gulf Sci. 6(2):167-173.

G-27

Natural depletion of dissolved oxygen to hypoxic (<2.0 mg/l) or anoxic levels in bottom waters of the continental shelf of the northwestern Gulf of Mexico has been recognized since the mid-1930s. Subsequent, but primarily unpublished, studies suggest this is a recurrent hydrographic feature off Louisiana. Little has been published about the effects of natural hypoxia on fishes, shrimps and other macroinvertebrates in the northwestern Gulf despite its apparent frequency and the valuable fisheries in that region. This paper documents sharply reduced abundance and the elimination of both fishes and shrimps coincident with hypoxia off Texas and presents general observations about decreases in common benthic macroinvertebrates.

Pechmann, K. B., J. O. Ellis, F. G. Everdale, S. Z. Green, I. C. Sheifer and M. K. Stern. 1986. Marine Environmental Assessment. Gulf of Mexico. 1985 Annual Summary. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Marine Environmental Assessment Division, Washington, D. C., 114 p.
F-9 through G-27

The 1985 annual assessment presents a synoptic view of several economic sectors and their direction and indirect relations to the physical and biological aspects of the marine and atmospheric environments. The geographical area considered is Key West, Florida to Brownsville, Texas. A summary of weather and oceanographic events during 1985 over the region is presented. Three economic sectors appear in the report: fisheries, recreation and transportation.

Perry, H. M. 1980. Dinoflagellate blooms occur off Louisiana. Coastal Oceanography and Climatology News 3(1):3.
G-7.1, G-8.1, G-10

Widespread dinoflagellate blooms were reported off Louisiana in September. A fish kill, attributed to the presence of this water mass, occurred later in the afternoon. On September 24, areas of red water were noted in Breton and Chandeleur Sounds. Samples taken west of the Mississippi River contained large numbers of the toxic dinoflagellate, *Gonyaulax monilata.*

Perry, H. M. and J. A. McLelland. 1981a. Blooms continue to cause red tides in coastal waters of Mississippi. Coastal Oceanography and Climatology News 4(1):1-2.
G-2.3, G-5.1

While small nearshore plankton blooms have occurred frequently in local waters for many years, large-scale outbreaks of discolored water in Mississippi Sound and the adjacent Gulf of Mexico were not observed prior to 1974. Since then, several major outbreaks of red tide have occurred. The causative organisms include *Oscillatoria erythraea, Gonyaulax monilata*, and *Prorocentrum minimum.*

Perry, H. M. and J. A. McLelland. 1981b. First recorded observance of the dinoflagellate *Prorocentrum minimum* (Pavillard) Schiller 1933 in Mississippi Sound and adjacent waters. Gulf Res. Rep. 7(1):83-85.
G-2.3, G-4, G-5

This paper documents the occurrence of the dinoflagellate *Prorocentrum minimum* in Mississippi Sound and adjacent coastal waters. Outbreaks of discolored water are attributed to blooms of *P. minimum* in February 1977 and in January and February 1981. Data are presented on the seasonality of the organism in St. Louis Bay. Observations on water appearance and a descriptive analysis of the cells are presented for the 1981 blooms.

Perry, H. M., K. C. Stuck and H. D. Howse. 1979. First record of a bloom of *Gonyaulax monilata* in coastal waters of Mississippi. Gulf Res. Rep. 6(3):313-316.
G-2.3

Data are presented on a bloom of the toxic dinoflagellate *Gonyaulax monilata* in coastal waters of Florida, Alabama, Mississippi and Louisiana. This paper documents the first record of a bloom of this species in Mississippi Sound and adjacent Gulf of Mexico.

Poirrier, M. A. 1979. Epifaunal invertebrates as monitors of water quality in Lake Pontchartrain. Pages 105-111 in J. W. Day, Jr., D. D. Culley, Jr., R. E. Turner and A. J. Mumphrey, Jr. (eds.), Environmental Conditions in the Louisiana Coastal Zone. Proceedings of the Third Coastal Marsh and Estuary Management Symposium, March 6-7, 1978, Baton Rouge, Louisiana. Division of Continuing Education, Louisiana State University, Baton Rouge, Louisiana.
G-7

The distribution and abundance of epifaunal invertebrates was investigated as a means of assessing and monitoring the impact of adverse water quality upon aquatic life. Species zonation along pollution and salinity gradients in Lake Pontchartrain was studied. Many species occurred in zones along these gradients, indicating a relationship between water quality and distribution, and, hence, potential as indicator species. As in other studies, the number of species decreased along pollution gradients and highly polluted habitats were dominated by tolerant, opportunistic forms. Salinity was found to be the factor most highly correlated with species distribution. Several species appeared to be good salinity indicators because of changes in abundance and morphology along salinity gradients.

Poirrier, M. A. 1978. Studies of salinity stratification in southern Lake Pontchartrain near the Inner Harbor Navigation Canal. Proc. La. Acad. Sci. 41:26-35.
G-7

Stratification was studied at 12 stations located within 10 km of the Inner Harbor Navigation Canal in Southern Lake Pontchartrain. Surface and bottom measurements of salinity, temperature and dissolved oxygen were made monthly from July 1976 through June 1977. Salinity stratification occurred in late spring, summer and fall and mixing occurred in winter. Stratification decreased with distance from the canal, and low bottom dissolved oxygen concentrations were found at stratified stations.

Poirrier, M. A., J. S. Rogers, M. A. Mulino and E. S. Eisenberg. 1975. Epifaunal Invertebrates as Indicators of Water Quality in Southern Lake Pontchartrain. Tech. Rept. No. 5, Louisiana Water Resources Research Institute, Louisiana State University, Baton Rouge, Louisiana, 43 p.
G-7

The distribution and relative abundance of estuarine epifaunal invertebrates can be used to detect water quality differences. Epifaunal invertebrate associations were affected by salinity and stormwater discharge. Differences among both biological and physico-chemical stations were related to discharge of more saline water by the Industrial Canal and quality differences of outfall canal discharge. In 1973, the opening of the Bonnet Carre Spillway added alkaline nutrient-rich, fresh water from the Mississippi River and affected all water quality parameters. Gradual changes occurred as the river water was flushed from the Lake. Increased phytoplankton growth resulted from the addition of nutrients. Epifaunal invertebrates were not greatly affected because 26 predominantly estuarine taxa were present 6 weeks after the spillway was closed.

Pokryfki, L. B. 1985. Measurement and Analysis of Hypoxia in Texas-Louisiana Coastal Waters. M.S. Thesis, Texas A&M University, College Station, Texas, 130 p.
G-7.1, G-27

Hypoxia, and occasionally anoxia, occur annually in the northern Gulf of Mexico. Significant parameters preceding and partially causing hypoxia, and the spatial extent of hypoxia, are determined. Temporal trends of salinity, temperature, sigma-*t*, bottom dissolved oxygen, and river discharge, off Cameron, Louisiana are described and statistically analyzed using 4 years (1981-1984) of data obtained from the Strategic Petroleum

Reserve Program. A special cruise was conducted in July of 1984 to measure the spatial extent of hypoxia in coastal waters from Galveston, Texas to 74 km east of Cameron, Louisiana. A "best-fit" linear model estimating bottom dissolved oxygen concentration contained the salinity and temperature variables. Time-series analysis of the SPR data revealed time lags between low bottom dissolved oxygen and peak river discharge (2-mo lag), and low salinity (1-mo lag). A time-series model more accurately predicted bottom oxygen concentrations during hypoxic events using the river discharge and density gradient variables.

Pokryfki, L. B. and R. E. Randall. 1987. Nearshore hypoxia in the bottom water of the northwestern Gulf of Mexico from 1981 to 1984. Mar. Environ. Res. 22(1):75-90.
G-7.1, G-27

Hypoxia, and occasionally anoxia, occur annually in the northern Gulf of Mexico. Important physical properties preceding and partially causing hypoxia and the spatial extent of hypoxia are determined. Temporal trends of salinity, temperature, sigma-*t*, bottom dissolved oxygen, and river discharge offshore Cameron, Louisiana, are described and statistically analyzed using 4 years (1981-1984) of monthly data. A cruise was conducted in July 1984 to measure the spatial extent of hypoxia in coastal waters from Galveston, Texas, to 74 km east of Cameron, La. A "best-fit" linear model estimating bottom dissolved oxygen concentrations contained the salinity and temperature variables. Time series analysis of the data revealed time lags between low bottom dissolved oxygen and peak river discharge (2-mo lag), and low salinity (1-mo lag). The time-series model using the river discharge and density gradient variables more accurately predicted bottom dissolved oxygen concentrations during hypoxic events.

Post, Buckle, Schuh and Jernigan, Inc. 1984. Hydrodynamic and Water Quality Analysis of Caloosahatchee Estuary. Draft Report. Southwest Florida Regional Planning Council, Ft. Meyers, Florida. (not in hand)
F-12

Price, K. C. 1974. Analysis of Water Quality Data - Timbalier Bay, Louisiana (August, 1972 - January, 1974). Final Report, Part I. Gulf South Research Institute, New Iberia, Louisiana.
G-11

Low oxygen concentrations were found at one station in July. All others were greater than 4 or 5 ppm.

Price, K. C. 1979. Onshore hydrography of Timbalier Bay, Louisiana. In C. H. Ward, M. E. Bender and D. J. Reish (eds.), The Offshore Ecology Investigation. Effects of Oil Drilling and Production in a Coastal Environment. Rice University Studies, Texas 65(4&5):145-157.
G-11

Synoptic measurements of salinity, temperature, dissolved oxygen, and transparency were made in Timbalier Bay, Louisiana, over a 2-yr period (1972-1974) to assess the effects of petroleum-related activities upon these parameters. A total of 214 stations was sampled. No measurable effects attributable to such activities were found. Seasonal effects during the study period accounted for the greatest variations observed.

Pulich, Jr., W. M. 1980. Ecology of a hypersaline lagoon: The Laguna Madre. Pages 103-122 in P. L. Fore and R. D. Peterson (eds.), Proceedings of the Gulf of Mexico Coastal Ecosystems Workshop, September 4-7, 1979, Port Aransas, Texas. Biological Services Program Publ. FWS/OBS-80/30, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C.
G-26

A coastal Gulf of Mexico ecosystem, the Texas Laguna Madre has long been a fascinating place to scientists because it represents one of only three oceanic hypersaline lagoons in the world. The purpose of this paper is to 1) describe the present habitat of the Laguna, pointing out major changes that have occurred in the last

decade; 2) present evidence for the probable causes of the evolutionary developments; and 3) outline some critical ecological questions which require future study if the dynamic Laguna ecosystem is to be preserved.

Pulich, Jr., W. M. and W. A. White. (in press). Decline of submerged vegetation in the Galveston Bay system: Chronology and relationships to physical processes. J. Coastal Res. (not in hand)
G-17

Pulich, Jr., W., W. A. White, M. Castiglione and R. J. Zimmerman. 1991. Status of submerged vegetation in the Galveston Bay system. Pages 127-132 in F. S. Shipley and R. W. Kiesling (eds.), Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Publication GBNEP-6, 220 p.
G-17

See Shipley and Kiesling (1991).

Pullen, E. J., W. L. Trent and G. B. Adams. 1971. A Hydrographic Survey of the Galveston Bay System, Texas, 1963-66. NOAA Technical Report NMFS-SSRF-639, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, NMFS Biological Laboratory, Galveston, Texas, 13 p.
G-17

Water temperature and salinity data, taken during 1963-1966, and dissolved organic nitrogen, total phosphorus, and dissolved oxygen data taken during 1964-1966 from Galveston Bay, Texas were analyzed by area and habitat (depth strata). Temperatures ranged from 0.4 to 36.0 °C during the study. Salinities ranged from 0.1 to 36.6 ppt. Dissolved organic nitrogen concentrations ranged from 1 to 300 µg- at/l. Total phosphorus concentrations ranged from 0.1 to 47.5 µg at/l. Dissolved oxygen concentration ranged from 0.2 to 13.6 ml/l. Lowest oxygen concentrations were in the channels and highest and similar concentrations were in the peripheral and open-water habitats. Oxygen values were inversely correlated with water temperatures.

Rabalais, N. N. 1987. Oxygen depleted waters on the Louisiana continental shelf. Pages 314-320 in Proceedings of the Seventh Annual Information Transfer Meeting, Minerals Management Service, November 4-6, 1986. OCS Study MMS 87-0058, U.S. Dept. of the Interior, Minerals Management Service, New Orleans, Louisiana.
G-7.1

Rabalais, N. N. 1988. Hypoxia on the continental shelf of the northwestern Gulf of Mexico. Pages 81-87 in T. Mitchell (ed.), Physical Oceanography of the Louisiana-Texas Continental Shelf. Proceedings of a Symposium, May 24-26, 1988, Galveston, Texas. OCS Study MMS 88-0065, U.S. Dept. of the Interior, Minerals Management Service, New Orleans, Louisiana, 198 p.
G-7.1

In mid-summer of 1985, 1986, and 1987, critically depressed dissolved oxygen concentrations below 2 mg/l occurred over large (ca. 8000 to 9500 km^2) areas of the shelf from the Mississippi River delta onto the upper Texas coast. Stations in 5 to 30 m water depth situated along a transect off Terrebonne and Timbalier Bays were sampled intensively from June 1985 through 1986. Strong pycnoclines and oxyclines and low oxygen conditions were persistent through the middle of August 1985, after which the water column was mixed by waves from a series of tropical depressions and hurricanes. Areas of oxygen deficient bottom waters began to develop as early as mid-April through late May in 1986 but did not become persistent until mid-June. The summer of 1986 was an inactive hurricane season, and stratified waters and low oxygen conditions persisted through mid-October. The zones were persistent, continuous, and intense from mid-June through mid-August.

Rabalais, N. N. 1990. The Dead Zone. Gulfwatch 2(2):1,4,7.
G-7.1

Rabalais, N. N. and D. F. Boesch. 1986/87. Extensive depletion of oxygen in bottom waters of the Louisiana shelf during 1985. Coastal Ocean Pollution Assessment News 3(4):45-47.
G-7.1

Bottom water oxygen data from 1985 on the southeastern Louisiana shelf for June through November and shelfwide for July are summarized. Hypoxia was present when monitoring began on June 14 and continued through early August. The extent of oxygen-depleted bottom waters in July covered 8000 km^2. A series of tropical storms and hurricanes mixed the water column from August 14-15 through late October.

Rabalais, N. N., M. J. Dagg and D. F. Boesch. 1985. Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters: Gulf of Mexico. Report to the U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Services, Ocean Assessments Division, Rockville, Maryland, 60 p.
G-1 through G-27

Oxygen depletion occurs in the estuaries and continental shelf waters of the northern and northwestern Gulf of Mexico even though these regions are characteristically shallow and usually subject to wind mixing. Hypoxia or anoxia is most frequent in disturbed habitats, harbors and channels, or where freshwater runoff can provide a mechanism for density stratification. Significant oxygen depletion occurs not only in shallow bays and estuaries where patterns and causes are often identifiable but also in larger areas offshore, especially to the west of the Mississippi River and the Atchafalaya River, where patterns and causes are less well known. Hypoxia is observed frequently in many regions, for instance, Wolf and Perdido Bays, Mobile Bay, Mississippi Sound, Lake Pontchartrain, and the Louisiana inner continental shelf.

Rabalais, N. N., B. A. McKee, D. J. Reed and J. C. Means. 1991b. Fate and Effects of Nearshore Discharges of OCS Produced Waters. Vol. I. Executive Summary, Vol. II. Technical Report, Vol. III. Appendices. Rept. No. OCS Study/MMS 91-0004, 91-0005, 91-0006, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana, 48 p., 337 p., 225 p.
G-9, G-10, G-11, G-1

Estimates as of March 1991 indicate that 253,994 bbl/d of produced waters originating on the Federal OCS are piped ashore for treatment and discharge into nearshore waters. This represents 25 % of the produced waters generated on the Federal OCS and 13% of all produced waters discharged into the coastal waters of the State. Of the 15 facilities that discharge OCS-generated produced waters into the coastal environments of Louisiana (as of February 1990), ten discharges in seven areas were studied. The volumes discharged in the study areas ranged from 3000 to 106,000 bbl/d. The receiving environments of these effluents included the shallow, nearshore continental shelf; high energy, freshwater distributaries of the Mississippi River delta; and brackish and saline coastal environments with moderately to poorly flushed waters. Elevated levels of dissolved solids (salinity), volatile organic hydrocarbons, sulfides, and total radium activities identified the brine effluent in the waters overlying the sediments. Where the water column was strongly stratified and/or sulfides were present in near-bottom waters, low oxygen concentrations were measured. Sediments up to 1300 m from the produced water discharges exhibited evidence of contamination by petrogenic hydrocarbons. Effects on benthic macroinfauna were demonstrated at most of the study areas. Bioaccumulation studies showed the clear potential for uptake and accumulation of produced water origin contaminants by oysters, both in close proximity to the discharges and at great distances from the discharges.

Rabalais, N. N., R. E. Turner, W. J. Wiseman, Jr. and D. F. Boesch. 1986a. Hydrographic, Biological, and Nutrient Characteristics of the Water Column in the Mississippi River Delta

Bight, June, 1985 to December, 1985. Data Report No. 2, Louisiana Universities Marine Consortium, Chauvin, Louisiana.
G-7.1

In June 1985, a focused study was initiated to assess the spatial and temporal extent, intensity, and potential causes of oxygen depletion in the northern Gulf of Mexico. Hypoxic bottom waters were studied along two transects (one off Cat Island Pass near Cocodrie and one off Belle Pass off Port Fourchon) in the Mississippi River Delta Bight area. Temperature, pH, dissolved oxygen, conductivity, salinity and depth were measured with a Hydrolab Surveyor II Water Quality Data System at 1-, 2-, or 3-m intervals through the water column. Water for chlorophyll and nutrient analyses was collected from surface and bottom waters in Niskin bottles. Selected parameters (dissolved oxygen and sigma-*t*) are illustrated for each transect on each sample date. Hydrographic, chlorophyll, and nutrient data for the cruises follow the figures.

Rabalais, N. N., R. E. Turner, W. J. Wiseman, Jr. and D. F. Boesch. 1986b. Hydrographic, Biological, and Nutrient Characteristics of the Water Column on the Louisiana Shelf, July and September, 1985. Data Report No. 3, Louisiana Universities Marine Consortium, Chauvin, Louisiana.
G-7.1

In June 1985, a focused study was initiated to assess the spatial and temporal extent, intensity, and potential causes of oxygen depletion in the northern Gulf of Mexico. Two shelfwide, quasi-synoptic cruises were conducted from the Mississippi River to the Texas border during mid-July and early September, 1985. Temperature, pH, dissolved oxygen, conductivity, salinity and depth were measured with a Hydrolab Surveyor II Water Quality Data System at 1-, 2-, 3- or 5-m intervals through the water column. Water for chlorophyll and nutrient analyses was collected from surface, mid-depths, and bottom water in Niskin bottles. Selected parameters (dissolved oxygen and sigma-*t*) are illustrated for each transect on each cruise. These and additional parameters are contoured for the entire shelf. Hydrographic, chlorophyll, and nutrient data for the cruise follow the figures.

Rabalais, N. N., R. E. Turner, W. J. Wiseman, Jr. and D. F. Boesch. 1991a. A brief summary of hypoxia on the northern Gulf of Mexico continental shelf: 1985-1988. Pages 35-47 in R. V. Tyson and T. H. Pearson (eds.), Modern and Ancient Continental Shelf Anoxia. Geological Society Special Publication No. 58, The Geological Society, London, 470 p.
G-7.1

Oxygen-deficient conditions occur from April to October on the inner to middle continental shelf of the northern Gulf of Mexico and may cover up to 9500 km^2 during mid-summer off the Louisiana coast. Hypoxic bottom waters are found in 5-60 m water depth, 5-60 km offshore and extend up to 20 m above the bottom. Salient forcing functions contributing to hypoxic water formation, maintenance and break-up are presented.

Ragan, J. G., A. H. Harris and J. H. Green. 1978. Temperature, salinity and oxygen measurements of surface and bottom waters on the continental shelf off Louisiana during portions of 1975 and 1976. Nicholls State University Prof. Paper Ser. (Biol.) 3:1-29.
G-7.1

The data presented in this 1975-1976 study contribute to the existing hydrographic data base and are unique in some respects. They exceed the scope of previous efforts in covering a wider range of depth contours (6-110 m) in all geographical regions of the Louisiana Shelf, and includes oxygen as well as temperature and salinity data for surface and bottom waters. Temperature, salinity and dissolved oxygen were recorded at 1 m above the bottom and one meter below the surface at each station. Most transects were occupied four to six times between September 1975 and August 1976. Hydrographic data were taken in conjunction with an effort that was mainly designed to sample shrimp and fish.

Randall, J. M. and J. W. Day, Jr. 1987. Effects of river discharge and vertical circulation on aquatic primary production in a turbid Louisiana (USA) estuary. Neth. J. Sea Res. 21(3):231-242.
G-12

Aquatic primary production was measured at two sites in Fourleague Bay, a shallow, turbid estuary on the central Louisiana coast receiving flow from the Atchafalaya River. Riverflow strongly influenced spatial and seasonal patterns of production. Net production was negatively correlated with seasonal changes in riverflow at both sites (upper Bay and lower Bay). Maximum production rates occurred at intermediate salinities. At low salinities in the upper Bay, production was apparently limited due to turbidity; at higher salinities in the lower Bay, production declined despite greater water clarity, apparently due to nitrogen limitation.

Ray, S. M. 1981. Areas of low dissolved oxygen, Gulf of Mexico. Pages 16-17 in P. F. Sheridan and S. M. Ray (eds.), Report of the Workshop on the Ecological Interactions between Shrimp and Bottomfishes, April, 1980. NOAA Technical Memo. NMFS-SEFC-63, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Southeast Fisheries Center, Galveston Laboratory, Galveston, Texas.
G-7.1, G-27

Comments on the occurrence of low oxygen waters on the southeastern Louisiana shelf during 1973-1974, the central Louisiana shelf in 1978, and the upper Texas coast in 1979. Hypoxic bottom waters on the continental shelf may seriously affect annual recruitment, migration, population distribution, food supply, and mortality of the shrimp and bottomfish. Consideration of this phenomenon would seem to be of critical importance, since the shelf region of the northern Gulf of Mexico that is most likely to be affected by hypoxic conditions related to influx of fresh water coincides with major areas of shrimp and bottomfish production.

Reitsema, L. A. 1980. Vol. II - Determine Seasonal Abundance, Distribution and Composition of Zooplankton. In W. B. Jackson and G. M. Faw (eds.), Biological/Chemical Survey of Texoma and Capline Sector Salt Dome Brine Disposal Sites off Louisiana, 1978-1979. NOAA Tech. Memo NMFS-SEFC-29, NOAA/NMFS Final Report to DOE. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Galveston, Texas, 133 p.
G-7.1

Five stations were sampled for zooplankton at each of two sites offshore Louisiana during four collection periods during 1978 and 1979. A bongo net and neuston net were deployed three times at each station during four seasons. Each site is a proposed location for the offshore disposal of brine for the Strategic Petroleum Reserve Program. The purpose of this study was to characterize the sites in terms of the seasonal and spatial zooplankton and ichthyoplankton communities. The two sites were similar in terms of dominant taxa and the density of planktonic organisms. Cluster analyses indicated greater differences between collecting dates than between sites in terms of the taxa collected and their densities.

Renaud, M. L. 1985. Annotated Bibliography on Hypoxia and its Effects on Marine Life, with Emphasis on the Gulf of Mexico. NOAA Technical Report NMFS-21, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, 9 p.
G-2, G-6 through G-15, G-17, G-27

This bibliography contains 73 annotated references from publications and reports concerning hypoxia, ≤2.0 ppm dissolved oxygen concentration, in the Gulf of Mexico. Instances of hypoxia from similar habitats and the effects of low oxygen levels on marine or estuarine organisms are also included.

Renaud, M. L. 1986a. Detecting and avoiding oxygen deficient sea water by brown shrimp, *Penaeus aztecus* (Ives), and white shrimp *Penaeus setiferus* (Linnaeus). J. Exp. Mar. Biol. Ecol. 98:283-292.
G-7.1

Detection and avoidance of oxygen deficient sea water (≤3.0 ppm dissolved oxygen) by white shrimp *Penaeus setiferus* (Linnaeus), and brown shrimp, *Penaeus aztecus* (Ives), was measured under laboratory conditions. Shrimp were acclimated to control salinity (22 %) and temperature (22 °C) for a minimum of 2 days and to the test chamber for 1 h before recording data. White shrimp detected and significantly avoided intruding water containing ≤1.5 ppm dissolved oxygen. Brown shrimp were more sensitive and avoided water having dissolved oxygen concentration ≤2.0 ppm. Hypoxia along coastal Louisiana, west of the Mississippi River Delta, could markedly affect shrimp stocks by increased natural mortality through 1) physiological stress, 2) increased interspecific and conspecific competition, and 3) increased predation.

Renaud, M. L. 1986b. Hypoxia in Louisiana coastal waters during 1983: Implications for fisheries. Fish. Bull. 84(1):19-26.
G-7.1, G-27

Hypoxic bottom water (<2.0 ppm dissolved oxygen) was present in shallow (9-15 m) waters south of central Louisiana in June and July 1983. It was patchy in distribution from south of Barataria Pass to south and west of Marsh Island. Data suggested that bottom water hypoxia did affect the abundance and distribution of shrimp and bottomfish. Offshore bottom water dissolved oxygen was significantly correlated with 1) combined catches of brown and white shrimp ($r = -0.56$, $P < 0.002$), 2) fish biomass ($r = 0.56$, $P < 0.001$), and 3) vertical density gradient ($r = -0.73$, $P < 0.001$). Several hypoxic stations were in regions designated as potentially hypoxic through a posteriori analysis of satellite data.

Reyer, A. J., C. L. Holland, D. W. Field, J. E. Cassells and C. E. Alexander. 1988. The Distribution and Areal Extent of Coastal Wetlands in Estuaries of the Gulf of Mexico. National Coastal Wetlands Inventory. Strategic Assessment Branch, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, Maryland, 18 p.
F9-G27

This report describes the areal extent and distribution of coastal wetlands in Texas, Louisiana, Mississippi, Alabama, Florida, and a small section of Georgia that drain into the Gulf of Mexico. The wetlands data are based entirely on an evaluation of National Wetland Inventory maps produced by the U.S Fish and Wildlife Service.

Rice, K. W., L. W. McEachron and P. C. Hammerschmidt. 1988. Trends in Relative Abundance and Size of Selected Finfishes in Texas Bays: November 1975 - December 1986. Management Data Series No. 139, Texas Parks and Wildlife Dept., Coastal Fisheries Branch, Austin, Texas, 192 p.
G-16, G-17, G-19, G-21, G-22, G-23, G-24, G-26.1, G-26.2

Trends in relative abundance and size of red drum, spotted seatrout, black drum, sheepshead, southern flounder, Atlantic croaker, sand seatrout, gafftopsail catfish, Gulf menhaden, hardhead catfish, pinfish, spot, and striped mullet have been monitored since 1975 using a standardized fishery independent gill net and bag seine sampling program in Texas bay systems. The 1986 data continue to show that the impacts of management decisions based on optimum sustained yield, effects of catastrophic events, and stock recruitment relationships can be measured by using estimates of relative abundance based on the fishery independent monitoring program.

Richards, F. A. and A. C. Redfield. 1954. A correlation between the oxygen content of sea water and the organic content of marine sediments. Deep Sea Res. 1:279-281.

G-7.1, G-27

There is considerable opinion but little direct evidence that the oxygen content of overlying water masses is important in determining the organic content of marine sediments. Data now available from the northwestern Gulf of Mexico indicate a clearcut inverse relationship between the organic content of the sediments and the oxygen content of the overlying waters. The zones of maximum organic content and minimum oxygen correspond well, and closely follow the edge of the continental shelf. It is probable that in this region, the high organic content of the sediments is due to the presence of water of low oxygen content immediately above the bottom, and the smaller oxygen diffusion gradient available to provide oxygen to the subsurface layers of sediment.

Riley, C. M., S. A. Holt, G. J. Holt, E. J. Buskey and C. R. Arnold. 1989. Mortality of larval red drum (*Sciaenops ocellatus*) associated with a *Ptychodiscus brevis* red tide. Contrib. Mar. Sci. 31:137-146.
G-23

Historically, the occurrence of red tides in Texas coastal waters has not been well documented. The most recent bloom of the red tide organism *Ptychodiscus brevis* occurred during October and November 1986, a time of year when many species of commercially important fish spawn and their larvae are abundant in local estuaries. Peak density of *P. brevis* averaged 7000 cells/ml at monitoring sites but transient patches of extremely high concentrations (10,000-47,680 cells/ml) were commonly found in the bays near Port Aransas during the entire month of October. Hatch rates of laboratory spawned red drum eggs were unaffected by all red tide concentrations tested. However, once hatched, larvae were negatively affected by all concentrations >40 cells/ml, based on dilution experiments with natural populations of *P. brevis*.

Riley, G. A. 1937. The significance of the Mississippi River drainage for biological conditions in the northern Gulf of Mexico. J. Mar. Res. 1(1):60-74.
G-2.1, G-5.1, G-7.1

This study is summarized as follows: 1) The Mississippi River carries large quantities of nutrient salts in the Gulf of Mexico. The quantity of phosphate per unit volume is approximately four times as much as the amount found in the sea water of the surrounding region. 2) In the Gulf there is a superficial zone of high phosphorus content around the mouth of the Mississippi, extending from Mobile Bay westward to longitude 91°W. There is a zone of high phytoplankton content near the river which roughly coincides with the area of high phosphorus. 3) It is suggested on purely theoretical grounds that some other nutrient which is discharged from the Mississippi in the same manner as phosphate is a limiting factor in the region. 4) A few notes are presented on the distribution of copper in the Gulf. It was present in all samples analyzed in both soluble and combined form.

Roberts, B. S. 1979. Occurrence of *Gymnodinium breve* red tides along the west and east coasts of Florida during 1976 and 1977. Pages 359-383 in D. L. Taylor and H. H. Seliger (eds.), Toxic Dinoflagellate Blooms. Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, October 31 - November 5, 1978, Key Biscayne, Florida. Developments in Marine Biology - Vol. 1, Elsevier North Holland, New York.
F-15.1

The occurrence of a *Gymnodinium breve* red tide off southwest Florida from September to December 1976 provided further evidence the Florida red tides develop in a predictable progression of initiation, support and maintenance.

Robison, D. E. 1985. Variability in the vertical distribution of ichthyoplankton in lower Tampa Bay, Florida. Pages 359-383 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea

Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

Previous studies have demonstrated that many zooplankton taxa are able to effect landward transport into, and retention within, positive estuaries by regulating their vertical distribution. The present study was undertaken to determine whether or not ichthyoplankton in lower Tampa Bay exhibit such regulatory abilities. An evaluation of the net nontidal flow over four tidal cycles revealed that, during the summer rainy season, a sufficient degree of density stratification occurred so as to result in a tidally averaged, two-layered circulation pattern. From this information it is concluded that larval fish have a greater probability of achieving landward transport and/or estuarine retention by remaining near the bottom during all tidal phases.

Rucker, J. B., R. P. Stumpf and W. W. Schroeder. 1990. Temporal variability of remotely sensed suspended sediment and sea surface temperature patterns in Mobile Bay, Alabama. Estuaries 13(2):155-160.
G-2

Distribution patterns of suspended sediments and sea surface temperatures in Mobile Bay were derived from algorithms using digital data from the visible, near-infrared, and infrared channels of the advanced very high resolution radiometer (AVHRR) on the NOAA-TIROS-N satellite. Closely spaced AVHRR scenes for January 20, 24, and 29, 1982, were compared with available environmental information taken during the same period. A complex interaction between river discharge, winds, and astronomical tides controlled the distribution patterns of suspended sediments. These same variables, coupled with air temperatures, also governed the distribution patterns of sea surface temperatures.

Russell, J. L. and J. A. Baskin. 1989. Baffin Bay, Texas. Pages 31-38 in J. A. Baskin and J. S. Prouty (eds.), South Texas Clastic Depositional Systems. Guidebook Published by the Corpus Christi Geological Society of the Annual Meeting of the Gulf Coast Association of Geological Societies, Corpus Christi, Texas.
G-25

Baffin Bay in Kleberg and Kenedy Counties, Texas is a unique coastal plain estuary in the U.S., because it is commonly hypersaline, with reverse estuarine circulation. Only ephemeral streams drain into the Bay. It is commonly recognized as one of the few large hypersaline bays in the world. The hypersalinity is the result of reverse estuarine circulation caused by evaporation, with natural inflow of fresh water associated only with heavy rains of tropical storms. The only permanent sources of water entering the Bay are from sewage outfalls, a large pertrochemical plant, and disposal of brines from oil and gas production.

Russell, M. 1977. Apparent effects of flooding on distribution and landings of industrial bottomfish in the northern Gulf of Mexico. Northeast Gulf Sci. 1(2):77-82.
G-2.1, G-5.1, G-7.1

River discharge possibly affected bottomfish distribution from January - June 1972 and 1973. Normal commercial concentrations of industrial bottomfish were not seen on the inshore grounds from Mobile Bay, Alabama to Trinity Shoal, Louisiana during peak flood periods in 1973. Comparison between river runoff and annual bottomfish landings for the last 17 years indicates that flooding may be beneficial to annual production by increasing availability of nutrients and extending the estuarine nursery boundaries.

Sackett, W. M., J. M. Brooks, B. B. Bernard and C. R. Schwab. 1979. Low-molecular-weight hydrocarbons and hydrographic project. Chapter 3 in P. L. Parker (ed.), Environmental Assessment of the South Texas Outer Continental Shelf, Biology and Chemistry. Vol. I. Final Report for 1977 to Bureau of Land Management. Contract No. AA550-CT7-11, University of Texas Marine Science Institute, Port Aransas Marine Laboratory, Port Aransas, Texas.
G-27

This report contains a comprehensive tabulation and analysis of all low-molecular-weight hydrocarbon, dissolved oxygen, and nutrient data taken as part of the BLM South Texas Outer Continental Shelf program in 1977. The above mentioned parameters were measured at Stations 1-3, on the four transects during the three seasonal sampling periods (winter, spring and fall). Oxygen values are controlled throughout most of the year in the upper 50 to 70 m of the STOCS area by physical processes. Nutrient concentrations were typically low, being representative of open Gulf surface water. Nitrate was limiting to productivity and disappeared during the summer and early fall. Phosphate and silicate were affected by the spring increase in productivity but were generally regenerated by fall. Increased continental runoff during the spring months was reflected by high silicate values at nearshore stations.

Sackett, W. M. and J. M. Brooks. 1976. Productivity and low-molecular weight hydrocarbons project. Pages 331-373 in P. L. Parker (ed.), Environmental Assessment of the South Texas Outer Continental Shelf, Chemical and Biological Survey Component for 1975. Report to Bureau of Land Management. Contract No. 08550-CT5-17, University of Texas Marine Science Institute, Port Aransas Marine Laboratory, Port Aransas, Texas.
G-27

This report contains a comprehensive tabulation of all the analyses of samples for the BLM-South Texas OCS area during 1975. This includes analyses of 1) methane, 2) ethene, 3) ethane, 4) propene, 5) propane, 6) dissolved oxygen, 7) nitrate, 8) phosphate, 9) silicate, 10) temperature and 11) salinity for three depths at each of the 12 stations during each of the seasonal sampling periods. In addition, this report contains hydrographic and hydrocarbon data obtained in the South Texas OCS region during 1975 that were not taken as part of the South Texas OCS contract. This includes: 1) more sampling depths on the 12 stations during the August-September sampling period; 2) 5 stations with methane, nutrient and hydrographic data; and 3) hydrocarbon "sniffer" data across part of the South Texas OCS area during a cruise in early October.

Sackett, W. M., J. M. Brooks and B. B. Bernard. 1977. Selected water column measurements: Low-molecular-weight hydrocarbons, nutrients and dissolved oxygen. Chapter 15 in P. L. Parker (ed.), Environmental Assessment of the South Texas Outer Continental Shelf, Biology and Chemistry. Vol. II. Final Report for 1976 to Bureau of Land Management. Contract No. AA550-CT6-17, University of Texas Marine Science Institute, Port Aransas Marine Laboratory, Port Aransas, Texas.
G-27

Data for the baseline monitoring of the South Texas Outer Continental Shelf for winter, spring and fall of 1975 for the entire study area and along transect II off Port Aransas for monthly monitoring. Data are for dissolved oxygen, phosphate, nitrate, silicate, temperature, salinity, and low-molecular-weight hydrocarbons in water samples.

Sager, D. R. 1976. Temporal and Spatial Distribution of Phytoplankton in the Lower Atchafalaya River Basin, Louisiana. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana, 158 p.
G-12

In a survey of the phytoplankton and physiochemical characteristics in this basin, 76 genera representing Chlorophyta, Euglenophyta, Chrysophyta, Pyrrophyta, and Cyanophyta were identified. Swamp, lacustrine and riverine habitats were distinguished on the basis of their distinctive phytoplankton assemblages and water quality. The majority of taxa peaked during low water (summer and fall) when habitats were differentiated, rather than during flood periods when the entire basin was inundated.

Sale, M. J., P. R. Kaufmann, H. I. Jager, J. M. Coe, K. A. Cougan, A. J. Kinney, M. E. Mitch and W. S. Overton. 1988. Chemical Characteristics of Streams in the Mid-Atlantic and Southeastern United States (National Stream Survey-Phase I). Vol. II: Streams Sampled,

Descriptive Statistics, and Compendium of Physical and Chemical Data. Publ. No. EPA/600/3-88/021b, U.S. Environmental Protection Agency, Washington, D.C., 595 p.
F-26, F-27

This second volume of the National Stream Survey-Phase I report presents basic data and provides supplemental analyses of populations that are not included in Volume I (see Kaufmann *et al.* 1988). Separate tables are presented for the following groups of variables: major cations and anions; acid neutralizing capacity, pH, and related variables; aluminum, other metals, and dissolved organic carbon; and nutrients and other water quality variables.

Saloman, C. H. 1973a. Hydrographic Observations in Tampa Bay, Florida - 1970. Data Report No. 77, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, 246 p.
F-15

Hydrographic data include water temperature, salinity, total phosphorus, total Kjeldahl nitrogen, pH, dissolved oxygen, turbidity, water transparency, chlorophyll *a*, *b* and *c*, astacin and nonastacin carotenoids, and primary productivity based on chlorophyll *a*. Also included are hourly observations of rainfall, air and water temperature, and wind direction and velocity for October through December. Methods of collecting and analyzing samples are indicated. Tables summarize data collected from 30 permanent stations by mean, range, and number of observations according to month and area. Other tables summarize the mean, range, and number of observations of samples taken twice daily at the laboratory dock.

Saloman, C. H. 1973b. Hydrographic Observations in the Gulf of Mexico off Pinellas County, Florida (November 1970 - January 1972). Data Report No. 78, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, 228 p. (not in hand)
F-15.1

Saloman, C. H. 1974. Hydrographic and Meteorological Observations from Tampa Bay, and Adjacent Waters - 1971. Data Report No. 84, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington, 554 p.
F-15, F-15.1

See Saloman (1973a).

Saloman, C. H., J. H. Finucane and J. A. Kelly, Jr. 1964. Hydrographic Observations of Tampa Bay, Florida, and Adjacent Waters, August 1961 through December 1962. Data Report No. 4, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C., 112 p.
F-15, F-15.1

See Saloman (1973a).

Saloman, C. H. and J. L. Taylor. 1968. Hydrographic Observations in Tampa Bay, Florida, and the Adjacent Gulf of Mexico, 1965-66. Data Report No. 41, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Biological Laboratory, St. Petersburg, Florida, 393 p. (not in hand)
F-15, F-15.1

Saloman, C. H. and J. L. Taylor. 1971a. Hydrographic Observations in Tampa Bay and the Adjacent Gulf of Mexico - 1967. Data Report No. 55, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Biological

Laboratory, St. Petersburg, Florida, 67 p. (not in hand)
F-15, F-15.1

Saloman, C. H. and J. L. Taylor. 1971b. Hydrographic Observations in Tampa Bay and the Adjacent Gulf of Mexico - 1968. Data Report No. 63, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Biological Laboratory, St. Petersburg, Florida, 208 p. (not in hand)
F-15, F-15.1

Santos, S. L. and J. L. Simon. 1980. Response of soft-bottom benthos to annual catastrophic disturbance in a south Florida estuary. Mar. Ecol. Prog. Ser. 3(4):347-355.
F-15

A portion of Hillsborough Bay, part of the Tampa Bay estuary, undergoes annual summer defaunation, presumably due to hypoxia. Dissolved oxygen levels are very low (<1.0 mg/l) at the times of the defaunations. In the ensuing period between defaunations, recolonization occurs. Monthly samples for 42 consecutive months were collected by Scuba-diver-operated, handheld PVC cores and screened through a 0.5-mm sieve. Eight species, *Mysella planulata*, *Ampelisca abdita*, *Streblospio benedicti*, *Grandidierella bonnieroides*, *Mulinia lateralis*, *Mediomastus californiensis*, *Cyclaspis* sp. and *Nereis succinea* were numerically dominant, accounting for more the 95 % of the total density during the entire period. These eight species are all classified as *r*-strategists and utilize several dispersal mechanisms to attain large populations rapidly. Circumstantial evidence is presented which indicates that *Ampelisca abdita*, although classified as an *r*-strategist, may be an effective interference competitor.

Santschi, P. H. and J. O. Samuell. 1991. The cycling of nutrients in Galveston Bay: Factors regulating their concentrations. Pages 105-106 in F. S. Shipley and R. W. Kiesling (eds.), Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6, 220 p.
G-17

See Shipley and Kiesling (1991).

Schomer, N. S. and R. D. Drew. 1982. An Ecological Characterization of the Lower Everglades, Florida Bay and the Florida Keys. Biological Services Publ. FWS/OBS-82/58.1, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C., 246 p.
F-9, F-10

A conceptual model of the study area identifies four major ecological zones: 1) terrestrial and freshwater wetlands, 2) estuarine and saltwater wetlands, 3) Florida Bay and mangrove islands, and 4) the Florida Keys. These zones are delineated by differences in basic physical-chemical background factors which in turn promote characteristic ecological communities.

Schroeder, W. W. 1976. Physical Environmental Atlas of Coastal Alabama. Publ. No. MASGP-76-034, Mississippi-Alabama Sea Grant Program. G. C. Marshall Space Flight Center, National Aeronautics and Space Administration and Marine Science Programs, University of Alabama System, Dauphin Island Sea Lab, Dauphin Island, Alabama.
G-1, G-2, G-2.1, G-2.2

Schroeder, W. W. 1979. The dissolved oxygen puzzle of the Mobile Estuary. Pages 25-30 in H. A. Loyacano, Jr. and J. P. Smith (eds.), Symposium on the Natural Resources of the Mobile Bay Estuary, Alabama. Alabama Coastal Area Board, Mississippi-Alabama Sea Grant Consortium and U.S. Fish and Wildlife Service. U.S. Army Corps of Engineers District, Mobile, Alabama.
G-2

The dissolved oxygen system in the Mobile Estuary remains essentially unknown. Some information is available on the quantitative annual cycle and macro-scale distribution patterns during oxygen depletion periods. Recent unpublished research has provided the first look at oxygen-consuming processes. Virtually nothing is known about oxygen-producing processes, environmental factors responsible for the on-set, maintenance and termination of oxygen depletion periods or meso- to micro-scale distribution patterns during oxygen depletion periods.

Schroeder, W. W., J. R. Abston, S. J. Parker and A. W. Schultz. 1988. Annotated Bibliography of Selected Geological Oceanography References and a Bibliography of Related Material, East Louisiana, Mississippi, Alabama, and Northwest Florida Continental Shelf. Project R/ER-16, Contract No. NA85AA-D-SG005, Mississippi-Alabama Sea Grant Consortium, Dauphin Island Sea Lab, Dauphin Island, Alabama, 27 p.
F-24.1, G-2.1, G-5.1, G-7.1

Schroeder, W. W. and G. F. Crozier. 1974. Hydrographic and current structure on the western continental shelf of the northeastern Gulf of Mexico. Pages 395-404 in R. E. Smith (ed.), Marine Environmental Implications of Offshore Drilling in the Eastern Gulf of Mexico. Proceedings of a Conference, January 31 - February 2, 1974, University of South Florida, St. Petersburg, Florida. State University System of Florida, Institute of Oceanography, St. Petersburg, Florida.
G-2.1, G-5.1

The interest developing in the offshore areas of Mississippi and Alabama stimulated a series of cruises in 1973 by personnel from the Marine Environmental Sciences Consortium. The Alabama Estuarine and Continental Shelf Oceanographic Survey has been concerned with the relationship of Mobile Bay to Mississippi Sound and the continental shelf, as well as the areas involved in the possible "superport." Recent support of the University of South Alabama will extend these activities to the east toward Panama City. Development of the program has led to the establishment of several standard cruise tracks.

Schroeder, W. W., S. P. Dinnel and W. J. Wiseman, Jr. 1990. Salinity stratification in a river-dominated estuary. Estuaries 13(2):145-154.
G-2

Analysis of salinity data from Mobile Bay indicates that stratification-destratification events within this broad, shallow estuary are not uncommon. These events are related to the strength of the winds, through their influence on wave generation and subsequent bottom drag coefficient increase, and to the strength of river discharge. They do not appear to be due to the strength of tidal currents, as has been observed elsewhere. Furthermore, river flow appears to be the dominant control, the winds being important only in the absence of large freshwater discharges. The annual spring freshet can flush most of the salt from the Bay. During other times of the year the relative strengths of river discharge and wind stress change the bay from highly stratified to nearly homogeneous and back on a variety of time scales ranging from daily to seasonal.

Schroeder, W. W. and W. R. Lysinger. 1979. Hydrography and circulation of Mobile Bay. Pages 75-94 in H. A. Loyacano, Jr. and J. P. Smith (eds.), Symposium on the Natural Resources of the Mobile Bay Estuary, Alabama. Alabama Coastal Area Board, Mississippi-Alabama Sea Grant Consortium and U.S. Fish and Wildlife Service. U.S. Army Corps of Engineers District, Mobile, Alabama.
G-2

Mobile Bay's salinity regime ranges from Bay-wide influence of high salinity Gulf of Mexico waters during extended periods of low river discharge to dominance by freshwater under flooding river conditions. However, no set seasonal salinity pattern exists because of the river system's high degree of variability on day-to-day, month-to-month and year-to-year scales. On the other hand the Bay's thermal regime has a well defined seasonal structure directly linked to atmospheric temperatures. Circulation is poorly understood. It appears to

be a two-layer system even though the Bay is very shallow. Surface drogue studies suggest a highly variable system in the lower Bay.

Schroeder, W. W., W. J. Wiseman, Jr., A. Williams, Jr., D. C. Raney and G. C. April. 1990. Climate and oceanography. Pages 27-51 in Mobile Bay: Issues, Resources, Status, and Management. Proceedings of a Seminar, November 17, 1988, Washington, D.C. NOAA Estuary-of-the-Month Seminar Series No. 15, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Estuarine Programs Office, Washington, D.C.
G-2

Despite long periods of repetitious weather, especially during the summer, the climate of the Mobile Bay region is quite variable. During severe weather, systems often dissipate or strengthen when approaching the coast. A monitoring program, consisting of both land and buoy observation stations, should be developed to allow prediction of the impacts of meso- and micro-scale systems, particularly on economically important aspects of the area.

Schroeder, W. W. and W. J. Wiseman, Jr. 1988. The Mobile Bay estuary: Stratification, oxygen depletion, and jubilees. Pages 41-52 in B. J. Kjerfve (ed.), Hydrodynamics of Estuaries. Vol. II. Estuarine Case Studies. CRC Press, Boca Raton, Florida.
G-2

Jubilees, mass migrations of estuarine organisms to the shores of Mobile Bay, have been presumed to be induced by hypoxic bottom waters. A review of new and historic data sets corroborates this hypothesis and elucidates the processes causing hypoxia. Hypoxia may be frequent and widespread during the summer, stratified season, whereas the winter climatology appears generally to preclude its occurrence. Interactions of the Bay's geomorphology, water column structure, circulation, biological activity, and man-made modifications result in oxygen depletion zones. These, in turn, elicit a movement response from certain estuarine biota. The relationships between these factors are the subject of this paper. During summer months, strong haline stratification isolates the bottom waters of Mobile Bay from direct air-sea interaction. High temperatures increase metabolic rates and benthic consumption reduces near-bottom dissolved oxygen content of the water column to values that are stressful to the biota. This hypoxic water is advected by tides and wind-driven baraclinic motions. This movement appears to be responsible for the jubilee phenomenon in the Bay.

Schropp, S. J., F. D. Calder, G. M. Sloane, K. O. Swanson, J. C. Carlton, G. L. Halcomb, H. L. Windom, F. Huan and R. B. Taylor. 1991. A Report on Physical and Chemical Processes Affecting the Management of Perdido Bay. Results of the Perdido Bay Interstate Project. Alabama Dept. of Environmental Management, Mobile, Alabama and Florida Dept. of Environmental Regulation, Coastal Zone Management Section, Tallahassee, Florida, 323 p.
F-28, G-1

Objectives of this study were to describe physical and chemical processes affecting dissolved and particulate nutrient and suspended solid transport in the Perdido River basin and the fate of these materials in Perdido Bay. The results show that the bay receives nutrients from anthropogenic sources, dominated during this study by materials delivered by Elevenmile Creek. The results also show that physical conditions controlled by the natural forces of wind, streamflow, and tide, are such that stratification and hypoxia occur during a major portion of the year. Summer and early fall months are critical periods when maximum natural stresses (hypoxia) are imposed on the Bay and its biological communities. The results of sediment studies indicate that, at present, the Bay does not suffer from acute toxic contamination. There is evidence of some contamination from urban runoff, but not at the levels encountered in other, more developed, parts of Alabama and Florida.

Schurtz, M. H. and K. M. St. Pé. 1984. Water Quality Investigation of Environmental Conditions in Lake Pontchartrain. Report on Interim Findings. Louisiana Dept. of

Environmental Quality, Water Pollution Control Division, Baton Rouge, Louisiana.
G-7

This study was initiated to address in general the concern of the Louisiana public over the apparently deteriorating water quality of Lake Pontchartrain, and specifically to further investigate an environmental situation that resulted in speculation that "dead zones" cover large areas of the lake bottom. A prominent concern central to the "dead zone" issue was speculation that toxic chemicals may be the cause of the observed depressed species diversity of bottom dwelling animals in the southeastern part of the lake. The study determined the occurrence and distribution of chemicals, toxic and otherwise, in the southern portion of the lake that have resulted from anthropogenic origin; and provided an overall water quality assessment to ascertain any phenomena, in particular water pollution, that may be adversely affecting the ecological balance of the lake. The evaluation concluded that severe dissolved oxygen depletions in 1980 resulted from salinity stratification and that there was no evidence that toxic chemicals caused the defaunated areas.

Seadock, Inc. 1974. Environmental Report. Vol. I and II. Summary. Texas A&M University, Texas A&M Foundation, College Station, Texas.
G-18, G-21, G-27

A comprehensive environmental report has been prepared in support of the proposed project. The environmental study was conducted over a period of a full year. It included both marine and terrestrial field studies conducted by recognized environmental authorities. The Texas A&M Research Foundation conducted the marine studies. This summary presents a brief description of the existing environment and an assessment of the environmental effects of the proposed project.

Seaton, A. M. 1979. Nutrient Chemistry in the Barataria Basin - a Multivariate Approach. M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana, 124 p.
G-10

A general survey of nutrient chemistry in the fresh and estuarine waterbodies of the Barataria basin was initiated in winter 1976. Physical, chemical, and biological water quality parameters were sampled quarterly from February 1976 through August 1977 along a 120-km transect extending the length of the basin. Twenty-three sampling stations were selected to reflect the range of nutrient conditions and general water quality in the basin. Multivariate statistical analyses (i.e., cluster and factor analysis) were utilized to create a general characterization of water quality in both the estuarine and freshwater areas. The parameters selected for the analysis were: total organic nitrogen, total phosphorus, Secchi disk depth, chlorophyll *a* and total inorganic nitrogen. The multivariate analysis clearly documents the change in nutrient dynamics between a dry year (1976) and a wet year (1977).

Seaton, A. M. and J. W. Day, Jr. 1979. The development of a trophic state index for the quantification of eutrophication in the Barataria Basin. Pages 113-125 in J. W. Day, Jr., D. D. Culley, Jr., R. E. Turner and A. J. Mumphrey, Jr. (eds.), Environmental Conditions in the Louisiana Coastal Zone. Proceedings of the Third Coastal Marsh and Estuary Management Symposium, March 6-7, 1978, Baton Rouge, Louisiana. Division of Continuing Education, Louisiana State University, Baton Rouge, Louisiana.
G-10

A systematic investigation of the variability in water parameters in the Barataria Basin was initiated in 1976. The objectives of this study was to measure changes in a number of physical, chemical, and biological parameters on a fresh-saline transect and to elucidate reasons for the change. The development of a trophic state index is the result of the search for appropriate tools to accomplish this objective. It is concluded that: 1) most of the Barataria Basin above the Gulf Intracoastal Waterway appears to be eutrophic; 2) multivariate analysis techniques provide a good quantitative approach in examining the eutrophication process; and 3) with further refinement, these techniques should be able to be applied to the remainder of the coastal zone.

Seiler, R., G. Guillen and A. M. Landry, Jr. 1991. Utilization of the upper Houston Ship Channel by fish and macroinvertebrates with respect to water quality trends. Pages 39-45 in F. S. Shipley and R. W. Kiesling (eds.), Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6, 220 p.
G-17

See Shipley and Kiesling (1991).

Shampine, W. J. 1971. Chemical, Biological, and Physical Data for the Major Lakes and Reservoirs in Louisiana. Basic Records Report No. 5, U.S. Dept. of the Interior, Geological Survey, Water Resources Division, Louisiana District. Louisiana Dept. of Public Works, Baton Rouge, Louisiana, 98 p.
G-7, G-11, G-11.1, G-14

Includes data on Lake Boudreaux, Lake Calcasieu, Lake De Cade, the Grand Lake complex, Lake Maurepas, Lake Mechant, and Lake Pontchartrain. The lowest dissolved oxygen value was for Lake Mechant (3.3 mg/l); no others were below 4.5 mg/l.

Shaw, J. K., P. G. Johnson, R. M. Ewing, C. E. Comiskey, C. C. Brandt and T. A. Farmer. 1982. Benthic Macroinfauna Community Characterizations in Mississippi Sound and Adjacent Waters. Contract No. DACW01-80-C-0427. Final Report to U.S. Army Engineer District, Mobile, Alabama.
G-2, G-2.1, G-2.2, G-2.3, G-5.1

This report presents the results of a study of benthic macroinfauna communities in Mississippi Sound and adjacent areas. This information will be utilized by the U.S. Army Corps of Engineers in developing a regional dredging plan for the Mississippi Sound and vicinity. During planning, consideration will be given to the impacts of removal and placement of dredged material on each of the benthic communities. The analyses will include: 1) effect of time of dredging operation on the benthos, 2) effect of dredging operation on benthic community structure, and 3) effect of dredging operations on the abundance and areal distribution of a community.

Shaw, R. F., B. D. Rogers, J. H. Cowan, Jr. and W. H. Herke. 1988. Ocean-estuary coupling of ichthyoplankton and nekton in the northern Gulf of Mexico. Am. Fish. Soc. Symp. 3:77-89.
G-7.1, G-27

Both gulf menhaden *Brevoortia patronus* and sand seatrout *Cynoscion arenarius* spawn offshore in the Gulf of Mexico during winter and spring. After a cross-shelf transit, their larvae later enter estuarine nursery areas. We have integrated new and existing early life history data on the occurrence of these species in the continental shelf ichthyoplankton and as late-stage larvae and juveniles in Louisiana estuaries to document this recruitment process.

Shepard, F. P. and G. A. Rusnak. 1957. Texas bay sediments. Publ. Inst. Mar. Sci. Univ. of Texas 4(2):5-13.
G-17, G-21, G-22, G-23, G-26

The purpose of the study was to determine differences between sediments in bays of a humid area and those in areas of semiaridity. The differences in the bays range from over 80 ppt in Laguna Madre to approximately 1 ppt at the mouths of some of the rivers entering the bays on the northern Texas coast. Detailed results are presented for San Antonio Bay and Laguna Madre. Texas bay deposits have such definite environmental characteristics that these bay facies should be easily recognized in the Tertiary sediments which are now largely buried by recent deposits along the Texas coast.

Sheridan, P. F. 1992. Comparative habitat utilization by estuarine macrofauna within the mangrove ecosystem of Rookery Bay, Florida. Bull. Mar. Sci. 50(1):21-39.
F-11

Abundance and biomass of juvenile and adult decapods and fishes in adjacent intertidal mangrove, seagrass, and open water habitats were compared using a quantitative drop sampler in July, September and December 1988 and April 1989. Fish densities were higher in non-vegetated, open waters than in flooded red mangrove prop roots or mixed seagrass beds. Shrimp densities were higher in seagrass habitats than in open waters or among mangrove prop roots. On a monthly basis, among-habitat differences in density or biomass of major taxa did not exhibit any patterns, with the exception of shrimp which were always significantly more numerous in seagrasses than in one or both alternate habitats. Flooded red mangroves were, at times, utilized by both resident and transient fishes and crabs (but not by shrimps) at densities similar to those in seagrasses and open waters.

Shew, D. M., R. H. Baumann, T. H. Fritts and L. S. Dunn. 1981. Texas Barrier Islands Region Ecological Characterization: Environmental Synthesis Papers. Biological Services Program, Publ. FWS/OBS-81/32. National Coastal Ecosystems Team, Biological Services Program, U.S. Fish and Wildlife Service, Washington, D.C., 413 p.
G-17 through G-27

The report is a synthesis of selected environmental literature for the Texas Barrier Islands Region and is a part of the Texas Barrier Islands Region Ecological Characterization Study. The region includes the coastal counties and extends 64 km inland and offshore for 9 nautical miles, or the State-Federal demarcation. The papers address the geology, climate, hydrology and hydrography, and the biology of each of six drainage basins along the Texas coast: Galveston, Matagorda-Brazos, San Antonio, Copano-Aransas, Corpus Christi and Laguna Madre, as well as the marine system offshore.

Shiller, A. M. and E. A. Boyle. 1991. Trace elements in the Mississippi River Delta outflow region: Behavior at high discharge. Geochim. Cosmochim. Acta 55(11):3241-3251.
G-7.1

Samples for dissolved trace element analysis were collected in surface waters of the plume of the Mississippi River during a period of high discharge. These field data are compared to the results of laboratory mixing experiments. The studies show that Cu, Ni, and Mo are largely unreactive in the plume. Surprisingly, Fe also appears to show little reactivity; the pronounced flocculation removal of Fe frequently observed in other estuaries is not seen in this system. This difference may be a consequence of the alkaline nature of the Mississippi which results in low dissolved Fe concentrations in the river. Zinc, another particle-reactive element, also shows little reactivity. The chromium distribution shows apparent non-conservative behavior indicative of estuarine removal; however, temporal variation in river concentrations is a more likely explanation for this behavior.

Shipley, F. S. and R. W. Kiesling (eds.). 1991. Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6, 220 p.
G-17

A compilation of summaries of current status of scientific data concerning multiple aspects of the Galveston Bay system. Topics include resource agency programs, point and non-point source pollution, the Houston Ship Channel, toxicants in water, toxicants in aquatic organisms, toxicants in birds, oil spill impacts, oilfield produced water, nutrients, pollutant transport, habitat studies, ecological surveys, faunal surveys, biological studies, physical features, inflow and hydrology, salinity, modeling, and information synthesis.

Shirzad, F. F., C. J. Klein, III and S. P. Orlando, Jr. 1989. Revised Physical and Hydrologic Characteristics for the Mississippi Delta Region Estuaries. National Estuarine Inventory:

Supplement 3. Strategic Assessment Branch, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, MD, 18 p.
G-8.1, G-9, G-10, G-11

A supplement to the National Estuarine Inventory Data Atlas of 1985 for the named estuaries. The supplement divides the Mississippi Delta into four distinct systems: Breton and Chandeleur Sounds, Mississippi River, Barataria Bay, and Terrebonne and Timbalier Bays. Each system presentation addresses the physical and hydrologic characteristics, spatial depictions of salinity zones and their variability, tide gauges, and head of tide. New data, such as volume by salinity zone, and freshwater retention time as an indicator of flushing, have been added.

Sikora, W. B. and B. J. Kjerfve. 1985. Factors influencing the salinity regime of Lake Pontchartrain, Louisiana, a shallow coastal lagoon: Analysis of a long-term data set. Estuaries 8(2A):170-180.
G-7

Lake Pontchartrain, Louisiana, is a 1630 km shallow brackish lagoon with a mean salinity from 1.2 ppt in the west to 5.4 ppt in the east. The construction of a 120 km long deep-water connection to the Gulf of Mexico in 1963, was expected to cause a 5 ppt increase in lagoon salinity. However, the actual increase was everywhere in the lagoon less than 2 ppt. Analysis of 31 years of daily salinity and discharge records indicated that discharge is the most important factor controlling salinity variations in Lake Pontchartrain. Seventy-four percent of low-frequency salinity variations are explained by freshwater discharge and the completion of the deep-water canal. Lake Pontchartrain experiences annual variations of salinity as high as 8%. This salinity signal has remained constant since the beginning of the salinity records in 1946. It appears that the deep-water canal is not responsible for observed die-back of freshwater swamps and retreat of lagoon shorelines.

Sikora, W. B., J. P. Sikora and A. M. Prior. 1981. Environmental Effects of Hydraulic Dredging for Clam Shells in Lake Pontchartrain, Louisiana. Report to U.S. Army Engineer District, New Orleans, Contract No. DACW29-79-C-0099. Coastal Ecology Laboratory, Center for Wetland Resources Publ. No. LSU-CEL-81-18. Louisiana State Univ., Baton Rouge, Louisiana, 140 p.
G-7

The results of the experimental shell dredging lead to the following conclusions: 1) bulk density of sediments is reduced and the conditions persist for long periods, 2) a detrimental effect on the macrofauna and meiofauna was produced and persisted for two years, 3) benthic biomass production was reduced, 4) seasonal recruitment was similar but there was differential survival at the dredged site, 5) species diversity did not differ, 6) benthic community of Lake Pontchartrain has reached an equilibrium with present levels of pollution and consists of a low number of species characterized as being tolerant of pollution, and 7) the direct impacts of dredging have the potential to maintain a benthic community of low biomass in the open lake.

Simmons, E. G. 1957. An ecological survey of the Upper Laguna Madre of Texas. Publ. Inst. Mar. Sci. Univ. of Texas 4(2):156-200.
G-26.1

Considerable interest has been shown in the Laguna Madre because of its unusual salinity conditions. This report is concerned with the plant life, invertebrates and vertebrates of the area and the relationship of these to basic physical and biological factors in the environment.

Simon, J. L. 1974. Tampa Bay estuarine system - A synopsis. Florida Scientist 37(4):217-244.
F-15

The tremendous surge in population and development in the area has placed a severe drain on the system which comprises five contiguous areas - 1) Old Tampa Bay, 2) Hillsborough Bay, 3) Tampa Bay, 4) Boca Ciega Bay,

and 5) Terra Ceia Bay. The system extends over some 346 square miles and includes 212 miles of shoreline. Coliform bacteria counts in Old Tampa Bay and Hillsborough Bay have been high enough to justify limiting contact sports and shellfishing. Water quality is affected by discharges from 55 sewage treatment plants, more than 90 industries and over 100 marinas. Primary productivity is among the highest in the world. A great diversity of marine life is present from both temperate and tropical regions. Projects in progress or proposed threaten every part of the System and a means for proper management must be established to avoid a degradation of its waters.

Sklar, F. H. and R. E. Turner. 1981. Characteristics of phytoplankton production off Barataria Bay in an area influenced by the Mississippi River. Contrib. Mar. Sci. 24:93-106.
G-7.1, G-10

Phytoplankton particulate production was measured in coastal waters along a transect west of the Mississippi River delta using *in situ* and light-box techniques. Seasonal changes in light-box surface production (0.2-155.0 mg C/m^3/h), chlorophyll *a* (1-26 mg Chl *a*/m^3), and assimilation number (0.15-42.0 mg C/mg Chl *a*/h) were all correlated with riverflow. Seasonal changes in the riverflow volume altered the nutrient supply, water color, turbidity and salinity/temperature regimes. Changes in nutrient concentrations were indicative of nitrogen limitation. Annual particulate phytoplankton production was 290 g C/m^2.

Skupien, L. 1989. Stress. A way of life for Mobile Bay. Gulfwatch 1(4):2-3/7.
G-2

This article discusses the various forces at work in creating stress on the Mobile Bay area. It describes the efforts being made to change this pattern.

Smith, C. J. and R. D. DeLaune. 1985. Recovery of added ^{15}N-labelled ammonium-N from Louisiana Gulf coast estuarine sediment. Estuarine Coastal Shelf Sci. 21(2):225-233.
G-10

The loss of added ^{15}N-labelled NH_4^+ from bottom sediment was studied *in situ* in a shallow saline Louisiana Gulf Coast lake (Airplane Lake in the Barataria estuary). ^{15}N enrichment in the organic N fraction increased rapidly during the first 15 days of incubation and then increased slowly from 15 to 123 days. After the initial rapid ^{15}N loss and the ^{15}N-labelled NH_4^+ had been immobilized in the organic pool, there was no further statistically significant loss of ^{15}N from the sediment between 15 and 337 days. Correspondingly low denitrification rates were measured.

Smith, N. P. 1988. The Laguna Madre of Texas: Hydrography of a hypersaline lagoon. Pages 31-40 in B. J. Kjerfve (ed.), Hydrodynamics of Estuaries. Vol. II. Estuarine Case Studies. CRC Press, Boca Raton, Florida.
G-26

The purpose of this paper is to summarize results of studies that provide insight into the effects of physical processes acting upon or within the lagoon. Integration of available information reveals a hypersaline lagoon, reflecting the semiarid climate, but modified by low-frequency meteorologically forced exchanges with adjacent coastal bays.

Stanley, D. W. 1992. Historical Trends: Water Quality and Fisheries, Galveston Bay. University of North Carolina Sea Grant College Program Publication UNC-SG-92-03. Institute for Coastal and Marine Resources, East Carolina University, Greenville, North Carolina, 100 p.
G-17

The overall goal of this study was to prepare a systematic comparison of long-term trends of water quality in four important U.S. estuaries, and to try to relate the water quality trends to changes in fishery resources. This

project had four specific objectives: 1) to document long-term trends in water quality and, where possible, identify causes, consequences and significance; 2) to assess whether problems are similar or unique to each estuary; 3) to assess whether progress is being made in improving conditions in water quality and fishery resources and whether there are examples of success that would be useful for estuarine managers and researchers elsewhere; 4) to glean examples of the useful integration of research and policy.

Steidinger, K. A. 1973. Phytoplankton ecology: A conceptual review based on eastern Gulf of Mexico research. CRC Crit. Rev. Microbiol. 3:49-68.
F-15, G-18, G-7.1, G-24

A review based on eastern Gulf of Mexico data that is applicable to many temperate and tropical regions. Phytoplankton distributions are grouped into estuarine, coastal/open Gulf, open Gulf diatom communities, and open Gulf dinoflagellate communities. Communities are composed of year-round resident coastal species that fluctuate in dominance and secondarily "visitors." Diatoms dominate inshore coastal areas while dinoflagellates and coccolithophores often dominate open Gulf waters. Microflagellates numerically dominate in eastern Gulf coastal and estuarine environments. Florida red tide ecology is outlined.

Steidinger, K. A. and W. E. Gardiner. 1985. Phytoplankton of Tampa Bay - a review. Pages 147-183 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

This paper contains an introduction to phytoplankton, a description of the Tampa Bay estuary, a historical account of phytoplankton studies, and a discussion and summary. It includes two tables: 1) number of Tampa Bay system phytoplankton species/varieties and genera by major grouping, and 2) number of species of diatoms and dinoflagellates in common between other geographical areas and the Tampa Bay system.

Steidinger, K. A. and E. A. Joyce, Jr. 1973. Florida Red Tides. State of Florida, Department of Natural Resources, Educational Series No. 17. Marine Research Laboratory, Florida Department of Natural Resources, St. Petersburg, Florida, 26 p.
F-9 through F-24

The first documented fish kill associated with discolored water in Florida occurred in 1844, but the causative organism, *Gymnodinium breve*, was not identified until 1948. Red tides and research results over the period 1953-1973 are discussed and summarized. Red tides are natural phenomena along the Florida Gulf coast, but major incidents are sporadic.

Stephens, C. F. and C. H. Oppenheimer. 1972. Silica contents in the northwestern Florida Gulf coast. Contrib. Mar. Sci. 16:99-108.
F-22

Analyses of the river and bay waters of the northwestern Florida Gulf Coast indicate that weathering of silica is active and that the fresh waters and runoff are significant sources of silica for the estuarine waters. An eighteen month study of the distribution of silica in the St. Marks River and Apalachee Bay indicates that active inorganic processes contribute to the loss of silica as dilution is not entirely responsible for the change. Silicate content of the surface waters ranged from 240 µg-at/1 in fresh water at 10 miles from the open Apalachee Bay to less than 1 µg-at/1 in the Bay where salinity is 34 %. The St. Marks River has an average discharge of 1000 cfs which, if containing 200 µg-at Si/1, would have an average discharge of approximately 15.5 metric tons of silica per day. Other areas of the shore estuarine environment show similarly high silica values and are relative to salinity.

Stern, D. H., B. H. Atwell, E. L. Merz and M. J. Vinet. 1968. A Summer Limnological Study of Lake Pontchartrain, Louisiana. Technical Report No. 3, Louisiana Water Resources Research Institute, Louisiana State University, Baton Rouge, Louisiana, 83 p.
G-7

Basic physical, chemical, and biological data were collected in the summer of 1968 in preparation for future investigations of the lake. Biweekly samples were collected at 26 during June and July. Field measurements at each station included the following physical and chemical factors: dissolved oxygen, pH, relative light transmissions, salinity, Secchi disc visibility, specific conductivity, and total alkalinity. Laboratory analyses of the lake water included the following factors: aluminum, barium, coliform bacteria, copper, cyanide, detergents, nitrate-nitrogen, orthophosphate, silica, sodium and chloride ions, sulfate, tannins and lignins, total hardness, total iron, total nitrogen and turbidity. Plankton tows were made during most station visits, and bottom sediments were collected from most stations in June. The plankton composition and abundance was studied, and the pH and organic matter content of the bottom sediments were examined.

Stern, D. H. and M. S. Stern. 1969. Physical, Chemical, Bacterial, and Plankton Dynamics of Lake Pontchartrain, Louisiana. Technical Report No. 4, Louisiana Water Resources Research Institute, Louisiana State University, Baton Rouge, Louisiana, 60 p.
G-7

Preliminary and intensive studies from November 1968 to July 1969 showed that the discharge of stormwater into Lake Pontchartrain affects the water quality and biorhythm of aquatic microorganisms. Especially after heavy rains in Orleans Parish, the presence of coliforms renders the nearshore water and beaches unsafe for some water sports. Lake sediments, stirred up by wind waves and during heavy rains, increase the turbidity; the reduced light available for photosynthesis results in the death of phytoplankton, which add to the bottom organic materials and subsequently furnish food for more planktonic growth, and thus hastens the filling of the lake. Recommendations include: counting of fecal coliforms to determine water quality; prohibition or discouragement of water sports at certain beaches after summer rains; careful regulation of proposed chlorination of storm water owing to presence of ammonia, which retards the disinfection process, and because of unreacted chlorine, which will disrupt the natural food chain; and basin-wide cooperation to prevent or reduce further pollution.

Stetson, H. C. 1953. The sediments of the western Gulf of Mexico. Part I - The continental terrace of the western Gulf of Mexico: Its surface sediments, origin and development. Papers in Physical Oceanography and Meteorology 12(4):1-45.
G-7.1, G-27

During the winter of 1947 the research vessel, Atlantis worked in the western half of the Gulf of Mexico. The primary purpose of the cruise was to determine the texture and organic content of the surface and near-surface sediments with their contained foraminiferal fauna, from the shelf, the slope, and the Sigsbee Deep. Surface samples and cores up to 11 ft were obtained from 551 stations. A number of plankton tows and hydrographic stations were made and bathythermograph readings were taken to the depth of 100 m every 5 miles. Rock dredging was carried out on two of the coral capped hills or "bioherms" which are numerous in the vicinity of the 80-fm curve.

Stone, J. H. (ed.). 1980. Environmental Analysis of Lake Pontchartrain, Louisiana, Its Surrounding Wetlands, and Selected Land Uses. Vol. I, 581 p. and Vol. II, 1219 p. Prepared for U.S. Army Corps of Engineers District, New Orleans, Louisiana. Publ. No. LSU-CEL-80-08, Coastal Ecology Laboratory, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana.
G-7

A year-long study during 1978-1979 was made of selected ecological components and processes of Lake Pontchartrain and its surrounding wetlands and of selected land uses in its drainage basin or watershed. A large

report with chapters on preliminary modeling of the Lake Pontchartrain ecosystem by computer simulations; a trophic analysis of Lake Pontchartrain, Louisiana, and surrounding wetland tributaries; computation of drift patterns; general hydrography of Lake Pontchartrain; general hydrography of the tidal passes; nutrient and carbon geochemistry; structure and function of the phytoplankton community; the distribution and abundance of plankton; productivity of the swamps and marshes that surround Lake Pontchartrain; changes in the submerged macrophytes of the Lake; macrobenthic survey; nekton; aspects of the life history of *Anchoa mitchilli*; fish food habits; microplankton movement through the tidal passes; selected commercial fish and shellfish data; preliminary survey of higher vertebrates; recent land use changes in the watershed; and urbanization, peak streamflow and estuarine hydrology of Louisiana.

Stuntz, W. E. 1982. Coastal anoxia in the northern Gulf of Mexico. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, Louisiana.
G-7.1

A large area of low oxygen was found along the coast of Louisiana in June and July of 1982. The anoxia was restricted to the bottom waters in depths from 46 m shoreward. Bottom trawl samples were taken at each of the stations. In areas where the oxygen levels were less than 2 ppm, the catches of fish were very low and were made up mostly of pelagic species. No commercial shrimp were taken in the low oxygen areas. Water temperatures were very high in the area, which may indicate an area where circulation is limited, at least during some periods. The biological implications of this situation are of considerable interest, due largely to the potential impacts on the commercial shrimp species.

Stuntz, W. E., C. E. Bryan, K. Savastano, R. S. Waller and P. A. Thompson. N.D. SEAMAP Environmental and Biological Atlas of the Gulf of Mexico, 1982. Southeast Area Monitoring Assessment Program (SEAMAP) of the Gulf States Fisheries Commission, Ocean Springs, Mississippi, 155 p.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

In this first of a series of of biological and environmental atlases, the objectives of the 1982 surveys were to determine distribution and abundance of ichthyoplankton and trawl-caught organisms and to document the environmental factors that might affect their distribution and abundance.

Stuntz, W. E., N. Sanders, T. D. Leming, K. N. Baxter and R. M. Barazotto. 1982. Area of hypoxic bottom water found in northern Gulf of Mexico. Coastal Oceanography and Climatology News 4(4):37-38.
G-7.1

During a recent SEAMAP cruise to assess shrimp and bottomfish distribution and abundance, an area of low dissolved oxygen was found in bottom water along the coast of Louisiana. The area of low oxygen concentration was found in depths of 9-46 m along the coast from 89°30.5'W to 91°30.1'W. Based on our data, the area of low oxygen certainly had an impact on demersal fish and invertebrate distribution. Of interest, especially from the commercial fishing point of view is how the bottom-dwelling species respond to the low oxygen.

Summers, J. K. and V. D. Engle. 1992. Evaluation of sampling strategies to characterize dissolved oxygen conditions in northern Gulf of Mexico estuaries. Environ. Monitoring and Assessment. (in press)
F-27, F-28

Dissolved oxygen was continuously monitored in eight sites of northern Gulf of Mexico estuaries in August 1990. Monte Carlo analyses on subsamples of the data were used to evaluate several commonly used monitoring strategies. Monitoring strategies which involve single point sampling of dissolved oxygen may

often misclassify an estuary as having good water quality. In the case of shallow, often well-mixed estuaries that experience diurnal cycles, such monitoring often does not occur at night, during the time of lowest dissolved oxygen concentration. Our objective was to determine the minimum sampling effort required to correctly classify a site in terms of the observed frequency of hypoxia. Tests concluded that the most successful classification strategy used the minimum dissolved oxygen concentration from a continuously sampled 24-h period.

Swingle, H. A. 1971. Biology of Alabama estuarine areas - cooperative Gulf of Mexico estuarine inventory. Ala. Mar. Resour. Bull. 5:1-123.
G-1, G-2, G-2.2

Twenty trawl stations, five seine stations, and four plankton stations were sampled monthly from January 1968 through March 1969. A total of 162 species of fishes and 44 species of invertebrates were collected from the estuarine waters of Alabama. Seventy-six species of fishes are documented from other sources. The areal and seasonal distributions of the species are discussed. Also presented are data on the density of oysters on the public reefs and historical fisheries statistics.

Swingle, H. A. and D. G. Bland. 1974. A study of the fishes of the coastal watercourses of Alabama. Ala. Mar. Resour. Bull. 10:17-102.
G-1, G-2, G-2.2

Trawl or seine samples were collected monthly at 23 stations within the brackish water zone of the coastal watercourses of Alabama. A total of 104 species of fishes and 19 species of invertebrates was collected from December 1970 through May 1972. Water salinity, temperature and dissolved oxygen values are presented and are correlated to some extent with species abundance and diversity. The species composition of altered and unaltered watercourses and the species composition of estuarine waters are discussed. The number of species of marine, estuarine and freshwater fishes taken was approximately equal, but marine and estuarine individuals made up 96 % of the total catch. Marine and estuarine species of fishes and invertebrates dominated the population down to about 2 ppt. Freshwater species were dominant at salinities below 1 ppt but the number of individuals was still exceeded by marine and estuarine species.

Tarver, J. W. 1972. Occurrence, Distribution and Density of *Rangia cuneata* in Lakes Pontchartrain and Maurepas, Louisiana. Tech. Bull. No. 1, Louisiana Wild Life and Fisheries Commission, New Orleans, Louisiana, 8 p.
G-7

Samples of *Rangia cuneata* populations were taken with a modified 18-in oyster dredge throughout Lakes Pontchartrain and Maurepas to determine the occurrence, distribution, and density of clam populations. Depth, bottom type, salinity, temperature, and turbidity were recorded with each sample. A total of 187 samples yielded 237,963 *Rangia* clams. *Rangia* catches ranged from 0 to 1,517 clams per 3-min tow, and specimen sizes ranged from 8 to 64 mm, with a mean height of 30.9 mm. Though all the monthly stations reported that the mean height varied from month to month, the data indicate that *Rangia* populations were stable, having no major fluctuations in mean height during the study. The presence of low salinity, high turbidity, and a substrata of sand, mud and vegetation remnants during the sample period seems to have resulted in a high clam density and, consequently, a small clam size.

Tarver, J. W. and R. J. Dugas. 1973. A Study of the Clam, *Rangia cuneata*, in Lake Pontchartrain and Lake Maurepas, Louisiana. Tech. Bull. No. 5, Louisiana Wild Life and Fisheries Commission, New Orleans, Louisiana, 97 p.
G-7

Samples of *Rangia cuneata* were taken by utilizing a Peterson and modified oyster dredge throughout Lakes Pontchartrain and Maurepas to determine the occurrence, distribution and density of clam populations. Hydrological, sedimentological and plankton samples were analyzed in an effort to determine some of the

factors affecting the distribution, density and growth of *R. cuneata*. Mortality and the effects of dredging operations on the environment are briefly discussed. Annual shell production and overfishing factors are discussed and recommendations to the industry are also proposed.

Tarver, J. W. and L. B. Savoie. 1976a. Phase I - Area Description. Pages 1-6 in An Inventory and Study of Lake Pontchartrain-Lake Maurepas Estuarine Complex. Tech. Bull. No. 19, Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana.
G-7

The study was initiated to investigate the composition, general distribution, and abundance of commercially or potentially important fauna inhabiting the Lake Pontchartrain-Lake Maurepas estuarine complex, so that comparisons with previously completed wetland research in Louisiana and the northern Gulf of Mexico might enable administrators to efficiently manage Louisiana's renewable coastal zone resources. Vertebrate and macroinvertebrate populations were sampled, and molluscan benthic communities were empirically determined. Zooplankton was estimated. Hydrological and climatological parameters were collected at four stations. Grain size determinations were made.

Tarver, J. W. and L. B. Savoie. 1976b. Phase III - Hydrology and Water Chemistry. Pages 101-144 in An Inventory and Study of Lake Pontchartrain-Lake Maurepas Estuarine Complex. Tech. Bull. No. 19, Louisiana Wildlife and Fisheries Commission, New Orleans, Louisiana.
G-7

Although there are many interdependent factors to which the hydrology of Lakes Pontchartrain and Maurepas may respond, probably one of the most significant is wind speed and direction, followed by the discharge of adjacent rivers. Some authors attribute major hydrological changes to tidal fluctuation, but in the case of these lakes this factor would seem to have generally less effect than characteristically recognized. Tidal movements seldom exceed a 1- to 2-ft change. This would seem to preclude the use of tidal stages to explain some hydrological changes.

Taylor, J. L. 1974(1975). The Charlotte Harbor estuarine system. Fla. Sci. 37(4):205-216.
F-13

The estuary is about 35 by 30 miles at the extremes with more than 200 miles of shoreline and comparatively little contamination. Vegetation includes salt marsh, mangrove and other peninsular Florida Gulf Coast communities which are highly productive. Of 246 fish species, 18 produce a harvest with a dockside value of ca. $3,000,000. Dredging and development have had an adverse effect on more than 11,000 acres near Port Charlotte, Punta Gorda, Cape Coral and Fort Myers. An additional 25,300 acres are closed to shellfishing because of pollution. Further manmade changes threaten the value of the estuary as a fishing ground and hatchery for commercially valuable marine fishes.

Taylor, J. L. 1970. Coastal development in Tampa Bay, Florida. Mar. Pollut. Bull. 1(NS)(10):153-156.
F-15

In 1962, a site on Tampa Bay's western shore was selected for the U.S. Bureau of Commercial Fisheries Estuarine Research Laboratory. The scientific program included biological, chemical and physical studies of estuaries in the eastern Gulf of Mexico to determine the effects of environmental factors on fisheries in the Gulf. Tampa Bay was well chosen as a starting point for these investigations because the estuary contains many unchanged areas as well as areas that have been altered by dredge-fill operations, harbor and channel construction, and effluents from domestic sewage and industry. Sufficient work has been completed in all major areas of the bay to show some of the natural features that promote fishery production as well as some effects of pollution and coastal development.

Teague, K. G., C. J. Madden and J. W. Day, Jr. 1988. Sediment-water oxygen and nutrient fluxes in a river-dominated estuary. Estuaries 11(1):1-9.
G-12

Sediment oxygen uptake and net sediment fluxes of dissolved inorganic and organic nitrogen and phosphorus were measured at two sites in Fourleague Bay from August 1981 through May 1982. Sediment oxygen uptake averaged 49 $mg/m^2/h$. On the average, ammonium was released from the sediments and nitrate was taken up. Very different nitrate fluxes were observed at the two sites, with sediment uptake at the upper, river-influenced, high nitrate site and release at the lower, marine-influenced, low nitrate site. Phosphate fluxes were low and often negative. Dissolved organic nitrogen fluxes varied greatly. Total dissolved nitrogen and phosphorus fluxes indicated the sediments were a nitrogen and phosphorus source at the lower bay, and a nitrogen sink and phosphorus source in the upper bay.

Temple, R. F., D. L. Harrington and J. A. Martin. 1977. Monthly Temperature and Salinity Measurements of Continental Shelf Waters of the Northwestern Gulf of Mexico, 1963-65. NOAA Technical Report NMFS SSRF-707, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D.C., 26 p.
G-7.1, G-27

Temperature and salinity observations made monthly from January 1963 to December 1965 at 48 stations in the northwestern Gulf of Mexico are presented. Off the coasts of Louisiana and Texas, monthly average temperatures of surface and bottom waters at station depths of 7, 14, 28, 46, and 73 m exhibited seasonal trends that were similar over a 3-yr period. Salinities of surface and bottom waters varied markedly at 7- and 14-m stations, whereas at deeper stations seasonal fluctuations were restricted primarily to surface waters. The magnitude of yearly salinity fluctuation decreased with an increase in distance offshore.

Texas Department of Water Resources. 1980a. Guadalupe Estuary: A Study of the Influence of Freshwater Inflows. Rept. No. LP-107, Texas Dept. of Water Resources, Austin, Texas.
G-22

In 1975, the 64th Texas Legislature enacted Senate Bill 137, a mandate for comprehensive studies of "the effects of freshwater inflow upon the bays and estuaries of Texas" Reports published as a part of the effort were to address the relationship of freshwater inflow to the health of living estuarine resources (e.g., fish, shrimp, etc.) and to present methods of providing and maintaining a suitable ecological environment. The technical analyses were to characterize the relationships which have maintained the estuarine environments historically and which have provided for the production of living resources at observed historic levels. Seven major estuaries on the Texas coast are part of this series.

Texas Department of Water Resources. 1983. Laguna Madre Estuary: A Study of the Influence of Freshwater Inflows. Rept. No. LP-182, Texas Dept. of Water Resources, Austin, Texas.
G-25, G-26, G-26.1, G-26.2

See TDWR (1980a).

Texas Department of Water Resources. 1980b. Lavaca-Tres Palacios Estuary: A Study of the Influence of Freshwater Inflows. Rept. No. LP-106, Texas Dept. of Water Resources, Austin, Texas.
G-21

See TDWR (1980a).

Texas Department of Water Resources. 1981a. Nueces and Mission-Aransas Estuaries: A Study of the Influence of Freshwater Inflows. Rept. No. LP-108, Texas Dept. of Water Resources, Austin, Texas.
G-23, G-24

See TDWR (1980a).

Texas Department of Water Resources. 1981b. Sabine-Neches Estuary: A Study of the Influence of Freshwater Inflows. Rept. No. LP-116, Texas Dept. of Water Resources, Austin, Texas.
G-16

See TDWR (1980a).

Texas Department of Water Resources. 1981c. Trinity-San Jacinto Estuary: A Study of the Influence of Freshwater Inflows. Rept. No. LP-113, Texas Dept. of Water Resources, Austin, Texas.
G-17

See TDWR (1980a).

Texas Water Development Board. 1973. Coastal Data System User Documentation. Vol. I, revised Feb. 1977, Storage Reference Manual, 156 p. Vol. II, revised June 1976, Retrieval Reference Manual, 173 p. Texas Water Development Board, now Texas Department of Water Resources, Austin, Texas.
G-16 through G-24, G-26

This manual describes the mechanics of estuarine data storage and retrieval for the Texas Coastal Data System. Information is given for basic data coding methods, data header information, parameter coding, hydrographic coding, and biological coding. Chemical, physical, and biological data on all of the bays and estuaries along the Texas Gulf coast. The data were collected in a cooperative effort by several State and Federal agencies at numerous sampling locations in several bays.

Thayer, G. W., D. R. Colby, W. F. Hettler, L. F. Simoneaux and D. S. Peters. 1985. Alteration of freshwater inflow patterns can impact the fishery function of estuaries. Coastal Ocean Pollution Assessment News 3(3):33-34.
F-11

The upland and wetland areas of coastal Florida have undergone extensive development in the past 20 years, and concerns have been expressed that this development may be responsible for reductions in sport and commercial fisheries in some areas. One development was in the area called Golden Gates Estates near the Ten Thousand Island area in south Florida. The pattern of freshwater inflow into an estuary in the area, Faka Union Bay, was greatly altered by channelization of the upland drainage basin in the vicinity of Golden Gate Estates in the 1960s. The channelization resulted in a point source discharge of freshwater into Faka Union Bay during the rainy season rather than the overland flow that normally occurs.

Thomas, W. H. and E. G. Simmons. 1960. Phytoplankton production in the Mississippi Delta. Pages 103-116 in F. P. Shepard, F. B. Phleger and T. H. van Andel (eds.), Recent Sediments, Northwest Gulf of Mexico. Proceedings of a Symposium Summarizing the Results of Work Carried on in Project 51 of The American Association of Petroleum Geologists (1951-1958), 1959, Scripps Institute of Oceanography, La Jolla, California. The American Association of Petroleum Geologists, Tulsa, Oklahoma.
G-7.1, G-8.1

At 138 stations in the eastern Mississippi Delta area, measurements were made of phytoplankton produced (C^{14} uptake), chlorinity, temperature, suspended solids, Secchi disc depth, inorganic phosphate, soluble silica, and soluble Kjeldahl nitrogen. In addition, the phytoplankton in the water were identified and enumerated.

Thompson, P. A. and N. Bane (eds.). 1986a. SEAMAP Environmental and Biological Atlas of the Gulf of Mexico, 1983. No. 13. Southeast Area Monitoring Assessment Program (SEAMAP) of the Gulf States Fisheries Commission, Ocean Springs, Mississippi, 179 p.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

Overall survey objectives were to assess the distribution and abundance of ichthyoplankton and trawl-caught organisms, and document environmental factors that might affect their distribution and abundance. This second in a series of SEAMAP biological and environmental atlases presents resource survey data, in a summarized form, collected during 1983 surveys.

Thompson, P. A. and N. Bane (eds.). 1986b. SEAMAP Environmental and Biological Atlas of the Gulf of Mexico, 1984. No. 15. Southeast Area Monitoring Assessment Program (SEAMAP) of the Gulf States Fisheries Commission, Ocean Springs, Mississippi, 171 p.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

In keeping with the program goal of establishing a coordinated, long-term resource database, it was decided to continue the same types of survey activities conducted in 1982 and 1983, but in addition, to add a plankton survey for mackerel in August of 1984.

Thompson, P. A. and T. D. Leming. 1978. Seasonal Description of Winds and Surface and Bottom Salinities and Temperatures in the Northern Gulf of Mexico, October 1972 to January 1976. NOAA Technical Report NMFS SSRF-719, U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D.C., 44 p.
G-2.1, G-5.1, G-7.1

Seasonal surface and bottom salinities and temperatures in the northern Gulf of Mexico are described. The area surveyed, from October 1972 to January 1976, was between Mobile Bay, Ala. (long. 88°00'W), and Atchalfalaya Bay, La. (long. 91°30'W), from 5 to 50 fm (9 to 91 m).

Thompson, P. A., T. Van Devender and N. J. Sanders, Jr. (eds.). 1988. SEAMAP Environmental and Biological Atlas of the Gulf of Mexico, 1985. No. 17. Southeast Area Monitoring Assessment Program (SEAMAP) of the Gulf States Fisheries Commission, Ocean Springs, Mississippi, 338 p.
F-15.1, F-24.1, G-2.1, G-5.1, G-7.1, G-27

In keeping with the program goal of establishing a coordinated long-term resource database, it was decided to continue the same types of survey activities conducted in 1982, 1983 and 1984 but with several exceptions. The offshore plankton survey conducted during April-May 1982, 1983 and 1984 was cancelled due to other NMFS commitments. A coordinated July-August Squid/butterfish Survey was established for the northern Gulf of Mexico. The plankton survey for mackeral of August 1984 was not requested in 1985. Finally, a Shrimp/Groundfish Survey was added to the survey activities between September and December.

Trask, P. D. 1953. The sediments of the western Gulf of Mexico. Part II - Chemical studies of sediments of the western Gulf of Mexico. Papers in Physical Oceanography and Meteorology 12(4):47-120.
G-7.1, G-27

In 1947, the Woods Hole Oceanographic Institution organized an expedition to investigate the bottom sediments and oceanography of the northwest Gulf of Mexico. The main objective was to investigate the environmental conditions of deposition of the sediments in the offshore waters more than 10 fm in depth in order to throw light on the oceanography of the northwest part of the Gulf of Mexico and to develop ecological criteria that would benefit geologists in their efforts to determine the condition of deposition of ancient sediments deposited in the geologic past in adjacent areas.

Treat, S. F., J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.). 1985. Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota. (parts in hand)
F-15

Trebatowski, B. 1988. Observations on the 1986-1987 Texas Red Tide (*Ptychodiscus brevis*). Rept. No. 88-02, Texas Water Commission, Austin, Texas, 48 p.
G-19 through G-27

From August 1986 through January of 1987, a red tide caused by the unarmored dinoflagellate *Ptychodiscus brevis* impacted Texas coastal and Gulf of Mexico waters from Galveston to Port Isabel, Texas and extended into Mexican waters. The red tide resulted in extensive fish kills, human respiratory and dermal irritation and closure of shellfish harvesting. This report documents the movement of and area impacted by the red tide, through plankton and water chemistry samples and boat and aerial surveys. Water chemistry data from samples taken during the bloom were in agreement with those of other red tide studies but failed to correlate with cell densities. *P. brevis* densities ranged to an estimated high of 1.1 million cells per ml (Rockport Harbor). Vertebrate and invertebrates killed during the event were estimated at greater than 22.2 million.

Trefry, J. H., S. Metz, R. P. Trocine and T. A. Nelsen. 1985. A decline in lead transport by the Mississippi River. Science 230(4724):439-441.
G-9

Input of pollutant lead to the Gulf of Mexico from the Mississippi River have declined by about 40 % within the past decade. This decrease has been determined from annual lead loads of the Mississippi River and from the lead record in Mississippi Delta sediments. The observed trend is consistent with reduced consumption of lead in gasoline in the United States. More than 90 % of the riverborne lead is associated with suspended sediments. Most of this particle-bound lead is deposited within 50 km of the river mouth and is not easily leached at pH values above 3.

Turner, R. E. and R. L. Allen. 1982a. Bottom water oxygen concentration in the Mississippi River Delta Bight. Contrib. Mar. Sci. 25:161-172.
G-7.1

Bottom-water oxygen concentrations in the Mississippi River Delta Bight are commonly below saturation values. Hypoxic conditions most often occur in shallow depths, west of the delta during summer. The hypoxic layer may be only a few meters thick and located on the bottom. An unusual midwater oxygen-depleted zone was observed south of Mobile Bay. The oxygen-minimum layer from deep water in the Gulf of Mexico may connect with low oxygen zones at the shelf break. *In situ* decomposition of material sinking from the surface layers is the most likely major oxygen consuming process. Lack of vertical mixing due to stratification probably contributes to the hypoxic summer conditions when oxygen concentration values are lowest.

Turner, R. E. and R. L. Allen. 1982b. Oxygen concentration and plankton respiration in the Mississippi River Delta Bight. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of

the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, Louisiana.
G-7.1

Bottom oxygen concentrations on seven cruises within the Mississippi River Delta Bight (MRDB) are observed to be commonly below complete saturation. Hypoxic conditions (less than 3 mg/l) most often occur in shallow depths, west of the delta, during summer. The hypoxic layer may be only a few meters thick and located near the bottom. Community plankton respiration rates in the bottom waters of the (MRDB) ranged from 0.12 to 8 mg oxygen/m3/h in July and in November 1976. Mean values were similar on both cruises, and between east and west halves of the delta in July. The observed rates are high enough to significantly influence and possibly dominate factors influencing bottom water oxygen concentration, although benthic oxygen demand is also a major additional factor.

Turner, R. E. and R. L. Allen. 1982c. Plankton respiration rates in the bottom waters of the Mississippi River Delta Bight. Contrib. Mar. Sci. 25:173-179.
G-7.1

Community plankton respiration (CPR) rates in the bottom water of the Mississippi River Delta Bight ranged from 0.12 to 8 mg oxygen/m^3/h in July and November 1976. Mean values were similar on both cruises, and between east and west halves of the delta in July. The observed rates are high enough to influence significantly and possibly dominate factors influencing oxygen concentrations. In July, CPR was correlated with variations in chlorophyll *a* concentrations, thus indicating that phytoplankton sinking is probably a major factor determining regional variations in CPR.

Turner, R. E., R. M. Darnell and J. Bond. 1980. Changes in the submerged macrophytes of Lake Pontchartrain (Louisiana): 1954-1973. Northeast Gulf Sci. 4(1):44-49.
G-7

The only submerged grasses found in the lake in 1954 were *Ruppia maritima* and *Vallisneria americana*. There was an apparent decline in the abundance of these two species from 1954 to 1973. Much of the loss occurred in the vicinity of the New Orleans beachfront and near the entrance to the estuary. There is an apparent decrease in these two species along the shoreline from 1954 to 1973 which amounts to a 25-33 % reduction. Other species shifts were noted.

Turner, R. E., R. Kaswadji, N. N. Rabalais and D. F. Boesch. 1987. Long-term changes in the Mississippi River water quality and its relationship to hypoxic continental shelf waters. Pages 261-266 in Estuarine and Coastal Management - Tools of the Trade. Proceedings of the Tenth National Conference of the Coastal Society, October 12-15, 1986, New Orleans, Louisiana. The Coastal Society, New Orleans, Louisiana.
G-7.1, G-9

See Turner and Rabalais (1991a) citation for a more thorough treatment of the data.

Turner, R. E. and N. N. Rabalais. 1991a. Changes in Mississippi River water quality this century. Implications for coastal food webs. BioScience 41(3):140-147.
G-5.1, G-7.1, G-9, G-12

Nitrate concentrations in the largest U.S. watershed, the Mississippi, doubled since the beginning of the century, primarily since the 1950s. The concentration of silicate has been halved in the same period resulting in a decrease in the silicate:nitrate atomic ratio from about 4 to 1. Nitrogen loading from the Mississippi and Atchafalaya Rivers to the continental shelf increased about two times over the past 30 years. The biological responses in the Mississippi watershed are consistent with the hypothesis that silicon depletion is a consequence of increased phosphorus supply and results in silicon depletion and a silicon-limited diatom

population. These changes in nitrate, phosphate and silicate has almost certainly changed estuarine phytoplankton communities (especially the diatoms), if not led to increased phytoplankton production. The effect of the probable decline in diatom abundance, a likely source of the organic matter fueling oxygen consumption rates in offshore hypoxic zones, may have been compensated for by increased abundances of other algal types, especially flagellates.

Turner, R. E. and Y. S. Rao. 1990. Relationships between wetland fragmentation and recent hydrologic changes in a deltaic coast. Estuaries 13(3):272-281.
G-5, G-6, G-9 through G-16

Patterns in coastal wetland loss in the northern Gulf of Mexico were examined using aerial imagery from 1955-1956 and 1978. Canals and their spoil banks are spatially related to wetland-to-water conversion which is evident up to 2 km away from those manmade features. The indirect impacts of canals and spoil banks vary regionally, for example, with sediment compaction rates that increase with increasing sediment deposition. These results are consistent with the hypothesis that canals and spoil banks are a major factor driving wetland loss rates because they change wetland hydrology.

Turner, R. E., W. W. Schroeder and W. J. Wiseman, Jr. 1987. The role of stratification in the deoxygenation of Mobile Bay and adjacent shelf bottom waters. Estuaries 10(1):13-19.
G-2, G-2.1

Oxygen depletion in the shallow bottom waters of Mobile Bay, Alabama, and in adjacent nearshore and continental shelf waters, is shown to be directly related to the intensity of water column stratification. Low wind speeds are coincidental with the onset of water column stratification and the occurrence of hypoxic events. Hourly, daily, and seasonal changes in the relationship between percent oxygen saturation or oxygen concentration in the bottom waters and surface-bottom density differences indicate that the oxidized materials are recently formed, and not relic or overwintering carbon sources. The influence of density structure (water column stratification) in the oxygen-depleted coastal water masses is compared to Mobile Bay.

U.S. Fish and Wildlife Service. (in prep.). An Evaluation of Finfish and Shellfish Resource Changes in the Perdido Bay Vicinity. Prepared by Division of Ecological Services, Panama City Field Office. U.S. Dept. of the Interior, Fish and Wildlife Service, Southeast Region, Atlanta, Georgia, 99 p.
G-1, F-28

The purpose of this report is to identify and document changes in selected finfish and shellfish resources, using presently available information. No new field or laboratory studies were performed in conjuction with this report. Conclusions based upon the results of 96 statistical analyses performed for this report are included.

U.S. Geological Survey. 1980. Water Resources Data for Louisiana. Vol. III. Coastal Louisiana. U.S. Geological Survey Water-Data Report No. LA-80-3, Water Year 1980, U.S. Dept. of the Interior, Geological Survey, Baton Rouge, Louisiana. (not in hand)

Van Hoose, M. S. 1988. Biological Assessment of the Perdido Bay System. Report to the Alabama Department of Economic and Community Affairs. Alabama Marine Resources Division, Dauphin Island, Alabama.
G-1, F-28

In response to public uneasiness concerning industrial discharge, the Alabama Dept. of Economic and Community Affairs contracted the Alabama Dept. of Conservation and Natural Resources to conduct an extensive sampling survey of the Perdido Bay estuary. Nine trawl samples and six seine stations were taken monthly throughout the estuary. The survey monitored finfish, commercially important shrimp and crabs, and hydrographic parameters (dissolved oxygen, temperature, and salinity). This report includes the results of the survey from April 1987 to March 1988. Samples showed an abundance of fish life throughout Perdido Bay

each month. Critically low dissolved oxygen exists in Eleven Mile Creek probably the result of treated paper mill effluent being dumped there. The condition is confined to the creek as there is no noticeable impact on finfish and hydrographic conditions in the upper area of the bay.

Van Sickle, V. R., B. B. Barrett, T. B. Ford and L. J. Gulick. 1976. Barataria Basin: Salinity Changes and Oyster Distribution. Sea Grant Publ. No LSU-T-76-02. Tech. Bull. No. 20, Louisiana Wildlife and Fisheries Commission. Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana, 22 p.
G-10

The biology, production, and distribution of the American oyster in the Barataria Basin have been correlated with environmental factors that determine spatfall, growth, reproduction, and mortality. Mortalities resulting from predation and disease are often associated with increased levels of salinity and temperature. Oysters thrive in the mixture of fresh and salt water found in many of our estuaries; their distribution is found to be directly related to salinity. This paper explains the interrelationships that exist between salinity and other environmental parameters affecting oyster populations.

Van Vleet, E. S. 1985. Hydrocarbons in Tampa Bay - a review. Pages 130-146 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

This paper reviews the extent to which petroleum hydrocarbons and chlorinated hydrocarbons are impacting the marine environment of Tampa Bay, Florida. The sparse data presently available tend to indicate that most of the Bay is still much cleaner with respect to petroleum and chlorinated hydrocarbon contamination than many other anthropogenically impacted estuaries around the U.S. Areas of unusually high concentrations of these compounds have been reported around the Bay, however.

Waldrop, R. D. 1983. Characteristic seasonal conditions in Barataria Bay waters on the north shore of Grand Terre Island, Louisiana. Proc. La. Acad. Sci. 46:97-105.
G-10

Cycles of temperature, tidal occurrence, tidal depth, and salinity were analyzed with data obtained from the Louisiana Dept. of Wildlife and Fisheries, Seafood Division. The data were taken from continuous recorders on the north shore of Grand Terre Island, Louisiana, and were summarized to exemplify seasonal conditions in adjacent Barataria Bay waters during six week periods in the spring, summer, and fall. Photoperiods were included to complete each seasonal profile. The limits given for the indicated variables may be useful for accurate laboratory simulation in studies of seasonal physiology and behavior of aquatic species in lower Barataria Bay, Louisiana.

Ward, C. H., M. E. Bender and D. J. Reish (eds.). 1979. The Offshore Ecology Investigation. Effects of oil drilling and production in a coastal environment. Rice Univ. Studies 65:1-589.
G-7.1, G-11

Ward, Jr., G. H., N. E. Armstrong and the Matagorda Bay Project Teams. 1980. Matagorda Bay, Texas: Its Hydrography, Ecology and Fishery Resources. Biological Services Program Publ. FWS/OBS-81/52, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C., 230 p.
G-21

The purpose of the report is to present compiled available information on the Matagorda Bay system and to synthesize the present knowledge of the hydrography and ecology of the system. Chapters cover the

hydrography (physiography, circulation, hydrology, sedimentary processes), water quality, inflow and waste discharges, fish and wildlife resources, species profiles of vegetation, shellfish and finfish, and a preliminary assessment of perturbations.

Wardle, W. J., S. M. Ray and A. S. Aldrich. 1975. Pages 257-263 in V. R. LoCicero (ed.), Proceedings of the First International Conference on Toxic Dinoflagellate Blooms. The Massachusetts Science and Technology Foundation, Wakefield, Massachusetts.
G-27

This report documents the occurrence of blooms of the toxic dinoflagellate *Gonyaulax monilata* in the offshore coastal waters of Texas at Galveston. Blooms of 1.2 to 1.9 x 10^6 cells per liter were recorded in August of 1971 and 1972, respectively. Despite extensive monitoring in late July and August of 1973, no *G. monilata* were noted in the offshore area of Galveston Island. It was suggested that the absence of the red tides during these years was related to relatively low salinities and temperatures in the Galveston Bay drainage area during the month of August.

Weiss, W. R. and T. D. Phillips. 1985. The meroplankton of Tampa Bay. Pages 345-358 in S. F. Treat, J. L. Simon, R. R. Lewis, III and R. L. Whitman, Jr. (eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Sea Grant Project No. IR/82-2. Grant No. NA80AA-D-00038. Florida Sea Grant College, Report No. 65, Burgess Publishing Co., Minneapolis, Minnesota.
F-15

Information on the planktonic, early developmental stages of fish and invertebrates (meroplankton) has been collected in a variety of studies conducted in the Tampa Bay area over the last 20 years. Early, largely qualitative investigations documented the importance of the bay system as a spawning site and nursery for species important to Gulf of Mexico fisheries. More recent studies have provided quantitative estimates of relative abundance, seasonality, and to some extent, spatial distribution of meroplaktonic organisms in the estuarine and coastal waters of the area. However, because of "state of the art" limitations to the study of meroplankton organisms, as well as the restricted areal coverage of the quantitative investigations, additional data collection is needed before a comprehensive assessment can be made of the relative value of the various subareas of the bay system as spawning and nursery grounds.

Wells, F. C. and C. R. Demas. 1977. Hydrology and Water Quality of the Atchafalaya River Basin. Water Resources Technical Report No. 14, Louisiana Dept. of Transportation and Development, Office of Public Works, Baton Rouge, Louisiana, 53 p.
G-12

Water quality of the Atchafalaya River is controlled by the discharges and chemical quality of the Red, Black and Mississippi Rivers. The major anion and cation present in the Atchafalaya Basin Floodway are bicarbonate and calcium, respectively. Chemical quality in the Atchafalaya Basin Floodway is closely related to the chemical quality of the river at Simmesport. Differences in concentrations in the major ions between the river at Simmesport and the swamp areas of the floodway are most pronounced during periods of low flow. Dissolved oxygen concentrations generally exceed 6 mg/l in the main channel and major distributaries; however, dissolved oxygen concentrations fall below 4 mg/l in the floodway during periods of low flow. Concentrations of nitrogen and phosphorus, heavy metals, and pesticides in the floodway are relatively low. Nutrient and suspended solid concentrations decrease as distance from the main channel and major distributaries increases.

Wells, L. and P. N. Froelich. 1982. Estuarine nutrient geochemistry in Ochlockonee Bay, Florida (Abstr.). EOS 63(3):56.
F-23

Nutrient and related data are being gathered at monthly intervals in the Ochlockonee River and Bay, a simple "two-end-member," unperturbed estuary in Florida. Samples, taken at intervals of 1-2 ppt over the full salinity gradient, are analyzed. These data are used in a simple estuarine model to quantify removal and input fluxes. With the river flow values and seasonal removal patterns, one can then calculate nutrient fluxes to the ocean from such systems.

Whitledge, T. E. 1985. Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters. Executive Summary. Report to U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Assessment, Ocean Assessments Division. Brookhaven National Laboratory, Oceanographic Sciences Division, Upton, New York, 28 p.
F-9 through G-27

This is the executive summary for the Nationwide Review conducted in the northeast, southeast, Florida, Gulf of Mexico, and west coast. The principal investigator for each area was to assess the health of the estuarine and coastal environments in the U.S. as indicated by low oxygen concentrations, eutrophication, or mass mortalities of organisms. Following the literature compilations, all principal investigators and key personnel attended a workshop to discuss the results of the respective regional compilations and prepare common products to represent a nationwide summary. The major product of the workshop was a list of impacts found in the study representing: 1) priority hypoxia areas, 2) potential hypoxia areas, and 3) areas lacking data but with potential dissolved oxygen problems.

Whitledge, T. E. 1989. Data Synthesis and Analysis, Nitrogen Processes Study (NIPS), Nutrient Distributions and Dynamics in Lavaca, San Antonio and Nueces/Corpus Christi Bays in Relation to Freshwater Inflow. Part I: Results and Discussion. Final Report for Bays and Estuaries Program, Environmental Systems Section, Texas Water Development Board. Tech. Rept. No. TR/89-007, University of Texas Marine Science Institute, Port Aransas, Texas. (whole document not in hand)
G-22

Whitledge, T. E. and W. M. Pulich, Jr. (conveners). 1991. Report, Red Tide Symposium and Workshop, 15-16 July 1991. Marine Science Institute, The University of Texas, Port, Aransas, Texas, 44 p.
G-25, G-26

The "brown tide" bloom of an aberrant Chrysophyte sp. phytoplankter occurred for more than 18 months and extended into both upper and lower Laguna Madre, Texas. Great concern for the Laguna Madre ecosystem was shown during the brown tide event by local, state and regional groups, but little previous knowledge was available about this unusual phytoplankton bloom. This report includes the agenda, abstracts of presentations, and summary of findings by the workshop participants convened to discuss the data and results on brown tide and other unusual phytoplankton blooms.

Williams, C. D., D. M. Nelson, L. C. Clements, M. E. Monaco, S. L. Stone, L. R. Settle, C. Iancu and E. A. Irlandi. 1990. Distribution and Abundance of Fishes and Invertebrates in Eastern Gulf of Mexico Estuaries. NOAA's Estuarine Living Marine Resources Project Report No. 6, National Oceanic and Atmospheric Administration, Strategic Assessment Branch, National Ocean Survey, Rockville, Maryland, 105 p.
F-9, F-11, F-12, F-13, F-15, F-19, F-22, F-24, F-25, F-26, F-27, G-1, G-2

This report presents information on the spatial and temporal distribution, relative abundance, and life history characteristics of 36 fish and invertebrate species in 13 estuaries along the Eastern Gulf of Mexico coast. Its purpose is to disseminate data developed in NOAA's Estuarine Living Marine Resources (ELMR) project. The objective of ELMR is to develop a consistent data base on the distribution and abundance of selected fishes and invertebrates in the Nation's estuaries.

Williams, H. B. 1956. A Chemical and Bacteriological Survey of the Waters and Muds in a Western Portion of Lafourche Parish, Louisiana. C.S.I. Contribution No. 56-5, Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana.
G-10

This summary report presents chemical and bacteriological data that resulted from five field trips into the Grand Bayou Blue section of Lafourche Parish, Louisiana, made from December 1954 to November 1955 and the correlation and interpretation of those data. The following experimental determinations were made; pH, temperature, specific gravity, specific conductance, absolute turbidity, differential refractive index, total solids before and after ignition, chlorinity, dissolved oxygen, biological oxygen demand, sulfate, soluble and oxidizable forms of sulfur, type of bacteria, bacteriological count, and sulfur content of the muds.

Williams, J. and R. M. Ingle. 1972. Ecological notes on *Gonyaulax monilata* (Dinophyceae) bloom along the west coast of Florida. Florida Marine Research Laboratory, Leaflet Series: Volume I - Phytoplankton, Part 1 (Dinoflagellates) No. 5. Florida Dept. of Natural Resources, Marine Research Laboratory, St. Petersburg, Florida, 12 p.
F-12, F-13, F-14, F-15, F-15.1

The study documents the first record of *Gonyaulax monilata* along Florida's west coast, along with associated fish kills. The bloom was concentrated in early August 1966 in estuaries and offshore waters from Estero Island to Doctors Pass. Later in August and September, this species was distributed along the coast from Anna Maria Island to Cape Roman. Following the *G. monilata* outbreak, a *Gymnodinium breve* bloom occurred in late October offshore Tampa Bay.

Wilson, W. B. and S. M. Ray. 1956. The occurrence of *Gymnodinium brevis* in the western Gulf of Mexico. Ecology 37(2):388.
G-27

During 1953-55, seawater samples were collected at Galveston, Texas and along the Gulf coast between Galveston and Florida, but no *G. brevis* were observed. In September 1955 a fish kill near Port Isabel, Texas was associated with a bloom of *G. brevis*. The bloom extended down the coastline of the Mexican state of Tamaulipas for approximately 200 km.

Windham, C. M., T. L. Bradley, M. H. Schurtz and P. Romanowsky. 1980. Lake Pontchartrain Crab Kill. Louisiana Department of Wildlife and Fisheries, and Louisiana Department of Natural Resources, Baton Rouge, Louisiana, 10 p.
G-7

Several reports were received by the Louisiana Dept. of Wildlife and Fisheries during the month of August, 1980 concerning dead crabs in Lake Pontchartrain. A preliminary survey on August 20 indicated that an oxygen problem existed. A more detailed survey was conducted on August 28 and 29. Twenty-six stations were sampled during this 2-d period. The data indicates that a dense layer of high salinity anoxic water was present in the Lake during August 1980. Communication with various crab fishermen indicated that this area of poor water quality would move depending on wind and tide. Thus, crabs could enter traps in areas of good water quality and could not leave the area when water quality conditions became poor. It is probable that this phenomena was the cause of the crab kill. Subsequent samples taken in September have shown that the water column is now well mixed and the deoxygenated layer has dispersed.

Windsor, Jr., J. G. 1985. Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters: Florida Region. Project Completion Report to Brookhaven National Laboratory, Upton, New York and U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Assessment, Ocean Assessment Division, Rockville, Maryland, 177 p.
F-9 through F-28

The coastal regions of Florida have been most impacted in recent years by rapid population growth and its associated burdens. The most significant burden on estuaries and coastal waters of Florida appears to have been the discharge of untreated or improperly treated municipal sewage. Other impacts are from industrial processes related to wood, paper and pulping, agriculture, fertilizer mining and processing, and commercial shipping. Areas with sufficient data to suggest a definite problem with oxygen depletion were listed as Perdido Bay, Tampa/Hillsborough Bay, and Biscayne Bay. An area with marginal or deteriorating water quality with respect to oxygen depletion was listed as Pensacola and Escambia Bays. Two areas were placed on the list of suspicious areas which are either lacking data or have insufficient data to suggest an oxygen problem: Indian River, Banana River, Mosquito Lagoon systems and the Florida Keys.

Wiseman, Jr., W. J. 1982. Physical processes which may impact the oxygen depletion zone over the Louisiana shelf. Abstr. for Proceedings of the Third Annual Gulf of Mexico Information Transfer Meeting, August 24-26, 1982, New Orleans, Louisiana. U.S. Dept. of the Interior, Minerals Management Service, Outer Continental Shelf Office, New Orleans, Louisiana.
G-7.1

To date, there is no clearly demonstrated relationship between physical processes on the Louisiana shelf and the oxygen depletion zone found in the same region. One can, though, speculate about quite plausible interactions. Any process which provides a source of carbon for the inner shelf waters, or which isolates these waters from processes which renew the dissolved oxygen concentration, will contribute to an oxygen depletion zone. Three such mechanisms have been observed in the Louisiana Bight, the area immediately west of the Mississippi River Delta: 1) The effluent from the Mississippi River flowing westward over the mid and inner shelf; 2) the intrusion of high salinity water along the bottom from farther offshore; 3) a well-mixed bottom layer often found throughout the Louisiana Bight.

Wiseman, Jr., W. J., W. W. Schroeder and S. P. Dinnel. 1988. Shelf-estuarine water exchange between the Gulf of Mexico and Mobile Bay, Alabama. Am. Fish. Soc. Symp. 3:1-8.
G-2, G-2.1

One month of current meter data from Main Pass, which connects lower Mobile Bay with the Gulf of Mexico, demonstrated shelf-estuarine exchange driven by north-south wind stress at periodicities longer than the tide. Riverine discharge fluctuations may modulate the gravitational circulation over time scales shorter than seasons. Tidal diffusion, long-period advection, and the mean circulation are of equal importance to dispersion of water through Main Pass.

Wiseman, Jr., W. J. and E. M. Swenson. 1987. Long-term salinity trends in Louisiana estuaries. Pages 101-121 in R. E. Turner and D. R. Cahoon (eds.), Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Vol. II: Technical Narrative. OCS Study MMS 87-0120, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana.
G-7, G-8, G-9, G-10, G-11, G-12, G-13, G-14, G-15

The goal of this study was to analyze existing records of salinity from the Louisiana coastal zone to determine whether or not they support the notion that significant long-term trends in the estuarine salinity regime have occurred. These data were analyzed to determine the long-term (30 to 40 years), seasonally adjusted trends. The authors were primarily concerned with the salinity regime as it relates to both natural and man-induced factors. Thus, the task had two major objectives; to determine the secular trends (if any) in the salinity regime and to identify the factors that may be controlling these changes. They were particularly interested to see if the existing salinity records indicated the occurrence of changes of sufficient magnitude to impact the vegetation.

Wiseman, Jr., W. J., E. M. Swenson and J. Power. 1990. Salinity trends in Louisiana estuaries. Estuaries 13(3):265-271.
G-7, G-8 through G-15

If long-term trends in the character of the estuarine salinity field are contributing to land-loss in coastal Louisiana, then evidence of the presence of these trends may exist in historical salinity records. Nonparametric tests for the presence of a trend in the time series of various salinity statistics were performed. The results appear to be strongly influenced by climatological variations of decadal scale. Statistically significant trends were found at many stations. Both increasing and decreasing trends occurred with no apparent underlying spatial pattern. The observed changes during the time covered by the available records were generally too small to be lethal to the dominant marsh plants.

Wiseman, Jr., W. J., R. E. Turner, F. J. Kelly, L. J. Rouse, Jr. and R. F. Shaw. 1986. Analysis of biological and chemical associations near a turbid coastal front during winter 1982. Contrib. Mar. Sci. 29:141-151.
G-7.1

An intense front separates the waters of the nearshore region from those of the Louisiana inner shelf. Horizontal salinity gradients often exceed 0.25 ppt km^{-1}. Data from hydrographic cruises and moored instruments are used to characterize the variability in and around the front during winter/spring, when the structure is most changeable. A modified empirical orthogonal function analysis explains 88 % of the data variability with three basic patterns: 1) high nitrate and silicate concentrations are strongly associated with the low-salinity nearshore waters; 2) an association between high chlorophyll *a* concentration and low temperature reflects, we believe, both parameters' relationship with turbid shallow depths rather than a direct interaction; 3) coincidental high ammonia and zooplankton concentrations are, presumably, due to excretion. In contrast to oceanic fronts, these shelf fronts do not lead to regional boundary zones of increased biologic activity.

Witzig, A. S. and J. W. Day, Jr. 1983. A Multivariate Approach to the Investigation of Nutrient Interactions in the Barataria Basin, Louisiana. Final Report to the Louisiana Water Resources Research Institute. Project - A-047-LA, Coastal Ecology Laboratory, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana, 36 p.
G-10

A study of nutrient chemistry in the Barataria basin was designed to illustrate seasonal and spatial variability along a fresh to saltwater gradient and to assess the impact of human induced alterations on the water chemistry of the system. These impacts include high nutrient loads in runoff from agricultural and urban development and an extensive network of canals dredged through the wetlands. Twenty-three sampling stations were sampled quarterly in 1975-1977 along a 120-km transect to reflect the high diversity of water types within the basin. Parameters measured included total and dissolved organic nitrogen, total phosphorus, nitrate-nitrite nitrogen, ammonium nitrogen, chlorophyll *a*, secchi depth, salinity, conductivity, dissolved oxygen and temperature. Multivariate statistical techniques were used to provide an holistic approach to the interpretation of chemical data. The analyses suggested that the variation in water chemistry between the upper and lower basin would be much less with fewer human impacts.

Wolfe, S. H. (ed.) 1990. An Ecological Characterization of the Florida Springs coast: Pithlachascotee to Waccasassa Rivers. USFWS Biological Report No. 90(21), U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C. and Minerals Management Service, New Orleans, Louisiana, 323 p.

Wolfe, S. H. and R. D. Drew (eds.) 1990. An Ecological Characterization of the Tampa Bay Watershed. USFWS Biological Report No. 90(20), U.S. Dept. of the Interior, Fish and Wildlife Serivce, Washington, D.C. and Minerals Management Service, New Orleans, Louisiana, 334 p.
F-15

Wolfe, S. H., J. A. Reidenauer and D. B. Means. 1988. An Ecological Characterization of the Florida Panhandle. FWS Biological Report No. 88(12), OCS Study MMS 88-0063, U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C. and Minerals Management Service, New Orleans, Louisiana, 277 p.
F-23, F-24, F-25, F-26, F-27

The Florida Panhandle is one of the most rapidly developing regions in the entire State. Many Panhandle commercial interests, especially fishing and tourism, are highly dependent upon the maintenance of relatively unaltered habitats. Critical decisions on the preservation or economic development of particular areas are often made without knowledge of the composition, dynamics, and sensitivity of the local habitats and the associated flora and fauna to perturbations. Additionally, higher level interactions between systems and habitats are often overlooked. This report is an extensive review and synthesis of available literature on the local physical setting and ecology and a discussion of important impacts on the habitats within the Panhandle region. Included are projections of possible future impacts and identification of areas that need further research before they are permanently altered.

Wright, L. D. 1970. Circulation, Effluent Diffusion, and Sediment Transport, Mouth of South Pass, Mississippi River Delta. Technical Report No. 84, Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana, 56 p.
G-9

A study was conducted at the mouth of South Pass, Mississippi River, to ascertain the influence exerted by interaction between effluent and ambient fluids; tides; waves; winds; bottom topography and channel mouth geometry; regional coastal currents; horizontal and vertical density gradients; and hydrologic regime of the Mississippi River. It is concluded that fluid and sediment dissemination at the mouth of South Pass is associated with an intricately interacting multipurpose system. Patterns cannot be adequately explained in terms of any single process such as turbulent jet diffusion.

Zein-Eldin, Z. P. and M. L. Renaud. 1986. Inshore environmental effects on brown shrimp, *Penaeus aztecus*, and the white shrimp, *P. setiferus*, populations in coastal waters, particularly of Texas. Mar. Fish. Rev. 48(3):9-19.
G-27

This discussion compares and contrasts responses of the two species to single factors and their interaction, giving only limited literature citations. Implications for the two species are then explored. The purposes of this paper are to 1) provide, in an easily accessed tabular format, representative information and literature sources relating environmental factors to several inshore life stages of brown and white shrimp and 2) bring attention to those factors, their interactions, and life stages for which information is lacking.

Zieman, J. C. and R. T. Zieman. 1989. The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile. Biological Report No. 85(7.25), U.S. Dept. of the Interior, Fish and Wildlife Service, Research and Development, Washington, D.C., 155 p.
F-15

The greatest losses of seagrass habitat are caused by the effects of physical damage from dredging and the chronic stresses placed on the plants by suspended sediments and eutrophic algal growth, manifested in the form of increased turbidity and resultant light reduction.

Zimmerman, M. S. and R. J. Livingston. 1979. Dominance and distribution of benthic macrophyte assemblages in a north Florida estuary (Apalachee Bay, Florida). Bull. Mar. Sci. 29(1):27-40.
F-22

A comparative analysis was made concerning the distribution of benthic macrophyte assemblages in shallow portions of Apalachee Bay. This included a comparison of areas affected by bleached kraft mill effluents with appropriate uncontaminated control stations. Meter-square samples of benthic macrophytes were collected monthly in both areas. Relative dominance was generally high in the unpolluted areas. Four species of red algae were found at all stations. It was postulated that selective removal of dominant species by bleached kraft mill effluents allowed recruitment of various "rare" species in areas of chronic impact, thus contributing to anomalous patterns of community structure when compared to published data from other pollution-stressed benthic systems.

Zimmerman, M. S. and R. J. Livingston. 1976. Effects of kraft-mill effluents on benthic macrophyte assemblages in a shallow-bay system (Apalachee Bay, North Florida, USA). Mar. Biol. 34:297-312.
F-22

A 14-mo study was carried out to determine the impact of kraft-mill effluents on the offshore benthic macrophyte distribution in a shallow north Florida bay. A polluted river drainage system was compared to an adjoining (unpolluted) one. The affected area was characterized by elevated levels of color and turbidity. Near-shore coastal systems in Apalachee Bay were affected by gradients in water quality in addition to natural (seasonal) fluctuations in key physical and chemical parameters.

Zotter, J. 1979. *Exuviella baltica*: A bloom organism of the Galveston Bay system. Pages 195-198 in D. L. Taylor and H. H. Seliger (eds.), Toxic Dinoflagellate Blooms. Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, October 31 - November 5, 1978, Key Biscayne, Florida. Developments in Marine Biology - Vol. 1, Elsevier North Holland, New York.
G-17

This report documents the occurrence of high cell concentrations of the dinoflagellate *Exuviella baltica* Lohmann in three different environmental areas of the Galveston Bay System. Data were recorded once every three weeks from 18 December 1976 through 5 March 1977 during a 12-mo study of live nannoplankton. Concurrent blooms of *Exuviella baltica* (to 2.8×10^5 cells/ml), the green alga *Chlorella* sp. (to 2.0×10^5 cells/ml), and the blue-green alga *Schizothrix calcicola* (to 5.2×10^4 cells/ml) were recorded in each of three different environmental areas in Galveston Bay and adjacent waters during the winter months. Total cell concentrations of nannoplankton during the apparently non-toxic blooms were from 6.7×10^3 cells per ml to 4.2×10^5 cells per ml.

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