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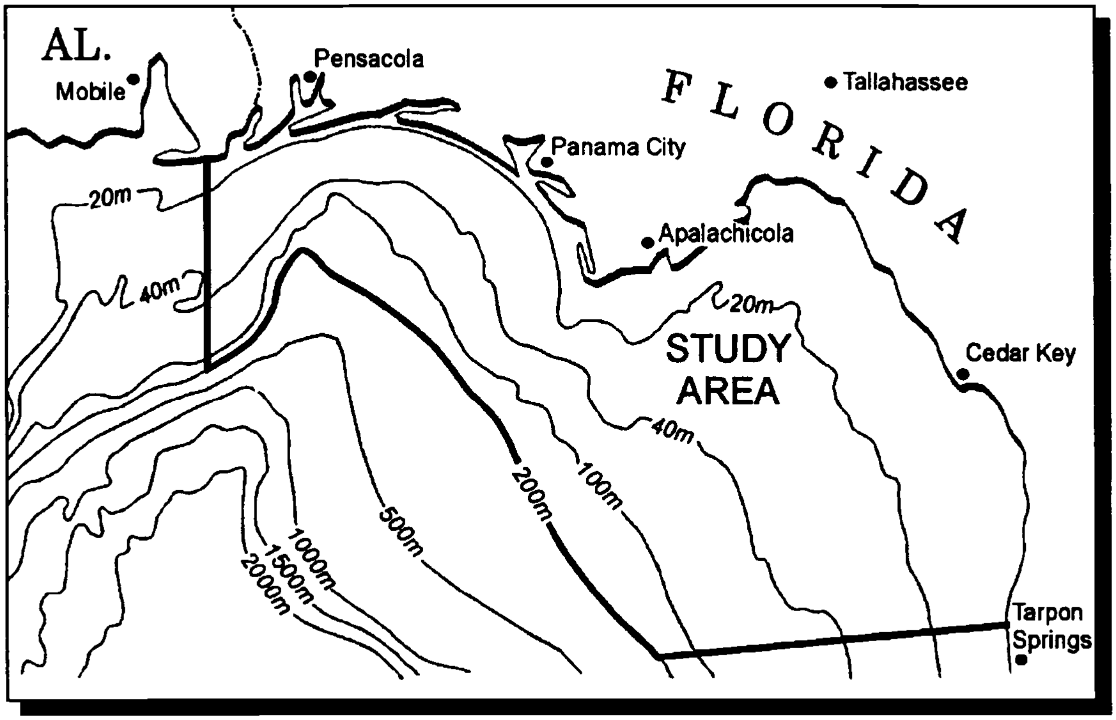

Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Data Search and Synthesis

Synthesis Report

U.S. Department of the Interior
U.S. Geological Survey
Biological Resources Division

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Data Search and Synthesis

Synthesis Report

August 1997

Prepared under BRD contract
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by
Science Applications International Corporation
Raleigh, North Carolina 27605

in cooperation with the

**U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region**

PROJECT COOPERATION

This study was procured to meet information needs identified by the Minerals Management Service (MMS) in concert with the U.S. Geological Survey, Biological Resources Division (BRD).

DISCLAIMER

This report was prepared under contract between the U.S. Geological Survey, Biological Resources Division and Science Applications International Corporation. This report has been technically reviewed by the BRD and the MMS, and has been approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the BRD or MMS, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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ACKNOWLEDGMENT

Although key authors are listed for each chapter, other members of the project team reviewed, edited, and amended this report to enhance its content and clarity. This was a team effort.

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Chapter 1 – INTRODUCTION

1.1 Background

With the possibility of oil and gas development and production and the associated potential for ecological and environmental impacts, the Biological Resource Division (BRD) of the United States Gelogical Survey (USGS)initiated a phased sequence of studies which should produce a comprehensive description of the dominant environmental processes, the ecological communities, and their potential sensitivities to development in the project study area (Figure 1-1). As the first phase in the process of establishing a rational base for management and leasing decisions by the Minerals Management Service (MMS), the present project conducted a comprehensive search and integration of regional environmental information.

Specific project objectives are to gather environmental and socioeconomic information related to the continental shelf ecosystem and associated coastal and estuarine communities. This information was then be used to describe elements of the ecosystem in the study area, establish an understanding of the environmental processes that drive the system, and identify those processes that are potentially sensitive to anthropogenic activities, particularly oil and gas development and operations.

1.2 Project Organization

As described below, planned project activities focused on the two primary tasks:

(A) Information Collection –

- Conducted literature searches to identify, review and annotate citations and data relevant to the meteorological/physical oceanographic, geological, chemical, biological and socioeconomic conditions in the study area. The results of these searches were compiled into separate Annotated Bibliographies for each of these topical areas.

(B) Information Synthesis –

- Developed the present Final Synthesis Report describing the above environmental topics as they relate to the study area.

- Information in these topical descriptions were used to develop a multi-level Conceptual Ecosystem Model relating various compartments of the ecosystem. The conceptual model provides a basis to help organize requirements and activities in future studies as well as identify important data gaps.

- Site specific environmental material and descriptions are presented describing six estuarine/nearshore areas: Pensacola Bay, Choctawhatchee Bay, St. Andrew Bay, St. Joseph Bay, Apalachicola Bay, and the Florida Big Bend Area (Figure 1-1).

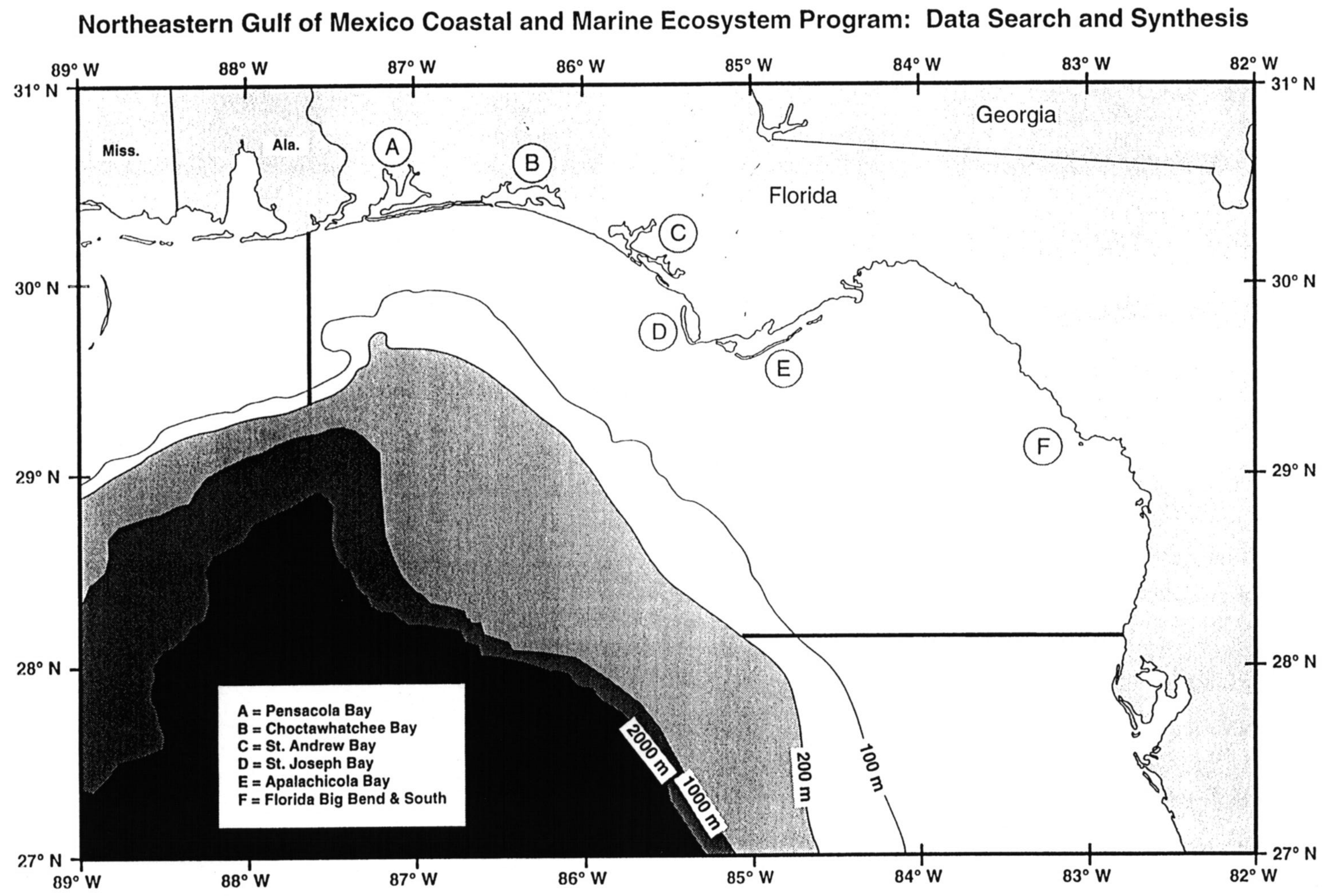


Figure 1-1. Map of the study area showing the general bathymetry, study area boundaries and the location of the six estuaries identified for special study.

1.3 Program Activities

1.3.1 Information Collection

The first key activity was to conduct a search for topically and geographically relevant citations and data. Much of this was done electronically using such on-line data bases available from DIALOG and National Technical Information Service (NTIS). The results of these searches are presented in six separate Appendices (A-F) to this Synthesis Report. Operationally, these appendices are inclusive such that some citations will appear in more than one volume. This approach was taken intentionally to reduce the need for a user to have to review the complete set of appendices to identify information relevant to a particular topical area.

The results of these searches have been entered into a bibliographic/ citation data base manager called Papyrus. A copy of the Papyrus formatted data base as well as a digital (word processor) version of each of the appendices has been provided to the National Biological Survey to facilitate both distribution and access to this information.

1.3.2 Information Synthesis

Principal Investigators for chapters in this report were selected for their familiarity with the present study area. In defining the project team, such a knowledge base was essential to efficient and timely development of the overall synthesis. This reservoir of regional knowledge was supplemented with the results of the Information Collection phase. The authors had access to the relevant annotated bibliographies as the present descriptive material was being developed.

For this study no original research little supplemental analysis was conducted. One exception was Socioeconomics. Dr. F. Bell (FSU) was also a Principal Investigator on a companion NBS study, being conducted concurrently by Continental Shelf Associates, investigating fisheries with the study area. Dr. Bell conducted additional analyses and associated description which were supported by both this and the companion program.

1.4 Program Participants

Information is collection occurred at several levels. For time and cost efficiency, the on-line/electronic bibliographic searches were conducted by personnel in the SAIC Center for Technical Research, which specializes in these activities. Lists of key words to be used in the search strategy were developed in collaboration with the Principal Investigators for each discipline. During the search process, PIs had opportunities to review possible citations to help remove those having no obvious application to the present program objectives. When a topical list of citations was completed, it was imported into the database.

Those program participants having a key role in the Information Collection phase are listed below with their associated activities:

- Meteorology/Physical Oceanography – Dr. Evans Waddell and Mr. Paul Blankenship (SAIC).

- Geology – Mr. David Inglin (SAIC).

- Chemistry – Ms. Margaret Murray (SAIC).

- Biology – Dr. Sneed Collard (UWF) and personnel with Barry Vittor and Associates (BVA).

- Socioeconomic – Dr. Fred Bell (FSU).

In addition, Dr. Sneed Collard visited many government, state and university laboratories along the Gulf coast to identify appropriate unpublished information relevant to the study area. Mr. Paul Blankenship was the resident expert in the use and importing of citations into the Papyrus software.

As described below, this report has a chapter for each of the topical disciplines, and a chapter describing the Conceptual Ecosystem Model. The decision was made not to integrate the various material around some other organizing principle. Thus, material in each chapter is similar to that submitted by the chapter authors. The authors are:

- Meteorology – Dr. Robert Wayland

- Physical Oceanography – Dr. Peter Hamilton and Dr. Evans. Waddell

- Geology – Dr. Richard Davis and Mr. David Inglin

- Chemistry – Dr. Jane Caffrey

- Biology – Dr. Sneed Collard and Dr. Carl Way

- Socioeconomics – Dr. Fred Bell

- Conceptual Ecosystem Model – Mr. Steven Pace

The program is managed by Dr. Evans Waddell. Supporting the PM is the Science Review Board which has as members Dr. William Schroeder (Dauphin Island Sea Lab) and Dr. John Hitron (UWF). Dr. Hitron has the additional responsibility of reviewing work being done by Continental Shelf Associates in a companion study that focuses primarily on fisheries in the study area.

1.5 Report Organization

This report is organized into eight chapters as follows:

Chapter 1:	Introduction – provides a general overview of the program objectives, procedures and participants
Chapter 2:	Meteorology and Physical Oceanography – describes many of the general processes affecting local weather conditions and

circulation patterns. Also describes ecologically significant physical parameters.

Chapter 3: Geology – describes the general geological conditions including an overview of the geological history and aspects of sediment dynamics.

Chapter 4: Chemistry – describes many of the key chemical concentrations and cycles, especially those relevant to the regional ecosystem

Chapter 5: Biology – the largest chapter presents a description of many of the key flora, fauna and biologically important conditions on the shelf and in the six estuaries/nearshore areas identified for special study.

Chapter 6: Socioeconomics – Describes many of the key marine related economic patterns and conditions in the coastal counties in the study area with a particular emphasis on the role of the marine fishery, both commercial and recreational.

Chapter 7: Conceptual Ecosystem Model – presents conceptual ecological relationships at three levels or tiers. The levels from 1 to 3 have increasing levels of detail and complexity.

Chapter 8: Summary – describes some of the key points and insights developed in the various topical and process chapters.

The six appendices (A-F) containing the annotated bibliographies are incorporated as separate documents. Appendix G of this report are a series of Socioeconomic Summaries for each coastal country described in Chapter 6.

Chapter 2 - THE PHYSICAL ENVIRONMENT

by Dr. Peter Hamilton,
Dr. Evans Waddell
and
Dr. Robert Wayland
Science Applications International Corp.

2.1 Introduction

This chapter presents a general description of key meteorological and physical oceanographic conditions and processes which are significant to the ecosystem in the study area. The objective has been to use the existing literature and published data to describe such things as patterns and ranges of conditions, with some general discussion of responsible processes. Specifically, the material presented is not meant to provide a detailed understanding of the potential physical mechanisms. Rather, the objective is to provide an ecologically meaningful framework within which to view such things as energy paths, material transport, recruitment and limiting environmental conditions. As will become apparent, there are a number of physically important variables and processes in the study area that are neither well-resolved nor understood, which point to the need to expand the regional oceanographic data base with tailored measurement and synthesis program(s).

Chapter 2 is split into two related primary sections, Meteorology (Section 2.2) and Physical Oceanography (Section 2.3). The Annotated Bibliographies, appendices to the main report, are divided on this same basis and are presented as two separate appendices, A and B, respectively.

2.2 Meteorology

2.2.1 Introduction

Synoptic climatology of a geographic region is based primarily on the types of air masses which seasonally dominate the local weather. In general, mid-latitude locations are characterized by two distinct seasonal weather patterns, which are linked synoptically by less well-defined transition periods. Meteorological conditions found within the northeastern Gulf of Mexico (NEGOM) follow this generic scenario quite well and are characterized by two distinct synoptic seasons: winter (December - March), and summer (May - October). Between these two dominant weather regimes are brief transitional periods of approximately one month duration (e.g. April and November). The region does not experience the lengthier spring and fall transitional periods, which characterize the mid-latitude continental sections of the United States. The Gulf of Mexico has been divided into eastern, central and western regions for previous oceanographic and meteorological studies. The west Florida Shelf region, or eastern Gulf of Mexico, is characterized by the persistence of warm, moist maritime tropical (mT) air masses throughout most of the year. The central and western Gulf of Mexico, while dominated by the warm, moist mT air masses in the summer, are exposed to strong arctic intrusions of cold, dry continental polar (cP) air masses during the winter season. The "collision zone" between these two differing air masses in winter months is often found in the northeastern Gulf of Mexico, causing it to be a prime location for the formation and development of winter extratropical cyclones (low pressure systems). Additionally, the warm shallow shelf waters in summer months, coupled with the warm Loop Current to the south of this region, have also made the NEGOM the landfall target of several major tropical systems over the past 30 years (Florida A&M University, 1988).

Several major global circulation features play a role in defining the synoptic climatology of the Gulf of Mexico. However, the two dominant circulation features influencing the region are the respective positions of the polar front (e.g. polar jet stream) and the Atlantic sub-tropical gyre (e.g. "Bermuda High"). The Atlantic sub-tropical gyre dominates the winter circulation patterns of the eastern Gulf of Mexico, with its strong clockwise circulation advecting warm tropical air into the region. This circulation feature is responsible for the relatively mild winter conditions observed along the southwestern and central Florida coast. The other winter meteorological feature in the Gulf of Mexico is the southward excursion of the polar jet stream. The high-amplitude patterns of the winter polar jet stream bring strong, cold, dry continental air masses into the region. These cold air outbreaks (CAO) provide a great deal of energy to the marine atmospheric boundary layer (MABL) over the shallow inner shelf regions of the northern Gulf. Fernandez-Partegas and Mooers (1975) found these strong polar outbreaks to occur at 3- to 10-day intervals during the period between October and March. Reviewing records for the past 103 years in Louisiana, Mortimer et al. (1988) determined that approximately every five years, the Gulf coastal region experiences severe freeze conditions, resulting from a strong CAO. Dimego et al. (1976) observed approximately 8-9 frontal passages per month in the northeastern Gulf of Mexico during winter. The frequency of frontal systems decreases markedly during the core summer months (e.g., 2 per month from June through August), with slight increases on either end of this period (e.g., 3-5 per month in May and September/October).

During the summer months, the northward migration of both the Atlantic sub-tropical gyre and the polar jet stream allow the Gulf region to be influenced strongly by the northeast trade winds. The increased influence of the trade winds on the region provides the steering mechanism for tropical wind/pressure systems which form in the eastern Atlantic to find their way into the Gulf. In past decade (1985-1995), the northeastern Gulf has experienced an increase in the number of tropical systems, relative to the previous 10-year period. However, although the region is subjected to varying extremes of synoptic weather from hurricanes and extratropical cyclones to cold air outbreaks, the relatively warm waters of the surrounding Gulf of Mexico serve as a stabilizing influence, resulting in a mean synoptic climatology which is mild (Florida A&M University, 1988). The following sections will describe in detail the individual elements of the synoptic climatology of the northeastern Gulf of Mexico: temperature, winds and extratropical/tropical storms.

2.2.2 Air and Sea Surface Temperature Climatology

Mean annual variations in surface temperature at National Weather Service (NWS) locations across the northeastern Gulf of Mexico region are similar.

Tables 2-1 through 2-4 summarize the mean monthly surface temperature conditions at the NWS sites located in Mobile, Alabama; Pensacola, Florida; Apalachicola, Florida and Tampa, Florida. The observations presented in these Tables represent the long-term 30-year climatic mean. The greatest variability in the temperature data is found during winter months (December – March), where there is approximately a 5.6°C (10°F) temperature difference between Mobile and Tampa during January. The northern tier cities show little variation during the winter, exhibiting monthly mean temperature differences less than 1.7°C (3°F). However, Pensacola and Apalachicola, Florida are slightly warmer (e.g. <1.1°C [2°F]) than Mobile, Alabama during winter, which is attributed to their close proximity (nominally less than 16 km) to the warmer Gulf waters. Tampa is located far enough south that only the strongest cold air outbreaks reach the region, leaving this area considerably milder than the northern locations during winter.

During the summer months (May – October), variations in the north-south and east-west surface temperature patterns are greatly reduced. All four of these locations experience sea/land breeze circulations during summer. The resulting daytime marine influence moderates extreme air temperatures at these continental locations. The summer reduction in temperature variability in the northeastern Gulf of Mexico is attributed to the northward retreat of the polar jet stream, which results in a reduction in frontal activity and the stabilizing influence of the increased presence of the moderating northeast trade wind circulation. Florida A&M University (1988) observed similar seasonal trends in temperature across the entire Gulf of Mexico utilizing data collected over a 17-year period.

The sea breeze circulation, which flows inland at the coastline on fair-weather days, is generated by the temperature differential between the "hot" land mass and the relatively cool ocean region. This thermal contrast increases during daylight hours (maximized in early to mid-afternoon) producing pressure differences in the lowest levels ($\lesssim$ 300 m) of the atmosphere, which causes the low-level "sea breeze" to occur. However, during nightime hours, the pressure difference is markedly reduced and is sometimes reversed, creating a much weaker land breeze (Simpson 1994).

The magnitude of the sea breeze and its inland/offshore extent are very localized phenomena. In hot, tropical environments, where the synoptic pressure gradient is relatively constant, sea breeze winds reach 6 to 7 m s^{-1} on average. However, in mid-latitude locations the movement of other synoptic phenomena (i.e. anticyclones and cyclones) often moderate the spatial/vertical extent and magnitude of the local sea breeze. Hsu (1988) has documented sea breeze circulations in the Gulf of Mexico with along coast dimensions of approximately 200 km, which extend 30-40 km inland during the strongest part of the events. The overall vertical extent of sea breeze circulations systems in the Gulf can reach 3 km (i.e. ~700 mb).

Of particular interest to oceanographic processes is the variation in mean monthly sea surface temperature (SST) relative to the overlying air temperature. This temperature differential is the mechanism which allows the exchange of surface sensible and latent heat energy between the lowest layers of the atmosphere and the ocean surface layer. Wayland and Raman (1989, 1994) have documented large instantaneous sensible (200-300 $W \cdot m^{-2}$)

Table 2-1. Long-term climatological data collected at the Mobile, Alabama National Weather Service (NWS) station for the interval 1951-1980.

PARAMETER	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANN.**
TEMPERATURE (°F)													
Daily Max	60.6	63.9	70.3	78.3	84.9	90.2	91.2	90.7	87.0	79.4	69.3	63.1	77.4
Daily Min	40.9	43.2	49.8	57.7	64.8	70.8	73.2	72.9	69.3	57.5	47.9	42.9	57.6
Monthly Mean	50.8	53.6	60.1	68.0	74.9	80.5	82.2	81.8	78.2	68.5	58.6	53.1	67.5
PRECIPITATION (inches)													
Monthly Mean	4.59	4.91	6.48	5.35	5.46	5.07	7.74	6.75	6.56	2.62	3.67	5.44	64.64
T'Storm Days	2.0	2.3	4.9	4.9	7.2	11.9	18.0	14.3	7.4	2.1	2.3	2.2	79.5
PRESSURE (mb)													
Monthly Mean	1012.8	1011.6	1009.3	1008.8	1007.5	1007.9	1009.3	1008.9	1008.5	1010.6	1011.5	1013.1	1010.0

Table 2-2. Long-term climatological data collected at the Pensacola, Florida National Weather Service (NWS) station for the interval 1951-1980.

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN.
TEMPERATURE (°F)													
Daily Max	61.2	64.1	68.9	76.8	84.2	89.0	89.7	90.0	86.3	79.9	69.7	63.2	76.9
Daily Min	43.0	45.5	50.8	59.4	66.1	72.1	73.9	73.6	70.2	60.0	49.3	44.3	59.0
Monthly Mean	52.1	54.8	59.9	68.1	75.2	80.6	81.8	81.8	78.3	70.0	59.5	53.8	68.0
PRECIPITATION (inches)													
Monthly Mean	4.37	4.69	6.31	4.99	4.25	6.30	7.33	6.67	8.15	3.13	3.37	4.66	64.22
T'Storm Days	2.0	3.0	5.0	4.0	6.0	11.0	15.0	15.0	7.0	2.0	2.0	1.0	71.0
PRESSURE (mb)													
Monthly Mean	1016.6	1016.1	1013.1	1013.5	1010.5	1012.2	1012.7	1012.9	1011.5	1014.2	1015.5	1016.4	1013.8

Table 2-3. Long-term climatological data collected at the Apalachicola, Florida National Weather Service (NWS) station for the interval 1951-1980.

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN.
TEMPERATURE (°F)													
Daily Max	61.1	63.1	67.6	75.0	81.8	86.4	87.5	87.7	84.7	78.3	69.0	62.7	75.4
Daily Min	46.3	48.5	53.8	61.5	68.0	73.6	75.2	75.2	72.4	63.3	53.2	47.6	61.6
Monthly Mean	53.7	55.8	60.7	68.3	74.9	80.0	81.4	81.5	78.6	70.8	61.1	55.2	68.5
PRECIPITATION (inches)													
Monthly Mean	3.07	3.78	4.70	3.61	2.78	5.30	8.02	8.07	9.00	2.88	2.68	3.32	57.21
T'Storm Days	2.0	2.0	4.0	3.0	5.0	10.0	16.0	16.0	10.0	2.0	1.0	2.0	71.0
PRESSURE (mb)													
Monthly Mean	1020.3	1020.4	1017.8	1017.5	1014.7	1016.5	1016.9	1016.7	1015.2	1017.0	1019.0	1020.1	1017.7

Table 2-4. Long-term climatological data collected at the Tampa, Florida National Weather Service (NWS) station for the interval 1951-1980.

PARAMETER	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANN.**
TEMPERATURE (°F)													
Daily Max	70.6	71.9	76.1	82.4	87.5	89.9	90.1	90.4	89.0	83.9	77.1	72.0	81.7
Daily Min	50.1	51.7	55.9	61.6	66.9	72.0	73.7	74.0	72.6	65.5	56.4	51.2	62.6
Monthly Mean	60.4	61.8	66.0	72.0	77.2	81.0	81.9	82.2	80.8	74.7	66.8	61.6	72.2
PRECIPITATION (inches)													
Monthly Mean	2.33	2.86	3.89	2.10	2.41	6.49	8.43	8.00	6.35	2.54	1.79	2.19	49.38
T'Storm Days	1.0	2.0	2.0	3.0	6.0	14.0	21.0	21.0	12.0	3.0	1.0	1.0	87.0
PRESSURE (mb)													
Monthly Mean	1020.2	1019.7	1018.2	1017.7	1015.4	1016.5	1017.6	1017.3	1015.2	1016.5	1018.8	1019.7	1017.7

and latent heat (300-400 W·m^{-2}) fluxes over the shelf during extreme CAOs. Huh et al. (1984) documented the effects of CAOs on shelf hydrography in the northeastern Gulf of Mexico.

In an effort to document these processes for the northeastern Gulf of Mexico, approximately eight years of meteorological data was obtained from the National Data Buoy Center (NDBC) Coastal-Marine Automated Network (C-MAN) station located at Dauphin Island, Alabama, and an additional four years of data was also obtained for NDBC buoy 42015, which is located in relatively shallow water just offshore of Dauphin Island.

Figures 2-1a through 2-1c show the respective monthly mean SST time series for surface air temperature, sea surface temperature, air-SST and the sensible heat flux for the Dauphin Island data record. Similarly, Figures 2-2a through 2-2c display similar time series for NDBC buoy 42015. The most noteworthy observation from these Figures is the tendency of the sea surface temperature to follow the surface air temperature quite closely. At both Dauphin Island and buoy 42015, the mean monthly SST is generally (except for a couple of isolated occurrences) greater than the mean monthly surface air temperature, indicating that the prevailing mean heat flux is from the oceanic air-water surface layer into the marine atmospheric boundary layer. The largest temperature differential at these shelf locations occurs during the summer months (Figures 2-1a and 2-2a), which is attributable to the coastal location of the SST measurements. This result differs from the earlier finding of Florida A&M University (1988), where the deep water buoys across the central Gulf (~26°N) were analyzed. For those deep water locations, the air-SST differential was maximized during winter and minimized during summer.

2.2.3 Wind Climatology

The wind climatology of the northeastern Gulf can be divided into two distinct periods, winter and summer, just as can the temperature and storm climatologies. Winter is characterized by frequent frontal incursions and extratropical cyclones, which produce large shifts in wind speed and wind direction in response to rapidly changing atmospheric pressure and thermal gradients. In general, the summer is characterized by light and variable winds originating from the northeast trade wind circulation. The reduced influence of the Bermuda High and lack of frontal activity serves to reduce mean pressure fluctuations across the region. In response to the strong differential heating of the land and adjacent waters along the coast during the summer months, significant sea/land breeze circulations develop (Sonu, et al. 1971). The summer months are subject to an occasional tropical system, but these storms tend to move relatively rapidly through the region, causing only a short-term, but at times intense, "pulse" to the atmospheric and oceanographic systems.

Mean wind roses for the four National Weather Service stations discussed above are presented in Figure 2-3a,b for the winter period (December – March). The westernmost stations (e.g., Mobile and Pensacola) show the seasonal dominance of the polar Jet Stream, while the easternmost stations are dominated by the influence of the Atlantic sub-tropical gyre. At Mobile and Pensacola, the influence of the polar jet results in a substantial

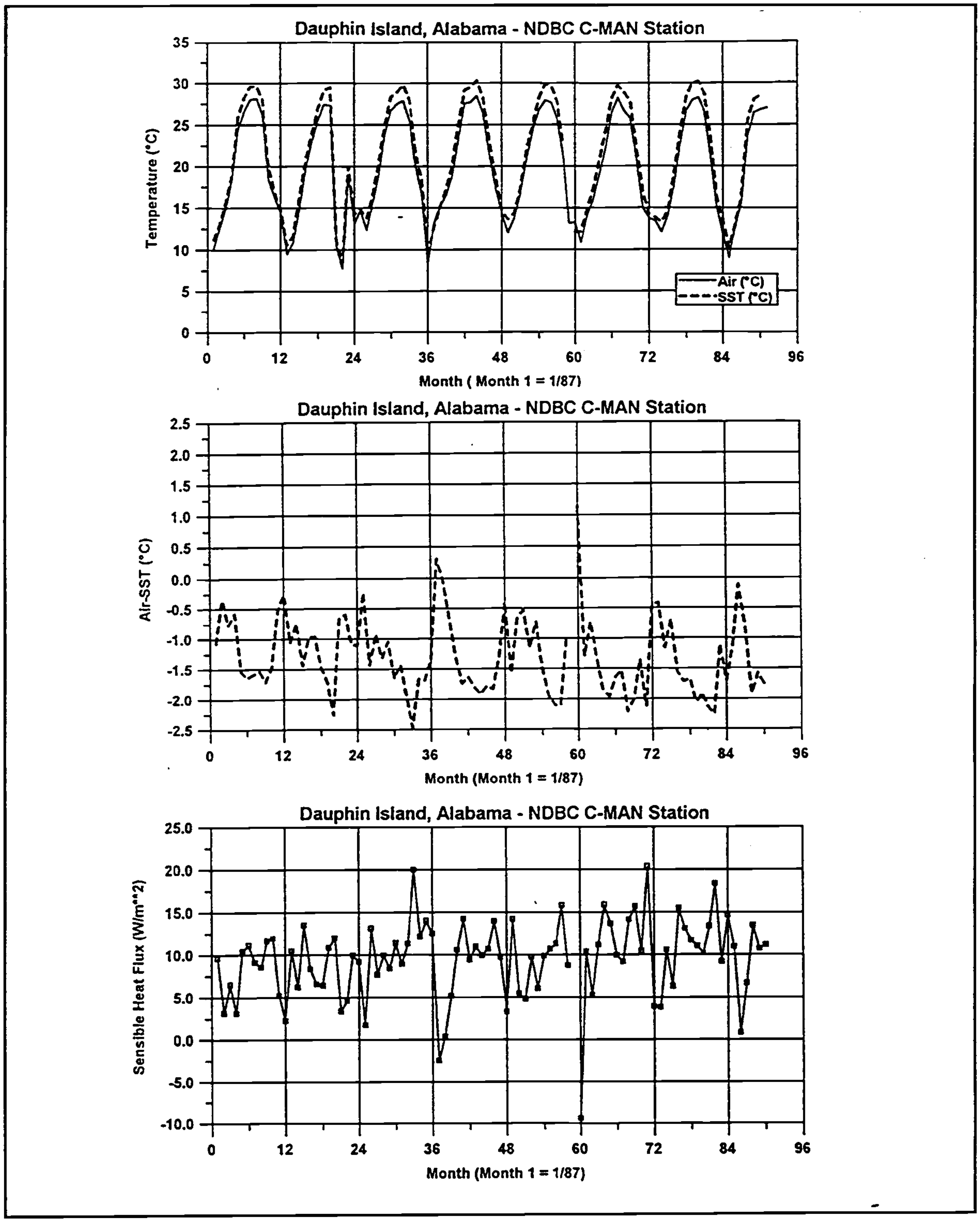


Figure 2-1. Monthly mean air(°C), sea surface temperature (°C), air-SST (°C) and sensible heat flux ($W \cdot m^{-2}$) for the period 1987-1994 for the NDBC C-MAN station located at Dauphin Island, Alabama.

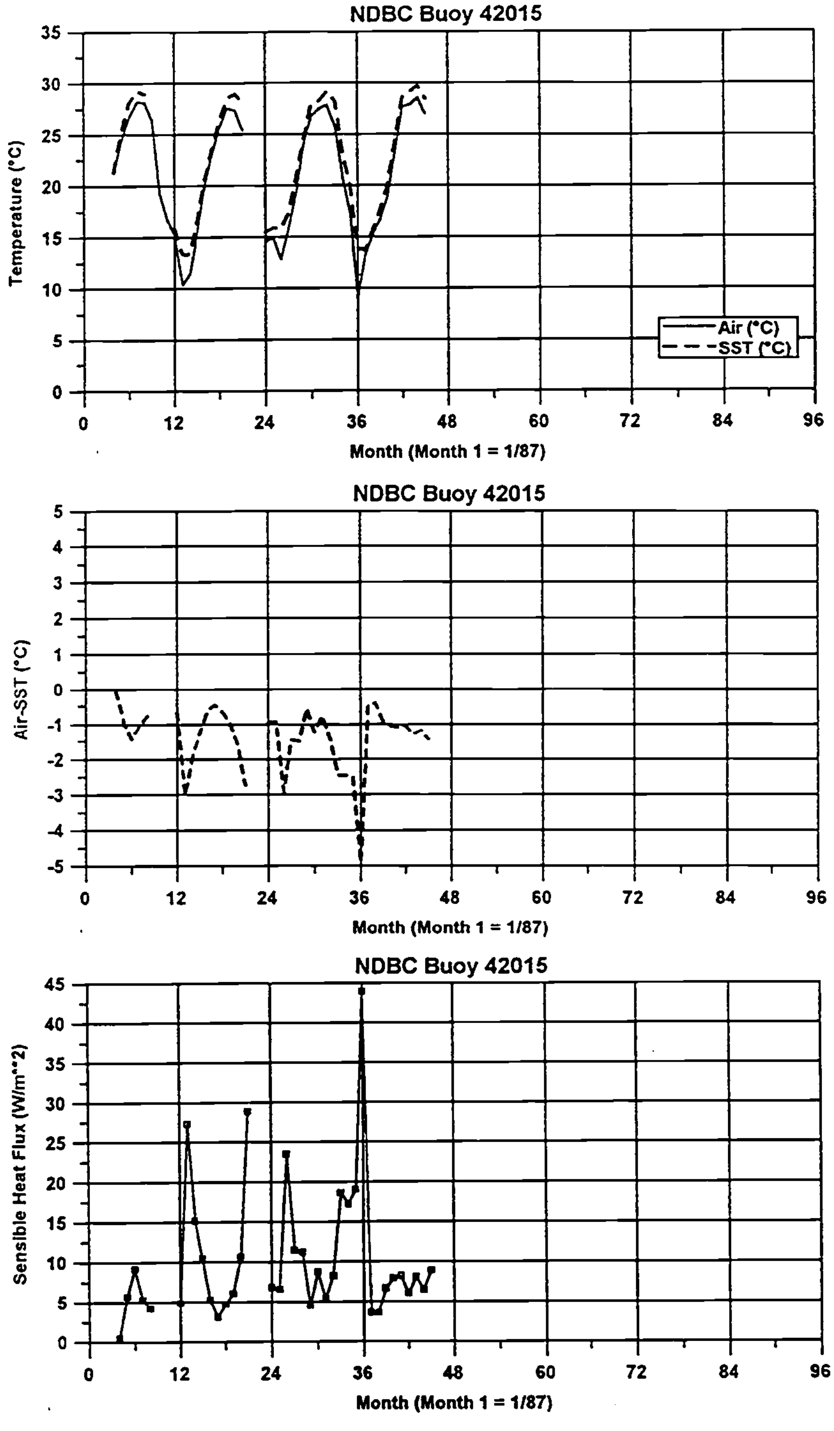
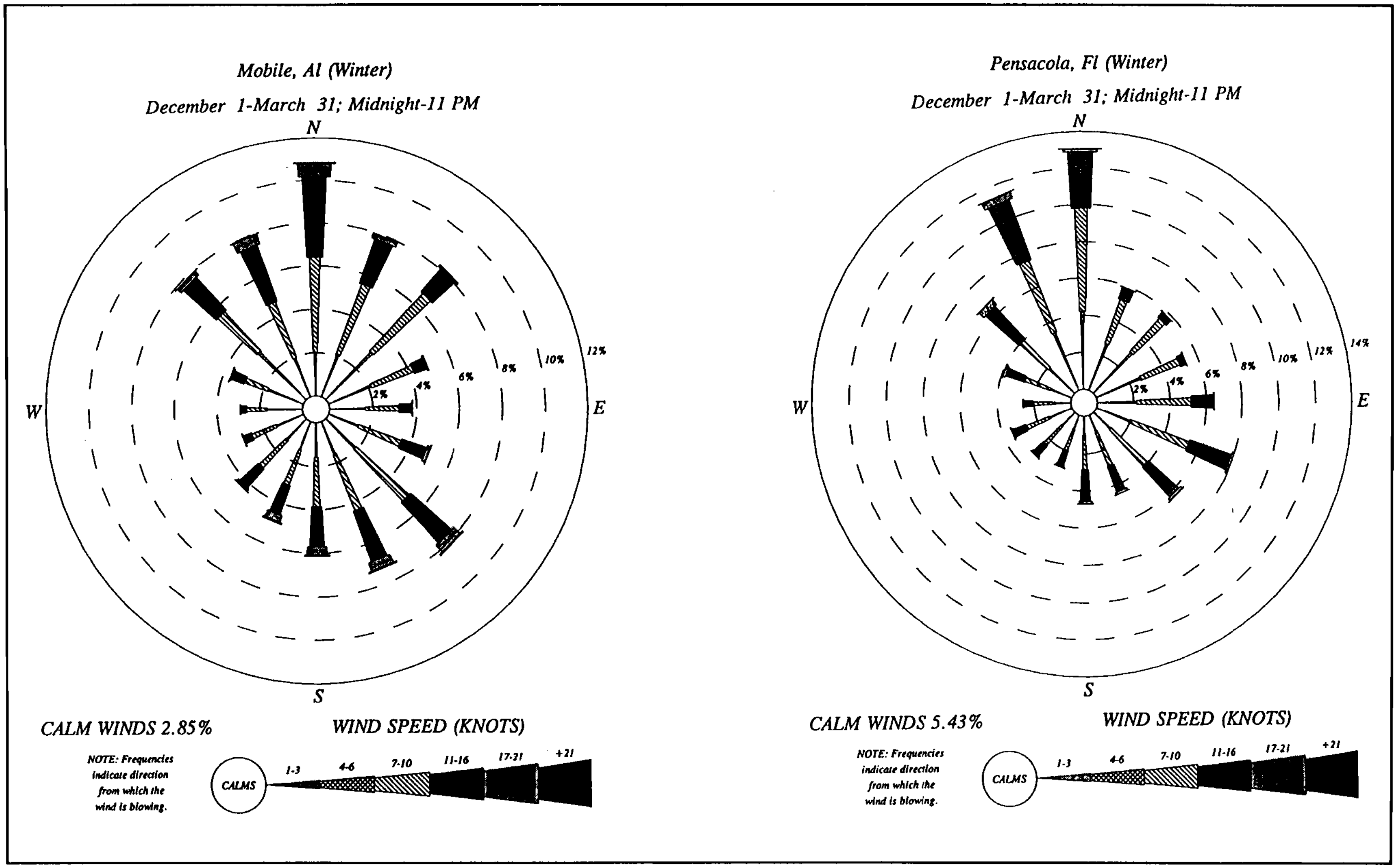


Figure 2-2. Monthly mean air temperature (°C), sea surface temperature (°C), air-SST (°C) and sensible heat flux ($W \cdot m^{-2}$) for the period 1987-1994 for NDBC buoy 42015.



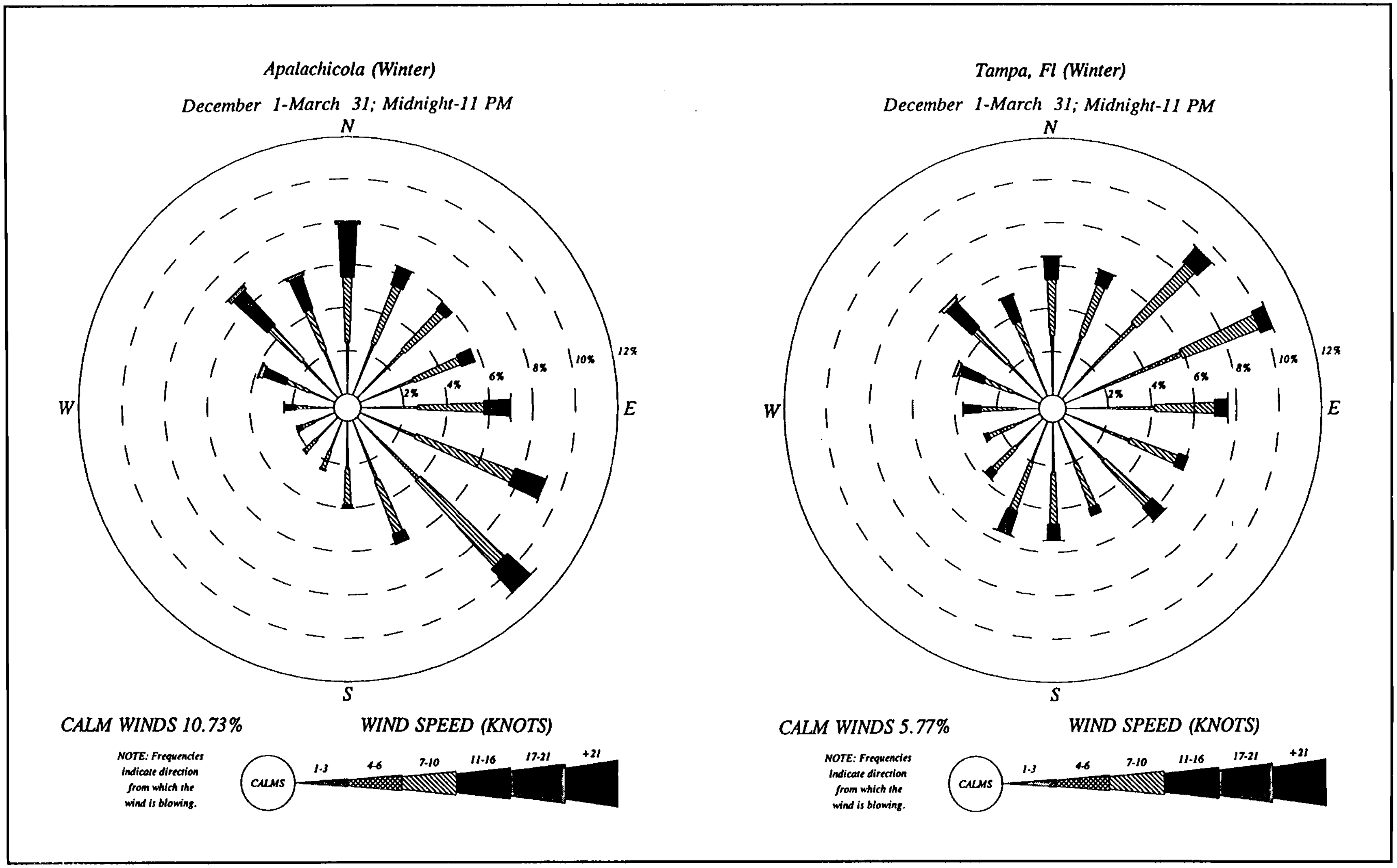
Mobile, Al (Winter)

December 1-March 31; Midnight-11 PM

Pensacola, Fl (Winter)

December 1-March 31; Midnight-11 PM

Figure 2-3a. Winter (December – March) wind roses for the National Weather Service stations at Mobile, Alabama and Pensacola, Florida. Data is for the nine-year period 1984-1992.



Apalachicola (Winter)

December 1-March 31; Midnight-11 PM

Tampa, Fl (Winter)

December 1-March 31; Midnight-11 PM

Figure 2-3b. Winter (December – March) wind roses for the National Weather Service stations at Apalachicola, Florida and Tampa, Florida. Data is for the nine-year period 1984-1992, except for Apalachicola, which is for the period 1988-1991.

northerly component to the winter wind patterns. At more easterly locations around the Florida Panhandle, the influence of frontal activity is reduced and the increased importance of the Atlantic sub-tropical gyre is observed. At Apalachicola, the predominant winter flow is off the ocean from the southeast, while at Tampa, the mean circulation for this interval is more easterly. This circulation pattern is indicative of a synoptic wind pattern flowing clockwise around the Bermuda High. However, at all four locations, there is considerable variability in the seasonal wind rose, indicating the frequency of frontal passages, storm systems and other perturbations in the synoptic flow.

The summer (May – October) wind roses for the four NWS stations are displayed in Figure 2-4a,b. In general, these data show the decreased influence of both the Atlantic sub-tropical gyre and the polar jet stream on the wind climatology of the eastern Gulf of Mexico, and an increase in the frequency of calm wind conditions. Data from Tampa also show increased influence of trade winds, which results in a significant easterly component during summer. The northern three stations are on the fringe of the trade wind circulation, and thus do not display a significant trade wind component. Additionally, each location shows an increase in onshore flow during summer, which is attributable in part to the increased influence of the sea breeze circulation systems.

The NDBC C-MAN station at Dauphin Island and Buoy no. 42015, located just offshore of the island (e.g. 42015), show similar distinct seasonal wind patterns as well (Figure 2-5). The mean monthly time series that are shown in Figure 2-5 indicate a similar increase in wind speed during winter, followed by the expected decrease in magnitude during the summer months. The mean monthly wind flow is from the south-southeast during winter, and becomes southerly to southwesterly during summer.

2.2.4 Storms

The Gulf of Mexico storm season climatology is affected by both extratropical and tropical cyclone tracks. Florida A&M University (1988) summarized both of these climatologies for the entire Gulf region. Thus, for specific details the reader is referred to the earlier document; however, a subset of this information which is relevant to the northeastern Gulf of Mexico will be presented here.

Winter storm climatology for the Gulf of Mexico is dependent upon the genesis and transit of extratropical cyclones within the region. Using a 100-year data set developed by Hayden (1981), an analysis of storm tracks (based on 2½° by 5° grid cells) indicates that the Texas-Louisiana shelf has the highest occurrence (4.2 storms, ± 2.4) for extratropical cyclones during winter (December – March). The mean frequencies and standard deviations decrease markedly to the east and south of this region. Below approximately 25°N latitude, the mean winter storm frequency is generally less than 1. Grid cells representing the northeastern Gulf of Mexico have winter seasonal storm frequencies of 2.9 (±1.9) and 2.1 (±1.7), respectively. In a more recent study, Johnson, et al. (1986) observed similar patterns in a winter data set collected between 1977-1983. In that study, approximately 80% of all winter cyclones in the Gulf region

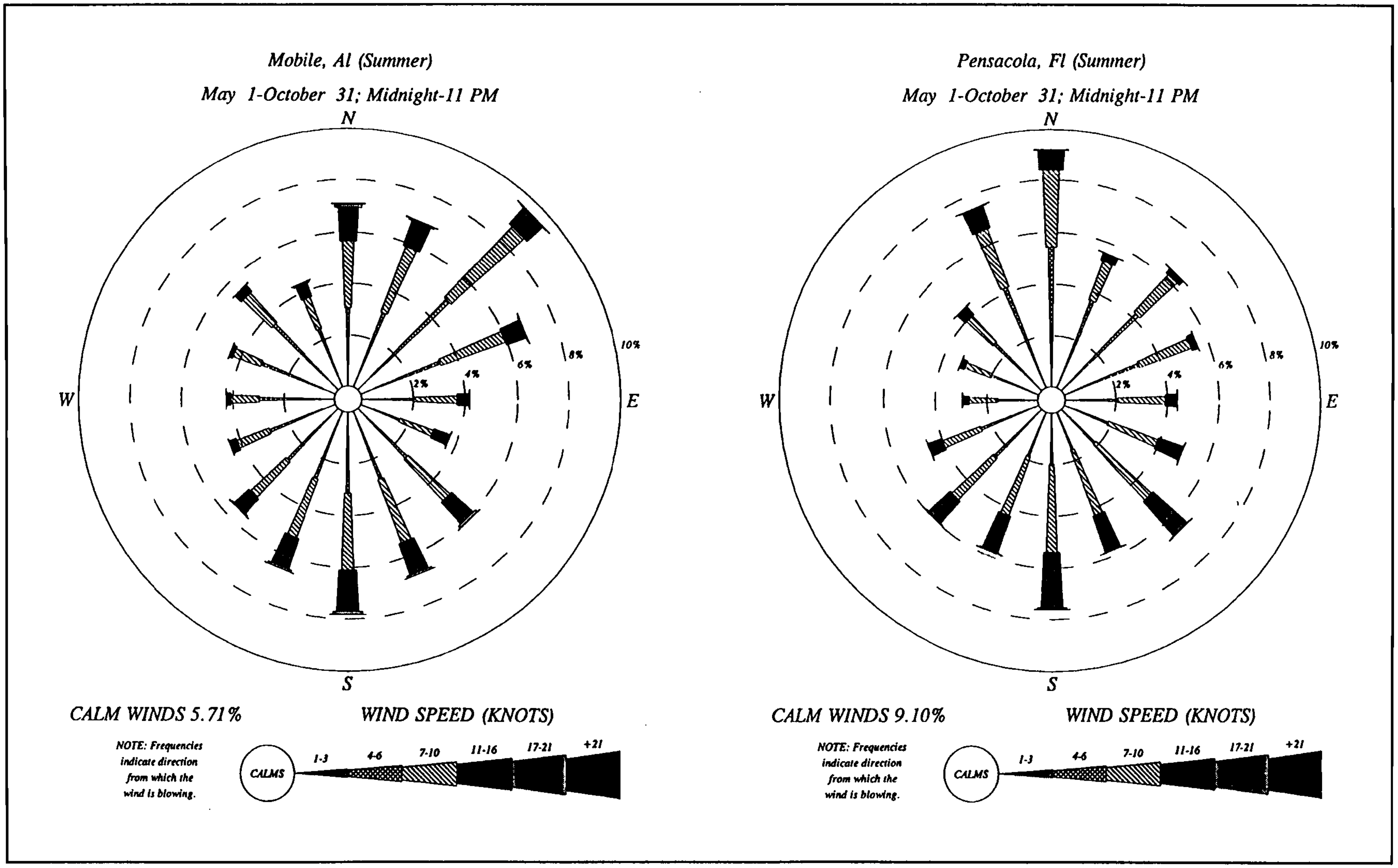


Figure 2-4a. Summertime (May - October) wind roses for the National Weather Service stations at Mobile, Alabama and Pensacola, Florida. Data is for the nine-year period 1984-1992.

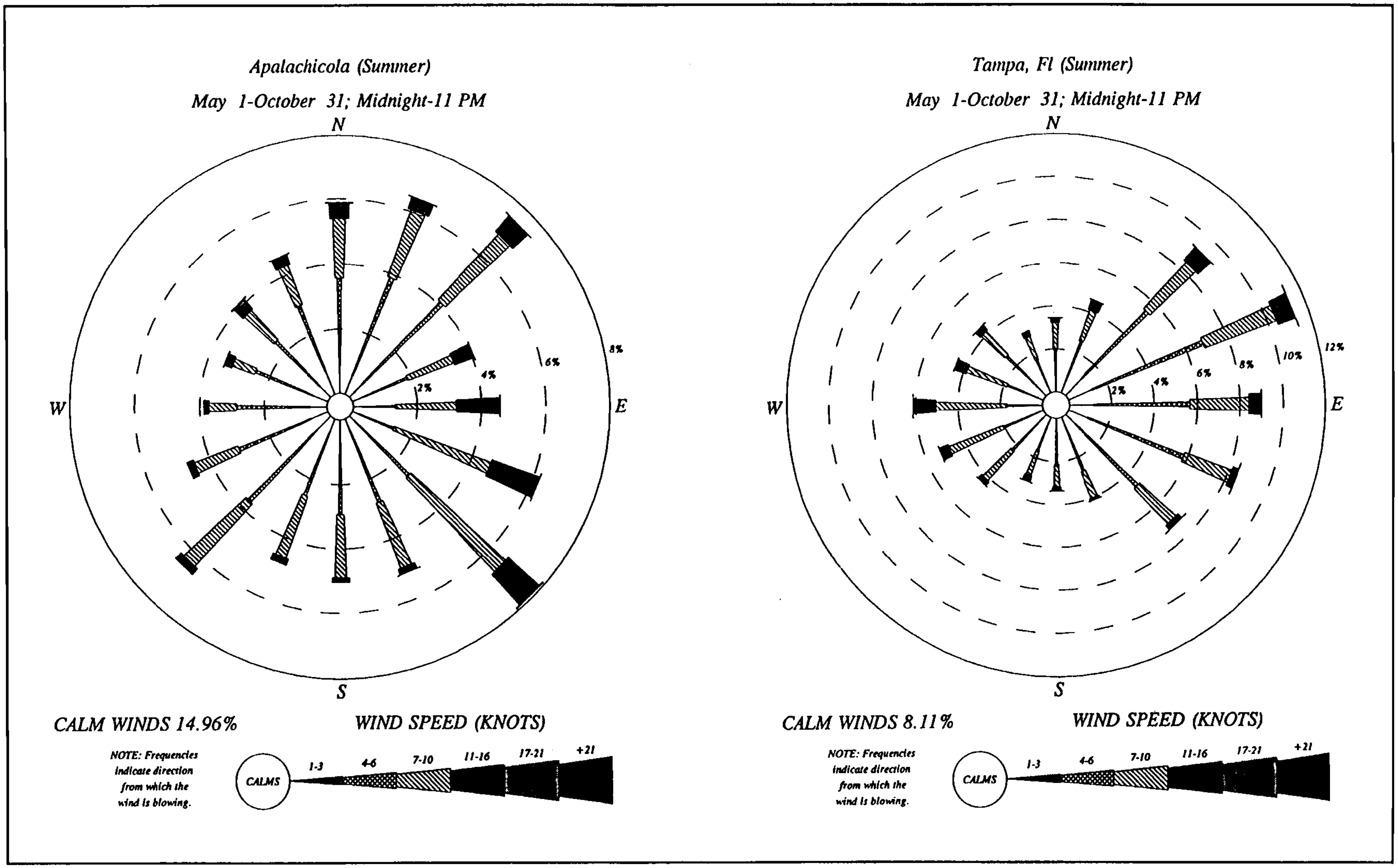


Figure 2-4b. Summertime (May - October) wind roses for the National Weather Service stations at Apalachicola, Florida and Tampa, Florida. Data is for the nine-year period 1984-1992, except for Apalachicola, which is for the period 1988-1991.

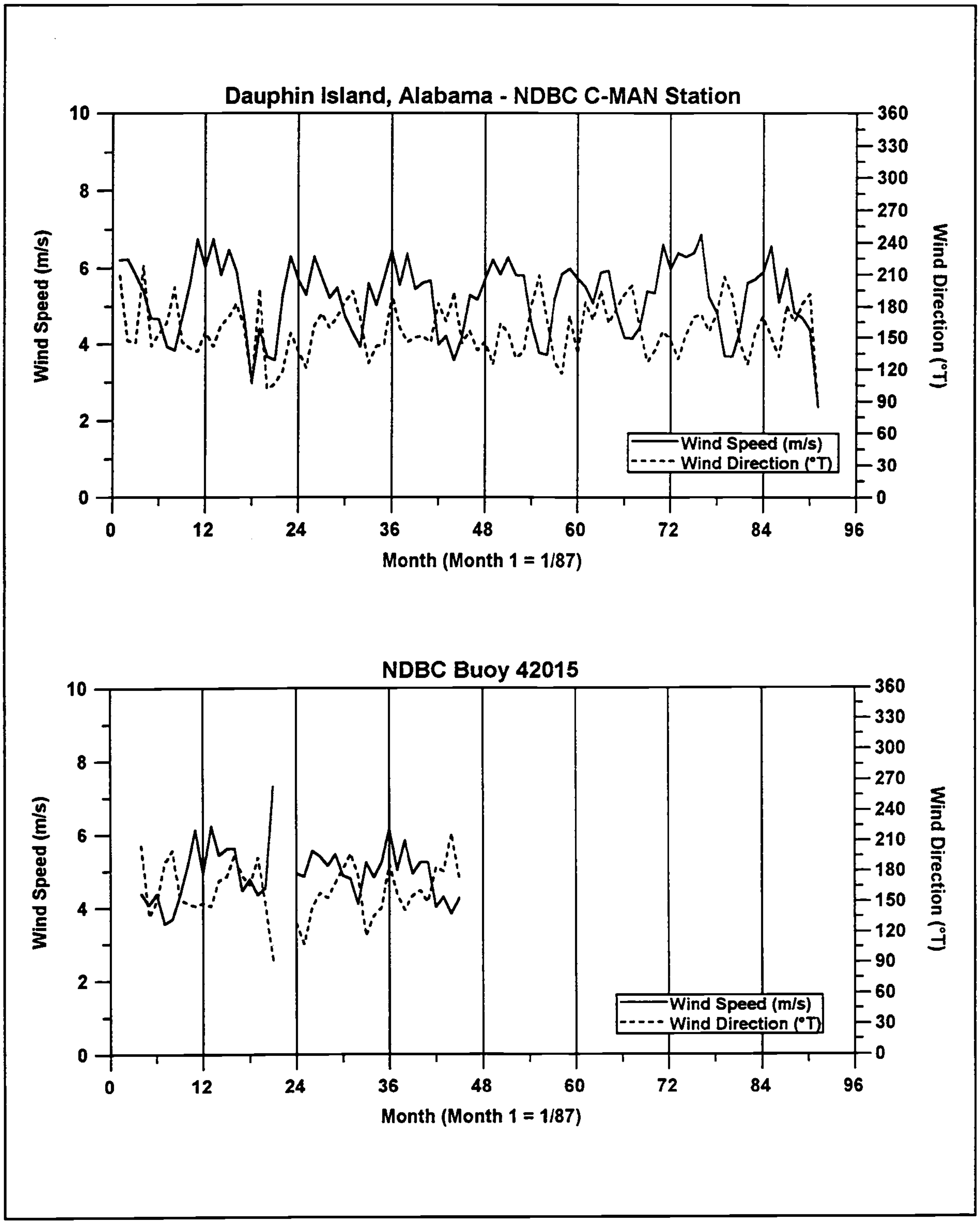


Figure 2-5. Wind speed ($m \cdot s^{-1}$) and direction (°True) for the period 1987-1994 for (a) the NDBC C-MAN station located at Dauphin Island, Alabama, and (b) NDBC buoy 42015.

developed in the west-central Gulf of Mexico (e.g., west of 90°W latitude), leaving only 20% to develop in the central and eastern Gulf.

The north-central Gulf of Mexico, while not the major region of winter cyclogenesis in the Gulf, is also an important location for extratropical activity. In the northeastern Gulf, cyclogenesis generally occurs along stalled or slow-moving frontal boundaries residing across the northern tier of the region. Storms developing in the north-central Gulf region, which are generally linked dynamically to stronger upper-level storm centers, tend to track eastward along the frontal boundary (e.g., across the northeastern Gulf of Mexico), crossing over the Florida Panhandle and recurving northward along the Atlantic seaboard. Such systems are capable of extracting large amounts of heat from the oceanic surface layer of the NEGOM, and of generating sufficiently strong surface winds to create vigorous mixing of the shallow shelf waters.

An analysis of the summer (May – October) cyclone data shows that the storm frequency maxima shift towards the central and southeastern Gulf of Mexico, reflecting the increased influence of tropical systems on the Gulf-wide storm track climatology. Essentially, the summer storm track climatology for the Gulf of Mexico is determined by the frequency and direction of tropical cyclone systems. With the polar Jet Stream positioned well north of the region, the opportunity for frontal incursions and subsequent extratropical cyclogenesis events in the Gulf region is infrequent.

Neumann and Pryslak (1981) conducted a detailed analysis of tropical cyclone activity for the North Atlantic basin, including the Gulf of Mexico. This summary documented the frequency of occurrence (based on 2½° by 2½° grid cells) for both tropical storms (e.g., sustained winds of 34 knots [39 mph or 18 m/s]) and hurricanes (e.g., sustained winds of 64 knots, [74 mph or 33 m/s]) in the basin. Their results indicate that the southeastern and central Gulf of Mexico have the highest frequency of occurrence for tropical storm systems. The Yucatan Channel is the most likely entry point into the Gulf of Mexico for tropical storms forming in the Caribbean and further east in the Atlantic Ocean. Tracks that storms forming early in the hurricane season tend to move into the Gulf through the Yucatan, while storms forming late in the season often recurve northward, prior to reaching the Straits of Florida and the Gulf of Mexico. The standard hurricane season begins on June 1 and ends on November 30. When considering only storms that reach hurricane intensity, they have an almost equal probability of entering the Gulf from either the Straits of Florida or the Yucatan Channel.

Figure 2-6 summarizes decadal tropical cyclone activity in the northeastern Gulf of Mexico over the past 100 years. The region has been divided into two smaller areas: the Big-Bend area and the Panhandle area. The average number of storms influencing the region has declined markedly over the interval between 1976-1985, reaching an all-time low of 7 storms per decade. Over most of the 20th century, the region has averaged 10-12 cyclones per decade. In general, the frequency of occurrence for cyclones has tended to be out-of-phase between the Big Bend area and the Panhandle region over much of the past century (e.g., increased activity in one area is associated with decreased activity in the other).

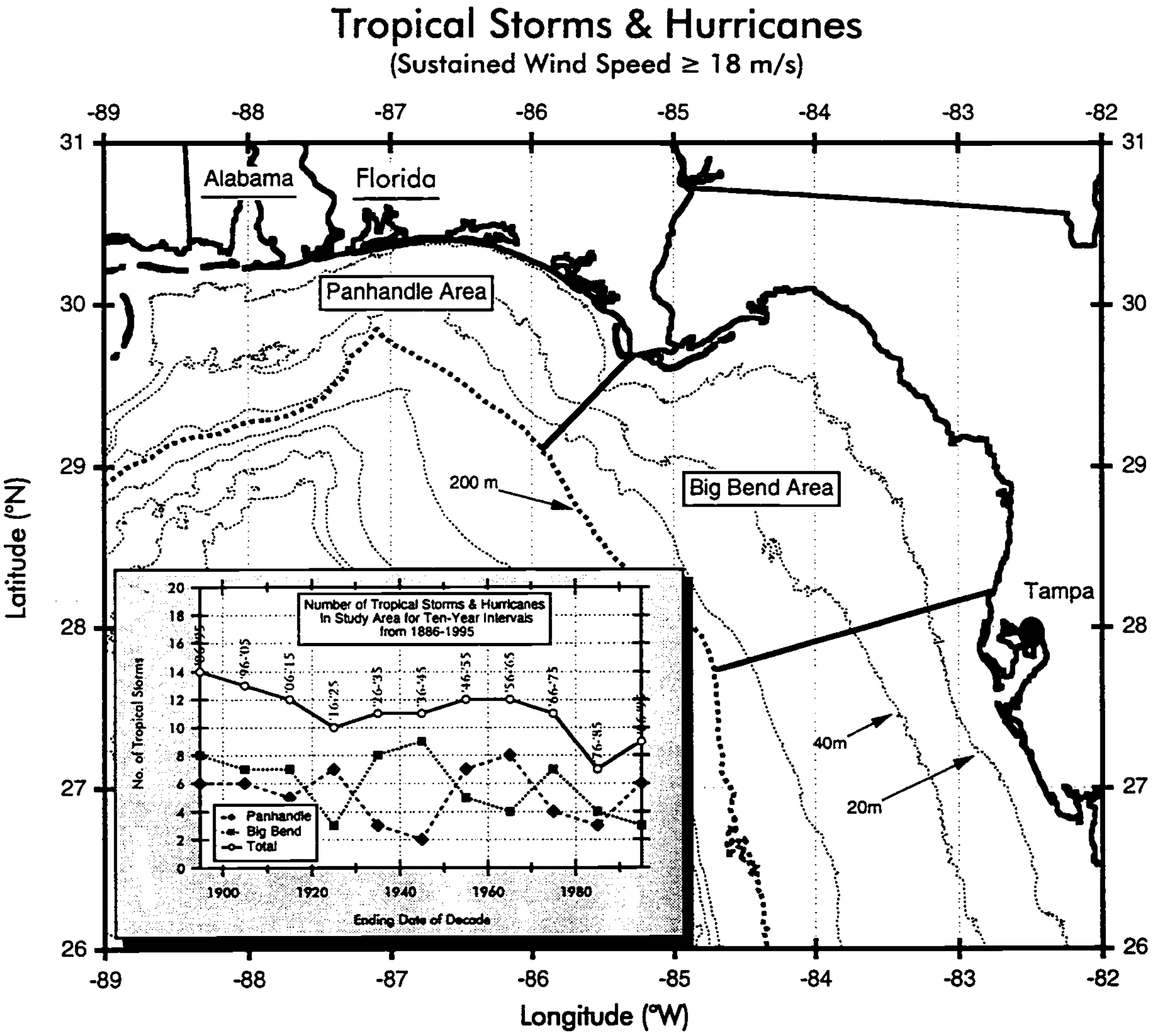


Figure 2-6. Summary of tropical cyclone activity for the northeastern Gulf of Mexico for the period 1886-1985. Data extracted from the NOAA/NCDC/Asheville HURDAT database.

2.3 Physical Oceanography

2.3.1 Introduction

The study region includes the shelf, and upper slope and offshore of the Florida Panhandle and the west Florida shelf north of Tampa Bay. The natural division between the eastern and western Gulf of Mexico for physical oceanographic process is about 90°W longitude, between the Mississippi Delta and the Yucatan Peninsula. East of the Delta, the Loop Current (LC) dominates the circulation of the eastern basin. West of the delta, the circulation is dominated by large, westward and southwestward propagating LC anticyclones which interact with the topography, existing LC eddies, secondary cyclones and smaller scale anticyclones to generate complex circulation patterns. Similarly, the northern shelf, east of the delta, should be considered all one system because of shelf geometry and major fresh water inputs from the Mississippi, Mississippi Sound and Mobile Bay just west of the study area. Therefore, this review of circulation processes will include some aspects of the Mississippi and Alabama shelf waters east of the Mississippi Delta.

The shelf narrows from about 120 to 60 km from just east of the Chandeleur Islands to the head of the DeSoto Canyon. There is an extensive area of shallow water behind the barrier islands consisting of the Mississippi, Chandeleur and Breton Sounds. The slope (200 - 2000 m) is fairly broad with complex, rough topography between the Mississippi Delta and DeSoto Canyons (Figure 2-7). East of Pensacola, the shelf remains narrow until Cape San Blas, where it abruptly broadens to about 200 km and becomes the Big Bend area of the west Florida shelf. This area includes the very shallow, broad inner-shelf waters of Apalachee Bay and waters further south off Cedar Keys. Between the head of the DeSoto Canyon and 26°N latitude, the slope becomes progressively steeper, particularly below 1000m. This very steep slope is known as the Florida Escarpment.

This review of the physical oceanography is organized starting with the deep eastern basin. The Loop Current (LC) and its variability is discussed, then the effect of LC and related circulations on the slope and outer shelf of the NEGOM. Other aspects of slope currents are also explored, including secondary small-scale cyclones and anticyclones that are believed to be prevalent over the NEGOM slope. Eddies and LC intrusions are known to influence the outer shelf; however, the mid- and inner-shelf circulations have important contributions from wind forcing and the input of fresh water from the Mississippi and coastal rivers. The latter has a strong east-west gradient, with most of the fresh water input in the west. Mississippi River water flows onto the outer and middle shelf, unlike the other rivers which discharge into sounds, bays or the shallow nearshore zone. Coastal river plumes and fronts are likely to be present in some inner-shelf areas.

Wind-forced shelf circulation patterns are also likely to be complex because of the changes in direction in the trend of the shelf isobaths, the changes in shelf width and the existence of sharp corners in the coastline, such as at Cape San Blas. Continental shelf waves are known to be a significant factor in coastal sea-level fluctuations on the west Florida shelf.

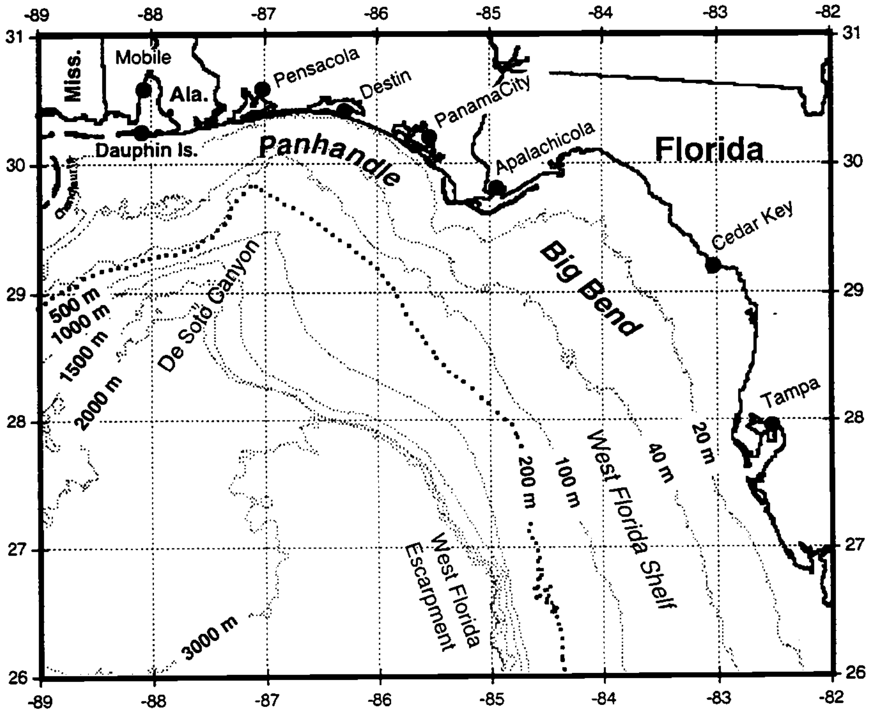


Figure 2-7. Map of the region showing bathymetry, various features and key locations.

The following sections begin with a view of the Loop Current, and then the conditions on the slope and shelf.

2.3.2 Loop Current

The Loop Current is a branch of the Gulf Stream system, which enters the Gulf of Mexico through the Yucatan Channel and exits through the Straits of Florida. The clockwise circulation of the LC extends northwards as a quasi-stationary meander that shows considerable variability in the northward extent and the shape of the front between the LC and the Gulf waters (Vukovich, 1986). In winter and spring, there is sufficient contrast between the warm LC and Gulf surface waters that the LC is clearly observed in cloud-free Advanced Very High Resolution Radiometer (AVHRR) satellite images (Figure 2-8). In summer (June to November), high humidity and almost uniform surface water temperatures across the Gulf make the LC difficult to distinguish in AVHRR satellite data, Maximum surface current velocities in the LC range from 100 to 200 $cm \cdot s^{-1}$. Flows extend down to about 800 m, which is the depth of the Straits of Florida sill. Below 1900 m, the depth of the sill in the Yucatan Channel, Gulf of Mexico is a closed basin with a maximum depth of 3600 m. Figure 2-9 shows the temperature structure of a moderately extended LC obtained from an AXBT survey. Features to note are the closed temperature contours in the center and the cold pools along the west Florida slope. Deployment of a drifter in the LC in 1985 showed that closed anticyclonic circulation is present in the center and that the LC can extend northwards from 24°N to 27°N latitude in as short a time as two months (Lewis and Kirwan, 1987). The velocity structure obtained from AXCPs on the east-west directed center line of this survey is shown in Figure 2-10. Strong northward and southward surface flows are seen near the western and eastern edges, respectively. Flows are strongly sheared vertically and horizontally on the outer edges, but there is a suggestion of more depth-independent solid body rotating type flows over the upper 200 m at stations 8 and 12. This is similar to the velocity structure measured across a warm anticyclonic eddy (Cooper et al., 1990). Below the 800 m depth of LC flows, there is a suggestion of opposing counter currents. The northward deep flows over the steep west Florida slope have been confirmed with current meter observations (Molinari and Mayer, 1982; Hamilton, 1990). When extended far to the north the LC can shed a large warm anticyclone. Such a detached eddy, known as a LC eddy, has a diameter of 200 to 300 km and subsequently moves westward and southwestward into the western Gulf basin. Figure 2-11 shows hydrographic, drifter and current meter data for the LC and a recently detached eddy [eddy B or "Fast" eddy (Lewis and Kirwan, 1987)] and its position 4 months later. Numerical models of LC eddy shedding suggest that the detachment process is quite slow and there are connecting circulations between the eddy and the LC even after the center of the eddy has reached 90°W longitude (a practical measure that the eddy is free of the LC and will continue to propagate into the western Gulf). There are many examples from AVHRR imagery of LC eddies detaching and reattaching to the LC a number of times over several months before finally being shed. There have been many investigations of the frequency of LC eddy shedding. An early study (Maul, 1977) postulated an annual cycle for LC growth and retreat. Early numerical models (Hurlburt and Thompson, 1980) suggested that a fundamental period was about 14 months. However, recent studies of the northward extension using approximately 12 years of AVHRR data supplemented by

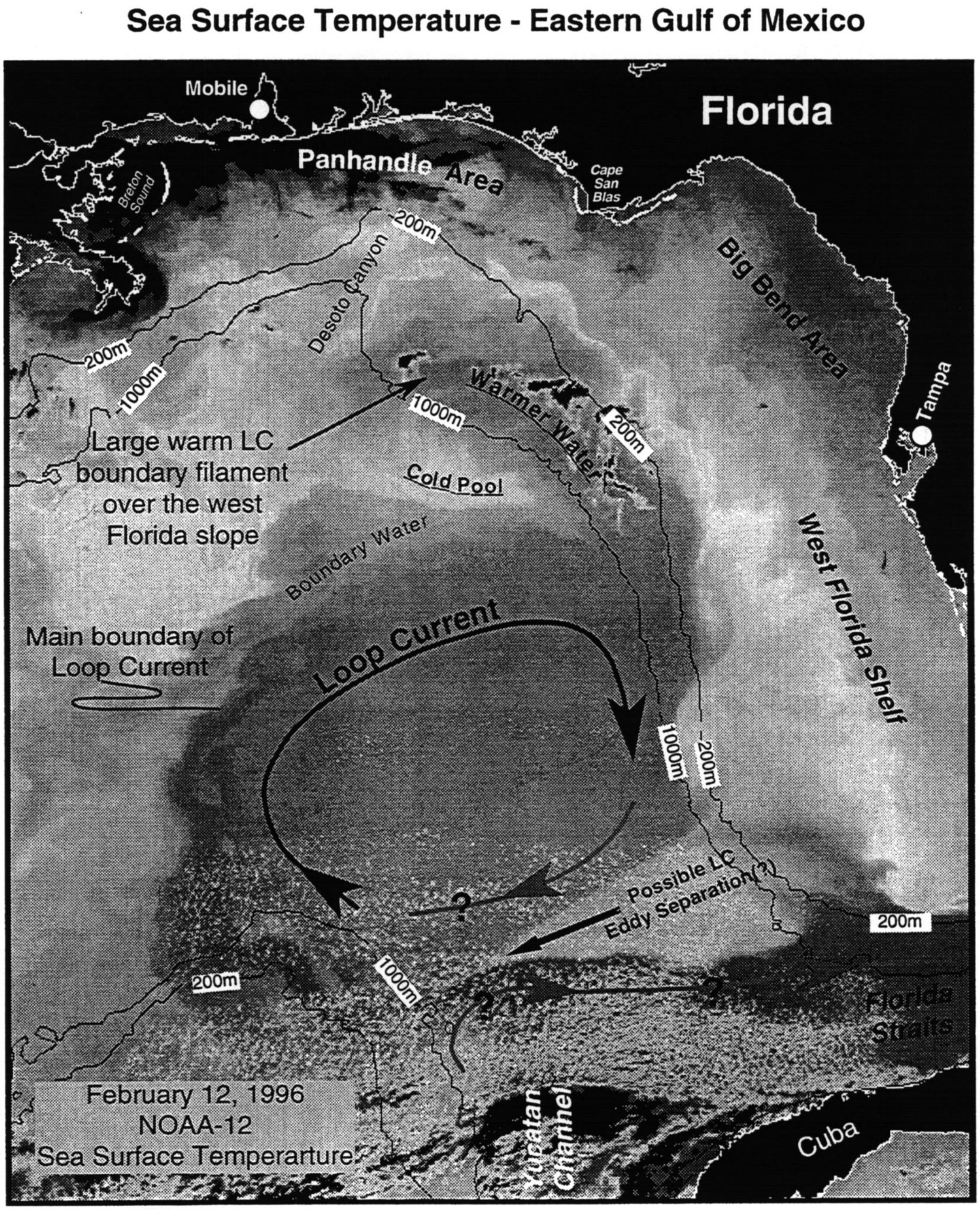


Figure 2-8. Labeled satellite image showing Loop Current, possible LC eddy separation, large boundary filament over slope and outer shelf offshore of the Big Bend Area.

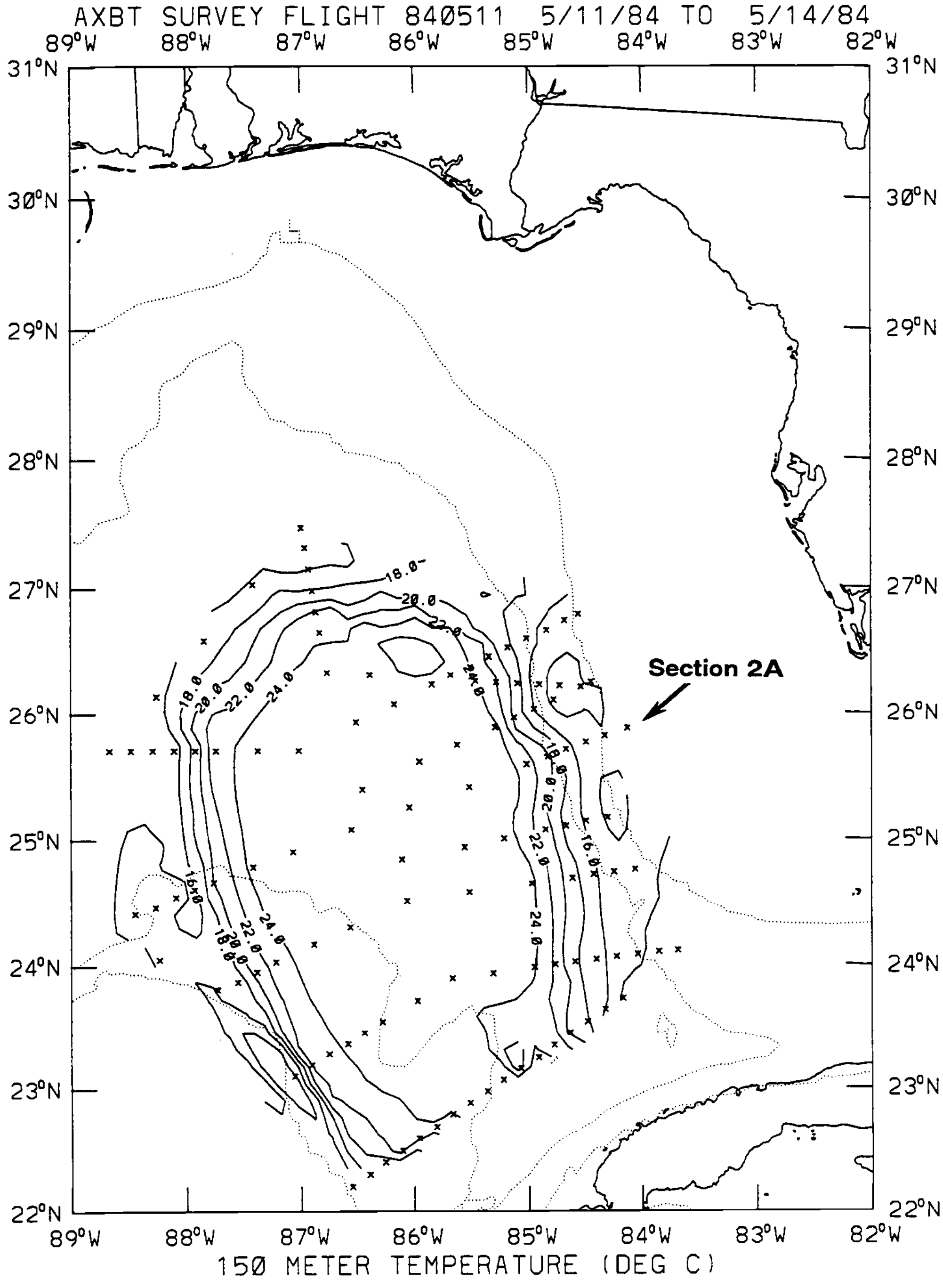


Figure 2-9. Contours of the temperature at 150 m depth clearly showing the general depressed isotherm structure of the relatively warm LC. There were three relatively shallow cyclonic features along the west Florida slope boundary of the LC.

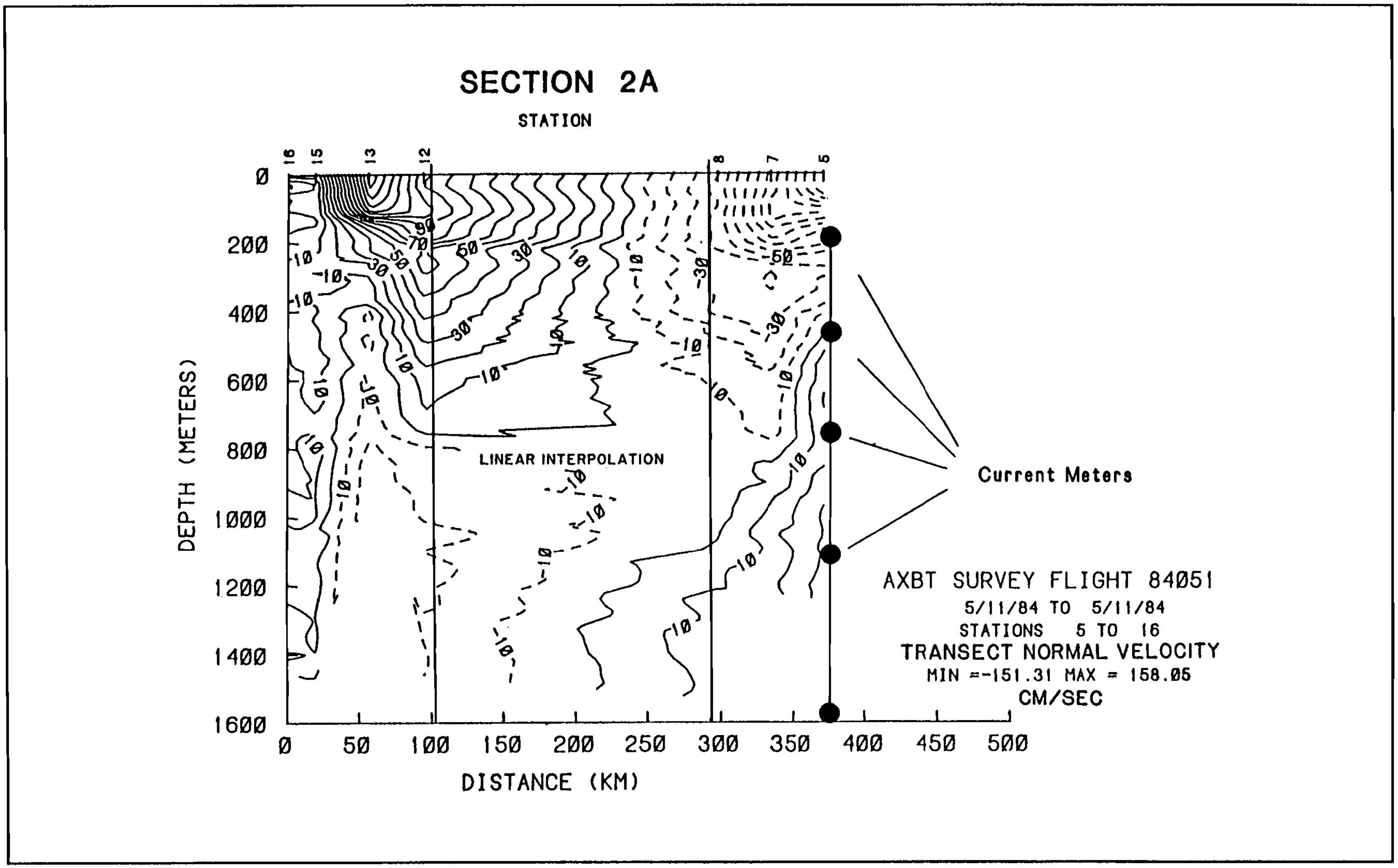


Figure 2-10. Normal velocities for an east-west transect shown in Figure 2-9. These AXCP data agreed well with the subsurface current meter observations.

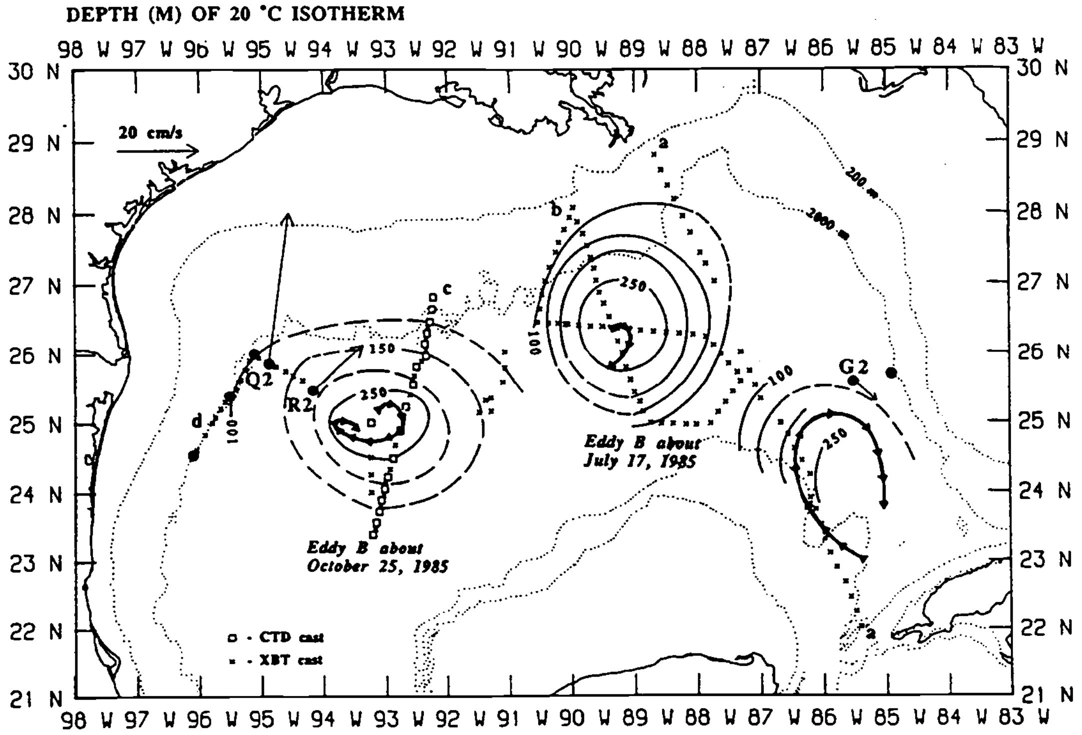


Figure 2-11. Two realizations of Eddy B from hydrography (depth of 20°C isotherm), Lagrangian drifters and daily average 300-400 m measured current vectors (from Hamilton, 1990).

regular XBT transacts between the Mississippi Delta and the Yucatan Channel (Hamilton, 1990; Brown et al. 1986; Brown et al. 1989) have shown that the fundamental period is about 8-9 months (Sturges, 1992; 1994). Significant peaks are found at about 5 months and 14-16 months. These are thought to be the result of modulations of the fundamental period by the annual cycle of the transport in the Yucatan Channel, and by the Florida Current (Sturges, 1992). The times of LC eddy separations are known to be highly variable, and tabulations by Vukovich (1988, 1995) show that the period between separation of successive eddies can vary from 6 months to 17 months. The description of the genesis of eddy B by Lewis and Kirwan (1987) indicates that the LC can grow in a sufficiently short time for a new eddy to be shed in as little as 5 to 6 months after the previous shedding event. The extent of the northward penetration, and whether the axis of LC is northward or deflected towards the Mississippi Delta, are thought to be related to the position and angle of separation of the LC front from the Yucatan shelf. The theory is based on simple conservation of vorticity arguments (Reid, 1972) and there is evidence (Molinari and Morrison, 1988) that the further north and the larger the westward deflection of the front at the point of separation from the Campeche Bank, the larger the area of the eastern Gulf is covered by LC water.

An extended LC often has a multitude of frontal features, including large filaments of LC water extending from the front and cold cyclonic circulations associated with frontal eddies. Figure 2-9 shows 3 pools of cold water between the LC and the west Florida slope. These eddies are similar in character to those found along the Gulf Stream front in the South Atlantic Bight (Lee et al., 1981), both in dimensions and speed (Paluszkiewicz et al., 1983). The eddies appear to propagate around the LC front, from the Campeche Bank around to the Dry Tortugas, where they often stall and grow. This Dry Tortugas eddy eventually moves into the Florida Straits and can cause large deflections of the Florida current between Key West and Cay Sal Bank (Lee et al., 1995). It is thought that similar frontal eddies can exist on recently shed LC anticyclones. Over the deep water of the eastern basin, the cyclonic circulations of the frontal eddies can be quite vigorous, and appear to be part of the cause of the streamers and filaments that are often found north of an extended LC. Filaments are found over the outer west Florida shelf (Paluszkiewicz et al., 1983) where, because of the shallow water, they become stranded and dissipate.

Deep currents in the eastern basin are also dominated by the LC. Hamilton (1990) showed that periodic extensions of the LC caused energetic fluctuations of currents below 1000 m, and that the deep water off the west Florida shelf was a generation zone for Topographic Rossby Waves (TRWs). These waves propagate westward towards the Mexican slope at a typical group velocity of ~9 $\text{km} \cdot \text{day}^{-1}$. Thus, deep currents are not necessarily directly related to upper-layer eddy circulations, particularly in the western basin. Numerical models (Oey, 1995) suggest that a preferred region for the generation of TRWs is the northeast corner of the Gulf, in the deep water at the base of the DeSoto Canyon. However, according to the barotropic instability theory of Malanotte-Rizzoli et al. (1987), the energy source for these waves is the fundamental period fluctuations of the LC.

Within the LC and major LC eddies, but away from boundaries, a consistent T-S relationship is found which has a subsurface salinity maximum of about

36.65 ppt with a corresponding temperature of about 22.5°C at an approximate depth of 125-150m (SAIC, 1988). Outside of these core waters, lateral mixing in the upper Å150m dilutes salinities causing scatter in the T-S relationship. As found in these studies as well as other surveys, for water depths of 200m or greater and temperatures of Å16°C, the T-S relationship in the Gulf has little scatter which allows temperature to be an excellent surrogate for salinity.

2.3.3 Slope Processes

Currents and water mass structures over the continental slope, between the Mississippi Delta and the west Florida shelf off Tampa, can be expected to be highly variable. An extended LC, or recently shed LC eddies, may affect flows over the slope directly or indirectly through frontal eddies and filaments. However, when the LC front is far to the south, strong current events are still observed on the northern slope. These are thought to be secondary cyclones and anticyclones, which seem to be ubiquitous in the Gulf of Mexico. Little quantitative information is known about these eddies over the NEGOM slope. Recent surveys of the Texas – Louisiana slope have described incidences of these eddies (Hamilton, 1992), and there are expected to be similarities between the two slope regions. Most of the evidence for the existence of secondary eddies over the NE Gulf slope comes indirectly from satellite imagery, which often shows LC filaments wrapped cyclonically or anticyclonically around cold or warm eddies, respectively.

Current meter observations over the slope are sparse. However, the indications are that strong eastward upper layer currents (~60 cm·s^{-1}) that last for several weeks can occur between the Mississippi Delta and the DeSoto Canyon (Molinari and Mayer, 1982; Ebbesmyer et al., 1982; Kelly, 1991). There is also nonpublic/proprietary data from a number of deep water sites that show similar events. Most of these are accompanied by higher temperatures and can be attributed to the direct impingement of the LC or a recently shed LC eddy on the slope. It is expected that slope sites closer to the delta are more likely to experience eddy events than sites further to the east. On the west Florida slope, direct LC intrusions are likely to be quite rare. Three years of current meter observations at 26°N latitude, south of the study area (SAIC, 1987) show only 2 (or possibly 3) events of strong southward currents (>60 cm·s^{-1} at the shelf break) that can be attributed directly to the LC moving over the shelf break. At a similar mooring at 27.5°N latitude, off Tampa, only one high-speed event was observed over 3 years of measurements. Thus, the upper slope on the east side of the DeSoto Canyon is not expected to be impacted directly by LC flows.

On the slope in the NE Gulf, indirect LC effects, such as filaments and diluted LC-derived surface waters, have been observed to be advected over the slope and outer shelf. Huh et al. (1981) describes an intrusion of LC water up the DeSoto Canyon to within 8 km of the shore. Kelly (1991) defines three types of intrusions onto the Florida-Alabama-Mississippi shelf and slope: (1) filaments intrude up the axis or along the east side of the DeSoto Canyon, similar to the event described by Huh et al. (1981); (2) the exchange of outer shelf water with a frontal eddy on the northern periphery of the LC [or recently shed LC eddy]; and (3) the northward advection of diluted warm LC-derived waters directly onto the shelf. A sketch of these three types of intrusions is given in Figure 2-12 (Kelly, 1991). For a two-year long data set, Kelly (1991) estimates that LC intrusion affects the slope and outer shelf by one of the three mechanisms about 44% of the time.

The processes that advect filaments or LC derived intrusions onto the outer shelf are not clear at the present time. They probably involve the interaction of frontal eddies with secondary cyclones and anticyclones over the slope. Typical current speeds of events that are not caused by the LC, or by large LC eddies, are 20-30 $cm \cdot s^{-1}$, and can be eastward or westward (Molinani and Mayer, 1982; Kelly, 1991). Along-slope coherence between observations is usually low for moorings separated by less than 50 km. On the Louisiana – Texas slope, cyclones and anticyclones with diameters on the order of 50 to 100 km have been observed a number of times. They tend to be long-lived (6 months or more) and relatively stationary (Hamilton, 1992). An explanation for the characteristics of non-LC flows observed over the slope in the NE Gulf would probably involve similar eddies. Figure 2-13 shows a drifter track on the Louisiana – Texas slope which shows the existence of a number cyclones and anticyclones. Also shown in this Figure is a drifter making two circuits of a similar-sized anticyclone just southeast of the delta. The northern edge of the LC was at about 27°N latitude at this time. An AVHRR image for January 12, 1988 (Figure 2-14) clearly shows a secondary cyclone just west of the DeSoto Canyon which is separated from the northern LC front by more than 150 km. There is, therefore, circumstantial evidence that secondary eddies, similar to these observed further west of Louisiana and Texas, are also common on the slope of the NE Gulf.

Figure 2-15 presents monthly mean, maximum and minimum temperatures and salinities computed using in-situ, time series measured 150m below the local water surface on the upper slope in the DeSoto Canyon during MAMES (Kelly, 1991). Allowing for some instrument error, these data are consistent with the temperature and salinity relationship expected in LC eddies and slope water masses below the seasonal thermocline. As such these provide a reasonable indication of the range of conditions which might be expected at this depth on the slope adjacent to the shelf break.

Drennan (1965) presented hydrographic survey data illustrating transport of relatively high salinity water onto the upper slope and outer shelf in the Panhandle portion of the study area. In Figure 2-16, surface salinities measured during a spring cruise (March-April 1965) suggest the presence of a cyclonic feature in the DeSoto Canyon which was drawing less saline water off the shelf while high salinity, and possibly LC water (≥36ppt), moved onshore. The scale of this feature and corresponding exchange incorporated the slope and outer shelf on both the eastern and western flanks of the DeSoto Canyon.

2.3.4 Shelf Processes

2.3.4.1 Wind-Forced Circulation

Wind stress on the water surface is often a key circulation producing/ forcing mechanism for shelf environments. In the present study area, some

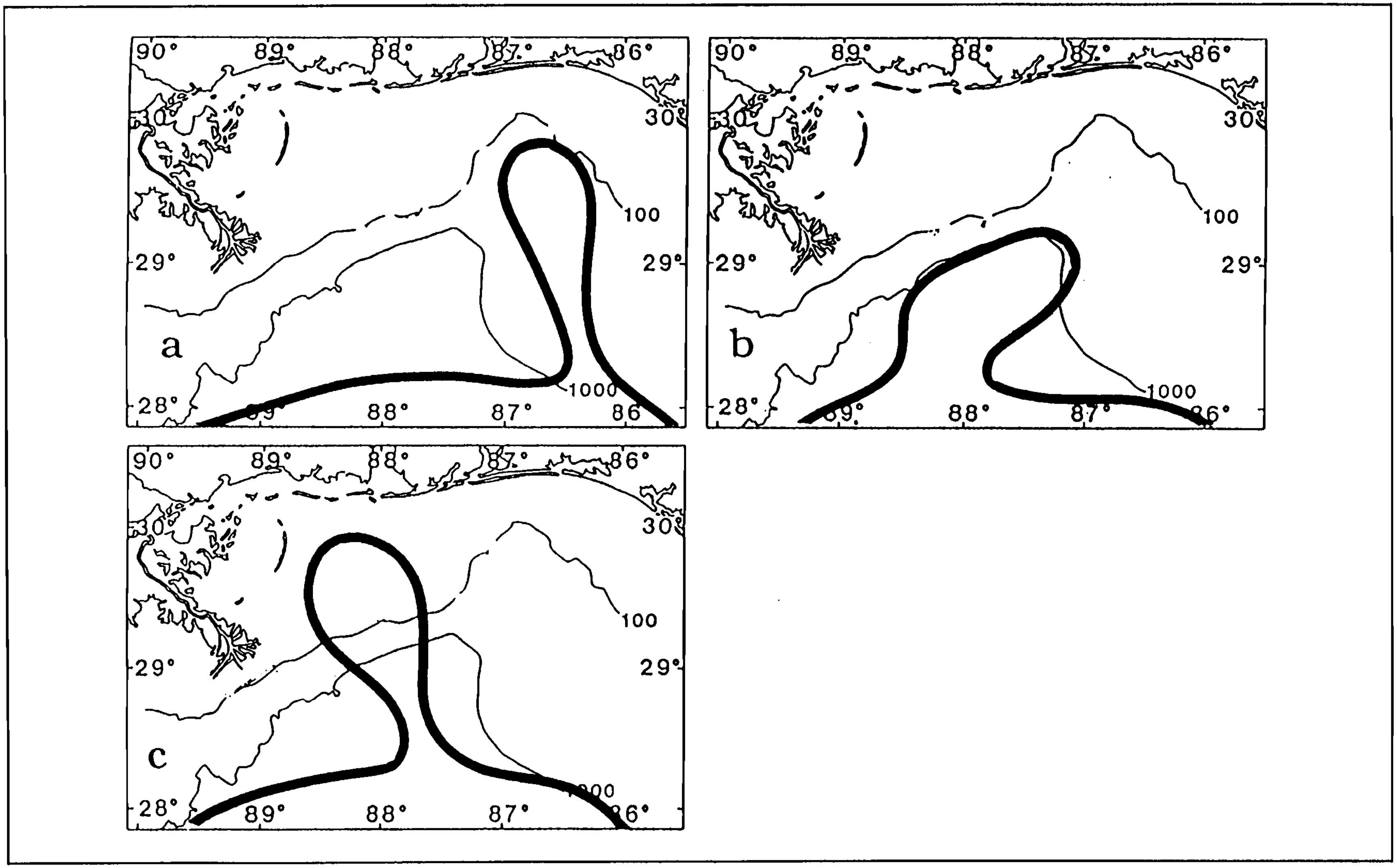


Figure 2-12. Simple illustrations of three types of LC/filament interactions over the Mississippi/Alabama/ Florida Panhandle slope and shelf (from Brooks, 1991).

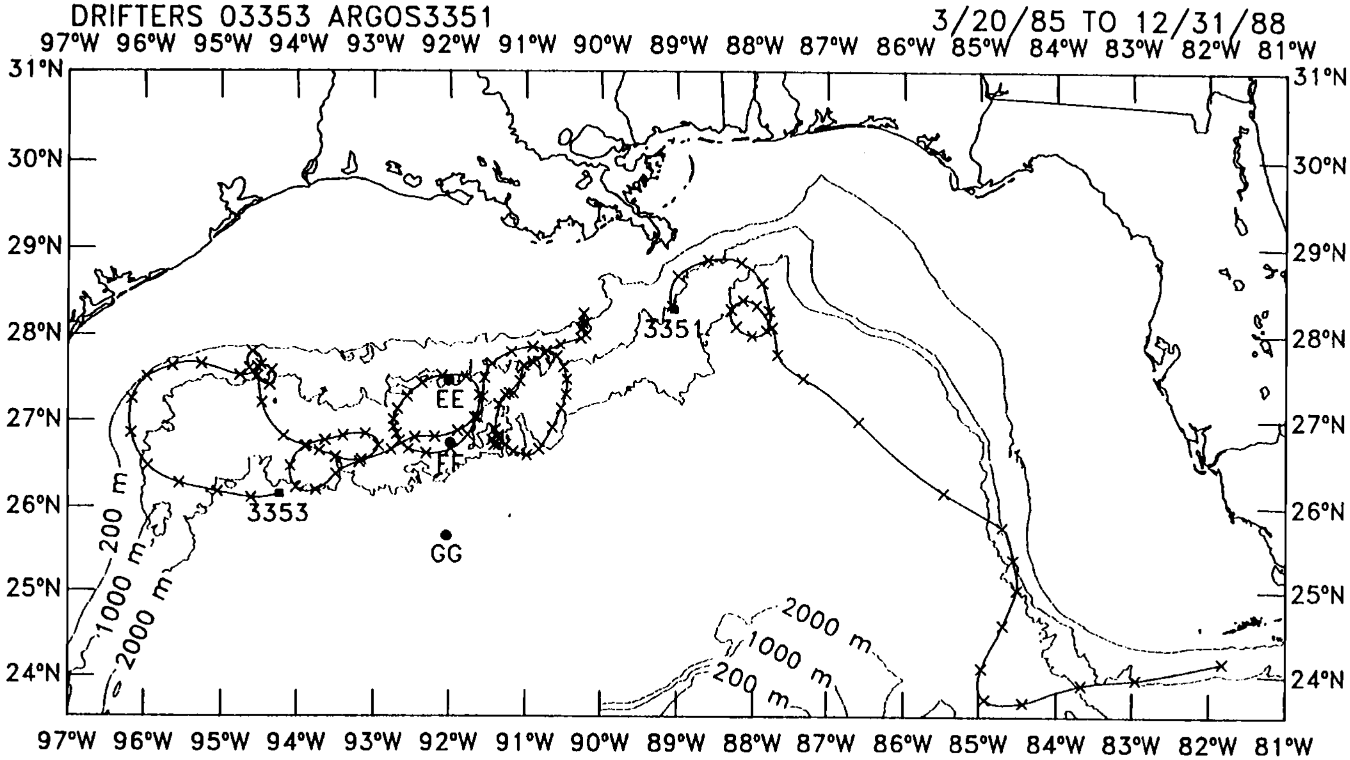


Figure 2-13. Trajectories of two drifters with " × " placed at a daily interval. No. 3353 shows cyclonic/anticyclonic slope eddies offshore of Louisiana and Texas. No. 3351 shows anticyclonic motion on most probably related to LC boundary features. This drifter is eventually entrained in the LC and moves out of the Gulf.

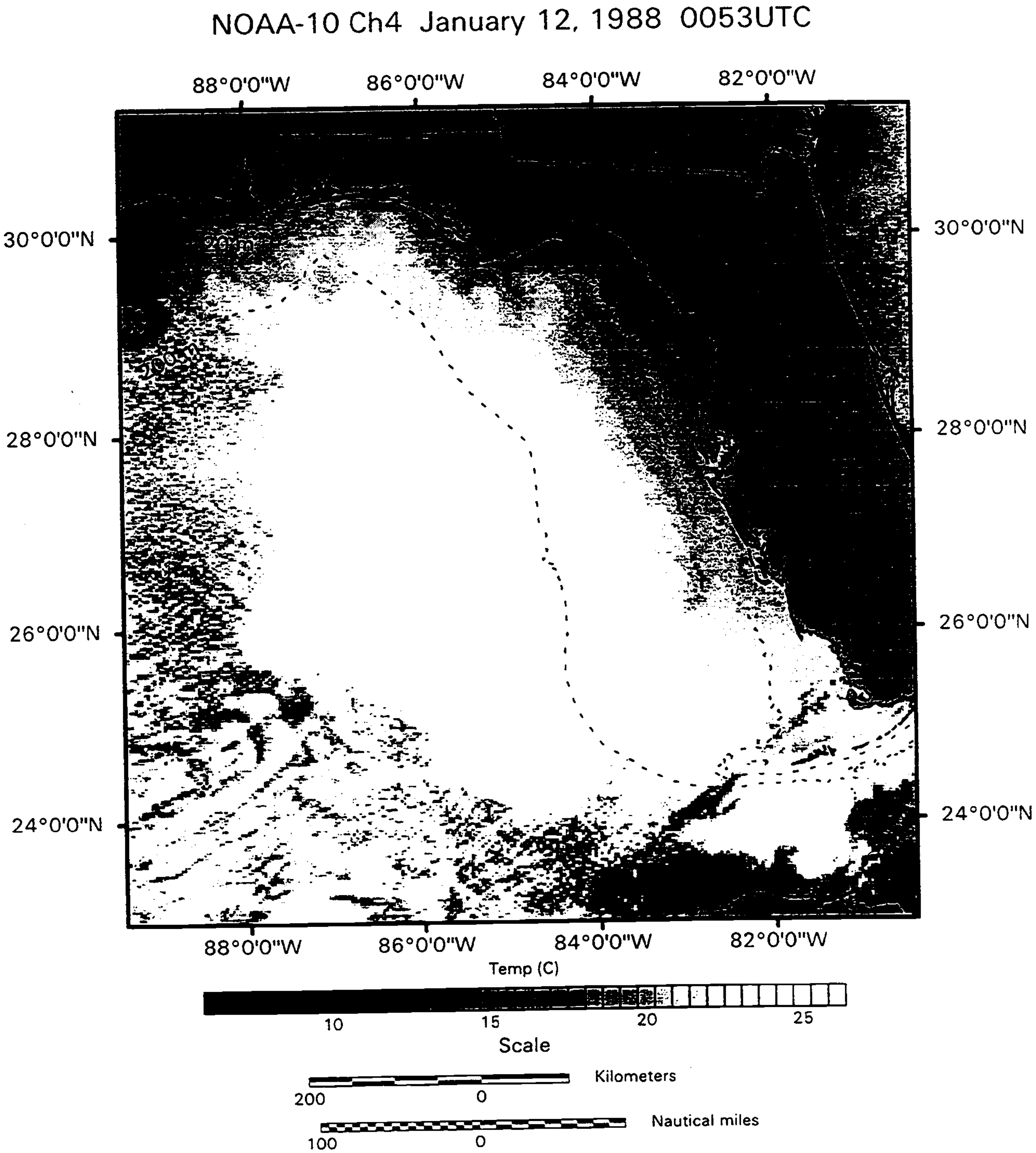


Figure 2-14. SST image showing an eddy over the upper slope on the eastern wall of the De Soto Canyon.

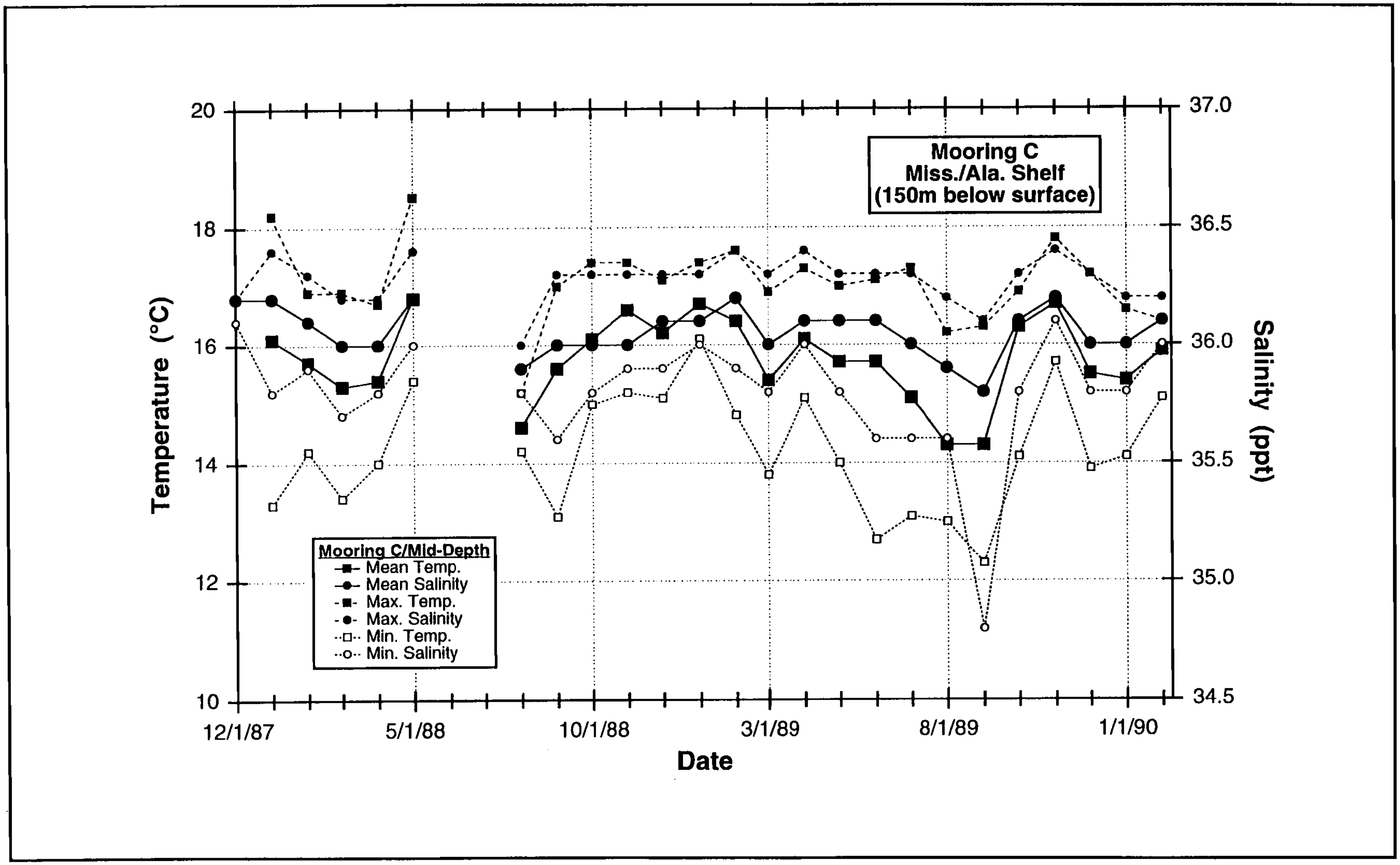


Figure 2-15 Monthly mean, maximum and minimum temperatures and salinities computed from data taken at 150m on Mooring C from the MMS-funded MAMES project. Circles are salinity; squares are temperature. (See Figure 2-17 for mooring location.)

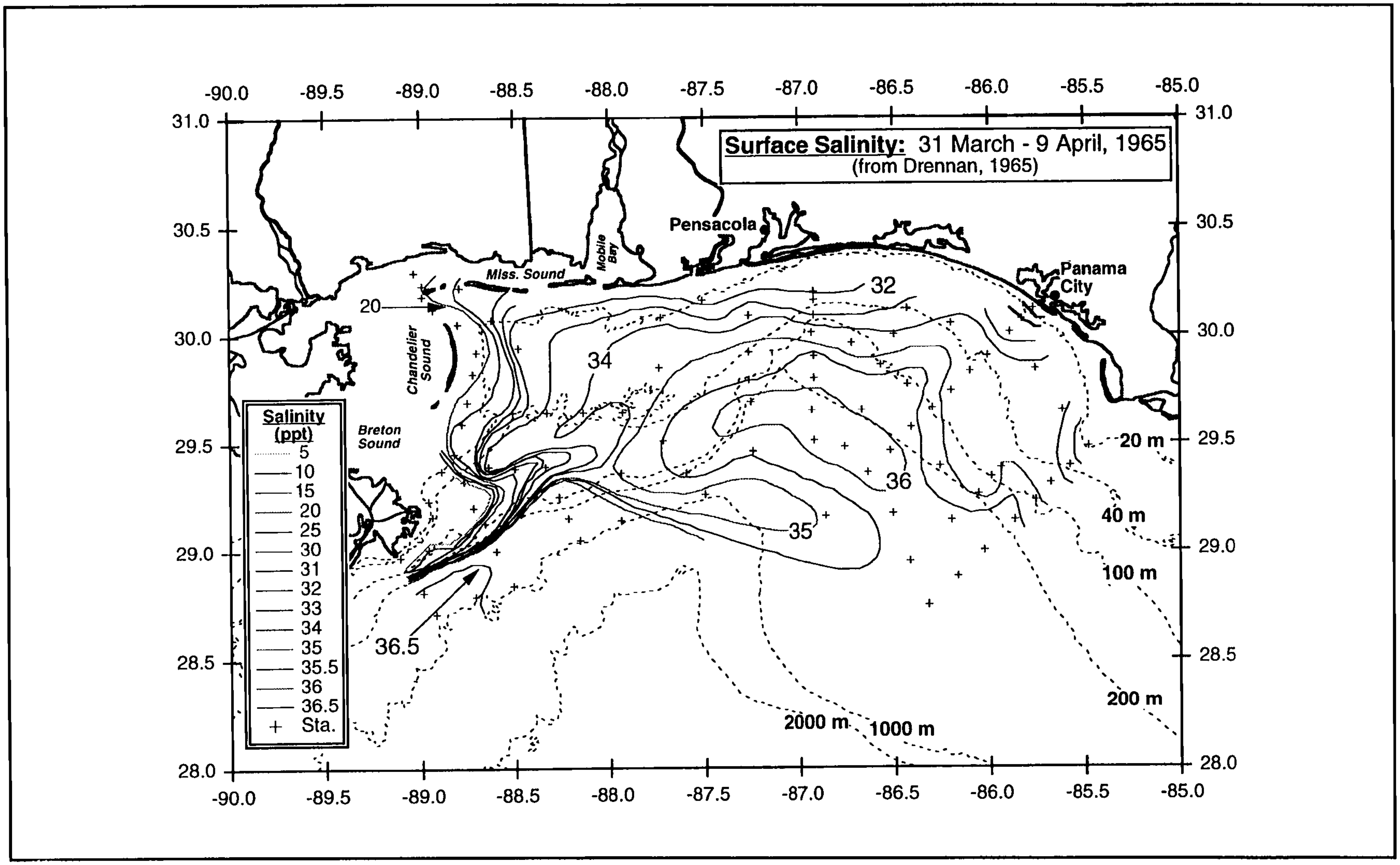


Figure 2-16 Plot of surface salinity contours digitized from a figure in Drennan (1965). Distribution of surface salinity shows an cyclonic feature in the DeSoto Canyon transporting slightly fresher shelf water offshore onto the slope while more saline water moved onshore.

of the most vigorous wind forcing takes place in winter, when there are strong fluctuations in the wind (several day periodicity) caused by frequent incursions of cold fronts from the north. The northern Gulf of Mexico shelf is an area of cyclogenesis for winter storms caused by the meeting of cold, dry continental polar air with warmer, more humid subtropical air over the Gulf. Warm surface waters found seaward of the shelf break in winter are a crucial component to the genesis of winter storms. In summer, synoptic-scale winds are relatively weak and from the east or southeast. A substantial sea-breeze system is present over shallower inshore waters (Sonu et al. 1971). The calm conditions of summer are sometimes interrupted by the passage of hurricanes or tropical storms. The region of the Florida Panhandle, and Alabama and Mississippi coasts, has often been severely impacted by tropical storms and their associated storm surges, traveling north over warm Gulf of Mexico waters.

On the west Florida shelf, the wind-forced response of middle and inner shelf waters has been studied by Mamorino (1982, 1983), Mitchum and Sturges (1982) and Mitchum and Clarke (1986). Weather band (2-10 day periods) sea-level and current fluctuations increase in amplitude towards the north from Key West. The explanation is in terms of a forced continental shelf wave propagating southward with the alongshore wind stress fluctuations, and an associated free continental shelf wave which cancels out the sea-level response at the southern boundary (Mitchum and Clarke, 1986). At Florida's Big Bend, the shelf narrows by a factor of 3 and wind-forced current magnitudes increase by a factor of 2 between the same isobath off Cedar Key and northwest of Cape San Blas (Mamorino, 1983). Coastal sea level response decreases slightly over the same region.

The nearshore and mid-shelf regions to the west of the DeSoto canyon have been less studied as regards wind forcing. The delta obstructs the shelf to the west, and shelf currents measured just south of the delta show weak to intermittent fluctuating flows when not under the influence of the LC or an eddy interacting with the slope topography (Wiseman and Dinnel, 1988). Chuang et al. (1982) indicated that inshore waters respond to the local alongshore wind. There has been little study of the connections between the wind-forced continental shelf wave response on the wide west Florida shelf and the more complex NE Gulf shelf. The effect of blocking by the delta on wind-forced flow has also not been considered or modeled. Kelly (1991) reports that hurricanes generate strong currents which promote flushing of the shelf.

Current measurements at the shelf break on both the west Florida (Mamorino, 1983; Niiler, 1976; SAIC, 1987) and the NE Gulf shelves (Kelly, 1991) show very weak or no relationship to the local wind. The fluctuations tend to be of longer period than wind-forced responses and more likely are caused by LC or slope eddy activity as discussed above.

2.3.4.2 <u>Shelf Water Temperature and Salinity</u>

Because of its ecological importance, as well as being a variable which changes in response to important environmental and circulation-producing mechanisms, mean temperature and variability in and adjacent to the study area are discussed. To support this, search was made to identify and acquire selected field observations which could be used to characterize conditions and patterns that might be expected in this study area.

In terms of geographic locations and depths of measurements, the most appropriate and representative observations were made as part of the Mississippi/Alabama Continental Shelf Ecosystem Study (Kelly, 1991) and the Gulf of Mexico Physical Oceanography Program, Years 1,2,4 and 5 (SAIC, 1987). Measurements made during these two MMS-funded studies bracketed the present study area. Observations discussed were derived from temperature time series measured at current meters or an NDBC buoy (42015). The general locations of these shelf and upper slope moorings and the inner shelf buoy, as shown in Figure 2-17, are just west or south of the present study area boundaries.

Information presented is primarily the monthly mean and extreme (max. and min.) temperatures. These statistics were selected since they indicate many of the key patterns as well as when certain ecologically important temperature thresholds were or were not exceeded. While the overall data sets are not all coincident, the general patterns are consistent with that expected for the shelf in the northern Gulf of Mexico. Although the observations taken west of the Mississippi Delta are well away from the present study area, they are included to illustrate the broad regional similarity of certain patterns on the shelf in the northern Gulf.

Temperatures measured near or at the water surface are shown in Figure 2-18. There are concurrent observations from west of the delta and on the Miss./Ala. shelf (A, B, and C in Figure 2-17). Also shown are air (A) and sea surface (S) temperatures measured at NDBC Buoy 42015. The annual cycle of temperatures is clearly evident. During fall and winter an increasingly strong cross-shelf temperature gradient develops, with warmer water near the shelf break and colder surface waters near the shore. Following the occurrence of minimum monthly means, near-surface-cross shelf temperature gradients disappear as the surface waters warm, coincident with and approximately equal to the increasing air temperature. Maximum surface temperatures occur in late June through September. Following this, surface waters cool with the shorter days and decreasing air temperature. Minimum monthly mean near-surface water temperatures occur in January/February. When minimum mean temperatures occur in the shallow nearshore region, near-surface temperatures at the shelf break are ~6°C warmer. Fairly consistently for the inner shelf data, monthly mean sea surface temperature remained higher than the adjacent air temperature, indicating that the mean heat flux was from the water to the air throughout the year.

During fall, as air temperatures and surface waters cool, the general vertical temperature stratification decreases as heat is removed from the upper portion of the water column (Huh et al. 1984). As shown in Figure 2-19 the entire water column is eventually overturned (transformed from vertically stratified to vertically well mixed) due to the increased heat flux from water to air during more vigorous CAOs. The specific timing of this transformation can vary interannually and depends substantially on the local wind speed, and cumulative and specific air-water temperature differences during CAOs. These strong fronts, that are often associated with developing atmospheric low pressure systems, can also provide a source of mechanical energy to facilitate vertical mixing.

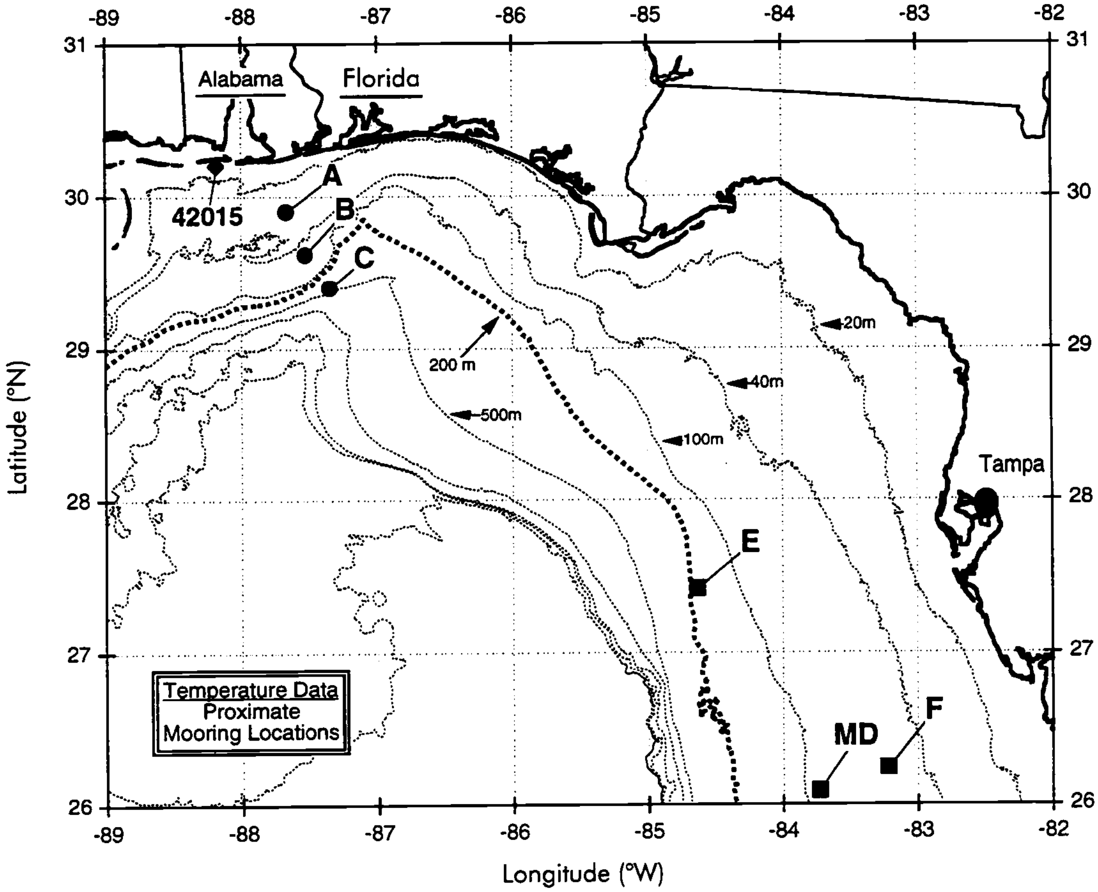


Figure 2-17. Map with mooring positions shown. Moorings A, B and C were part of the Mississippi – Alabama Shelf Study. Moorings E, F and MD were part of the Gulf of Mexico Physical Oceanography Study.

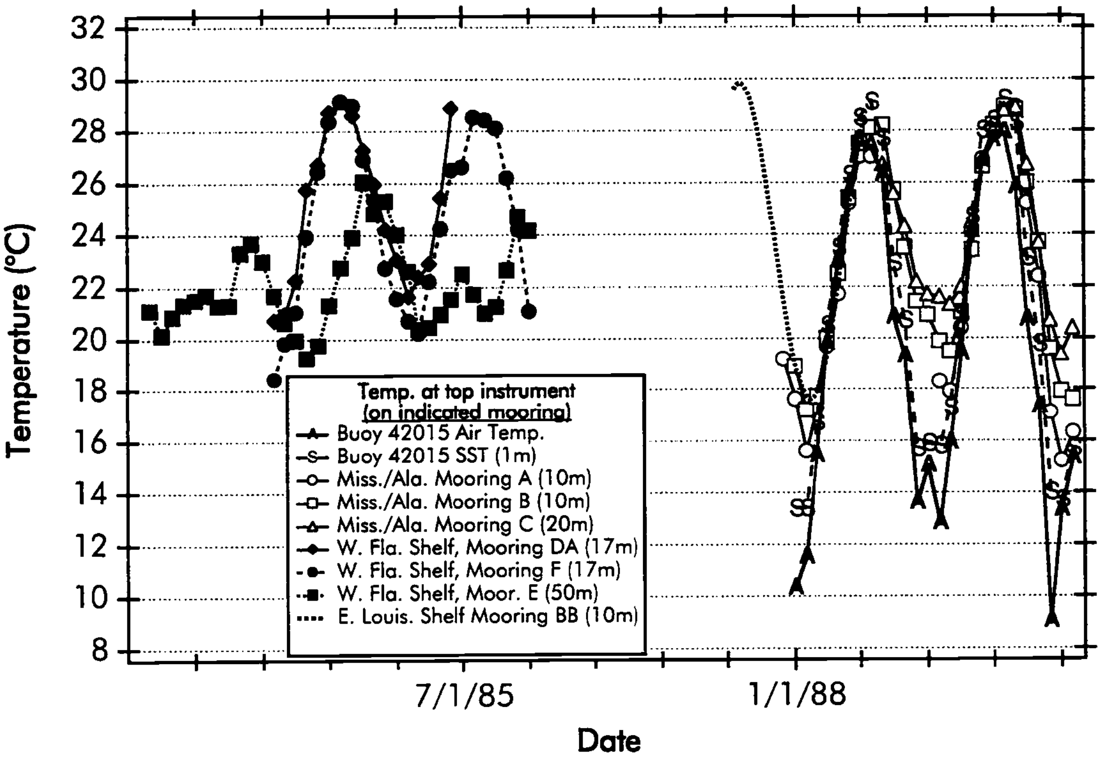


Figure 2-18. Near surface monthly mean temperatures for indicated moorings. Included are air and water temperatures measured at NDBC Buoy 42015.

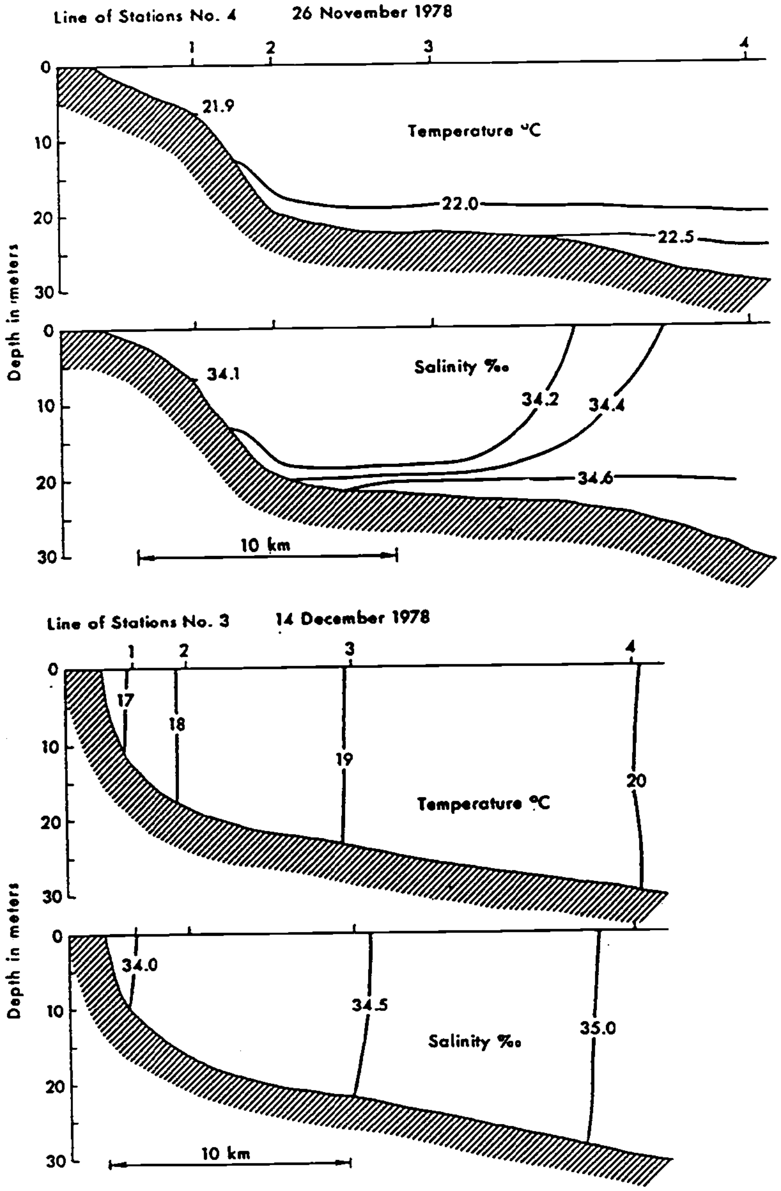


Figure 2-19. Changes in shelf water stratification due to passage of a front and cold air outbreaks offshore of the Florida Panhandle (from Huh et al., 1984).

Figure 2-20, for Mooring B on the Mississippi/Alabama shelf from November 1988 to March 1989, the vertical water column continued to cool with relatively weak vertical stratification as compared to the summer months. Comparable observations just south of the study area showed essentially no vertical stratification in the mean during winter (Figure 2-21). Figure 2-20 also illustrates the more intense stratification of mean temperatures in summer, which reached a maximum of ~7°C in September during both years shown.

The mean temperature pattern reflects the cumulative influence of higher frequency changes, which produced the monthly extreme temperatures (maximums and minimums) shown in other Figures. From an ecological perspective, the magnitude and duration of the minimum temperatures may be a significant limiting factor to habitat suitability.

For near surface waters the monthly range of temperatures (max.-min.) was ~4°C, with maximum annual temperatures (~30°C) occurring in September in 1988 and 1989. Although generally somewhat less than near the water surface, the range of monthly near-bottom temperatures was occasionally as large or larger than further up in the water column. Minimum temperatures at this mid-shelf location were approximately 15-16°C, usually in February/March.

At Mooring C (Miss./Ala.), located just seaward of the shelf break in 459 m of water, the warmer winter temperatures (Figure 2-22) moderated the amplitude of the annual mean temperature cycle as compared to further onshore (Figure 2-18). However, the monthly range was on occasion considerably larger, primarily due to the presence of much cooler water (see minimum temperature of ~21.5°C in July 1989.) At 150 m depth on Mooring C, the mean temperatures had no recognizable seasonal pattern and varied on the order of 2°C while the an annual range of measured temperatures was ~6°C.

Similarity of annual shelf temperature cycles across the northern Gulf of Mexico and on the northern half of the west Florida shelf is not surprising, since many of the controlling conditions are quite similar. Water over the slope is a relatively constant reservoir of warm water (heat) with weaker seasonal fluctuations. Many of the shelf sites are affected by the same cold air outbreaks and associated atmospheric low pressure systems. Certainly, from Mobile Bay eastward, sources of fresh water are rather limited (see Section 4.3) so that the shelf density structure is dependent in large part on the annual (and shorter interval) changes in temperature.

As discussed previously, higher frequency and aperiodic processes such as LC eddies/gyres on the slope and outer shelf can have more localized impacts. Kelly (1991) identified regular temperature changes near the shelf break which were directly related to the influence of the LC or related features such as eddies and filaments. Images of sea surface temperature patterns and in-situ observations suggest that some of the warmer offshore waters move across the shelf break and extend part of the way across the shelf. Satellite imagery often show that lower sea surface temperatures in winter are at times correlated with water depth. Thus, off

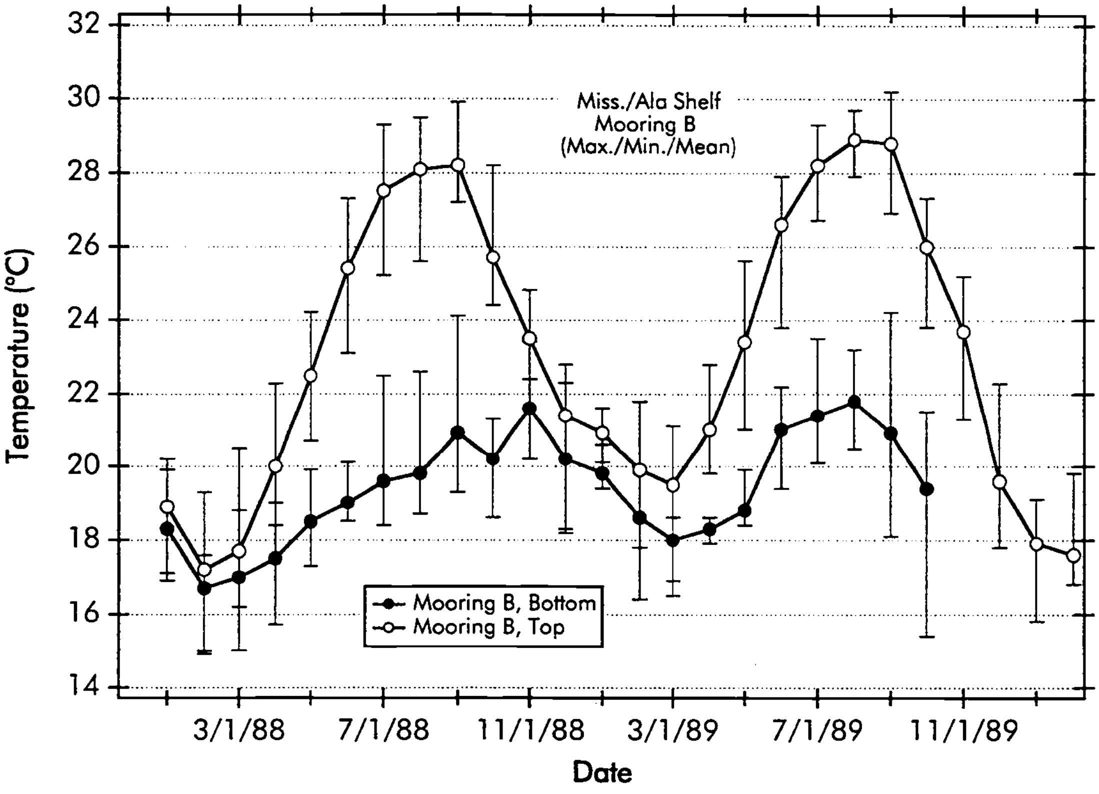


Figure 2-20. Monthly means, maximums and minimums from Mooring B (midshelf) offshore of Alabama.

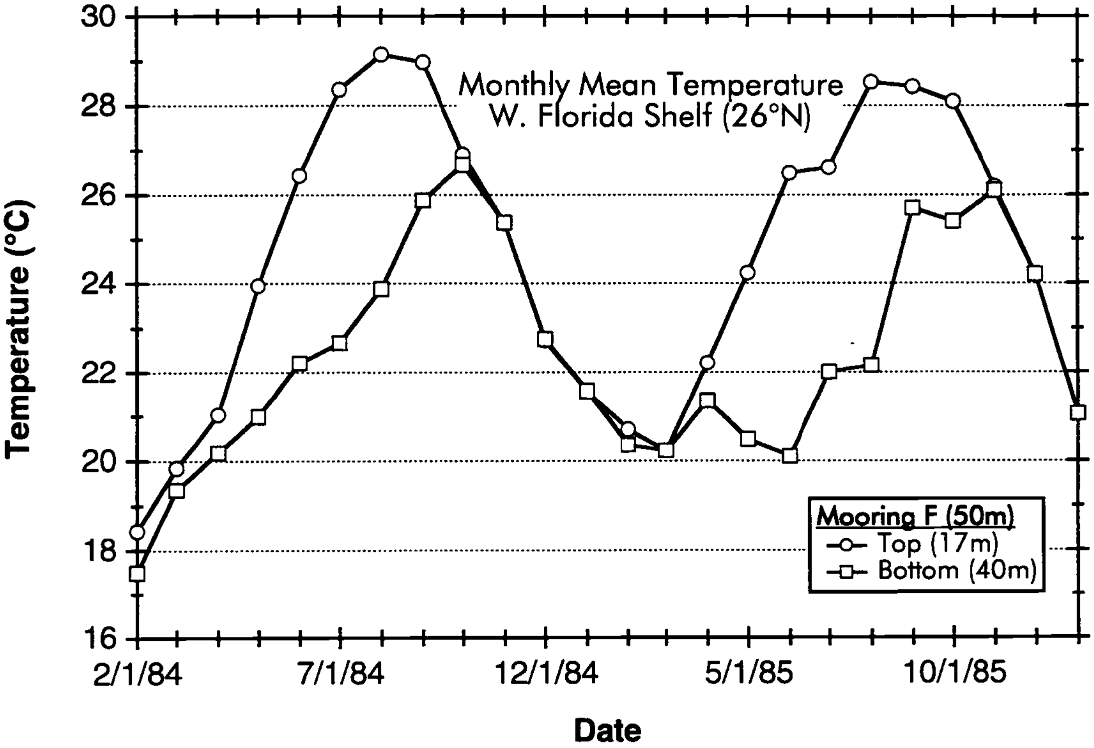


Figure 2-21. Monthly means, maximums and minimums from Mooring F (midshelf) offshore of Fort Meyers, FL.

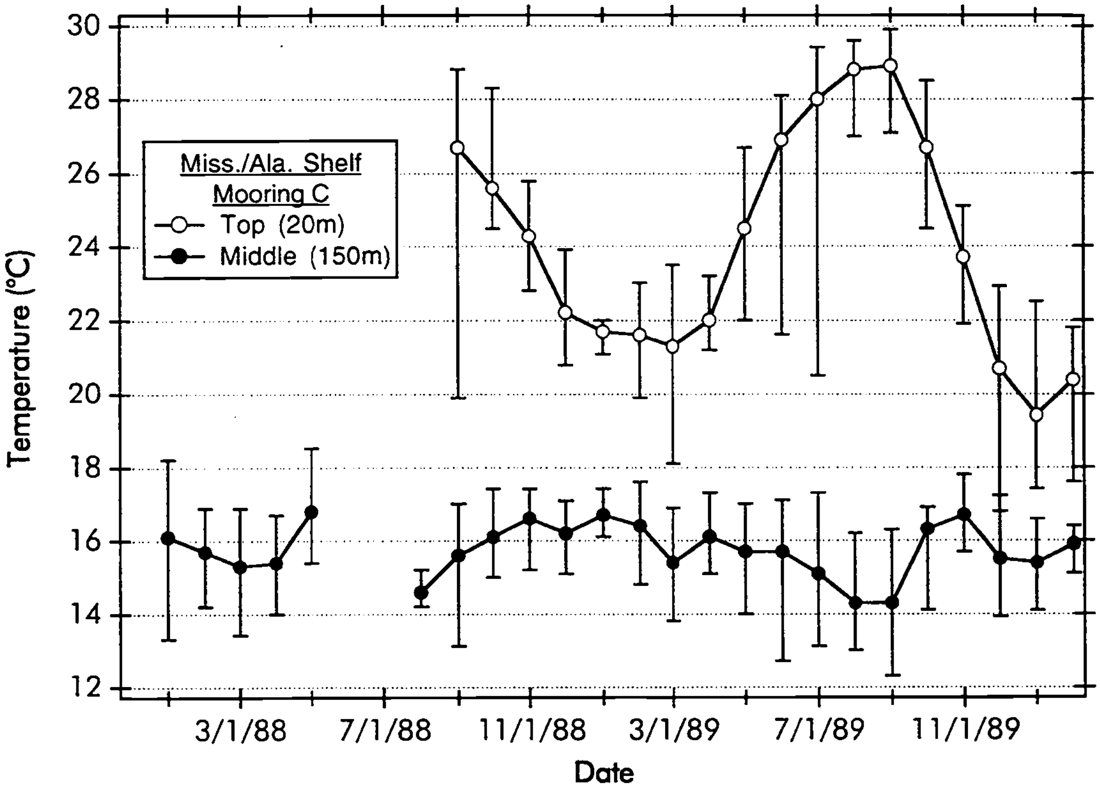


Figure 2-22. Monthly means, maximums and minimums from Mooring C (upper slope) offshore of Alabama.

the Big Bend area with its broader, more gently sloping shelf bottom, temperature gradients were weaker than over the narrower shelf at the head of DeSoto Canyon and east towards Appalachicola Bay (Figure 2-8).

Kelly (1991) used observations made during five MAMES cruises to reconstruct surface and near bottom salinity, temperature and dissolved oxygen (DO) on the shelf just to the west of the present study area. Of particular interest were patterns of DO which was almost always greater than 5 ml/l with lower values being associated with near bottom water at the shelf break and on upper slope. An exception to this was one cruise in August 1988, when DO values of ≤4.5 ml/l were found over the mid-shelf south of Mobile Bay associated high salinities (≥36.5 ppt).

As shown in Figure 23a,b monthly mean near surface salinities over the mid- to inner shelf were generally lower and had greater variability than similar computed variables measured over the upper slope. The monthly and annual range were similarly greater at the shallower location which was closer to lower salinity estuarine discharges.

2.3.4.3 River Flow and Buoyancy Forcing.

River runoff to the Alabama – Mississippi shelf is highly visible. About 30% of the annual average discharge of 14,000 $m^3 \cdot s^{-1}$ of the Mississippi River is thought to be discharged eastwards onto the outer shelf (Kelly, 1991). This is the largest freshwater source in the region and significantly freshens the outer shelf region. The next-largest source is the flow of the Alabama and Tombigbee Rivers into the Mobile Bay/Mississippi Sound system. The average discharge is about 2,200 $m^3 \cdot s^{-1}$ into Mobile Bay and about 1,220 $m^3 \cdot s^{-1}$ into Mississippi and Chandeleur Sounds. West of Mobile Bay, the average discharge is about 800 $m^3 \cdot s^{-1}$, primarily from the Pascagoula and Pearl Rivers (Dinnel, 1988). In the Florida Big Bend region, the rivers are small (the Apalachicola and the Suwannee) with annual average discharge of about 1000 $m^3 \cdot s^{-1}$. There is, thus, a strong west-to-east gradient in buoyancy input to the shelf, and an unusual situation in that as much fresh water input is discharged onto the outer as the inner shelf.

Mississippi River water can become entrained in Loop Current and cyclonic eddies in the region. An example of this process is shown in Figure 2-16 from Drennan (1965) which showed fresher surface water coming from the delta and being incorporated in an outer shelf and slope cyclonic circulation. Low surface salinities (≤20ppt) were found well seaward of the Chandelier Islands. Note the very strong coastal front just offshore of South Pass.

The overall effect of coastal and riverine discharge on the mean shelf-wide circulation is unclear. It is generally believed that there is a cyclonic gyre between the delta and the DeSoto Canyon. Evidence for this is based primarily on hydrographic data and surface drift bottle studies (Chew et al., 1962; Tolbert and Salsman, 1964). Outer-shelf current meter moorings (Kelly, 1991) suggest eastward mean flow, which could be considered as the southern part of the gyre. However, these records are dominated by LC or LC eddy interactions with the slope. Thus, it is not clear if these are he

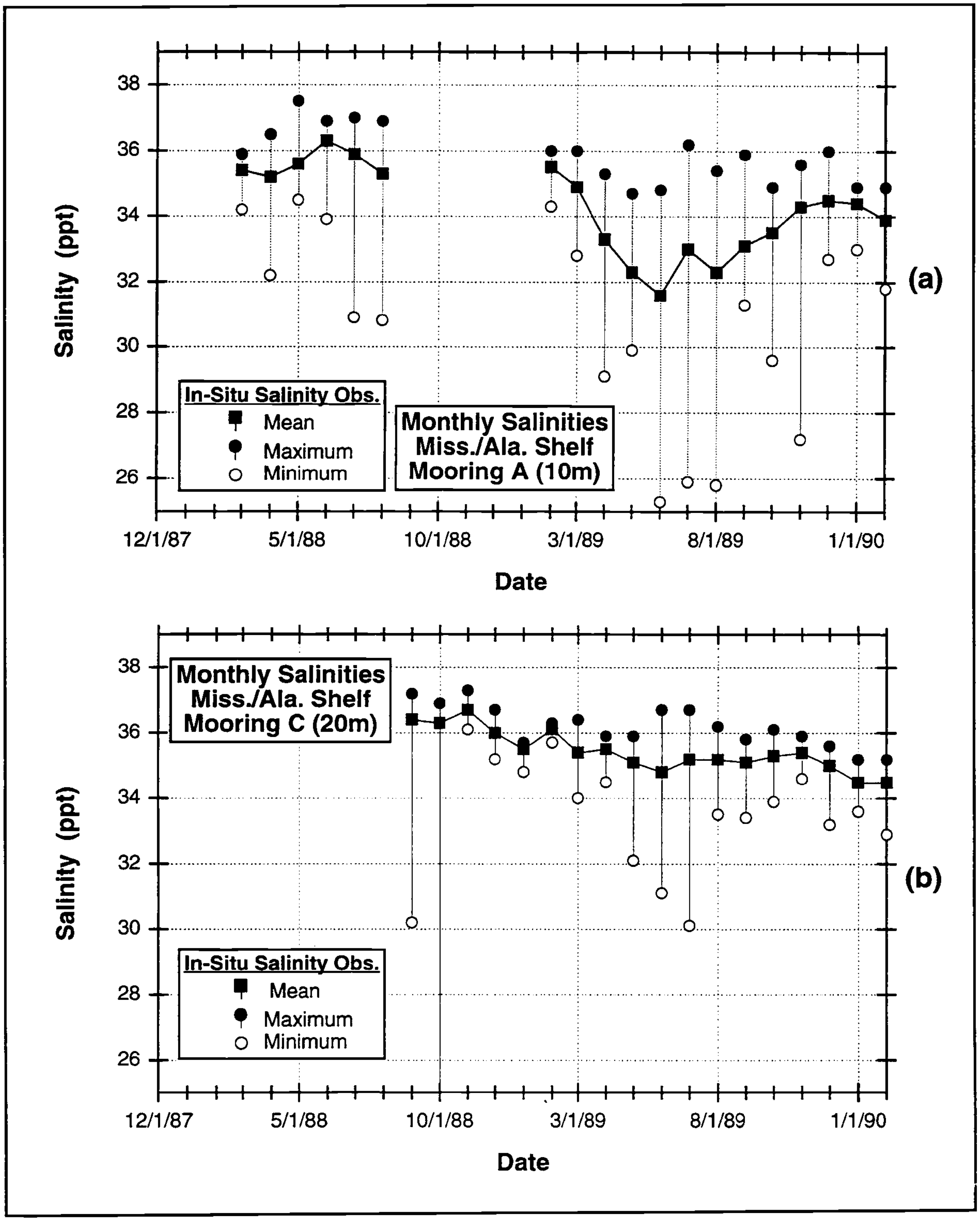


Figure 2-23. Monthly mean, maximum and minimum salinities computed from data taken near the water surface. (a) data measured at 10m depth on Moorings A located on the inner half of the shelf; (b) data measured at 20m depth on Mooring C located on the upper slope in 430m of water.(See Figure 2-17 for mooring locations.)

normal conditions or if different circulation patterns exist when LC or LC eddy influences are absent. The hydrographic data presented in Kelly (1991) suggest that a wide variety of temperature and salinity distributions can exist over the Mississippi-Alabama shelf, depending on the fresh water discharge and whether LC-derived intrusions are present.

Equivalent analyses of the Florida Big-Bend region do not seem to have been carried out, so mean flow patterns are not available. However, the relatively low river discharge into the region, and the dominance of wind-forced fluctuating flows in the mid-shelf region, would indicate that only weak buoyancy-driven mean flows are likely except in shallow nearshore areas.

2.3.4.4 Tides and Inertial Currents

The majority of the Gulf of Mexico is dominated by the diurnal tides (K_1 and O_1) which are basically uniform in amplitude and phase across the Gulf. K_1 and O_1 constituents have amplitudes of about 16 cm. In the northeast corner of the Gulf, however, the semi-diurnal tides dominate, with M_2 amplitudes of about 35 cm in Apalachee Bay. In the Gulf, the small M_2 tide is mostly locally generated in the main basin by the astronomical tide generating forces (Reid and Whitaker, 1981), and then amplified across the wide west Florida shelf. The basic features of the M_2 tide and tidal currents are well explained by the shelf-tide theory of Battisti and Clarke (1982a, b). The theory is also reviewed by Clarke (1991). The major axes of the semi-diurnal and diurnal current ellipses are directed perpendicular to the isobaths and have amplitudes of about 10 $cm \cdot s^{-1}$ (M_2), 7 $cm \cdot s^{-1}$ (K_1) and 4 $cm \cdot s^{-1}$ (O_1) (Mamorino, 1982; 1983). West of Cape San Blas, where the shelf is narrow, M_2 tidal current amplitudes are smaller (3 $cm \cdot s^{-1}$) and the K_1 and O_1 constituents begin to dominate the surface tide. In the Mississippi sound region, tides are predominantly diurnal and current amplitudes are small (3-4 $cm \cdot s^{-1}$).

Inertial currents are internal waves with a frequency near "f", the Coriolis parameter. In the study area the inertial period is approximately 24 hrs. Inertial currents can be characterized as a nearly horizontal current vector rotating clockwise at a frequency near "f". They are generated by sudden changes in surface wind stress, and large rapidly moving storms such as hurricanes generate inertial wakes. One such example is currents measured in the DeSoto Canyon during the landfall of Hurricane Frederic at Dauphin Island on September 13, 1979 (Figure 2-24). Inertial surface currents with amplitudes of about 100 $cm \cdot s^{-1}$ which persisted for more than 5 days after the passage of the eye were observed in deep water (Shay and Ellsberry, 1987).

The phase difference between orthogonal velocity components is clearly seen in Figure 2-24a. In Figure 2-24b, cross isobath velocities at differing depths are shown to illustrate the vertical structure of the horizontal currents. Both the current amplitudes and relative phases vary with depth. By approximately September 19, 1979, cross-isobath currents at 437 m were greater than surface currents which had been generally decreasing with after hurricane passage. From Figure 2-24b currents at increasing depths were in directions different than surface currents.

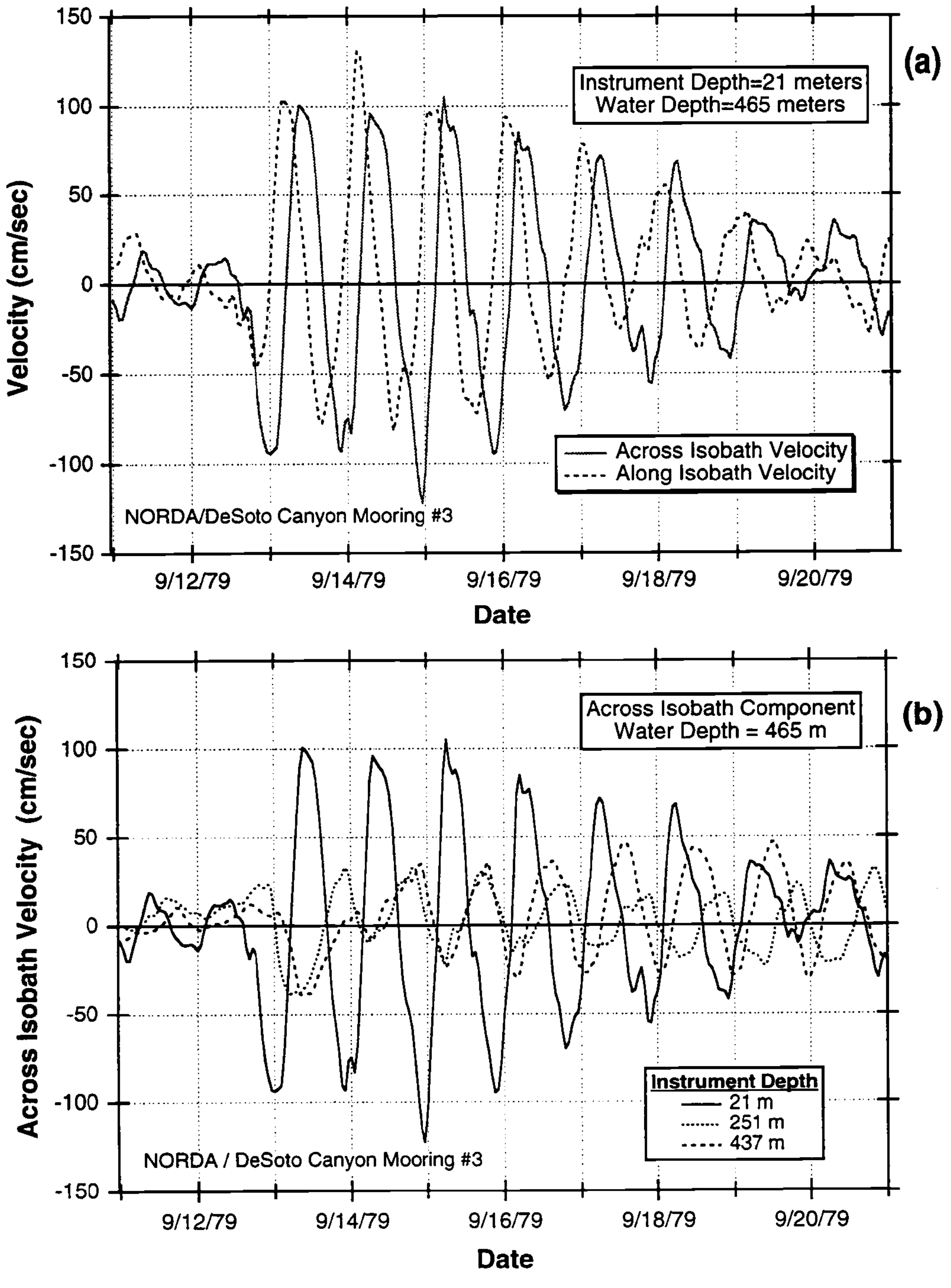


Figure 2-24. Currents measured at the NORDA/DeSoto Canyon mooring during passage of a hurricane. (A) across and along isobath current components; (B) across isobath currents at indicated depth.

Inertial period currents are often vigorous at shelf break sites during the summer when the water column is highly stratified. At 26°N latitude, on the west Florida shelf, inertial currents of amplitudes ~50 $cm \cdot s^{-1}$ were quite common during three summers of measurements (SAIC, 1987), and not related to any strong wind events. It is possible that at this site, inertial energy was being trapped in the cyclonic shear zone of the LC front. However, strong inertial currents not related to hurricanes have been observed on the Louisiana (SAIC, 1989) and the Alabama – Mississippi shelf breaks (Kelly, 1991). The reasons for the strong inertial response of outer shelf waters in the Gulf of Mexico are not known at the present time.

2.3.4.5 Nearshore Processes

The discharge of fresh water into the nearshore zone has not been studied in any detail in the study region. Shallow regions of Apalachee Bay are dominated by tidal currents and a discharge of brackish water which forms a coastal frontal zone (CFZ). This CFZ extends about 20 km offshore to the 20 m isobath. Vertical and horizontal mixing by tidal and wind-driven currents generates offshore gradients of density which can drive two-layer onshore-offshore flows that are comparable in magnitude to the alongshore currents. Such diffuse CFZs have been primarily studied in the Georgia Bight (Blanton et al., 1989). There have been some models of these zones (Garrett and Loder, 1981; Werner et al., 1993). In the Florida Big Bend region, there are additional complications of the change in direction of the coastline and changes in shelf topography. Interaction of the major river outflows (Apalachicola and Suwanee) with this CFZ are likely to be highly dynamic with the formation of multiple river plume fronts as the outflows interact with tidal and wind-forced shelf currents (e.g., Garvine, 1991).

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Chapter 3 - THE GEOLOGICAL ENVIRONMENT

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3.1 General Geological Setting

The area of interest is located in the northeast portion of the Gulf of Mexico sedimentary basin. The study area includes two geologically and geomorphologically distinct areas: the Big Bend area and the panhandle coast. They are separated by Ochlockonee Bay. The Big Bend area is characterized by open coast marshes that rest on a karstic Eocene limestone surface. The panhandle coast is comprised of numerous estuaries with a nearly continuous barrier/inlet system.

Peninsular Florida is underlain by a carbonate platform that contains thousands of meters of Cenozoic (67 mya to present) marine limestones, dolomites, sands, and clays overlying Pre-Cambrian (about 700 mya) to mid-Mesozoic (about 150 mya) basement rocks. These marine sedimentary rocks contain very little siliciclastic material below the Miocene, due to the absence of input from terrestrial sources to the north before the Suwannee Channel was closed. Since that time, siliciclastic sediments from the Appalachians and the Coastal Plain have made their way south onto the Florida peninsula. In contrast, the Gulf Coast contains a huge accumulation of terrigenous siliciclastic sediments that were provided by the Mississippi River and other fluvial systems.

3.1.1 Origin of Florida Peninsula

The Florida Platform is built on basement rocks which represent a fragment of the African Plate left behind in the Mesozoic when the continents broke apart. During its early geologic history, the platform was intermittently covered by shallow seas, and cut off from the mainland by a seaway known as the Gulf Trough or Suwannee Channel (Figure 3-1). The Gulf Trough cut through the study area in the area of Cape San Blas, connecting two ancient depositional basins, the Southeast Georgia Embayment and the Apalachicola Embayment. The majority of the marine sedimentary rocks and evaporites were deposited during this time. During the early Miocene (~20 mya) there was renewed uplift in the Appalachian Mountains which caused increased erosion and a corresponding increase in sediment supply to the southeast United States. This influx of sediment eventually caused the closing of the Gulf Trough. After that time the carbonate sediments became mixed with siliciclastic material from the Appalachian Mountain erosion. Eventually the area became covered with siliciclastic sediments, which today dominate the southern and western portion of the study area.

3.2 Shoreline Geomorphology

The coast of the study area is comprised of two general regions (Figure 3-2): 1) the Big Bend marsh coast, and 2) the panhandle barrier chain

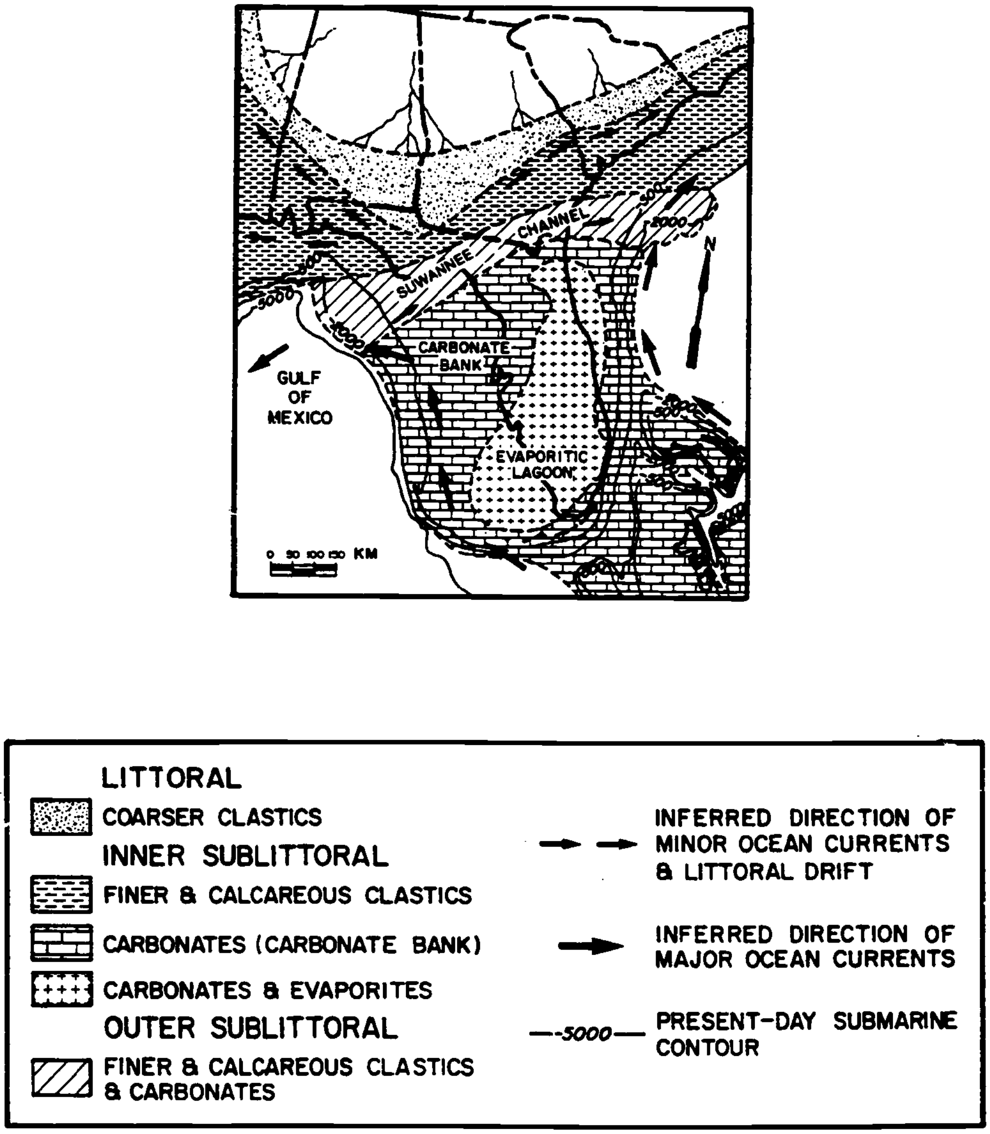

Figure 3-1. Location of the Suwannee Channel, which created a barrier to terrigenous sediment transport during the deposition of the carbonate sediments on the Florida Platform until the early Miocene (~20 mya, from McKinney, M.L., 1984).

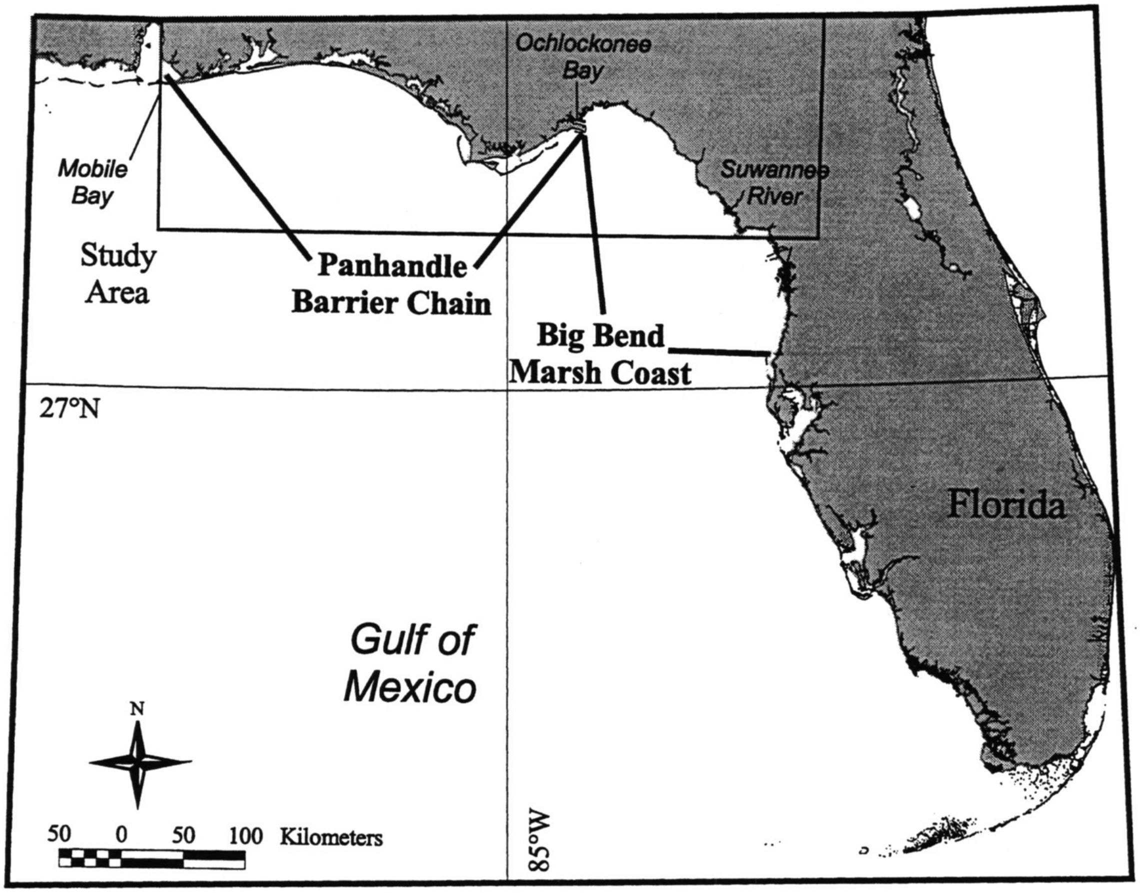

Figure 3-2. Location of the Panhandle barrier chain and the Big Bend marshy coast within the study area.

including the Apalachicola Delta area. Ochlockonee Bay effectively divides these two regions. The geomorphic province known as the Gulf Coastal Lowlands (White, 1970) dominates the geomorphology inland of the coast. The lowlands contain marine terraces of various ages on the inland side. In the seaward direction, the marsh coast is bounded by a broad, low-gradient continental shelf. A similarly gently-sloping shelf is present off the Apalachicola Delta. The slope of the shelf increases markedly as one moves to the west of this area.

3.2.1 Big Bend Marsh Coast

The Big Bend marsh coast is a very low-gradient shoreline with very limited sediment cover. The 300 km shoreline of marshy coast is bounded on the south by the west Florida Barrier Island Chain, beginning in northern Pasco County, and to the northwest by Ochlockonee Bay. When compared to the barrier coasts to the north and south, the marsh coast has had little study (Hine et al., 1988) until a recently completed 5-year study conducted by the US Geological Survey.

Historic upland geomorphology has played an integral role in creating the present-day Big Bend coast. The quartz sands, whose ultimate source was the Appalachian Mountains, were concentrated along the Brooksville Ridge to the east, preventing them from being deposited on this portion of the coast. Very few large streams capable of transporting this sediment to the coast have formed along this part of Florida, and thus the area is starved of sediments. There are numerous short spring-fed streams originating near the coast but these carry little sediment. The only large river that enters the Big Bend area is the Suwannee River (Figure 3-2), which drains a mostly karst limestone terrain and thus carries little sediment (Wright, 1996). Consequently, the Eocene limestones are either exposed, or thinly covered by sediments, both at the shoreline and on the adjacent shelf. The result of having limestone at or near the surface, exposed to weathering and dissolution by ground water, is a karst topography and an extremely irregular shoreline [Figure 3-3] (Hine et al., 1988; Davis et al., 1992).

Karst terrain exhibits a range of morphologic scales from small scale variations (centimeters to meters) to regional scale features (kilometers). In the Big Bend area, medium scale karst features are represented by tidal creeks, created by dissolution and enlargement of joint features in the underlying limestone, and islands, created in areas with less severe erosion of the surface limestone. Embayments associated with the larger streams of the area and marsh archipelagos in areas of higher elevation represent the largest scale of karst features (Davis et al., 1992).

Embayments are created by increased dissolution due to the presence of springs near the shoreline. These embayments provide a good habitat for development of oyster bioherms, with lower salinities, strong tidal flows and a rock substrate. These bioherms extend for several kilometers in a north-south orientation, forming barriers and creating depositional basins with distinct sedimentary processes. The oyster colonies have mostly died, however, and the bioherms are being subjected to severe erosion. The marsh archipelagos form on the limestone highs which lie between the embayments

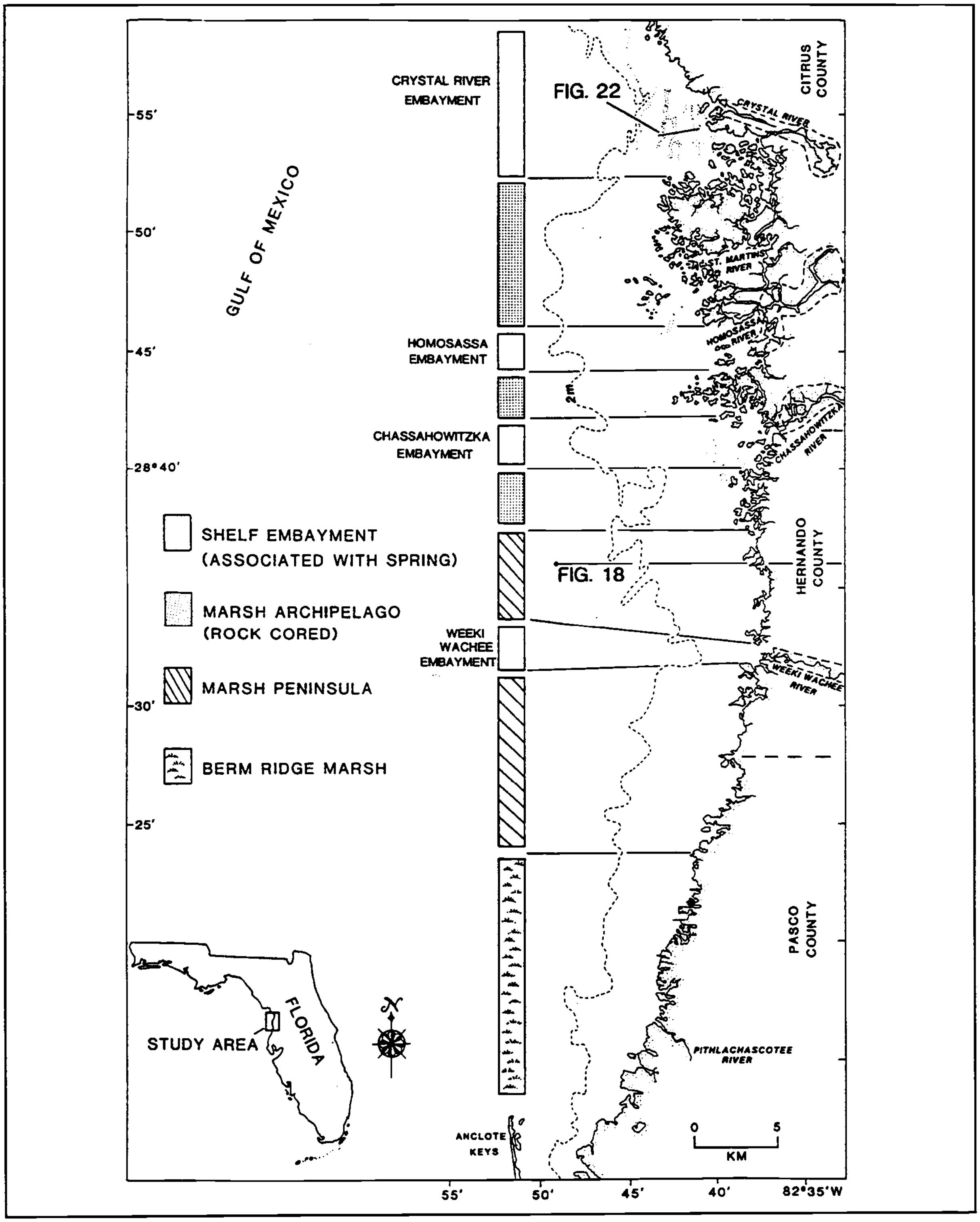

Figure 3-3. The shoreline of a portion of the Big Bend marshy coast, showing distribution of major morphologic elements (from Hine et al., 1988).

and are comprised of limestone-cored islands separated by creeks (Hine et al., 1988).

Along portions of this coast exposed to higher wave energies, quartz and skeletal sand berm-ridge shorelines border the slowly eroding marshes. During storms, and as sea-level rises, the sands from these beach segments overwash onto the marsh surface, creating a transgressive berm-ridge morphology (Hine et al., 1988).

3.2.2 Panhandle Barrier Chain

The panhandle barrier chain is made up of a series of spits and islands which extend from the eastern side of the Apalachicola River delta to the mouth of Mobile Bay (Figure 3-2). Included in this chain, from east to west, are Dog Island, St. George Island, St. Vincent Island, St. Joseph Spit, Crooked Island, Shell Island, Alligator Point peninsula (across St. Andrews Bay), Choctawhatchee peninsula, Santa Rosa Island, Perdido Key peninsula, and Mobile Point peninsula.

The most-studied portion of this chain is the eastern portion associated with the Apalachicola River delta and Cape San Blas (Donoghue, 1993; Otvos, 1992; Donoghue, 1992; Donoghue and Tanner, 1992; Arthur et al., 1989; Schnable and Goodell, 1968; Stewart and Gorsline, 1962). The Apalachicola River represents the largest river on the west coast of Florida and one of the only continuing sources of fine-grained sediments. Cape San Blas is a classic example of a cuspate foreland including a barrier spit (St. Joseph's Spit). To the east are three barrier islands (Dog Island, St. George Island, and St. Vincent Island), all with relatively complex developmental histories. Beach-dune ridges with varying orientations are found both on the barrier islands and on the mainland shoreline.

To the west of the Cape San Blas promontory the barrier spits, islands, and some mainland beach areas form a gently curving shoreline. These barriers are not unlike those of the Apalachicola delta, with their primary geomorphic features being beach-dune ridges. The shape of the barrier features vary from east to west, with only limited barrier-spit formation in the area closest to Cape San Blas and very long, narrow islands or attached barriers near the mouth of Mobile Bay. This region also contains four estuaries including St. Andrews Bay, Choctawhatchee Bay, Pensacola Bay, and Perdido Bay (Figure 3-2). The rivers in the area discharge their sediment loads into these bays, creating bayhead deltas.

3.3 Bathymetry

The bathymetry of the study area also exhibits a different nature across this coastal region, particularly in the general slope of the various areas (Figure 3-4). To the east, the slope of the shelf averages 1:3000 (Davis et al., 1992), increasing to the west of the cape to an average of 1:1000 (Parker et al., 1992). The shelf break in the study area has a gradual increase in slope over a wide area (Parker et al., 1992), but distinct changes in slope of the shelf occur around 60 m and 130 m (Ballard and Uchupi, 1970). One of the major bathymetric features within the study area is the De Soto Canyon, which is located near the western extent of the study area (Figure 3-4). The canyon is evident in the bathymetry from the

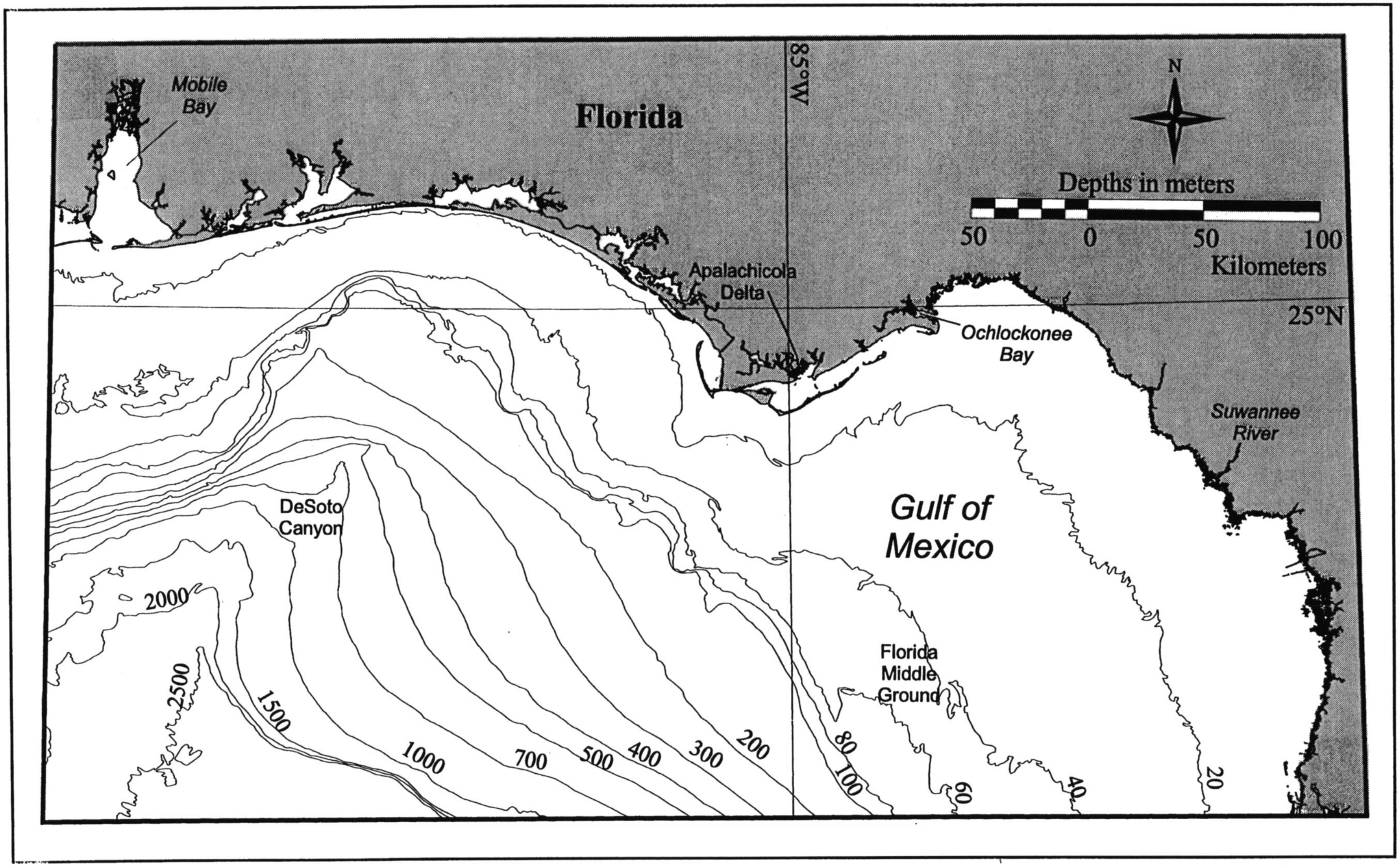

Figure 3-4. General bathymetry within the study area (depths in meters).

40 m contour seaward of Santa Rosa Island to greater than 1000 m. This section will describe the smaller-scale features present within the study area starting closest to shore and working seaward.

The bathymetry in the estuaries in the panhandle area is generally shallow and smooth. Depths reported for Apalachicola Bay range from 2 to 4 m [Figure 3-5] (Kofoed and Gorsline, 1963). In some areas of the estuaries oyster bioherms are present, creating linear ridges. Inlets which empty the estuaries range from about 2 m to 16 m in depth and have small (if any) ebb-tidal deltas, and moderate to large flood-tidal deltas associated with them (Hine et al., 1986).

Along the Big Bend coast, stream channels from spring-fed rivers are the landward extent of the study area. These are relatively narrow channels carved into the limestone, which may extend into the nearshore zone. The Homosassa River, to the south of the study area, flows out into the nearshore through a channel which has a relief of 5 m and a length of 9 km (Hine et al., 1988). Most of the stream channels in the area are not this large. The major exception to this generalization is the Suwannee River, which has its headwaters in the Okefenokee Swamp in southern Georgia. This river extends for over 100 km and drains a large area of the northern Florida peninsula. Although discharge is modest, there is a well-developed Holocene delta at its mouth (Wright, 1996).

The majority of the nearshore zone within the Big Bend area is typified by an irregular bottom with few significant areas of relief. There is no obvious surface pattern to this intricate bathymetry. These irregular features are due to a karst terrain being overlain by a thin and discontinuous veneer of Holocene sediments (Figure 3-6). Many of the larger karst features have been filled in by sediments, thereby masking some of the irregularities (Hine et al., 1988; Wright, 1995).

The Florida Middle Ground (FMG)(Figure 3-4) is one of the most significant features within the Big Bend area. Located about 110 km south-southwest of Apalachicola Bay, it consists of an area of 700 km^2 with depths from 30 to 50 m. It was originally described by Jordan (1962) as an "old river delta...flanked by embankments 50 feet high". The FMG is a coral reef system that consists to two parallel ridges trending north-northwest separated by a wide, flat central valley and a series of pinnacles to the south of the main ridges (Brooks and Doyle, 1991). The ridges are 12 to 15 meters in height with their crests at 30 meters water depth. Recent work by Mallinson, et al. (1996) indicates that the reef is built on a basement of karstic limestone which is thought to be Miocene in age. Growth of the FMG is believed to have begun during high sea-level stands of the Pleistocene. The development probably was triggered by a combination of a break in slope of the bathymetry and the convergence of circulation patterns and water masses from the Florida Loop current, the West Florida Estuarine Gyre, and Florida Bay Waters. This convergence in the circulation may allow transport and settling of Caribbean reefal organisms to the FMG (Brooks and Doyle, 1991). Another theory on the development of the FMG suggests that the reef developed on bathymetric highs of river banks formed during a sea-level low stand. The reef is thought to have developed during the subsequent sea-level rise (Donoghue, 1993; Jordan, 1962).

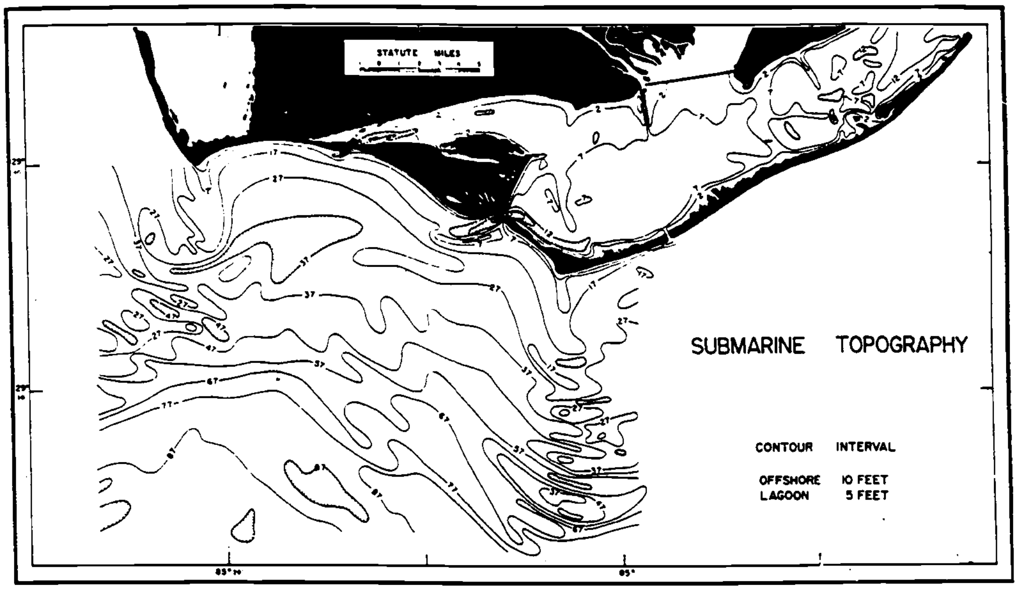

Figure 3-5. Contour map of Apalachicola Bay and the nearshore region (from Kofoed and Gorsline, 1963).

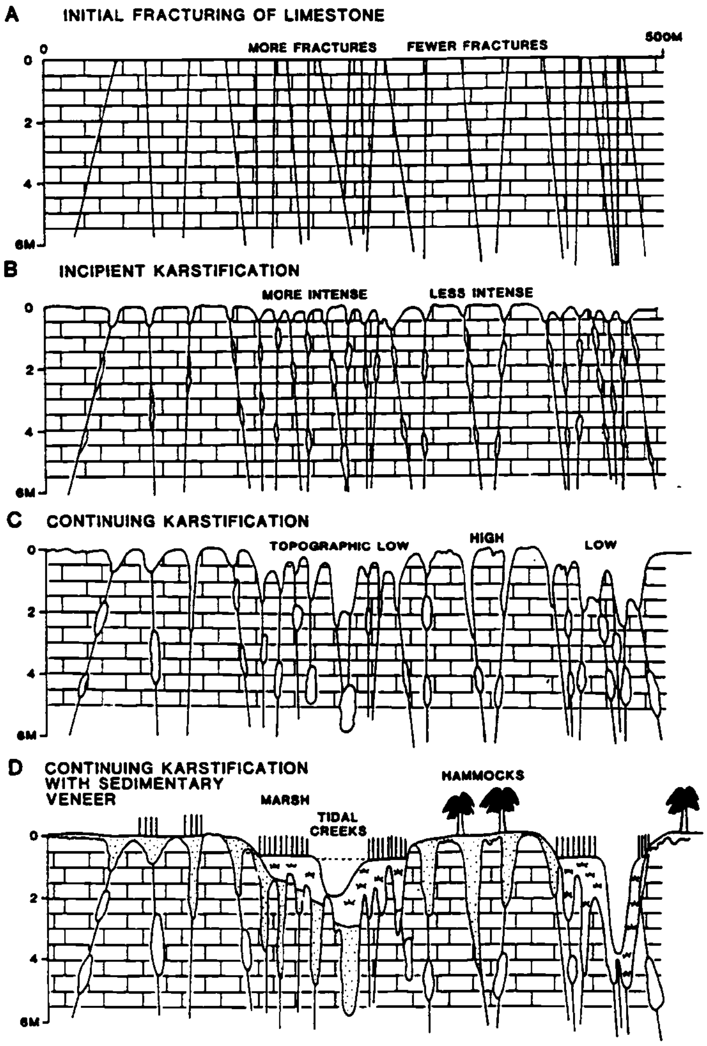

Figure 3-6. Formation of karst terrain. Panel D illustrates the present situation in the marshy coast (from Hine et al., 1988).

Within the panhandle portion of the study area, the nearshore zone is covered with linear ridges [Figure 3-7] (Hyne and Goodell, 1967; Parker et al., 1992), which are located around the 20 m isobath. Those ridges described by Parker et al. (1992) on the western side of the study area have an average height of 2 m, an average spacing of 0.5 km, and extend between 300 m and 2.65 km laterally.

A series of shoals extends 60 km offshore from Cape San Blas and is evident in the 60 m contour (Ballard and Uchupi, 1970). The genetic relationship between these shoals and the cape will be discussed in the section on Sediment Dynamics.

Ballard and Uchupi (1970) describe six ridge and valley complexes which straddle the 60 m contour, with the northernmost ridge occurring at the southern extent of the present study area. The slope of the shelf increases around the 60 m contour from an average slope of 0.5 $m \cdot km^{-1}$ to 2 $m \cdot km^{-1}$ (Gould and Stewart, 1956). A series of protuberances is evident in the 60 m contour westward from Cape San Blas, which correspond with the major rivers along the coast (Ballard and Uchupi, 1970). Another set of ridge and valley features lies across the 160 m contour. The northernmost ridge of this series lies directly south of Cape San Blas.

3.4 Sediments and Surface Geology

The distribution and composition of sediments in the study area demonstrates its transitional nature. The surface sediments of the study area can be divided into several zones (Doyle and Sparks, 1980; Figure 3-8). The portion of the study area west of Cape San Blas is dominated out to the 100 m contour by the relatively uniform MAFLA sand sheet. Within this same depth zone (0 to 100 m) to the east of Cape San Blas, three sedimentary facies are found, representing a transition from the nearshore quartz sand-dominated environment to the offshore carbonate sand environment. Below 100 m there is a transition to a fine-grained carbonate facies (Gould and Stewart, 1956; Doyle and Sparks, 1980).

Generally, the nearshore quartz-rich sands within the region are relatively uniform. The average mean grain size is 0.325 mm (medium sand) and varies from 0.137 mm to 0.796 mm between Mobile Bay and Apalachee Bay. The sediments are moderately well-sorted, indicated by the average standard deviation of the grain-size distribution of 0.79 Φ. The average amount of fines (silt and clay particles) present in the nearshore sands is about 2% (Arthur et al., 1989).

There is no correlation between depth and sediment grain size, but there is a correlation between the composition and grain size (Gould and Stewart, 1956). The coarse to medium sands are composed of algal and phosphoritic grains. Medium to fine sands are generally composed of quartz, shell, oolitic, algal, and foraminiferal grains.

Heavy minerals comprise an average of about 1% of the quartz-rich sediments within the study area (Gorsline, 1966; Birdsall, 1979) with few, if any, heavy minerals represented in the carbonate facies. The heavy mineral suite present in the study area includes magnetite, ilmenite, rutile,

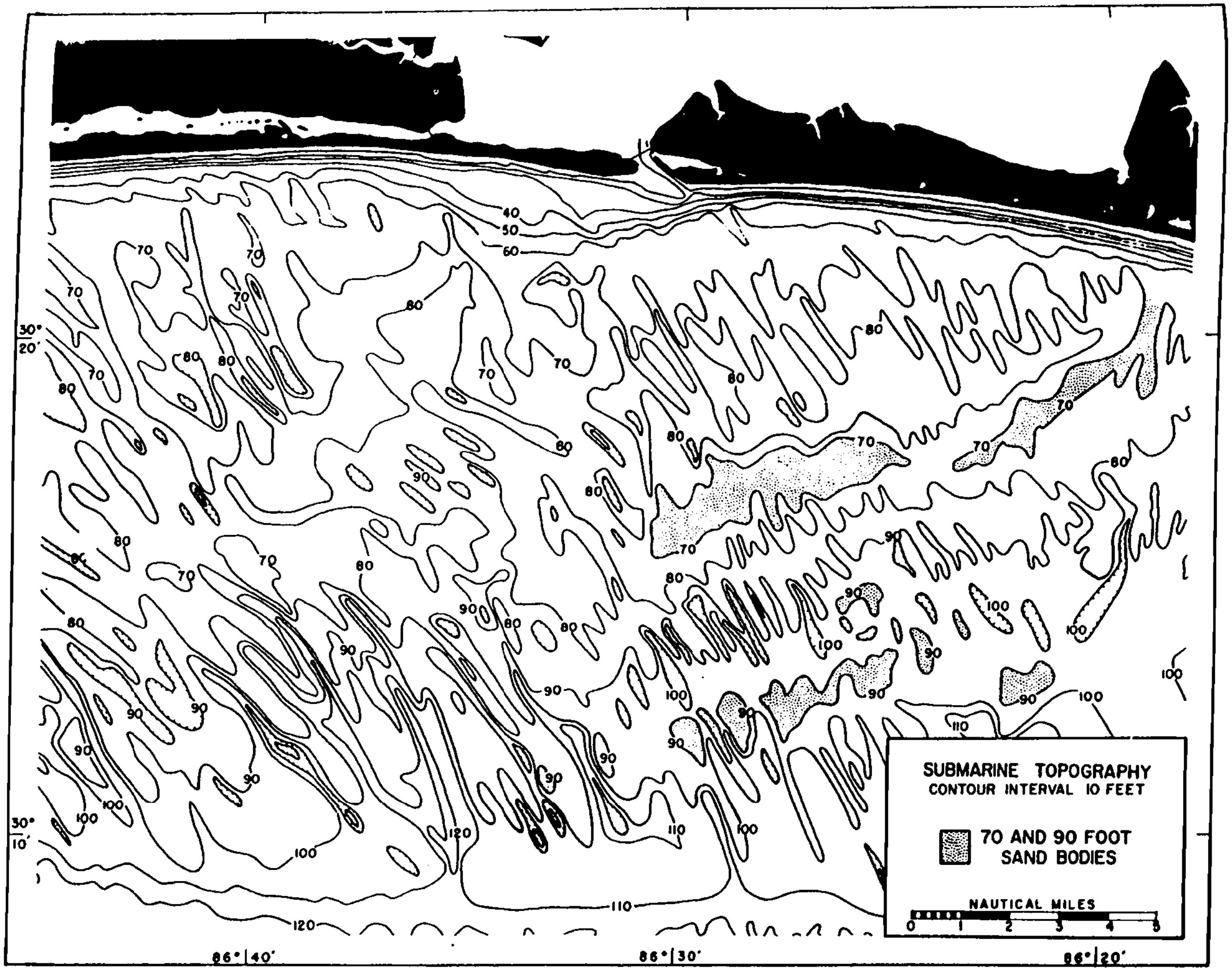

Figure 3-7. Linear features are shown in the bathymetry for the area off Choctawhatchee Bay between the 60 ft (18 m) and the 110 ft (33 m) contours (from Hyne and Goodell, 1967).

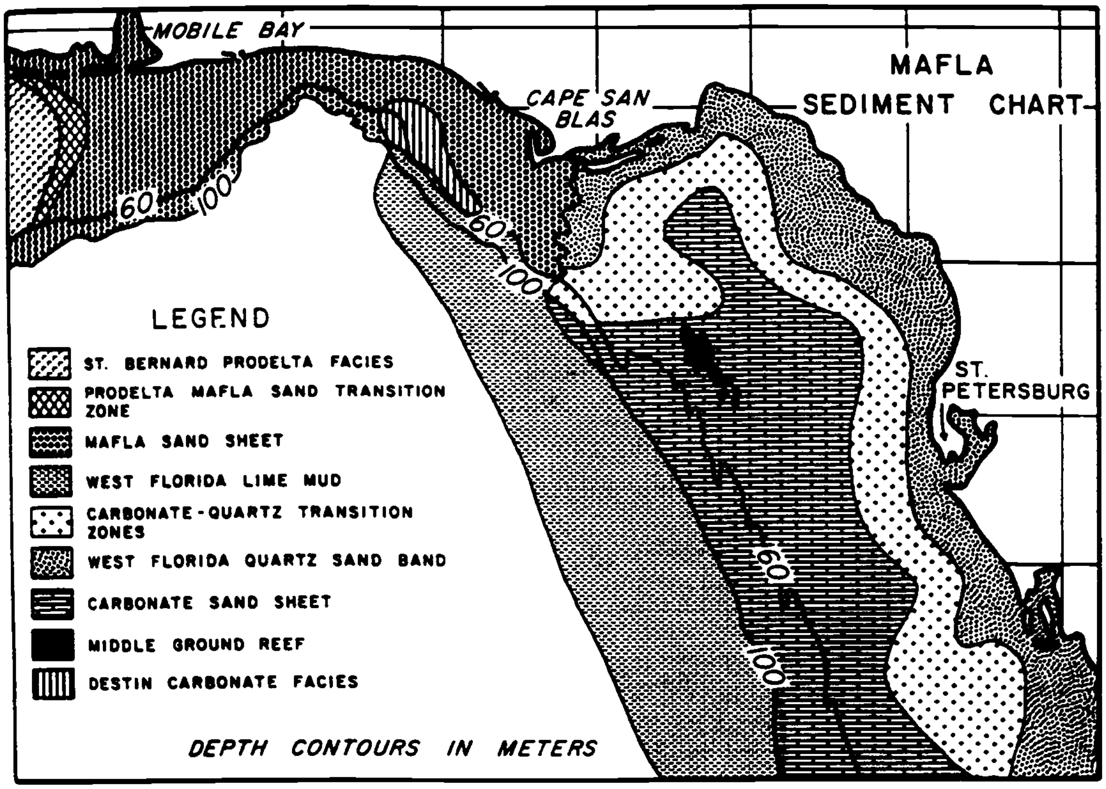

Figure 3-8. Sedimentary facies found in the study area (from Doyle and Sparks, 1980).

leucoxene, kyanite, staurolite, tourmaline, and zircon, with other minor minerals. This suite is similar to that found in sediments from Mississippi to Florida. Heavy mineral concentrations tend to be higher in the west than in the east, with elevated concentrations in the area of Cape San Blas (Arthur et al., 1986, 1989).

Clay minerals are present in small amounts within the sediments of the region. Clay mineralogy is dominated by smectite and kaolinite, with a small amount of illite. Smectite is characteristic of the Mississippi River drainage system and is the dominant clay mineral on the west side of the study area. East of Cape San Blas, kaolinite becomes more important, indicating some influence from the rivers of northwest Florida (Doyle and Sparks, 1980). Mazzullo and Peterson (1989) came to the same conclusions based on a study of the roundness and surface textures of the quartz silt grains of the study area.

The offshore carbonate sand facies is made up of several sediment types including broken shell, algal sand, ooid sand, and foraminiferal sand and silt (Gould and Stewart, 1956). The lime-mud facies that lies at the seaward limit of the entire study area is made up of foraminifera tests and coccoliths. Small amounts of terrestrial clays from the Mississippi River are found in these sediments, with higher amounts to the west due to the closer proximity to the river.

3.4.1 **Big Bend Area**

Little information has been found concerning the sedimentology of the Big Bend portion of the study area. Doyle and Sparks (1980) provides an investigation that covers the area with the most detail, but their study area does not extend to the shoreline or intertidal zone. Gould and Stewart (1956) provides an in-depth study of the central Florida west coast and a reconnaissance look at the panhandle area. Hine et al. (1988) provides a cursory description of the sediments in the shoreline and nearshore zone, but their study area lies to the south of this review's target area. The area examined by Arthur et al. (1986, 1989) extends into Apalachee Bay, which covers the western portion of the Big Bend area.

The marshy, intertidal zone of the Big Bend area is dominated by a veneer of peaty muds with numerous limestone outcrops. At the shoreline, some beaches of shelly sand are present. The nearshore zone is sediment-starved with only a thin veneer of shelly quartz sediments The area is marked by with over 75% carbonate (Doyle and Sparks, 1980). The distribution of the various sediment types is not uniform over wide areas. Rather, it is patchy, with numerous bedrock outcrops (Doyle and Sparks, 1980).

The surface sediment cover at the FMG is patchy. About 50 percent of the area covered by sediments and the remaining area is exposed reefal materials. The ridge crests are predominantly coarse to very coarse sands. Sediments generally become finer away from the ridges with fine and very fine sands found in depressions within the ridges as well as adjacent to the ridges. Carbonate content for sediments on and adjacent to the ridges ranges from 70% to 99%, lower values occurring away from the ridge crests. Fine grained quartz sand makes up the remainder of the sediments. Mollusc shell fragments are the dominant type of carbonate grain making up an average of 36% of the carbonate fraction. Additional major constituents of the carbonate fraction include barnacles (8%), benthic foraminifera (3-4%), annelid tubes (3-4%), bryozoa (3-4%), and coralline algae (2%). Barnacle fragments are a good sedimentological indicator because they are rare in the sediments of the surrounding shelf. Clay minerals make-up less than 5% of the sediments at the FMG. Hydrobiotite is the only clay mineral detected. (Brooks and Doyle, 1991).

The FMG reef flanks are dominated by large blocks of reef material broken from the reef structure. These blocks range from 1 to 3 meters on a side Few lithoclasts were found in the sediments surrounding the reef indicating that the reef material either breaks down to individual components, or they are not broken down into sand-sized particles(Brooks and Doyle, 1991).

3.4.2 Panhandle Area

Fine sediments predominate in the estuaries along the panhandle, deposited by the rivers that drain into them. Detailed investigations of the sediment distributions within the estuaries of the Florida panhandle are found in Kofoed and Gorsline (1963; Apalachicola Bay), Stewart and Gorsline (1962; St. Joseph Bay), and Boone (1973; Mobile Bay). Considering that similar sediment sources and mechanisms of deposition exist throughout the panhandle area, it is safe to extrapolate the nature of the remaining estuaries from these sources. Indeed, the descriptions of these estuaries are very similar.

Sediments within Apalachicola Bay are made up of sand and silt. The bay is surrounded by a margin of sandy beaches created through winnowing of fine sediments by the higher energy present at the shoreline. Looking toward the central portion of the bay, silt content increases until it is the dominant sediment texture at depths greater than about 2 m. Shell gravel and gravely sands are also found in the bay. Only small amounts of carbonate sediments are found in Apalachicola Bay, and they are concentrated in shoal areas where oyster reefs are common. Organic matter accounts for only 1 to 2% of the sediments by weight (Kofoed and Gorsline, 1963).

In contrast to the discontinuous sediment cover of the Big Bend area, a fairly continuous blanket of quartz sand extends from the shoreline to about 80 km offshore within the panhandle area (Gould and Stewart, 1956). Sediments generally contain less than 25% carbonate within this facies that

Doyle and Sparks (1980) call the MAFLA sand sheet. An exception to this is the Destin carbonate facies, an area of carbonate sands (>75% carbonate) off Panama City (Doyle and Sparks, 1980). To the west of Mobile Bay, the MAFLA sand sheet grades into the pro-delta and delta sediment of the Mississippi River (Coleman et al., 1991). Thin veneers of fine-grained sediments covering the sands of the inner shelf have been reported (Hyne and Goodell, 1967; Stauble and Warnke, 1970).

At a smaller scale there is variation in the sediments present within the area. Kofoed and Gorsline (1963) describe a basin in the area between the Cape San Blas and Cape St. George shoals that is dominated by fine sands and silts, which are transported to the basin from Apalachicola Bay. The shoals themselves contain coarser sands and shell gravel.

3.5 Sediment Dynamics

In general, the highest rate of sediment movement occurs along the coast where wind, waves, and tides directly influence the sediments. The variations in geomorphology and bathymetry result in varying levels of wave and tidal energy input. This varying energy leads to distinctly different processes within each of the two portions of the study area. Because of the very low wave energy, the marshy Big Bend coast tends to be tide-dominated, despite the small tidal range. The barrier/inlet coast tends to be wave-dominated, with a smaller tidal range and larger waves than the Big Bend area. Moving further offshore, the tidal forces and breaking waves play a decreasing role. Here, shelf currents play an increasing role in the movement of bottom sediments. This section will discuss the various mechanisms within the study area that influence the movement of sediments.

3.5.1 Coastal Sediment Transport

There are several sedimentary environments within the study area. These areas include rivers, deltas, estuaries, tidal inlets, beaches and salt marshes. Each of these environments has specific processes that affect the movement of sediments. The limestone substrate of the Big Bend area creates a very different environment from the unconsolidated sandy sediment/fluid interface of the Panhandle area.

3.5.1.1 Big Bend Area

The Big Bend area rivers drain an exposed limestone surface which erodes through dissolution and provides very little sediment input. This is one reason for the continued lack of sediment within this area. Sediment sources for this area are transported into the area from adjoining areas and carbonate producing organisms. Tanner (1960) indicates that this area is a "Zero" energy coast due to the wide, shallow, and gently sloping shelf, relatively low average breaker height, and limited tidal range. This designation is actually incorrect, although it is widely used. There have been many severe storms, including hurricanes, that have impacted this coast and that have caused substantial change (e.g., Goodbred and Hine, 1995). The lack of sediment is actually the most important factor in the absence of beaches, barriers, etc. along this coast. These conditions create a relatively stable area with limited sediment movement.

Much of the sediment movement in the area occurs during winter extratropical storms. During these storms, wind-generated tides can reach 225 cm with 190 cm waves, much greater than the average spring tides of 90 cm and winter significant wave heights of 45 cm. Under storm conditions, sand from the shoreline is transported into the marsh areas through overwash (Hine et al., 1988). In the shallow water areas the sediments are moved about, resulting in uncovering of some limestone features and blanketing of others.

Sediment transport in the marsh system occurs through a number of mechanisms. During storms, the high-wind tides provide a route by which sediment can be carried far up into the marshes. Suspended sediment is carried by the water as it flows up into tidal creeks and across the marsh surface, where it settles out as the flow velocity decreases around the marsh grasses (Frey and Basan, 1985; Leonard, 1994). Along the marsh borders, the marshes retreat as waves cut into the base of the marsh sediments and wash the sediments onto the marsh surface. Larger grain sizes are introduced into the marsh by this overwash process.

Most of the large sediment particles are skeletal in origin, with the majority of them being oyster fragments. It should also be noted that the abundant benthic community includes many filter feeders. These worms and bivalves ingest large amounts of suspended sediments and convert the fine particles to sand-sized pellets. These pellets are fairly cohesive and are difficult to transport. They comprise a large portion of the sediment in the Suwanee River delta.

The processes that created the karst features described previously are still active in the Big Bend in areas where springs are actively discharging in the nearshore region. These processes include surface dissolution from acidic pore waters from overlying marsh sediments, and regional dissolution due to mixing-zone undersaturation (Hine et al., 1988). A result of these processes of dissolution is the collapse of the limestone surface, creating sinkholes.

3.5.1.2 Panhandle Area

The coastal region in the western portion of the study area is a more diverse and dynamic place than the Big Bend coast. It resembles a typical coastal plain paralic system with well-developed fluvial/estuarine systems and barrier/inlet systems. The steeper inner shelf results in more sediment transport due to the increased energy.

Rivers in this area introduce some fine-grained sediments to the coastal zone. Most of these sediments are trapped in estuaries. As the velocity of the river flow decreases when entering the bay, the sediments settle out and form bayhead deltas within the enclosed bays. Only a fraction of this sediment is carried into the open Gulf. The Mobile River, one of the largest rivers in the area, discharges about 4×10^9 kg of sediment annually (Parker et al., 1992) into its bay, with only about 30% reaching the Gulf (Parker et al., 1992). The other rivers in the area provide negligible amount of sediment to the open Gulf.

The Apalachicola River carries an annual average of 1.5×10^9 kg of sediment (Donoghue, 1993). This sediment is mostly deposited as a delta which protrudes beyond the mainland coast into Apalachicola Bay, an estuary protected by a series of four barrier islands. This sediment volume seems small when compared to the 200×10^9 kg of sediment discharged annually by the Mississippi River. Donoghue (1993) indicates that the Apalachicola River is the only river in the eastern Gulf of Mexico which is annually discharging sufficient sediment to fill its estuary, considering the present rate of sea level rise. Estimates of the vertical accumulation rates for Apalachicola Bay average 8 $\mathrm{mm \cdot yr^{-1}}$, and the rate of progradation of the delta lobes averages 2.2 $\mathrm{m \cdot yr^{-1}}$ (Donoghue, 1993). A substantial part of this accumulation rate is due to the extensive oyster community filtering suspended sediment and producing pelleted mud.

The small amount of sediment from the estuaries that is transported to the open Gulf moves through tidal inlets. Depths of these tidal inlets range from about 2 m at the mouth of Choctowhatchee Bay to 16 m at West Pass, which empties Apalachicola Bay. In general these inlets lack well-developed ebb-tidal deltas because wave energy and longshore drift tend to transport any sediment carried by the tidal currents down the coast. Some fine-grained sediment is carried out onto the shoreface and shelf. Kofoed and Gorsline (1963) describe a basin area, lying between the tidal inlets that empty Apalachicola Bay, which contains deposits of silts and clays apparently discharged from those inlets. This is one route by which sediment is carried offshore from the shoreline to the continental shelf.

Longshore transport is one of the primary sediment transport mechanisms along the shoreline. Longshore transport occurs through the interaction of waves with the coastline. Gorsline (1966) indicates that there is a net longshore drift to the west within the panhandle area with transport rates increasing from 50,000 $\mathrm{m^3 \cdot yr^{-1}}$ just west of Cape San Blas to 150,000 $\mathrm{m^3 \cdot yr^{-1}}$ near Pensacola. Other researchers, examining specific portions of the panhandle, have come to the conclusion that there are actually a number of drift cells within the area, with little transfer between the cells (Stone et al., 1992; Stapor, 1971). Both schools of thought submit values for the volume of sediment transported along the coast each year that are within the same range as Gorsline (1966).

3.5.2 <u>Shoreface and Shelf</u>

Waves provide the primary mechanism for sediment transport along the shoreline. Further offshore, at a depth of about 10 m, direct movement of sediment by waves becomes less important and movement of sediment by shelf currents becomes more important. This area of transition is known as the shoreface. Within the Big Bend area this zone extends several kilometers from the shoreline. The limited energy and very gently sloping limestone surface provide a distinct contrast to the classic shoreface zone of terrigenous shelves.

Along the panhandle of Florida the shoreface extends to water depths of 15 to 18 m (Boone, 1973). This region is characterized by active and variable sediment transport created by the interaction of waves and currents. Four scales of bedforms are created by this transport: 1) wave-generated ripples that change position with the orientation of waves (Vause, 1959), 2) megaripples with spacing of 2 to 3 m, 3) sand waves with spacing on the order of 100 m, and 4) kilometer-scale sand ridges (Niedoroda et al., 1985).

The presence of a ridge and trough topography along the upper shelf provides an indicator of the sediment dynamics of this area. Parker et al. (1992) conclude that they represent large-scale bedforms and that they are genetically related to similar large-scale bedforms on other continental shelves due to their similar shapes, and to the textural distribution of sediments. Swift and Field (1981) postulate that the ridges on the north Atlantic shelf are formed as the shoreface retreats. It is also thought that they are produced by downwelling during storm flows (Niedoroda et al., 1985). Offshore-directed currents are created through the piling up of water at the shoreline by wind and waves. Sediment is eroded from the tops of the ridges by wave agitation and transported offshore by these currents. They demonstrate this by presenting an evolutionary succession of ridge forms extending from nearshore to offshore. Following Swift and Fields (1981) model, sediment is eroded from the onshore side of the ridges and deposited on the offshore side as storm related currents flow from onshore to offshore.

The primary sedimentary processes occurring further out onto the shelf, beyond all but hurricane wave influence, are deposition of pelagic sediments, slumping, and bioturbation. Foraminiferal oozes are deposited as pelagic organisms settle to the shelf floor. Sedimentation rates obtained from cores on the upper slope indicate accumulation as high as 20 cm per 1,000 years (Doyle and Holmes, 1985). These rates are an order of magnitude higher than deep-sea oozes of the same composition (Doyle and Holmes, 1985).

The De Soto Canyon is a bathymetric anomaly, and seems to be an anomaly of sediment accumulation as well, due to the large volume of sediments that have been deposited there throughout the Quaternary Period. Antoine (1972) speculates that there is some interaction between the bottom currents in the area and the shelf. He presents some erosional features on seismic reflection profiles that cross the canyon. Antoine concludes that since there are no rivers associated with the canyon, there must be some erosion by ocean currents.

The FMG also represents a bathymetric anomaly on an otherwise flat portion of the shelf. The dominant process that occurs on the ridges of the FMG is winnowing. This is indicated by the large size of grains and the thin layer of sediments found on the tops of the reef structures. Fine-grained sediments are being winnowed leaving the coarse grains made up mostly of mollusc shell fragments. Bathymetric control of the currents driving the winnowing process account for the patchy distribution of sediments in the FMG. The bathymetric highs show the largest grain sizes while the low lying central valley, which acts as a sediment sink, contains a larger percentage of fine-grained materials. Sediment accumulations within the low lying areas of the FMG are generally thicker than the surrounding shelf indicate that the reefs provide some sheltering from the currents that redistribute the sediments on the open shelf. The FMG acts to trap sediments thus reducing the off-shelf movement of sediments much like a shelf-edge reef. Sediment accumulation and reef growth at the FMG are insufficient to keep pace with rising sea-level, therefore it is currently being drowned (Brooks and Doyle, 1991).

3.6 Summary

The study area is located across a geologic and morphologic transitional area. Ochlockonee Bay is the divide between the Big Bend coast to the east and the panhandle area to the west. Geologically, the area represents the transition from a sediment-starved carbonate platform (the Florida Platform), represented in the Big Bend area, to the United States mainland terrigenous sedimentary system, with a large supply of sediments (the Gulf Coastal Plain), represented by the panhandle area.

The Big Bend coast is lined by marshes, with numerous tidal channels extending into them, built directly on the limestone surface. The tidal channels are formed by erosion along fractures in the limestone. The continental shelf is wide, with an irregular, low-gradient limestone surface with patchy sediment cover. These sediments are generally medium sands with quartz dominating the nearshore and carbonate sands becoming dominant offshore. Due to the low energy input to the area, the majority of sediment transport occurs during storm events. During these events, sediment is moved about on the shelf, erosion and overwash occur at the shoreline, and deposition occurs in the marshes. The area continues to be sediment-starved due to a lack of longshore drift into the area from neighboring regions and a lack of sediment-carrying rivers entering the area.

The panhandle coast is a smooth arcuate shoreline with a number of barrier islands, spits, and mainland sandy beaches. Several estuarine systems line the coast and effectively trap nearly all sediment currently being carried by rivers. Thus, the sediments of the open coast are comprised primarily of sands reworked from previous deposits present on the narrow shelf. These sands are relatively uniform medium sands with small amounts of heavy minerals, carbonate sediments, and clay. Their composition indicates that they were transported to the coast by local rivers from the Appalachian Mountains during times of lower sea level.

Increased wave energy in the panhandle area creates increased sediment transport. At the shoreline, overall sediment movement is generally to the west, but many reversals in the longshore drift exist along the coast, resulting in a compartmentalized coast with little net transport. On the shoreface and upper shelf, out to the 60 m contour, the sediment surface is irregular, with large scale bedforms. Several authors have interpreted these to indicate offshore transport of sediments during storm conditions.

Offshore of the 60 m contour, the distinction between the Big Bend and the panhandle coast becomes less apparent. Contours generally flow smoothly from the Big Bend area to the De Soto Canyon (the western edge of the study area). Overall, the energy input to the area is low. Carbonate sediments composed of foraminifera tests and coccoliths are the dominant outer shelf sediment.

Other features of interest within the study area include the De Soto Canyon, Cape San Blas, and the Florida Middle Ground. The De Soto Canyon is the western boundary of the present study area. The canyon represents a drowned ancient river valley that is in the process of being filled in by sedimentation. It is speculated that the feature is presently being maintained by ocean currents eroding the sediments (Antoine, 1972). Cape San Blas is a cuspate foreland that is prograding to the east and is experiencing rapid shoreline retreat on the south. A series of shoals extends from the cape offshore with some expression as deep as 60 m. The Florida Middle Ground is a coral reef system. The two primary ridges of the reef complex are 15 m high in depths of 30 to 50 m. The shallow portions support living coral reefs. Growth at the FMG is insufficient to keep up with the current rise of sea-level, thus the reefs are being drowned.

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Chapter 4 - THE CHEMICAL ENVIRONMENT

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4.1 Introduction

This review provides a summary of what is known about the major inputs of nutrients, metals and organics to the NEGOM study area, and the processes affecting them in the estuarine and nearshore regions. The study area has a low population density and therefore, problems associated with urbanization and industrialization are less than other areas in the Gulf of Mexico and along the Atlantic coast. This discussion will emphasize the literature from Pensacola Bay to the Suwanee River, starting with a general introduction to the physical, geological and biological setting, and emphasizing riverine inputs to this region. Some literature from Mobile Bay, Ala. and the blackwater Ogeechee River, Ga. is included to supplement information gaps. Three case studies are provided. The Suwanee River Basin is characterized by blackwater and spring-fed rivers, and has no major urban centers in the watershed; some agricultural inputs are present. The Chattahoochee-Flint-Apalachicola River system has urban inputs into the Chattahoochee and Flint Rivers, while the Apalachicola River basin has agricultural inputs. Bayou Texar is part of the Escambia/Pensacola Bay system, which has significant urban inputs.

4.1.1 Physical Setting and Processes

The northeastern Gulf of Mexico is subtropical with average air temperatures between 7-33°C, and average rainfall of 132-150 $\mathrm{cm \cdot yr^{-1}}$ (Livingston, 1984; Crane, 1986). Temperatures in the rivers, estuaries, and shallow coastal zone generally follow air temperature (see Chapter 2). Average January surface water temperature along the nearshore coast is 16°C, increasing offshore to 19.5°C, while July surface water temperature averages 30°C (NOAA, 1985). Salinity at the shelf break varies between 34-36.5 psu (Nowlin, 1972; Nowlin and Hubertz, 1972), while nearshore regions experience wider salinity variations, particularly in estuaries such as Apalachicola Bay that have significant riverine inputs. Circulation in the Gulf of Mexico is dominated by the Loop Current which brings water in through the Yucatan Straits, flows in a clockwise direction, and exits through the Florida Straits. In January, water also flows in a clockwise direction along the coast, while weaker flows are reversed in July (NOAA, 1985). Mixing between the central Gulf of Mexico and the shelf is limited except during upwelling along the shelf break (SAIC, 1988), meanders of Loop Current (Tester et al., 1993) or during winter storm passage (Dagg, 1988). In addition, hurricanes can greatly increase the exchange between shelf and offshore waters (Ichiye, 1972).

Numerous small rivers and streams discharge into the northeastern Gulf of Mexico, and from east to west include the Withlacoochee, Suwanee, Aucilla, Fenholloway, Econfina, Wacissa, Wakulla, Sopchoppy, Ochlockonee, St. Marks, the Chattahoochee-Flint-Apalachicola system, Choctawhatchee, Yellow and Escambia Rivers. Seasonal flow patterns depend on river type, with alluvial rivers having high flow in spring and summer and low flow during late summer and fall (Wharton et al., 1982). Blackwater rivers tend to respond to local precipitation while spring-fed rivers show little deviation over an annual cycle (Wharton et al., 1982). Spring-fed rivers include the St. Marks, Wakulla, Wacissa, and Suwanee. The highest river stages on the Suwanee usually occur after early spring rains, although extensive flooding occurs following hurricanes (Crane, 1986). Discharges range from less than 50 $m^3 \cdot s^{-1}$ by the Withlacoochee, Ochlockonee and Yellow Rivers, to 844 $m^3 \cdot s^{-1}$ from the Chattahoochee-Flint-Apalachicola river system and 100-300 $m^3 \cdot s^{-1}$ from the Suwanee, Choctawhatchee and Escambia Rivers (NOAA, 1985). Flow in the Chattohoochee-Flint-Apalachicola system is regulated by a dam which forms Lake Seminole. The channel is dredged to approximately 3 m to allow barge traffic upriver.

Estuarine systems along the coast vary from lagoonal systems like Apalachicola Bay, that have relatively long retention times, to more open systems like Apalachee Bay. The major estuaries are the Suwanee estuary, Apalachee Bay, Apalachicola Bay, Choctawhatchee Bay and Pensacola Bay. Embayments with insignificant freshwater inputs are St. Joseph Bay and St Andrews Bay. The astronomical tide range is between 0.4-1 meter and can be either diurnal or semidiurnal. Apalachicola Bay is a transition zone between the diurnal tides of west Florida and the semidiurnal tides of the Florida Peninsula (Livingston, 1984). Typical wind-forcing associated with fronts can lead to water elevation changes on the order of 20-30 cm (Marmer, 1954; Livingston, 1983). Hurricanes can cause severe tidal surges. For example, Hurricane Agnes, in 1972, caused a two-meter tide surge in Apalachicola Bay (Livingston et al., 1978).

4.1.2 Geologic Setting

Formation of the modern coast occurred following sea level rise between 4-6 thousand years ago (Arthur et al., 1986; Donoghue and White, 1995). The northeastern Gulf of Mexico can be divided into two segments, with the dividing line at Cape San Blas. The western section is dominated by quartz sands and fine clays such as smectite and kaolinite (Doyle and Sparks, 1980), while the eastern section is characterized by a limestone platform with overlying carbonate deposits (Doyle and Sparks, 1980; NOAA, 1985). Shelf sediments are a mixture of quartz sands inshore, carbonate sands offshore, and patches of shell, calcareous algae, and coral fragments (Doyle and Sparks, 1980).

Watersheds of the northeastern Gulf of Mexico are part of either the northern physiographic zone or the central physiographic zone (Crane, 1986). The northern physiographic zone, located along the Florida Panhandle, is a broad continuous upland region stretching inland from the coast Crane, 1986). The central physiographic zone, which occurs in north central Florida, is comprised of a series of ridges and broad valleys (Crane, 1986). Karst features such as sinkholes, dry stream courses, underground rivers, springs, caves and abandoned spring heads are common through the central zone (Crane, 1986). The three-dimensional, subterranean network characteristic of the central zone has been formed from the dissolution of carbonate bedrock by organic and carbonic acids continually enlarging open spaces and fractures in the rock.

The continental shelf off the northern zone is a depositional environment. Weathering of the crystalline rocks of the Southern Appalachians occurred during the Pleistocene when sea level was lower and was the source for most of the inner shelf sediments (Arthur et al., 1986; Donoghue and Greenfield, 1991; Donoghue, 1992). These sediments have been reworked, and offshore sediment sources have also contributed to their makeup (Arthur et al., 1986). Modern delta formation by the Apalachicola River began about six thousand years ago, with development of barrier islands beginning about four thousand years ago (Donoghue and White, 1995). Currently, the delta is prograding and filling in Apalachicola Bay (Donoghue, 1992). The Apalachicola River carries 1.5 million metric tons of sediment per year on average (Donoghue and Greenfield, 1991), although much of the upstream sediment transport has been reduced following construction of the Jim Woodruff Dam in 1954 (Arthur et al., 1986). The Chattahoochee-Flint-Apalachicola River system is typical of fluvial systems which flow onto marginal seas like the Gulf of Mexico (Donoghue, 1992; Nittrouer and Wright, 1994).

Hurricanes have a strong impact on barrier islands, which experience washovers and sand loss during these storms. Increased development on barrier islands makes them vulnerable to significant economic losses from damage by hurricanes. In addition, the construction of marinas, jetties and other structures on barrier islands or along the coast can alter circulation and sediment transport, and increase pollution.

4.1.3 **Biological Setting**

The mild, subtropical climate supports rich and diverse biotic communities. Blackwater rivers, swamps, saltmarshes, barrier island, soft bottom, seagrass and coral reef communities make up the mosaic of the northeastern Gulf of Mexico. Swamp forests and bottomland hardwoods are widespread along the rivers. Cypress and tupelo are the major species in the swamps. There are extensive saltmarshes along the coast, which are dominated by *Spartina alterniflora* and *Juncus romerianus*. Net aboveground annual production in saltmarshes around Apalachicola Bay is about 500 $g \cdot m^{-2} \cdot yr^{-1}$ (Livingston, 1984; 1985). Seagrass beds are widespread in the shallow (water depth <4.5 m) nearshore region and can comprise between 5-25% of the open water area (Deegan et al., 1986; Iverson and Bittaker, 1986). The major seagrass species are *Thalassia testudinum, Syringodium filiforme, Halodule wrightii, Halophila decipiens, Halophila engelmanni and Ruppia maritima* (Iverson and Bittaker, 1986). Seagrasses in this region are limited by light (Iverson and Bittaker, 1986). Seagrass production ranges from 320-500 $g \cdot m^{-2} \cdot yr^{-1}$ in Apalachicola Bay (Livingston, 1984; 1985). Small and scattered coral reefs occur offshore in 40-100m of water (NOAA, 1985). Phytoplankton production in the bays and estuaries ranges from 6 $\mu g\ C \cdot l^{-1} \cdot hr^{-1}$ off the Econfina River to 40 $\mu g\ C \cdot l^{-1} \cdot hr^{-1}$ in Apalachicola Bay (Myers and Iverson, 1981). Within Apalachicola Bay, integrated daily production of phytoplankton ranges between 63-1700 mg $C \cdot m^{-2} \cdot d^{-1}$ (Livingston, 1984). Diversity of the vegetation on barrier islands is high, although production may be limited by nutrient-poor beach sands (Barbour et al., 1987).

In contrast to most of the U.S. coastal zone, human population density in much of the study area is low. Although 80% of the coastal counties have less than 64 people per square mile (NOAA, 1985), the coastal counties of western Florida are projected to have some of the largest population increases in the entire Gulf of Mexico over the next two decades (NOAA, 1990). The major cities are Pensacola and Panama City. The total population for the counties bordering the Gulf of Mexico (Escambia to Citrus) was nearly 900,000 in 1993. Agriculture, particularly forest production, is important, while manufacturing and other industrial activities are a small percentage of the regional economy. As a result, inputs of nutrients, heavy metals, and organics to the coast are low, although there are some point sources which will be discussed below.

4.2 Chemical Properties and Distributions

4.2.1 Shelf Characteristics

The northeastern Gulf of Mexico can be divided into 2 provinces based on salinity: estuarine and shelf. Estuaries are strongly influenced by freshwater inputs and seasonal discharge characteristics. The shelf is influenced by excursions of the Loop Current, which bring Gulf gyre water onto the shelf. Gulf gyre water is typically very oligotrophic. Nutrient concentrations have typical oceanic distributions with slightly higher concentrations nearshore (0.5-0.8 μM NO_3^- , 0.2-0.4 μM DIP, 4.7-13.4 μM DSi) than in the surface gyre (0.2 μM NO_3^- , 0.1 μM DIP, 3.2 μM DSi), and high concentrations at depth (25-35 μM NO_3^- , 1.5-2 μM DIP, 20-30 μM DSi) (El-Sayed et al., 1972; SAIC, 1988). Chlorophyll-a concentrations on the shelf and in the gyre were usually low. Chlorophyll-*a* concentrations nearshore were about 0.41 $\mu g \cdot l^{-1}$, about 0.2 $\mu g \cdot l^{-1}$ on the shelf and about 0.1 $\mu g \cdot l^{-1}$ in the Gulf gyre (El-Sayed et al., 1972; NOAA, 1985; SAIC, 1988). Primary and secondary production on the shelf are enhanced following storm-induced upwelling and vertical overturning that mixed nutrient-rich bottom water with surface shelf water (El-Sayed et al., 1972; Dagg, 1988). Just south of the study area on the west Florida shelf, dissolved oxygen concentrations in November 1983 were about 6.4 $mg \cdot l^{-1}$ at the surface and about 4 $mg \cdot l^{-1}$ in bottom water (SAIC, 1988).

Most studies of the shelf have focused on nutrient and carbon cycling in the Mississippi River plume off Louisiana. Riverine discharge onto the west Florida shelf is an order of magnitude lower than the Mississippi/ Atchafalaya discharge, so nutrient and contaminant inputs, as well as the salinity regime, are radically different. Because the basic conditions on the shelf are so different, most of the research in water chemistry from the Mississippi shelf is not very applicable to the west Florida shelf. For example, a recent study of bacterial dynamics in the Gulf of Mexico found no consistent differences in bacterial numbers, biomass or production between the west Florida shelf, slope and offshore stations, although readings at a series of stations in the plume of the Mississippi River were very different from those measured at eastern Gulf of Mexico stations (Pomeroy et al., 1995). In addition, their experiments suggested that bacterial production on the west Florida shelf was limited by phosphorus and potentially carbon.

4.2.2 Dissolved and Particulate Constituents

Most of the numerous small rivers entering the northeastern Gulf of Mexico can be characterized as either alluvial or blackwater. Each type has different physical and chemical characteristics, particularly with respect to inorganic ion and organic carbon concentrations. Alluvial rivers, such as the Apalachicola, have dissolved inorganic ion concentrations about an order of magnitude greater than total organic carbon concentrations (Wharton et al., 1982). Most of the dissolved inorganic ions come from minerals, leached from parent rocks and soils in the headwaters during weathering, and include chloride, sodium, potassium, magnesium, calcium and phosphate. Atmospheric deposition is not a significant source of these inorganic ions (Winchester and Fu, 1992). In contrast, blackwater rivers, such as the Suwanee, are rich in refractory organic compounds such as fulvic and humic acids and generally have a 1:1 ratio of dissolved inorganics to total organic carbon (Wharton et al., 1982). Precipitation dominates the water budgets of these rivers, which can have pH values as low as 4, although this varies depending on flow (Wharton et al., 1982). A comparison of dissolved inorganic ion and organic concentrations for the Apalachicola and Suwanee Rivers is given in Table 4-1.

4.2.3 Humics

Humic compounds are very complex and have varying composition. Humics from acidic waters have a larger percent of oxygen and lower percent carbon content than humics from neutral pH waters (Chlou et al., 1987). Humic compounds from the Suwanee River have been widely used to examine the properties of organic compounds.(Chlou et al., 1987; Serkiz and Perdue, 1990; Thorn and Mikita, 1992; Schlautman and Morgan, 1993). Humics or refractory dissolved organic carbon (DOC) can be a significant source of carbon monoxide (CO) by photochemical oxidation (Valentine and Zepp, 1993). Although CO is not a greenhouse gas, it is highly reactive with other trace gases in the atmosphere (Valentine and Zepp, 1993). Carbon monoxide production rates were much higher in the Suwanee River, which had higher DOC concentrations than either the Intracoastal Waterway or a nearshore island (Valentine and Zepp, 1993).

4.2.4 Decomposition and the Formation of Biogenic Gases

This section provides a brief overview of the major microbial processes responsible for the decomposition of organic matter, emphasizing those processes, such as methanogensis and denitrification, that result in the formation of biogenic gases.

Decomposition of organic matter has not been measured in the northeastern Gulf of Mexico, except for methanogenesis in a freshwater marsh and denitrification in Ocklockonee Bay. Decomposition of organic matter usually occurs through a sequence of electron acceptors. These electron acceptors, in order from highest energy yields to lowest, are oxygen, nitrate, oxidized manganese, oxidized iron, sulfate, and carbon dioxide (methanogenesis). The greatest energy yields are obtained from oxygen (Fenchel and Blackburn, 1979), and aerobic respiration dominates in the water column in moist (not saturated) soils, and at the sediment-water interface. In sediments and saturated soils below the aerobic zone, other pathways dominate. Dissimlatory nitrate reduction to either nitrogen gas (denitrification) or ammonium usually represents between 8-37% of organic matter mineralized (Sorensen, 1987) and is most important when nitrate concentrations are high, or when nitrate production by nitrification is high. Iron and manganese reduction occur after nitrate is depleted. Sulfate reduction is most important in marine systems because sulfate

Table 4-1. Chemical characterization of Apalachicola and Suwannee Rivers. Values for constituents in $mg \cdot l^{-1}$ (except for specific conductance, which is in $\mu mho \cdot cm^{-1}$, and pH, which is in standard units).

Constituent	**Apalachicola**[a]	**Suwannee**[b]
Stream water:		
pH	5.7 - 7.8	3.9 - 7.3
Total dissolved solids	56 - 97	
Specific conductance	68 - 127	155
$CaCO_3$ alkalinity	20 - 49	
chloride	2.9 - 4.7	
sulfate	1.6 - 7.2	
calcium	6.1 - 29	
DO	4.8 - 11.4	
TOC	6 - 9	
DOC	6.7	30 - 80
TN	0.7 - 1.0	
DON	0.6	
TP	0.02 - 0.10	
SPM		0.85
Groundwater:		
pH	4.6 - 7.5	4.3 - 9.0
Total dissolved solids	18 - 34	
Specific conductance	10 - 46	200 - 500
$CaCO_3$ alkalinity	-	100 - 300
chloride	1.9 - 3.6	0.6 - 10
sulfate	-	0 - 50
calcium	37	0.1 - 494
DO	-	
TOC	4.8 - 5.5	
DOC	4 - 9	
TN	0.3 - 0.8	
DON	0.1 - 0.2	
TP	0.01 - 0.20	

[a] from Elder and Mattraw, 1982; Mattraw and Elder, 1984; Elder, 1985; and Winchester and Fu, 1992

[b] from Crane, 1986

concentrations are generally much higher than in freshwater systems (mM vs. µM concentrations). Hydrogen sulfide, produced during sulfate reduction, is toxic to many organisms and complexes with metals such as iron, manganese, cadmium, mercury and other trace metals. Methanogenesis is normally the major route of decomposition in freshwater systems. Recent interest in methane has increased because it is a greenhouse gas.

4.2.4.1 <u>Methane</u>

Wetlands are extremely active sites of mineralization, including methane production, and may be responsible for about 40% of the atmospheric methane flux (Cicerone and Oremland, 1988). Plants enhance methanogenesis by increasing organic carbon concentrations at the surface and at depth in the root zone, or rhizosphere (Chanton and Dacey, 1991). Organic carbon collects at the surface by accumulation of aboveground biomass or the trapping of allochthonous material within grassbeds. Release of DOC by plant roots and rhizomes, as well as turnover of belowground biomass, contribute to organic carbon pools in the rhizosphere. Emergent plants can also serve as conduits transporting methane from the rhizosphere (where it is produced) to the atmosphere through plant lacunae (Chanton and Dacey, 1991; Chanton et al., 1993). Because of this enhanced methane transport, vegetated sediments generally have lower methane concentrations and higher dinitrogen gas concentrations than unvegetated sediments (Chanton and Dacey, 1991). Rates of methanogenesis in freshwater marshes are much higher than methane emission to the atmosphere because of methane oxidation (Chanton and Dacey, 1991; Epp and Chanton, 1993). In addition, methane oxidation can be enhanced by plant processes (Chanton and Dacey, 1991; Epp and Chanton, 1993). Emergent and submersed plants can release significant amounts of oxygen from roots and rhizomes, which can enhance aerobic processes such as methane oxidation (Caffrey and Kemp, 1991; Chanton and Dacey, 1991). Between 23-90% of methane produced was oxidized during greenhouse and field experiments with several freshwater marsh species from the northeastern Gulf of Mexico (Epp and Chanton, 1993). A complex interaction of many factors such as water level, temperature, nutrient loading, species composition, organic matter content of sediments, and sediment oxygen consumption controls methane emission from wetlands (Chanton et al., 1993). Although the significance of all of these interactions is not understood, one unifying relationship is that methane emission is about 3% of net ecosystem production over a wide range of biomes, from the Arctic tundra to subtropical freshwater marshes in the Everglades (Whiting and Chanton, 1992).

Methane production has not been measured in northeastern Gulf of Mexico swamp forests or bottomland hardwoods. However, research in a similar area in Georgia (Ogeechee River) suggested that swamp forests and flooded bottomland hardwood forests were regions of enhanced methane flux to the atmosphere. Pulliam (1993) found that methane flux only occurred at flooded sites when temperatures exceeded 15°C and that about half of the methane produced was oxidized in the water. Methanogenesis in the Ogeechee River basin represented about 20% of the total soil respiration at flooded sites, but only a small fraction (4%) of the total respiration of aboveground leaf litter within the basin as a whole (Pulliam, 1993). A model of methane emission within the basin suggested that changes in precipitation which affect floodplain inundation and temperature have the most significant effects on methane emission (Pulliam and Meyer, 1992).

4.2.4.2 Nitrous Oxide

Nitrous oxide formation occurs during nitrate reduction and nitrification, so any increase in rates of these nitrogen transformations results in increased nitrous oxide production (Vitousek and Matson, 1993). Nitrous oxide fluxes are generally a very small percentage of denitrification rates, usually <6%, and often less than 1% (Seitzinger, 1988). Nitrous oxide fluxes in Ochlockonee Bay were 0.02-0.05 μmol $N \cdot m^{-2} \cdot hr^{-1}$ and were less than 0.1% of denitrification rates (Seitzinger, 1987). Enhanced rates of

N_2O flux have been measured from eutrophic sediments (Seitzinger, 1988) and from agricultural soils (Vitousek and Matson, 1993).

4.2.4.3 Organic Sulfur Compounds

Dimethyl sulfide (DMS) and other organic sulfur compounds in the atmosphere may affect climate and atmospheric chemistry, so the contribution of oceanic fluxes of DMS and other organic sulfur compounds have been measured (Kiene, 1993). DMS and dimethyl-sulfonium proprionate (DMSP), a precursor of DMS, are produced by marine algae – both macroalgae, such as *Ulva*, and phytoplankton, particularly *prymnesiophytes* (Iverson et al., 1989). DMSP appears to be an osmotic regulatory agent (Iverson et al., 1989). Total concentration of DMS in the water column was greatest in the freshwater reaches of the estuary where chlorophyll-a concentrations were highest (Iverson et al., 1989). However, DMS concentrations normalized to chlorophyll-a increased with increasing salinity and were higher in Ochlockonee Bay than in either Chesapeake or Delaware Bays (Iverson et al., 1989). Their results suggested that DMS production per unit of chlorophyll-a was higher in more saline regions. An oxidation product of DMS, dimethylsulfoxide (DMSO), was highly variable in rainwater samples collected from Mobile Bay, perhaps due to a combination of industrial sources (paper mills) and biogenic sources such as wetlands and coastal waters (Kiene and Gerard, 1994).

4.2.5 Trace Metals

Trace metal concentrations within the northeastern Gulf of Mexico are generally low (Windom et al., 1989; Hanson et al., 1993). Metal inputs are less than 0.018 $g \cdot m^{-2} \cdot yr^{-1}$ from most of the Gulf counties, and less than 0.175 $g \cdot m^{-2} \cdot yr^{-1}$ for the four more urbanized Gulf counties (NOAA, 1985). Metal concentrations in the environment are strongly dependent on the source, whether physical and chemical weathering of silicate minerals and metal oxides, or anthropogenic inputs (Windom et al., 1989). Grain size distribution also has an important role in determining metal concentrations in the environment because most metals are associated with clays, the fine-grained fraction (Windom et al., 1989). Organic matter content and metals such as cadmium and mercury are often positively correlated (Lindberg and Harriss, 1974; Windom et al., 1989; Hanson et al., 1993). Organic-metal complexes are particularly important in controlling the availability of metals in the environment (Bruland, 1983; Cross and Sunda, 1985; Kennish, 1992). In sediments, complexation with hydrogen sulfide or polysulfates can lead to high porewater concentrations of metals such as mercury (Lindberg and Harriss, 1974). In addition, pH and the oxidation-reduction condition (redox) of sediments has a significant affect on availability of metals, which varies depending on the metal (Brannon et al., 1977; Gambrell et al., 1980). In Mobile Bay sediments, soluble levels of mercury were highest under either acid (pH=5), reduced conditions or near neutral (pH=8), oxidized conditions; the greatest recovery of radioisotope-labeled lead occurred under oxidizing conditions, while most of the zinc seemed to be associated with colloidal hydrous oxides (Gambrell et al., 1980). The role of acid volatile sulfide pools in binding the cationic metals cadmium, copper, lead, nickel, and zinc has been demonstrated by DiToro et al. (1991).

The geology of Florida is dominated by carbonate minerals, which are relatively metal-poor. However, metal composition normalized to aluminum concentrations from estuarine and marine sediments is similar to the crustal composition except for arsenic, copper, manganese and nickel (Windom et al., 1989). Arsenic-rich phosphate deposits in the region are probably the source for higher arsenic levels, while copper, manganese and nickel are depleted in coastal plain soils (Windom et al., 1989). Although trace metal concentrations are generally low throughout this region, lead and zinc in Pensacola Bay were elevated (between 15-50 ppm lead and between 60-280 ppm zinc), particularly near the port facility (Windom et al., 1989). An analysis of trace metal contamination along Atlantic and Gulf coasts also indicated metal contamination in Pensacola Bay, although the level and frequency of occurrence was far less than heavily polluted sites like Baltimore and Boston harbors (Hanson et al., 1993).

Much of these metal data and the organic contaminant data presented in a later section were collected as part of the NOAA National Status and Trends Program (NS & T). This program was designed to examine spatial and temporal trends of contaminants in sediments and bivalves (oysters and mussels). Measurements were made over five years (1986-1990) at sites along the Atlantic, Gulf and Pacific coasts. Median metal concentrations in oysters from the Status and Trend sites for the first three years of the program are listed in Table 4-2 (Presley et al., 1990). Choctawhatchee Bay had much higher concentrations of silver, cadmium, iron, mercury, lead, and zinc than the median value for the Gulf of Mexico. Arsenic concentrations were high in St. Andrew, Apalachicola and Suwannee estuary oysters compared to the median Gulf of Mexico value, while mercury in oysters from the Suwannee estuary was higher than the median Gulf of Mexico value. In Pensacola Bay, mercury and selenium were higher than median Gulf values. Biota can be significantly affected by point sources of metals, particularly epibiota on chromated-copper-arsenate (CCA) treated wood, which was developed to replace creosote and PCP treated wood (Weis et al., 1993). Algae (*Ceramium* sp.) collected from a CCA wood dock in Pensacola Bay had significantly higher concentrations of copper and arsenic than algae growing on rocks from the region (Weis et al., 1993). Barnacles (*Balanus eburneus*) and mussels (*Brachidontes recurvis*) also had significantly higher levels of these contaminants, particularly from an area with restricted circulation, than animals from the reference site (Weis et al., 1993).

Trace metal concentrations have also been measured in freshwater sediments and biota from the Apalachicola River. Metal concentrations in Apalachicola River sediments and clam tissues were generally low, and there were no significant point sources of metals within the basin (Elder and Mattraw, 1984). Silver, mercury and molybdenum were below detection limits (0.2, 1.0, 2.0 ppm respectively) in sediments, while the lowest detectable concentrations were for cadmium (3 ppm); arsenic, beryllium, tin and iron were also low (≤5 ppm), while chromium, copper, lead, cobalt, nickel and zinc were intermediate (≤70 ppm) and high for manganese (1200 ppm) (Elder and Mattraw, 1984). Metal concentrations in the clam, *Corbicula manilensis,* were generally lower than sediment concentrations, about 0.1 ppm for arsenic, cadmium, lead and mercury, about 0.6 ppm for chromium, 8.7 ppm for copper and 20 ppm for manganese and zinc (Elder and Mattraw, 1984).

Table 4-2. Median trace metal concentrations in oyster for Gulf of Mexico and major embayments of the northeastern Gulf of Mexico (Presley et al., 1990) and clams (*Corbicula manilensis*) from Apalachicola River (Elder and Mattraw, 1984). Values were calculated for each embayment (6 stations) over the three year sampling period (1986-1988), except for values from Apalachicola River which are median values from 1979-80. All values are ppm dry weight except for mercury which is ppb dry weight (Presley et al., 1990).

Trace Metal	**Gulf of Mexico**	**Pensacola Bay**	**Choctawhatchee Bay**	**St. Andrew Bay**	**Apalachicola Bay**	**Apalachicola River**	**Suwannee River**
Silver	1.9	1.4	3.4	0.7	1.8	n.d.	1.0
Arsenic	8.0	7.3	5.6	13.5	10.8	<0.1	17
Cadmium	3.8	3.0	5.2	0.9	2.6	<0.1	3.3
Chromium	0.45	0.5	0.5	0.5	0.4	0.6	0.5
Copper	123	44	95	87	62.5	8.7	34
Iron	252	345	368	100	322	n.d	225
Mercury	95	115	350	51	105	<100	190
Manganese	12.5	14	12.2	6.9	14.1	20	13.5
Nickel	1.6	1.7	1.2	2.0	1.3	n.d.	0.7
Lead	0.4	0.4	1.5	0.7	0.2	0.1	0.3
Selenium	2.8	4.1	5.8	0.8	2.4	n.d.	1.3
Tin		<0.2	<0.2	0.2	0.2	n.d.	<0.2
Zinc	1730	1550	3550	710	525	20	1400

n.d. - no data

Elder and Mattraw (1984) observed no trends upstream or downstream, nor was there any obvious seasonal pattern, although the seasonal sampling was limited. Winger et al. (1985) also measured concentrations of metals in the Apalachicola River in a variety of organisms (mayflies, *Corbicula*, threadfin shad, channel catfish, largemouth bass, water snakes and little green herons) and found generally low to moderate concentrations of cadmium, mercury, arsenic, selenium and lead. In contrast to the study by Elder and Mattraw (1984), Winger et al. (1985) found higher concentrations below the confluence of the Apalachicola and Chipola Rivers than in the upper Apalachicola River. The highest cadmium and lead concentrations, 0.63-1.01 ppm and 0.31-1.13 ppm, respectively, occurred in mayflies (Winger et al., 1985). Arsenic levels were highest in threadfin shad and *Corbicula*, 1.07 ppm and 1.75 ppm respectively (Winger et al., 1985). Selenium concentrations were highest in the eggs from the largemouth bass and channel catfish, 0.67-1.03 ppm and 0.78-2.08 ppm, respectively, while mercury concentrations were highest in the herons, 0.67 ppm (Winger et al., 1985). Metal concentrations higher than 0.5 ppm may be harmful (Winger et al., 1985). The higher concentrations found in the downstream portion of the Apalachicola River may be a result of contamination from battery salvage operations in the upper Chipola River basin (Winger et al., 1985).

The NOAA NS&T Program has defined high metal concentrations as those greater than the geometric mean of the national data set for any single chemical plus one standard deviation. Sediment samples collected in the northeastern Gulf containing "high" NS&T metal concentrations were found in: Apalachicola Bay (As), Panama City (Zn), St. Andrew Bay (Hg, Pb), Choctawhatchee Bay (As, Pb), and Pensacola Bay (As) (NOAA, 1991). The Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) sampled estuaries in the GOM from 1991-1994. EMAP statistical summaries for the Louisanian Province have characterized sediments as contaminated if concentrations exceed effects thresholds established by Long and Morgan (1990) and Long et al. (1995) known as Effects Range Low (ER-L) and Effects Range Median (ER-M). These thresholds are based upon a national data set containing measured sediment chemical concentrations and associated biological effects that include a wide range of biological responses, e.g., toxicity, pathology, community composition, diversity. ER-L values are those below which 10% of the effects data occur and ER-M values are those above which 50% of the effects data occur. Biological effects are not expected below ER-L concentrations and they are predicted at concentrations above the ER-M. None of the metals measured in 1991-1993 exceeded the respective ER-M values. The following ER-L values were exceeded: 1991 for Cr (<1% of the area of western Florida estuaries) and Hg (15% of the estuarine area) Summers et al., 1993); 1992 for Cr, Ni, Pb, and Sn in 7% of the estuatine area (Macauley et al., 1994); and in 1993 for As (30% area), Cr (20% area), Hg (7% area), and Ni (23% area) (Macauley et al., 1995).

Not surprisingly, metal contamination is greatest in areas with the greatest human activity (Hanson et al., 1993). The effect of metals on organisms depends on factors such as which metal is considered, the concentration, chemical speciation, the species of organism and the developmental stage of the organism. Although a variety of factors affect metal toxicity, in general, there is a trend of decreasing toxicity from mercury to cadmium, copper, zinc, nickel, lead, chromium, aluminum, and cobalt (Kennish, 1992). The results of these studies in the northeastern Gulf of Mexico show that trace metals distributions are very different between sediments and biota. The survey of metals in sediments suggests that trace metal distributions generally follow the distribution expected from weathering of crustal rocks, except in Pensacola Bay (Windom et al., 1989; Hanson et al., 1993). In contrast, trace metal concentrations in oysters show numerous "hot spots," particularly in Choctawhatchee Bay, that are not correlated with either sediment concentrations or known anthropogenic inputs (Presley et al., 1990).

4.2.6 Radioactivity

Significant anthropogenic sources of radioactive isotopes do not occur in the northeastern Gulf. Uranium concentrations are often enhanced in phosphate rocks and subsequent radioactive decay leads to the production of radon and radium (Crane, 1986; Cowart and Burnett, 1994). Average activity of radium in rivers ranges between 10-30 $\mathrm{dpm \cdot 100L^{-1}}$ (Burnett et al., 1990). However, radium and radon activities are very high in groundwater and spring fed rivers such as the Suwanee ($^{226}\mathrm{Ra} = 210\ \mathrm{dpm \cdot 100L^{-1}}$) (Crane, 1986). West Florida shelf waters have much higher radium and radon activities than other coastal waters (Fanning et al., 1982). Radium sources in estuarine and marine waters can come from dissolved radium in river water, radium desorbed from particles at the freshwater/estuarine interface and sediments (Fanning et al., 1982; Cowart and Burnett, 1994). Measurements of radium from the Suwanee River showed higher downstream activities than upstream, as well as a significant variability over a seasonal cycle (Burnett et al., 1990). This study suggests that discharge from submarine springs and seeps may be a significant source of radium to offshore waters, as well as a potential source of other constituents such as nutrients. Thus, radium and radon may be useful tracers of groundwater and provide useful information about groundwater inputs to estuarine and marine environments. Although groundwater inputs to estuaries of the northeastern Gulf of Mexico have not been measured, many studies over the last 10 to 15 years have shown that groundwater can be a significant input of nutrients and freshwater to many estuarine systems (Valiela et al., 1992).

4.2.7 Organic Contaminants

Organic contaminants include a wide range of compounds with varying composition, reactivity, and sources. Polyaromatic hydrocarbons (PAH) and chlorinated hydrocarbons (such as DDT and PCBs) will be the major focus, although information about heterocycles (nitrogen, carbon, and sulfur) and organophosphates (pesticides) will be included as available. In general, inputs of organic contaminants are low in the northeastern Gulf of Mexico.

Lipid biomarkers have been used extensively to trace sources of organic matter in sediments (Sever et al., 1972; Palacas, 1972). Organisms are significant sources of hydrocarbons in the environment (Kennish, 1992). There are several basic kinds of hydrocarbons: alkanes, which are linear or branched chains of carbons with single carbon-carbon bonds; alkenes, which are also linear or branched chains of carbons, with one or more double bonds between carbon atoms; cycloalkanes, are rings with single bonds between the carbon atoms; and aromatics, which are rings with double bonds (benzene being the simplest example). Biogenic hydrocarbons have a distinctly different combination of compounds than do petroleum hydrocarbons. Biogenic hydrocarbons are characterized by: alkanes with an odd number of carbons greater than even-numbered alkanes (CPI); few cycloalkanes and, when present, are 1-3 chain rings; simple aromatics with on 1-2 alkyl group substitutions; while alkenes are very common (Kennish, 1992). The alkane, C17, is a hydrocarbon that is often found in blue-green algae (Sever et al., 1972). Other biomarker ratios such as pristane/*n*-C17, *n*-C18/phytane and pristane/phytane are useful for determining the likely source of the hydrocarbons. High pristane/*n*-C17 ratios are characteristic of bacteria, and some algal species, although low ratios have been found from other benthic algae and phytoplankton samples (Palacas et al., 1972). Concentrations of coprostanol, which is a biomarker indicative of anthropogenic inputs from sewage or livestock, were less than the average for the whole Gulf of Mexico (51 sites) at 6 of the 7 sites in the northeastern Gulf of Mexico, with the higher than average coprostanol value occurring in St. Andrew Bay (Wade et al., 1988).

4.2.7.1 Hydrocarbons

Hydrocarbon concentrations in Choctawhatchee sediments ranged from 6-50 ppm in organic-poor sands (0.15% organic carbon) to 60-470 ppm in organic-rich mud (3.6% organic carbon) and 240-930 ppm in muddy bayou sediments (Palacas et al., 1972). Pristane:*n*-C17 ratios were high and CPI (odd:even ratio) was low in the sandy sediments, suggesting a marine source, while the high CPI in the muddy sediments indicated that terrestrial plants were the likely source (Palacas et al., 1972). There was no indication of hydrocarbon pollution in any of the samples. Hydrocarbon concentrations in the west Florida shelf sediments ranged between 1.5 and 4.1 ppm, and decreased with increasing water depth (Gearing et al., 1976; Lytle and Lytle,, 1976). Low molecular weight alkanes (*n*-C17 and C18), which are the main constituents of marine algae, dominated the hydrocarbon signal (Gearing et al., 1976; Lytle and Lytle, 1976). Sediments along most of the eastern portion of the Florida shelf had pristane/phytane ratios suggestive of marine organisms, while sediments off of the Apalachicola River and further west had signatures more typical of inputs from terrigenous organic material and petroleum (Gearing et al., 1976).

Polyaromatic hydrocarbons (PAHs) are a complex class of hydrocarbons that are hydrophobic, but rapidly sorb to organic particles. Concentrations of PAHs in estuarine and marine environments are generally highest in sediments, lowest in the water column and intermediate in the biota (Kennish ,1992). In the northeastern Gulf of Mexico, inputs of PAHs from the watersheds are less than 0.09 $g \cdot m^{-2} \cdot yr^{-1}$ from most of the coastal counties (NOAA, 1985). Mean PAH in sediments from 51 Status and Trend sites throughout whole Gulf is 0.5 ppm, with a range of <0.005 (limit of detection), to 36.7 ppm (Wade et al., 1988). Based on the ratio of phenanthrene:anthracene, Wade et al. (1988) suggested that the source of the PAH was probably not fresh petroleum but may have been weathered petroleum. Sediment PAH concentrations measured by NOAA NS&T exceeded the "high" values in Panama City, St. Andrew Bay, and Choctawatchee Bay (NOAA, 1991, O'Connor and Ehler, 1991). EPA's EMAP detected exceedences of total PAH ER-L values of 4,000 ppb in 5% of the area of western Florida estuaries in 1991 (Summers et al., 1993) and 14% of the estuarine area in 1992

(Macauley et al., 1994), while PAHs were not elevated in 1993 samples (Macauley et al., 1995).

PAH concentrations in oysters were 0.5 ppm, with a range of <0.02 (limit of detection), to 18.6 ppm throughout the whole Gulf with similar phenanthrene:anthracene ratios (Wade et al., 1988). PAH body burden at 5 stations along the northeastern Gulf of Mexico ranged between 0.02-13.3 ppm over a four-year interval (Wilson et al., 1992; Jackson et al., 1994). The highest concentrations (0.9-13.3 ppm) consistently occurred in St. Andrew Bay oysters, while the lowest concentrations (0.04-0.4 ppm) generally occurred at Cedar Key (Wade and Sericano,1989; Wilson et al., 1992). Median values of PAH concentrations in oysters from the major embayments over a five-year interval were 46 ppb for the Suwannee, 57 ppb for Apalachicola Bay, 1800 ppb for St Andrew Bay, 429 ppb for Choctawhatchee Bay, and 197 ppb for Pensacola Bay (Jackson et al., 1994). One potential source for these high PAH concentrations in St Andrew Bay was a minor oil spill (<10,000 gallons) in the 1970's (NOAA, 1985).

No oil development in the Florida coastal zone is currently allowed, so direct local inputs associated with oil field production are not a problem in Florida. However, new fields are rapidly being developed in Mobile Bay and the Alabama shelf (Hagar, 1985; McCabe, 1985; Mancini et al., 1984). Successful oil exploration in the Mobile Bay region has led to speculation that significant oil and gas reserves may exist in comparable geologic formations off of Florida (Hagar, 1985).

Pensacola Bay is the site of a long term (over 80 years) significant anthropogenic input of PAHs from a creosote wood treatment plant, which is now a Super Fund site (Elder and Dresler, 1988). Creosote is a complex mixture of polyaromatic hydrocarbons, phenols, and nitrogen heterocycles, although PAHs comprise about 90% of the total (Elder and Dresler, 1988). Groundwater and stream sediments near the site are highly contaminated with a variety of PAHs (Table 4-3) including naphthalene at 200 ppb and anthracene at 140,000 ppb (Rostad and Periera, 1987; Elder and Dresler, 1988). Water samples from the stream and estuary near the plant, as well as surficial sediment samples, had no detectable concentrations of PAHs (Elder and Dresler, 1988). Oyster drills (*Thais haemastoma*) and oysters (*Crassostrea virginica*) near the creosote site accumulated phenanthrene, fluoranthene and pyrene, while oysters also accumulated benzo[a]anthracene and chrysene; neither accumulated naphthalene (Elder and Dresler, 1988). The effect of PAHs on organisms depends on chemical structure, molecular weight, the organism, how easily the compound can be metabolized, and the intermediate breakdown compounds (Kennish, 1992). Low molecular weight PAHs often cause acute toxicity, but are not usually carcinogenic (Kennish, 1992). On the other hand, high molecular weight PAHs are not as toxic, but are often carcinogenic, mutagenic or teratogenic (Kennish, 1992). PAHs can become carcinogenic or mutagenic after being partially metabolized by organisms (Kennish, 1992). Toxicity tests of the groundwater, streamwater and ultrafiltered groundwater from this site all caused a toxic or teratogenic response in newly spawned inland silversides (*Menidia beryllina*) [Middaugh et al., 1991]. However, when groundwater, streamwater and ultrafiltered groundwater were diluted by 10:1 and 100:1, embryos in the diluted ultrafiltered groundwater survived with a greater than 90% hatching rate and most of the larvae appeared normal, while the other

Table 4-3. Concentrations of polyaromatic hydrocarbons found in snails (*Thais haemostoma*), Pensacola Bay sediments and inflowing stream sediments from creosote-contaminated Super Fund site. Concentrations in $\mu g \cdot kg^{-1}$ (detection limit 40 $\mu g \cdot kg^{-1}$ for sediments).

Compound	**Stream Sediment**[a]	**Pensacola Bay Sediment**[a]	**Snail**[b]
di-n-butyl phthalate	<40 - 2,000	<40 - 2,900	n.a.[c]
naphthalene	200 - 300	<40	n.a.[c]
phenanthrene	<40 - 12,000	<40	65.6 - 194
fluoranthene	17,000 - 62,000	<40 - 190	25.9 - 60.8
pyrene	11,000 - 32,000	<40 - 160	22.7 - 40.4
benzoanthracene	5,000 - 15,000	<40 - 75	n.a.[c]
chrysene	7,000 - 10,000	<40 - 100	n.a.[c]
acenaphthene	5,000 - 19,000	<40	2.06 - 8.08
fluorene	3,000 - 32,000	<40	1.34 - 6.28
anthracene	3,000 - 140,000	<40	9.03 - 24.7

[a] from Elder and Dresler, 1988

[b] from Rostad and Pereira, 1987

[c] n.a. - data not available

treatments showed a teratogenic or toxic response (Middaugh et al., 1991). Although relatively low concentrations of PAH were found in the water, sediments, or biota of the Pensacola Bay estuary, even these concentrations may have a deleterious effect on biota (Middaugh et al., 1991).

Distributions of particular creosote-derived compounds are determined by factors such as solubility and susceptibility to degradation, as well as physical and hydrologic factors such as sediment resuspension and increased flushing during storm events (Elder and Dresler, 1988). The phenolic and heterocyclic components of creosote are rapidly and effectively biodegraded, as are many of the PAHs (Elder and Dresler, 1988). Elder and Dresler (1988, p. 127) described 5 characteristics that determined the likelihood of a contaminant being bioaccumulated:

- "resistance to biodegradation;
- resistance to chemical transformation reactions such as photochemical oxidation;
- capacity to be transported rather than deposited in non-mobile forms;
- bioavailability, or capacity to be incorporated into tissues of the organism;
- resistance to depuration, or tendency to remain in tissues of the organism."

For PAHs, the number of rings and characteristics such as n-octonal/water partition coefficients may be useful diagnostics of bioaccumulation in the absence of direct experiments (Rostad and Periera, 1987; Elder and Dresler, 1988; Wade et al., 1988; Farrington, 1989).

4.2.7.2 Chlorinated Organics and Organophosphates

Organochlorines bind to suspended matter and are soluble in lipids (Nimmo et al., 1971a), often accumulating in fatty tissues of organisms at 10^2-10^4 times the ambient concentrations (Kennish, 1992). These properties have a significant effect on their distribution in the environment. Common examples of organochlorines include the pesticide DDT and degradation products, DDE and DDD; dieldrin; chlordane; and PCBs. For the 51 Status and Trend sites throughout the Gulf of Mexico, the DDT average was 6.19 and 44 ppb in sediments and oysters, respectively (Wade et al., 1988). A similar trend of higher accumulation in oysters than in sediments occurred for PCBs (9.84 ppb sediment, 172 ppb oyster) and a variety of chlorinated hydrocarbons (chlordane 0.5 ppb sediment, 20.7 ppb oyster) (Wade et al., 1988). Sediment DDT concentrations measured by NOAA exceeded the NS&T "high values in Panama City, St. Andrew Bay, and Choctawatchee Bay (NOAA, 1991). EMAP detected exceedences of the following pesticides and their areal extent in western Florida estuaries: 1991 for chloradane (1%), dieldrin (2%), endrin (1%), and DDE (1%)(Summers et al., 1993); 1992 for dieldrin (32%)(Macauley et al., 1994); and 1993 for chloradane (8%), dieldrin (28%), endrin (12%) (Macauley et al., 1995).

Measurements of DDT-R (DDT, DDE, DDD), PCB and Mirex in sediment and biota from Lake Seminole (Apalachicola River headwaters) and Apalachicola Bay over a four-year interval (1972-1976) showed rapid declines after the first year of sampling (Livingston et al., 1978). By 1974, concentrations had dropped to 34 ppb DDT and 55 ppb PCB in *Rangia cuneata*, 10-14 ppb DDT-R and 32-39 ppb PCB in *Callinectes sapidus*. In contrast, a later study (1978) of organochlorine insecticides and PCBs found higher concentrations in a variety of organisms in Apalachicola River than did this previous study (Winger et al., 1985). Organochlorine insecticides and PCB concentrations were measured in the Apalachicola River in mayflies, *Corbicula,* threadfin shad, channel catfish, largemouth bass, water snakes and little green herons, and were generally higher in animals from the upstream stations compared to those at downstream stations (Winger et al., 1985). DDT residue concentrations were highest in eggs from largemouth bass, water snakes and herons, 1.86 $\mu g \cdot g^{-1}$, 1.01 $\mu g \cdot g^{-1}$ and 1.1 $\mu g \cdot g^{-1}$, respectively, while PCB concentrations were high in herons, largemouth bass and eggs from largemouth bass, 1.72 $\mu g \cdot g^{-1}$, 1.4 $\mu g \cdot g^{-1}$ and 1.7 $\mu g \cdot g^{-1}$. Herons, largemouth bass eggs and channel catfish had the highest concentrations of toxaphene, 1.28 $\mu g \cdot g^{-1}$, 0.83 $\mu g \cdot g^{-1}$ and 0.8 $\mu g \cdot g^{-1}$, respectively. Concentrations of contaminants were generally higher in higher trophic levels. Winger et al. (1985) concluded that organic contaminants in the Apalachicola River biota are higher than recommended levels proposed by the National Academy of Science. Another study was conducted in 1979-1980 and sediments, particulate detritus and clam (*Corbicula manilensis*) tissues from the Apalachicola River were analyzed for a series of organochlorine pesticides (aldrin, chlordane, DDD, DDE, DDT, dieldrin, endosulfan, endrin, heptachlor, heptachlor epoxide, lindane, methoxychlor, mirex, perthan, strobane, toxaphene), organophosphate pesticides (diazinon, ethyl parathion, ethyl trithion, methyl parathion, methyl trithion, ethion, malathion), chlorinated phenoxy acid herbicides (silvex; 2,4-D; 2,4-DP; 2,4,5-T) and polychlorinated biphenyls (PCBs). These organic contaminants were either undetectable or present at concentrations less than 20 ppb (Elder and Mattraw, 1984). Only chlordane, PCB, DDD and DDE were above detection limits (0.1 ppb) in fine-grained sediments (Table 4-4). Organic concentrations in detritus were generally higher than in sediments, particularly chlordane, DDD, DDE, dieldrin and PCB. Highest concentrations of organic contaminants were found in clam tissues. Elders and Mattraw (1984) observed some temporal variability in organic contaminants, although the resolution of their sampling program was not fine enough to determine a seasonal pattern. They also observed that chlordane and PCB concentrations in clam tissues generally decreased downriver, although concentrations at the headwaters were highly variable. They concluded that nonpoint discharges were the major source of organic contaminants to the Apalachicola River.

Table 4-4. Median concentrations of organic contaminants in Apalachicola River sediments, detritus and whole body tissue from the clam, *Corbicula manilensis*, tissue in ppb (Elder and Mattraw, 1984).

Compound	**Sediment**	**Detritus**	**Clam**
chlordane	<1.0	6.9	21.0
DDD	0.4	2.3	8.0
DDE	1.3	2.5	18.0
DDT	<0.1	<0.1	3.0
dieldrin	<0.1	0.5	2.0
heptachlor epoxide	<0.1	<0.1	0.3
PCB	1.0	2.1	21.0

Herbicides, organophosphorus insecticides, aldrin, heptachlor, lindane, mirex, perthan, methoxychlor were below detection limits (<0.1 ppb) in all samples. Endrin, endosulfan, strobane and toxaphene were below detection limits (<0.1, <0.1, <1, <10 ppb respectively) from all of sediment and detritus samples and from over half of clam samples.

PCBs, specifically Arochlor 1254, have been a serious contaminant in Escambia Bay following its accidental release from a chemical plant in 1969 (Nimmo et al., 1971a). Shortly after the release, water samples near the plant had Arochlor concentrations of 274 ppb. These declined to less than 5 ppb in the following months, and by 1974 only trace amounts could be detected, or concentrations were below detection limits (Wilson and Forester, 1978). In the Escambia River near the plant outfall, sediment concentrations were generally higher (about 486 ppm) than water concentrations, although the sediment concentrations from further downstream were lower, and decreased from 78 ppm in 1970 to about 1 ppm by 1972 (Nimmo et al., 1975; Wilson and Forester, 1978). In December 1971, Arochlor 1254 concentrations in Escambia Bay waters ranged from nondetectable (<0.03 ppb) to 8.6 ppb, while sediment concentrations ranged from nondetectable (10 ppb) to 30 ppm (Nimmo et al., 1975). Arochlor concentrations varied depending on sediment type, with higher concentrations in the silty compared to sandy sediments (Nimmo et al., 1971a).

Significant concentrations of Arochlor were measured in a variety of invertebrates following the spill: 14 ppm in several shrimp, *Penaeus* spp., and 0.45-1.5 ppm in fiddler crabs, *Uca* spp. (Nimmo et al., 1971a). A long term study of oyster populations in Escambia Bay showed that whole body concentrations decreased over time, from 2.5 ppm to between 0.1-0.5 ppm after 7 years (Wilson and Forester, 1978). Wilson and Forester (1978) observed a strong seasonal variation in Arochlor concentrations with higher concentrations during spawning when lipid contents are highest in oysters. No detectable Arochlor concentrations were measured in *Spartina* or *Zostera*, while concentrations were significant in higher trophic levels; even shrimp from Pensacola Bay, about 35 km away, had significant concentrations (Nimmo et al., 1975). In contrast, Arochlor was not detected in shrimp collected from the adjacent Perdido or Choctawhatchee Bays (Nimmo et al., 1975).

Toxicity tests were done on shrimp collected from Pensacola and Tampa Bays, and several other organisms common to the area. Arochlor 1254 was toxic to juvenile shrimp, causing 51% mortality after 15 days exposure to 1 ppb (Nimmo et al., 1971b). Shrimp seemed to be affected during molting, although adults were not as susceptible as juveniles (Nimmo et al., 1971b). Arochlor also reduced the growth of ciliates and caused mortality and/or histopathological changes in shrimp, oysters and spot at 1 ppb concentrations (Nimmo et al., 1975). PCBs are very stable and persistent compounds, with relatively slow degradation rates compared to other organic contaminants (Kennish, 1992). Bacteria can degrade PCBs but the rate depends on the degree of chlorination (more chlorines, less degradation) and the position of the chlorine (Kennish, 1992). PCBs tend to bioaccumulate and are not easily metabolized. The estimated half-life of these compounds in estuarine and marine environments is 8-15 years (Kennish, 1992).

4.2.7.3 Pulp Mill Effluents

A number of pulp mills operate within the drainage basin of the northeastern Gulf of Mexico (NOAA, 1985). Effluent from pulp mills is a complex mixture of organic acids, polythionates, lignins, sulfides and inorganic compounds (Zimmerman and Livingston, 1976). Chlorinated organic compounds are a significant fraction of the Kraft process pulp mill effluent, which appears to consist of a chlorinated thiolignin (30%) and other high molecular weight chlorinated lignin compounds (70%) (Watts and Locke, 1993). In the 1970's, discharge of relatively untreated effluent from Kraft process pulp mills into freshwater and estuaries led to low dissolved oxygen concentrations, increased turbidity and color in the water column and a reduction in seagrass and macroalgal biomass (Zimmerman and Livingston, 1976). Improvements in mill operations led to improved water quality (particularly dissolved oxygen) and water color, and a partial recovery of the seagrass beds (Livingston 1980). Discharge of chlorinated organic compounds continues to this day and is of local concern because discharge from the mill is the predominant source of the water to the Fenholloway River. Effluent from the mill has been implicated as the source of contamination of residential drinking water wells in the region (Watts and Locke, 1993). A Kraft process pulp mill also discharges into St. Andrew Bay (Grady, 1981), although no published studies of the effects of this effluent on St. Andrew Bay were identified.

4.2.8 Case Studies

4.2.8.1 Chattahoochee-Flint-Apalachicola River and Apalachicola Bay

The Chattahoochee-Flint-Apalachicola River system is the largest river system in the northeastern Gulf of Mexico. The watershed is 50,800 km^2 and drains parts of Georgia, Alabama and Florida. The headwaters of the Apalachicola river begin at the Jim Woodruff Dam, where the Chattahoochee and Flint Rivers join. There are 16 other lock and dam structures on these two rivers. The Apalachicola River is 170 km long and drains 3,100 km^2, and is joined by the Chipola River which also has a drainage basin of 3,100 km^2. The 454 km^2 floodplain is regularly inundated during high flow between February and April (Elder et al., 1988). Mean annual flow is 650 $m^3 \cdot s^{-1}$, while low flow is about 290 $m^3 \cdot s^{-1}$ and high flow is greater than 2,910 $m^3 \cdot s^{-1}$ (Elder et al., 1988). Average annual rainfall is 147 cm and evapotranspiration is 114 cm. Mean air temperatures are 11°C in January and 27°C in July. The water budget for the Apalachicola River is dominated by streamflow from upstream (80%) and the Chipola River; evapotranspiration, groundwater and precipitation are not significant terms in the budget (Elder, 1985). Apalachicola river pH ranges between 5.7-7.8. The forested floodplain is the largest in the state of Florida and has about 211 different tree species, dominated by tupelo, gum, oak and cypress (Leitman et al., 1983). Flooding restricts the species composition of the forest to flood-tolerant species and has important impacts on biogeochemical processes and productivity in the basin (Mitsch and Gosselink, 1986). With the advent of flooding in the basin, soils become saturated and decomposition changes from mainly aerobic to anaerobic processes, such as denitrification, sulfate reduction and particularly methanogenesis. Flooding can supply nutrients to the forested floodplain and flowing water enhances flushing, leading to increased oxygen and decreased carbon dioxide and methane concentrations in soils. These factors are partly responsible for the high productivity of forested floodplains, some of which is exported as organic carbon and used by downstream ecosystems (Mitsch and Gosselink, 1986). Annual litterfall in the Apalachicola basin was high, about 800 $g \cdot m^{-2}$, and represented an important source of organic carbon (Elder and Cairns, 1982). Decomposition rates of litter were 300 $kg \cdot ha^{-1} \cdot yr^{-1}$ for nitrogen and 30 $kg \cdot ha^{-1} \cdot yr^{-1}$ for phosphorus (Elder and Cairns, 1982). Most transport of organic carbon occurred (73 $tons \cdot yr^{-1}$) during peak spring runoff, but was also important in the summer (45 $tons \cdot yr^{-1}$) when primary production was high (Elder et al., 1988). Most organic carbon in the system was dissolved (6.7 $mg \cdot l^{-1}$), while only a small fraction was particulate (0.7 $mg \cdot l^{-1}$) [Mattraw and Elder, 1984]. The finest particulate size (45-63 μm) transported most of the particulate carbon out of the floodplain (Elder et al., 1988).

Total nitrogen (TN) and phosphorus (TP) concentrations were not seasonally variable and the TN:TP ratio was between 12 and 15 for most sites in the main channel of the Apalachicola River (Elder, 1985). TN:TP ratio for precipitation data was near 10, while the small tributary streams had lower concentrations of TN and TP and variable TN:TP ratios. In contrast, dissolved inorganic nitrogen (DIN = nitrate + nitrite + ammonium) to soluble reactive phosphorus (SRP) ratios in the river increased from 23 at the headwaters to 40 at the mouth (Elder and Mattraw, 1982). In contrast to the TN:TP ratios, these high DIN:SRP ratios, which represent available nutrients, suggest that primary production in the river may be phosphorus-limited. Nitrate and dissolved organic nitrogen (DON) are the major nitrogen species in the Apalachicola River. Nitrate concentrations are generally lowest in late summer ($0.02\ mg \cdot l^{-1}$) and highest in late winter ($0.44\ mg \cdot l^{-1}$), while DON increases during flooding from $0.20\text{-}0.25\ mg \cdot l^{-1}$ (Elder, 1985). Particulate organic nitrogen (PON) concentrations were about $0.15\ mg \cdot l^{-1}$, while ammonium concentrations were about $0.05\ mg \cdot l^{-1}$ and decreased from headwaters to mouth (Elder, 1985). Soluble reactive phosphorus (SRP) decreased from $15\ mg \cdot l^{-1}$ at the headwaters to $8\ mg \cdot l^{-1}$ at the mouth with a concomitant increase in dissolved organic phosphorus (DOP) from 0 to $13\ mg \cdot l^{-1}$ and particulate phosphorus from 35 to $40\ mg \cdot l^{-1}$ over the length of the river (Elder, 1985).

The Apalachicola River has no significant anthropogenic sources; the few municipal sewage treatment plants in the watershed serve small communities and did not affect nutrient inputs (Mattraw and Elder, 1984). Mattraw and Elder (1984) also developed a nutrient budget for the river which showed that upstream nutrient inputs from Chattahoochee and Flint Rivers were the major source of nutrients for the Apalachicola River, as was the Chipola River was a significant source of nitrogen and phosphorus. Atmospheric deposition, groundwater and evapotranspiration were smaller terms in the total budget.

In contrast, atmospheric deposition was an important source of ammonium within the basin (Mattraw and Elder, 1984). A regional analysis by Winchester and Fu (1992) of atmospheric inputs of nitrate, sulfate and ammonium suggested that the atmosphere was the principal source of these constituents to the Apalachicola River. Their analysis suggests that sulfate is a conservative tracer of acid deposition, but that nitrate and ammonium are affected by burial, uptake and denitrification. In addition, transformations of DIN to DON within the river may explain the increased DON observed within the Apalachicola River basin. Measurements of nitrous oxide or dinitrogen gas have not been made, although measurements of nitrous oxide from other agricultural areas suggest that nitrous oxide efflux may be a significant component of the nitrogen budget (Winchester and Fu, 1992; Vitousek and Matson, 1993). There is a seasonal cycle in the transport of nutrients and detritus in Apalachicola River with 50% of nitrogen and phosphorus and 60% of particulate detritus occurring within an 86-day interval during peak discharge (Elder and Mattraw, 1982). Elder and Mattraw (1982) also observed that leaf decomposition was enhanced during prolonged inundation. The Apalachicola River and forested floodplain seem to act as a transformer, changing inorganic inputs to organic outputs.

Apalachicola Bay is 62,900 ha in size and has a well-mixed water column, although some parts can be seasonally stratified (Livingston, 1984). In the early 1980's, oysters made up 7% of the open water area, while submerged grassbed represented 10% and marshes 14% of the area (Livingston, 1984). Apalachicola Bay, near the river mouth, had a highly variable nutrient and salinity regime over the annual cycle and was characterized by high secondary production, while stations in the adjacent St. George Sound had little variability in salinity or organic matter (Federele et al., 1986). Nutrient concentrations were generally higher in the bay in winter than summer (Livingston, 1984). Nutrient concentrations were greater near the freshwater end, with peaks in 10 μM nitrate and 0.8 μM phosphate in the spring and an average of 3.3 μM nitrate and 0.37 μM phosphate throughout year (Myers and Iverson, 1981). Generally low concentrations occurred in the oligotrophic reaches of St. George Sound where nitrate concentrations averaged 0.55 μM and phosphate concentrations averaged 0.19 μM. Myers and Iverson (1981) measured chlorophyll-a concentrations between 3-9 $\mu g \cdot l^{-1}$ with a peak in late summer in the freshwater end. They also measured higher phytoplankton productivity in the freshwater region, while both chlorophyll-a concentrations and primary productivity were much lower in the more saline and oligohaline region. Primary production in Apalachicola Bay, as well as Ocklockonee Bay and the Econfina estuary, was limited by phosphate (Myers and Iverson, 1981), although both nitrate and phosphorus may limit production in Apalachicola Bay in the summer (Livingston, 1984).

The river is a source of nutrients to the bay (NOAA, 1985; Elder and Mattraw, 1982) and can lead to enhanced microbial productivity and secondary productivity within Apalachicola Bay (Livingston, 1980). Nitrogen inputs to Apalachicola Bay were 560 mmol $N \cdot m^{-2} \cdot yr^{-1}$ with only 2% coming from sewage and phosphorus inputs were 14 mmol $P \cdot m^{-2} \cdot yr^{-1}$ (Livingston, 1984). Increased development on St George Island, particularly from seepage of nitrate from septic tanks, has the potential to increase nutrient inputs to Apalachicola Bay. No studies directly examining this impact were identified, although work from other marine and estuarine systems suggests that groundwater inputs of nitrate from septic tanks can have deleterious impacts (Capone and Batista, 1985; LaPointe, 1992; Valiela et al., 1992).

4.2.8.2 Suwanee River

The Suwanee River originates in the Okefenokee Swamp, while the lower part of the Suwanee River Basin receives much of its flow from the Florida aquifer (Crane, 1986). The whole drainage basin includes 28,600 km^2 in South Georgia and 11,000 km^2 in Florida. A study of the groundwater chemistry of the Suwanee River Basin showed that low pH values (4.3) occurred in the northeastern part of the basin, and that pH increased to 6.5-7 in springs near the coast (Crane, 1986). A similar gradient occurred in the distribution of major ions which changed from dominance by calcium, bicarbonate and magnesium in the upstream groundwater springs to increased concentrations of sodium, chloride, potassium and sulfate in springs near the coast (Crane, 1986). Nutrient concentrations were generally low (<36 μM NO_3^- , 18 μM NH_4^+ , 2 μM orthophosphate), except near septic tanks, or agricultural sites where NO_3^- levels reached 1900 μM. The Suwannee River has extensive tidal wetlands, with freshwater tidal marshes and swamps comprising 4615 ha and saltwater marshes making up 6720 ha of the basin (Leadon and Wetterqvist, 1986). Wetlands in this area help to maintain freshwater in the coastal aquifer which is susceptible to saltwater intrusion following drainage of wetland (Leadon and Wetterqvist, 1986). Species diversity of both plants and animals is high (Leadon and

Wetterqvist, 1986, Mason et al., 1994). The river is considered pristine because of the lack of urban development in the watershed (Burnett et al., 1990), although there are some point and nonpoint sources of organic waste and toxic contaminants (Mason et al., 1994).

Little is know about the cycling of organic matter within the Suwanee River and estuary. Nutrient concentrations in the river are low (Mason et al., 1994). Studies in the Ogeechee River, a blackwater river in coastal Georgia, may provide insight to the cycling of organic matter in blackwater rivers like the Suwanee. The Ogeechee has a low algal biomass because of light limitation, and high bacterial and protozoan densities, as well as high macroinvertebrate densities (Carlough, 1994). About 96% of the organic carbon is dissolved, while the particulate matter is very fine (<50 μm) amorphous material, rich in bacteria, extracellular organic material and protozoans (Carlough, 1994). Significant organic production can also occur on snags which are covered with thick biofilms rich in bacteria (Couch and Meyer, 1992). Bacterial production is fueled by uptake of DOC from the water or leaching out of the wood (Couch and Meyer, 1992).

4.2.8.3 Bayou Texar/Pensacola Bay

Bayou Texar is a subestuary of Pensacola Bay, although exchange between the two is restricted. Extensive urban development in the watershed led to an overloading of the waste treatment system in the region in the early 1970's (Moshiri et al., 1981). That study, which provided this excellent overview of the chemical status of the estuary, showed that the bayou received most of the nutrient inputs from sewage and storm water runoff. Nitrogen concentrations were high, particularly in the freshwater region where average NO_3^- concentrations were 44 μM, but decreased downstream to 5 μM in Pensacola Bay, while NH_4^+ concentrations ranged between 1.8-7 μM. Phosphate concentrations were generally low, between 0.1-0.5 μM for PO_4^{3-}, and between 0.5 and 1.7 μM for total phosphate. Primary productivity was highest at the freshwater end, with rates between 60-70 mg $C \cdot m^{-3} \cdot h^{-1}$, while rates near Pensacola Bay were between 30-40 mg $C \cdot m^{-3} \cdot h^{-1}$. As a result of the high nitrogen inputs, development of intense algal blooms occurred during warm, clear and calm weather and the degradation led to periodic low oxygen events. In addition, blooms of *Gymnodinium*, a red tide dinoflagellate, may have contributed to the numerous fish kills in Bayou Texar. Improvements in water quality and reduction in the number of fish kills occurred after several engineered changes were made to the flow regime, which enhanced exchange between the Bayou with Pensacola Bay. These included dredging the bayou to a uniform depth, dredging the channel and removing structures which impeded flow between the bayou and bay, building a storm water holding system, and slowing the flow of freshwater from the major creek to the bayou. Subsequent studies comparable to Moshiri (1984) for the status of this estuary in the 1980's and 1990's were not located.

4.3 Chemical Cycles

4.3.1 Nutrient Cycling

Northeastern Gulf of Mexico estuaries are strongly influenced by nutrient inputs from rivers. Agriculture, including silviculture, represents the dominant nitrogen and phosphorus inputs. Because this region is generally sparsely populated, particularly along the coast, sewage inputs are less important, except near major cities such as Pensacola and Panama City. It is difficult to make general statements or draw conclusions about the current status of nutrient cycling within the northeastern Gulf of Mexico because of the lack of data for some regions, including the Suwanee estuary, Choctawhatchee Bay, St. Andrew Bay, St. Joseph Bay and the lack of recent data (within the last 10-15 years) for other regions, including Apalachicola Bay and Pensacola Bay. Despite the lack of information, some hypotheses can be examined based on information from other estuarine and marine systems. It would be expected that there would be significant differences between blackwater/spring fed systems like the Suwanee and alluvial river systems like the Apalachicola. The Suwannee has low nutrient concentrations and highly colored water, so phytoplankton productivity would be expected to be lower due to a reduced euphotic zone within the river, although bacterial productivity may be high. There have not been any comparative studies of the Suwannee or Apalachicola Rivers to examine whether phytoplankton productivity is light-limited and whether differences between light attenuation by humics versus inorganic particles is significant.

The role of physical processes has an important impact on nutrient cycling. The effect of freshwater inputs to estuaries has been discussed previously. Mixing of shelf and nearshore water is also important in controlling concentrations of nutrients and contaminants. Because of low tidal energy in the region, the effect of fronts and hurricanes can have an important effect on mixing of nearshore and offshore water (Darnell, 1992). Gulf of Mexico water from the shelf and gyre has very low nutrient and contaminant concentrations so it would dilute concentrations of these substances nearshore.

4.3.1.1 Primary Production

In estuaries, phytoplankton and seagrass production are often controlled by light and nutrient availability. The most complete study of phytoplankton production in the northeastern Gulf of Mexico showed that phosphorus often limited summer phytoplankton productivity in several estuaries (Myers and Iverson, 1981). The most productive areas found by that study were brackish (mean salinity 3-12 psu) stations in Apalachicola Bay and Ocklockonee Bay which had higher nitrogen and phosphorus concentrations, but were more turbid than the other stations. This suggests that nutrient inputs are more important than the light regime, which may be expected since these are very shallow systems. In contrast, seagrass production in the region is controlled by light limitation, with beds in Apalachicola Bay occurring in less than 1 m water depth, compared to beds down to 4.5 m for the rest of the region (Iverson and Bittaker, 1986). Seagrass beds along the northeastern Gulf of Mexico, as in other region, trap organic matter (Grady, 1981). Higher organic inputs generally lead to greater rates of decomposition and nutrient cycling. Thus, rates of nutrient cycling are often higher in seagrass beds than unvegetated sediments, although concentrations of nutrients in water and sediments may be low. Enhancement of a variety of nutrient transformations, such as ammonium mineralization, nitrification, denitrification, and nitrogen fixation have been measured in seagrass beds in other regions (O'Neill and Capone, 1989; Caffrey and Kemp, 1990).

4.3.1.2 Ochlockonee Bay

The most recent and complete information about nutrient cycling exists for Ochlockonee Bay, which is a small, pristine system. Ochlockonee Bay is similar to Apalachicola Bay in that the major input of nutrients is from nonpoint sources (Kaul and Froelich, 1984; Seitzinger, 1987). Primary production in the Bay is about 28 $\mu g\ C \cdot l^{-1} \cdot h^{-1}$ and can be limited by either nitrogen or phosphorus depending on sampling date, although there are not enough data to resolve a seasonal pattern (Myers and Iverson, 1981). This contrasts with the results from Apalachicola Bay, which had slightly higher productivity, 38 $\mu g\ C \cdot l^{-1} \cdot h^{-1}$, and phosphorus limitation of production for most of the experiments (Myers and Iverson, 1981). Nutrient budgets for Ochlockonee Bay were calculated by Kaul and Froelich (1984) for silica, nitrate and phosphorus. Riverine inputs of silica equaled estuarine outputs and the internal cycle of silica was about 18% of the yearly riverine input (Kaul and Froelich, 1984). Their budget also showed that 97.5% of the phosphorus inputs from the river were exported out of the estuary, so only 2.5% of phosphorus inputs were buried in sediments. They were not able to balance the nitrate budget because they did not measure ammonium, nitrous oxide or dinitrogen concentrations, nor rates of nitrification and denitrification which were probably significant. Seitzinger (1987) found that denitrification rates in Ochlockonee Bay averaged 73 $\mu mol\ N \cdot m^{-2} \cdot hr^{-1}$ over an annual cycle, with benthic nitrogen fluxes (mainly ammonium) able to supply about 20% of the nitrogen requirements of the phytoplankton. Ammonium fluxes were greatest in the June, while nitrate fluxes were greatest in March, and denitrification removed about 54% of the nitrogen coming in from the river (Seitzinger, 1987). For these relatively pristine estuaries, nutrient inputs and outputs seem to be in balance, with none of the positive feedback loops characteristic of more eutrophic estuaries like Chesapeake Bay (Kemp et al., 1989). However, recent data are lacking for more urbanized areas such as Pensacola Bay.

4.3.1.3 Hypoxia/Anoxia

Hypoxia (water column oxygen concentrations $<2\ mg \cdot l^{-1}$) and anoxia (water column oxygen concentration = $0\ mg \cdot l^{-1}$) often occur in eutrophic systems and are a severe problem in other areas of the Gulf, including Lake Pontchartrain, Mobile Bay and the Mississippi River plume (May, 1973; Turner et al., 1987; Darnell, 1992). Water column stratification, high organic inputs, warm temperatures and calm conditions combine to promote hypoxia/anoxia (Turner et al., 1987). For well-mixed estuaries such as Apalachicola Bay, one would not expect hypoxia to be common. However, areas with restricted circulation, particularly harbors, marinas and canals, would be at risk; hypoxic events have occurred around St George Island and the city of Apalachicola (Livingston, 1984). Bayou Texar, which is a subestuary of Pensacola Bay, had summertime anoxia in the 1970's (Moshiri et al., 1974), although a series of changes to the flow regime and inputs to the bayou appeared to reduce the problems (Moshiri et al., 1981). However, the status of Bayou Texar over the last 15 years is unknown. Hypoxic bottom water conditions were detected by instantaneous sampling in the EMAP western Florida estuaries in 1991, 1992, and 1993 in 1, 7, and 0% of the estuarine area, respectively. Comparable figures for the estuarine area experiencing dissolved oxygen <5 $mg \cdot l^{-1}$ were 13, 23, and 48%, respectively (Summers et al., 1993, Macauley et al., 1994, Macauley et al., 1995). These data indicate that, while severe oxygen stress is minimal in extent (<10% of the area), moderate stress may be widespread (i.e., approaching 50% of the area) in estuaries of the region.

Given the current low nutrient inputs, hypoxia does not seem to be a severe problem in the region. However, because the same conditions (periodic stratification, warm temperatures and calm weather) exist in the river-dominated estuaries of the northeastern Gulf of Mexico (Apalachicola Bay, Choctawhatchee Bay, Pensacola Bay) as in estuaries in the central and western Gulf of Mexico, hypoxia/anoxia could become a problem in the future if nutrient or organic loading to these systems increases.

4.3.2 Red Tides

Red tides are common in the Gulf of Mexico and are caused by blooms of two dinoflagellate species, *Gonyaulax monilata* and *Gymnodinium breve* (Darnell, 1992). *G. breve* was widespread in nearshore, shelf and gyre waters during the summer, but only occurred in warmer gyre waters during the winter (Tester et al., 1993). *G. breve* blooms develop 18-74 km offshore, and most remain offshore, although dense blooms (5×10^7 $cells \cdot l^{-1}$) can occur inshore when offshore water is transported inshore (Geesey and Tester, 1993). Nitrogen and phosphorus limitation of these red tide species has not been observed (Geesey and Tester, 1993), although iron may be important (Wells et al., 1991). Red tides such as *G. breve* can cause neurotoxic shellfish poisoning and can irritate human respiratory systems (Tester et al., 1993).

4.3.3 Contaminant Cycling

Direct relationships between human activities and contaminant inputs have been observed in many estuarine and coastal systems, where contaminant concentrations usually seem to increase following population growth. What happens to these contaminants varies, particularly within different ecosystems. For example, one would expect that contaminant cycling would be very different between alluvial and blackwater systems, or between phytoplankton-dominated and seagrass-dominated systems. In part, this is due to the link between contaminant and organic matter cycling.

For metals, concentrations and reactivity are dependent on dissolved organic carbon because of organic-metal complexation, particulate concentrations, pH, and redox conditions. Many trace metals are particle reactive, transported down rivers in particulate fractions, and deposited in estuarine and nearshore sediments. In sediments, redox and the formation of metal-sulfides depends on organic loading, with lower redox conditions occurring in organic-rich marine sediments, where sulfate reduction dominates. Because of diagenesis reactions in sediment, metals can be released back into the water column. The availability of ligands such as organic carbon compounds and sulfides, and environmental conditions such as pH and redox, control metal speciation in the environment. Metal speciation is the dominant factor controlling bioavailability of metals to organisms (Cross and Sunda, 1985).

Organic contaminants can also be particle reactive. Degradation of these compounds by bacteria is dependent on nutrient concentrations and redox. Degradation is usually higher when nutrient concentrations are high, while degradation of many toxic organics seems to be less efficient under anaerobic conditions (Kennish, 1992). Because of the lipophilic nature of many organic contaminants, concentrations of these contaminants are highest in the biota. Specific responses of some organisms to specific contaminants have been described above. A general effect or response to low levels or to complex mixtures of contaminants is difficult if not impossible to separate from natural factors (Möller, 1985; Overstreet, 1988). Pathological conditions such as parasites, parasitic diseases, microbial infections, neoplasia and mortality have been linked to pollution, although specific responses are affected by temperature, salinity, pH, dissolved oxygen concentrations, resistance, genetic predisposition and behavior (Overstreet, 1988). A survey of disease among oysters and fish from Mobile, Pascagoula and Pensacola Bays showed more pathological conditions closer to river effluents and industry, although none of the estuaries was severely unhealthy (Couch, 1985).

The effect of contaminants on communities and ecosystems is important, but has not been addressed by most of the previously cited studies. Most of these have focused on using bioassays such as the LD_{50} type toxicity test to examine immediate and lethal effects of contaminants. Unfortunately many LD_{50} studies have critical flaws and these approaches can not be used to determine the ecological effects of contaminants (Howarth, 1989). Some of the common problems with using these tests to determine the effects of oil pollution are described by Howarth (1989). They are: (1) using adults, although eggs and larvae are often more sensitive; (2) adding particular oil concentrations, but not actually measuring the oil concentration during the experiment, so that the concentration that the organism is exposed to is unknown; (3) using species because they are easy to culture in the laboratory, not because of their importance in a particular ecosystem; (4) laboratory experiments usually do not have the same UV radiation as in the environment and photo-oxidation by UV can produce more toxic compounds (Howarth, 1989). Contaminants can have sublethal effects such as interfering with reproductive success, slowing growth rates and altering behavior (Howarth, 1989). Lethal and sublethal effects can have a impact on population abundances, community composition and ecosystem processes, although it is difficult to attribute changes directly to pollution because environmental factors can also have a significant effect on populations, communities and ecosystems (Howarth, 1989; Kelly, 1989; Klerks and Levinton, 1989). Decreases in species composition have been observed in many polluted environments and are usually attributed to a replacement of sensitive species with more pollution tolerant species (Howarth, 1989; Klerks and Levinton, 1989). The pollution tolerance of some species may be a result of enhanced genetic capability to become resistant to toxic substances. Klerks and Levinton (1989) suggest that this capacity can limit the usefulness of standard bioassay experiments because development of resistance can not be incorporated into these kinds of experiments.

The goal of most research on toxic contaminants is to understand the effect of contaminants on the environment, particularly the biota. One approach is to use concepts from nutrient cycling and try to draw parallels between nutrient cycling and contaminant cycling. A review by Farrington (1989) applies some of these concepts by describing the different aspects of organic contaminant cycling in the environment:

- "routes of entry of compounds to the environment and routes of movement through ecosystems;
- reactions of these compounds to the environment, either chemical, photochemical or biological transformations/degradation;
- rates of movement and reactions;
- reservoirs of short-term (days-months) and long-term (years to decades) accumulations."

Certainly most of the 4 R's are applicable to metal cycling as well. Trying to develop tests of how contaminants affect ecosystems is quite difficult, but not impossible (Howarth, 1989; Kelly, 1989). Often microcosms and mesocosms are useful tools for studying effects of contaminants on ecosystems under more controlled conditions (Gearing, 1989; Howarth, 1989; Kelly, 1989). For example, the effect of drilling muds on *Thalassia* beds was tested with microcosms (Morton et al., 1986; Kelly et al., 1987 [as cited in Kelly, 1989]). The results of these experiments showed that drilling muds reduced primary production by *Thalassia* and decomposition of organic matter. In addition, chlorophyll-*a* concentrations in *Thalassia* and epiphytic algae were reduced, as were numbers of the dominant macrofauna (Kelly, 1989). These effects were observed in treatments with drilling muds and with clay particles (at same SPM concentration as drilling muds), suggesting that indirect effects, such as physical disturbance and reduced light levels can be as important as toxic effects (Kelly, 1989). The power of these kind of approaches is that they incorporate more of the complexity found in the environment, such as interactions between trophic levels and different processes, and indirect effects can also be examined.

4.4 Conclusions

The estuarine and coastal zone of the northeastern Gulf of Mexico has a rich biotic community, but a low population density. This results in relatively low inputs of nutrients, heavy metals, and organics to the coast, although some significant point sources of trace metals, PAHs, and PCBs have been found in sediments and biota in Pensacola Bay, Choctawhatchee Bay and St. Andrew Bay. Spills of PCBs and oil can account for some of the high concentrations that have been found in sediments and biota. However, the sources of elevated trace metal concentrations, such as silver, cadmium, lead, mercury and zinc in Choctawhatchee Bay, are unknown.

The EPA has recently produced a summary of the extent and severity of sediment contamination in U.S. surface waters including estuaries (EPA, 1996) as part of its National Sediment Inventory (NSI). Using sediment chemical concentration, tissue residue data, and information on sediment toxicity the NSI established three tiers that classify watersheds as having a high probability of adverse effects to aquatic or human health (Tier 1), an intermediate probability of adverses effects (Tier 2), and no indication of adverse effects (Tier 3). Ninety-six water bodies in the continental U.S. were identified to fall in Tiers 1 or 2. Only one of these, Choctawatchee Bay, is found in the northeastern Gulf region as a result of metals, in particular mercury, and PAH contamination.

Although groundwater inputs have not been directly measured in the northeastern Gulf of Mexico, some evidence suggests that it may be a source of freshwater to estuaries and the coastal zone in this region. Thus, contaminantion of groundwater with nutrients, metals or organic contaminants could easily be transferred to the coastal zone. Rivers are the other major source of freshwater and nutrients to estuaries and the coastal zone. The Apalachicola River and forested floodplain appears to transform inorganic inputs from upstream to organic outputs which are exported to Apalachicola Bay and support high primary and secondary production there. For the relatively pristine estuaries such as Ocklockonee Bay, nutrient inputs are moderate, while recycling and losses within the estuary seem to be in balance with no evidence of eutrophication which is common in many other estuaries.

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Chapter 5 - THE BIOLOGICAL ENVIRONMENT

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5.1 Introduction

This chapter presents available information on the biology of a study area encompassing the northeastern Gulf of Mexico continental shelf and Florida panhandle estuarine waters. Detailed discussions of the physical environment of the region may be found in Chapter 2 (Physical Oceanography and Meteorology), Chapter 3 (Geology), and Chapter 4 (Chemistry).

The study area is relatively large geographically, but lacks identifiable ecological boundaries. Consequently, ecosystems within the region can not be considered to be members of a coherent ecological unit. The study area is transitional with respect to its climate (Fernald and Purdum, 1992) and the biogeographical affinities of its flora and fauna (Hedgpeth, 1953; Briggs, 1973; Britton and Morton, 1989). Nearshore estuarine and marine communities throughout the region include species with temperate ("Carolinian") and subtropical-tropical ("West Indian") affinities, but the former decrease, and the latter increase from west to east, from north to south, and with depth and distance from shore (Collard and D'Asaro, 1973; Lyons and Collard, 1974).

With some exceptions, descriptions of marine ecosystems in the ecologically heterogenous northeastern Gulf of Mexico emphasize water quality conditions and anthropically-related losses of large, abundant or commercially valuable organisms from estuaries. Knowledge of shelf communities is scanty, as is information on physicochemical and biological processes. Because biological models use highly condensed information to identify pathways of energy flow within ecological systems, it is essential to recognize biases and gaps in the regional database. In addition to the deficiencies noted, problems specific to individual geographic areas and/or to ecosystems and communities within them are discussed in appropriate subsections of the chapter. To the extent that the gappy database permits, we attempt to characterize major biological features of the region by describing those communities within ecosystems that share similar ecological functions.

5.1.1 Area Description

The Gulf of Mexico is a marginal sea of the Western North Atlantic Ocean. Darnell et al. (1990) reported the Gulf to have a maximum east-to-west width of about 1,600 km, a maximum north-to-south length of about 900 km, and a surface area of more than 500,000 km^2. The Gulf has a maximum depth of 3,850 m in the Sigsbee Deep. Continental shelves of the Gulf of Mexico equal about 35% of its surface area, or about 200,000 km^2 (Darnell et al., 1990). The continental shelf off the Florida panhandle/Big Bend is widest in the eastern part of the region. It narrows south of Choctawhatchee Bay, where it deepens rapidly, via rugged terraces and rocky outcrops, into DeSoto Canyon, the major physiographic feature of the eastern Gulf basin. The canyon trends southwest as it widens and deepens (Figures 1-1 and 5-1).

Tropical water from the Caribbean Sea/Atlantic Ocean enters the Gulf of Mexico through the Yucatan Channel. This water forms the Gulf of Mexico Loop Current which affects circulation in the entire basin. The behavior of the Loop Current is complex (see Chapter 2), and has a profound affect on the distribution of salinity, energy and biota in the Gulf of Mexico, as noted by, among others, Collard and Ogren (1990, Figure 5-2). The Loop Current may flow almost directly from the Yucatan Channel to the Straits of Florida. More commonly, however, the current flows north into the eastern Gulf basin, where it meanders, becomes unstable, and sheds one or more anticyclonic rings or eddies. Water derived from the Loop Current or its westerly translating eddies may cross the shelf boundary, advecting tropical organisms (ichthyoplankton, meroplanktonic invertebrates, etc.) into the neritic waters of the shelf.

According to Darnell et al. (1990), coastal waters annually receive some $10^{12} \cdot m^3$ of fresh water from rivers. While the Mississippi River is the largest source of fresh water, northeastern Gulf coast river discharges are significant. As a result of these river discharges and freshwater springs located on the shelf, coastal waters of the Big Bend are brackish.

The Florida Department of Environmental Protection (FDEP, 1994) described the coastline from Perdido Key east to Apalachee Bay as being characterized by high energy barrier islands with sand beaches. From west to east these islands (the "Gulf Barrier Chain" of Brooks, 1973) are: Perdido Key; Santa Rosa Island; Shell Island; St. Vincent Island; Little St. George Island; St. George Island; and Dog Island. Further along the coast Piney Island, Jug Island, and the Cedar Keys exhibit some of the protective functions of barrier islands; however, Fernald and Purdum (1992) consider Dog Island in Apalachicola Bay to be the easternmost barrier island in the panhandle (Figure 5-3). The coastal area from Apalachee Bay to Cedar Key is a low energy, marsh-dominated shoreline. Fernald and Purdum (1992) describe this area as almost featureless, with the lowest relief in the panhandle.

Tombolos, spits, headlands, and offshore shoals provide the mainland shoreline with varying degrees of protection from the full force of storm winds and waves. From west to southeast, these coastal barriers include Crooked "Island" (two spits separated by "Hurricane Pass" which opens St. Andrew Sound to the Gulf of Mexico); St. Joseph Spit; a complex of bars and shoals from Cape San Blas to Cape St. George; and Alligator Harbor Spit. Major sand dunes on barrier islands and mainland beaches from Perdido Key to Cape San Blas were severely eroded, and in some areas (*e.g.*, Navarre, Pensacola Beach, Fort Walton Beach to Destin, and Mexico Beach) were virtually destroyed by Hurricanes Allison, Erin and Opal in 1995. The severe damage and/or destruction of these large dunes left large areas of northwest Florida's nearshore marine habitats (*i.e.*, salt marshes) vulnerable to further damage by storms. Santa Rosa Island is the longest barrier island in the eastern Gulf of Mexico, extending some 50 miles from

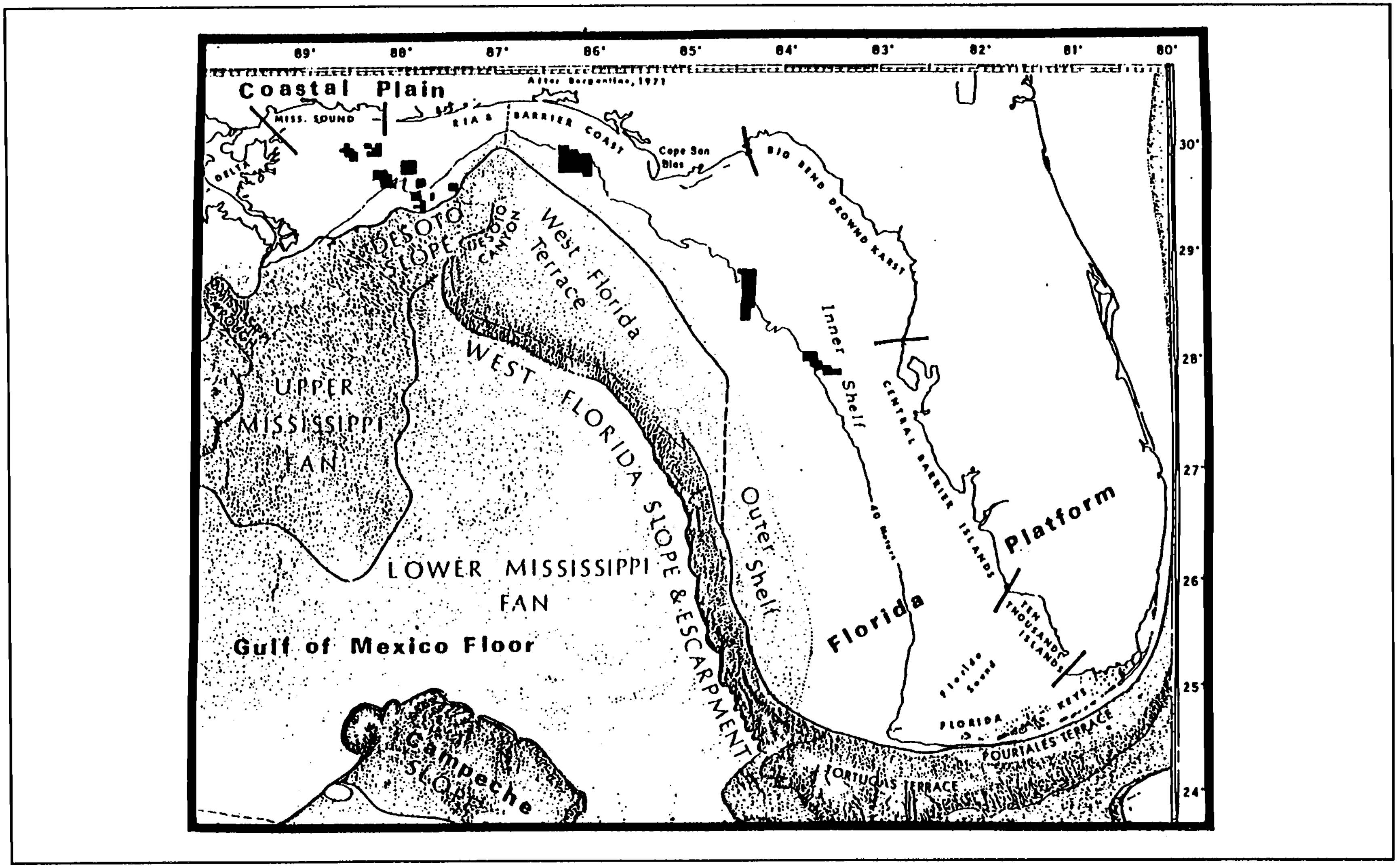


Figure 5-1. Map of the eastern Gulf of Mexico (from Pyle et al., 1975).

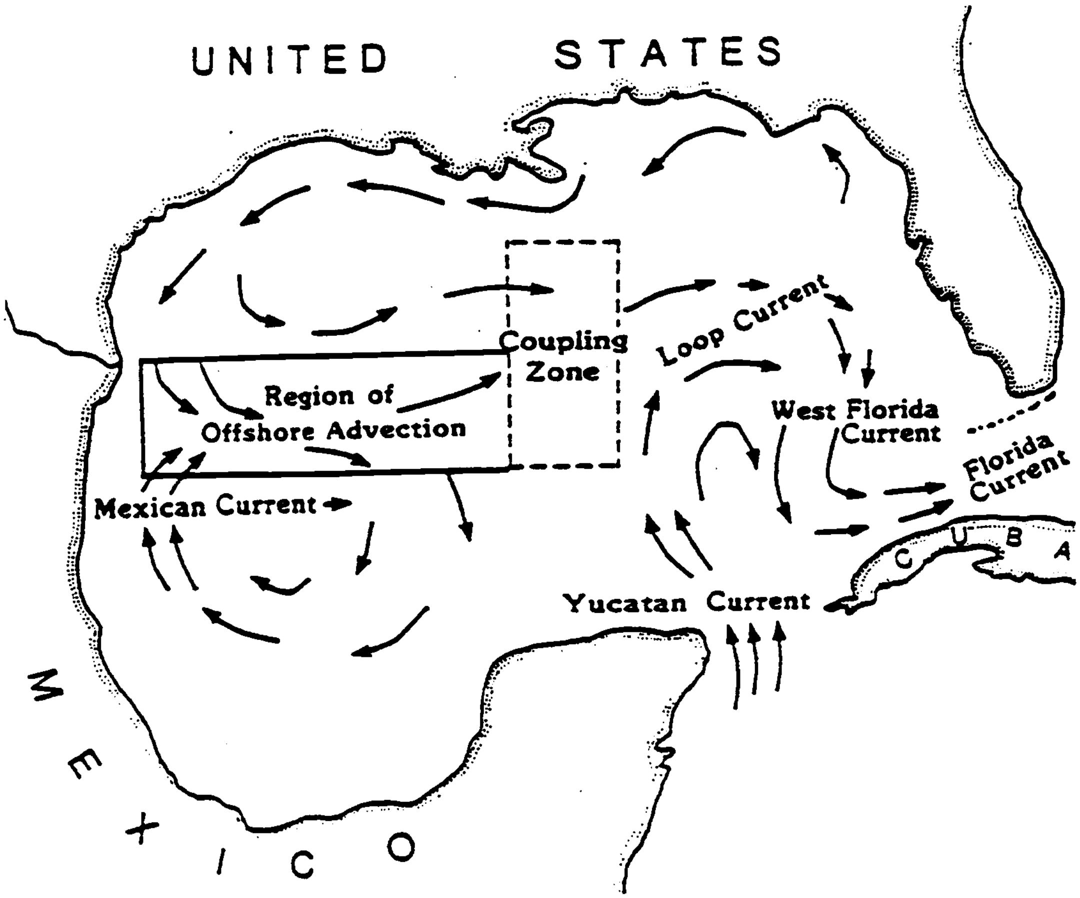


Figure 5-2. Generalized circulation in the Gulf of Mexico (from Collard and Ogren, 1990).

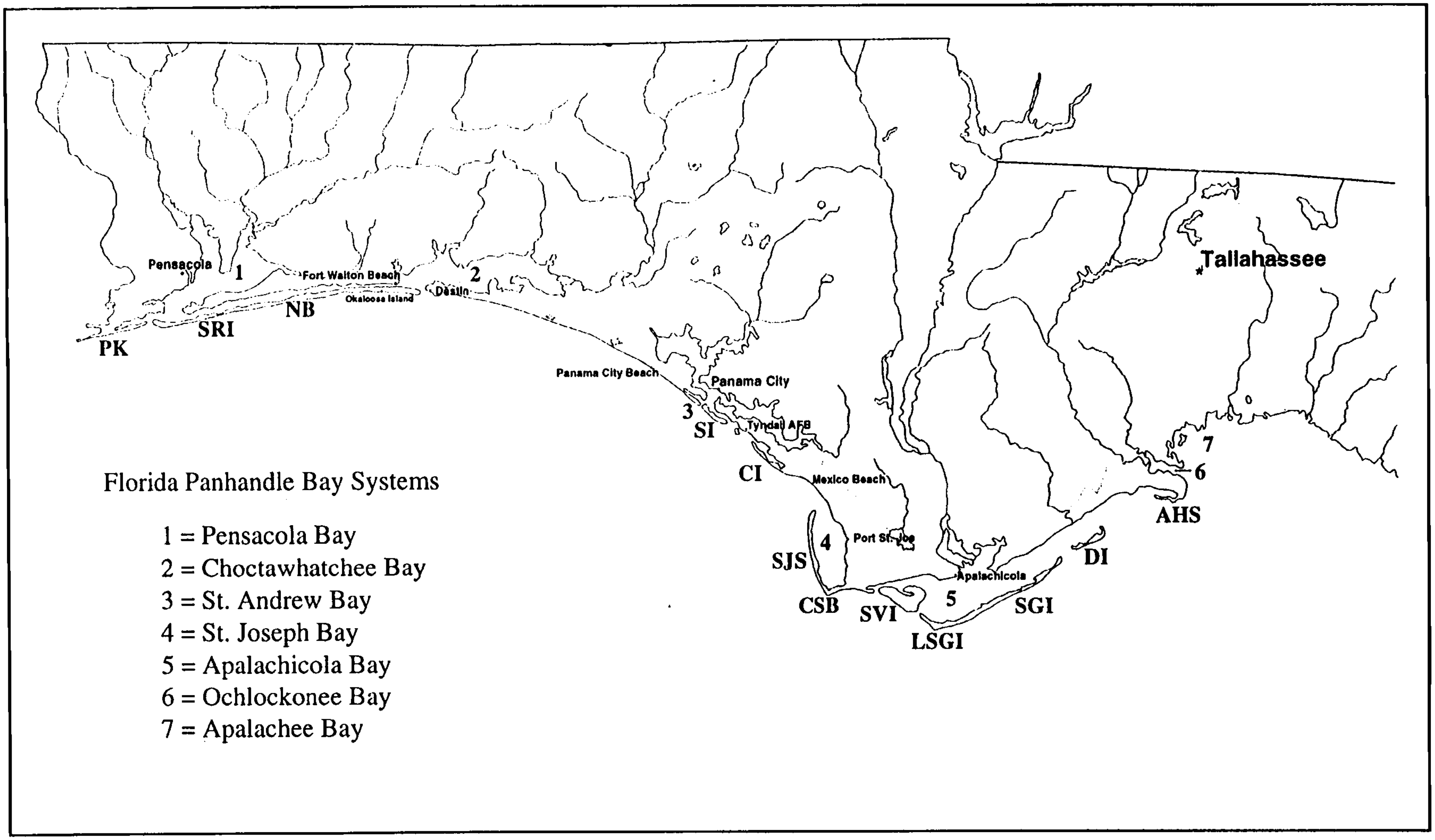


Figure 5-3. Western Florida Panhandle showing bay systems and barrier islands (from NOAA 1986). PK=Perdido key; SRI=Santa Rosa island; NB=Navarre Beach; SI=Shell Island; CI=Crooked Island; SJS=St. Joseph Spit; CSB=Cape San Blas; SVI=St. Vincent Island; LSGI=Little St. George Island; SGI=St. George Isalnd; DI=Dog Island;and AHS=Alligator Harbor Spit.

Pensacola Pass to East Pass Channel. According to Brooks (1973), Santa Rosa Island receives longshore sediment drift from the Miramar-Grayton Beach area to the east, and from the inner shelf between Pensacola, Florida, and Morgan Point, Alabama. There are no barrier islands between East Pass Channel and Shell Island off Panama City. The Apalachicola barrier island chain (Dog, St. George, Little St. George, and St. Vincent Islands), Cape San Blas and its associated bars and shoals, and St. Joseph Spit were formed largely by the longshore drift of sediments deposited in the Gulf by the Apalachicola River. West of St. Joseph Spit, "the 25 m depth contour approaches shore and a considerable amount of sediment is funneled into deep water" (Stout, 1984). The bathymetry of this area has not been charted since Hurricane Opal in 1995; however, extensive shoaling has been observed from the eastern end of Crooked "Island" to west of Cape San Blas-St. Joseph Spit, and from an imaginary line connecting Cape San Blas and the mainland (Port St. Joe-Mexico Beach-eastern Tyndall Air Force Base).

Sea level on the northwest Florida coast has risen from 0.02-0.2 cm per year during the past century (*e.g.*, Galtsoff, 1954; Fernald and Purdum, 1992), but there is general agreement that the shoreline has remained relatively stable during this same period. Because of very low relief in eastern portions of the panhandle, continued sea level rise will eventually result in changes in the extent and/or distribution of estuaries and salt marshes.

5.1.2 Data Gaps

Ogden's (1992) description of the West Florida Shelf applies to the mosaic of physiographic and biological features present in the northeastern Gulf of Mexico. Both areas consist of "a network of spatially and temporally interconnected ecosystems..." Region-wide knowledge of the northeastern Gulf is lacking in many areas, and we list only major, fundamental data gaps with broad scope.

1. Nutrient sources, sinks and cycles. Effects of nutrient enrichment.
2. Physical processes driving nutrient exchanges between coastal ecosystems (estuaries, salt marshes, seagrass meadows) and the shelf.
3. Transport and fate of toxic substances, nutrients and organisms (microbes, meroplankton, fish eggs and larvae) within and between estuaries and shelf waters.
4. Identification and distribution of primary and secondary producers.
5. Levels of production in coastal and shelf waters.
6. Taxonomic and trophic structure of coastal and shelf benthic microbial, plant and animal communities.
7. Coupling between water column and benthic communities, and between estuary-shelf and shelf-ocean basin communities.
8. Impacts of fresh water on shelf ecosystems.
9. Impacts of catastrophic events (storms, toxic algae, toxic spills) on community structure.
10. Impacts of coastal development, including pollution, on

estuarine and nearshore communities.

11. Status and trends in fisheries resources and management.

5.2 Continental Shelf

The following sections describe the general environmental setting and biology of the continental shelf. Known data gaps are provided at the end of the section.

5.2.1 Environmental Setting

Physiographically, the panhandle shelf is dominated by DeSoto Canyon. An inner shelf drops off via a series of rocky terraces to an outer "shelf-slope" region south of Destin. East and west of Destin, the shelf deepens gradually to the shelf break at the head of the canyon. In broad overview, inner shelf sediments of the panhandle west of Alligator Harbor are predominantly quartz sands to approximately the 20 m isobath. From Crooked Island to the east, this sandy, shallow depth zone becomes progressively broader, extending more than 30 miles offshore in the Big Bend region. Lyons and Collard (1974) described nearshore sediments east of Alligator Harbor as comprised of a thin veneer of quartz sand and organic debris overlying the limestone plateau of the Ocala-Middle Ground Arch. Limestone outcrops protrude through this veneer and provide hard substrate. Hopkins et al. (1979) described sediments off Pensacola as soft clastics, coarse sand and shell rubble at depths of 30-35 m, with algal cemented nodules at 90-95 m depths. Rocky outcrops occur off Panama City in depths of about 20 m, and these increase in number on transitional terraces in depths of about 30-100 m, which divide inner and outer portions of the shelf in the western panhandle. Rock pinnacles are common at depths of 30-100 m off Pensacola and Choctawhatchee Bays (Collard, unpubl. data).

5.2.2 Biology

Information about eastern panhandle continental shelf biology is scarce compared to knowledge of the West Florida or western Gulf of Mexico shelves. The MAFLA Program (Mississippi-Alabama-Florida), which included portions of the panhandle shelf, is the only major non-proprietary investigation of the region accomplished to date (Alexander et al., 1977a, 1977b; State University System of Florida, Institute of Oceanography, 1978; Dames and Moore, 1979a, b, and c). The use of information on the distribution and abundance of benthic invertebrates gained during MAFLA and subsequent, smaller-scale, investigations of the region (e.g. Hopkins et al., 1979), provides the most useful and least equivocal basis on which to base a brief biological characterization of the panhandle shelf.

5.2.2.1 Plankton

Primary production in panhandle shelf waters is influenced by nutrients in pulse, seasonal or annual river and estuarine discharges into the Gulf of Mexico. Apalachicola River water has been observed 160 miles offshore (Livingston and Joyce, 1977), and St. Andrew, Choctawhatchee and Pensacola Bay water often extends a considerable distance offshore. Mississippi River water has been observed more than 50 miles offshore southeast of

Pensacola (Collard, unpubl. data). Bogdanov et al (1969) reported that productivity was high on the northern part of the Florida shelf due, in part, to upwelling in the vicinity of DeSoto Canyon. Steidinger (1973) reported that phytoplankters in the northern Gulf were mainly cosmopolitan species typical of temperate and subtropical waters. Productivity generally decreased, and species diversity increased with distance from shore.

The most comprehensive investigations of zooplankton in panhandle shelf waters were accomplished by Maturo (water column), and by Collard (neuston) during MAFLA cruises of 1975-1978 (Maturo et al., 1975; Collard, 1978, 1981; Dames and Moore, 1979a, b, and c; State University System of Florida, Institute of Oceanography, 1978). During this period, a series of stations were established from nearshore to near the shelf break off Pensacola, and in the Big Bend region. A large suite of physical and chemical measurements (e.g. temperature, salinity, pH, dissolved oxygen, chlorophyll, sea state, light, etc.) were collected with plankton samples, which were counted and identified to the species level. Identifications also included larvae and subadult stages. Sampling intervals were dense, and accounted for hourly, daily, seasonal and annual variations in species, their relative abundances, and their geographic distributions relative to oceanographic conditions and watermasses. More than 600 invertebrate species were collected with neuston and plankton nets, and data were analyzed for patterns. Zooplankton nets of varying mesh sizes were used in collections and the ecologically very important gelatinous plankters were significantly undersampled (Collard, 1978).

Results of more than 200 statistical analyses clearly showed that none of the observed variation in species assemblages, biomass, numerical abundance, or in time and space could be accounted for with respect to any single or combination of the abiotic variables measured. Standard errors of mean values in both parametric and nonparametric tests were often more than 10^3 times larger than the mean. For this reason, we feel that the inclusion here of quantitative values of either biomass or numbers would be misleading (Collard, 1984).

In all samples, mero- and holoplanktonic crustaceans dominated the catch. Of these, pontellid copepods were most abundant near the surface, and other calanoid copepods dominated midwater catches. Other significant zooplankters included larval fishes, chaetognaths, bivalve and gastropod veligers, and occasionally, salps, doliolids, appendicularians, pteropods, hydromedusae and siphonophores. As noted, gelatinous zooplankters were undersampled. Cladocerans occurred in pulses, and sometimes nearly equaled the larger species of copepods in numerical abundance. Annual zooplankton abundance in panhandle shelf waters appeared to be greatest in frontal zones associated with river plumes, watermass boundaries (e.g. Loop Current eddys near the shelf break), and in upwelling areas near the head of DeSoto Canyon. Seasonal variation in abundance varied from year to year (e.g. Turner et al., 1979; Turner and Collard, 1980), but in most extra-estuarine areas sampled, numerical zooplankton abundance was higher during winter and spring.

5.2.2.2 **Benthos**

Descriptions of the benthos may or may not be representative of the Panhandle shelf as a whole. It is clear, however, that species richness is relatively high, which suggests that water column and primary production is relatively high. The following summarizes studies of benthic organisms (macroepifaunal and macroinfaunal) including beach and outer shelf communities found within the region.

Macroepifauna

As reported in Dames and Moore (1979), the 25 most abundant macroepifaunal taxa collected in shelf waters during the period 1975-1978 included eight crustaceans (6 shrimp, 1 portunid crab, 1 hermit crab); five molluscs (2 squid, 2 snails, 1 scallop); eight echinoderms (2 brittle stars, 1 crinoid, 2 sand dollars, 1 seastar, 1 sea urchin, 1 basket star); and four cnidarians (1 soft coral, 3 hard corals). Clusters of macroepifaunal species assemblages occurred in the following depth zones (see Table 5-1).

Table 5-1. Clusters of macroepifaunal species assemblages found in different depth zones on the panhandle shelf (from Dames and Moore, 1979).

Depth Zone	**Species Assemblage**	
33-50 m	*Chlamys benedicti* *Laevicardium pictum* *Sicyonia brevirostris* *Solenocera atlantidis* *Scyllarus chacei*	*Pylopagurus coralinus* *Palicus alternata* *Luidia clathrata* *Ophiolepsis elegans*
80-110 m	*Bebryce grandis* *Paracyathus pulchellus* *Mesopenaeus tropicalis*	*Iliacantha subglobosa* *Anthenoides piercei*
170-190 m	*Turgurium caribaeum* *Murex beauii* *Aequipecten glyptus* *Parapenaeus longirostris* *Acanthocarpus alexandri*	*Myropsis quinquespinosa* *Pyromaia arachna* *Gonyplax hirsut* *Squilla heptacantha*

Hopkins (1979) continued work on the benthic macroinvertebrates of the panhandle shelf, and reported collections of echinoderms roughly south of Pensacola, as an area that is "enormously rich in species, and virtually unknown" (pers. comm.). Hopkins (1979) found, from collections made 25-50 km south of Pensacola in 1988-1989, 30 species of echinoderms. Taxa collected on coarse sand and shell rubble at depths of 30-35 m included five asteroids, two ophiuroids and three regular echinoids. Taxa collected on soft clastic sediments at the same depths included three asteroids and two irregular echinoids. Hopkins reported a distinct increase in numbers and species of echinoderms associated with "a unique habitat of algal cemented nodules and coralline red algae" at depths of 90-95 m.

Macroinfauna

During 1977-1978 MAFLA collections, over 1,200 macroinfaunal species were identified (Dames and Moore, 1979). The one hundred most abundant species were relatively ubiquitous (nearly 75% of the taxa were collected at more than half of the stations.) Only six of the top 100 taxa were present at less than 25% of the stations. Dominants included: 87 polychaetes; 10 crustaceans; and 3 molluscs. The ten most abundant taxa occurred in densities of greater than 35 individuals $\cdot m^{-2}$ per station per sampling period. The next 20 most-abundant taxa had average densities of greater than 17 individuals $\cdot m^{-2}$, and most of the remaining 70 taxa occurred in densities of less than 17 individuals$\cdot m^{-2}$. Overall, densities of macroinfauna ranged from 138 to 15,583 individuals$\cdot m^{-2}$. The authors noted that a density of 5.9 individuals$\cdot m^{-2}$ is equivalent to about one individual in an area about the size of this page.

No latitudinal trends in numbers of species or in density of macroinfauna were found, but highest densities were observed nearshore, and the lowest densities of animals occurred offshore, as was the case with macroepifauna and meiofauna (Dames and Moore, 1979). In general, infaunal density decreased with a combination of increasing percent fine sediments and increasing depths.

More than 1,000 species of polychaetes were recovered from 1974 MAFLA collections. These included about 750 different confirmed species, of which at least 50 (from nearly 200,000 animals counted), were new to science. Sixty families (including all major families) were identified, of which seven were new to the Gulf of Mexico. The polychaetes, as a group, represented a mix of cosmopolitan species (the smallest group), with some 25-30% (each) of the remainder representing Caribbean, Carolinian and endemic Gulf of Mexico species.

Of about 10,500 crustaceans recovered from box cores during 1977-1978, more than 85% were identified to species level. Ninety families and 360 species were represented in the collections, of which decapods and amphipods accounted for 72% of the species and 65% of the total number of specimens. Nearly one-third of the 360 species collected were new to science.

Beach Communities

Much of the mainland coast of the western Florida panhandle is protected from heavy wave shock by barrier islands. Barrier island beach communities experience only low to moderate energy wave shock, except during strong storms, due to gentle foreshore slopes along all but the extreme western panhandle area off Pensacola. Because beaches are comprised of unstable quartz sands, however, intertidal macroinvertebrate species are adapted to survive maceration by burrowing. The beach flea, *Emerita*, and the bivalve, *Donax*, for example, can bury themselves almost instantaneously. This ability enables them to live directly in the surf zone. The latter two species have somewhat patchy distributions, but are found on sandy Gulf beaches throughout the panhandle, where they migrate up and down the beach with the tides.

A shallow trough running parallel to the shoreline usually occurs just offshore of the sandy beaches of the western and central panhandle coasts. Benthic invertebrates living in the trough are partially protected from wave action during normal tide and surf conditions. Relatively stable sand substrates in the trough result in the replacement of rapid burrowers by whelks, olive shells, sand dollars, and the seastar, *Astropecten*. A second (or third) sand bar usually occurs further off the beach, separated from the first sand bar by a deeper, broader trough. Waves break on the shallow surface of these sand bars, and *Donax-Emerita* communities are again found. Seaward of the sand bar, as the beach gradually slopes into deeper water, a third group of animals, including *Dinocardium, Encope*, and the common seastar, *Luidia*, are found. These assemblages are characterized in Figure 5-4.

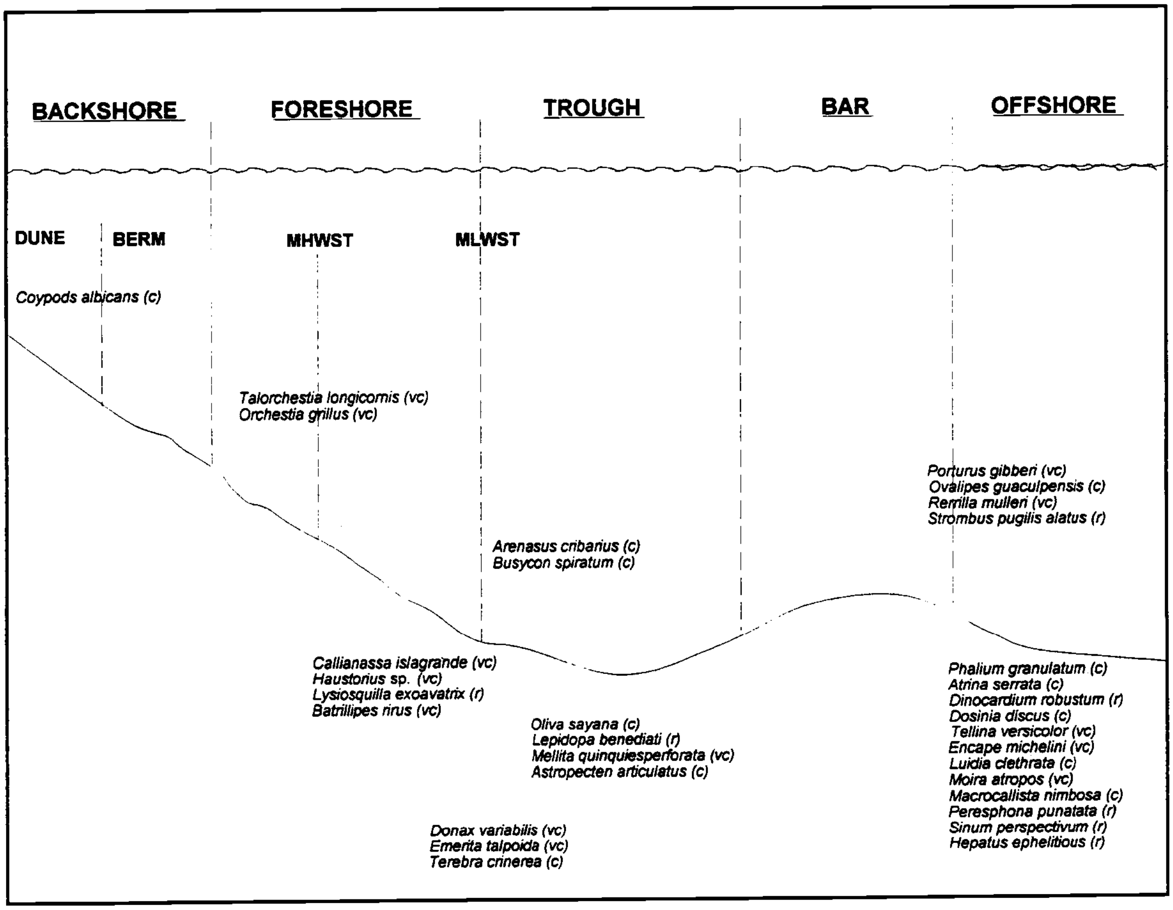
Invertebrates in the zero to low energy beaches in the Big Bend region are similar to the foreshore "trough communities" described above, with increasingly subtropical affinities.

Shelf Communities

Beach and foreshore communities intergrade with the shallow shelf community, which occurs at depths of about 10-30 m (Lyons and Collard, 1974). Many species found in shallower water also occur at these and greater depths (Figure 5-5). As depth increases, areas of mud, hard clay, carbonate, and patchy rock and shell hash substrates become more common. The species composition of otter trawl and Cape Town dredge collections becomes progressively less predictable with distance from shore and with depth, but the extreme variation observed in catches is speculated to depend more on substrate type than either depth or distance offshore (Millender, pers. comm.; Collard, unpubl. data). Trawl collections from depths of 30-400 m in the steeply terraced region near the head of DeSoto Canyon may be dominated by ahermatypic corals, echinoderms, gastropods, decapods, holothurians, or clumps of calcareous algae. Several hundred trawls made in close proximity to each other (less than a nautical mile apart) in this area during the period 1970-1994 exhibited enormous variation in the numbers and species of animals caught (Collard, unpubl. data). Species diversity appears to be greater in water depths from 20-30 m to ca.100 m, than in shallower water, and West Indian taxa become more common with increasing depth. Clearly, however, shelf benthic communities have not been sampled sufficiently well to permit even general characterizations of species assemblages to be made.

5.2.2.3 Fish

Darnell's (1990) synopsis of regional demersal fish, based on collections totalling in excess of 2,245,000 fish, includes the following. "Depth related zonation reveals nearshore, mid-shelf, outer shelf, and trans-shelf assemblages. Estuary related species are particularly prominent on the northwestern Gulf shelf, while rock and reef related species are most important in the fauna of the eastern Gulf shelf. Recognizable elements in the shelf fauna also include species of tropical affinity; open ocean and upper slope species; inhabitants of seagrass beds, mangrove swamps, and carbonate rubble and shell hash; burrowers in soft bottoms; and inhabitants



MHWST = mean high water spring tide
MLWST = mean low water spring tide
vc = very common
c = common
r = rare

Figure 5-4. Beach and foreshore benthic macroinvertebrate communities (after Collard and D'Asaro, 1973).

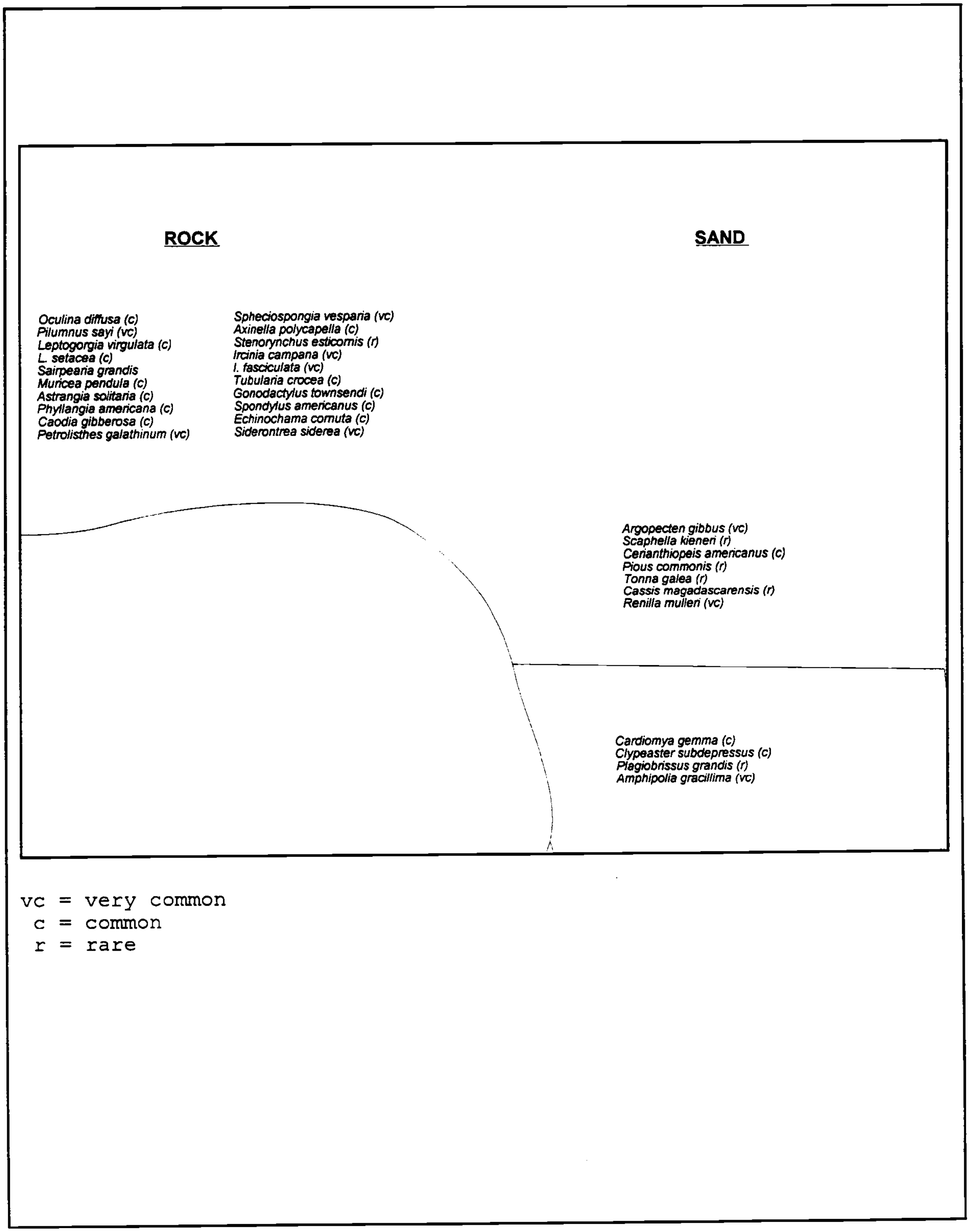


Figure 5-5. Shallow shelf benthic invertebrate assemblages (after Collard and D'Asaro, 1973).

of the upper water column. The eastern Gulf shelf is inhabited by twice as many fish species and eight times as many unique species as the northwest shelf, reflecting the great diversity of habitat types in the eastern Gulf. A few key species numerically dominate the ichthyofauna of the northwestern shelf, but dominance is spread through many species in the east. Seasonal shifts in species density primarily reflect inshore/offshore seasonal migrations of estuary related species, but seasonal inshore/offshore density shifts are also observed among the true shelf residents. Trophically the shelf systems are supported by precipitated plankton and organic detritus derived from rivers, bays and estuaries, seagrass beds, and mangrove swamps, although attached algae are also important producers in the east. Mollusks, polychaetes, and small crustaceans which feed upon this material, in turn, support the demersal fish communities whose species are generally short-lived. Larger long-lived predators are mostly seasonal migrants which appear in the northern Gulf during the warmer months. Bottom-feeding generalists are prominent in the northwest, while specialists are in great evidence in the east."

According to Dames and Moore, (1979), the distribution of fishes on the northern Florida shelf is "particularly homogeneous", and similar to the ichthyofauna of northern and southern portions of the Gulf (see Table 5-2). The authors remarked that similarities reflected the distribution of calcarious substrates in the three areas. Trawl collections made from 1974-1978 comprised 292 species, "about half the species known from the Gulf of Mexico, and nearly all of the demersal fish previously reported from the Gulf".

5.2.2.4 Sea Turtles and Marine Mammals

The distribution and abundance of marine mammals and adult sea turtles in panhandle shelf waters varies seasonally and from year to year. The distributions of these animals is not well known, but may be related to watermass preferences, food source availability and reproductive cycles.

Post-hatchling sea turtles are too rarely seen to discuss objectively, but Collard and Ogren (1990) are of the (minority) opinion that small turtles do not purposefully associate themselves with sargassum. They are found in or near convergence zones where they fetch up (with or without sargassum present) as buoyant plankters. Solitary loggerhead turtles are seen everywhere in shelf waters during warm water months.

Most of the leatherback turtles and marine mammals (save porpoises) observed by Collard on more than 40 cruises (1970-1994), were near watermass boundaries where their presumed forage was also concentrated. *Tursiops truncatus* and *Stenella frontalis* are the most common porpoises in panhandle waters. Although there is little evidence to support this speculation, the abundance of the latter species appears to be increasing in rough proportion to an apparent decrease in numbers of the former. *Ziphius cavirostris* (Cuvier's beaked whale), *Physeter macrocephalus* (sperm whale), and *Globicephala macrorhynchus* (short-finned pilot whale) are probably the most common species of large marine mammals in panhandle shelf waters.

Table 5-2 Habitat-depth assemblages described by Dames and Moore, (1979).

Shallow Sand Indicative Species:		
	Dasyatis sayi	[bluntnose stingray]
	Eucinostomus gula	[silver jenny]
	Micropogon undulatus	[Atlantic croaker]
Deep Reef Indicative Species:		
	Holocentrus bullisi	[deepwater squirrelfish]
	Chaetodon aya	[bank butterflyfish]
Sponge Reef Indicative Species:		
	Apogon quadrisquamatus	[sawcheek cardinalfish]
	Gobiosoma xanthiphora	[yellowprow goby]
Shallow Reef Indicative Species:		
	Hypoplectrus puella	[barred hamlet]
	Evermannichthys spongicola	[sponge goby]
	Epinephelus morio	[red grouper]
	Rypticus maculatus	[whitespotted soapfish]
	Astrapogon stellatus	[conchfish]
Mid-Shelf Sand Indicative Species		
	Synodus intermedius	[sand diver]
	Centropristis ocyurus	[bank seabass]
	Syacium papillosum	[dusky flounder]
	Sphoeroides dorsalis	[marbled puffer]

5.2.3 Data Gaps

1. Artificial reefs of various sizes and materials are being deployed with increasing frequency on the inner shelf. Some of these reefs are unstable during heavy storm conditions because of their small size and/or placement in inappropriately shallow water depths. While much has been written about the presumed benefits of artificial substrates (increased productivity, etc.), relatively little work has been done on assessing the possible negative impact of these materials on natural communities. For example, it would be of value to know whether the translocation and/or destruction of artificial reefs during the three hurricanes of 1995 negatively impacted live bottom communities in the vicinity of their original location.

2. The long-term impact of artificial reefs on the abundance and sustainable yields of recreationally and commercially important fish species remains unknown, although a relatively large literature on the subject is available.

3. An unknown, but possibly significant amount of military debris (e.g. aircraft, missiles, ordnance) has accumulated in shelf waters of the northeastern Gulf of Mexico. The short- and long-term ecological impact of this material should be assessed.

4. Propagules of tropical organisms (zooplankton, benthic invertebrates, fishes), are recruited onto the continental shelf during intrusions of Loop Current, or Loop Current Transitional Water. The extent, mechanisms, and impacts of nutrient and biotic coupling between Gulf of Mexico basin and shelf waters (including coastal embayments) should be documented.

5. The upwelling of nutrient-rich water south of Cape San Blas, and at the edge of the West Florida Escarpment is apparently common. Primary production in this water (the "Green River" seen in satellite images of the northern Gulf) may have a major trophodynamic impact on many or all water column and shelf ecosystems, and should receive intensive investigation.

6. The distribution of sargassum and its associated organisms in the eastern Gulf of Mexico has received scant attention. Remote sensing of the distribution of "Gulf weed" (primarily *Sargassum natans* and *S. fluitans*) may reveal valuable information about sea states and, more importantly, the distribution and longevity of frontal zones and frontal boundaries. Sargassum as an important habitat (e.g. for larval fishes; hatchling and post-hatchling sea turtles) has not been investigated in the eastern Gulf of Mexico.

7. The occurrence and impact of exotic invertebrate species introduced to shelf and estuarine waters via the release of ballast water has not been adequately investigated.

5.3 **Estuaries**

From Perdido Bay to Apalachicola Bay, much of the mainland coast is fronted by a series of estuaries and associated sounds. East of Ochlockonee Bay, the upper Big Bend coastline is entirely estuarine in terms of salinity, biota and ecological function.

Of the major estuaries west of the Big Bend, Pensacola, Choctawhatchee, and Apalachicola Bay-St. George Sound systems are coastal-plains drowned river valleys. These systems receive water from one or more rivers and streams, and discharge into coastal-trending sounds bounded by barrier islands. Brackish water from these estuary-sound systems flows via one or more passes between barrier islands into the Gulf of Mexico. St. Andrew Bay is also a coastal plain (bar-built) estuarine system, but unlike those named above, receives fresh water primarily from relatively small, non-fluvial streams and land runoff. Econfina Creek, the largest stream in the St. Andrew Bay watershed, enters the system indirectly via Deer Point Lake, which was created by a man-made dam at the mouth of North Bay. St. Joseph

Bay, Alligator Harbor and St. Andrew (Crooked Island) Sound are marine lagoons partially impounded by well-developed sand spits. St. Andrew Sound became decoupled from the St. Andrew Bay system as a result of Hurricane Eloise in 1975. All three marine lagoons have salinities near those of open Gulf of Mexico waters.

5.3.1 Environmental Setting and Characteristics of Florida Panhandle Estuaries

Ochlockonee Bay is the easternmost estuary in the panhandle that conforms to conventional estuarine classification schemes (see Kennish, 1989). Apalachee Bay is not impounded by land features, yet its brackish waters and biota clearly qualify it as an estuarine ecosystem. Apalachee Bay lies within the upper portion of the Big Bend region, and its geographical boundaries vary with the quantity and distribution of fresh water contributed by rivers, streams, springs and land runoff. Included among the larger streams entering Apalachee Bay are the Anclote, Pithlachascotee, Weeki Wachee, Homosassa, Chassahowitzka, Waccasassa, Ochlockonee, Aucilla, St. Marks, Crystal, Withlacoochee, Spring Warrior, Econfina, Fenholloway, Steinhatchee and Suwannee Rivers.

Pensacola, Choctawhatchee, St. Andrew and Apalachicola Bays are not unitary estuaries, but estuarine systems. The components of these systems (*i.e.*, connected bays and their associated bayous) exhibit non-trivial differences in their physical, chemical, and biological characteristics and, therefore, in their ecological functions. The Pensacola Bay System, for example, is comprised of Escambia, Blackwater, East and Pensacola Bays. Significant biological differences in these system components are attributable, in part, to differences in water received from distinct riverine watersheds and drainage basins. As an example, Blackwater Bay receives water from the Blackwater and Yellow Rivers. The former is an Outstanding Florida Water and the lower reaches of the latter are protected as an aquatic preserve. The moderately polluted Escambia River empties into a more heavily polluted Upper Escambia Bay. East Bay River discharges into East Bay which, until the mid- to late 1980s, was relatively pristine. Pensacola Bay receives water from, and is influenced by, each of these subsystems (*i.e.*, watersheds, rivers, bays) comprising the Pensacola System. The kinds, magnitudes of influence and interactions that component parts of the system have on one another are likely to be significant, but have not been described in detail (Collard, 1991).

5.3.1.1 Estuarine Climatic Features

Both local and regional climatic features influence the organization and fundamental characteristics of estuarine ecosystems. The seasonal and, in some cases, episodic impact of these abiotic variables on northeastern Gulf of Mexico estuarine systems are briefly discussed in the following paragraphs. A complete discussion of meteorological conditions within the study region is provided in Chapter 2 (Physical Oceanography and Meteorology)of this document.

5.3.1.2 Seasons

In the Florida panhandle, solar and biological "seasons" do not coincide, and the division of a year into three-month-long seasons (winter, spring, summer and fall) is not justifiable when evaluating seasonal changes in estuaries of the region, Using data from 1924-1942, Moskovits (1955) considered the following seasons to occur in the Pensacola region, based on an analysis of average temperature maxima and minima (the authors have modified his time intervals and terminology): winter occurs from December-February (or mid-March), for a duration of two and a half to three months; spring is a transitional period from March-May (or mid-March to mid-May), with a duration of two to three months; summer lasts from June-September (or mid-May to September), a duration of four to four and a half months; and fall, another transitional period, lasts from October-November, or for about two months. Both "summer" and "winter" may be longer than indicated in this scheme, and transition periods may be abrupt.

Fernald and Purdum (1992) suggested that from Pensacola through the middle of Taylor County, winter begins on 1 November or earlier, with an average maximum temperature of 75°F or lower. South of Taylor County, winter begins between 1 November and 1 December. Spring (from Pensacola to about Turkey Point) begins on 1 April or later, when the average maximum temperature rises to 75°F or higher. South of Turkey Point, spring begins between 1 March and 1 April. Summer (from Pensacola to about St. George Island) begins on 1 June or later, when the average maximum temperature reaches 88°F or higher. South of Apalachicola Bay, summer begins earlier, between 1 May and 1 June. Fall (Pensacola to about Steinhatchee) begins on 3-4 October, when the average minimum temperature falls to 60°F or lower. In the Cedar Key area, fall begins during the period 4 October to 1 November. The time of the first and last freeze of a given year are variable. In the panhandle, dates of the first and last freeze are 15 November to 15 December, and 1 March to late March, respectively. Seasons along the Florida panhandle coast are approximately as follows:

Season	Occurrence	Duration
Spring	March-April	2 months
Summer	May-September	5 months
Fall	October	1 month
Winter	November-February	4 months

Florida panhandle coastal areas experience two major seasons: a lengthy warm to hot summer, and an almost equally long cool to mildly cold winter. Spring and fall transitional seasons while of short duration, are periods of significant physical, chemical and biological change which are most pronounced in estuaries of the western panhandle.

5.3.1.3 Temperature

Seasonal air temperatures divide the climatically transitional panhandle into three "subregions" whose boundaries are discernable, but not sufficiently distinct to be considered biogeographical zones (discussed later in this chapter). The Pensacola Bay System, Big Lagoon, Santa Rosa Sound and the lower reaches of Choctawhatchee Bay, support a largely temperate fauna and flora year-round, and the incursion of tropical species into this area is relatively uncommon. St. Andrew Bay and the St. Andrew Sound lagoon are transitional warm-temperate embayments during cooler months, and gain a fair number of subtropical-tropical species during hot summer months, depending on upstream Gulf recruitment patterns (Hydroqual, Inc. and Barry A. Vittor & Associates, Inc., 1993). Many subtropical and all tropical invertebrates and fishes die during the winter. St. Joseph Bay, the Apalachicola System (including St. George Sound), Ochlockonee Bay, and Upper Apalachee Bay support a largely subtropical biota. Southern and deeper portions of this Big Bend estuary are increasingly subtropical, and some tropical species are present year-round (Myers and Ewel, 1990; Livingston et al., 1974 et seq.; Lyons and Collard, 1974; Collard, 1992, 1993, 1995 unpublished data).

5.3.1.4 Precipitation

The amount of fresh water discharged into panhandle estuaries (as pulses or average volumes per unit time) has a large impact on estuarine biota. Local and watershed precipitation patterns control river output which, along with winds, tides, and the strength of the pycnocline, influence assemblages of stenotopic (species with low physiological tolerances for changes in environmental conditions) sessile invertebrates and motile invertebrates and fishes. Episodic flooding of several days duration may cause mass mortalities of many species in any of the panhandle estuaries and, less frequently, in coastal lagoons such as St. Andrew Sound and the shallow portions of St. Joseph Bay.

Rainfall amounts vary in the panhandle from season-to-season, year-to-year, over shorter time scales (e.g., during large storms), and over longer periods of time (e.g., El Nino Southern Oscillation conditions). For this reason, the use of seasonal and annual averages must be used with caution.

According to Fernald and Purdum (1992), the area from Pensacola Bay through St. Andrew Bay receives roughly 60 inches of rain per year. Other forms of precipitation (snow, hail, etc.) are rare and insignificant. Some 25-30% of the annual total rainfall throughout the region falls during September storms and hurricanes. St. Joseph Bay receives 56-60 inches of rain each year, and the rest of the coastal panhandle receives 52-56 inches of rain annually. These figures should be used cautiously for modeling purposes, for they are somewhat misleading. The total amount of fresh water entering an estuary over a given period of time must be used to calculate the magnitude of forcing functions. Total precipitation in watersheds as well as runoff from rivers and the land surface, contribute very large volumes of fresh water to panhandle estuaries. Estimates or measures of river flows at the few gauging stations in the region provide accurate information, but do not account for the very large variation in output during even a single season. Thus, one of the most important abiotic variables affecting the hydrology, chemistry and biota of panhandle estuaries cannot be evaluated with acceptable levels of confidence.

5.3.1.5 Hurricanes and Storms

Williams et al. (1993) reported that from 1871-1922 (122 years), 180 of almost 1,000 North Atlantic hurricanes or tropical storms, "have struck, passed immediately offshore or adjacent to the Florida coastline." Historically, hurricane landfalls have been more frequent in the panhandle and southwest Florida than in other parts of the State. The favored statistic used in forecasting Florida hurricane landfalls is one per 10-15 years. Williams et al. (1993) have examined the possibility that hurricanes occur in temporal patterns or cycles. Between 1870-1880, four hurricanes struck eastern Florida from the east or southeast, and 17 struck the western Florida coast or the panhandle. This pattern continued through the turn of the century. From 1901-1930 there were fewer tropical storms (22 hurricanes and 17 tropical storms) than during the previous 30 year period, and more strikes came from the southeast. The worst of these destroyed Pensacola in 1906, and the city was again damaged in July 1916, October 1916, and September 1917. After 1919, the "cycle" of tropical cyclone activity changed, and most hurricane landfalls occurred in south Florida. Table 5-3 presents a list of Florida panhandle hurricanes occurring from 1885 through 1995. Additional information concerning tropical storms in the study area is presented in Chapter 2 of this report.

In addition to hurricanes and tropical storms, Florida experiences more thunderstorms than any place on earth except East Africa (Williams et al., 1993). For example, thunderstorms occur some 70-80 days per year in St. Andrew Bay. Winds associated with these convective storms promote turbulent mixing in shallow bays, which increases near-bottom dissolved oxygen concentrations.

5.3.1.6 Seasonal Wind Patterns

Prevailing winds are northeasterly in the Pensacola area during winter, and northerly in the remainder of the panhandle. In spring, Pensacola area winds are southeasterly, and southerly in the rest of the panhandle. During summer months prevailing winds are southwesterly, becoming southeasterly further to the east and south. In the fall, prevailing winds are northeasterly throughout the panhandle (Fernald and Purdum, 1992). During warm months, coastal winds in the panhandle are monsoon-like: onshore during the day, and offshore as land areas cool more rapidly than coastal waters (a sea-breeze system).

5.3.1.7 Estuarine Circulation

Accurate knowledge of water movements and their causes is fundamental to understanding the fate and transport of gasses, dissolved and suspended chemicals, plankton, and other biological conditions in estuarine systems. Water movements and the distribution of salinity in estuaries are influenced by river flow, tidal currents, seiching, Langmuir circulation, advective processes, winds, basin geometry, and many other factors, such as the semi-permanent gyres reported to occur in Tampa Bay and Upper Escambia Bay. Knowledge of the complex and highly variable circulation patterns and small scale, current and water column temperature/salinity profiling be imprudent to attempt to describe "characteristic" circulation patterns in any estuarine system using these data.

Table 5-3. Listing of Florida panhandle hurricanes from 1885-1995.

Date	**Primary Affected Area**
1856	Choctawhatchee Bay
1885	St. Joseph Bay
1886	Apalachicola Bay (2)
1887	Choctawhatchee Bay
1888	Big Bend
1894	Apalachee to Apalachicola Bays
1895	St. Andrew Bay
1896	Big Bend (Dixie Co.)
1898	Apalachicola Bay
1906	Pensacola; St. Joseph and St. Andrew Bays
1911	Pensacola Bay
1915	Apalachicola Bay
1916	Pensacola Bay (2)
1917	Pensacola Bay
1924	St. Joseph; St. Andrew Bays
1926	Pensacola Bay
1928	Apalachicola Bay
1929	Apalachicola Bay
1935	Big Bend (Taylor Co.)
1936	Choctawhatchee Bay
1941	Apalachicola Bay
1949	Apalachicola Bay
1950	Cedar Key
1953	Between Choctawhatchee and St. Andrew Bays
1956	Choctawhatchee Bay
1966	Apalachicola Bay
1968	St. George Sound
1972	St. Andrew to St. Joseph Bays [**Agnes**]
1975	Choctawhatchee to St. Andrew Bays [**Eloise**]
1985	Big Bend [Elena] Pensacola to St. Joseph Bay [**Kate, Juan**]
1986	Apalachee Bay [**Charley**]
1995	St. Joseph to Pensacola Bays [**Allison, Erin, Opal**]

5.3.1.8 Tides and Sea Levels

Two general tidal patterns are observed in the panhandle: diurnal, from Pensacola Bay to Cape San Blas; and mixed semidiurnal, from Apalachicola Bay to Ochlockonee Bay. Tidal ranges along the panhandle coast have amplitudes ranging from 0.4 - 1.2 m. Tidal amplitudes along the coast are somewhat greater east of Cape San Blas; however, the tidal range experienced on both the coast and within a given estuary is significantly influenced by wind velocity, direction and duration. Tidal currents in panhandle estuaries are generally weak, except in lower reaches near passes and channels communicating with the Gulf of Mexico (e.g. East Pass Channel at Choctawhatchee Bay). These currents aid in mixing processes, but may not result in net transport (e.g. of nutrients, pollutants, plankton) over a tidal cycle. Circulation and diffusion in some estuaries (e.g. Pensacola Bay) are too weak effectively to reduce pollutant concentrations through mixing processes.

On the northeast Gulf coast, monthly sea level rises above the mean annual level beginning in May, and remains above the mean level from June through December. Higher sea levels coupled with southerly (*i.e.*, monsoonal) winds, result in increased marsh flooding even on neap tides (Stout, 1984). Annual sea level cycles are ecologically important, particularly in shallow relief regions of the panhandle (*e.g.*, Apalachee Bay) where salt marsh abundance may increase or decrease significantly in abundance over the course of a year.

5.3.1.9 Data Gaps

1. Perhaps the single most important data gap in the northeastern Gulf of Mexico database is the lack of knowledge of estuarine circulation patterns, and how these vary with tides, river flows, seasonal temperature changes, winds, and inner shelf currents. Detailed information about currents and mixing processes in terms of local forcing functions is prerequisite to understanding the fate, transport and distribution of salinity, dissolved oxygen, nutrients, toxicants, plankton, turbidity and other variables needed to create useful models of these systems.

2. There is a significant need for knowledge about the extent and importance of coupling (exchanges of nutrients, toxicants, suspended materials) between estuaries and coastal waters.

3. Little is known about the amount or impact of watershed or local stormwater runoff into northeastern Gulf estuarine systems. There are far too few river gauging stations in place.

5.3.2 Environmental Quality of Panhandle Estuaries

Most of the physicochemical characteristics used to evaluate estuarine quality are highly variable over relatively short time scales. Among these characteristics are circulation patterns, the distribution of dissolved and particulate substances, pollutant and nutrient loading, water and sediment quality, stormwater and river runoff, chemical kinetics and human use patterns. Because of variability, both "snapshot" assessments and trends in estuarine environmental quality are often difficult to discern. For example, when predictable low dissolved oxygen levels occur near the bottom during summer months and a fish kills results, an estuary may be judged to have poor water quality (Collard, 1991). In contrast, when industrial wastewater discharges into panhandle estuaries decreased during the economic downturn of the 1970s, a gradual improvement in water quality was erroneously declared to be a trend. Many short-term changes (e.g., in fishing pressure, occurrences of toxic algal blooms, dredging activities and watershed precipitation) may incorrectly suggest that favorable or unfavorable trends in estuarine quality have begun (Olinger et al., 1975; Collard, 1991).

Population growth in the Florida panhandle has increased dramatically in the past 20 years, particularly in urban areas surrounding the Pensacola, Choctawhatchee, and St. Andrew Bay systems (Florida Statistical Abstracts, 1994). Environmental impacts of this growth, which is forecast to continue, are poorly understood and have been underestimated. Historical descriptions of coastal environments that have significantly changed or no longer exist (e.g. salt marshes, seagrass meadows, oyster reefs) as a consequence of population growth and development must be used with caution.

Three hurricanes impacted shallow shelf, estuarine and salt marsh environments of the panhandle during 1995. The last and most damaging storm of the year, Hurricane Opal, struck the area in October 1995 as this report was being written, and much of the pre-hurricane environmental information being used to characterize coastal ecosystems became problematic within a matter of hours. The impacts of these storms on coastal and nearshore habitats and biota have not been published to date.

5.3.2.1 Estuarine Pollution

Pollutants such as oil, heated water, nutrients, caustic substances and poisons enter estuaries via urban, agricultural and construction site runoff, domestic and industrial wastewater, land disposal and mining operations. These, and other pollutants, may drastically affect estuarine communities such as seagrass meadows. Species react in different ways to pollution stress, depending upon their dispersive capability, stage of development, numbers, tolerance limits and physiological state; and on the type of pollutant and its concentration and residence time in the environment.

As noted by Hand et al. (1994) in their review of panhandle estuaries, "The assessment of public health and aquatic life impacts found several concerns. Many of these problems are associated with estuaries and are of a persistent nature." Examination of the literature suggests that most panhandle estuaries are pollution sinks (e.g. McNulty, 1961), and it appears that most estuaries have been anthropically impacted to some degree. The extent to which individual estuaries, bayous, and lagoons are "polluted" is only superficially discussed in the present review. The amounts, distributions, residence times, interactions, and effects of pollutant substances (in the broadest sense) or pollution conditions (e.g. turbidity levels, color, dissolved oxygen concentrations, low/high pH, elevated biological, chemical or sediment oxygen demand [BOD, COD or SOD, respectively]; seagrass scarring; and habitat destruction) on species, communities and ecosystems, are highly variable and (quantitatively) poorly known. Symptoms of pollution, such as fish kills, algal blooms, turbidity, declining fisheries, closed shellfish harvesting areas, and decreased swimming and fishing activities are noted in subsequent sections where recent data were available.

According to Paulic and Hand (1994), "Water quality problems are evident around the densely populated, major urban areas such as... Pensacola..." No other estuaries in the panhandle were mentioned. These authors found that 63% of the total estuarine areas evaluated fully supported, and 33% partially supported their designated uses. Paulic and Hand (1994) concluded that the primary causes for water bodies not fully supporting their designated uses varied by water body type. For estuaries, "[the] primary causes are identified as algal blooms, nutrient enrichment, suppressed dissolved oxygen levels, and turbidity." No estuaries in the panhandle region were found to be "worse." "No change" was reported for Apalachicola Bay and the mouth of St. Andrew Bay. Big Lagoon (between Perdido and Pensacola Bays) was found to be "better" in terms of its designated use.

5.3.2.2 Nutrients

The susceptibility of estuaries to nutrient discharges may serve as an important indicator of the future condition of their habitats and faunal assemblages. Pensacola Bay was found to have a "medium susceptibility" to increases in the concentration of dissolved substances, and was in the "medium range" for additional Total Kjeldahl Nitrogen (TKN) and phosphorus. Pensacola Bay was "not likely to be influenced by minor changes (< 20%) in nutrient loadings." St. Andrew Bay also had a "medium" susceptibility for dissolved substance concentrations, but was "in the low range for TKN and phosphorus... [and] not likely to be influenced by minor changes (< 20%) in nutrient loadings (Paulic and Hand, 1994). Other estuaries in the panhandle had low susceptibility to increased nutrient loadings.

5.3.2.3 Metals

According to Paulic and Hand (1994), toxic metals in the water column of panhandle estuaries included: As, Cd, Cr, Cu, Fe, Pb, Hg, Ni and Zn. Water column concentrations of Hg, Fe and Pb were generally above Florida standards, which are determined as a function of water hardness (*assumed to be 100 mg/l as calcium carbonate). Florida metals criteria (ppb) are:

As = 50 Cd = 1.1 Cr = 207*
Cu = 12* Fe = 1000 Pb = 3.2*
Hg = 0.012 Ni = 158* Zn = 106

5.3.2.4 Sediment Contaminants

Isphording (1983) stated that, "The true pollutant hazard of a bay or estuary can ... be most accurately evaluated by analysis of the fine particulate matter that occurs in the colloidal phase just above the sediment-water interface." This latter type of information is not available for the panhandle estuaries. However, information on contaminants within sediments is presented as Table 5-4 (from Paulic and Hand, (1994).

Table 5-4. Summary of sediment contamination for panhandle estuaries by habitat (from Paulic and Hand, 1994).

Habitat	**Contaminant**
Suwannee Sound	PAH
Apalachee Bay	PAH, PCB, Pesticides
Apalachicola Bay	PAH, PCB, Pesticides
Choctawhatchee Bay	PAH, Pesticides
Boggy Bayou	PAH, Pesticides
Old Pass Lagoon	PAH
Pensacola Bay	PAH, PCB
Bayou Grande	PAH, PCB, Cd, Cr, Hg, Pb, Zn
Bayou Chico	PAH, PCB, Cd, Cr, Hg, Pb, Zn
Escambia Bay	PAH, PCB
Pensacola Harbor	PAH, PCB
East Bay	PAH
Lower Pensacola Bay	PAH, PCB
St. Joseph Bay	Hg, Pb, Zn
St. Andrew Bay	Zn, Pb, Cu, PAH, PCB, Pesticides
Watson Bayou	Cd, Hg, Zn, PAH, PCB, Pesticides

5.3.2.5 Data Gaps

1. "Water quality" monitoring in panhandle estuaries is generally accomplished in the immediate vicinity of known industrial or domestic effluent outfalls for compliance purposes. Many, perhaps a majority, of these data are not entered into the STORET database (Collard, 1991). Biannual 305(b) statewide assessments of environmental conditions and quality, which are largely based on STORET data, do not provide accurate status and trend reports on panhandle estuaries, and may be misleading.

2. The assimilative capacity of nutrients and toxic substances in panhandle estuarine water and sediments is not known in sufficient detail. Until estuary-specific information on circulation and mixing processes is understood, quantitative determinations of loading and assimilative capacities can not be made.

3. Integrated, multidisciplinary, monitoring programs of estuarine

physical, chemical, sedimentological and biological conditions are needed to understand and evaluate environmental conditions and trends in panhandle coastal environments.

5.3.3 Estuarine Habitats

This section provides a brief review of seagrass, salt marsh and oyster reef communities because of their significant functional importance in panhandle estuaries. Less well-known assemblages are described to the extent that relevant information was available.

5.3.3.1 Salt Marshes

Salt marshes are complex coastal communities usually dominated by one or a few species of relatively large, perennial, salt-tolerant, or halophilic plants (e.g., *Juncus roemerianus*, *Spartina* spp.), and the microbiota, flora and fauna associated with them. Dominant plant species may be intertidal (*J. roemerianus*, *S. alterniflora*), or live above mean sea level (MSL) with their roots in hydric, salty soils (e.g., *Spartina patens*).

Distribution

According to Stout (1984), large, well developed, but discontinuous stands of *Juncus roemerianus* border the low-energy shorelines, sounds, lagoon and bays from Cedar Key to the Pearl River estuary in Mississippi. South of Cedar Key, mangroves begin to co-dominate with *J. roemerianus*. FDEP (1994) reported that, "Salt marshes dominate the coastal landscape from Apalachicola Bay to Tampa Bay... [but] West of Apalachicola Bay, estuaries have few salt marshes." These apparently disparate assessments are artifacts of perception. Salt marshes along the low-relief Big Bend coast are more extensive in area than those in the western panhandle. However, significantly large areas of non-urbanized, low-relief shorelines and river floodplains of the panhandle support well-developed salt marsh communities, as do barrier island sound-side shorelines (e.g. Crooked Island, Santa Rosa Island). *J. roemerianus* dominates 31% of the marsh areas in the Florida panhandle (Stout, 1984).

Ecological Functions

According to Stout (1984, and authors cited therein), salt marshes have four major ecological functions. First, large quantities of organic matter are produced per unit time. Some of this detritus remains in the marsh as peat; some is recycled in marsh food webs; some is (passively or via consumers) transported out of the marsh; and some is dissipated into estuaries. Second, marshes are the exclusive habitat of several species of algae and seed plants, a large variety of invertebrates and birds, and numerous species of reptiles and mammals. A third function is that these areas provide substantial protection to adjacent low-lying uplands from saltwater intrusion, coastal erosion, drifting debris, and salt spray. According to Stout (1984), marshes protect shores only in major embayments, such as St. Andrew and Choctawhatchee Bays. However, *J. roemerianus* marshes provided at least some protection to shorelines around Escambia Bay, Santa Rosa Sound, St. Andrew Sound and St. Joseph Bay during Hurricane

Opal (unpubl. data). The fourth ecological function of salt marshes described by Stout (1984), is their importance as nursery grounds for commercial and sport species. Odum and Smith (1981) elaborated on this function of marshes, noting that in fish and wildlife life history cycles, marshes provide (1) sites for reproduction, (2) a conducive environment for early life stages (*i.e.*, they play a "nursery" role), and (3) areas where young animals can find and utilize concentrated, high quality food.

Table 5-5 provides an estimate of the relative value of three subsystems of coastal marshes (*i.e.*, high marsh, intertidal marsh and tidal channels) to various animal groups, without consideration of any indirect value of the high marsh to fishes, such as the export of dissolved organic carbon. Table 5-6 estimates relative importance of coastal marshes to the life-history functions of these same three principal animal groups, and Table 5-7 presents a partial listing of some estuarine-dependent species from the Gulf and southeast Atlantic coasts.

Intertidal Marsh Flats

It has been reported that the most abundant infaunal animals inhabiting intertidal marsh substrates are crustaceans and polychaetes (Whitlach, 1982; Montague and Weigert, 1990). Marsh infauna are represented by the following feeding guilds: surface deposit feeders; suspension feeders; conveyor-belt deposit feeders and burrowing deposit feeders; as well as herbivores, detritivores, carnivores and omnivores. These animals serve as forage for a large number of predatory animals, including birds, crabs and fishes.

Table 5-5. Relative value of indicated marsh subsystems to listed animals (from Table 1, Odum and Smith, 1981).

Animal	**High marsh**	**Intertidal marsh**	**Tidal channels**
Fishes	Low-Moderate	High	High
Waterfowl	High	Mod.-High	Mod.-High
Furbearers	High	High	Moderate

Table 5-6. Relative importance of coastal marshes for three life-history functions of the three principal animal groups found in marshes (from Odum and Smith, 1981).

Animal Groups	**Reproduction**	**"Nursery"**	**Feeding**
Fisheries			
Finfish	Low	High	High
Shellfish	High	High	High
Waterfowl	Low-Moderate	Low-Moderate	High
Furbearers	High	High	High

Table 5-7. Listing of some of the estuarine-dependent species from the Gulf and southeast Atlantic coasts (from Odum and Smith, 1981).

Common Name	Scientific Name	Use
Menhaden	*Brevoortia* spp.	N,F
Mullet	*Mugil* spp.	N,F
Spotted seatrout	*Cynoscion nebulosus*	N,F
Grey seatrout	*C. regalis*	N,F
Sand seatrout	*C. arenarius*	N,F
Red drum	*Sciaenops ocellatus*	N,F
Tarpon	*Megalops atlantica*	N,F
Silver perch	*Bairdiella chrysura*	N,F
Croaker	*Micropogon undulatus*	N,F
Spot	*Leiostomus xanthurus*	N,F
Jacks	*Caranx* spp.	N,F
Summer flounder	*Paralichthys dentatus*	N,F
Striped bass	*Morone saxatilus*	S,N,F
Bluefish	*Pomatomus saltatrix*	N,F
Shrimp	*Penaeus* spp.	N,F
Blue crab	*Callinectes sapidus*	N,F
Oyster	*Crassostrea virginica*	S,N,F
Bay scallop	*Argopecten irradians*	S,N,F

(N = nursery dependence, F = feeding by juveniles and adults, and S = spawning dependence).

Salt Marsh Microbial Communities

Within the *Spartina* spp.-*Juncus-Distichlis spicata* communities of Mississippi and Alabama, 60 species of fungi, yeasts and actinomycetes were recorded (Stout, 1984). Plate counts were always highest on the surface. In below ground plates, counts were always lowest in *Spartina alterniflora* areas. A survey of Florida panhandle salt marshes -- dominated by the same plants -- would likely yield a similar diversity of microbes.

Salt Marsh Invertebrates

In her survey, Stout (1984) found the following invertebrates to be among the common and abundant animals in salt marshes:

Meiofauna: nematodes, harpactacoid copepods

Insects: flies, bugs, beetles.

Polychaetes: *Scoloplos fragilis; Neanthes succinea; Amphicteis gunneri; Laeonereis culveri.*

Molluscs: *Littoraria irrorata; Polymesoda caroliniana; Neritina* *usnea; Melampus bidentata; Cerithidea scariformis; Detracia floridana.*

Crustaceans: *Halmyrapseudes bahamensis; Cyathura polita; Palaemonetes pugio; P. intermedius; Callinectes sapidus; Uca* spp.

Salt Marsh Fishes

Fishes species listed by Stout (1984) as common representatives of salt marshes are presented in Table 5-8. As with most of the non-insect invertebrates, most of the fishes listed are not salt marsh-limited, and are frequently collected in nearby sand flat, seagrass and oyster reef habitats.

Table 5-8. Common fishes found in salt marshes (from Stout, 1984).

Common Name	**Scientific Name**	**Status**
tidewater	*Menidia beryllina*	permanent
longnose	*Fundulis similis*	permanent
Gulf killifish	*F. grandis*	permanent
marsh killifish	*F. confluentis*	permanent
sheepshead	*Cyprinodon variegatus*	permanent
diamond	*Adinia xenica*	permanent
sailfin molly	*Poecilia latipinna*	permanent
spot	*Leiostomus xanthurus*	nursery user
bluefin	*Lucania parva*	permanent
bay anchovy	*Anchoa mitchilli*	nursery user
striped mullet	*Mugil cephalus*	nursery user
pinfish	*Lagodon rhomboides*	nursery user

Salt Marsh Birds

Stout (1984) reported that five orders and 41 species of birds were known to nest, roost, forage or visit salt marshes of the northern Gulf of Mexico. While her list is not repeated here, we note that birds are trophically important components of salt marsh food webs: as consumers (predators, scavengers, seed eaters); prey (eggs, young and adults are eaten by raptors, mammals, snakes); and as contributors of nutrients via their fecal deposits.

Data Gaps

1. The post-hurricane areal extent and species composition of salt marshes has not been adequately assessed.

2. Except in general terms, nutrient cycling via microbial and detrital food webs within salt marsh areas of panhandle coastal ecosystems have not been sufficiently investigated.

3. Trophodynamic coupling (i.e. import and export of organic carbon) between salt marshes and estuaries is unknown, except in general terms (see Data Gaps 1 and 2).

5.3.3.2 Submerged Aquatic Vegetation (Excluding Algae)

The dominant forms of submerged aquatic vegetation (SAV) in brackish waters are seagrasses. This taxonomic group of plants is emphasized in the following discussion, along with two non-seagrass species, *Vallisneria americana,* and *Ruppia maritima*. *Vallisneria americana* is found in abundance in fresh to slightly brackish water environments (e.g. at the mouths of rivers discharging into estuaries), and is ecologically important in these areas. *R. maritima* is widely distributed in estuarine and nearshore marine ecosystems, and is the ecologically functional equivalent of the true seagrasses.

Seagrasses are salinity-tolerant flowering plants which form patchy beds or meadows in estuarine and coastal marine waters at all but polar latitudes. They are neither true grasses nor strictly marine (Humm, 1953). Of approximately 12 genera of seagrasses worldwide (Dawes, 1987) those from the northern Gulf of Mexico include *Thalassia testudinum, Halodule wrightii, Halophila* spp. and *Syringodium filiforme*.

Seagrasses play important roles in the ecology of estuaries, and changes in their relative abundance can provide a direct measure of changes in the biological "quality" of an estuary. The decline and ultimate disappearance of seagrasses in the Pensacola Bay System during the 1970s and 1980s, for example, likely reflected declines in water quality, benthic animal diversity, and fisheries yields (Collard, 1991). According to the Florida Department of Natural Resources (1987), "Seagrasses are a valuable part of Florida's marine environment but they are disappearing at an alarming rate. Dredge and fill projects and degraded water quality, as well as other activities, are responsible for their precipitous decline."

Distribution

Major factors which determine the distribution of seagrasses are climate, salinity, light, and turbidity. These environmental factors and the difficult-to-define variable known as "water quality" also regulate the abundance, distribution and growth of seagrasses. *Halodule wrightii* is usually found in waters of 10‰ or greater, while *Thalassia testudinum* is usually found in water with average salinities greater than 20‰. *Ruppia maritima* is often found in mixed stands with other submerged fresh and saltwater species. *Halophila* spp. are usually found in abundance in waters of near ocean-strength salinities.

In general, seagrass beds cover a greater area in the eastern than in the western portion of the panhandle (Humm, 1953). Humm (1974) noted that, "The seagrass beds between Tarpon Springs and Port St. Joe are probably the most important community of the inner shelf in basic productivity. Apparently they far exceed the basic productivity of phytoplankton in the area they occupy, perhaps several thousand square miles of inner shelf bottom. Humm (1974) also noted that, "Our lack of knowledge of these seagrass beds is appalling."

BCM Converse, Inc. (1987) reported that, on an areal basis, St. Joseph Bay contains more seagrass than any other bay in the [western] Florida panhandle. In total acreage, the St. Andrew Bay system has more seagrass than any of the other panhandle estuaries. In contrast, Pensacola Bay effectively lost all of its once abundant seagrasses by 1976 (Collard, 1991). This estuarine system has, since approximately 1955, been one of the most anthropically impacted estuaries in the Florida panhandle.

The distribution of Florida seagrasses is currently being mapped by the Florida Marine Research Laboratory (FDEP, St. Petersburg, unpublished data); their GIS-formatted maps should provide very accurate distribution and abundance information. Table 5-9 summarizes the distribution of seagrasses in the panhandle as of 1984.

Ecological Functions

In those estuaries and shallow shelf waters of the panhandle where they occur, seagrass meadows, and to a lesser extent, smaller patches (seagrass beds), have a number of critical ecological functions. According to numerous authors (summarized in Wolfe et al., 1988), these include: trapping and stabilizing bottom sediments; producing and exporting photosynthate; serving as direct food sources for invertebrates, some fishes and green sea turtles; producing large quantities of detritus and dissolved organic matter; providing substrate for microbes, algae and invertebrates that are a food source for other organisms; providing refuge for small and/or young invertebrates and fishes from larger predators; providing habitat(s) for epifauna, infauna and fishes; and linking trophic dynamic-biogeochemical cycles of coastal areas. Numerous fishes (e.g. speckled trout) and commercially important invertebrates (e.g. scallops) have been reported to require seagrass as nursery areas and/or sources of forage (e.g., Heck and Thoman, 1984; Zieman et al., 1984; Wooters, 1990).

Community Structure

Kikuchi and Peres (1977) reported four sub-habitats associated with seagrasses: sediment fauna; rhizome and stem animals (e.g. amphipods, bivalves, polychaetes); leaf periphyton (microbiota, anemones, hydroids, ectoprocts, crustaceans, echinoderms, nematodes, polychaetes, gastropods); and nekton which swim among the leaves (e.g. crustaceans, fishes). In his review of seagrass-associated invertebrate communities of thesoutheastern United States , Virnstein (1987) reported considerable faunal diversity and temporal variability within and between sites. Many species, especially decapod crustaceans, were widely dispersed, but dominant species were similar in most areas. Virnstein observed that while some combination of crustaceans, gastropods and polychaetes dominated in all seagrass areas, the structure of communities, even at nearby sites, was widely variable in both space and time.

Certain species of macrofaunal predators such as *Lagodon rhomboides* and *Penaeus duorarum,* were found to have a significant impact on invertebrate distribution and abundance. These species and others (*Lytechinus variabilis, Fasciolaria* spp., *Busycon* spp., etc.), are abundant throughout Florida seagrass ecosystems.

Table 5-9. Distribution of seagrasses in the panhandle (from Savastano et al., 1984).

Water Body	Bottom Area	Seagrass
Alligator Harbor	1,637	261
St. George Sound	30,762	3,392
East Bay	3,981	1,434
Apalachicola Bay	20,960	1,125
St. Vincent Sound	5,540	10
St. Joseph Bay	17,755	2,560
St. Andrew Sound	1,906	151
East Bay [St. Andrew]	7,557	464
St. Andrew Bay	10,615	1,029
West Bay	7,118	626
North Bay	2,704	417
Choctawhatchee Bay	34,949	1,252
Santa Rosa Sound	9,947	1,897
East Bay [Pensacola]	14,906	0
Escambia Bay	9,754	0
Pensacola Bay	16,435	627

Trophic Considerations

Submerged plant communities trophically link terrestrial, intertidal and aquatic communitie found in estuarine ecosystems. For example, seagrasses are important primary producers, consumers of nutrients through both their leaves and roots, and a source of energy in detrital food webs. Detritus allows nutrients to be retained in sediments, or recycled by microbially-mediated chemical processes which provide the main source of nutrients for seagrass growth (McRoy and Barsdate, 1970; McRoy et al., 1972; Zieman, 1987).

Seagrasses are slow to decompose, which may result in a "time release mechanism" in the detrital cycle (Zieman, 1987). Detritivores typically assimilate nutrients associated with detrital microflora with efficiencies of 50% to nearly 100%. Cammen (1980), for example, found that 26% of the carbon requirements, and 90% of the nitrogen requirements of deposit-feeding polychaetes were met by their ingestion of microbial biomass generated from plant detritus. Carbon is exported as particulate or dissolved organic matter (Fenchel and Jorgensen, 1977; Lee, 1980). A generalized food web is depicted as Figure 5-6.

In a study in Texas bays, more than 340 animals were reported to consume seagrass tissues (Fry and Parker, 1979). However, the energy flow models of Stewart (1975) and Thayer et al.(1975) estimated that invertebrate macrofauna consumed about 75% of net primary production. These authors (in

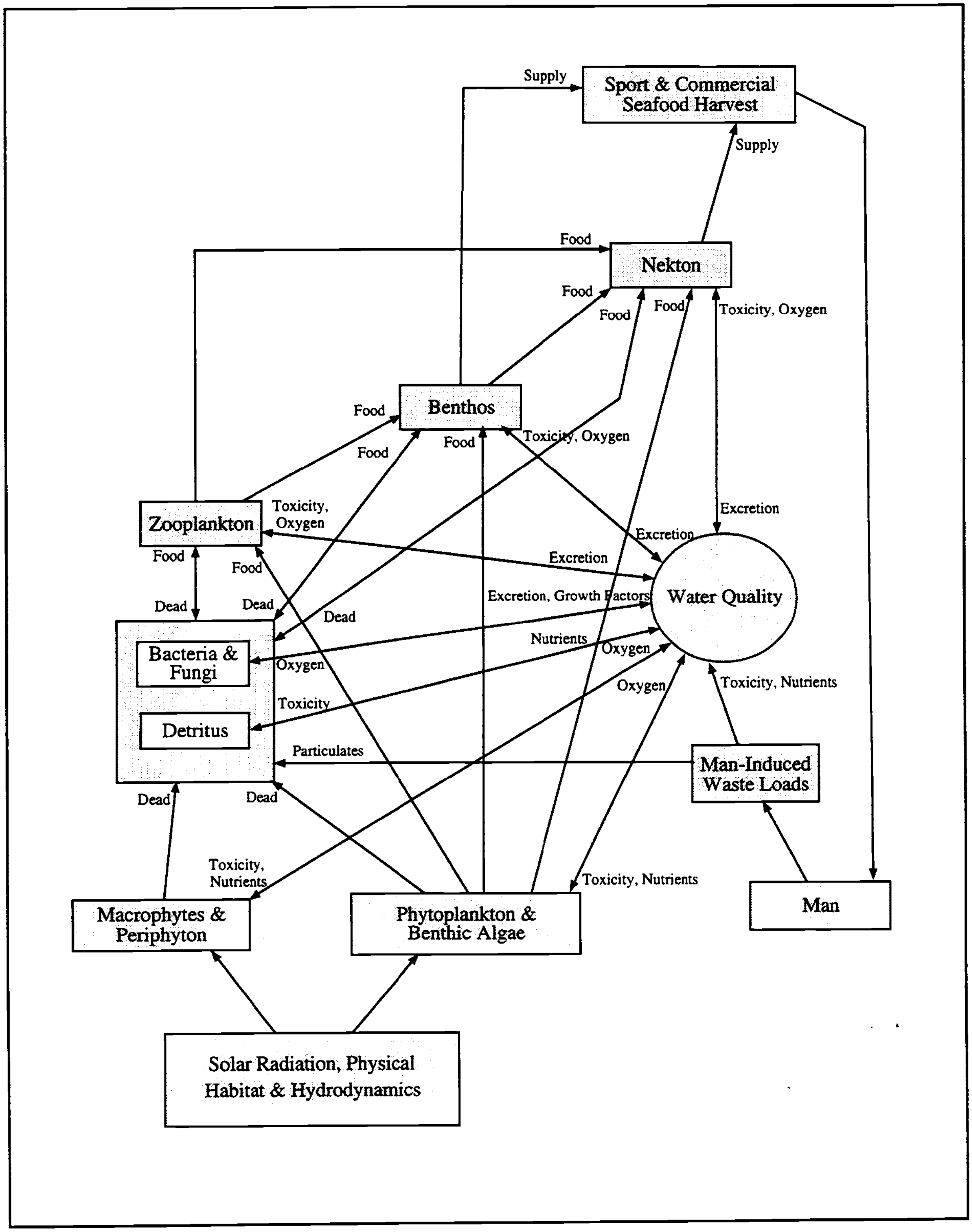


Figure 5-6. Energy flow in a generalized food web (from Seaman, 1985).

Zieman, 1987) suggested that the predominant pathway of energy flow through seagrass ecosystems occurs in the following sequence: senescent seagrass leaves colonized with very large numbers of aufwuchs (fouling organisms) fall off and drift to the bottom where they decay via microbial digestion, and/or are eaten by invertebrates which recycle nutrients through the microbial loop. In addition to the downstream drift of detrital particles, some nutrient export into adjacent areas probably occurs via the fecal deposits of motile herbivores (e.g. shrimp, sea urchins) and carnivores.

Stingrays and Propeller Scars

The progressive disappearance of seagrass meadows in the Florida panhandle has been attributed primarily to dredge and fill projects and degraded water quality (Florida Department of Natural Resources, 1987). The general causes of seagrass declines were discussed in an earlier section of this report (Estuarine Pollution). Here, two additional causes of seagrass damage are mentioned. The first (destruction by stingrays) is relatively minor and biological in nature; and the second (propellor scarring) is a major, anthropic cause of seagrass destruction that appears to be increasing, but can be mitigated. Valentine et al. (1994) reported that stingrays *(Dasyatis americana)* and sand dollars *(Mellita quinquiesperforata)* did not damage the root-rhizome system of *Thalassia* in St. Joseph Bay, but caused damage in *Zostera* beds. Collard (unpubl. data) found that adult *D. sabina* and *D. americana* caused significant damage to the root-rhizome system of *Halodule wrightii* in St. Andrew Sound. The rays made hundreds of one- to two-meter-wide feeding depressions in shoal grass beds that, during the period of observation (1992-1995) have not recovered. Stingrays have also enlarged unvegetated patches created by bioturbating organisms. Sand dollars have not been observed in the seagrass beds in St. Andrew Sound, although they are quite abundant in subtidal sand-flat habitats. Stingrays enter the Sound by the thousands during spring, and the cumulative impact of their feeding activities has been significant in controlling the distribution and density of *Halodule*. It is believed that stingrays may have a non-trivial impact on *Halodule* and a lesser impact on *Thalassia* in the panhandle estuaries and lagoons used as nurseries by these animals. Sargent et al. (1995) summarized data on the impact of boat propeller scarring in seagrass beds. An increase in recreational boating accompanying recent population increases near panhandle estuaries has accelerated the destruction of meadows already severely stressed by other human activities. Most of the scarring observed in 1992-1993 aerial surveys occurred in water less than 2 m deep. Most scarring was "light" (less than 5% of the seagrass community was scarred). The panhandle andBig Bend area had the least "medium" and "severe" (> 20%) scarred acreage, but in western panhandle embayments, "medium to severe" scarring was prevalent in the few acres of seagrasses still remaining. The authors observed that in areas with little seagrass acreage, any scarring may have a critical effect on habitat functions. *Halodule* was found to recover faster (0.9-1.8 years) than *Thalassia* (10 years, or never) because of the shallower rhizome-root system in the former. *Halodule* is usually the first seagrass species to recolonize an area.

Table 5-10 documents the acreage of scarred seagrasses to the nearest ten acres in each Florida coastal county, and Table 5-11 presents the same information as percentages.

Data Gaps

1. Post-hurricane areal distributions of SAV have not been documented.

2. The contribution to primary and secondary production by SAV-associated organisms (epiphytes, drift algae, motile invertebrate species) is unknown for most of the region. For example, while St. Andrew Bay, St. Andrew Sound, and St. Joseph Bay are geographically close neighbors, SAV in each system supports significantly different assemblages of epiphytes, which may be reflected in different community trophic structure (Collard, unpubl. data).

3. Trophic coupling between SAV, marsh and oyster reef communities has not been determined.

4. The meaning of "SAV-dependent", especially with respect to fishes (e.g., *Cynoscion nebulosus*) is often unclear or problematic.

5. The true cause(s) of SAV die offs in most panhandle estuary-lagoon systems have not been determined.

5.3.3.3 Oyster Reefs

Oyster reef communities form the structural and functional bases of the preeminent hard-substrate faunal assemblages found in panhandle estuaries. *Crassostrea virginica* is the keystone species of a reef biocenosis that includes several hundred species (Wells, 1961). Because they inhabit estuaries which are increasingly surrounded by people and their waste products, these animals are particularly vulnerable to anthropic stressors. Large, episodic swings in the health and abundance of oyster reefs are relatively common, and localized mass mortality events are not uncommon. Prolonged periods of low dissolved oxygen levels during periods of warm weather and intense water column stratification, may severely stress, and sometimes cause the death of oyster communities. The susceptibility of oysters to microbial pathogens (*Vibrio* spp., *Pseudomonas* spp. and *Perkinsus marinus*) also increases when water temperatures are high; *P. marinus* may be the cause of mass mortalities in *C. virginica*. Oyster reefs may be suffocated by excessive sedimentation from floods, storms, or dredge and fill operations. The impact of dredging on oyster communities has long been a subject of controversy (e.g. Florida Department of Environmental Regulation, 1984; Isphording et al., 1984; Schropp and Windom, 1988; Goldberg, 1990). Regardless of the method used to remove or displace sediments, some increase in turbidity always occurs in the immediate vicinity of the dredging site. Clearly, however, the degree to which turbidity increases, length of time it persists, size of the affected area, duration of time that non-particulate sediment constituents remain in the water column, and sedimentation rates and fallout patterns, depend upon a wide range of chemical (e.g. toxic substances in the sediments) and

Table 5-10. Acreage of scarred seagrasses to the nearest ten acres in each Florida coastal county (after Sargent et al., 1995).

County	Acreage					
	Total	**Light Scarring**	**Moderate Scarring**	**Severe Scarring**	**Mod/sev. Scarring**	**Total Scarring**
Bay	10,530	4,050	820	80	900	4,950
Dixie	111,130	2,470	1,020	0	1,020	3,490
Escambia	2,750	510	180	10	190	700
Franklin	19,840	440	370	0	370	810
Gulf	8,170	4,200	530	110	640	4,840
Jefferson	10,500	420	80	0	80	510
Levy	132,400	9,970	120	0	120	10,090
Okaloosa	3,450	310	80	0	80	390
Sta. Rosa	2,270	450	110	0	110	560
Taylor	162,860	8,100	60	0	60	8,160
Wakulla	29,630	2,060	730	0	730	2,790
Walton	710	10	0	0	0	10
State Totals	**2,658,290**	**109,870**	**48,630**	**15,470**	**64,100**	**173,960**

(Light scarring = presence of scars in less than 5% of the delineated polygon; moderate scarring = 5-20%; severe scarring = more than 20%.

physical variables (e.g. local current patterns), as well as the relative proximity of the dredge site to oyster reefs and co-occurrence of other stressors. Since, in the aggregate, these variables are unique at and in the vicinity of each dredging location, any speculation about the general impact of dredging on oyster communities would be frivolous. In a worst case scenario, a relatively large volume of hopper-removed, contaminated, fine sediments, dredged from a stressed (e.g. eutrophied, polluted) estuary in mid-summer, near a stressed oyster reef, disposed overboard near the reef, could suffocate and/or poison, and/or severely depress the health of the community.

1. Increased turbidity would decrease downwelling light levels, and algae associated with the reef would die;

2. Suspension-filter-feeding animals (including oysters, polychaetes, ascidians and the like) would suffocate;

3. With the death of reef-associated organisms, biological and chemical oxygen demand would increase, and depress dissolved oxygen levels;

Table 5-11. Percentage of scarred seagrasses by intensity level within each Florida coastal county (after Sargent et al., 1995).

County	Percent					
	Total	Light Scarring	Moderate Scarring	Severe Scarring	Mod/sev. Scarring	Total Scarring
Bay	10,530	3.7	1.7	0.5	1.4	2.8
Dixie	111,130	2.2	2.1	0.0	1.6	2.0
Escambia	2,750	0.5	0.4	0.1	0.3	0.4
Franklin	19,840	0.4	0.8	0.0	0.6	0.5
Gulf	8,170	3.8	1.1	0.7	1.0	2.8
Jefferson	10,500	0.4	0.2	0.0	0.1	0.3
Levy	132,400	9.1	0.2	0.0	0.2	5.8
Okaloosa	3,450	0.3	0.2	0.0	0.1	0.2
Santa Rosa	2,270	0.4	0.2	0.0	0.2	0.3
Taylor	162,860	7.4	0.1	0.0	0.1	4.7
Wakulla	29,630	1.9	1.5	0.0	1.1	1.6
Walton	710	0.0	0.0	0.0	0.0	0.0
State Totals	2,658,290	4.1	1.8	0.6	2.4	6.5

Dredging would, under these possible, but unlikely circumstances, have some or all of the following consequences:

4. Individual animals, if not killed by the direct or indirect impacts of sedimentation, would be highly stressed, more susceptible to disease and predation, and unsuitable for human consumption;

5. The availability of hard substrate for recruiting spat would be reduced;

6 .Reproductive success would decrease for all members of the community;

7. The oyster community would be replaced by fugitive or opportunistic species of polychaetes, small bivalves and amphipods.

The U.S. Army Corps of Engineers is well-aware of the consequences of dredging under such conditions, and is required to avoid them when possible. Contractors may not be as knowledgeable. The more likely problem with dredging in estuaries is that: (1) the location and extent of viable oyster reefs may not have been adequately documented prior to dredging; (2) the health of oysters potentially threatened by dredging may not have been recently assessed; (3) contaminants in sediments to be dredged may not be known; (4) local current and mixing patterns may be variable and/or unknown; and (5) pre-dredging assessments, monitoring, and post-dredging assessment may be superficial, or not made at all. One or more of these five (of several other possible) problems may have adversely impacted oyster reef communities in panhandle estuaries, but there are no published data with which the question can be answered.

Major predators of oysters include *Busycon contrarium, Thais haemostoma, Callinectes sapidus, Menippe mercenaria, Melongena corona, Urosalpynx*, many other invertebrate predators, fouling and boring organisms, birds (e.g., herons, gulls), and mammals (e.g., raccoons, humans). Predation is reduced in salinities below about 15‰, which excludes some snails (e.g., *Thais*) and crabs (e.g., *Menippe*).

Since the ecological importance of oyster reefs is high, information on the distribution and area occupied by these animals is desirable. However, published estimates of area coverage must be used with caution, because the impacts of 1995 hurricanes on oyster reef communities in panhandle estuaries, while believed to have been extensive, have not been documented (FDEP, pers. comm.). Pre-hurricane (1993) data on some oyster harvesting areas are summarized by Paulic and Hand (1994).

Apalachicola Bay supports the largest number of oyster reefs in Florida and, despite periodic fluctuations as noted above, it is likely to retain its viable oyster reef communities. Other estuaries in the panhandle also had extensive oyster reefs, but their size has diminished greatly in the past two to three decades. It is suspected that the magnitude of loss in oyster reefs may be similar to that of seagrass meadows.

Depending on latitude, oysters in the northern Gulf generally spawn from March through October, when water temperatures reach and remain above 20°C. Mass spawning generally occurs at temperatures above 25°C. (U.S. Army Corps of Engineers, 1982, 1984). According to these authors, larvae drift in a westerly direction along the coast, and settle on any hard (or compact) substrate available. Physical oceanographic data on longshore drift do not entirely support the view of a general westward transport of planktonic oyster larvae.

The volume of water filtered by oysters is prodigious. Estimates are as high as 1500 times body volume per hour, independent of food, tide or time of day (U.S. Army Corps of Engineers, 1982, 1984). As suspension-filter-feeders, oysters rival the benthic tunicates (Collard, 1993).

5.3.3.4 Data Gaps

1. Biological organisms associated with oyster communities (especially microbes and algae) need to be assessed in terms of total community production.

2. Quantitative post-hurricane damage assessments need to be made and recovery rates monitored.

3. Inter-community trophic coupling needs to be assessed (e.g. SAV-

oyster reefs and bars; oyster reef-muddy bottom infaunal communities).

5.3.4 Estuarine Organisms and Communities

5.3.4.1 Primary Production

Discussions of primary productivity or production conventionally begin with taxonomic or narrative descriptions of producing communities, followed by estimates of the relative contributions made by each taxonomic group (as rates or yields) to the total amount of carbon fixed per unit area per unit time. Such values, when measured over a lengthy period of time, using multiple methods (to mitigate the inherent flaws of each method), are useful when: (1) comparing the relative productivity of different geographical areas or ecosystems; (2) evaluating the assimilative capacity of a body of water for nutrient loading/processing; (3) using the distribution and quantities of chlorophyll as indicators of physical oceanographic processes (upwelling, frontal boundaries); or (4) using chlorophyll c as an indicator of stress in eutrophic estuaries. Quantitative measures of productivity, in whatever form, and however carefully obtained, are estimates that must be used with caution in energy flow models.

Most surveys of primary producers in the water column emphasize large organisms, the diatoms and dinoflagellates. While important to total water column production, microflagellates, other nannophytoplankters and picoplankters (prochlorophytes, photo- and chemosynthetic bacteria) likely produce more, or much more photosynthate (organic compounds) than the first two groups.

In estuarine waters, there is often, but not always, a general increase of primary water column production with increasing salinities (toward the mouths of estuaries). Water column production is, however, considered by most authors to be less, or much less than the total production of seagrasses, their epiphytes, benthic algae, diatoms, bacteria, and cyanophytes. Water color, turbidity, salinity, nutrient availability, flushing rates, the presence/absence of toxic substances and herbivorous zooplankton are some of the many variables that influence variation in estuarine production. Primary production in nearshore shelf waters is also variable, and depends on those factors mentioned, as well as distance from shore. In general, nutrient levels and primary production decrease, and species diversity increases with distance from shore, except in areas of upwelling or frontal zones convergences. These latter regions, themselves variable in location and intensity, concomitantly support higher numbers of consumer individuals.

Data Gaps

1. Water column and benthic primary and secondary production are coupled in complex, poorly understood ways. Peaks of benthic secondary production may occur in the same area, or some distance away from areas of high primary water column production. These relationships require investigation.

2. Relationships between the microbial loop, water column, and benthic primary production need to be elucidated.

3. Relationships between "water quality" (e.g. transparency, nutrients, toxicants) and primary production need to be evaluated.

4. Relationships between levels of seasonal primary production and benthic species diversity need to be assessed.

5. Primary producers other than diatoms, dinoflagellates and seagrasses need to be assessed in terms of their contribution to total carbon fixation.

5.3.4.2 Zooplankton

According to numerous authors (e.g. Hopkins, 1973), the copepod, *Acartia tonsa*, is the principal holoplanktonic species in terms of biomass in estuaries of the eastern Gulf. The zooplankton biomass peaks during summer months, and increases with increasing salinities within estuaries (Hopkins, 1973). Seasonal incursions of ctenophores and chaetognaths into higher salinity estuaries, however, can result in rapid declines in zooplankton species diversity and numbers.

Shelf waters of the Gulf of Mexico advect a wide variety of meroplankton species into panhandle estuaries. These plankters fetch up in areas where the watermasses in which they are embedded take them. When appropriate biological, chemical or physical settlement cues and substrates are present, meroplankters leave the water column, metamorphose and become members of the benthos (Collard, 1991). Thus, whether or not a particular benthic species is present or absent in a given estuary during a given season or year, depends to a large extent on whether its pelagic larval stage was transported into the estuary by currents.

As an example, Livingston (1984) reported that 92% of the eggs and 75% of the larval ichthyoplankton in Apalachicola Bay were *Anchoa mitchilii* in 1975. Of the non-fish zooplankton, the copepod, *Acartia tonsa,* made up 92.5% of the catch in East Bay, and 68.2% in Apalachicola Bay. Barnacles made up 11.7% of zooplankton catches. Menzel (1971) reported that the only abundant zooplankters in Apalachicola Bay were the calanoid copepods *Acartia tonsa, Anomalocera ornata, Labidocera aestiva* and *Paracalanus crassirostris.*

The reported abundances of *Acartia tonsa* and *Anchoa mitchilli* in Apalachicola Bay are not remarkable, and agree with the findings of, for example, Hopkins (1966) in St. Andrew Bay. *Labidocera aestiva* and the other calanoid species reported by Menzel (1971) were also found by Turner et al (1979) in shelf waters of the panhandle.

The apparent paucity of zooplankton species listed in the previous two paragraphs should not be misinterpreted. Zooplankton assemblages of Apalachicola Bay waters are very diverse, as evidenced by the diversity of benthic species whose eggs and/or larvae are members of the meroplankton.

Data Gaps

1. The relationship between meroplankton and adult benthic communities in estuaries has not been adequately investigated. Whereas the water column may be of sufficient quality to support the eggs and larval stages of species that metamorphose and become members of the estuarine benthos as adults, sediment conditions may not support them following this habitat shift. This information would provide a much more accurate measure of estuarine conditions than is presently available.

2. Seasonal recruitment and export of larvae into and out of estuaries to/from coastal waters is poorly understood. It might be assumed, for example, that estuarine species diversity is high/low because of good/poor water/sediment conditions, when these measures of biological quality are actually the result of good/poor recruitment from shelf waters. This problem is one of a number of difficult, but important questions that involve coupling between the embayments (estuaries and lagoons) and shelf waters of the panhandle.

3. Flushing times under given tide and river flow conditions are not accurately known for any of the panhandle estuaries. Average flushing rates are of very little practical or theoretical value. For example, planktonic stages of species that require a period of time in brackish environments for development will perish (regardless of water or sediment quality, or substrate suitability and availability) if flushing rates are too slow, too rapid, or too variable. In the latter instance, higher than predicted seasonal, annual (or longer period) variability in benthic species assemblages may occur.

4. The advection of large numbers of non-fish plankton predators (e.g. chaetognaths, ctenophores, jellyfish, chondrophores) into an estuary may rapidly reduce the diversity and abundance of other zooplankton. Unless these predator "blooms" have been accounted for, reductions in plankton abundance may be erroneously attributed to degraded water quality conditions. When the inevitable dieoff of such predators occurs, and their bodies sink and decay, biological oxygen demand increases, and dissolved oxygen levels decrease, which may precipitate not only fish mass mortalities, but benthic invertebrate dieoffs. These occurrences have occurred in the Pensacola Bay system (Collard, 1991), and were attributed to "pollution".

5.3.4.3 Benthic Macroinvertebrates

Wolfe et al. (1988) stressed that, "The short and very arbitrary naming and delineation of habitats are made with the following caveats: (1) the environment is a continuum of habitats, each one unique (e.g. not each oyster reef is exactly the same), each one dependent to varying degrees upon the others, and (2) many organisms use multiple habitats during different times of the day or different life stages and, therefore, cannot be assigned precisely to a single habitat." This point should be regarded as given throughout the following discussion.

Factors Controlling the Distribution of Benthic Invertebrates

Scanland (1966) noted that, "No single abiotic factor may be said to be most influential in determining the absolute composition of a community." Numerous abiotic factors and conditions influence the species composition of benthic invertebrate communities and, as noted earlier, most of these are highly variable, particularly in estuaries. Temperature, salinity, turbidity and other environmental conditions (sediment chemistry, dissolved oxygen, etc.) in a given region or estuary vary at different magnitudes and at different time scales. We presumptively assume that abiotic variables within a given habitat have different impacts on each species within the habitat. Because neither the scale of overall variation nor the degree of impact of these variables on species or communities are known, the following discussion of habitats is general in scope.

Suitable abiotic environmental conditions are pre-conditions for the presence or absence of each species found in a given habitat-type. However, species richness, community structure and function are, in large part, the result of complex biological interactions involving predation, competition, physiological tolerance limits, and the attributive characteristics of populations, including their fecundity and longevity. Unfortunately, except for commercially important species (blue crabs, oysters, scallops, penaeid shrimps, some hard clams), little is known about the natural history or population biology of panhandle invertebrates. It is assumed that representatives of the several feeding guilds (direct and indirect deposit feeders, suspension-filter feeders, carnivores, herbivores, omnivores) contribute to the production, consumption and processing of energy in each of the estuarine and shelf habitats discussed. It is not presently possible to provide quantitative information on the contributions to energy flow made by individual species.

The physical and chemical characteristics of sediments play a crucial role in the organization of benthic habitats and biological communities. In estuaries, sedimentation rates are generally much higher than in the ocean, and the transport and re-suspension of fine-grained sediments is more frequent and of greater biological consequence.

The duration of annual minimum water temperature controls the distributional limits of many benthic species. Seasonal temperature fluctuations are larger in western than in eastern panhandle nearshore environments, and variation in faunal abundance and species diversity appear to be greater west of Cape San Blas than in the Big Bend area. Hedgpeth (1954) suggested that as waters cool, there is a general exodus of animals from estuaries into the Gulf. While motile species (e.g. *Penaeus* spp.) may be cued by cooling water temperatures to migrate from estuaries to the Gulf, other authors have reported that infaunal species diversity in western panhandle estuaries reaches a maximum during cooler months suggesting that there may be an inverse relationship between water temperature and benthic invertebrate abundance in western panhandle estuarine systems.

Salinity fluctuations of as much as 30 ppt occur episodically in panhandle estuaries during periods of droughts and floods. Pulse or longer term (days) elevations or decreases in salinity can result in mass mortalities of sessile organisms.

Data Gaps

1. Most of the data gaps mentioned in the previous section (zooplankton) apply to deficits in our understanding of benthic invertebrates.

2. Difficult, and perhaps intractable problems exist in the general area of translating (micro- or mesocosm) toxicity test results from laboratory conditions to natural communities. This has been a much-discussed subject, and space does not permit a review here. The major points to be made are: (1) species tested in laboratory environments often do not (or can not) live in the environments for which laboratory conditions are meant to be surrogates; (2) elements, chemicals and compounds used in bioassay experiments are often in different form (e.g. oxidation state, ligand-bound) in the laboratory than in field conditions; (3) interactions with other compounds are usually not accounted for in laboratory tests; and, most importantly (4) marine organisms do not live in statistical environments – they live in real ones.

Biogeographic Provinces

An unknown number of benthic macroinvertebrate species are distributed throughout the estuaries and shelf waters of the Florida panhandle. Based on species lists compiled by various authors, it is suspected that the number is relatively large. BCM Converse (1987), for example, noted that the polychaetes, *Axiothella mucosa, Heteromastus filiformis, Laeonereis culveri, Prionospio heterobranchia* and *Streblospio benedicti*) are found in shallow water sand and seagrass habitats from Miami to Apalachee Bay. These species are also common in the western panhandle (e.g. Hydroqual, Inc. and Barry A. Vittor & Associates, Inc., 1993). The wide distributions of such species, many of which are numerically abundant and ecologically important, makes it difficult to identify distinct biogeographical provinces in panhandle coastal waters, and brings into question the reality of such boundaries or their geographical limits.

As a result of their work on benthic communities in Biscayne Bay, McNulty et al. (1962) concluded that, "Clearly no generalization can be made from the Florida data." Among the decapod crustaceans, Williams (1965) estimated that only ten percent are disjunct at peninsular Florida. Abele (1970), regards the Carolinian Province to be a transitional area, not a faunal province or a biogeographical unit. It is recognized for heuristic purposes, that certain estuarine and inner shelf habitats are putatively West Indian, Transitional, or Carolinian, primarily in terms of their correspondence to climatic (i.e., temperature) regions.

Benthic Invertebrate Communities

Panhandle brackish and marine benthic invertebrate communities are identified and defined by their dominant species, which are recognized as being diagnostic of and usually abundant in the community which they characterize. Examples of these species are included in Peterson-like habitat diagrams from Collard and D'Asaro (1973) shown in Figures 5-7 through 5-10. "Dominant" species are members of conspicuous and comparatively well-studied taxa. Many numerically important groups (e.g. nematodes, foraminiferans, platyhelminths, sponges, small crustaceans) are poorly known in the panhandle and, except in general terms, their roles in benthic communities are unknown. Noting the cautions written by Wolfe et al. (1988), seven types of brackish-marine benthic macroinvertebrate communities found in the Florida panhandle are identified. These communities are not mutually exclusive and have fuzzy boundaries. However, the assemblages summarized as habitat diagrams represent the major recognizable benthic invertebrate habitats of the Florida panhandle.

Marsh and Delta [Low Salinity] Communities

Marshes and deltas are characteristically low salinity, low energy environments with organically rich bottom sediments. These conditions exclude all but transient stenohaline species, and benthic communities are comprised of a mix of freshwater and marine animals. Grass shrimp (*Palaemonetes*), fiddler crabs (*Uca* spp.), and marsh snails (*Littoraria irrorata, Neritina reclivata*) are common. Figure 5-7 depicts a cross-section of characteristic species found in low salinity areas (marshes and deltas) of the panhandle (Beccasio et al., 1982; Stout, 1984; Livingston, 1984; Myers and Ewel, 1990; NOAA, 1990; Field et al., 1991; Hackney et al., 1992). Salt marsh communities occur at the margins of most panhandle estuaries and lagoons. True deltaic communities, while not as ubiquitous as non-deltaic marshes along the panhandle coast, are common features of the larger rivers (e.g. Yellow and Apalachicola Rivers).

Oyster Reef Communities

Oyster shells and the spaces between their valves and shells provide a complex, three-dimensional hard substrate habitat for many species that would not be found in the absence of *Crassostrea virginica*, a keystone species (Figure 5-8). Oyster reefs are most abundant in Apalachicola Bay.

Bay and Sound Communities

Bays and sounds are brackish water environments most of which, when not significantly stressed by humans, support an abundant and diverse benthic fauna. The benthic invertebrates of panhandle bays and sounds are characterized by oyster reefs, and mixed polychaete, peracarid crustacean (amphipods, isopods, tanaids), molluscan (small bivalves and gastropods), echinoderm (infaunal synaptid holothurians, epifaunal sea urchins and sand dollars) and penaeid shrimp communities (Figure 5-9). Seagrass meadow, oyster reef and hard ("live bottom") habitats support the most diverse assemblages of microbes, algae, microfauna, meiofauna, macrofaunal invertebrates and fishes in bays and sounds. However, non-vegetated, non-reef bay bottoms (sand, mud, peat, shell hash) are also inhabited by very large numbers and species of microbes, algae, invertebrates and fishes whose ecological role in food webs is crucial to the function of bay and sound ecosystems. St. Joseph Bay (arguably the least impacted bay-sound

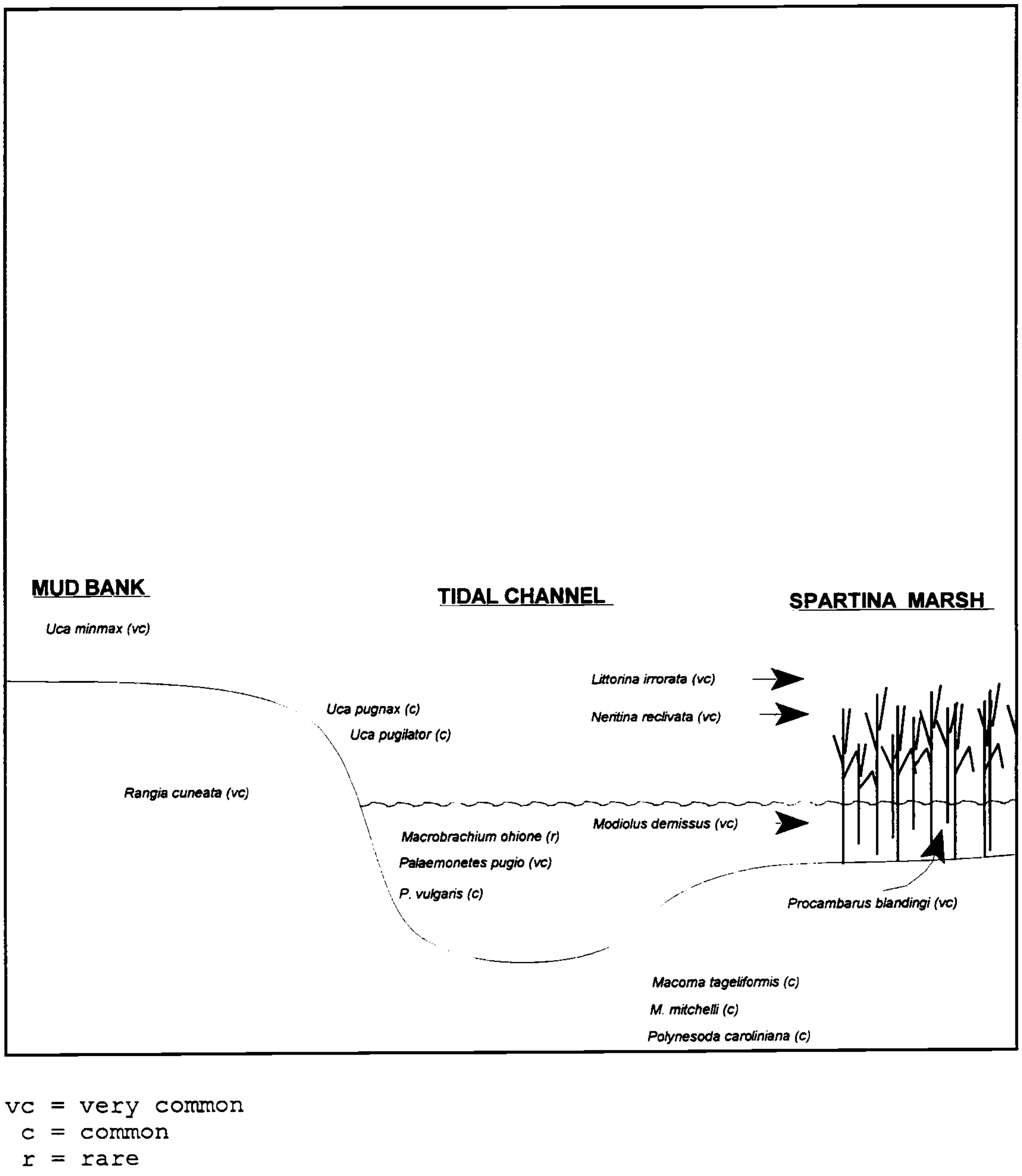
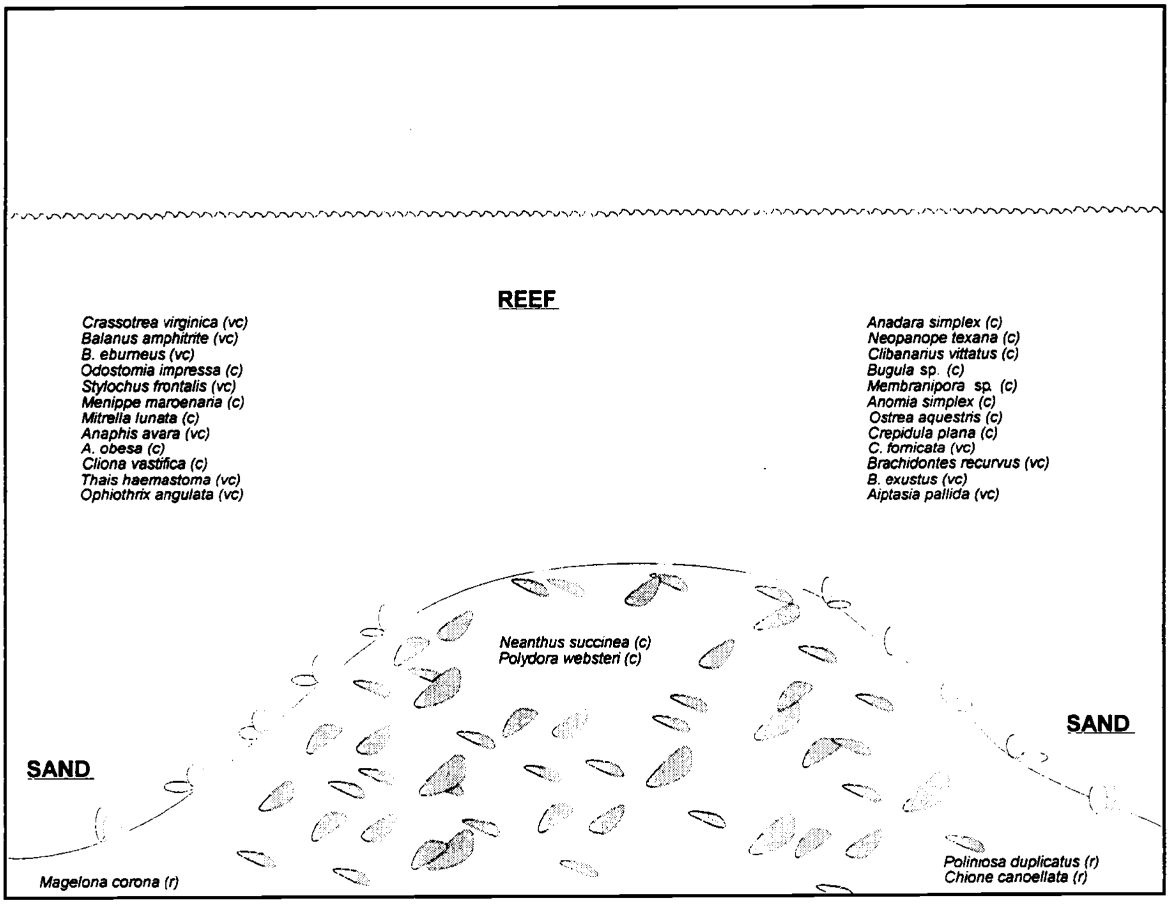
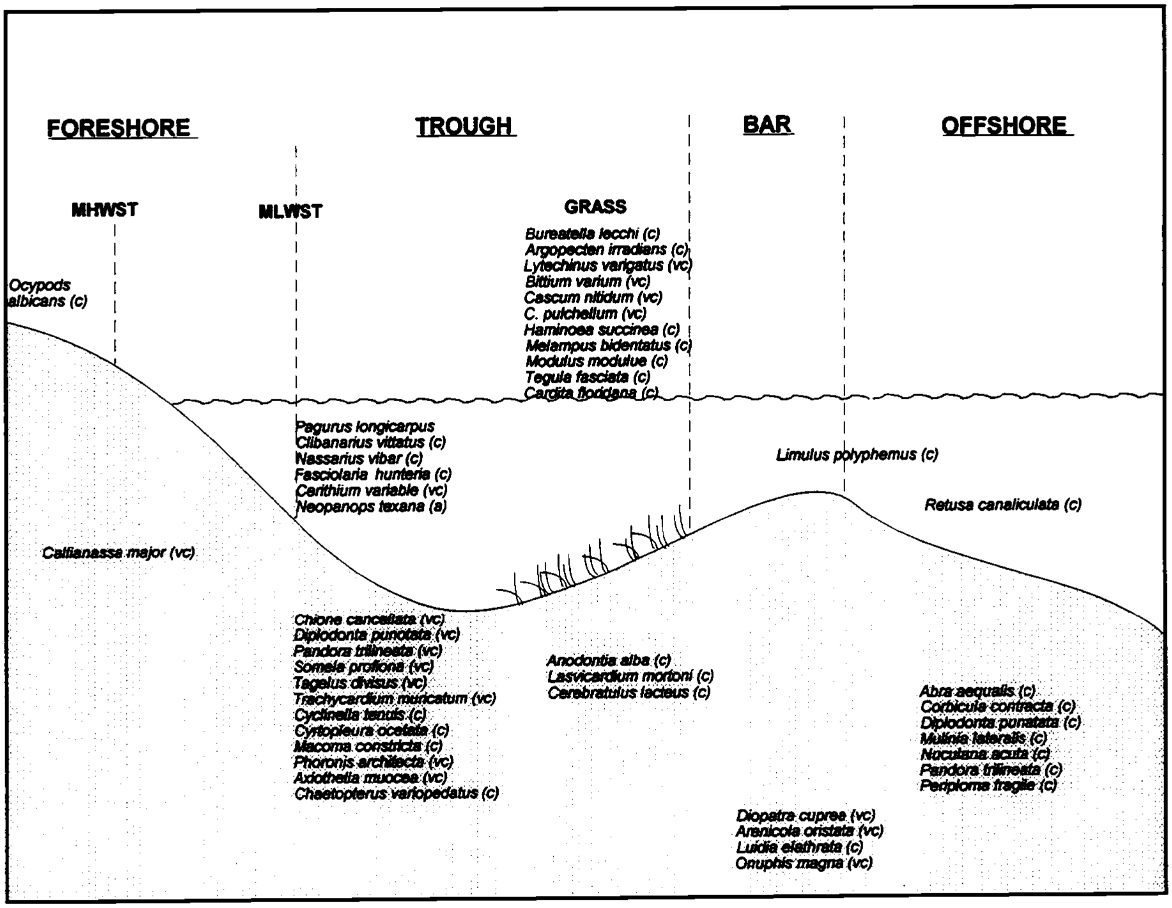


Figure 5-7. Low salinity marsh and delta macroinvertebrate communities (after Collard and D'Asaro, 1973).



vc = very common
c = common
r = rare

Figure 5-8. Schematic diagram of a characteristic oyster reef community in Panhandle brackish waters (after Collard and D'Asaro, 1973).



MLWST = mean low water spring tide
a = abundant
vc = very common
c = common
r = rare

Figure 5-9. Bay and sound macroinvertebrate communities (after Collard and D'Asaro, 1973).

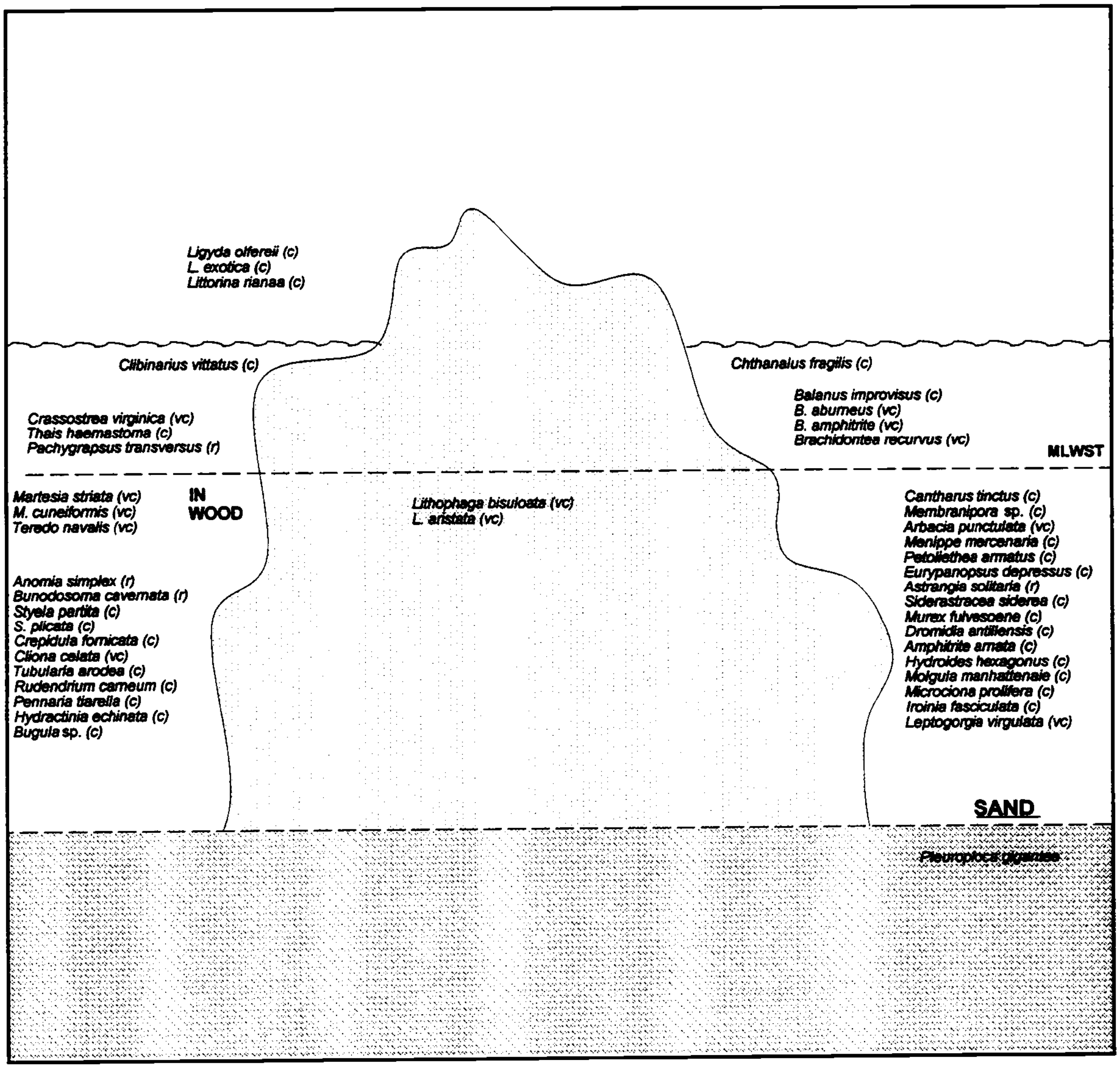
system in the panhandle), and other examples of this important community are provided in characterizations of individual bay systems in subsequent sections of this chapter.

Hard Substrate and Fouling Communities

Hard substrates (including oyster shells, man-made structures and trash) evolve through increasingly complex successional seres into complex, sheltered environments inhabited by annelids, nudibranchs, tunicates, hydroids, turbellarians, shrimps, nemerteans and the vulnerable young stages of many species. Such communities provide forage for predators (e.g. stone crabs, drills, nereids, carnivorous gastropods), and scavengers (e.g. *Melongena, Callinectes, Pagurus, Petrochirus*). A composite hard substrate community is shown in Figure 5-10. Fouling communities are found at all depths in panhandle marine and brackish waters. They are especially conspicuous in the lower intertidal and subtidal portions of pier pilings in ports and marinas where salinities average 20 ppt or greater. These communities are also found on breakwaters, suspended ropes and cables, artificial reefs, oyster reefs, discarded tires, abandoned crab traps, ship's hulls (including those with copper sheathing) and, in a strict sense, on seagrass blades. Among the most conspicuous year-round members of fouling communities in the panhandle are the solitary tunicates, *Styela plicata*, and their colonial relatives,*Didemnum* spp., *Distaplia bermudensis*, *Diplosoma* spp., and *Amouricium constellatum*, and the barnacle, *Balanus eburneus*. The bryozoan, *Bugula neritina*, and various species of filamentous green algae are abundant during cooler months.

Fouling assemblages are considered to be a sub-category of hard substrate communities. As described by Wolfe et al. (1988), panhandle fouling community development occurs in the following predictable sequence. The first organisms to colonize clean substrates are slime-producing bacteria, diatoms and cyanophytes. Depending upon the type of substrate (wood, plastic, metal, etc.), water depth and temperature and, especially, larval availability, this first sere may persist for periods of days to weeks (Collard, unpubl. data).

After "processing" by microbes, substrates are colonized by barnacles, gammarid and caprellid amphipods, bryozoans, tunicates, hydroids, young gastropods and bivalves. Most of these organisms are suspension or filter-feeders. Again, depending on temperature, larval availability and, perhaps, phytoplankton and meroplankton abundance (Collard, unpubl.), a fairly rapid increase in species diversity may occur, followed by an extended period of gradually increasing species settlement. Successful animals (e.g. tunicates, bryozoans, sponges) often grow rapidly, decreasing available space in some cases (e.g. on substrates dominated by colonial tunicates with antifouling chemicals in their tests), or increasing space with their own bodies, shells, etc. Following a sometimes rapid, sometimes extended period of increasing complexity and density, stabilization of the community occurs with the loss or decrease in abundance of some species. Tunicates such as the common sea squirt, Styela *plicata*, may simply tear away from vertical substrates because of their weight; other species are preyed upon by fishes or invertebrates (e.g. crabs). After full



MLWST = mean low water spring tide
vc = very common
c = common
r = rare

Figure 5-10. Composite hard substrate community (after Collard and D'Asaro, 1973).

development, fouling communities tend to be dominated by a few large, persistent species such as sponges, solitary or colonial tunicates and barnacles that support a continuously changing assemblage of sessile and motile associated organisms (Collard, unpubl.data). In western panhandle estuaries and lagoons, seasonal temperature decreases result in the disappearance of a majority of species and recolonization during spring seems to follow the "broken stick" model of MacArthur.

5.3.4.4 **Fishes**

As a group, adult estuarine and marine fishes (including elasmobranchs) in panhandle waters are much better known than the invertebrates. Most of the fishes have been described taxonomically, and their distributions are adequately known. However, detailed information about the natural history, reproductive biology, population dynamics and trophic dynamics of most fish species is scarce. This is especially true with respect to the biology of sharks and rays, some of which are estuarine-dependent.

Comp and Seaman (1985) reported that, "Most estuarine-dependent species [of fishes] are spawned in offshore coastal waters, then migrate to the estuaries where a variety of habitats such as mangrove forests, marshes, seagrass beds, oyster bars, and sand and mud flats offer food and protection from predators." These authors also pointed out that (the same) ten or fewer species of fishes were numerically dominant (70% or more of the number of individuals, regardless of the total number of species or individuals captured) in most of Florida's estuaries. The two most abundant species collected in estuaries were the bay anchovy, *Anchoa mitchilli*, and the pinfish, *Lagodon rhomboides*.

The diversity and abundance of fishes in a given panhandle estuary vary seasonally and year to year. Species whose eggs or larvae are recruited from Gulf waters via advective transport depend on favorable upstream and local conditions (e.g. winds) that move them into or out of estuaries at appropriate times in their life cycles. After entering estuaries, eggs, larvae and adults require suitable environmental conditions (*i.e.*, water quality, salinity), forage (e.g. detritus, phytoplankton, zooplankton, benthos), and habitat (e.g. salt marshes, seagrasses, oyster reefs) in order to survive, grow and/or reproduce. In like fashion, eggs and larvae produced in estuaries, must find egress via currents that transport them offshore into suitable environments.

With respect to numerically abundant, widely distributed panhandle estuarine species, Kobylinski (1979) reported that *Micropogonias undulatus* (croaker) are omnivores, and feed on polychaetes, harpactacoid copepods, detritus and bivalves. *Leiostomus xanthurus* (spot) forage chiefly on polychaetes and detritus. Of the two most common species, the bay anchovy (*Anchoa mitchilli*) preferentially feeds on calanoid copepods but also consumes other zooplankters. *A. mitchilli* is in turn consumed by the common species, *Cynoscion arenarius*. The pinfish, *Lagodon rhomboides*, changes its preferred diet with age and, at various stages in its life cycle, feeds on seagrasses, aufwuchs, grass shrimp and other small invertebrates. Direct observation suggests that pinfish are opportunistic feeders (Collard, unpubl.). Table 5-12 summarizes the dominant species of fishes in the Crystal River, Cedar Key, Apalachicola Bay and St. Andrew Bay estuaries. Species reported to occur in individual panhandle estuaries are treated in subsequent sections of this chapter.

5.3.4.5 Threatened and Endangered Species

Endangered, threatened, rare, special concern, and other categories of animal and plant species in Florida have been variously defined by federal and state agencies, as well as by committees of professional biologists. In the coastal panhandle region, as elsewhere in the state, many more plants than animals have been identified as endangered or threatened in some way; many more vertebrates than invertebrates have been so classified; and more fresh water than marine species are recognized as under some threat or potential threat of harm or extinction. U.S. News and World Report (December 24, 1995, p. 28) listed the Florida panhandle coastal zone as one of six regions in the country (including Alaska and Hawaii) where wildlife is in the greatest danger.

An official list of endangered and potentially endangered fauna and flora in Florida was published by the Florida Game and Fresh Water Fish Commission (7 volumes, June, 1994).

Panhandle-region species having special status include: subspecies of the Atlantic sturgeon; the green, hawksbill, Kemp's ridley, and leatherback sea turtles (endangered); the loggerhead sea turtle (threatened in Florida); West Indian manatee (especially in the Suwannee River); sperm whale (edge of the continental shelf); Cuban snowy plover (a rare summer breeder on outer beaches and bars); least tern (a summer resident), and the various subspecies of beach mice found on barrier islands (Beccasio et al., 1982). It appears that populations of subspecies of the beach mouse, *Peromyscus polionotus* (i.e., west of Perdido Inlet, Perdido Key, Santa Rosa Island, Destin to Panama City mainland, and St. Joseph Spit) were significantly impacted during Hurricane Opal. Additionally, sea turtle eggs that had not hatched prior to this hurricane were killed by salt water. Anecdotal information suggests that some hatchling and post-hatchling turtles perished by being cast ashore during the storm. Island and mainland beaches in the western panhandle were so heavily impacted by storm surge and waves that shorebird and sea turtle nesting areas were destroyed or significantly reduced in size.

5.4 Florida Panhandle Estuaries

Thw following sections discuss the major Florida panhandle estuaries in order from west to east. Of necessity the discussions under various categories are not to the same level of detail for all estuaries. The section headings are the same for each estuary. As in previous sections data gaps are identified where appropriate.

5.4.1 Pensacola Bay

The discussion in this section is based largely on Collard (1991) except where noted otherwise.

Table 5-12. Percent of dominant fish species in Crystal River, Cedar Key, Apalachicola Bay, and St. Andrew Bay estuaries (from Comp and Seaman, 1985).

Dominant Fish Species	**Estuary**			
	Crystal River	**Cedar Key**	**Apalachicola Bay**	**St. Andrew Bay**
Anchoa mitchilli			41	
Fundulis similis				8
Menidia beryllina				28
Sygnathus scovelli		6		
Eucinostomus argenteus				8
Orthopristis chrysoptera	13	18		
Lagodon rhomboides	27	46		22
Bairdiella chrysoura	19	5		
Cynoscion arenarius			9	
Leiostomus xanthurus	11			10
Micropogon undulatus			31	
Percent of Catch	**70**	**75**	**81**	**76**
Total Species	**100**	**122**	**76**	**88**

5.4.1.1 Environmental Setting

Pensacola Bay is the fourth largest estuarine system in Florida. The estuary is about 126,000 acres in area and has a coastline of some 550 miles (Reidenauer and Shambaugh, 1986). Isphording (1989) calculated that the volume of Pensacola Bay was 5.095 X 10^{11} cubic-feet. Extensive watersheds feed each of the four major streams entering the system. Isphording also reported that the drainage area of Pensacola Bay was 6990 square miles and that annual river flows were 11,600 cfs. The Escambia River, the largest stream entering the estuary, forms an extensive distributary delta before discharging into upper Escambia Bay. The Yellow and Blackwater Rivers discharge into Blackwater Bay; and East Bay River empties into the eastern portion of East Bay (Figure 5-11).

The Escambia River is the fifth largest river in Florida, with stream flows ranging from about 500 to 50,000 cfs. The Blackwater River receives water from three tributary streams: Big Juniper, Big Coldwater and Pond Creeks. Stream flows range from about 100 to 6,000 cfs in Big Coldwater Creek, and 60 to 5,000 cfs in the Blackwater River. The Yellow River discharges through an extensive delta system into the northeastern part of Blackwater

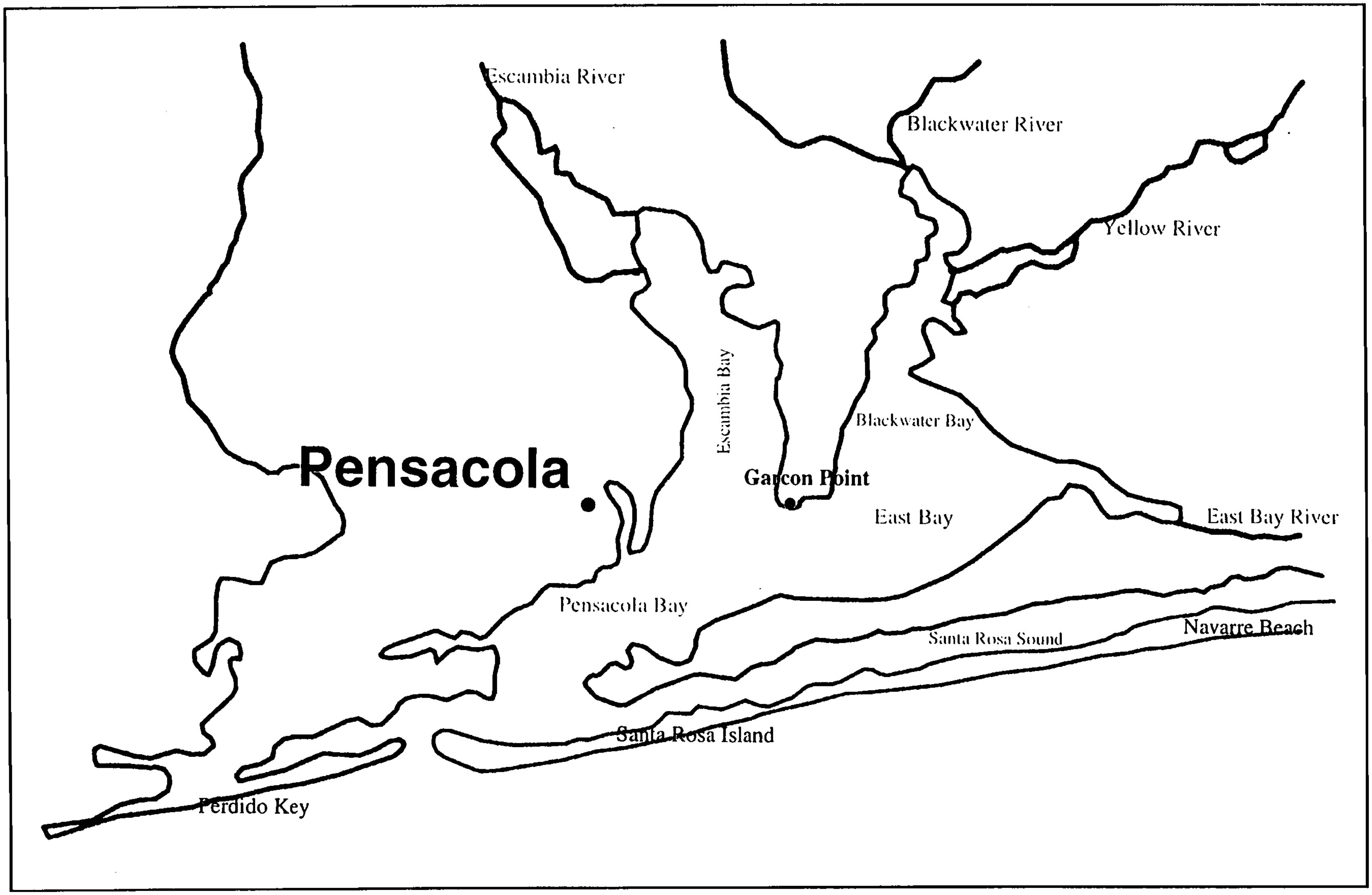


Figure 5-11. Schematic map of the Pensacola Bay system.

Bay with stream flows ranging from about 100 to 10,000 cfs. Discharge volumes of the East Bay River have not been determined. Freshwater input into the Pensacola Bay System is generally highest from February to April, and lowest in October to November. High pulse inputs have been recorded throughout the year, however, and wide month-to-month, season-to-season, and year-to-year variation in discharge flows are characteristic of tributaries. Escambia Bay receives about twice the volume of fresh water than Blackwater-East Bays. Variation in riverine input into the system is some 2-3 orders of magnitude between extreme low and high flows.

Five physiographic sub-systems are recognized in the Pensacola estuary: (1) Upper Escambia Bay; (2) Lower Escambia Bay; (3) Pensacola Bay; (4) Blackwater Bay; and (5) East Bay (Table 5-13). The Pensacola Bay System drains the Western Highlands physiographic region of northwest Florida and southeastern Alabama.

Based on its origin and geometry, Pensacola Bay is a broad, wedge-shaped, drowned-river-valley estuary with a large width to depth ratio. Salinity values range from 34-35 ppt near Pensacola Pass to 0.5 ppt or less in the upper bays. Saltwater extends several miles upriver to the fall line in the fluvial tributaries of Escambia and Blackwater Bays. Overall, the system is a low relief, coastal plain estuary partly blocked by a barrier island. The upper half of the system is a moderate relief, "Y" shaped ria, and upper Escambia and Blackwater Bays are delta-front estuaries with ephemeral distributaries (Escambia and Yellow Rivers) with interlobate embayments. Santa Rosa Sound is a bar-built estuary bounded seaward by Santa Rosa Island.

Sub-sections of Pensacola Bay conform to definitions of salt wedge, partially mixed, vertically homogenous, or sectionally homogenous estuaries at certain times. Salt wedge conditions are present when the bay is vertically stratified and river flow is high. A salt wedge is probably present in Pensacola Bay most of the time because of its depth and proximity to the Gulf of Mexico. During periods of low river flow, wind mixing causes the halocline to break down or weaken in upper Escambia, Blackwater and East Bays, which become partially mixed.

When river discharges into Blackwater and Escambia Bays are low, turbulent wind mixing (e.g. during summer thunderstorms and winter frontal passages), causes shallow portions of the upper bays to become vertically homogenous for short periods of time. During the same conditions a vertical boundary separates horizontal sections of the central portion of the system east of Garcon Point, and the bay becomes, for probably short periods of time, sectionally homogenous. According to the classification scheme of Odum and Copeland (1974), Pensacola Bay is a natural temperate ecosystem with seasonal programming (i.e. with seasonally predictable characteristics) as well as an emerging new system associated with man.

Table 5-13. Comparisons of Pensacola Bay sub-systems (from Olinger et al., 1975, and Reidenauer and Shambaugh, 1985).

Sub-system	**Surface Area (km^2)**	**Volume (10^6 m^3)**	**Average Depth (m)**
Pensacola Bay	135	800	6
Bayou Grande	4	10	2
Bayou Chico	1	2	2
Bayou Texar	1.5	3	2
Escambia Bay			
Escambia Bay	95	225	2.5
Mulatto Bayou	1	1	1.5
Blackwater Bay			
Blackwater Bay	25	50	2
Catfish Basin	1	1	1
East Bay			
East Bay	110	260	2.5
East Bay Bayou	5	5	1

5.4.1.2 Hydography and Oceanography

Few physical oceanographic studies of Pensacola Bay have been accomplished, and details of circulation patterns and mixing processes are poorly understood. When winds are light, little energy is available for mixing, and flushing rates tend to be slow in most portions of the system other than lower Pensacola Bay. Materials entering the Pensacola Bay System via tributaries and bayous tend to be trapped and remain in the system for extended periods of time. Weak currents and tides, high river flows, and intense solar heating in summer months contribute to conditions of intense vertical stratification, low dissolved oxygen concentrations below the pycnocline, and the accumulation of pollutants in the system. The Pensacola Bay System is river-controlled much of the time, and turbulent mixing is low in the absence of wind stress. When benthic biological respiration and COD are unsatisfied, dissolved oxygen levels decrease with depth, and DO may be exhausted in portions of the system where BOD, COD or SOD are high. Diffusion of oxygen from the atmosphere and surface fresh waters are insufficient to satisfy the sub-halocline oxygen demands of phytoplankton and chemical processes. Low dissolved oxygen conditions have precipitated fish kills and other mass mortalities in the bay.

Tides

In a hypothetical estuary with no tides, winds, other energy inputs or friction between fresh water near the surface and denser ocean water beneath it, static conditions exist. Fresh water flows out to sea on the surface and sea water extends upestuary to the fall line. The Pensacola Bay System, for variable periods of time, effectively approximates this zero energy-no motion condition.

The tidal prism in the Pensacola system is small (about 0.5 m), and tidal currents are of importance primarily near the mouth of the system and in bayous. Tidal cycles at Pensacola are diurnal most of the time. However, during two-to-three-day periods when the moon crosses the equator, semidiurnal tides occur (Marmer, 1942).

Based on records from 1923-1941, Marmer (1942) reported that, disregarding equatorial tides, the mean tide range at Pensacola was 0.39 m (1.27 ft). A maximum range of 0.43 m (1.4 ft) was recorded in 1932, and a minimum of 0.34 m (1.12 ft) was recorded in 1941 (a nine-year, half-cycle interval). During the period of record, tides were highest in June and December-January, and lowest in March-April and August-October. The former period roughly corresponds to periods of high rainfall and river flow, and the latter to the "dry" season. Provost (1971) observed that highest tides occur every four years, when the moon is at perigee.

Sea Level

Marmer (in Galtsoff, 1954) reported that between 1924-1950, sea level at Pensacola rose by nearly (0.15 m (0.5 ft), or about half the tidal range. During the period 1924-1941 sea level rose more than 0.03 m (0.1 ft) per year, and from 1941-1950 the rate of sea level rise slowed to a little over 0.009 (0.03 ft) per year.

Circulation

Gallagher (1971) reported that Coriolis force directs high salinity water into Pensacola Bay on the right (facing the direction of current flow), and out of each subsystem (Blackwater, East and Escambia Bays) on the left. Olinger et al (1975) reported that circulation in 1973-1974 varied between a two-layer flow with entrainment and a two-layer flow with vertical mixing. The latter condition was infrequently encountered, and the system characteristically showed little vertical mixing.

Major current major current reversals due to wind stress have been reported throughout the bay system (Edwards, 1976; Ketchen and Staley, 1979). According to Ketchen and Staley (1979), wind velocities of less than 8 kn for a period of time (not specified) could result in a complete reversal of current directions at all depths. Gorsline (in Lauff, 1967) reported that, "Slicks, foam lines and debris lines are common [in Pensacola Bay]; they separate tidal water masses of slightly different composition which move in variable directions in the estuary..."

Olinger et al. (1975) reported that flushing was more rapid in Pensacola Bay than in other parts of the system. A model based on average river flow and average tides indicated that flushing of the Pensacola Bay System should take on the order of 34 days, but a 60-day reduction in flushing time may occur with tidal mixing. In conditions of low flows and weak tidal mixing, flushing of the Pensacola Bay System may take as long as 200 days. Under certain wind conditions current reversals occur. Surface currents flow landward and deeper currents flow seaward. When current reversals occur, wastes are sometimes transported to the north and remain in the system (Upper Escambia Bay) for longer periods of time than calculated flushing rates may indicate. Ross (1973) postulated that a semi-permanent cyclonic gyre was present in Upper Escambia Bay, and if true, water would tend to be recirculated within this subsystem. Data indicate that substances in waters entering Upper Escambia Bay are retained within the bay for extended periods of time, and Stursa (1973) stated that, "Much of Escambia Bay is considered to be a 'dead' estuary."

Coupling

Corcoran (1973) reported that shelf currents and Pensacola Bay water coupling occurs. His data showed that a large tongue of water moves to the east from either Mobile Bay or Mississippi Sound, suggesting that some of the chemical compounds and trace metals (e.g. Cd, Zn) found at higher than expected concentrations in Pensacola Bay may have entered from shelf waters. Indications of nitrate enrichment in the bay from shelf waters was reported by La Rock (1973).

5.4.1.3 Water and Sediment Quality

Moskovits (1955) was the first investigator to report that water quality in the Pensacola Bay system had deteriorated due to the commencement of operation for several industrial operations. Facility discharges increased nutrients, toxic waste products and BOD into Bay waters. A series of investigations during the period 1955-75 (Olinger et al., 1975) concluded that water quality continued to worsen in wetern portions of the system through the study interval. This study was the only comprehensive ecological investigation of the Pensacola Bay system undertaken. Commensurate with a nationwide economic downturn, industrial effluents decreased, and water quality within the system appeared to increase and was considered to be the beginning of an improving trend. Collard (1991) however, reviewed all water quality investigations undertaken for the system through 1990 and concluded that water quality progressively worsened during the period 1955-75 and has remained essentially unchanged since that time, as evidenced by the total disappearance of once huge seagrass meadows and productive oyster reefs.

Olinger et al. (1975) distinguished three major habitats based on sediment type in Pensacola Bay: (1) a broad central plain of mud; (2) a transition zone close to shore with steep slopes and sediments grading from mud to sand and, (3) a sandy shelf around the bay margins. In addition, eight benthic habitats, eight benthic habitats based, in part, on non-sediment characteristics were identified. These included: (1) sand shelf (25 % of the Pensacola Bay System); (2) transition zone (a narrow band paralleling the shore between predominantly sand and mud sediments); (3) mud plain (70% of the bay bottom, consisting of a thin, flocculent, soupy-sticky, gel-like layer about 15 cm thick); (4) oyster bed (undersampled); (5) submerged aquatic vegetation (SAV) (no seagrasses were found during the 1973-74 sampling period, but brackish-freshwater *Vallisneria americana* beds were sampled in Escambia, East, and Blackwater Bays); (6) sewage treatment plant (STP) discharge (primarily sand); (7) industrial outfall (included all three major sediment types in northeastern Upper Escambia Bay near Air Products and American Cyanamid), and (8) deep water mud (primarily silt and clay).

Eastern margins of the Pensacola Bay System had the widest shelves, shallowest slopes, and provided the best habitat for oysters in the system. The mud fraction of sediments increased everywhere with increasing depth. Total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC) also increased with increasing depth (with increases in fine sediments). TP and TN concentrations were higher and TOC was lower in Escambia than in East Bay. TP, TN, and TOC were higher in Choctawhatchee and St. Andrew Bays than in Escambia Bay. The presence of toxic compounds was not determined. Volatile organic compounds (VOCs) were highest in deep water; similar concentrations occurred in Escambia and East Bays in like sediments, and were higher in Pensacola than East Bay. It was concluded that volatile organics in Escambia Bay resembled concentrations found in other estuaries.

An area of higher BOD (biological oxygen demand) occurred in Escambia Bay at the zone of maximum mixing between salt and freshwater due to flocculation of dissolved riverine organic materials. Highest BOD levels occurred in Escambia Bay in general, but values were not considered remarkable except near industrial outfalls.

PCBs were found throughout the system, but concentrations were highest in muds, in channels, and near industrial outfalls in the northeast portion of Upper Escambia Bay. PCBs were estimated to have decreased about 90% per year from 1969 to 1974. Of 21 pesticides tested, only Dieldrin was detected in Escambia Bay. Eleven of 12 trace metals sampled for were present in higher concentrations in fine sediments. Seven metals were found in the same concentrations in Escambia and East Bays; four were higher in Escambia than East Bay; and one (titanium) was uniformly distributed throughout the Pensacola Bay System. Mercury was found in very low concentrations. The dredged channel in Escambia Bay was considered to be a sink for clay, fine organically rich sediments, nutrients, trace metals, and PCBs. "Black, gelatinous sludge" has been reported by numerous FDEP biologists (pers. comm.) in the eastern portions of the bay.

Brazzell (cited in Stith et al., 1984) characterized Upper Escambia Bay sediments as comprised of "black carbonaceous mud" containing 7.8-11.6% volatile organic solids. Brazzell stated that such sediments when resuspended had high BOD and long settling times. These sediments contained PCBs and trace metals and had a strong smell of hydrogen sulfide.

REMOTS® (SAIC, 1986) sediment profiling in Pensacola Bay in 1985 consisted of 200 images obtained from 104 locations. These techniques (described by

Germano and Rhoads, 1984), produced important information concerning depths of the apparent reduction potential discontinuity layer, or RPD. This is the sediment depth where redox values become approximately zero, as measured by Eh or as visually indicated by an often rust- or dark-colored band or layer in sediments. RPD depths of 10-20 cm are characteristic of uncontaminated, oxygenated sediments often colonized by Stage III successional seres (head-down feeders, bioturbators, biological bulldozers). Shallower RPD depths indicate that the reducing environment is close to or at the sediment-water interface (e.g. as a result of sediment overenrichment, toxic substances or chronically low bottom DO). Such benthic environments are able to support primarily surface suspension and/or deposit feeders of the types most frequently reported by FDER environmental staff (opportunistic polychaetes, tube-dwelling amphipods, and small bivalves). See Collard (1989) for details.

In general, SAIC REMOTS® findings agreed with the sediment descriptions of Olinger et al. (1975), and concluded that the majority of the bay bottom had RPD depths of between 4 and 10 cm. Deepest RPD depths were in high energy areas corresponding to Olinger's shallow sand substrate habitats. Shallowest RPD depths were found in "quiet" (low energy) areas, as expected. SAIC concluded that, "This suggests that the RPD depth is not strongly mediated by chemical stress factors [but the] area around the Port suggests both physical disturbance and anthropogenic disturbances." Chemical stress factors mentioned by SAIC included toxic substances and high BOD/COD, while "anthropogenic disturbances" included organic loading from discharges and dredging, reducing sediments, and high BOD/COD. Sediments profiled north of the Port suggested that the area had not recently been disturbed but had been so in the past, probably by dredging. Sediments around the Port and at the mouth of Bayou Chico were viewed as stressed due to "known organic inputs in these areas". Based on an organism-sediment index (OSI) low values calculated in shoal areas near Fair Point were attributed to natural physical disturbances (e.g. currents). In general, it was concluded that Pensacola Bay sediments were not overly stressed.

George (1988) summarized changes in sediments during the period 1965-1985: (1) the percentage composition of sand decreased by more than 50% in East Bay; (2) silt and clay-sized sediments were more than twice as abundant in East Bay; (3) grain sizes and percent sand increased seaward and toward the mouths of rivers in all segments of the Pensacola Bay System; (4) sediments changed from well-sorted to a more poorly-sorted, finer-grained condition throughout the Pensacola Bay System [Horvath (1968) reported mean grain size to be 4.1 (phi units) and George (1988) reported mean grain size to be 6.4]; (5) shoreline configurations had changed little; (6) carbonates had decreased by more than 50% in Pensacola Bay, and almost doubled in East Bay; (7) the cause(s) of fining of sediments in Blackwater Bay was unknown, but tentatively attributed to private damming of tributaries, or to the long-term effects of hurricanes; (8) an increase in coarser sediments in Upper Escambia Bay was tentatively attributed to 1985 quarrying activities in the Escambia River, and the increase in "fines" in the eastern portion of Pensacola Bay (eastern Upper Escambia Bay) was attributed, in part, to the action of submerged L&N railroad ties acting as a "snow fence", thus trapping finer sediment particles; (9) the percentages of surface sediment clay in the Pensacola Bay System ranged from 0.5% to 90.4%, with an average of 37.8%; the clay fraction increased northward from Santa Rosa Island, and toward the central, deeper portions of bays in the system; and (10) Blackwater Bay sediments were the most poorly sorted in the Pensacola Bay System [sorting was best in the southwest portion of Pensacola Bay near Pensacola Pass].

George (1988) reported organic carbon concentrations of zero to 7.5% (average 2.4%) in Pensacola Bay System sediments; the second highest levels in any northeast Gulf of Mexico estuaries, except for Mobile Bay. Blackwater Bay was lowest in sediment organics. The eastern shore of Pensacola Bay, off Garcon Point, had lower concentrations than the western shore, and organics were found to be high at the mouth of the Escambia River. No unusually high concentrations of organics were found in Blackwater Bay, East Bay, or Escambia Bay except in the center of the system, at the confluence of East and Pensacola Bays. Isphording et al. (1989) calculated that the estuary received an average annual sediment load of 1.08 million tons per year, and an average sediment input of 154.5 tons yr^{-1} mi^{-2} of drainage area.

Sediment grain size changes in subsystems of the Pensacola Bay System (see Table 5-14) can be postulated to have resulted in substantive changes in water column turbidity; changes in the distribution and diversity of benthic invertebrates and submerged vegetation; changes in the concentrations and distributions of chemical (toxic and nutrient) substances throughout the system; and changes in the flushing rates and residence times of chemicals sequestered in fine sediments.

Data collected and interpreted by Young (1982), Ryan et al. (1984), Isphording (1985), SAIC (1986) and FDER (1988) were different, in some ways significantly so. In contrast to conclusions reached by Brazzell (1984), the overall quality of sediments in the Pensacola Bay System has apparently not significantly improved during recent decades.

Escambia Bay sediment characteristics and currents were compared during low river flow conditions in 1969, and high flow conditions in 1970 (USEPA, 1971). In Upper Escambia Bay, unconsolidated sediments from less than two to greater than six feet thick were found. Forty-five percent of these sediments were found to contain greater than 0.2% total organic nitrogen, and 35% of the sediments contained total phosphorus concentrations greater than 0.3%. Total sediment oxygen demand in the samples ranged from 25-100 $g \cdot kg^{-2}$ (dry weight), and 30% of the sediments had a total oxygen demand greater than 100 $g \cdot kg^{-1}$. Organic content increased to 5% near the mouth of the Escambia River and was lowest (2.3%) in the southeast portion of Upper Escambia Bay, above the L&N trestle off Mulatto Bayou. It was concluded that most total organic carbon (72.6%) entered Upper Escambia Bay "via rivers in which Monsanto and Container Corporation discharge." Based on current measurements it was concluded that wastes discharged into the northeast portion of Upper Escambia Bay flow to the north and accumulate in the central and western portions of upper and lower Escambia Bays.

Table 5-14. Comparisons of 1968 and 1988 sediments in the Pensacola Bay System (George, 1988).

Comparison	**Pensacola Bay**	**Escambia Bay**	**East Bay**	**Blackwater Bay**
AVG. SAND PERCENT				
Horvath	58	48	59	--
George	49	46	22	35
AVG. SILT PERCENT				
Horvath	17	22	17	--
George	21	23	25	28
AVG. CLAY PERCENT				
Horvath	29	27	22	--
George	30	30	53	37

These authors also suggested that a cyclonic gyre may be a common feature of Upper Escambia Bay waters regardless of river flow conditions.

Sediment microbial activity was estimated to be similar in all sections of the Pensacola Bay System, including sewage treatment plants (STPs) and industrial outfalls. Microbial activity increased with increasing volatile organic concentrations until the latter reached 1%, at which time no further microbial activity increase was observed.

In connection with an oyster bed restoration project during the period March 1972 – June 1973, bottom conditions in most of Escambia Bay were characterized as flocculent, organic, anaerobic muds (Little and Quick, 1976). This qualitative description was in general agreement with sediment conditions reported in 1949, 1955, 1969, 1973 and 1974.

A special monitoring survey conducted in Pensacola Bay from the fall of 1987 to the summer of 1988 (FDER, 1988), compared conditions in the bay to those reported by Olinger et al. (1975). The six stations sampled for sediments and benthos provided reasonable coverage, but some station locations were different than those sampled by Olinger et al., (1975). With respect to sediments the FDER (1988) study reported that five of six stations were "heavily polluted" by arsenic, iron, and chromium; one of six was heavily polluted with copper, and one of six with mercury (near the Main Street STP). Five of the six stations sampled were found to be "heavily polluted" with volatile solids.

Sediments in Bayous Texar and Chico are reported to be of low biological-chemical quality. Sediments in the bayou are chronically over-enriched, as expected in heavily populated areas where bayous have historically been used as domestic or industrial sewers. Sediments are impacted by pulses of stormwater runoff from Carpenter's Creek and numerous (>65) stormwater drains. Hoffman, Woodland, and Gilmore Bayous appear to have the same basic problems as Bayou Texar. Recent information is not available for Mulat-Mulatto Bayou, Catfish Basin, Indian, Trout or Raccoon Bayous.

5.4.1.4 Biology

This section describes the salt marhes and submerged aquatic vegetation, benthos and fish communities found in Pensacola Bay

Salt Marshes and Submerged Aquatic Vegetation

Seagrass changes within the Pensacola Bay System were documented by Rogers and Bisterfield (1975), based on an analysis of aerial photographs taken from 1949-1974. At the time of writing the authors' stated that the Pensacola Bay System had productive "grass" beds in all bays of the system. Their finding, however, is not in agreement with those of other authors. The three most abundant species of SAV reported to occur in the Pensacola Bay System were *Thalassia testudinum* (marine-brackish, to about 2 m depth), *Halodule wrightii* (marine-brackish), and *Vallisneria americana* (fresh-brackish). The authors reported that *Ruppia maritima*, "is also fairly common in the fresh to brackish waters of the area". Rogers and Bisterfield (1975) concluded that: (1) Escambia Bay had extensive grassbeds along its entire shoreline in 1949; (2) seagrass losses occurred from 1949-1966. (3) declines accelerated from 1966-1968, and were still declining in 1968-1974; (4) seagrasses were mostly gone by 1970; (5) all SAV had disappeared from Escambia Bay except for a small patch of *Vallisneria* along the upper western shore, where there was a significant influence from the Escambia River; and (6) SAV had decreased in East Bay and Blackwater Bay by 1974, but some, including *Thalassia,* remained. The authors attributed declines in Pensacola Bay System SAV to sewage and industrial effluents, dredge and fill, beachfront operations, and changing watershed characteristics.

Seagrass beds along the southern shore of Pensacola Bay disappeared by 1974. Meadows in East Bay disappeared completely by 1976 and have not re-established themselves. Seagrasses have not disappeared, but have decreased in the Santa Rosa Sound portion of the Pensacola Bay/Gulf Breeze area. About a 50% reduction in seagrass area coverage occurred in beds around the Gulf Breeze Peninsula between November 1982 and November 1986. Beds of seagrass around Sabine Island remained about the same between 1982 and 1986.

Benthos

Based on the documents reviewed, benthic macroinvertebrate species diversity in Pensacola Bay is low, and has probably not changed significantly during the past 30-40 years. Low dissolved oxygen levels occur seasonally in northeastern Upper Escambia Bay and in most bayous. Sediments with high organic content occur in deep mud areas of the bay, in many or all of the bayous, in parts of Upper Escambia Bay, and (aperiodically), elsewhere in the system. Even though samples of the benthos have been collected on an irregular basis and have emphasized point-source locations, a sufficient number of samples have been collected to show conspicuous differences in species diversity within the system after differences due to salinity have been filtered out (Olinger et al., 1975).

During the period 1961-1990, more than 400 taxa of (primarily sessile) benthic macroinvertebrates were reported from Pensacola Bay; 145 taxa were collected in Escambia Bay, and a total of 82 taxa were known from East and Blackwater Bays. A large fraction of the total number of taxa known from Pensacola Bay was collected in 1986, during sampling of the aircraft carrier turning basin in lower Pensacola Bay. As many as 50-60% of the total number of species historically collected from all parts of the estuary were associated with either seagrass meadows, which disappeared by 1974-1976, or with oyster reefs, which have declined in abundance.

The benthic fauna of a large portion of the Pensacola estuary, except in well-flushed, high salinity areas, resemble pioneering communities (Rhoads and Germano, 1986). These communities consist of small, opportunistic, near-sediment surface tubiculous polychaetes, amphipods and bivalves, or their ecological equivalents. The most abundant and widely distributed species in the Pensacola estuarine system are polychaetes, the amphipod, *Carinoma tremaphoros,* and the small clam, *Tellina texana.* A comparison of macroinvertebrate species collected in the system by Cooley (1961-1963), the Florida Department of Environmental Protection (1980-1988); and the U.S. Navy (spring 1986) is presented as Table 5-15.

Olinger et al. (1975) reported that samples from 11 sand shelf stations showed an average of 13 species per station (18.5 in winter, 13 in summer). A total of 36 species were collected from this habitat in summer, and 24 in winter. A three-fold increase in numbers of organisms was collected during winter. Summer samples were dominated by the following species: the amphipod, *Grandidierella bonnieroides,* in numbers as high as 1000 m^2, the clam *Mulinia lateralis* (60% of the total number of animals collected), *Laeonereis culveri, Odostomia* sp., the clam, *Tagelus plebeius*, and *Haustorius* sp. Haustoriid amphipods comprised as much as 89% of the number of individuals in some samples. Winter samples were also dominated by *G. bonnieroides*, which occurred in larger numbers than *Mulinia lateralis.* The two other winter dominants were *Neanthes succinea* and *Monoculoides edwardsi.* Sand substrata were considered to have been undersampled. No statistical differences were found in numbers, biomass or species with respect to north, south, east or west sides of the system.

Ten transition zone stations were sampled by Olinger et al. (1975), yielding a total of 34 species and an average of 9.8 species per station. Numerical dominants were *Mulinia lateralis* and *Parandalia fauveli.* These and five other species accounted for 80% of the total number of animals collected. Species composition remained essentially the same in summer and winter, with a ten-fold increase in numbers of organisms in winter. The number of species/station in winter was 19.5, and in summer, 8.5. No differences in faunal assemblages were found in different areas of the transition zone.

Table 5-15. Macroinvertebrates found in the Pensacola Bay System from January 1980 to the present, compared with macroinvertebrates found by Cooley (1978). DER = samples taken by the Florida Department of Environmental Regulation, Navy = samples taken by the U.S. Navy (U.S. Department of the Navy, 1986), EB = East Bay, PB = Pensacola Bay, UEB = Upper Escambia Bay, "+" = present, "-" = absent.

GENUS	SPECIES	DER EB	DER PB	DER UEB	Navy PB	COOLEY
PLATYHELMINTHES						
	Stylochus ellipticus	+	+	+	-	+
RHYNCHOCOELA						
	Carinoma tremaphoros	+	+	+	-	-
	Cerebractulus lacteus	+	+	-	-	+
	Tetrastemma candidum	+	+	+	-	-
POLYCHAETA						
Polynoidae		-	-	-	+	+
	Lepidonotus sp.	-	+	-	-	+
	Sthenelais sp.	+	+	-	+	+
	Sthenelais boa	+	-	-	-	-
	Pisione sp.	-	+	-	-	-
	Bhawania heteroseta	-	-	-	+	-
	Chrysopetalum occidentale	-	+	-	-	-
Phyllodocidae		-	-	-	+	+
	Anaitides sp.	-	-	-	+	+
	Eteone heteropoda	+	+	+	+	+
	Phyllodoce arenae	-	+	-	+	-
Hesionidae		-	-	-	+	+
	Gyptis brevipalpa	+	+	-	-	-
	Heteropodarke lyonsi	-	-	-	+	-
Pilargidae		+	-	-	+	+
	Sigambra tentaculata	-	+	-	+	-
	Sigambra bassi	+	+	+	-	-
	Parandalia sp.	-	-	-	+	-
	Parandalia americana	-	-	-	+	-
Syllidae		+	-	-	-	+
	Brania clavata	+	-	-	-	-
	Nereis sp.	-	-	-	+	+
	Nereis succinea	+	+	+	-	+
	Laeonereis culveri	+	+	+	+	+
Nephtyidae		-	-	-	+	+
	Nephtys sp.	-	-	-	+	+
	Nephtys picta	+	-	-	-	+
	Aglaophamus verrilli	-	-	-	+	-
	Glycera americana	-	-	-	+	+
	Glycera dibranchiata	+	+	+	+	+
	Glycinde sp.	+	+	+	-	-
	Glycinde solitaria	-	-	-	+	-
	Gonaiada sp.	+	-	+	-	-
	Goniadides carolinae	-	-	-	+	-
	Progoniada sp.	+	-	-	-	-
	Diopatra cuprea	-	+	-	+	-
	Lumbrineris tenuis	+	+	+	-	-
	Lumbrineris ernesti	-	-	-	+	-
	Lumbrineris verili	-	-	-	+	-
	Lumbrineris culveri	-	+	-	-	-
	Arabella sp.	-	+	-	-	-
	Protodorvillea kefersteini	-	-	-	-	-
	Leitoscoloplus sp.	-	-	-	+	-
	Haploscoloplos foliosus	+	-	+	+	+
	Haploscoloplos fragilis	+	-	+	-	+
	Leitoscoloplus fragillis	-	+	+	+	-
	Scoloplos rubra	-	-	-	+	+
	Orbibia sp.	-	-	-	+	-

Table 5-15. Macroinvertebrates found in the Pensacola Bay System from January 1980 to the present, compared with macroinvertebrates found by Cooley (1978) continued.

GENUS	SPECIES	DER EB	DER PB	DER UEB	Navy PB	COOLEY
	Ariciedea sp.	-	+	-	-	-
	Aricidea cerruti	-	-	-	+	-
	Aricidea taylori	-	-	-	+	-
	Cirrophorus sp.	-	-	-	+	-
Spionidae		-	-	-	+	+
	Polydora socialis	-	-	-	+	+
	Polydora ligni	+	+	-	-	-
	Polydora websteri	+	+	+	-	+
	Polydora cornuta	-	-	-	+	+
	Prionospio sp.	-	-	-	+	-
	Prionospio heterobranchia	-	+	-	-	+
	Prionospio cristata		-	-	-+	-
	Apoprionospio pygmaea	-	-	-	+	-
	Prionospio dayi	-	+	-	-	-
	Spiophanes sp.	-	-	-	+	-
	Spiophanes bombyx	-	+	+	+	+
	Paraprionospio pinnata	+	+	+	+	+
	Streblospio benedicti	+	+	+	+	-
	Dispio unciata	-	+	-	-	-
	Scolelepis squamata	+	+	-	-	-
	Magelona sp.	-	+	-	+	+
	Spiochaetopterus costarum	-	+	+	-	-
	Mesochaetopterus sp.	-	+	-	-	-
Cirratulidae		-	+	-	+	-
	Tharys setigera	+	-	-	-	-
	Tharyx cf. *annulosus*	-	+	-	-	-
	Tharyx setosus	+	-	-	-	-
	Chaetozone sp.	-	-	-	+	-
	Cossura delta	-	+	-	-	-
	Armandia agilis	-	+	-	-	+
	Armandia maculata	-	-	-	+	-
	Travisia hobsonae	-	+	-	-	-
	Capitella capitata	+	-	+	+	+
	Heteromastus filiformis	-	+	-	-	+
	Notomastus sp.	-	-	-	+	+
	Mediomastus ambiseta	-	+	+	+	-
Maldanidae		-	-	-	+	+
	Axiothella mucosa	-	+	-	-	+
	Pectinaria gouldi	+	+	+	-	+
	Hobsonia florida	+	+	+	+	-
	Sabellides sp.	-	-	-	+	-
	Chone cf. *americana*	-	+	-	-	-
	Potamilla cf. *reniformis*	-	+	-	-	-
	Fabriciola trilobata	-	-	-	+	-
MOLLUSCA GASTROPODA						
	Neritina virginea	-	+	+	-	-
	Neritina reclivata	+	-	+	-	+
	Neritina usnea	-	-	-	+	-
	Littorina lineolata	-	-	-	+	-
	Zebina browniana	-	-	-	+	-
	Bittium varium	-	+	-	-	-
	Cerithium floridanum	-	+	-	-	-
	Epitonium multistriatum	-	-	-	+	+
	Crepidula maculosa	-	-	-	+	+
	Natica pusilla	-	-	-	+	+
	Polinices duplicatus	-	-	-	+	+
	Polinices cf. *hepaticus*	-	+	-	-	-
	Mitrella lunata	-	+	-	-	+
	Anachis translirata	-	+	-	-	-
	Anachis lafresnaya	-	-	-	+	-

Table 5-15. Macroinvertebrates found in the Pensacola Bay System from January 1980 to the present, compared with macroinvertebrates found by Cooley (1978) continued.

GENUS	SPECIES	DER EB	DER PB	DER UEB	Navy PB	COOLEY
	Nassarina vibrex	-	-	-	+	-
	Cantharus cancellarius	-	-	-	+	+
	Nassarius vibex	-	-	-	+	-
	Nassarius acutus	-	-	-	+	+
	Nassarius albus	-	-	-	+	-
	Olivella pusilla	-	-	-	+	-
	Olivella sayana	-	-	-	+	-
	Turbonilla conradi	-	-	-	+	+
	Pyramidella fusca	+	-	+	-	-
	Acteon punctostriatus	-	-	-	+	+
	Retusa canaliculata	+	+	+	-	-
	Cylichna bidentata	+	-	-	-	-
	Bulla striata	+	-	-	-	+
BIVALVIA						
	Nuculana acuta	-	-	-	+	+
	Nuculana concentrica	-	+	-	-	+
	Anadara transversa	-	+	-	-	+
	Modiolus demissus	-	+	+	-	-
	Modiolus americanus	+	-	-	-	+
	Branchiodontes recurvus	-	+	-	-	+
	Amygdalum papyrium	-	+	-	-	+
	Parvilucina multilineata	-	-	-	+	+
	Anodontia alba	-	+	-	-	-
	Crassinella lunulata	-	-	-	+	-
	Laevicardium mortoni	-	+	-	-	+
	Mulinia lateralis	+	+	-	+	+
	Mulinia caroliniana	-	-	-	+	-
	Rangia cuneata	+	+	+	-	+
	Ervilia concentrica	-	-	-	+	-
	Ensis minor	+	+	+	-	+
	Macoma cf. *tenta*	-	+	-	-	-
	Tellina lineata	-	-	-	+	+
	Tellina cf. *texana*	+	+	+	-	+
	Tellina sybaritica	-	+	-	-	-
	Tagelus plebeius	-	+	-	-	+
	Tagelus divisus	-	-	-	+	+
	Polymesoda caroliniana	-	-	-	+	+
Veneridae		-	-	-	+	+
	Anomalocardia cuneimeris	+	+	+	-	-
	Corbula cf. *contracta*	-	+	-	-	-
	Lyonsia hyalina	-	+	-	-	+
CRUSTACEA:						
CIRRIPEDIA						
	Balanus eburneus	-	+	+	-	+
PERACARIDA --MYSIDACEA						
	Mysidopsis bigelowi	+	-	+	-	-
	Mysidopsis bahia	+	-	-	-	-
	Bowmaniella floridana	+	+	-	-	-
PERACARIDA - CUMACEA						
	Leucon sp.	-	-	-	+	-
	Oxyurostylys smithi	+	+	+	+	+
	Cyclaspas sp.	-	+	-	-	-
PERACARIDA - TANAIDACEA						
	Leptochelia rapax	+	+	-	+	+
	Leptochelia squignyi	-	+	-	-	-
PERACARIDA - ISOPODA						
	Xenanthura brevitelson	-	-	-	+	-
	Cirolana sp.	-	+	-	-	-
	Sphaeroma quadridentatum	-	+	-	-	+
	Edotea triloba	-	-	+	-	-
	Munna reynoldsi	-	-	-	+	-

Table 5-15. Macroinvertebrates found in the Pensacola Bay System from January 1980 to the present, compared with macroinvertebrates found by Cooley (1978) continued.

GENUS	SPECIES	DER EB	DER PB	DER UEB	Navy PB	COOLEY
PERACARIDA - AMPHIPODA						
	Ampelisca sp.	-	-	-	+	-
	Ampelisca abdita	+	+	-	+	-
	Ampelisca cf. *verrilli*	+	+	-	-	-
	Ampelisca aggassizi	-	-	-	+	-
	Cymadusa cf. *compta*	+	+	-	-	-
	Lembos sp.	-	-	-	+	-
	Lembos smithi	+	-	+	-	-
	Microdeutopus gryllotalpa	-	-	+	-	-
	Cerapus tubularis	-	-	-	+	-
	Corophium sp.	-	-	-	+	-
	Corophium tuberculatum	-	-	-	+	-
	Corophium cf. *louisianum*	+	+	+	+	-
	Grandidierella bonnieroides	+	+	+	+	-
	Elamopus levis	-	-	-	+	-
	Gammarus macromucronatus	-	+	+	+	-
	Megaluropus myersi	-	-	-	+	-
	Melita nitida	-	-	+	-	-
	Melita longisetosa	-	-	-	+	-
	Delichiella appendiculata	-	-	-	+	-
	Acanthohaustorius sp.	-	-	-	+	-
	Acanthohaustorius intermedius	-	+	-	-	-
	Acanthohaustorius millsi	-	+	-	-	-
	Neohaustorius sp.	+	-	+	-	-
	Protohaustorius sp.	+	-	-	-	-
	Haustorius sp.	+	-	-	-	-
	Photis macromanus	-	-	-	+	-
	Microprotopus raneyi	-	-	-	+	-
	Listriella barnardi	-	+	-	+	-
	Monoculodes edwardsi	+	+	+	+	-
	Synchelidium americanum	-	+	-	-	-
	Metharpinia floridana	-	-	-	+	-
	Parametopella texensis	-	-	-	+	-
	Orchestia sp.	-	+	-	-	-
	Eudevenopus honduranus	-	-	-	+	-
	Caprella sp.	-	+	-	+	-
	Automate evermanna	-	-	-	+	-
EUCARIDA - DECAPODA						
	Penaeus sp.	-	+	-	-	+
	Trachypenaeus constrictus	-	-	-	+	-
	Sicyonia brevirostris	-	-	-	+	-
	Acetes sp.	+	-	-	-	-
	Palaemonetes pugio	-	-	+	-	+
	Ogyrides alphaerostris	-	-	-	+	-
	Pagurus sp.	-	-	-	+	+
	Pagurus longicarpus	-	+	-	-	+
	Pagurus gymnodactylus	-	-	-	+	-
	Clibanarius vittatus	-	+	-	-	+
	Albunea paretii	-	-	-	+	+
Majidae		-	-	-	+	+
	Callinectes sapidus	+	+	+	-	+
	Callinectes similis	-	-	-	+	+
Megalops		-	+	-	-	-
	Eurypanopeus depressus	-	+	-	-	+
	Panopeus herbstii	-	+	-	-	+
	Rhithropanopeus harrisi	-	-	+	+	-
	Pinnixa chaetopterana	+	+	-	-	+
	Pinnixa sayana	+	-	-	-	+
	Pinnixa floridana	-	-	-	+	+
INSECTA - ODONATA						
	Ischnura sp.	-	-	-	+	-

Table 5-15. Macroinvertebrates found in the Pensacola Bay System from January 1980 to the present, compared with macroinvertebrates found by Cooley (1978) continued.

GENUS	SPECIES	DER EB	DER PB	DER UEB	Navy PB	COOLEY
INSECTA - DIPTERA						
	Palpomyia sp.	-	-	-	+	-
	Chironomus sp.	-	-	-	+	-
	Polypedilum illinoense	-	-	-	+	-
	Polypedilum scalaenum	-	-	-	+	-
	Dicrotendipes neomodestus	-	-	-	+	-
SIPUNCULA						
	Phascolion sp.	-	-	-	+	+
PHORONIDA						
	Phoronis sp.	-	-	-	+	+
ECHINODERMATA						
Ophiuroidea		-	-	-	+	+
	Ophioderma brevispina	-	+	-	-	-
	Mellita quinquiesperforata	-	+	-	-	+
	Leptosynapta sp.	-	+	-	-	-
	Leptosynapta tenuis	-	+	-	-	-
CEPHALOCHORDATA						
	Branchiostoma caribaeum	-	+	-	+	+

Fourteen mud-plain habitat stations were sampled by Olinger et al., which was characterized as being covered with a 15 cm thick layer of gel-like flocculent, soupy material. Dominant species in this habitat were the polychaetes, *Sigambra bassi* (18.3%) and *Paraprionospio pinnata* (17.5%). These and five other species accounted for 85% of the community. In summer, an average of 5.5 species per station was collected, and in winter the number increased to 14.5 species per station. The number of individuals collected per station during winter was twice as high as the number collected in summer. No significant differences were found in dominant species between mud stations.

Olinger et al. (1975) collected 35 species of invertebrates from oyster beds, nine of which accounted for 89% of the number of individuals. Most of the species recovered from oyster beds were also found elsewhere in the bay. Twenty-eight of 35 species were collected only in Escambia Bay, and 16 species occurred in both East and Escambia Bays. The authors considered oyster beds to have been under-sampled.

Vallisneria americana was the only species of submergent vegetation sampled. Twenty-three species of invertebrates were collected in Escambia Bay, 24 in Blackwater Bay and 26 in East Bay. Industrial- discharge faunal assemblages were comprised of 25 species and an average number of 778 individuals per station. Species richness was not influenced by the sewage treatment (transitional sand-mud substrate), and samples were dominated by *Paraprionospio pinnata*. The industrial discharge habitat was indistinguishable from other habitats with primarily sandy substrates. Samples were dominated by three polychaetes (*L. culveri, P. pinnata,* and *P. fauveli*), *Mulinia lateralis* and *G. bonnieroides*. Species collected from mud substrata near the industrial outfall were similar in diversity and numbers to those collected from similar substrates in other parts of the system. At deepwater mud stations, eight species were collected with average total densities of 52 m^2. Samples were dominated by polychaetes, a cumacean and a small clam.

Results of Olinger et al. (1975) benthic macroinvertebrate collections are summarized as follows:

1. No north-south gradients of changes in community structure were found in the Pensacola Bay System.

2. Whereas many assemblages within the system could be discerned, they were all interrelated.

3. North-south salinity gradients within the system were not reflected by changes in biological community structure or species composition.

4. There were no biological trends within comparable habitats regardless of east-west salinity differences.

CH2M Hill (1985) reported that over 97% of all invertebrates at all stations in winter were polychaetes and bivalves. *Capitella capitata, Tellina texana* and haustoriid amphipods were dominants at all five stations, including *Vallisneria* beds. As suggested by Collard (1989) the bay benthos may not be successional, and these functional groups may be the dominant benthic organisms of the Pensacola Bay System.

Rakocinski et al. (1993) sampled macrofauna from 36 stations located along four 800 m seaward transects at Perdido Key. All collections changed markedly with distance from shore. Species richness ranged from 40 m^2 in the swash zone, to as many as 800 per m^2, 800 m offshore. The total density of animals ranged from 2,000 m^2, in the swash zone, to 20,000 m^2, 800 m offshore.

Species recorded from subsystems of the Pensacola estuary were also recorded from Pensacola Bay proper. Dominant animals in all years sampled were polychaete worms, amphipods, and small bivalve molluscs. The presence of echinoderms (mostly brittle stars) was an indication of higher salinity water near Pensacola Pass. Polychaetes were clearly dominant in species and numbers, followed by bivalves and arthropods. Of the arthropods, amphipods dominated assemblages.

About one-fourth as many species were collected in Escambia Bay (145) as in Pensacola Bay (466). Fourteen and 27 species, respectively, were identified as indicator species in Pensacola and Escambia Bays. In East and Blackwater Bays, during the decade 1974-1984, the number of benthic invertebrate species and the number of individuals varied considerably less than in Pensacola or Escambia Bays. Polychaetes and bivalves clearly dominated the assemblages sampled, and in 1980, occurred in sufficiently high numbers to indicate stressed conditions in East Bay. The high number of species collected by Olinger et al. in 1974 was reduced by half in the nine succeeding years. Seventeen of 82 species reported were considered to be potential indicators, a much higher proportion than in the other subsystems or their bayous.

Fishes

Finfish and invertebrate fisheries have declined in the Pensacola Bay System according to Reidenauer and Shambaugh (1986), NWFWMD (1990) and the Marine Fisheries Commission (FDNR, 1974 et seq.). Presumptive evidence of long-term fisheries declines has been reported by, among others, the Bream Fishermen's Association (pers. comm.), and mass media reports of polluted conditions in the system. Fisheries are discussed in Chapter X of this report. Among the principal indicators of declines in the biological quality of the Pensacola Bay system, are seagrass losses, episodic massive fish kills (particularly of the alewife, *Alosa pseudoharengus*), and reduced abundances of shrimp, crabs and oysters.

Using seines and trawls, 57 species of fishes representing 32 families were collected by Olinger et al. (1975). No significant increases in catch vs. effort (about one fish per hour) were noted to have occurred in the Escambia River or delta as a result of improved water quality, but fish kills decreased in the river by 86% between 1970 and 1974. Fish kills decreased in the Pensacola Bay System by 75% during the same period. The authors speculated that causes of fish kills in the system were due to nutrient excesses, PCBs, sewage, oil, phenols, toxic metals, pesticides, and "Other" industrial by-products. Olinger et al. (1975) reported that diversity in Escambia Bay was similar to or higher than in many other northern Gulf coast estuaries.

5.4.1.5 Data Gaps

1. Currents in the whole of the Pensacola Bay System require careful, long-term study. Without such information, fate and transport of nutrients, dissolved and suspended water column substances, and the distribution of plankton can not be known.

2. The bathymetry (and as a consequence, circulation patterns and flushing rates) in the Pensacola estuary may have been altered by Hurricane Opal, and should be re-charted.

3. Hurricanes impacting Pensacola Bay in 1995 re-distributed sediments and substances (nutrients, pollutants) sequestered in them. A comprehensive sediment survey is needed to determine the re-distribution of sediments types, which, if extensive, will affect the distribution of invertebrate communities, SAV, oyster reefs and fishes. It is possible that the resuspension of contaminated sediments and their subsequent export out of the bay during the three major storm events of 1995 improved the overall quality of the system.

4. It is erroneous to assume that a consistent, direct relationship between benthic secondary productivity and the number of species of macroinvertebrates will persist between sampling intervals in a given place, time or habitat-type. There is rarely a predictable, invariable relationship between the numbers of large sessile animals supported by a habitat and the numbers of smaller or larger sessile and motile organisms living in it. The variety and numbers of

resident species in a given habitat are directly and indirectly influenced by transient species (wide-ranging predators, for example), whose numbers and types have been undersampled in the Pensacola and the other estuarine and shelf regions discussed in this report.

5. Little information exists on fisheries by-catch species composition or abundance, and less in known about the recruitment of fishes into the system, or their residence times. The suitability and abundance of Pensacola Bay System invertebrate species as forage for commercially important predatory fishes is unknown, as is the carrying capacity of the system for fishes in general, and for schooling fishes in particular.

5.4.2 Choctawhatchee Bay

5.4.2.1 Environmental Setting

Choctawhatchee Bay is an east-to-west trending coastal basin 48 km long and 1.6-2.4 km wide in the Gulf Coastal Lowlands physiographic province of the Florida panhandle. With a surface area of 1,190 km^2, Choctawhatchee Bay is the largest drowned river valley estuary in the panhandle, and the third largest on the Gulf coast of Florida (Blaylock, 1983; Livingston, 1987; FDEP, 1994). Choctawhatchee Bay and its bayous are shown in Figure 5-12.

Choctawhatchee Bay communicates with the Gulf of Mexico through a shallow channel (East Pass) at Destin, Florida. Water in eastern portions of Santa Rosa Sound commingle with Choctawhatchee Bay water near Ft. Walton Beach. It is suspected that very little mixed Santa Rosa Sound-Choctawhatchee Bay water enters the Gulf of Mexico through Pensacola Pass 69 km to the west. The intracoastal waterway is a 32.2 km-long, man-made canal that connects Choctawhatchee Bay to West Bay in the St. Andrew Bay system.

The eastern portion of Choctawhatchee Bay near the Choctawhatchee River is shallow, with depths of 0.1 to 3 m (FDEP, 1994). Water depth progressively increases to 9 m, and reaches a maximum of 13-14 m northeast of East Pass (Blaylock, 1983; Wolfe et al., 1988; FDEP, 1994). The average depth of Choctawhatchee Bay is about 3 m (Sonu and Wright, 1975). Shoaling is achronic problem at East Pass Channel, which is periodically dredged to maintain controlling depths of 4 m (Collard, 1976). Choctawhatchee Bay receives about 95% of its fresh water inflow from the highly alluvial Choctawhatchee River (Seaman, 1985). Thirteen smaller streams, including Alligator, Black, Peach, Rocky, Turkey, Holmes, Camp Branch, Sandy, West Sandy and Bruce Creeks also discharge into the bay. The largest of these is Alaqua Creek (Blaylock, 1983). Base flow in the bay is high due to seepage from the Sand and Gravel Aquifer (Wolfe et al., 1988).

FDEP (1994) noted that the Navarre Bridge Causeway divides Santa Rosa Sound into nearly equal sized eastern and western portions, and contributes to a bi-directional tidal flow in the estuary. Santa Rosa Sound is nearly uniform in depth and salinity with mean annual values of 2.7 m and 24 ppt, respectively. Although Santa Rosa Sound and Choctawhatchee Bay are connected, their physical boundaries and water quality characteristics are

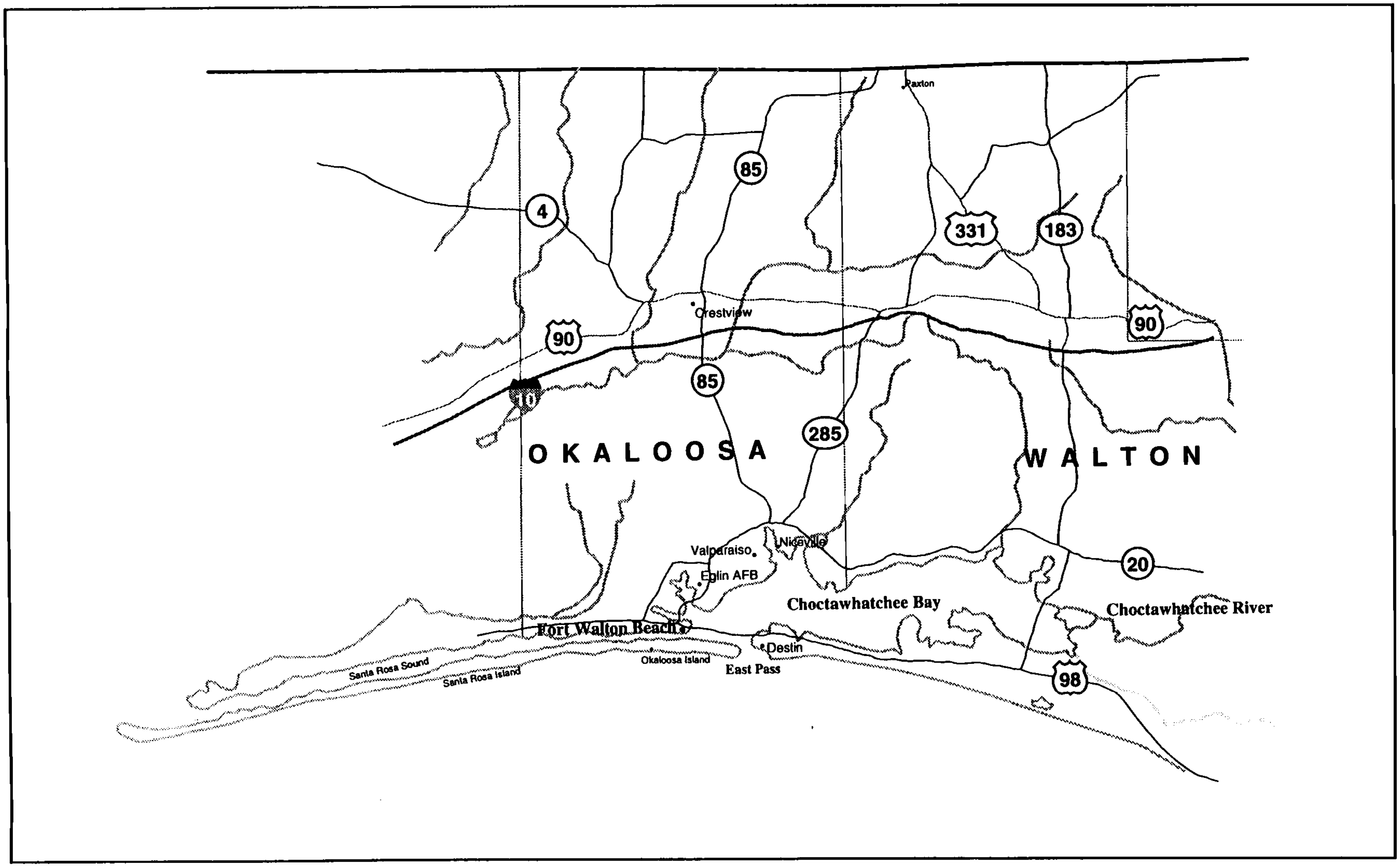


Figure 5-12. Schematic map of the Choctawhatchee Bay system.

quite different (FDEP, 1994). Bottom salinities at least in western portions of Santa Rosa Sound approach zero frequently. USEPA data (unpubl. data) suggest that average near-bottom salinities are about 15 ppt.

5.4.2.2 Hydrography and Oceanography

Choctawhatchee Bay is a low energy estuary with a non-storm tidal range of 0.2 m or less within the bay, and 0.4 m in the Gulf at East Pass (FDEP, 1994). Both eastern (Choctawhatchee River), and western (East Pass) ends of the bay are shallow relative to the central bay, and are at opposite ends of the salinity spectrum (0 and 34 ppt, respectively). Low tidal energy, a bowl-like bathymetry, and a single major point source of fresh water input result in a two-layered bay, in some ways reminiscent of a hypothetical estuary. Livingston estimated that salt water exchange was about 14 ppt during each tidal cycle, and that the overall flushing rate of Choctawhatchee Bay may exceed one year.

Whereas the friction of riverine fresh water flowing over deeper, saltier water causes some vertical, seaward-flowing entrainment of salt water and development of a mixed layer of variable, but generally shallow thickness, Choctawhatchee Bay is known to be strongly stratified (e.g. Collard, 1976; Blaylock, 1983; Livingston, 1986; FDEP, 1994). Livingston (1986) reported the presence of an extremely strong halocline, where salinity increased by 14 ppt with a two foot increase in depth. He recorded a maximum salinity below a halocline of 36.9 ppt LaGrange, Alaqua and Basin Bayous in eastern sections of the bay have relatively low salinities. Joe's, Indian, Horse-shoe and Hogtown Bayous have low to moderate salinities; and Upper Rocky and Boggy Bayous have moderate salinity at depth. Old Pass Lagoon, and Garnier Bayou have relatively high salinity according to Livingston (1986).

Horizontal, and to a somewhat lesser extent, vertical salinity gradients, depth of the mixed layer, and the depth and strength of the pycnocline are a function of river flows and wind mixing. A strong halocline seems to be present most of the time, throughout most of Choctawhatchee Bay. Collard (1976) reported that the western two thirds of the bay was highly stratified, and the eastern third was weakly stratified year round. Livingston (1986) reported that deeper bay waters were among the most highly stratified in the panhandle.

During warm summer months isohaline and slightly mixed upper water in the bay becomes even less dense, and a strong thermocline develops at approximately the same depth as the halocline. These two factors result in a strong pycnocline that resists turbulent mixing, and may result in drastically reduced dissolved oxygen concentrations in bottom waters depleted of the gas by BOD, COD and SOD.

Sonu and Wright (1975) studied the interactions between tides, water density distribution, longshore currents, waves and winds associated with East Pass. Pollutants moving with undiluted offshore water can approach the inlet for most of the tidal cycle. Sonu and Wright reported that, "During flood tides, a wave-induced longshore current is readily entrained into the inlet, whereas an ambient cross current, either driven by tide or sea breeze, tends to bypass the inlet by deflecting seaward at the jetty.

During ebb tide, these currents can still operate in strength in the underlayer, by-passing the inlet beneath the buoyant jet or approaching the inlet under a laterally expanding effluent along the adjacent surf zone. The effluent discharging with the jet can undergo strong buoyant expansion into the adjacent coast, forming a partially diluted effluent pool against the shore under a sea breeze. The land breeze and the instability at the density boundary between this nearshore effluent pool and the undiluted offshore water are the two most important factors affecting the eventual dispersion and diffusion of the tidal inlet effluent."

5.4.2.3 Water and Sediment Quality

Livingston (1986) described the development of Choctawhatchee Bay from its almost lake-like condition in the early 1920s, to the late 1980s. His historical account of modifications made to the estuary are useful in understanding its present characteristics. According to Livingston (1986) the first major modification of the bay occurred in 1929, when a new, direct channel was cut from the bay to the Gulf of Mexico at Destin. Prior to that time, flushing of the bay was much less than at present; water level was much higher; and overall salinity was (probably) much lower. Livingston (1986) suggested that a second major modification was made to the bay itself, with construction of a causeway across the eastern part of the bay. The causeway modified circulation patterns and altered the movement and deposition of sediment carried into the bay from the Choctawhatchee River. The most recent, and continuing major modifications of Choctawhatchee Bay are the result of, "considerable growth of agricultural land use" in the Choctawhatchee River basin, along with accelerating municipal development in western portions of the bay (Livingston, 1986).

Paulic and Hand (1994) assessed water quality in Choctawhatchee Bay as "generally good" (i.e. met its designated use), but threatened due to development in Destin and Fort Walton Beach. The occurrence of eutrophication and fish kills in Old Pass Lagoon at Destin was mentioned as a problem area. Water quality was assessed as "fair" in Jose, Rocky, Indian, LaGrange and Boggy Bayous and in Peach Creek and Jolly Bay at Black Creek. Water quality problems in these bayous and streams were attributed primarily to development and Waste Water Treatment Plant (WWTP) discharges. Paulic and Hand (1994) determined from available data and professional judgement that the Choctawhatchee River was of "generally good water quality", but several tributary systems (Alligator, Holmes, Camp Branch Creeks, West Sandy Creek and Bruce Creek) had problems with domestic or industrial discharges.

FDEP (1994) reported that nitrogen levels were highest in western portions of Choctawhatchee Bay (Cinco, Garnier, lower Rocky and Boggy Bayous) due to stormwater runoff from Destin Peninsula and adjacent developed areas. Low primary productivity in the bay was attributed to low concentrations of dissolved phosphorus.

Choctawhatchee Bay sediment characteristics vary from east to west with distance from the Choctawhatchee River (and smaller streams) and East Pass, respectively; and from shallow marginal areas to deeper depths in the central basin of the estuary. Fine sediments containing relatively high TOC and heavy metals are found in much of the eastern, Choctawhatchee River-dominated portions of the estuary, in some bayous (e.g. La Grange, Basin, Lower Rocky, Boggy, Garnier, Indian, and Hogtown Bayous), and in deeper portions of the basin, where silts and clays accumulate (e.g. Livingston, 1986; FDEP, 1994).

Livingston (1986) reported a fringe of medium- to well-sorted quartz sand from shore to the 6-8 foot depth contour in Old Pass Lagoon, and in Alaqua and Upper Rocky Bayou. The shelf drops sharply to a transition zone of silty sand, followed by a second shelf-slope transition zone where sediments become predominantly clay-silt in deeper water of the central and western portions of the estuary. Relic quartz sand characterizes the far western end of the bay, and fine sediments dominate eastern portions (Livingston, 1986).

SOD is reported to be fairly high in fine sediments because of hypoxia (oxygen concentrations $< 2 \text{ mg} \cdot \text{l}^{-1}$), relatively high nutrient concentrations and in some areas, the likelihood of high BOD (Livingston, 1986; Paulic and Hand, 1994; FDEP, 1994). Livingston (1986) did not find significant concentrations of toxic organic agents (pesticides, herbicides) in Choctawhatchee Bay sediments.

Using FDER guidelines for assessing metals concentrations in sediments (i.e. aluminum-to-metal ratios), (Ryan et al., 1984), Paulic and Hand (1994) and Livingston (1986) reported that fine sediments in some portions of urbanized western bayous (particularly Boggy Bayou) and deeper portions of the central and eastern bay basin were "enriched" or "possibly enriched" with several metals, including Al, As, Cd, Cu, Fe, Pb, Ni and Zn. The concentration and distribution of metals was patchy and attributed to natural processes, including river flow, basin physiographic characteristics, and anthropogenic activities such as urbanization and stormwater runoff. It was suggested that at least copper and lead, and possibly zinc and cadmium enrichment were associated with urban stormwater runoff and marina development in western portions of the bay. River influence was most evident for As, Cu and Ni. Urban runoff and marina activities explained in part elevated concentrations of Cu, Pb, Zn, Cd in Old Pass Lagoon sediments.

5.4.2.4 Biology

Livingston (1987) characterized Choctawhatchee Bay as an important nursery area for marine organisms and supported an active fishing industry. He noted, however, that productivity of the bay was perceived to be lower than in the recent past (i.e. early 1980s). This impression is widely held by biologists at Okaloosa Community College (Hamilton, pers. comm.), local commercial and sports fishers (pers. comm.), local residents (pers. comm.) and the mass media.

As is the case with the Pensacola estuary, Santa Rosa Sound, and St. Andrew Bay, Choctawhatchee Bay is increasingly exposed to, and undergoing adverse changes caused by anthropic stressors. Poorly flushed, urbanized bayous, in particular, appear to be changing at rates too rapid for accommodation by historically abundant transient and resident animals and plants.

Salt Marshes and Submerged Aquatic Vegetation

Choctawhatchee Bay exhibits a submerged vegetation coenocline, with fresh water species (*e.g., Cladium jamaicense*) dominant near freshwater sources. Species tolerant to slightly brackish water (*e.g., Vallisneria americana*) are found in shallow water with increasing distance from fresh water sources, and *Ruppia maritima* is the only submergent vascular plant found in brackish waters of the estuary (Livingston, 1987). True seagrasses are not supported in Choctawhatchee Bay because of low salinities in the bay's eastern reaches, high turbidity in deeper, saline portions of the bay, and current scouring of sand sediments in the vicinity of East Pass (Collard, pers. comm.). Fringing fresh-to-salt marsh dominants include, from east to west (fresh to more saline), the exotic *Phragmites australis, Spartina* spp., and *Juncus roemerianus* (Livingston, 1987). Fishes associated with SAV are discussed below.

Benthos

Livingston (1987) reported that as of 1968, a total of 110 species of benthic macroinvertebrate species (including freshwater taxa) had been recorded from Choctawhatchee Bay. Collard (1976), however, reported that otter trawl and grab samples taken during the summer suggested that the bottom of the bay was "biologically barren." All recent investigators (e.g. Collard, 1976; Taylor Biological, 1978; Livingston 1986; Livingston, 1987; FDEP, 1994), found that species diversity decreased to the east, with decreasing salinity.

In the most comprehensive investigation of Choctawhatchee Bay accomplished to date, Livingston (1987) found, based on collections made during 1985-1986, that benthic abundance and species composition was highly variable, but that Carolinian species predominated. Livingston reported that the lowest number and biomass of infauna occurred in mid-bay and in various bayous (Boggy, Lower Rocky and Garnier). Deep, mid-bay silt-clay substrates were dominated by the opportunistic polychaete, *Mediomastus ambiseta*, which was a numerical, but not a biomass dominant in the bay as a whole. The polychaete, *Carazziella hobsonae,* was numerically dominant in Old Pass Lagoon.

Livingston's 1985-86 collections showed that the highest number and biomass of the benthic biota occurred in shallow seagrass areas, and in deeper sections of the western portions of the bay. Such areas were dominated by tubiculous worms, *Mediomastus ambiseta, Aricidia philbinae, A. taylori,* and *Carazziella hobsonae*. In contrast, areas of the bay comprised of silt-clay sediments with high organic and metals concentrations were depauperate. Livingston (1987) stated that, "In any case, for the bay's size, the Choctawhatchee Bay infaunal biota can be characterized as depauperate in numerical abundance, dry weight biomass, and species richness."

Livingston (1986) described the trophic guild structure of the benthos as follows: Overall, below-surface browsers, scavengers and grazers were dominant at deep, mid-bay stations, but not in the metals-enriched western bayous or in Old Pass Lagoon. In the latter, above-surface feeding types dominated collections. Livingston suggested that this type of foraging could explain, in part, the high densities of animals observed, in spite of the presence of polluted sediments. Livingston (1987) concluded that, "the overwhelming bay-wide majority of such [epibenthic] organisms are detritivorous omnivores, and that "herbivory was also somewhat common". Two guilds clearly dominated in the Choctawhatchee Bay benthos: omnivorous scavengers of limited dispersal, and deposit-feeding omnivores having wide dispersal. A disproportionate fraction of all "guilds" were dominated by so-called opportunist indicator species (Livingston, 1987). "Clearly, the biological features of the infaunal macroinvertebrates were primarily associated with the various aspects of the sediments and, secondarily, with depth" (Livingston, 1987).

Over 30% of the benthic infaunal macroinvertebrates in Rocky Bayou were reported to be oligochaetes by Livingston (1987). Infaunal polychaetes were represented by *Mediomastus ambiseta, Aricidea philbinae, Streblospio benedicti, Fabricio* sp., *Prionospio heterobranchia, Lepidactylus* sp. *Chione duneri* and *Laeonereis culveri*. The macroepifauna of Rocky Bayou was dominated by *Penaeus duorarum, P. setiferus, P. aztecus, Callinectes sapidus* and *Lolliguncula brevis*.

Wolfe et al. (1988) reported that benthic collections near Fort Walton Beach showed a fairly healthy macroinvertebrate community, but that there was a significant decline in species diversity in the bay, near Piney Point. These observations support those of Livingston (1987) that species diversity decreased east of East Pass inlet.

Fishes

FDEP (1994) reported that a total of 330 species of fishes were collected from Choctawhatchee Bay, Pensacola Bay and Santa Rosa Sound during the period 1972-1992. Of the species collected in Choctawhatchee Bay, more than 91% of the catch was represented by only six species. During spring, 1994, a total of more than 302,000 individuals representing 117 taxa of fishes were captured in the bay using beach seines, offshore seines, gillnets, and trawls. *Leiostomus xanthurus, Lagodon rhomboides, Menidia* spp., and *Brevoortia* spp. accounted for 81.6% of all beach seine collections, and of these, twice as many *L. xanthurus* were captured as either *L. rhomboides* or *Menidia* spp. *Lagodon rhomboides* was the most abundant species collected in offshore seines (67.5% of the catch), followed by *Leiostomus xanthurus* (10.1%). Four numerically dominant taxa (75.2% of the total catch) were collected with experimental gillnets: *Arius felis* (52.1% of the total); *Cynoscion nebulosus; Mugil* spp.; and *Opisthonema oglinum* comprised the remainder. Trawl catches were dominated by *Leiostomus xanthurus* (84.2%), which together with *Brevoortia* spp. and *Anchoa* spp. made up 91.5% of all trawl catches.

Fishes were also collected by FDEP during fall 1994 with the same types of gear used during their spring sampling. Catch results are summarized below. Beach seine dominants (90.1% of the total) were *Leiostomus xanthurus, Menidia* spp., *Eucinostomus* spp. and *Anchoa* spp. *Menidia* spp.

were most common (25.8% of the total) in offshore seine catches, and 77.4% of experimental gillnet takes were comprised of *Leiostomus xanthurus* (49.6%), *Arius felis* and *Brevoortia* spp. Trawl hauls were dominated by *Leiostomus xanthurus* (34.5%), *Anchoa* spp., *Penaeus* spp. and *Eucinostomus* spp. At fixed beach seine stations, the numerically most abundant species caught was *Lagodon rhomboides,* followed by *Leiostomus xanthurus,* and the invertebrates, *Callinectes sapidus* and *Penaeus* spp. *Anchoa* spp. was most abundant (84.6% of the total) in offshore seine collections. *Anchoa* spp., *L. xanthurus* and *Mugil* spp. together made up 94% of the total offshore seine collections. Most of the numerically abundant species were dominant in all habitats.

Many seasonal tropical species occur at or near the Destin jetties. These include cocoa damsels (*Pomacentrus variabilis)*, angelfishes (Pomacanthidae), parrotfishes (Sparidae), spadefishes (Ephippidae) and butterflyfishes (Chastodontidae). It is likely that the young stages of many tropical species are advected to panhandle coastal environments, but a lack of suitable habitat (i.e. extensive rubble mounds) prevents them from becoming established during warm water months.

5.4.2.5 Data Gaps

1. The impact of Hurricanes Erin and Opal (August and October, 1995) on the water quality of Choctawhatchee Bay and its bayous has not been evaluated. However, the high storm surge and pulse of ocean water into Choctawhatchee Bay during this hurricane may have flushed a significant volume of resuspended fines out of the system. Sand dunes between Destin and Ft. Walton Beach were completely destroyed during the storm, permitting a free exchange between Gulf of Mexico and Choctawhatchee Bay water.

2. Environmental impacts of Hurricanes Erin and Opal on Choctawhatchee Bay water and sediment quality; flushing rates; bathymetry; nutrients, toxic chemicals and heavy metals pulse loadings; and suffocation of sessile benthic invertebrates (e.g. oysters) by sediments are not known. Based on personal observations, however, we speculate that the storm's impact on some or all of the variables mentioned may have been significant over short (weeks to months) and intermediate (months to several years) time scales.

3. A considerable quantity of military-related debris (bombs, bullets, etc.) may contribute to elevated levels of certain metals in Choctawhatchee Bay. An effort should be made to assess the distribution of submerged ordnance, as well as the overall impact of Eglin Air Force Base on the bay's ecology.

4. Primary productivity-production throughout the bay, and its distributional relationship with primary sources of nutrients (i.e. Choctawhatchee River, nutrient-rich bayous, marinas) needs to be assessed in order to determine food web relationships between organisms in the system.

5. Because of very rapid population growth in the area surrounding Choctawhatchee Bay, a monitoring program should be implemented to assess likely increases in levels of adverse anthropogenic impacts on the bay's ecosystems.

5.4.3 St. Andrew Bay

5.4.3.1 Environmental Setting

The St. Andrew Bay coastal plain estuary is a large bilobate embayment located in the Gulf Coastal Lowlands physiographic region of the central Florida panhandle. West and North Bays form the western lobe, and East Bay forms the eastern lobe of the embayment. St. Andrew Bay proper lies between the eastern and western portions of the estuary, and connects the Gulf of Mexico with West, North and East Bays (Figure 5-13). Panama City lies between East and West Bays (Saloman et al., 1982; Wolfe et al., 1988; Paulic and Hand, 1994). The estuary is approximately 31 miles (19.2 km) long, and trends from northwest to southeast parallel to the coast. North Bay extends inland approximately 13.5 miles (21.7 km) to Econfina Creek, its major freshwater source (Young et al., 1987).

St. Andrew Bay has a surface area variously estimated to be between 94 mi^2 and 108 mi^2 (Pristas and Trent, 1978), with a total volume of 3.13×10^{10} ft^3 (about 829,000 acre-feet) at mean high water (Saloman et al., 1982; NOAA/EPA, 1989). The estuarine drainage area of the system is 1,130 mi^2, with an average daily inflow of 4,500 cfs. Econfina Creek, with an average flow about 500 cfs, is the principal point-source of fresh water (via Deer Point Lake) into the system. For most of the year base flow in Econfina Creek is maintained by ground water from springs fed by the Floridan Aquifer (Musgrove et al., 1968). Unlike other major estuaries in Florida, the St. Andrew system has no fluvial streams, and its watershed lies entirely within the state. The St. Andrew Bay Resource Management Association (1992) described the bay system as having an average depth of 5.2 m (17 ft) and a maximum depth of 19.8 m (65 ft). Because natural tributaries that discharge into the system are clean, and several are spring-fed, St. Andrew Bay has clear water throughout most of its reaches. In addition to Econfina Creek, *Wolfe et al* (1988) consider the main tributaries in the St. Andrew Bay coastal drainage area to be Wetappo Creek, Sandy Creek, Bear Creek and Big Cedar Creek. Except for Econfina Creek, streamflows are unknown.

5.4.3.2 Hydrography and Oceanography

The St. Andrew Bay system communicates with the Gulf of Mexico through two passes. West Pass, constructed by the Army Corps of Engineers in 1934, is a 10 to 20 m deep, 152 m (500 ft) wide channel located about seven miles northwest of East Pass. It is, relative to the latter, of little significance to circulation patterns or flushing rates. East Pass is (or was, prior to October 1995) over a mile wide, and relatively shallow over most of its width (depths range from 2-8 m). A sand bar forms at the seaward opening of East Pass (due to longshore drift), and it must be dredged every 12-18 months.

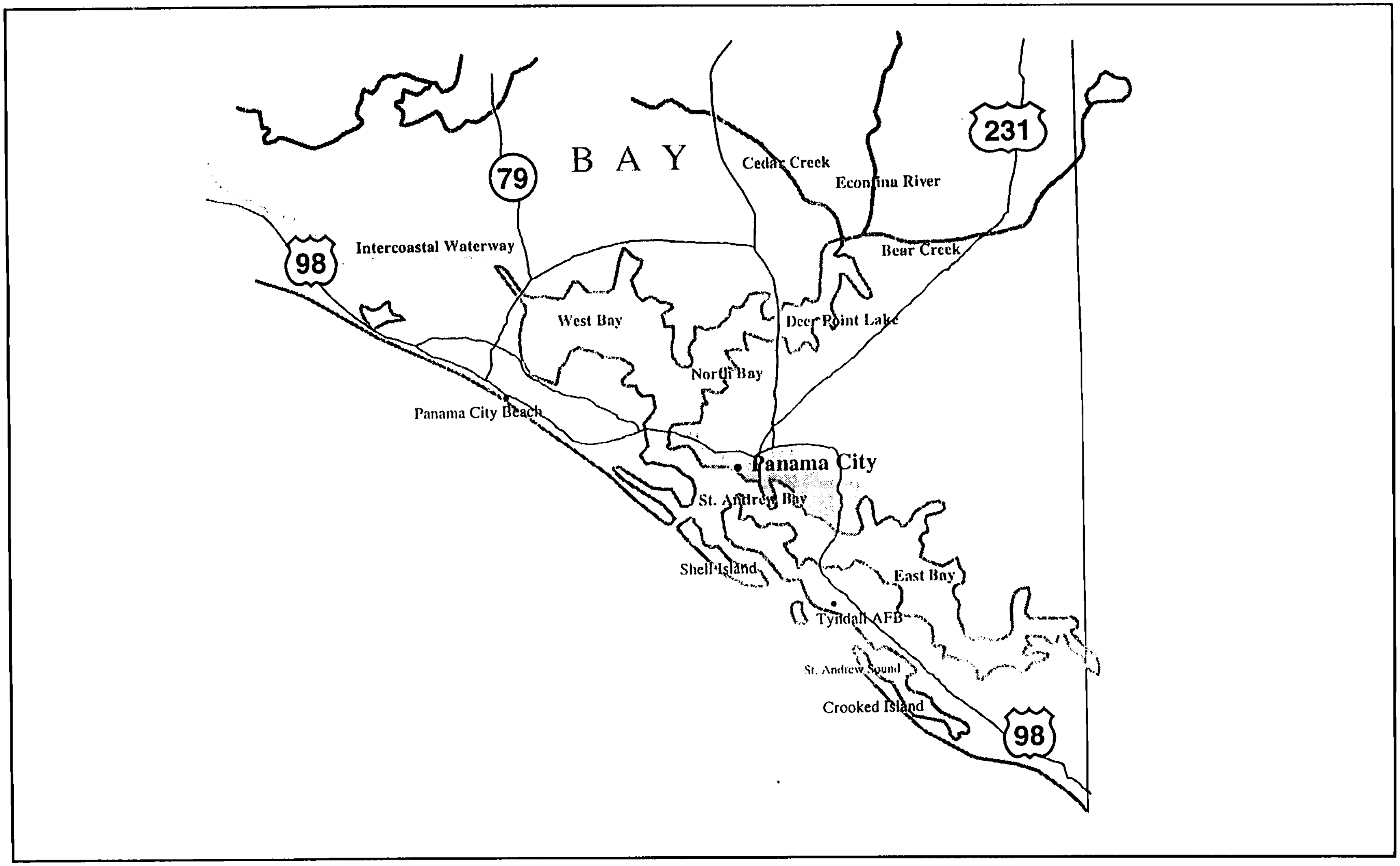


Figure 5-13. Schematic map of the St. Andrew Bay system.

Saloman et al. (1982) noted that as a result of low volumes of freshwater inputs and good flushing rates in most of the system, St. Andrew Bay has relatively clear, high salinity water. They found that Secchi depths are generally 6 m or more near Gulf passes, and nearly always greater than 1.8 m in North, West, and East Bays. Saloman et al. (1988) attributed clear waters of the system to: (1) clear incoming tidal and tributary waters; (2) forested uplands; (3) locally porous, sandy soils with a low silt-clay fraction; and (4) natural filters in the form of abundant tidal marshes and submerged aquatic vegetation that collect and stabilize suspended sediments and particulate detritus.

Under average conditions the salinity at the surface and bottom in North, West, and East Bays is about 10-30 ppt Surface salinity in East Bay falls as low as 5 ppt, the halocline is deeper, and turbidity is higher than in the other subsystems. Salinity in St. Andrew Bay rarely falls below 30 ppt at the surface and is usually 33 ppt or higher (Saloman et al., 1982). Following heavy rains, the salinity frequently falls below 10 ppt in the upper parts of North, West, and East Bays. At such times a well-defined, strong halocline may develop between relatively fresh surface waters and a lower wedge of highly saline water (Saloman et al., 1982). When heavy rainfall is of unusually long duration (several days) surface salinities of 0 ppt may occur throughout the system. Collard (unpubl. Data) measured salinities of 0 ppt at the surface, and 21 ppt in the bottom waters of central St. Andrew Bay during September 1994. Fernald and Purdum (1992) reported mean seasonal salinities in the system to be 35 ppt in winter, 34 ppt in spring, 35 ppt in summer, and 36 ppt in the fall.

There is disagreement with Naughton and Saloman (1978), who reported that, "Salinity stratification is minimal except in bayous and creeks during rainfall periods". Baskerville-Donovan, Inc. (1991) suggested that, "A strong halocline may often occur, but thermoclines are generally weak, with differences of only a few degrees Celsius."

Saloman et al. (1982) reported that summer water temperatures fluctuate between 26.7°C and 32.2°C. Spring and fall water temperatures average about 21.1°C, and winter temperatures fall to 12.8°C or less. Thermoclines are common, but seldom exceed a surface to bottom temperature difference of more than a few degrees. Surface water temperatures are summarized in Table 5-16.

Table 5-16. Sea-surface temperatures (°C) in the St. Andrew Bay system (after Saloman et al 1982).

	Winter	Spring	Summer	Fall
Maximum	24.4 (76°F)	28.9 (84°F)	30.0 (86°F)	26.7 (80°F)
Minimum	16.7 (62°F)	23.3 (74°F)	26.7 (80°F)	18.9 (66°F)
Mean	17.8 (64°F)	25.6 (78°F)	28.9 (84°F)	22.2 (72°F)

Although surface water temperatures are mild or warm most of the time, in most years; ice occasionally forms at the edges of quiet inlets and bays (e.g., Bureau of Submerged Lands and Preserves, 1991). Surface water temperature ranged between 5°C and 16°C in January, 1996 (Collard, unpubl. data).

Tides in the St. Andrew Bay system were reported by Saloman et al. (1982) to be diurnal, with a tidal range generally less than 1.2 m. Wave heights are usually less than 0.3 m, and tidal currents are generally less than 1 knot. The highest storm surge measured in the system was 5 m above mean sea level (MSL) (Saloman et al., 1982). Collard (unpubl. data) measured the October, 1995, storm surge in St. Andrew Sound as between 2.0 and 2.5 m above MSL.

Based on the analysis of tide gauges at six stations during the period August 1991 to January 1992, HydroQual, Inc. and Barry A. Vittor & Associates, Inc. (1993) reported that a spring-neap tidal cycle with an approximate period of two weeks, was clearly evident. The daily average water level at each location also varied with time, primarily due to varying hydrodynamic conditions in the Gulf of Mexico.

A circular current often develops in East Bay, when tides are flooding in the tidal inlets at a maximum rate. This creates a zone of poor circulation at the upper (northeast) part of the bay. The current in East Bay, however, maintains relatively good circulation in the rest of the bay. Whereas West Bay directly receives little fresh water from runoff or streams, it receives water from Deer Point Lake driven by strong tidal currents in St. Andrew Bay. Saloman et al. (1982) described the mass balance of water in the system. The net flow of water at the surface is northwest into West Bay; south from North Bay; northwest out of East Bay and to the Gulf of Mexico from the system as a whole. Mass balance for the lower layers of water (i.e. below the halocline) are northwest into West Bay; north into North Bay; southeast into East Bay; and north into the system from the Gulf of Mexico.

5.4.3.3 Water and Sediment Quality

Paulic and Hand (1994) stated that, "The St. Andrews (sic)Bay system generally exhibits good water quality. The major inflow, Econfina Creek, is nearly pristine, and most of the urbanized area is concentrated where the bay is better flushed by the Gulf. However, the bay is threatened, not only by the growth-induced nonpoint source pollution, but also by several important domestic and industrial point-sources." Watson and Beatty Bayous were judged to be degraded by urban stormwater and historic waste water treatment plant (WWTP) discharges. Watson Bayou was also reported to have high sediment concentrations of lead, mercury, cadmium, zinc, DDT, Chlordane, PCBs and polycyclic aromatic hydrocarbons (PAHs). Metals found in St. Andrew Bay included zinc, lead and copper.

NOAA (1989) evaluated the pollution susceptibility of St. Andrew Bay and predicted that its dissolved substance concentration potential was 0.76 mg l^{-1}, and its particle retention efficiency was 0.22 mg l^{-1} (volume to inflow). Both of these values correspond to "medium class" pollution susceptibility. The NOAA study estimated nutrient loadings for the system (Table 5-17)and its predicted concentration status (load in tons per year required to change its concentration class) [see Table 5-18].

Sources of TKN were calculated to be about 24-25% from point-source WWTPs, about 60% from point-source industrial facilities, about 20% from nonpoint agricultural runofn, and less than 5% from nonpoint urban runoff (about 75% from point source WWTPs and industry, and about 25% from nonpoint agriculture and urban sources). About 80% of phosphorous inputs were calculated to come from point-source WWTPs and industry, and about 20% from nonpoint agriculture and urban sources (NOAA, 1989).

NOAA (1989) estimated that St. Andrew Bay had a medium susceptibility for concentrating dissolved substances: "This dissolved concentration potential combined with the estimated nutrient loadings results in predicted concentrations within the low range for both nitrogen and phosphorous.

Table 5-17. Estimated nutrient loadings for the St. Andrew Bay system (from NOAA, 1989).

Sources	**Nutrients**	
	TKN ($tons \cdot yr^{-1}$)	**Phosphorous ($tons \cdot yr^{-1}$)**
Point	271	42
Nonpoint	872	61
Upstream	0	0

Table 5-18. Predicted concentration status for the St. Andrew Bay system (from NOAA, 1989).

	Concentration		**Increase By**		**Decrease By**	
Nutrient	($mg \cdot l^{-1}$)	Class	Load	%	Load	%
Nitrogen	0.087	(L)	173	15	N/A	N/A
Phosphorous	0.008	(L)	29	28	N/A	N/A

In St. Andrew Bay, the low nitrogen concentration classification may be influenced by a minor increase (< 20%) in nitrogen loading."

Ferrario (1990) reported that a site in St. Andrews (sic)Bay had a phenanthrene to anthracene ratio of 144 and showed high levels of alkylated PAHs, indicative of contamination by non-combusted petroleum products. Ratios were greater than 50, thus the sources of PAHs were not from rain or stormwater runoff, but likely from municipal, agricultural or industrial waste. Ferrario (1990) also reported that the highest concentrations of total DDTs in estuaries were usually associated with major river outfalls. However, St. Andrews (sic) Bay and Panama City, Florida, which receive no major river effluents, have not only the highest concentrations of total DDT but also the highest concentrations of PAHs, evidence of human impact on these areas.

The St. Andrew Bay Resource Management Association (SABRMA) (1992) reported that point-source pollution discharges exceeded 30 mgd, and that secondary domestic and industrial wastewater inputs were gradually increasing pollution levels in the system. Other causes for concern mentioned in the report were chronic stack emissions and a virtual lack of stormwater runoff or treatment controls. The SABRMA (1992) report concluded that the St. Andrew Bay system was still in generally good condition, but some of its bayous were deteriorating as evidenced by fish kills and seagrass losses. Baskerville-Donovan, Inc. (1991) calculated that there were currently approximately 30 major point-source discharges into the St. Andrew system.

Young et al. (1987) reported that West Bay received discharges from the West Panama City Beach WWTP, and thermal effluents from the Lansing Smith Power Plant at Warren Bayou. Saloman et al. (1982) calculated the Gulf Power thermal effluent to be some 200,000 gallons per minute, and the SABRMA (1992) reported that water temperatures from the outfall in Warren Bayou exceeded 40°C, higher than the upper lethal temperature of many estuarine species. Low DO levels were reported in the vicinity of the Panama City Beach WWTP by Hand and Paulic (1992).

According to Young et al. (1987), East Bay (connected to Lake Wimico and Apalachicola River by the Intracoastal Waterway) drained a number of acid sand-bottom streams, including Sandy, Wetapo, and Calloway Creeks. Environmental problems in East Bay included domestic and industrial wastewater discharges, sand mining in Cook's Bayou, non-point source impacts from Tyndall Air Force Base, stormwater runoff from surrounding urban areas, and draining of wetlands for pine tree silviculture.

In lower St. Andrew Bay, Young et al. (1987) reported that water quality degradation sometimes occurred in areas of tidal and wind concentration of the wastewater from outfalls at Gulf inlets and along beaches. Duke and Kruczynski (1992) reported that St. Andrew Bay was impacted by high coliform contamination from combined urban and nonurban sources. Hand and Paulic (1992) reported that water quality was depressed in an area around a paper mill, and that water in both Beatty and Watson Bayous was degraded by urban stormwater and historic WWTP discharges. Wolfe et al. (1988) reported that in 1984 Bay County showed elevated levels of As, Ba, Cr, small amounts of Pb, Se, F, N, and turbidity in untreated public water supplies.

Sediments in most of the St. Andrew Bay system are medium fine quartz sands about one foot thick (Wolfe et al., 1988; Fernald and Purdum, 1992). Clayey sands are found north and in the eastern portions of East Bay (Wolfe et al., 1988). Saloman et al. (1982) characterized shallow water sediments of the estuary as comprised of shell fragments and fine to course quartz sand. Substantial amounts of silt and clay sediments are present in many bayous, and in open bay areas at depth greater than 6.1 m (Saloman et al., 1982). Sediments around the margin of the bay system were reported by Baskerville-Donovan, Inc. (1991) to be predominantly quartz sands with shell hash. Grady (1981) reported that the average organic and carbonate content of sediments in seagrass beds were 1.9-fold greater than in sand flats. Tidal stream sediments were sandy silts containing moderate amounts of organic material. The total organic carbon content of these sediments ranged from 10% in shallow waters to 15% in deep waters.

In conjunction with biological sampling Saloman et al. (1982) reported that sediments consisted of moderately sorted fine sand, with finer sediments in quiet waters. Coarser sediments and shells were associated with oyster beds and reefs. Saloman et al. (1982) determined average sediment TOC to be slightly less than 1%, of which 70% consisted of plant detritus, and 30% of shell fragments and animal remains.

Ferrario (1990) reported the concentrations of 18 PAH compounds from 153 sediment and 145 oyster samples collected from 50 locations within the St. Andrew system. PAHs were detected in 89% of the sediment and 78% of the oyster samples (Wade et al., 1988). The total PAH concentration in both sediment and oysters ranged from about 10 ppb to 18,000 ppb, with fluoranthrene and pyrene generally accounting for more than 25 percent of the total. The highest value in both sediment and oysters was from Watson's Bayou in St. Andrew Bay. PAHs are reported to be carcinogenic, mutagenic, and/or teratogenic.

Baskerville-Donovan, Inc. (1991) reported that sediments in both St. Andrew and North Bays contained moderate amounts of contaminants such as heavy metals, hydrocarbons, and excess organic compounds and nutrients. Baskerville-Donovan (1991) stated, however, that, "These data indicate that estuaries in the St. Andrew Bay system contain lower sediment contaminant levels than most other estuaries in the northeastern Gulf of Mexico."

5.4.3.4 Biology

The biology of the salt marsh and submerged aquatic vegetation, benthos and fish in St Andrew Bay and St. Andrew Sound is discussed in the following paragraphs.

Salt Marshes and Submerged Aquatic Vegetation

St. Andrew Bay was reported by NOAA (1991) to have a total of 251,100 acres of coastal wetlands. Included in this total were 8,500 acres of salt marsh and 3,500 acres of tidal flats. Hand and Paulic (1992) noted that a dieback of salt marsh cordgrass (*Spartina* spp.) had occurred along the inner perimeter of St. Andrew Bay, but did not furnish quantitative information on causes or loss rates. Wolfe et al. (1988) noted that the shores of St. Andrew Bay are protected by marshes. It was not possible, however, to evaluate the degree of erosion mitigation or other protection actually provided by salt marshes in our post-Hurricane Opal observations of St. Andrew Bay.

Wolfe et al. (1988) reported that the St. Andrew Bay system contained the largest total acreage of seagrass stock in the panhandle. According to Brusher and Ogren (1976), the estuary had about 7,900 acres of submerged aquatic vegetation (SAV). *Vallisneria americana* was found in the fresher waters of lower Econfina Creek, and *Ruppia maritima* occurred near bayhead tidal streams. Of the true seagrasses, *Halodule wrightii* was also found around bayheads, and in shallow waters inshore of *Thalassia testudinum*. Grady (1981) observed that *Thalassia testudinum* was the dominant seagrass in unpolluted parts of the system. *Halodule wrightii* replaced *Thalassia* in polluted waters (Grady, 1981). In the high salinity waters of upper West Bay, SAV was reported to be primarily *Ruppia maritima* and *Halodule* *wrightii*, with only patchy beds of *Thalassia testudinum* (Young et al., 1987).

It was not possible to distinguish major changes in the distribution of seagrass meadows in St. Andrew Bay from visual and photographic observations made during an overflight of the area two weeks after Hurricane Opal (Collard, unpubl. data).

Seagrass meadows in St. Andrew (Crooked Island) Sound, a shallow marine lagoon bounded by Tyndall Air Force Base, were studied from mid-June to mid-August 1992. The study site was located at the narrowest part of the Sound about 3 km from its eastern origin. Seagrass meadows were monocultures of *Thalassia testudinum* and *Halodule wrightii*. Beds of the two species were often contiguous, with little or no overlap in distribution. Water temperatures during the study period ranged from 29.9 to 34.4 °C; salinity ranged from 30.1 to 36.0 ppt At the deepest station water depth ranged from 40 to 118 cm. A pycnocline was often present at mid-depths in deeper water. Currents in the Sound are complex, and react instantaneously to wind stress. Seagrass densities ranged from 951 leaves m^{-2} at the shallow *T. testudinum* to 2078 leaves m^{-2} at the deepest *T. testudinum* site. Reliable measures of *H. wrightii* densities were not obtained. Growth rates ranged from -0.3 cm day^{-1} to 2.5 cm day^{-1}. Fish and macroinvertebrate species diversity were high compared to other seagrass communities described in the literature. During a three day period a total of 57 species of fishes were collected using a small trawl and a crab scrape. This compares to a total of 128 species caught during both day and night trawl hauls over a one year period in the entire St. Andrew Bay estuarine complex. Heat and low tide exposure stress caused short-term diebacks in the shallowest beds, and contributed to a mass mortality of the sea urchin *Lytechinus variegatus*. Dominant macroepibenthic invertebrates included sea urchins, the Florida crowned conch, the horn shell, *Bittium varium*, blue crabs, hermit crabs, paleomonid shrimp, pink shrimp, mud crabs, hermit crabs, and arrow shrimp. Preliminary lists of species are included in the report. Infaunal species were inadequately sampled, and epiphytes were not sampled. Macroalgae were not found in or near the sampling area, an unusual, if not singular characteristic of the seagrass community in Crooked Island Sound. Damage to seagrass meadows in the sampling area was caused by boat propellers, recreational scallop harvesting and intrusive sampling by the author. No direct or presumptive evidence of pollution from anthropogenic activities in the area was detected. Compared to other coastal ecosystems in the northern Gulf of Mexico Crooked Island Sound is relatively undisturbed and biologically diverse.

Benthos

Saloman et al. (1982) identified benthic macroinvertebrates from 149 stations in the St. Andrew estuary during the summer of 1974. At a majority of stations they obtained one sample from an unvegetated sand substrate and one from a seagrass meadow. Samples were collected from Military Point, several bayous, and in central portions of the system. Collections from East Bay extended only to Pitt Bayou, and no collections were made in North or West Bays. Collections were also analyzed for sediment characteristics and carbon chemistry. Saloman et al. recorded a total of 242 species from their collections, which included 96 species of annelids (35% of the total species and 65% of the total number of animals); 89 species of crustaceans (33% of the total species and 23% of the total number of animals); and 69 species of molluscs (26% of the total number of species and 9% of the number of animals) collected. Ten taxonomic groups comprised the remainder of the catch (6% of the species and 9% of the individuals). Saloman et al. (1982) concluded that coelenterates and echinoderms may be limited, and that nemerteans, phoronids and cephalochordates may be favored in portions of the system that were sampled.

The most recent community analysis of benthos in the St. Andrew Bay system was accomplished by HydroQual, Inc. and Barry A. Vittor & Associates, Inc. (1993) during four seasonal sampling periods from May 1991 to May 1992. The following paragraphs refer to results of this work.

- Of the ten most abundant species collected, eight were polychaetes and the remaining two were an amphipod and a tanaid. The ten most widely distributed species included an unidentified nemertean, seven polychaetes, one mollusc and one species of isopod. Not surprisingly, the ten "most abundant" and ten "most widely distributed" species were not identical.

- The polychaetes, *Syllis cornuta* and *Nereis pelagica*; the amphipod, *Lepidactylus* sp., and the tanaid, *Kalliapseudes* sp., were among the ten most abundant species, but not among the ten most widely distributed. In contrast, *Glycinde solitaria, Heteromastus filiformis, Anodontia alba*, and a nemertean were listed among the ten most widely distributed species, but were not members of the most abundant group.

- The fewest species and number of individuals recovered during the investigation were obtained from samples collected in unvegetated sediments. Most of the 89 unvegetated sediment samples were taken in brackish water, in areas of higher than average currents/waves, in emergent spoil areas, or from polluted areas. The third highest number of species and individuals were recovered from 23 collections made in pure stands of *Halodule wrightii*, and the second highest number of species and individuals were recovered from 28 samples collected in mixed meadows of *H. wrightii* and *Thalassia testudinum*. The largest number of both species and individuals was collected from pure stands of *T. testudinum*.

- Within seagrass habitats, the number of species and individuals collected increased with increasing salinity; the lowest numbers were collected in lower salinity areas of East and West Bays.

- Seasonal collection comparisons revealed significant variability in infaunal macroinvertebrate abundance and diversity. May 1991 collections yielded 416 taxa (from 9 to 137 per station), and both numerical abundance and density varied widely, from 106 to 10,211 individuals per m^2. In September 1991, 385 taxa were recovered, and lower species abundance occurred at 20 of 29 stations (from 8 to 135 taxa per station). December 1991 collections recovered 414 taxa.

The May 1992 collections yielded the greatest number of taxa (455), and the highest and most variable between-station species abundances of the four sampling periods.

- The total number of taxa collected during the HydroQual, Inc. and Barry A. Vittor & Associates, Inc. (1993) study was 675. Of these taxa, polychaetes accounted for 61.5% of all infaunal individuals; arthropods comprised 20.5% of the total number of individual animals collected; and molluscs made up 13.5% of the individuals collected. Echinoderms and "other" taxa contributed only 4.4% of the total.

- Whereas polychaetes were most numerous, arthropods were the most speciose taxon with 41.5% of the total number of species. One third of all species collected were annelids, and 21.5% of the higher taxa were molluscs. When possible redundant taxa were excluded, sampling over all four seasons produced a total of 469 species: 169 annelids; 168 arthropods; and 112 molluscs.

- The polychaete, *Fabricinuda trilobata,* was the most abundant taxon collected during all four seasons, and equaled 18.7% of all organisms from the four surveys combined. *F. trilobata* was especially abundant in May 1992, when it accounted for 26% of the infauna.

To summarize, the ten most abundant species collected in the HydroQual, Inc. and Barry A. Vittor & Associates, Inc. (1993) survey accounted for 41.7% of the total infaunal taxa recovered. Nine of the ten species (five polychaetes, four molluscs, one crustacean) were among the numerical dominants during each survey.

Species assemblages were associated generally with depth (i.e. with similar substrata) rather than sample location. These data supported the findings of other workers who reported that East Bay had lower species diversity and numerical abundances than the rest of the system. East Bay, as noted above, is the most strongly stratified of the four subsystems in the St. Andrew estuarine system. A strong pycnocline is commonly associated with low dissolved oxygen levels and depauperate benthic communities.

HydroQual, Inc. and Barry A. Vittor & Associates, Inc. (1993) data showed that the benthic macroinfauna was diverse and abundant throughout the study area. The number of taxa was much higher than reported for other northern Gulf coast estuaries. Species abundance was highest in shallow waters, and correlated with depth, sediment texture and organic content. The lowest infaunal species diversity and abundance occurred in September 1991, a period of maximum thermal and salinity stratification throughout the system.

Prochaska and Mulkey (1983) reported that while Franklin County typically accounts for 90% of the statewide total of the annual Florida commercial oyster harvest, other counties, including Bay County "support some oystering". Prochaska and Mulkey (1983) stated that, "recreational data apparently do not exist... and whether the geographic distribution of effort parallels the commercial fishery [for oysters] is not known." Table 5-19 presents oyster reef coverage as of 1972. There is no reliable current information on the areal coverage of oyster reefs in the system.

Table 5-19 Oyster reef coverage in the St. Andrew Bay system (from McNulty et al., 1972).

Bay	Area (acres)
St. Andrew Bay	0
East Bay	46
West Bay	7
North Bay	6
St. Andrew Sound	0

Fishes

Ogren and Brusher (1977) trawled the deeper portions of the St. Andrew Bay system and collected 128 species of fishes. Seine samples collected within the St. Andrew estuary and along adjacent coastal beaches yielded 88 species (Naughton and Saloman, 1978) (see Table 5-20). Discussions of seasonal trends in distribution and abundance were provided in both papers.

Table 5-20. Fish community composition in St. Andrew Bay System, based on the top ten species reported in Florida from major individual studies (based on Naughton and Saloman, 1978).

Dominant Species	Total Number of Fishes (%)
Fundulus similis (longnose killifish)	8
Menidia beryllina (inland silverside)	28
Eucinostomus argenteus (spotfin mojarra)	8
Lagodon rhomboides (pinfish)	22
Leiostomus xanthurus (spot)	10
Percentage of Catch:	76

5.4.3.5 Data Gaps

1. Hurricane Opal struck the panhandle coast on 4 October, 1995. Based on observations and personal communications with state and federal agency personnel, the environmental impacts of this large storm on the coastline between Pensacola Beach and St. Joseph Spit-Cape San Blas were significant and, in some respects, extreme. Island and mainland beaches in the vicinity of St. Andrew Bay (including Crooked "Island" and Shell Island), sand dune, beach, and foreshore sediment translocation was so great that volumes can not be reliably

estimated. Although magnitudes are not known, some salt marsh vegetation (*Juncus, Spartina*), seagrass beds (*Halodule, Thalassia*), supratidal (*e.g., Ocypode*), intertidal (*e.g., Donax, Emerita*), foreshore, and estuarine infauna were destroyed or covered with sediments. It is likely that soft-bodied epifauna and infaunal animals exposed to wave shock (but not storm surge, *per se*) may have suffered large, probably temporary reductions in abundance. With the destruction of dune barriers separating estuarine areas from the open Gulf (particularly in western Choctawhatchee Bay, St. Andrew Sound, St. Andrew Bay inlets, and St. Joseph Bay), these areas have become very vulnerable to further storm damage. Ecological damage, and risk assessments should be made.

2. High levels of some contaminants are not readily explained by "sources of municipal and industrial waste". It is possible that St Andrew Bay has received (as noted in the section on Choctawhatchee Bay) wastes and/or debris as the result of historical military activities. Such sources may explain, in part, elevated levels of uncombusted petroleum products and (some) metals.

3. The distribution and areal coverage of oyster reefs and bars needs to be assessed.

5.4.4 Apalachicola Bay

5.4.4.1 Environmental Setting

Apalachicola Bay is a wide, shallow, 210 mi^2 estuary located on the eastern panhandle coast of Florida (Figure 5-14). The estuary lies at the mouth of the Apalachicola-Chattahootchee-Flint River system, and is separated from the Gulf of Mexico by a nearly complete semicircle of barrier islands: St. Vincent, Cape St. George, St. George and Dog Islands (Gorsline, 1963; FDNR, 1992; Donoghue, 1993). The bay communicates with the Gulf of Mexico through Indian, West and East Passes, and through St. George Sound and Sikes Cut, which is a man-made channel (Edmiston and Tuck, 1987). The Apalachicola River is the 21st largest river in the conterminous United States, with a mean annual flow of 25,000 cfs (Edmiston and Tuck, 1987). The river accounts for 35% of the total runoff from the west coast of Florida, and forms an extensive, compound, lobate-birdfoot delta which is gradually prograding into Apalachicola Bay (Wolfe et al., 1988; FDNR, 1992).

The Apalachicola Bay system is divided into four subsystems, based largely on their bathymetry (FDNR, 1992): (1) East Bay (north and east of the delta) has an average depth of about 1 m, and is surrounded by extensive marshes and swamps; (2) St. Vincent Sound, which has an average depth of about 1.2 m, and supports numerous oyster bars [this sound separates St. Vincent Island from the mainland, and communicates with the Gulf of Mexico by Indian Pass, which is about 4 m deep]; (3) Apalachicola Bay proper, which occupies the central and widest portion of the estuary, and is 2-3 m deep at mean low water; and (4) St. George Sound, which averages 3 m in depth, and is connected to the Gulf of Mexico through East Pass, separating Dog and St. George Islands (FDNR, 1992).

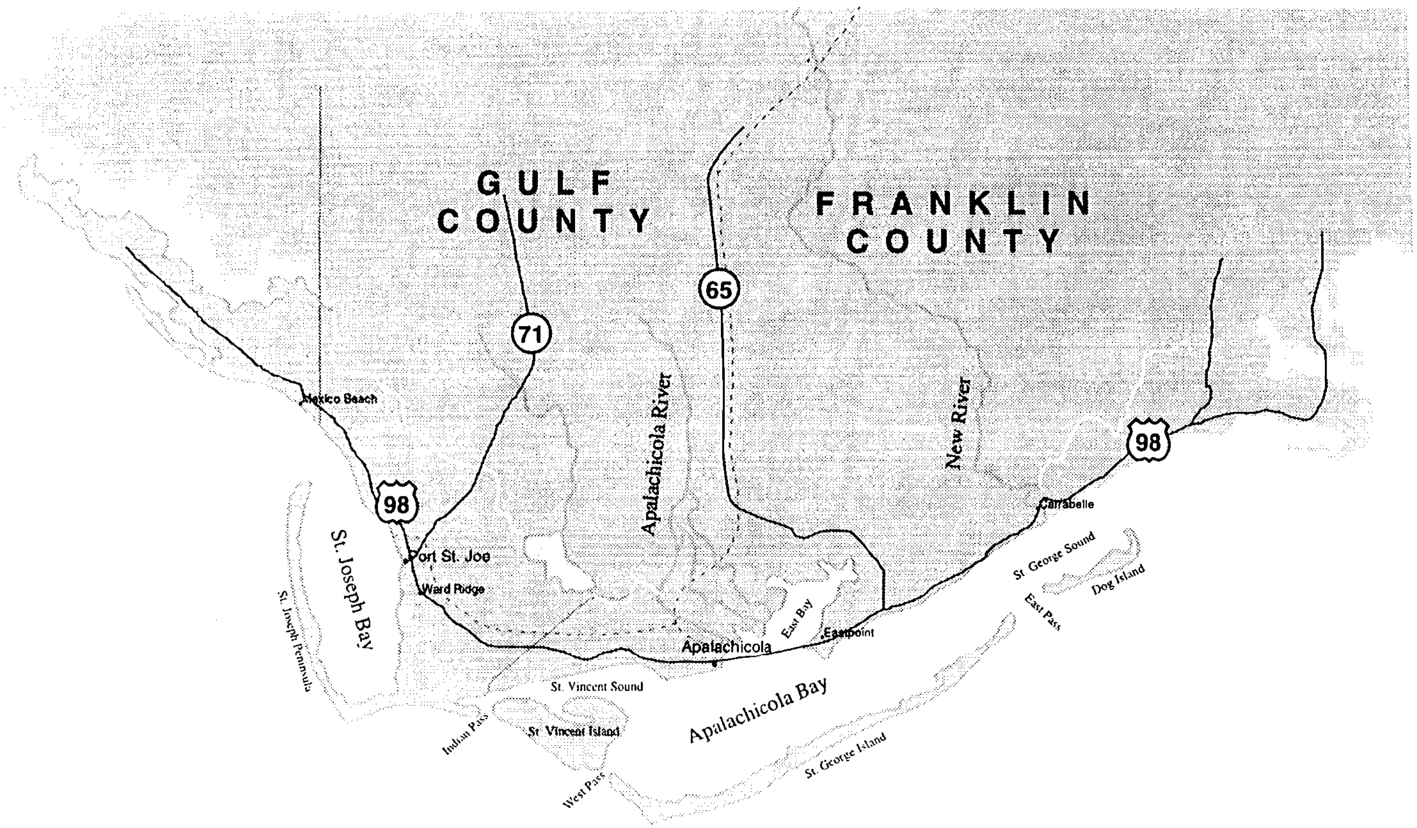


Figure 5-14. Schematic map of the Apalachicola Bay and St. Joseph Bay systems.

About 60% of Apalachicola Bay is a National Estuarine Research Reserve (NERR) consisting of 80,000 acres of mostly submerged land extending from the eastern tip of St. Vincent Island, to a line across St. George Sound at East Point to St. George Island. The reserve includes both East Bay and the Apalachicola River delta. The NERR and Apalachicola Bay have received continuous investigative attention for more than 25 years by Livingston and his students (Livingston, 1972 et seq.).

While located adjacent to the Apalachicola estuary, the coastal area between Ochlockonee Bay and the Apalachicola River is not well known (Wolfe et al., 1988). This 1,440 km^2 poorly drained area consists of two regions: an eastern portion of 830 km^2 drained by the New River and its tributaries which discharge into St. George Sound at Carabelle; and a western portion known as Tate's Hell Swamp, which drains into East Bay (Wolfe et al., 1988).

5.4.4.2 Hydrography and Oceanography

Apalachicola Bay has mixed tides of 0.30 to 0.61 m (1 to 2 ft), with maximum winter tides reaching 0.91 m (3 ft) (FDNR, 1992). Water movement in the bay is complex, and controlled by wind, currents and tides (Livingston, 1989). The FDNR (1992) report stated, "Over a typical year, river output can vary over tenfold." Circulation, mixing and stratification in the system are influenced, to a large extent, by this variation in riverine inputs. Winds, tides and fresh water flows each play important, and varying roles in current forcing. Because of its mean shallow depth, Apalachicola Bay is usually well-mixed and, with a maximum transport during ebbing tides of about 20,000 $m^3 \cdot s^{-1}$, flushing of the system is good (FDNR, 1992). Deeper water areas of the bay may become stratified with the development of a halocline (FDNR, 1992). Salinity is related to up-basin rainfall, resulting in a bottom salinity distribution of 0 to 35.6 ppt in various parts of the bay (Livingston, 1984). Circulation inside the barrier islands involves a net movement of water into the bay on the east, with major outflows to the west (FDNR, 1992).

5.4.4.3 Water and Sediment Quality

According to FDNR (1990), Hand and Jackman (1992) and Paulic and Hand (1994), the Apalachicola estuary and its tributaries have generally good water quality. However, Scipio Creek, at the mouth of the river is impaired by shrimping and marina activities, and by historic wastewater loading. Apalachicola Bay has very good water quality; and St. George Sound, at the eastern end of Apalachicola Bay, has good water quality except in the Carrabelle area which is improving. Water quality in St. Vincent Sound has not been evaluated in recent years.

Apalachicola Bay and the Apalachicola River are extremely productive ecosystems as evidenced by their designation by UNESCO as an International Biosphere Reserve. The river and bay are also Outstanding Florida Waters, and the largest of the 41 National Estuarine Research Reserves. The bay is also an Area of Critical State Concern, a State Aquatic Preserve, and a Priority Florida SWIM (Surface Water Improvement and Management) waterbody.

The Apalachicola River delta and Bay receive sediments from a watershed of more than 50,000 km^2 with average accumulation rates of about 4.3 mm yr^{-1} over the last century (Donoghue, 1993). Sediments entering Apalachicola Bay are generally unpolluted and contribute minimal nutrient loading to the system (Donoghue, 1993; FDNR, 1992). Muddy, soft bottom substrates cover some 78% of the open-water bottom of the bay, and form the dominant benthic habitat type (Livingston, 1984). The remaining sediments found in the system include sand, clay, sandy clay, clayey sand and carbonates from oyster shells. Apalachicola Bay sediments contain little silt (FDNR, 1992). It has been reported that terriginous sediments dominated the shelf off Apalachicola Bay.

Sediment metals to aluminum ratios suggest that only Cd, Cr and Zn are enriched in the bay (FDNR, 1992). Livingston (1989) reported that heavy minerals from 24 km off Apalachee Bay to offshore Pensacola Bay increased westward through the study area. Donoghue (1993) found that heavy, mineral rich sands concentrated by wind and waves produced significant gamma radioactivity in beach berms and coastal dunes on the barrier islands ringing Apalachicola Bay. The source of radioactivity was determined to be the detrital products of southern Appalachian crystalline rocks. Heavy mineral sand deposits were reported by Donoghue (1989) to be highly mobile, based on the distribution of radionuclides (uranium and thorium in monazite and zircon).

5.4.4.4 Biology

The Apalachicola Bay system is widely considered to be one of the few remaining relatively unpolluted, highly productive estuaries in Florida. Its temperate-subtropical climate, well-mixed and well-flushed waters produce rich fisheries yields, and its oyster reefs and organically rich, muddy substrates create a complex, highly diverse ecosystem.

FDNR (1992) summarized conditions in Apalachicola Bay. Overall high water quality coupled with seasonal flooding, nutrient and detrital export, and a variable salinity regime, provide ideal living conditions for estuarine biota and a highly productive system. The estuary is also surrounded by wetlands which interdict and remove toxic substances which enter the system.

Salt Marshes and Seagrasses

Marsh vegetation and river input are the major nutrient sources for food webs in Apalachicola Bay, which has an estimated annual production of about 103,080 metric tons $C \cdot yr^{-1}$ (Livingston, 1983; 1991).

Livingston (1983) estimated that seagrasses were present in about 10% of the total water area (30,480 ha) of Apalachicola Bay. Fringing beds of *Halodule wrightii* grew around St. George Island, and in the area from approximately Eastpoint to Carrabelle on the mainland. Mixed beds of *Halodule wrightii Thalassia testudinum* and *Syringodium filiforme* fringed the sound side of Dog Island, and covered Dog Island Reef, and Turkey Point Shoals. These beds also occurred as fringing stands on the mainland from Carrabelle to Alligator Harbor. Fringes of seagrass beds were reported to be fairly narrow and occupied a small portion of the estuary. The relatively small area coverage of seagrasses was not attributable to water depth, according to Livingston (1983). Wolfe et al (1988) suggested that high turbidity and sedimentation from river runoff decreased light, and produced an unsuitable substrate for seagrass growth in most areas of the bay.

Edmiston and Tuck (1987) reported that the densest seagrass beds (*H. wrightii* and *T. testudinum*) occurred along the northeast shoreline of St. George Island. No seagrasses were found in St. Vincent Sound. Large beds of seagrasses were reported to occur along the northern shore, on Bay Mouth Bar (at the entrance to the harbor), and in the eastern third of Alligator Harbor (Wolfe et al., 1988). These authors also reported the presence of extensive, continuous beds of seagrasses along the northern shore of the eastern half of St. George Sound. The distribution of seagrasses in the Apalachicola Bay system as reported by Livingston (1984) is summarized in Table 5-21.

Benthos

Livingston (1983) reported that the most abundant infaunal macroinvertebrates in Apalachicola Bay were the polychaetes, *Mediomastus ambiseta* and *Streblospio benedicti,* and the tanaid, *Hargeria rapax*. Other abundant species were amphipods (*Corophium, Ampelisca, Grandidierella bonnieroides, Gammarus mucronatus*), and the snail, *Neritina reclivata*.

Federle et al. (1983) determined that microbial community structure in St. George Sound sediments was controlled by epibenthic predators, whose abundances were, in turn, controlled by physical factors (i.e. the influence of the Apalachicola River on Apalachicola Bay).

Based on monthly infaunal collections made in *Halodule wrightii* beds during 1975-1976, Sheridan et al (1983) recovered a total of 58 species, an average of 35 per month. Sixteen species accounted for 84% of the total number of animals, and 89% of the total biomass. Numerical dominants were one amphipod, one tanaid, one polychaete and one clam (*Ampelisca vadorum, Hargeria rapax, Heteromastus filiformis* and *Aricidea fragilis,* respectively). Biomass dominants were three molluscan and one amphipod species (*Tagelus plebeius, Neritina reclivata, Ensis minor* and *Haploscoloplos fragilis*, respectively).

Samples collected by Livingston (1984) in East Bay were dominated by *Mediomastus ambiseta, Streblospio benedicti, Heteromastus filiformis, Ampelisca vadorum, Hobsonia florida, Hargeria rapax, Grandidierella bonnieroides* and *Paraprionospio pinnata*. Most of these infaunal species were associated with seagrasses. Leaf-litter dominants reported by Livingston (1984) were *Neritina reclivata, Palaemonetes* spp., *Corophium louisianum, Gammarus* spp., *Grandidierella, Melita* spp. and *Munna reynoldsi*.

The most abundant infaunal macroinvertebrates collected in Apalachicola Bay by FDNR (1992) were *Grandidieriella bonnieroides, Dicrotendipes* sp. (a larval chironomid), *Laeonereis culveri*, one nematode, *Mediomastus californiensis,* and *Amphiteis gunneri*. Peak numbers were recovered during September to March, and minimum numbers of individuals were collected from May to August. A biomass peak was observed during May through August, and

Table 5-21. Distribution of seagrasses in Apalachicola Bay (after Livingston, 1984).

Water Body	**Area (Ha)**	**Grassbeds (Ha)**
St. Vincent Sound	5,540	10
Apalachicola Bay	20,960	1,125
East Bay	3,981	1,434
St. George Sound (W)	14,747	624
St. George Sound (E)	16,016	2,767
Alligator Harbor	1,637	261
Total	62,881	6,211
Total Area	100	10

a minimum occurred during August to September. Seventy-eight percent of the samples collected by FDNR (1992) were from soft sediments, where the dominant animals were mostly polychaetes and amphipods. Menzel (1971) reported that the most abundant infaunal taxa Apalachicola Bay, Apalachee Bay and St. George Sound were as shown in Table 5-22.

It should be noted that Menzel's list of decapods contains planktonic species (e.g. *Lucifer faxoni*), intertidal species (e.g. *Uca* spp.), hermit crabs (e.g. *Clibanarius vittatus*), swimming and spider crabs (e.g. *Portunus gibbesi* and *Libinia dubia*), and seagrass-associated species (e.g. *Tozeuma carolinensis*). This suggests that most habitats were sampled using a variety of collection devices.

Tunicate species are identical to the list of "most common" tunicates found in St. Andrew Sound (Collard, unpubl. data), and quite different (except for the solitary species, *Styela plicata* and *Molgula occidentalis*) from those recovered in Alligator Harbor.

Apalachicola Bay produces 90% of the Florida oyster crop, and 10% of the nation's harvest (the bay is a major breeding ground for blue crabs, shrimp and finfish). The temperature, salinity, plankton and turbidity levels are optimum for oysters in Apalachicola Bay. Oyster bars covered about 7% of the bottom in Apalachicola Bay intertidal and subtidal sand and firm mud substrates in 1917 (FDNR, 1992). In their Shellfish Harvesting AreasSurvey (1990) [data from July 1979 to July 1989], Apalachicola Bay was determined to have 105,788 acres of "Conditionally Approved" and 6,798 acres of "Prohibited" oyster grounds. Winter harvesting areas totaled 76,188 acres, and summer areas totaled 29,000 acres. Table 5-23 gives approximate areas of oyster beds in Apalachicola Bay.

Table 5-22 Most abundant infaunal taxa in Apalachicola Bay, Apalachee Bay and St. George Sound.

Polychaetes:

Arenicola cristata
Diopatra cuprea
Laeonereis culveri
Onuphis eremita
Polydora websteri
Dexiospira 3 spp.
Heteromastus filiformis
Neanthes succinea
O. magna

Sixteen other polychaete species were reported to be "common".

Mollusca:

None of the molluscs were listed as abundant, but 80 species of bivalves and 89 species of gastropods (virtually all of the species collected) were listed as "common".

Arthropods:

Barnacles: *Chthamalus fragilis* (on seagrass)
Amphipods: None were "abundant"
Decapods:
Lucifer faxoni
P. setiferus
Synalpheus townsendi
Tozeuma carolinensis
Clibanarius vittatus
Pagurus (4 species)
P. galathinus
Callinectes sapidus
Eurytium limosum
Libinia dubia
Neopanope packardii
Pelia mutica
Portunus gibbesi
Uca pugilator
Penaeus duorarum
Hippolyte pleuracantha
Thor floridanus
Callianassa islagrande
Emerita talpoida
Petrolisthes armatus
Porcellana sayana
Eurypanopeus depressus
Hexapanopeus angustifrons
Menippe mercenaria
Panopeus herbstii
Pilumnus sayi
Sesarma cinereum
Uca pugnax

Echinoderms:

Arbacia punctulata
Lytechinus variagatus
Moira atropos
Ophiolepis elegans
Encope michelini
Mellita quinquiesperforata
Amphipolis gracillima
Leptosynapta crassipatina

Urochordata/Tunicata: (27 species reported)

Botryllus schlosseri
Diplosoma macdonaldi
Didemnum candidum
Clavelina picta
Styela plicata
Molgula occidentalis

Table 5-23 The distribution of oysters, *Crassostrea virginica*, in Apalachicola Bay (Livingston, 1984).

Water Body	**Area (ha)**	**Oyster Beds (ha)**
St. Vincent Sound	5,540	1,097
Apalachicola Bay	20,960	1,659
East Bay	3,981	67
St. George Sound (W)	14,747	1,489
St. George Sound (E)	16,016	3
Alligator Harbor	1,637	37
Total	62,881	4,352
Total Area (%)	100	7

Although conditions in Apalachicola Bay are normally optimum for the growth and reproduction of oysters, major storms and pandemic diseases occasionally cause mass mortalities. For example, Hurricane Elena destroyed 80-100% of the oysters in Cat Point and East Hole, the most productive (eastern) part of the bay (FDNR, 1992). Recovery of the population was rapid, however. Lowery (1992) suggested that Apalachicola Bay exports sediments during hurricanes, which increases water quality and oyster production. In contrast, Wilber (1992) observed that low river flows were followed two years later by decreased oyster production. Apalachicola River flows greater than 30,000 cfs for 100 days or more also decreased production. Environmental stress, perhaps exacerbated by anthropic stressors caused mass mortalities of oysters due to a stress-induced outbreak of the parasite, *Perkinsus marinus* ("Dermo" disease) (FDNR, 1992).

Public health concerns have increased in recent years because oysters are reservoirs of several human pathogens including *Vibrio cholerae, V. parahaemolyticus,* hepatitis "B", and several other parasites (Hood, pers. comm.).

Oysters and mussels are known to accumulate heavy metals in their tissues and shells, and are used as biomonitors of environmental quality. FDNR (1990) reported the following trace metal concentrations in Apalachicola Bay oysters collected from unpolluted areas of the bay (mean $\mu g \cdot g^{-1}$ wet weight, whole organism): Al 27.8; Cu 11.48; Fe 70.86; and Zn 111.26.

Apalachicola Bay supports a major fishery for stone and blue crabs; and all three species of penaeid shrimps (*Penaeus aztecus,* brown shrimp; *P. setiferus,* white shrimp; and *P. duorarum,* pink shrimp). White shrimp are the most abundant swimming macroinvertebrate in the bay, making up about 40% of trawl catches in low salinity areas (Livingston, 1983). Pink shrimp make up about 5% of the annual trawl catches in high salinity areas during spring and summer. Brown shrimp catches are 2-3% of trawl catches in variable salinities (Livingston, 1983).

Fishes

According to Livingston (1984), epibenthic marsh-associated, and open water fish assemblages in the Apalachicola estuary are characterized by relatively low species diversity, and numerical dominance by relatively few species. The three most numerous species (*Anchoa mitchilli*, *Micropogonias undulatus* and *Leiostomus xanthurus*) account for 70-80% of catches year round, but have different seasonal distribution patterns, probably related to salinity and life-history stage (Livingston, 1984). The bay anchovy (*A. mitchilli*), is the numerically dominant species in the system. This species is abundant throughout the estuary during January and February, but concentrates in the upper portions of East Bay during spring and early summer. In fall, *A. mitchilli* is most abundant around the mouth of the Apalachicola River and in portions of East Bay. "In contrast, the Atlantic croaker [*M. undulatus*] spawn near passes during fall and early winter; the juveniles occupy the estuary in peak numbers during late winter and early spring when salinities are usually less than 10-15 ppt. Spot [*L. xanthurus*] also spawn near passes, and peaks of abundance in the estuary generally coincide with those of the Atlantic croaker." (Livingston, 1984). Young sand seatrout (*Cynoscion arenarius*), another abundant species, enter the estuary in May, where they concentrate in lower salinity areas. They remain in these areas (near the river mouth, in East Bay, and northern regions of Apalachicola Bay) through June, but from July through September the species is found in greatest abundance at the river mouth. During the fall, numbers of sand seatrout decrease, their distribution within the estuary becomes dispersed, and they are not found in collections by winter or early spring (Livingston, 1984). Due to large numbers of juvenile spot and Atlantic croaker which spend their early developmental stages in brackish waters, peak numbers of fishes in Apalachicola Bay are recorded during the period February through April.

The standing crop of fish in Apalachicola Bay is about an order of magnitude higher than in other estuaries in the region according to Livingston (1991). Fishes commonly collected with seines in oligohaline waters of East Bay and mesohaline (Apalachicola Bay) marshes of the estuarine system are summarized in Table 5-24 (from Livingston and Thompson, 1975). Otter trawl collections of epibenthic fishes collected in various regions and habitats of the Apalachicola estuary from 1972 through 1982 are summarized in decreasing order of their abundance in Table 5-25 (Livingston (1984).

Table 5-24. Fishes collected from East Bay and Apalachicola Bay, Florida (after Livingston and Thompson, 1975).

East Bay Species

Scientific Name	Common Name
Ictalurus natalis	yellow bullhead
Micropterus salmoides	largemouth bass
Lepomis microlophus	redear sunfish
Lepomis punctatus	spotted sunfish
Poecilia latipinna	sailfin molly
Adinia xenica	diamond killifish
Cyprinodon variegatus	sheepshead minnow
Fundulus grandis	Gulf killifish

Table 5-24. Fishes collected from East Bay and Apalachicola Bay, Florida (after Livingston and Thompson, 1975) continued.

East Bay Species

Scientific Name	Common Name
Fundulus confluentus	marsh killifish
Fundulus similis	longnose killifish
Notemogonus crysoleucas	golden shiner
Lucania parva	rainwater killifish
Lucania goodei	bluefin killifish
Notropis sp.	shiners
Lepisosteus osseus	longnose gar
Cyprinus carpio	common carp
Anguilla rostrata	American eel
Pomoxis nigromaculatus	black crappie
Menidia beryllina	inland silverside
Anchoa mitchilli	bay anchovy
Brevoortia patronus	Gulf menhaden
Mugil curema	whit mullet
Mugil cephalus	striped mullet
Micropogonias undulatus	Atlantic croaker
Bairdiella chrysoura	silver perch
Stellifer lanceolatus	star drum
Cynoscion arenarius	sand seatrout
Paralichthys lethostigma	southern flounder
Trinectes maculatus	hogchoker
Eucinostomus gula	silver jenny
Lutjanus griseus	gray snapper
Gobiosoma bosci	naked goby
Microgobius gulosus	clown goby
Archosargus probatocephalus	sheepshead

Apalachicola Bay Species

Anchoa mitchilli	bay ancovy
Anchoa hepsetus	striped anchovy
Menidia beryllina	inland silverside
Eucinostomus gula	silver jenny
Synodus foetens	inshore lizardfish
Strongylura marina	Atlantic needlefish
Lucania *parva*	rainwater killifish
Fundulus similis	longnose killifish
Syngnathus *floridae*	dusky pipefish
Lagodon rhomboides	pinfish
Leiostomus xanthurus	spot
Bairdiella chrysoura	silver perch
Cynoscion nebulosus	spotted seatrout
Mugil cephalus	striped mullet
Orthopristis chrysoptera	pigfish
Opsanus beta	Gulf toadfish

Examination of Table 5-25 suggests that gear bias may have influenced the frequency-of-capture of some taxa (e.g. larger elasmobranchs and oyster-reef-associated species). However, there is strong support for Livingston's observation that ichthyofaunal species diversity in the Apalachicola estuary is rather low.

5.4.4.5 Data Gaps

Apalachicola Bay has received more long-term investigative effort than any estuary in Florida. While a case can justifiably be made that more work needs to be done in such areas as microbial ecology and process-related trophodynamics, no major data gaps were recognized.

5.4.5 St. Joseph Bay

5.4.5.1 Environmental Setting

St. Joseph Bay is located off the city of Port St. Joe in the central Florida panhandle (Figure 5-14). The bay is partially impounded by St. Joseph Spit. As one of only two coastal embayments in the eastern Gulf of Mexico that are not diluted by the inflow of fresh water (the other is St. Andrew Sound), Saint Joseph Bay is not an estuary, but a protected marine lagoon with open-Gulf salinities. The lagoon-like embayment has a surface area of about 73,000 acres, a mean depth of 7 m, and a maximum depth of about 12 m near the northern tip of St. Joseph Spit (FDNR, 1992).

St. Joseph Spit is connected to the mainland by a three mile long, narrow (less than one mile wide) arm extending eastward from Cape San Blas. The spit bends sharply at the Cape and extends about 15 miles northward in a gentle, convex-seaward arc (FDNR, 1992). Eagle Harbor, midway up the spit, may once have been an ancient pass (FDNR, 1992), and this area was breached during Hurricane Opal. Cape San Blas and St. Joseph spit have been lengthening due to the northward and westward erosion of sand from their western shores (FDNR, 1992). According to Balsillie (1975), the southern five miles of St. Joseph Spit was eroding at a rate of -9.4 meters per year, the largest historical, long-term erosion rate recorded in Florida.

Cape San Blas and St. Joseph Spit were heavily impacted by Hurricane Opal in October 1995. The Cape lost as much as 50% of its high sand dunes, and was breached in two places by storm surge and waves. Water from the Gulf of Mexico entered St. Joseph Bay carrying with it an unknown, but probably large amount of sand and silt. During an overflight, gross shoaling of the region was noted, from outside and west of St. Joseph Spit to the eastern "end" of Crooked Island (i.e. Mexico Beach-Tyndall Air Force Base), but significant changes were not detected within the bay itself.

The following observation warrants emphasis in light of Hurricane Opal: "Although the St. Joseph Spit is lined with dunes facing the Gulf of Mexico, these dunes almost without exception show signs of severe scarp erosion. Blowout conditions exist in some of the high dune areas on the spit. The topography is also low in the areas north and east of the cape. Therefore, in an event of 100 year frequency storm or hurricane, most coastal areas of Gulf County are subject to flooding" (FDNR, 1992). Most of coastal Gulf County was flooded in 1995.

5.4.5.2 Hydrology and Oceanography

Tides in St. Joseph Bay are best described as irregular; they are a "mix" of diurnal tides to the west, and semidiurnal tides to the east. The tidal range varies from less than 0.06 to 0.76 m (0.2 to 2.5 ft), and differs in time and magnitude from predictions (Tanner, 1966).

Surface water hydrology in St. Joseph Bay is influenced primarily by tidal exchange with the Gulf of Mexico (FDNR, 1992). During flood tides, a moderately strong current sweeps around St. Joseph Spit into the bay, and a counter-clockwise circulation pattern is established in the central portion of the system. This semi-permanent gyre is disrupted only at maximum flood tide. At the ebb, water flows out of the lagoon via a channel at the point of St. Joseph Spit, and across a shoal in the vicinity of the navigation

Table 5-25. Otter trawl collections of epibenthic fishes collected in various regions and habitats of the Apalachicola estuary from 1972 through 1982 (after Livingston, 1984).

<u>Species</u>

1. *Anchoa mitchilli*
2. *Micropogonias undulatus*
3. *Cynoscion arenarius*
4. *Leiostomus xanthurus*
5. *Polydactylus octonemus*
6. *Arius felis*
7. *Chloroscombrus chrysurus*
8. *Menticirrhus americanus*
9. *Symphurus plagiusa*
10. *Bairdiella chrysura*
11. *Etropis crossotus*
12. *Trinectes maculatus*
13. *Prionotus tribulus*
14. *Stellifer lanceolatus*
15. *Anchoa hepsetus*
16. *Porichthys porosissimus*
17. *Prionotus scitulus*
18. *Eucinostomus gula*
19. *Paralichthys lethostigma*
20. *Synodus foetens*
21. *Eucinostomus argenteus*
22. *Dasyatis sabina*
23. *Cynoscion nebulosus*
24. *Microgobius thalassinus*
25. *Urophycis floridanus*
26. *Lagodon rhomboides*
27. *Gobiosoma bosci*
28. *Chaetodipterus faber*
29. *Orthopristis chrysoptera*
30. *Brevoortia patronus*
31. *Dorosoma petenense*
32. *Peprilus burti*
33. *Peprilus paru*
34. *Stephanolepis hispidus*
35. *Sphaeroides nephelus*
36. *Ophichthus gomesi*
37. *Syngnathus louisianae*
38. *Sygnathus scovelli*
39. *Gobionellus boleosoma*
40. *Harengula pensacolae*
41. *Archosargus probatocephalus*
42. *Microgobius gulosus*
43. *Bagre marinus*
44. *Menidia beryllina*
45. *Monacanthus ciliatus*
46. *Caranx hippos*
47. *Centropristis melana*
48. *Sygnathus floridae*
49. *Ancyclopsetta quadrocellata*
50. *Chilomycterus schoepfi*
51. *Diplectrum formosum*
52. *Ictalurus catus*
53. *Sciaenops ocellatus*
54. *Astroscopus y-graceum*
55. *Hippocampus erectus*
56. *Lepisosteus osseus*
57. *Lucanis parva*
58. *Lutjanus griseus*
59. *Opsanus beta*
60. *Paralichthys albigutta*
61. *Ophidion beani*
62. *Aluterus schoepfi*
63. *Diplodus holbrooki*
64. *Gobionellus hastatus*
65. *Hypsoblennius hentzi*
66. *Menticirrhus saxatilis*
67. *Myrophis punctatus*
69. *Ogilbia cayorum*
70. *Oligoplites saurus*
71. *Pomatomus saltatrix*
72. *Rhinoptera bonasus*
73. *Scomboromorus maculatus*
74. *Selene vomer*
75. *Sphyraena borealis*
76. *Sphyrna tiburo*
77. *Sardinella anchovia*
78. *Caranx bartholomaei*
79. *Mugil* sp.
80. *Gymnura micrura*

channel into the bay. While (FDNR, 1992) reports that there are no currents at the southern end of St. Joseph Bay, it would seem that the high water clarity characteristic of the entire lagoon may be maintained by flushing currents induced during tidal exchanges.

During high flows, the Apalachicola River may feed St. Joseph Bay through the 5.5 mile long Gulf County Canal which connects the Gulf Intracoastal Waterway (ICWW) with Lake Wimico and St. Joseph Bay.

5.4.5.3 Water and Sediment Quality

As evidenced by the abundance of salt marsh vegetation and dense stands of SAV; clear water; and abundant and divers finfish, infaunal and shellfish communities, water quality in St. Joseph Bay is considered possibly to be of the highest quality of all panhandle embayments.

St. joseph Bay has no fluvial streams and , therefore, sediment input is low. In addition, the Bay is well flushed and anthropic loadings from discharge and construction activities are relatively minor.

Sediments in St. Joseph Bay are predominantly quartz sand, with patches of clayey silt, clayey sand, and sand-gravel mixtures. Clay is found in the deep central portion of the lagoon. Sand enters the lagoon from the east, and the remaining sediments are of *in situ* biogenous origin. Sedimentation rates are slow (FDNR, 1992).

5.4.5.4 Biology

St. Joseph Bay is located in a transitional climatic zone between the semi-tropical climate of peninsular Florida and the subtropical climate of southern Florida. This ecotone is reflected in the species composition of St. Joseph Bay's flora and fauna.

While information on the animal taxa inhabiting St. Joseph Bay are not available, observations of P. Hamilton, C.N. D'Asaro and R. Heard (pers. comm.), among others, strongly suggest that species diversity and abundance in St. Joseph Bay are very high. The lagoon supports numerous species representative of both Carolinian and West Indian faunal provinces (Collard, unpubl. data).

Salt Marshes and Submerged Aquatic Vegetation

According to FDNR (1992), *Juncus roemerianus* and *Spartina* spp. marshes occur in a narrow band around St. Joseph Spit, and widens near Pig Bayou. Salt marshes are a prominent feature of the shallow areas of the southern and southeastern portions of the bay, and extend for hundreds of feet into the bay. The intertidal zone include mud flats and a few tidal creeks (FDNR, 1992).

Five species of seagrasses cover about one-sixth of the bay bottom (FDNR, 1992). *Thalassia testudinum* is the most abundant species, but *Halodule wrightii* and *Ruppia maritima* are common and often occur in mixed stands with turtle grass. *Halophila englemanni* (star grass) is patchy throughout the bay, and *Syringodium filiforme* (widgeon grass) occurs in patches on the eastern side of the bay. St. Joseph Bay is reported to have the densest seagrass meadows on the northern Florida coast (FDNR, 1992).

Because of weak tidal currents, the bay is reported to function as a more-or-less a closed system. Therefore, the nutrient budget and food web of the bay are largely dependent upon the primary productivity of the bay itself (FDNR, 1992).

Benthos

The longshore current pattern described below by Tanner (1966) has biological implications that may explain, in part, observed differences in the macroinvertebrate faunas of St. Joseph Bay and St. Andrew Sound which are physiographically similar, and located only a few miles from each other (Collard, unpubl. data). "Waves are refracted around the Cape San Blas shoals in such a manner to arrive nearly parallel to the beach. This results in a bi-directional littoral drift system [and embedded meroplankton] which runs northward along the northern half of the spit, and southward along the southern portion."

The principal shellfish harvested in St. Joseph Bay include hard shell clams, *Mercenaria* spp., the sunray venus, *Macrocallista nimbosa*, bay scallops, *Argopecten irradians* and blue crabs, *Callinectes sapidus*.

Valentine and Heck (1993) reported that the annual infaunal macroinvertebrate production of *Modiolus americanus* beds in St. Joseph Bay ranged from 229 to 429 g ash-free dry mass (AFDW)$\cdot$ m^{-2}. In comparison, production in pure stands of *Thalassia testudinum* was 145 to 245 g AFDW$\cdot$ m^{-2}; 84 to 180 g AFDW$\cdot$ m^{-2} in *Halodule wrightii* beds; and 20 to 42 g AFDW$\cdot$ m^{-2} in unvegetated sand flats.

Fishes

Little information exists concerning fish populations within St. Joseph Bay. Among the major fishes taken by recreational fishers are spotted seatrout and Spanish and king mackerel.

5.4.5.5 Data Gaps

1. Although St. Joseph Bay is widely known by marine biologists as perhaps the only pristine coastal embayment remaining on the Florida panhandle, surprisingly little has been published about its biota. As a "semi-closed system", the bay's microbial communities, drift algae, seagrasses and associated organisms, benthic invertebrates, plankton, nekton, and diverse, numerically abundant transient avifauna may be trophodynamically closely coupled. Primary and secondary production within the bay, and export into surrounding coastal waters (largely to the west?), warrant investigation.

2. The impact(s) of recreational fishing (scallops, finfish) and shell gathering (e.g. live *Pleuroploca gigantea*), while not adequately documented, may be significant.

3. St. Joseph Paper Company has recently been bought, sold, and shut down for variable periods of time. The immediate and longer-term ecological consequences of mill activity should be documented/monitored for several years.

5.4.6 Apalachee Bay/Big Bend

5.4.6.1 Environmental Setting

Lyons and Collard (1974) characterized the Big Bend area (i.e. Apalachee Bay) as, "a huge, seagoing estuary extending from near Anclote Key to the vicinity of Alligator Harbor (Figure 5-15). Oyster reefs are common parallel to the shore, and vast beds of seagrasses are characteristic of the area. A thin veneer of quartz sand and organic debris overlies the limestone plateau of the Ocala-Middle Ground Arch. Occasional limestone outcrops protrude through this veneer to provide hard substrate. Species composition is predominantly the same found in estuarine seagrass or oyster reef communities. The shoreline receives only low energy waves." Zimmerman and Livingston (1976) described Apalachee Bay proper as a broad, shallow estuary lying between Alligator Point and Cedar Key, extending about 15 km offshore.

5.4.6.2 Hydrography and Oceanography

Livingston (1990) described the region from the Anclote Keys north to the Ochlockonee River as a massive, open estuarine system supplied by freshwater from the Anclote, Pithlachascotee, Weeki Wachee, Homosassa, Chassahowitzka, Crystal, Withlacoochee, Waccassa, Suwannee, Steinhatchee, Spring Warrior, Fenholloway, Econfina, Aucilla, St. Marks, and Ochlockonee Rivers. Livingston calculated the combined stream discharge of fresh water into Apalachee Bay to be approximately 1×10^9 gal$\cdot$ day^{-1}. Unlike central and western regions of the Florida panhandle, coastal waters of the Big Bend region are shallow and unprotected by barrier islands. The mainland shoreline gradually merges into the sea, and beaches are absent.

5.4.6.3 Water and Sediment Quality

Hand et al. (1994) summarized water quality conditions in the Big Bend area in very general terms. Water quality was evaluated as "good" in the following drainage basins and rivers: Suwannee River confluence; Aucilla River Basin; Econfina Creek/Steinhatchee River Basin; Econfina River to the Gulf of Mexico; Steinhatchee River to the Gulf of Mexico; Suwannee River to the Gulf of Mexico (manatees frequent the lower reaches of Suwannee River); Ochlockonee River Basin-Ochlockonee Bay to the Gulf of Mexico at Panacea; Waccasassa River Basin to the Gulf of Mexico; New River Basin; St. Marks River Basin; and Apalachee Bay, from Lost Creek through the St. Marks River. Much of Apalachee Bay water quality was evaluated as "excellent".

According to Hand et al (1994) Ochlockonee Bay has high nutrient levels and low macroinvertebrate diversity due to construction activities, clear cutting and (possibly) septic tank leachates. Using FDEP water quality and trophic state indices, waters at the mouth of Spring Warrior Creek were judged to be "fair" (Hand et al., 1994). The Fenholloway River was

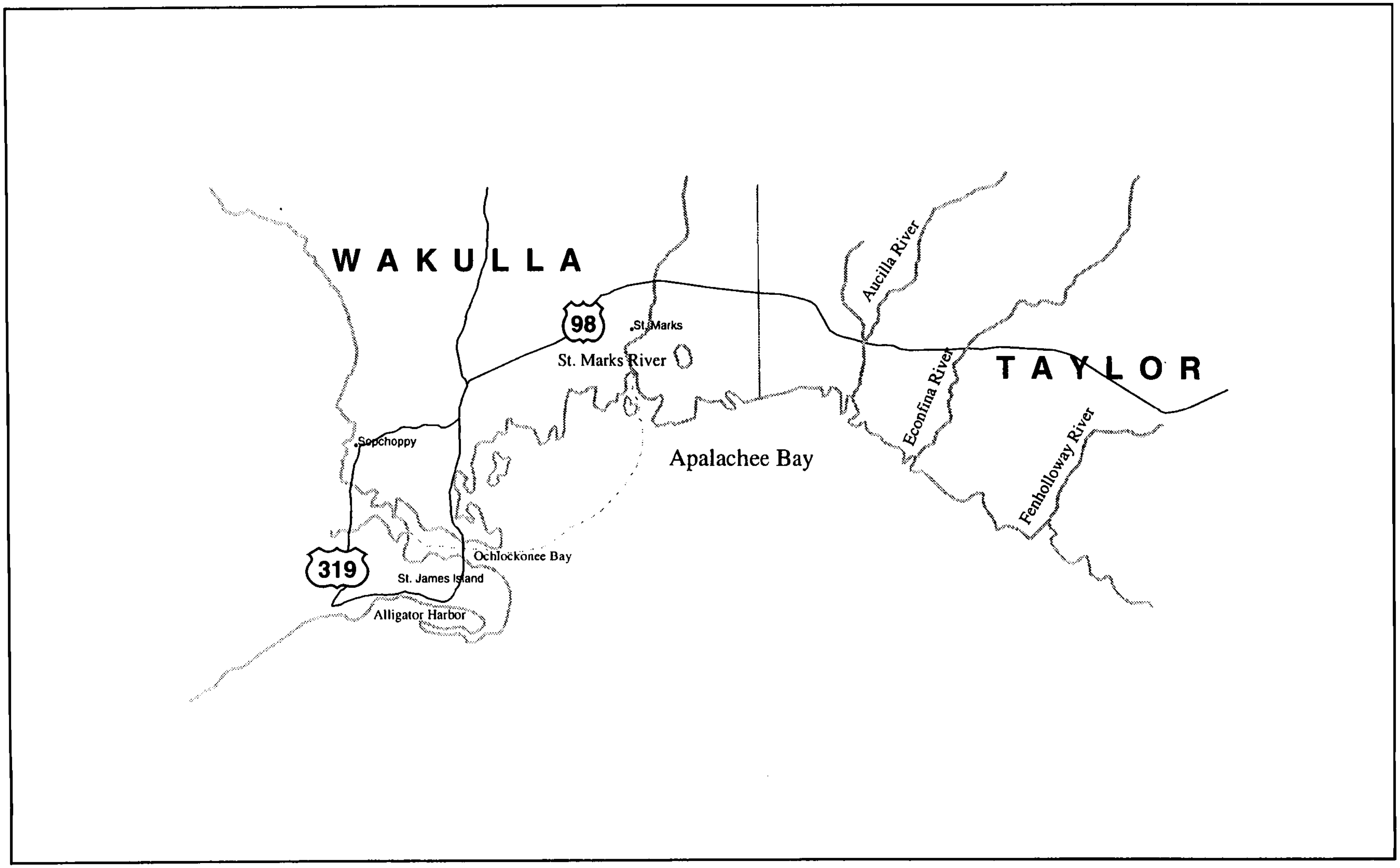


Figure 5-15. Schematic map of the Ochlockonee Bay/Apalachee Bay system.

assessed as "poor", the only Class V water body (industrial use only) in the state.

5.4.6.4 Biology

The paucity of information in the following paragraphs does not reflect the biological richness of the Big Bend estuary. In all important respects this brackish, shallow, quiet water open system supports complex, diverse assemblages of microbiota, invertebrates and fishes. It is widely recognized that the region should not be viewed as a simple, or single ecosystem, but as a mosaic of habitat types difficult to characterize in summarial fashion. For modeling purposes, it is reasonably prudent to suggest that Apalachee Bay and surrounds may be considered the functional ecological equivalent of a low energy, temperate-subtropical, composite oyster reef-seagrass estuary.

Salt Marshes and Submerged Aquatic Vegetation

Paulic and Hand (1994) reported that salt marshes dominate the coastal landscape from Apalachicola Bay to Tampa Bay. *Juncus* and *Spartina* marshes are characteristic of the headwaters and floodplains of a majority of the small rivers and streams entering Apalachee Bay from the St. Marks River to the Withlacoochee River.

Benthic macrophytes collected in Apalachee Bay by Zimmerman and Livingston (1976) were mainly warm temperate species, but included many eurythermal tropical species. Some species (e.g. *Polysiphonia harveyi*) has a disjunct distribution and a temperate origin. Thirty-nine species of macrophytes were recorded, but collections were dominated by 17 species of red algae, and the seagrass, *Thalassia testudinum*. The authors considered algal diversity to be low with respect to estuarine areas in Texas and Louisiana, but did not mention other panhandle estuaries. Species with warm-temperate distributions included *Halimeda incrassata, Digenia simplex, Laurencia poitei, Halophila engelmanni, Caulerpa, Penicillus, Udotea* and *Padina* species.

During the Florida Big Bend Seagrass Habitat Study (Continental Shelf Associates/Martel Laboratory, 1985) 3.7 x 10^6 acres (1.5 x 10^6 ha) of seagrass beds and meadows were mapped using aerial photography. Ground-truthing was accomplished by divers. Sixteen percent of seagrass areas were characterized as dense, 33% as sparse, and 19% as patchy seagrass beds. Results of the survey were plotted on a composite 1:250,000 scale map). According to the authors, "Species zonation patterns were similar to those observed elsewhere in Florida and the Caribbean." Commonly, a nearshore zone of pioneer or fringing species (primarily *Halodule wrightii*, and occasionally *Halophila decipiens*), was replaced by a zone of dense, bed-forming *Thalassia testudinum* and *Syringodium filiforme* in deeper subtidal waters. A fringe of *Halophila decipiens* and *Halophila engelmanni* with some *H. wrightii* in shallow areas formed an offshore zone. The unique feature of the Florida Big Bend area seagrass zonation pattern is the extended nature of an offshore fringing zone. Offshore fringing (or pioneer) species grow from a depth of 10 m to depths greater than 20 m. Seagrasses showed transitional tolerances to low salinity and temperature.

Benthos

Dugan and Livingston (1982) compared selected macroinvertebrate taxa of Apalachee Bay based on collections made in the lower reaches of the Fenholloway and Econfina Rivers during the period 1971-1980. Decapods comprised 95% of the total number of individuals collected during the study; molluscs accounted for 4%, and echinoderms made up 1% of the collections. Dugan and Livingston (1982) reported that the percentage composition of the samples was relatively constant, but numbers of individuals in the Fenholloway River were approximately twice those of the Econfina River estuary (Table 5-26). According to Hand et al. (1994), the Fenholloway River is biologically degraded, in contrast to the Econfina which was reported to have "good" water quality. Papermill-derived pollution abatement in the Econfina River began in 1975.

Wolfe et al. (1988) reported that Ochlockonee Bay, west of Bald Point had consistently high benthic macroinvertebrate diversity. In contrast, Hand et al. (1994) reported that Ochlockonee Bay has high nutrient levels and low macroinvertebrate diversity due to construction, clear cutting and (possibly) septic tank leachate. While it is not possible to explain the apparent discrepancy between the assessment of Hand et al. (1994), and Wolfe et al. (1988) with confidence, it is possible that: (1) sampling methods accounted for the differences observed; (2) the drift of Ochlockonee Bay water was to the east; (3) Wolfe et al. (1988) reviewed a different data set; or (4) "high diversity" meant different things to the different authors. Other interpretations are possible, including the most parsimonious, and probably correct, conclusion that the differences observed were real, and reflective of unremarkable variation in estuarine benthic population demographics.

Table 5-26. The most numerous ten species of benthic macroinvertebrates collected from 1971-1980 in Apalachee Bay (from Dugan and Livingston, 1982).

Econfina River Estuary	**Fenholloway River Estuary**
1 *Palaemon floridanus*	1 *Pagurus* n. sp.
2 *Pagurus* n. sp.	2 *Neopanope texana*
3 *Tozeuma carolinense*	3 *Palaemon floridanus*
4 *Neopanope texana*	4 *Tozeuma carolinense*
5 *Palaemonetes intermedius*	5 *Palaemonetes intermedius*
6 *Hyppolyte pleuracanthus*	6 *Periclemenes longicaudatus*
7 *Periclemenes longicaudatus*	7 *Hyppolyte pleuracanthus*
8 *Neopanope packardii*	8 *Neopanope packardii*
9 *Penaeus duorarum*	9 *Penaeus duorarum*
10 *Thor dobkini*	10 *Callinectes sapidus*

Fish

Menzel (1971) listed seven shark, ten ray, and 140 bony fish species associated with Apalachee Bay. Investigations of St. Mark's estuary and Wakulla marshes within the Bay resulted in a total of 55 fish species overall (comp and Seaman, 1985). In general, the dominant fish species found in Apalachee Bay are similar to those observed in other panhandle estuaries (e.g., anchvy, pinfish spot and mullet).

5.4.6.5 Data Gaps

1. The nature and magnitude of physical and biogeochemical coupling processes between riverine, brackish water and marine communities in the region may provide information of value in understanding fate and transport processes in the whole of the northeastern Gulf of Mexico.

2 The Big Bend includes northwestern portions of the West Florida Shelf and the eastern panhandle. This "open estuary" is ecologically unique in the Gulf of Mexico, and as indicated by the biogeographically mixed affinities of its biota, it appears to be an ecoregional transition zone. Production levels in, and energy export from the Big Bend should be assessed, as downstream flows may significantly impact the trophodynamic structure of communities to the south and west.

5.5 Summary and Major Data Gaps

The portion of the northeastern Gulf of Mexico (NEGOM) discussed in this chapter extends from the Florida-Alabama border to Citrus County, Florida, and from the shoreline to the continental shelf-slope boundary. The major physiographic feature of the NEGOM is DeSoto Canyon, which dominates the eastern Gulf of Mexico basin. The major coastal feature of the region is Cape San Blas, which lies northeast of the canyon (Figure 5-1). The shelf is relatively narrow near the head of DeSoto Canyon, and progressively broadens to the east and southeast. The panhandle, from Perdido Bay to eastern Apalachicola Bay-St. George Sound, is a moderate-to-low energy, sandy coast, characterized by an almost continuous chain of barrier islands and embayments. There are no barrier islands east of Ochlockonee Bay, which marks the western boundary of the low energy, brackish water Big Bend region.

Basin circulation in the NEGOM (Chapter 2) is dominated by the Loop Current, which brings warm, salty, oligotrophic water and tropical organisms into the eastern Gulf of Mexico. The behavior of the LC and its eddies is complex, and the extent and biological consequences of coupling between shelf and basin watermasses and currents are not clear. Periodic incursions of LC-derived water transport subtropical-tropical species into shelf and nearshore environments where, given suitable substrates and warm-water conditions, they form minor components of panhandle species assemblages. The role of shelf currents with respect to the fate and transport of nutrients, meroplankton (*e.g.*, larval fishes, developmental stages of benthic invertebrates), pelagic organisms (phytoplankton, zooplankton, fishes), and toxic substances, such as crude oil and trace metals, is poorly known. Net transport of sediments and larval organisms in nearshore/longshore currents is southeast from the eastern side of Cape San Blas, and northwest from the western side of the Cape. Circulation in panhandle estuaries is highly variable, and depends upon river flow, tides, basin geometry, bathymetry, winds and other factors. Regional estuaries are shallow, drowned river valleys, and may be well-mixed or highly stratified and hypoxic during summer months. Sediments, nutrients and pollutants are retained within these embayments.

The water quality of regional estuaries is reported to be generally good. However, some of the poorly flushed bayous and backwaters of most panhandle estuaries show evidence of degraded water and sediment quality attributed to pollution. Seagrasses have entirely disappeared from the Pensacola Bay system, and sediments in some areas of this estuary are heavily polluted from chronic exposure to industrial and domestic effluents.

Inner and middle shelf sediments west of Cape San Blas are predominantly sandy (Chapter 3) with patches of shell rubble and algal nodules. Fines accumulate in pockets between sand ridges. East of St Vincent Island in Apalachicola Bay, sediments are described as sandy near shore, transitional carbonate-quartz on the inner shelf, and carbonaceous on the middle shelf. Limestone outcroppings in the Big Bend, and rock pinnacles near the steeply terraced head of DeSoto Canyon provide hard substrates habitats. Species assemblages characteristic of unconsolidated, oxygenated sands dominate benthic shelf communities inshore of DeSoto Canyon. Sediments in water deeper than 100 m are comprised of compact clays, and the fauna of these substrates is depauperate.

As discussed in Chapters 2 and 4 of this report, nutrients are contributed to shelf waters via large fresh and brackish water discharges from the Mississippi River and Mobile Bay, respectively. In contrast, nutrient enrichment of shelf waters from western panhandle estuaries is relatively low. Numerous small rivers enter the Big Bend "open estuary" although their nutrient contribution to shelf waters is apparently minor. Upwelling along eastern portions of DeSoto Canyon, south of Cape San Blas, and along the northern portions of the West Florida Shelf brings deep, nutrient rich water into the euphotic zone.

Primary productivity in the NEGOM increases from offshore to coastal waters as a function of nutrient availability. Shelf phytoplankton production is highest in upwelling areas and coastal frontal zones, and may impact production rates downstream from these areas. However, neither the fate and transport of energy nor the relationship between water column primary production and benthic secondary production on the shelf have been investigated. Estuarine primary production is high or very high, and many of the region's estuaries have reached or exceeded their assimilative capacity for nutrients. Salt marsh, seagrass and benthic algal production varies considerably between different panhandle estuaries, but a majority have experienced decreases in marsh and submerged aquatic vegetation habitats during the past two to three decades. Losses of these two community types are accompanied by significant decreases in fish and invertebrate diversity, and are symptomatic of degraded environmental quality.

Although knowledge of benthic invertebrate communities on the NEGOM continental shelf is limited, epifaunal and infaunal species assemblages vary, as do the fishes, with depth and substrate type. In decreasing order of their numerical abundance and species diversity, polychaetes, decapod and amphipod crustaceans dominate shelf habitats. One fourth to one third of the polychaetes collected on the shelf were allied with either West Indian or Carolinian faunal provinces, some 25-30% were Gulf of Mexico endemics, and a somewhat smaller number of species were cosmopolitan. Outer shelf invertebrate collections suggest that tropical species become more common with increasing depth. The composition of estuarine benthic communities is regulated by a large suite of environmental variables. Among the most important of these are substrate type and quality, depth of the redox layer, salinity and water quality, including dissolved oxygen levels.

In general, the diversity of shelf and coastal fish communities is high and remarkably uniform throughout the region. The NEGOM shelf is reported to be inhabited by twice as many species and eight times as many unique (endemic) species as the northwestern Gulf shelf. Differences in the composition of fish assemblages on the shelf are related to depth and substrate type, and exhibit variation corresponding to developmental and reproduction-related movements from one habitat to another (e.g. open ocean to estuary). Estuaries in the NEGOM support similar fish faunas, with the same or very nearly the same ten numerically dominant species.

Hypoxia, anoxia, thermal and osmotic stress, pollutants and toxic algal blooms may contribute to, or cause the episodic mass mortality events reported from all of the region's embayments and large stretches of coastal waters. Decreased diversity within benthic invertebrate and fish communities as a result of the progressive disappearance of salt marsh and seagrass habitats constitute perhaps the least equivocal and most easily visible indicators of environmental degradation available. With reference to these indicators, it is speculated that a decrease in the overall environmental quality of panhandle embayments and coastal waters has occurred over the past 20-30 years. Continued growth of human populations in the panhandle coastal zone may promote a continuation of this trend which, although more difficult to discern, may eventually influence the quality of shelf habitats as well.

Previous sections have identified data gaps in specific areas. The following identify the major data gaps affeting knowledge of the shelf ecosystems as a whole and suggest topics for further study.

1. The frequency, duration, scale and physical-chemical characteristics of upwelled water in northern portions of the West Florida Escarpment (the "Green River"seen in satellite images of the northern Gulf), at the head of DeSoto Canyon, and in the region south of Cape San Blas, warrant investigation and documentation. Short-term, episodic upwelling in these, and possibly other areas associated with the NEGOM shelf-slope boundary, may bring nutrient-rich water to the surface, and periodically increase local and downstream primary productivity. If upwelling is a frequent occurrence in some or all of the areas mentioned, nutrient enrichment in the euphotic zone may influence patterns of water column production over relatively large

areas of the NEGOM and may, via trophic coupling (*e.g.*, developmental migrations, fecal pellet "fallout"), turbulent mixing, and downwelling at frontal boundaries, significantly impact secondary production in benthic communities of the shelf.

2. As discussed in Chapter 7 of this report, physical oceanographic processes in NEGOM shelf waters are complex. Knowledge of the origin, fate and transport of nutrients, toxic substances and pelagic organisms (primary producers, holozooplankton and meroplanktonic invertebrates and fishes) depends to a large extent on knowledge of episodic and "on average" interactions among coastal, shelf and Loop Current (or LC-derived) watermasses. The sources, pathways and sinks of energy flow within and between ecosystems and their major biological components is a fundamental ecological question. While some understanding of salt marsh, estuarine and nearshore trophodynamics in the NEGOM has been acquired, very little is known about ecological processes on the continental shelf. Lacking more detailed information on physical oceanographic processes, biological processes can neither be described nor understood.

3. Significant amounts of particulate and dissolved organic material, other nutrients, suspended sediments and fresh water discharged from the Mississippi River and, to a lesser extent, from Mobile Bay, enter NEGOM shelf waters. Water column and benthic communities of the outer shelf west of DeSoto Canyon may be influenced by Mississippi River water, while inner shelf community structure may be influenced by eastward flowing water from Mobile, and perhaps Perdido Bays. The physical-chemical and consequent biological significance of these two major freshwater discharges into western portions of the NEGOM have not been assessed.

4. The distribution of sand substrata on western portions of the middle shelf may not be uniform (see Figure 3-8). Echinoderms and other taxa characteristic of fine, clastic, carbonate, and hard substrates have been reported, and the distribution and areal extent of these non-sandy patches requires further documentation.

5. Biological communities of the Big Bend continental shelf and their trophodynamic interactions with coastal, West Florida Shelf, Loop Current, and upwelled basin water are poorly understood. This region of the NEGOM seems to be physicochemically and geologically unique, which may be reflected in the structure of its benthic biological communities. Because the biological importance of shelf communities of the Big Bend has not been adequately assessed, a multidisciplinary investigation of the area is warranted.

6. The quasi-seasonal occurrence of tropical pleuston (e.g., *Physalia*, *Velella*, *Porpita*), macroplankton (e.g., salps, pteropods) and reef fishes (e.g., *Chaetodon* spp., *Pomacanthus* spp.) in panhandle coastal waters suggests that intrusions of subtropical-tropical water may reach nearshore environments. While the occurrence of surface-associated organisms such as *Sargassum* spp., and some of the chondrophores, jellyfishes and ctenophores stranded on beaches or transported into estuaries can be explained by wind drift, subsurface

species are likely to have been advected inshore by currents. Presumptive evidence that the young stages of tropical species are advected to coastal waters is provided by observations of scuba divers and sportsfishers, who report that tropical invertebrates and fishes are commonly encountered on and near artificial "reefs". These reefs are commonly deployed on sandy (*i.e.*, soft) bottoms unsuitable for colonization by "live-bottom" epifaunal animals. The presence of tropical benthic adults on hard-substrates suggests that: (a) planktonic stages of subtropical-tropical species are not uncommon in shelf waters; (b) the predominance of soft substrates in the western portion of the NEGOM may limit the distribution of adults of these species in benthic shelf communities; and (c) benthic species assemblages characterized from trawl catches may not reflect the species composition and diversity of potential benthic communities, which are controlled by substrate type rather than by recruitment constraints. This speculative arguement has significance when, as is often the case, epibenthic species diversity is used as a surrogate indicator of environmental quality. The distribution of hard substrates in the NEGOM requires further investigation, and biological collections of shelf communities should accompany geological-sedimentological sampling.

7. The distribution of sargassum and its associated organisms in the eastern Gulf of Mexico has received scant attention. Remote sensing of the distribution of "Gulf weed" (primarily *Sargassum natans* and *S. fluitans*) may reveal valuable information about sea states and, more importantly, the distribution and longevity of frontal zones and boundaries. Sargassum as an important habitat (e.g. for larval fishes; hatchling and post-hatchling sea turtles) has not been investigated in the eastern Gulf of Mexico.

8. Artificial reefs of various sizes and materials are being deployed with increasing frequency on the inner shelf. Some of these reefs are unstable during heavy storm conditions because of their small size and/or placement in inappropriately shallow water depths. While much has been written about the presumed benefits of artificial substrates (increased productivity, etc.), relatively little work has been done assessing the possible negative impact of these materials on natural communities. For example, it would be of value to know whether the translocation and/or destruction of artificial reefs during the three hurricanes of 1995 negatively impacted "natural" live bottom communities in the vicinity of their original location. The long-term impact of artificial reefs on the abundance and sustainable yields of recreationally and commercially important fish species remains unknown, although a relatively large literature on the subject is available.

9. An unknown, but possibly significant amount of military debris (e.g. aircraft, missiles, ordnance) has accumulated in shelf waters of the northeastern Gulf of Mexico. The short- and long-term ecological impact of this material should be assessed. Should a Theater Missile Defense (TMD) program be initiated by DoD as planned, combusted and non-combusted accelerants and other debris will fall into NEGOM shelf waters. At the present time, no assessment of the potential

environmental impact of the program on shelf or nearshore waters have been made.

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Chapter 6 – SOCIOECONOMIC CONDITIONS

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6.1 Introduction

This study is an intensive analysis of the socioeconomic characteristics of northwest Florida that are related to the marine ecosystem. As Figure 6-1 indicates, northwest Florida includes 13 coastal counties, starting with Escambia County (i.e., a dot indicates a county that is part of this study) in the extreme northwestern part of Florida to Citrus County, just north of the Tampa metropolitan area. These coastal counties exhibit a great range of economic activities and marine ecosystem processes. As will be indicated, the economies of these counties depend greatly on and interact with the marine ecosystem; therefore, the emphasis of this report is to identify the extent and nature of this interaction. Since OCS activities must be analyzed within the context of the existing onshore and offshore economic activities, a baseline socioeconomic characterization of such an area as northwest Florida is important in identifying positive and negative potential impacts on the marine environment.

This summary, which reflects material from the individual county summaries in Appendix G of this report, is composed of five parts. First, key socioeconomic characteristics of the 13 counties are reviewed. Second, each county has critical industries which are defined as the export base, or those industries that derive income from outside the county. Such industries are the driving force behind the economic growth or decline of the region. Third, aspects of the local economies can affect the marine ecosystem. Industries can create environmental externalities which are linked in a negative way to the ecosystem by such things as wetland destruction, pollution and altered water flows. Such industries are named "ecosystem-sensitive" in that the level of economic activity in an industry has a direct bearing on the well-being of the marine environment. Those industries that are relatively independent of the ecosystem are identified and characterized as "ecosystem-insensitive." Discussion of this third part provides an indication how sensitive the marine environment is to the regional (county) economies. Fourth, the marine ecosystem directly supports key industries in the counties under analysis. Four such industries are analyzed:

1) commercial fishing,

2) recreational fishing,

3) saltwater beach use, and

4) marine recreational boating.

In addition, wetlands support the fishing industries as part of their economic function, and the saltwater marshes are reviewed in terms of their economic contribution to these industries.

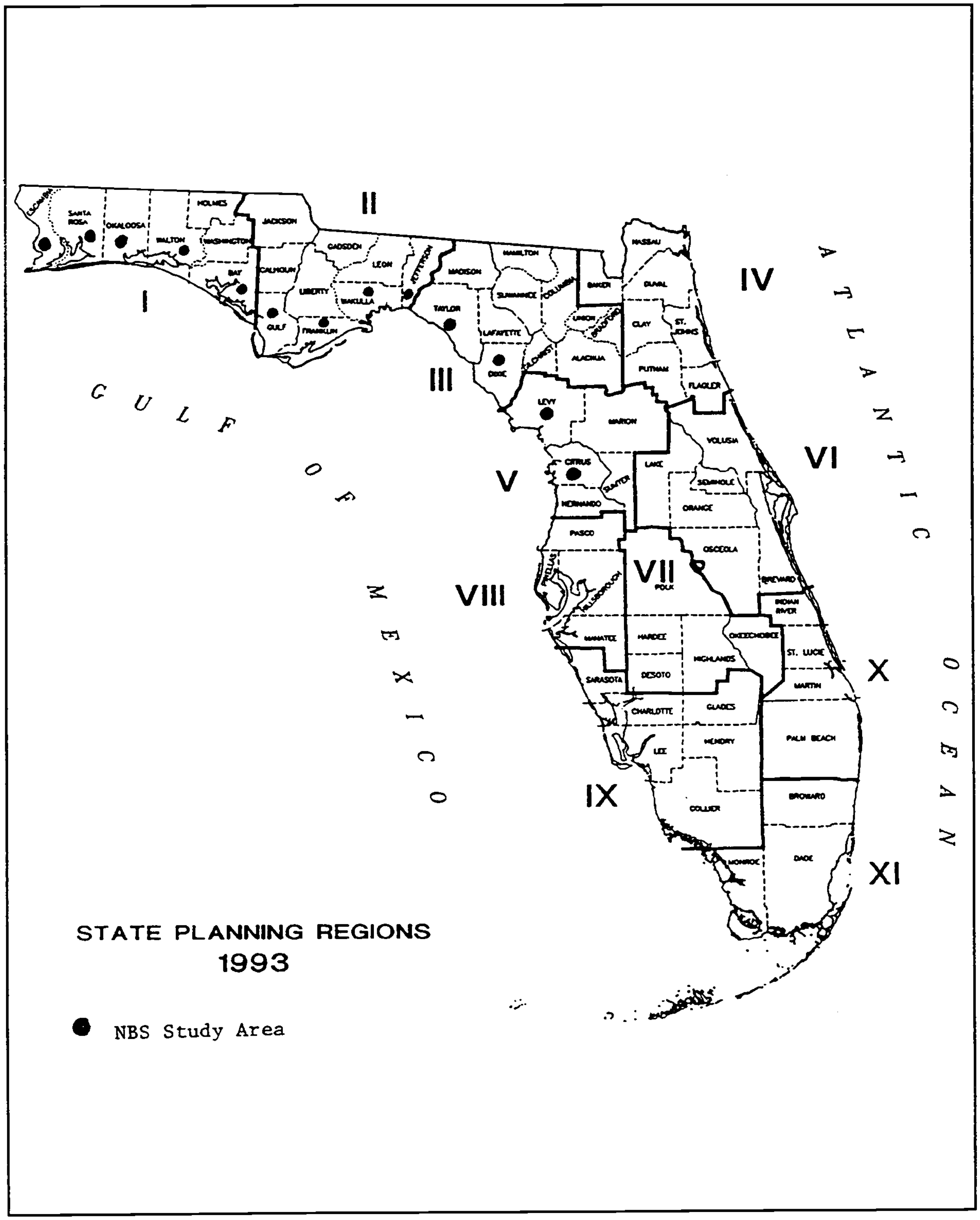

Figure 6-1. Map of the state of Florida indicating the 13 counties covered in this study.

The fifth part of this summary presents a review of water quality, which is critical to the marine ecosystem; this subject is related back to industries that contribute to negative impacts.

6.2 Socioeconomic Indicators

Table 6-1 shows key economic indicators reflecting the relative economic size and welfare of the 13 coastal counties in northwest Florida. Escambia County is the largest in terms of population, personal income, wages and employment, with nearly 271,000 inhabitants and nearly 144,000 workers. This is in marked contrast to Franklin County, which has but 10,000 inhabitants and slightly over 4,000 workers.

Table 6-1. A Summary of Socioeconomic Characteristics for Thirteen Counties in Northwest Florida, 1993

Counties	**Population (000)**	**Personal Income ($000)**	**Wages by Place of Employment**	**Employment**	**Per Capita Income**
Escambia	270.4	$4,569,565	$3,439,195	143,673	$16,899
Santa Rosa	94.5	1,564,823	1,964,348	30,741	16,556
Okaloosa	157.3	2,863,026	629,336	89,337	18,202
Walton	30.4	429,411	203,184	11,652	14,128
Bay	137.2	2,311,669	1,564,044	74,228	16,852
Gulf	12.0	174,258	109,891	4,692	14,482
Franklin	9.5	136,900	63,323	4,020	14,458
Wakulla	16.1	238,807	80,375	4,581	14,816
Jefferson	11.8	172,176	69,470	4,453	14,575
Taylor	17.3	236,255	170,156	7,541	13,690
Dixie	11.4	172,176	63,482	3,570	10,334
Levy	28.1	367,532	145,228	9,021	13,062
Citrus	101.9	1,558,130	641,140	32,585	15,295
Total	**897.9**	**$14,794,728**	**$9,143,172**	**420,094**	**$16,477**

Source: BEA, USDC

As shown in Table 6-1, there is a great disparity in economic size from county to county. In second and third place in terms of population and employment are Okaloosa and Bay Counties, respectively. The three most-populated counties are concentrated in the extreme western part of the 13-county region. One of the main reasons for this is their sandy beaches which attract tourists and retirees, coupled with their proximity to natural resources (e.g., forestry) and good transportation. In addition, these counties are close to Alabama, a rapidly growing state.

The 13-county region has a population of nearly 900,000 people, which is 6.6 percent of the 1993 state population. Although this is a large coastal area, the population density is less than the Florida average. There is still much open space in this area of Florida. In general, the population concentration declines from the extreme northwest area and around the Big Bend. It is not until Citrus County, on the southern edge of the study area, that population reaches over 100,000 people. This contrasts with Bay

County in the western portion of the region, where the tourist mecca of Panama City exists. The sparsely-settled counties do not have the attractive beaches, infrastructure and other amenities that characterize the more populated counties in the study area.

Another key economic indicator is per capita income, which is an economic welfare indicator and a gauge of relative affluence. The most western counties in the region also show the highest per capita income with Okaloosa County exhibiting the highest ($18,202 per person). Per capita income is lowest ($10,334 per person) in Dixie County. In general, there is a positive correlation between economic size and the level of affluence as measured by per capita income.

The marine ecosystem plays a dramatic role in enhancing the economic capabilities of each county. For example, Escambia County has a deep water port, while the region from Santa Rosa County to Bay County has some of the most attractive beaches in the world. These marine resources have been instrumental in increasing the population and attracting tourists and retirees to these areas. Also, military air bases help raise per capita income in these areas (i.e., the high percent of officers at such bases). Thus, it is not surprising that the economic size and affluence is prevalent. Other counties such as Franklin have marine resources, but do not have the resource variety found in the northwest counties. Franklin County's economy is dominated by commercial fishing of oysters and shrimp (see county summary in Appendix G). Relative to the state of Florida, the region's per capita income of $16,477 is below the state average of $20,828, due in part to a number of low-wage industries (i.e., services, paper manufacturing, etc.) and a lack of "high-tech" industries such as those found in central and southern Florida (i.e., Harris, McDonnell Douglas, IBM). In summary, there is a great variance in economic size and level of affluence among the 13 counties under study (a more detailed analysis can be found in the individual county reports in Appendix G).

6.3 <u>The Export Base of the Region</u>

When analyzing a regional economy, it is important to identify the principal reason(s) for any economic growth or decline. The export base theory is widely used to analyze this issue. In effect, there are two kinds of industries in a region or county. Those that depend on demand outside the county are what are called "export industries". These export industries either sell products outside the county or attract individuals into the region who in turn inject money into the local economy. Good examples in northwest Florida are exports of paper products and tourism. In these cases, money is injected into the local economy and undergoes a multiplier effect as workers spend money on "local industries;" workers in these local industries in turn spend money on other local industries.

Examples of local industries are usually found in the retail and service sectors. The multiplier effect is limited since there is leakage from the spending process because goods need to be imported. Most northwest Florida counties must import consumer durables such as autos, TV sets and washing machines.

In the county reports, export industries were identified by using what is called a "location quotient." This technique is simple and is usually fairly accurate in identifying the critical export industries in an area which are the driving force behind a region's growth. The degree to which the marine ecosystem interacts with export industries will be important in this analysis. For example, if an export industry, such as a pulp and paper plant, discharges toxic chemicals into estuaries, this might have an adverse impact on estuarine-dependent fisheries which form the basis for commercial and recreational fishing. Placing restrictions on the pulp and paper mills may raise prices, thereby making the company less competitive. This could in turn have negative multiplier effect on the region. Therefore, the identification of the export base through location quotients is important for this socioeconomic profile.

The location quotient is defined as follows:

$$\text{Location quotient (LC)} = \frac{\text{\% of Wages in industry in the region}}{\text{\% of Wages in industry in the U.S.}}$$

In computing the percent of wages, the base is either total wages or personal income in the region and in the United States. For example, assume the paper industry is 10% of personal income in a particular county, but only 1% at the national U.S. level. The LC would be 10, indicating an unusually high concentration of paper production in the region. The inference is that most, if not all, of the paper produced in the region is for export. Thus, an export industry has been identified. The simple formula for identifying how much paper is exported from the region is as follows:

% Exported = (1 minus 1/LQ)

In our example, the percent exported would be (1 - 1/10) or 90%. The balance is presumed to be consumed locally. In reality, LQ's higher than 2 are good indicators that possibly all the product is exported, especially if it is an intermediate product such as phosphoric acid or ammonia which is used by manufacturers outside the region. Thus, a LQ can be considered as an indicator, rather than a precise calculation of how much is exported and how much is consumed locally. This technique was used for all of the 13 counties in northwest Florida. The results are shown in Table 6-2, along with the total wages generated by that industry in 1993.

The far western part of the study area, from Escambia County to Franklin County, has been compared with a stool with two thick legs – the military and tourism – and one thin one which is industrial. It has been said that this area depends on beaches and bases. This is only partly true (Table 6-2). Escambia County is dominated by the military (i.e., Pensacola Naval Air Base) and tourism, but also has a substantial manufacturing export base of paper and printing. This county is also diversifying into being a regional health center for many counties both in Florida and Alabama.

Table 6-2. A Summary of the Principal Export Industries in the Thirteen Counties of the Northwest Florida Area.*

Escambia	**($3,439,195)**
Health Services	($466,890)
Federal Government, Civilian	(384,120)
Military	(296,766)
Water Transportation	(194,425)
Tourism	(103,456)
Paper & Allied Products	(80,966)
Printing & Publishing	(23,871)

Okaloosa	**($1,964,348)**
Military/Federal Government	($704,335)
Tourism	(129,840)
Engineering Services	(119,802)
Transportation Equipment	(36,008)
Real Estate	(28,144)
General Building	(23,558)
Electrical Machinery	(16,695)

Bay	**($1,564,044)**
Military	($170,262)
Federal Employees	(137,088)
Construction	(103,232)
Retail	(220,661)
Eating & Drinking Places	(71,855)
Hotels & Lodging	(42,606)
Real Estate	(24,222)

Franklin	**($63,233)**
Health Services	($9,212)
Fisheries	(3,329)
Building	(2,303)
Food Stores	(2,806)
Eating & Drinking Places	(2,330)
Lumber & Wood	(1,783)
Railroad Transportation	(926)

Jefferson	**($69,470)**
State & Local Governments	($20,215)
Agricultural Services	(3,867)
Utilities	(3,798)
Lumber & Wood	(3,607)
Apparel	(1,624)

Dixie	**($63,482)**
State & Local Governments	($21,143)
Lumber & Wood	(13,239)
Fishing	(1,151)
Forestry	(612)

Citrus	**($641,140)**
Construction	($66,524)
Retirement	(315,763)/1,558,130
Printing	(4,179)
Fisheries	(945)
Utilities	( )

Santa Rosa	**($629,336)**
Chemicals & allied products	($40,056)
Military	(65,927)
Federal Civilian	(25,245)
Textiles	(15,060)
Food & Kindred	(5,064)
Tourism	(19,208)
Bedroom Community	(488,438)/1,564,823

Walton	**($203,184)**
Construction	($15,691)
Food Stores/Tourism	(8,234)
Hotels/Tourism	(22,014)
Eating & Drinking Places/ Tourism	(9,097)
Real Estate	(4,400)
Apparel	(1,896)
Lumber/Wood	(1,259)

Gulf	**($109,891)**
Paper Products	($35,961)
Chemicals	(5,827)
Railroad Transportation	(2,717)
Fishing	(388)
Forestry	(200)

Wakulla	**($80,375)**
Food Stores	($2,858)
Food & Kindred	(1,735)
Fisheries	(1,176)
Petroleum Products	(415)
Chemicals	(19,000)
Water Transportation	(402)

Taylor	**($170,156)**
Lumber & Wood	($11,387)
Fabricated Metals	(6,833)
State & Local Government	(3,359)
Fisheries	(573)
Paper & Allied	(52,000)

Levy	**($145,228)**
Lumber & Wood	($3,993)
Agricultural Services	(3,359)
Fishing	(838)
Machinery	(323)

* Earnings in thousands of dollars

As shown, the military export industry generated nearly $297 million, or 8.7% of the $3.439 billion in wages generated in Escambia County. This does not include the multiplier effect of this injection of money by the federal government. As a general rule, for every dollar injected by an export industry into a small area like a county in northwestern Florida, an additional $.50 is generated. Thus, the military would generate nearly $446 million ($297 times 1.5) when the multiplier is taken into account, or 7.7% of total Escambia County wages. The reader can analyze the other counties with this illustration for the largest county in the region as measured by population and personal income, as discussed previously.

A group of industries present in most counties in northwest Florida is forestry, wood processing, paper production and printing. Of the 13 counties, nine have these industries as an important part of their export base. The reason for this is the abundance of forest products in this area. Recently, there has been less optimism about the future of northwest Florida lumber. In Dixie County, Georgia-Pacific's Chip-N-Saw plant, which produces lumber for the building industry, has resorted to week-long furloughs for employees. The lumber business is extremely weak in response to Canadian competition. Because of government subsidies, Canadian lumber can be imported into Florida at cheaper prices than those charged for products from the study area.

Santa Rosa County is really a "bedroom community" for Escambia County, as nearly two-thirds of its wages are generated by those commuting to Escambia County (Table 6-2). Okaloosa County is a high-income county and depends more than any other county on high-wage industries such as engineering services, transportation equipment and electrical machinery. Eglin Air Force Base is also a great part of this county's export base. Walton County is heavily dependent on tourism, which depends on sandy beaches as an attractive natural resource. Bay County extends the features of Walton County in terms of tourism, but adds Tyndall Air Force Base as an important export industry. The tourism theme falls off for Gulf County, which is heavily dependent on St. Joe's Paper Company or the forestry resource in the area. Franklin County is largely a single-industry area, with most of its export base still centered around the fisheries, especially oysters and shrimp. Wakulla County is similar to Franklin County with commercial fishing being an important export industry; however, Wakulla is the home of the manufacturing of gun powder (Olin Corporation) and is an important area for the arrival, at St. Marks, of crude oil imports from other Gulf states. Jefferson County has only about 10 miles of coastline and limited marine activities. Taylor County is highly dependent upon the forestry resource, except for the presence of a state facility. Finally, Levy and Dixie Counties continue the general theme of wood products and fisheries as the foundation for their export base. Notice that a large tourism component to the economic base really ends in Bay County. To the east of Bay County, the attractive sandy beaches are minimal or nonexistent, especially from Taylor to Citrus Counties.

6.4 The Socioeconomic Component of the Marine Ecosystem

For purposes of this analysis, industries are divided into two functional groupings to investigate the relation between the industry and the marine ecosystem. The first grouping is ecosystem-sensitive industries. By this, we mean industries that have been historically, or are presently, in conflict with the natural processes of the ecosystem. Such industries, including the household sector, create point or nonpoint discharge of substances that are biodegradable and/or non-biodegradable. In either case, there are negative externalities (i.e., damage to elements of the ecosystem such as fish or wetlands) that impact water quality, which is central to the viability of the marine ecosystem. Thus, an ecosystem-sensitive industry is defined as one that, without proper regulation, will have a negative impact on one or more elements of the marine ecosystem.

Table 6-3 shows the ecosystem-sensitive industries for the 13 county areas under study. These industries are not necessarily export industries as discussed in the last section. For example, local industries, such as stores in a shopping center, may produce nonpoint source pollution through extensive storm runoff. But, in the main, point source polluters are usually in manufacturing, which also tends to be part of the export base as defined in the last section.

In Escambia County, there is a deep-water port that produces many effluents. Also, paper and printing manufacturing have historically discharged toxic chemicals into streams leading into bays and inlets. As with all the other counties, this is described in some detail in the separate county reports in Appendix G. Santa Rosa County also has manufacturing industries – chemicals, textiles and food processing – that contribute to diminished marine water quality. In counties that are growing rapidly, the general building industry produces, as a byproduct of its activities, a lot of non-porous surfaces as well as homes with septic tanks which produce nonpoint source runoff and leaching, respectively. Thus, we have included this "industry" in Okaloosa County along with two manufacturing industries.

In Walton County, construction of homes for retirees and corresponding shopping areas are sources of nonpoint source water pollution. The apparel and lumber industries also contribute point source pollution in this county. Bay County has little manufacturing, but does have rapid growth – construction – that is associated with nonpoint source pollution. Gulf County is dominated by one paper company. Paper companies have come into great conflict with the marine ecosystem, as discussed in Appendix G. Franklin County, emerging from its sole dependence on the commercial fishing industry, is becoming attractive for tourism and retirement; therefore, Table 6-3 lists various development industries that have produced high coliform or bacterial counts in Apalachicola Bay, thereby preventing the harvest of oysters. In Wakulla County, the principal source of pollutants has been at St. Marks, where oil is imported into Florida. Thus, water transportation comes into conflict with the marine ecosystem. Other manufacturing industries are not consistent with the optimal marine environment, but do appear to be less of an ecological threat.

Jefferson County is largely rural, and depends on primary natural resources such as crops and timber for its economic base. However, the shortness of its Gulf coastline does not place Jefferson County in great conflict with the marine environment. Taylor County contributes its share of pollutants from industrial point sources, contributed primarily by manufacturing of

Table 6-3. A Summary of the Principal Ecosystem-Sensitive Industries in the Thirteen Counties of the Northwest Florida Area.*

Escambia	**($3,439,195)**	**Santa Rosa**	**($629,336)**
Water Transportation	(194,425)	Chemicals & allied products	($40,056)
Paper & Allied Products	(80,966)	Textiles	(15,060)
Printing & Publishing	(23,871)	Food & Kindred	(5,064)
Okaloosa	**($1,964,348)**	**Walton**	**($203,184)**
Transportation Equipment	($36,008)	Construction	($15,691)
General Building	(23,558)	Apparel	(1,896)
Electrical Machinery	(16,695)	Lumber/Wood	(1,259)
Bay	**($1,564,044)**	**Gulf**	**($109,891)**
Construction	($103,232)	Paper Products	($35,961)
		Chemicals	(5,827)
Franklin	**($63,233)**	**Wakulla**	**($80,375)**
Building	($2,303)	Food & Kindred	($1,735)
Food Stores	(2,806)	Petroleum Products	(415)
Eating & Drinking Places	(2,330)	Chemicals	(19,000)
Lumber & Wood	(1,783)	Water Transportation	(402)
Railroad Transportation	(926)		
Jefferson	**($69,470)**	**Taylor**	**($170,156)**
Agricultural Services	($3,867)	Lumber & Wood	($11,387)
Utilities	(3,798)	Fabricated Metals	(6,833)
Lumber & Wood	(3,607)	Paper & Allied	(52,000)
Apparel	(1,624)		
Dixie	**($63,482)**	**Levy**	**($145,228)**
Lumber & Wood	($13,239)	Lumber & Wood	($3,993)
Forestry	(612)	Agricultural Services	(3,359)
		Machinery	(323)
Citrus	**($641,140)**		
Construction	($66,524)		
Printing	(4,179)		
Utilities	(N/A)		

* Earnings in thousands of dollars

lumber and wood products. This theme can be extended to Dixie and Levy Counties. Finally, Citrus County is just north of the Tampa area and population growth has produced nonpoint source pollutants. This county also contains the Crystal River electric facility, powered by atomic energy, which is an ecosystem-sensitive facility.

Table 6-4 shows the ecosystem-insensitive industries for the coastal counties under discussion. Some clarification is needed. If any industry is based upon the resources of the marine ecosystem, we have designated this industry as an ecosystem-insensitive industry since it is not usually in conflict with the ecosystem. This may be too simplistic in that such industries can contribute to pollution. The commercial fishing industry is a good example. To the degree that growth is regulated, tourism is generally not in conflict with the marine ecosystem, since tourists use this system for recreational fishing and beach use. Also, the military, such as Eglin Air Force Base, is generally considered a "clean" industry as

Table 6-4. A Summary of the Principal Ecosystem-Insensitive Industries in the Thirteen Counties of the Northwest Florida Area.*

Escambia	**($3,439,195)**	**Santa Rosa**	**($629,336)**
Federal Government	($384,120)	Military	($65,927)
Military	(296,766)	Federal Civilian	(25,245)
Health Services	(466,890)	Tourism	(19,208)
Tourism	(103,456)	Bedroom Community	(488,438)/1,564,823
Okaloosa	**($1,964,348)**	**Walton**	**($203,184)**
Military/Federal Government	($704,335)	Food Stores/Tourism	($8,234)
Tourism	(129,840)	Hotels/Tourism	(22,014)
Engineering Services	(119,802)	Eating & Drinking Places/ Tourism	(9,097)
Real Estate	(28,144)	Real Estate	(4,400)
Bay	**($1,564,044)**	**Gulf**	**($109,891)**
Military	($170,262)	Railroad Transportation	($2,717)
Federal Employees	(137,088)	Fishing	($388)
Retail/Tourism	(220,661)		
Eating & Drinking Places/ Tourism	(71,855)		
Hotels & Lodging/Tourism	(42,606)		
Real Estate	(24,222)		
Franklin	**($63,233)**	**Wakulla**	**($80,375)**
Health Services	($9,212)	Food Stores	($2,858)
Fisheries	(3,329)	Fisheries	(1,176)
Jefferson	**($69,470)**	**Taylor**	**($170,156)**
State & Local Government	($20,215)	State & Local Government	($3,169)
		Fisheries	(573)
Dixie	**($63,482)**	**Levy**	**($145,228)**
State & Local Governments	($21,143)	Fishing	($838)
Citrus	**($641,140)**		
Retirement	($315,763)/1,558,130		
Fisheries	(945)		

* Earnings in millions of dollars

far as the marine ecosystem is concerned. Finally, state government is considered ecosystem-insensitive. In many areas in northwest Florida, prisons are being built, and they pose no threat to the marine environment. These are the kinds of industries that are listed in Table 6-4. The reader can review these industries and see the common theme, as discussed above, regarding ecosystem-insensitive industries. Admittedly, the line between the two kinds of industries is not always clear cut; however, for our purposes, we can identify those industries that should be considered when analyzing economic activities that come in conflict with and are not a natural part of the marine ecosystem.

6.5 Spending: Annual User Value and Asset Value of Selected Elements of the Marine Ecosystem

6.5.1 Annual Spending

To estimate the economic magnitude of the marine ecosystem in northwest Florida, available secondary data, both published and unpublished, was used to estimate annual spending by tourist and residents on the following economic activities: (1) recreational fishing, (2) recreational saltwater beach use and (3) recreational marine boating. In addition, the dockside value of commercial fishery landing by county was estimated. Thus, three critical resources in the marine ecosystem are evaluated: (1) marine fisheries, (2) saltwater beaches and (3) water areas. Finally, a critical resource of the marine ecosystem is saltwater marsh or wetlands, which perform many economic functions such as a support for marine fisheries (Appendix G). Table 6-5 shows the results of our analysis for the 13-county region.

The ex vessel or dockside landings were valued at $48.29 million dollars for the thirteen counties. By far, Wakulla County was the largest producer of commercial fisheries in northwest Florida, with over 25% of the total value of this region's landings. In terms of the value of landings this county was followed by Bay, Dixie, Okaloosa and Levy Counties. Every county except Jefferson showed landing of commercial fisheries. Thus, the commercial fisheries provide widespread income to practically every coastal county in our study area.

The other user of fishery resources in the region is the recreational angler. Recreational anglers include both residents and tourists. With the limited data available (see individual reports), it was estimated that saltwater anglers spent nearly $85 million dollars on travel, supplies, bait, food, lodgings and fishing equipment while fishing off the Gulf coast in the 13 counties in 1993. Okaloosa, Bay and Citrus Counties were about equal in spending and together accounted for over 38% of the saltwater angler spending in the region. In contrast to commercial fishing value, this spending is all at the retail level. Thus, the fishery resources off the coast of the study area produce a considerable amount of spending. Environmental damage to these resources would result in a loss in revenue and, of course, jobs in this area. This estimate of the recreational fishery is believed to be conservative.

Generally, there is no direct spending on saltwater marsh, which has a key input to many marine ecosystem elements, including the support of estuarine-dependent fishes. However, there is no organized market for wetlands as a support for fisheries. The owners of wetlands cannot collect revenue from fishermen for the contribution of their land. So, wetlands are filled in for other uses, such as hotels and marinas, which do have economic value in an organized market. This does not mean that the marsh has no economic value to fishermen. This concept will be discussed later, and is mentioned here to explain why spending for saltwater marsh was not placed in Table 6-5.

Table 6-5. A Summary of Spending and Value for Marine Resources in the Thirteen Counties in Northwest Florida, 1993 ($Millions).

Counties	Ex Vessel Fish Landings	Recreational Fishing Spending	Saltwater Marsh	Saltwater Beach Spending	Marine Boating
Escambia	$2.5	$8.1	N/A	$22.4	N/A
Santa Rosa	1.2	5.1	N/A	22.4	N/A
Okaloosa	6.0	10.2	N/A	21.3	N/A
Walton	.1	1.5	N/A	5.6	N/A
Bay	6.7	11.0	N/A	59.6	N/A
Gulf	3.8	3.7	N/A	2.5	N/A
Franklin	12.3	6.5	N/A	.7	N/A
Wakulla	2.8	5.9	N/A	**	N/A
Jefferson	*	.9	N/A	**	N/A
Taylor	1.3	7.3	N/A	**	N/A
Dixie	2.1	5.2	N/A	**	N/A
Levy	3.1	8.1	N/A	**	N/A
Citrus	6.4	11.2	N/A	**	N/A
Total	**$48.3**	**$84.6**	**N/A**	**$134.5**	**N/A**

*Insignificant
**No Significant Beaches
Source: See County Economic Profile.

One of the largest economic activities in the western part of the study area is tourism. Tourists usually mention Florida's beaches as a primary attraction. Table 6-5 shows an estimate of resident and tourist spending for beach-related goods and services (e.g., lodgings, food, travel, etc.) Of note, total spending at retail amounted to nearly $135 million in 1993 as a very conservative estimate. Because there are no major beaches from Wakulla County to Citrus County, spending estimates are negligible. This area is covered with wetlands rather than beaches, so tourism has been much slower to develop in this portion of the study area. Bay County showed the largest spending, nearly $60 million dollars, on beach-related goods and services, or 44% of all spending in the 13-county region. There were no estimates for spending on recreational boating in the Gulf of Mexico. There is, of course, an overlap between the general activity of recreational boating and offshore saltwater recreational fishing.

6.5.2 Annual User Value

Practically all of the marine ecosystem resources discussed above are common property resources. This means that there is no overt price charged for their use, even though there are associated expenditures and values as shown in Table 6-6. A day at the beach or a day engaged in recreational fishing may have no overt price, but still the recreationalist derives value from this experience. It is true that sometimes a license is required, but this is a nominal price per day of recreation. The concept of user value comes into play for such common property resources.

Table 6-6. A Summary of User Value for the Marine Resource in the Thirteen Counties in Northwest Florida, 1993 ($Millions).

Counties	**User Value Recreational Fishing**	**User Value Saltwater Beaches**	**User Value Marine Boating**
Escambia	$5.40	$2.85	$1.150
Santa Rosa	3.40	2.85	.390
Okaloosa	6.20	2.71	.845
Walton	.92	.72	.156
Bay	10.40	7.61	.867
Gulf	2.10	3.11	.169
Franklin	3.37	.09	.131
Wakulla	3.55	**	.305
Jefferson	.64	**	.040
Taylor	4.30	**	.219
Dixie	3.60	**	.138
Levy	6.00	**	.198
Citrus	8.00	**	.991
Total	**$57.88**	**$19.94**	**$5.6**

**No Significant Beaches
Source: See County Economic Profile

Estimates of user value may be obtained by the travel cost and contingent value methodologies (CV method) discussed in Appendix G. User value is a flow of value from the use of a common property resource. In Table 6-6, it is given on an annual basis for recreational fishing, beach use and boating. For saltwater recreational fishing, the user value generated in the 13-county region was nearly $60 million in 1993, with the largest value of $10.4 million generated in Bay County.

Because the beach area is limited to the western part of the study area and beach value per day are also significantly less than recreational fishing, user value from beaches was nearly $20 million, but less than recreational fishing. The user value of boating as a generic recreational activity was only $5.6 million in 1993. Such values would be of significant use in estimating losses if there were environmental damages to marine resources.

6.5.3 Asset Value

In Table 6-7, we estimated the asset value of four critical marine resources. Since the user value is a flow over time, then the asset value or the worth of the resources can be computed by use of the following formula:

$$\text{Asset Value of a Resource} = \frac{\text{User Value/Yr.}}{r}$$

where "r" is the discount rate. In effect, the above expression yields the

Table 6-7. A Summary of the Asset Value for the Marine Resource in the Thirteen Counties in Northwest Florida, 1993* ($Millions)

Counties	**Asset Value Recreational Fishing**	**Asset Value Saltwater Marsh**	**Asset Value Saltwater Beach**	**Asset Value Marine Boating**
Escambia	$180.0	$6.9	$95.0	$38.45
Santa Rosa	113.3	34.0	95.0	13.0
Okaloosa	207.0	1.6	90.0	28.2
Walton	30.7	14.3	23.4	5.2
Bay	346.0	43.6	253.0	28.9
Gulf	70.0	14.9	10.0	5.6
Franklin	112.0	98.0	3.0	4.4
Wakulla	118.0	98.8	**	10.2
Jefferson	21.0	20.2	**	1.3
Taylor	143.0	115.8	**	7.3
Dixie	120.0	108.0	**	4.6
Levy	200.0	188.0	**	6.6
Citrus	145.0	145.0	**	33.1
Total	**$1,806**	**$889.1**	**$569.4**	**$186.85**

*Values in Table 6 divided by .03 = Asset Value. See text for a discussion.
**No Significant Beaches
Source: See County Economic Profile.

value of an asset if the user value (i.e., profits for a private corporation) flows into perpetuity – forever or a long period of time. The real discount rate is about 3% so all the user values in Table 6-7 were divided by .03 to yield their asset value. The asset value of recreational fishing is over $1.8 billion, with the highest values in Bay and Okaloosa Counties. The saltwater beach resource has an asset value of one-half billion dollars even though the beaches are restricted to the western part of they study area. Bay County has an asset value of over one-quarter of a billion dollars. Generic recreational boating had an asset value of over $186 million.

Finally, the saltwater marsh also has a user value to commercial and recreational fishermen, and this value was estimated using the marginal productivity theory discussed in Appendix G. The asset value to the fisheries alone is over $889 million and is larger for the southeastern part of the study area where saltwater marsh is more abundant.

These asset values would answer a critical question in environmental damage cases, either naturally occurring or anthropogenic in origin. For example, if 10 percent of the saltwater beach area in northwest Florida were permanently destroyed, how much asset value was destroyed and what might the damage be. In this example, it would be $180 million. These baseline estimates will be of assistance in further policy problems regarding the coastal and marine ecosystem in northwest Florida.

6.6 Evaluation of Water Quality

6.6.1 Escambia County to Wakulla County

In general, rivers in this region have good water quality, with a number of near-pristine water bodies. The major pollution sources in the area include agricultural, silvicultural, and construction runoff. Additionally, several low-volume waste water treatment plants, especially in rural areas, are overloaded and/or poorly operating. Rapid coastal economic development threatens bays and lagoon waters. Finally, some high volume point source discharges, particularly from pulp and paper mills, adversely affect water quality.

The Perdido Bay basin has water quality problems in two major areas: Elevenmile Creek and Bayou Marcus Creek. Champion Paper Company discharges into both of these creeks. Dioxin contamination is a concern, as fish taken from the creek have had tissue levels of dioxin ranging from 8.1 to 25.7 parts-per-trillion. The EPA-recommended maximum level is 7 parts-per-trillion. Bayou Marcus Creek receives urban runoff and discharge from a waste treatment facility. The bay is threatened and partially degraded due to these point and nonpoint pollution sources. Perdido River has good water quality except for the area near its mouth that is affected by poorer quality bay waters.

The Escambia, Blackwater, and Yellow Rivers all drain into Pensacola Bay. They generally have good water quality except for localized areas downstream of point sources. In the Escambia River, these areas are in the northernmost reaches, with mostly domestic discharges, and in the southernmost reaches where there are industrial discharges. Trammel Creek, in the Yellow River basin, shows degraded conditions due to domestic discharge. The waste water treatment plant in that area has a history of discharge violations, with one of the more recent resulting in a large fish kill. Though the general water quality of Escambia, Blackwater, Yellow, and Perdido Rivers appears to be good, all four rivers have mercury contamination at high enough concentrations in the tissue of largemouth bass to warrant issuing limited consumption advisories.

The Pensacola Bay basin has water quality problems associated with urbanization around the City of Pensacola. The western bay receives the bulk of the treated wastewater and urban runoff, while Escambia Bay had industrial discharges. Fish kills have been a persistent problem in both Pensacola and Escambia Bays and their tributary bayous. Although the Choctawhatchee River generally has good water quality, it has a moderate degree of impact from agricultural runoff (turbidity, nutrients, pesticides, etc.). Additionally, several of the tributary systems within the basin have problems associated with domestic or industrial discharge. West Sandy Creek and Bruce Creek, in the western basin, receive discharge from DeFuniak Springs waste water treatment plant and the Showell Farm poultry processing plant, respectively. Most of these small treatments plants have been upgraded, or are in the process of being upgraded through Consent Orders. Choctawhatchee Bay has good water quality, but is threatened by development of its watershed. Of particular concern are spray field and/or urban runoff from developed areas at Ft. Walton Beach and Destin.

St. Andrews Bay has fairly good water quality, except for an area around a paper mill discharge. Most of the rest of the basin has good water quality except Beatty Bayou. High concentrations of lead, mercury, DDT, chlordane, PCB's, and polycyclic aromatic hydrocarbons have been found in sediments in Watson Bayou. Also, Deer Point Lake, the drinking water source for Panama City, has nutrient and aquatic weed problems. Both Ecofina Creek and Deer Point Lake have largemouth bass contaminated with mercury, resulting in limited consumption advisories. St. Josephs Bay has excellent water quality except for an area around its paper mill discharge.

Apalachicola Bay has very good water quality and supports Florida's largest commercial oyster fishery, although within this basin there are localized problems due to nonpoint source pollution from fish houses and marinas. The New River basin, which drains into the eastern end of Apalachicola Bay, has very good water quality. Little of this basin's area has been developed. At the eastern end of Apalachicola Bay is St. George Sound. In general the sound has good water quality with exception of the area near Carrabelle. The City discharged primary treated wastewater, but has recently made significant upgrades in its treatment.

The St. Marks, Wakulla, and Aucilla Rivers have excellent water quality except for a small stretch in the lower St. Marks that has oil-polluted sediments from oil spills, historic Seminole Asphalt discharge and marina activities.

6.6.2 Jefferson County to Levy County

The Steinhatchee River basin's major water quality problem area is the Fenholloway River, which is seriously affected by the effluent from a large paper mill. Although the discharge quality improved in the early 1970's, the river still has high nutrients and color, and low DO and biological diversity. An EPA study indicated impacts to the bay at the mouth of the Fenholloway. The Florida Department of Environmental Protection conducted a use attainability study of the river, and has changed its classification from Industrial (Class V) to Recreation (Class III). The upper and lower Suwannee River basins, which receive a considerable quantity of groundwater spring flow, have good water quality. Other direct threats to the Suwannee include agricultural and silviculture runoff, septic tank leachate, and nitrates from dairy farms. Major tributaries of the Suwannee are generally of good quality, but are threatened by local pollution sources.

6.6.3 Levy County to Citrus County

The water bodies in this basin are typically clear, high transparency waters which are major recreational and economic attractions. For example, Crystal River is one of the south's most popular diving sites and a wintertime manatee refuge. Crystal River and Kings Bay are designated as "Outstanding Florida Waters." The rivers along the west coast of Florida from the Waccassa River to the Anclote River are mostly small, spring-fed streams and generally have good water quality. However, problems of high nutrient inputs and high bacteria counts exist for many of these rivers. High total coliform counts in the Weeki Wachee River resulted in the closure of Rodgers Park to swimming. The only large river basin in this stretch of the west coast, the Withlacoochee River, originates in Green

Swamp, but also has significant groundwater inflow. This basin generally has good water quality.

The spring-fed rivers in the northern basin generally have very good water quality. Crystal River has relatively high nutrient input and, because of its high transparency, it is subject to dense aquatic weed growths in the Kings Bay area. Historical sources of nutrient input are the Crystal River waste water treatment plant discharge, spring discharge, septic tanks and stormwater runoff. The City of Crystal River has completed construction of a new inland spray field and has eliminated the surface discharge from their wastewater treatment facilities. In addition, the Homosassa River has a history of bacterial problems of unknown source, possibly residential canals and septic tanks. Also, the Weeki Wachee has some bacteria problems. Rodgers Park on the river has been closed since summer 1989 because of high coliform bacteria counts. The source of the bacteria is unknown. The lower Pithlachascotee and Anclote have also had some bacteria problems, presumably from septic tank drainage and/or urban runoff.

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Chapter 7 - CONCEPTUAL MODEL

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7.1 Introduction

This conceptual model of the northeastern Gulf of Mexico (NEGOM) study area is an abstract, qualitative representation of ecosystem components and their interactions with one another. It is designed to help managers understand the system and facilitate the development of testable hypotheses. The NEGOM model identifies the major components of this ecosystem (physical, chemical, biota and human influences) and the processes which link the components (energy and material transfers, and physical and biological interactions). The model also provides a framework for information synthesis activities and identification of data gaps that may be addressed in future research activities.

This model is built upon the Tuscaloosa Trend regional model (Barry A. Vittor and Associates, 1985), since some of the continental shelf processes in these adjacent areas are governed by large-scale physical and geological processes common to both. Modification of the existing model followed the collection of data, synthesis of information, and identification of different subsystems in this NEGOM study area.

Previous sections of this report discussed the physical oceanographic meteorological, chemical biological and socioeconomic elements of the ecosystem.

While clean-cut boundaries separating elements of the NEGOM ecosystem may not exist, for purposes of this discussion two areas, separated by a transition zone, may be defined.

- The panhandle area west of Cape San Blas characterized by estuaries behind barrier islands, a narrow continental shelf dominated by DeSoto Canyon, significant fresh water input from the Mississippi River and other rivers flowing into the estuaries, and relatively large sediment load;
- Transition zone from Cape San Blas eastward to Ochlockonee Bay characterized by low-energy barrier islands, broadening shelf, river input from the Apalachicola River, and sediments of quartz and feldspar sands;
- Big Bend [Ochlockonee Bay to Citrus County] characterized as an open brackish estuary with a broad continental shelf, low sediment load, and carbonate outcrops. This is also referred to as the west Florida shelf.

This chapter proceeds with definition of model levels, model components and methods of representations; discussion of the three model levels; followed by a discussion of the major areas of the model where data are missing or inadequate.

7.2 System Definition

7.2.1 Model Levels

Three levels of the model were developed to accommodate the large range of spatial and temporal scales present in this ecosystem. Modeling the ecosystem on a large or regional scale requires information occurring over larger spatial and temporal scales than functions which operate on small scale or lower level ecosystem components. The Marine Ecosystem Analysis (MESA) approach (McLaughlin et al., 1975) was used to model the NEGOM. It consists of:

- Level 1 - a comprehensive ecosystem representation;
- Level 2 - a depiction of major processes (sedimentary, biogeochemical and biological); and
- Level 3 - specific ecological applications (pelagic trophic dynamics, benthic trophic dynamics, nekton life stages, and marsh-estuarine interactions).

Each level "rolls up" into the one above it, with Level 3 representing the finest scale (resolution) of ecological interactions, Level 2 representing intermediate-scale processes and Level 1 incorporating all of the processes describing the entire ecosystem.

The boundary of the NEGOM ecosystem model also takes into account the relationship between the study area and adjacent interrelated ecosystems. The NEGOM shelf exchanges materials and energy with the atmosphere, adjacent estuaries, terrestrial and freshwater ecosystems, adjacent upcoast and downcoast continental shelf ecosystems, and with the deep ocean located seaward of the shelf break (approximately the 200 m isobath). The choice of the 200 m isobath as the seaward boundary of the system is a matter of convenience. On the west Florida shelf this isobath marks a location where bottom slope changes abruptly. In the panhandle region this is not necessarily the case. Nonetheless, the 200 m isobath is used throughout this study as a convenient definition of the shelf break. The boundaries and exchange processes of the region are depicted in the map shown in Figure 7-1. Specifically, the NEGOM study area includes the inshore and slope waters of the Florida panhandle and the west Florida shelf south to Citrus County. The area is in bounded on the west by Mobile Bay (Tuscaloosa Trend study area) and on the south by the southern portion of the west Florida shelf.

The subdivision of the ecosystem into homogeneous units (discretization) was accomplished by determining where natural discontinuities in the system's structure and functioning exist (e.g., the shelf break). Physical factors or features, such as solar radiation, salinity, water layers, bathymetry and geomorphology define how discretization is carried out, since clear-cut boundaries do not often separate subsystems in the NEGOM. Discretization involved dividing the ecosystem along major (large or steep) habitat gradients, such as segmenting the water column on a pycnocline, if present.

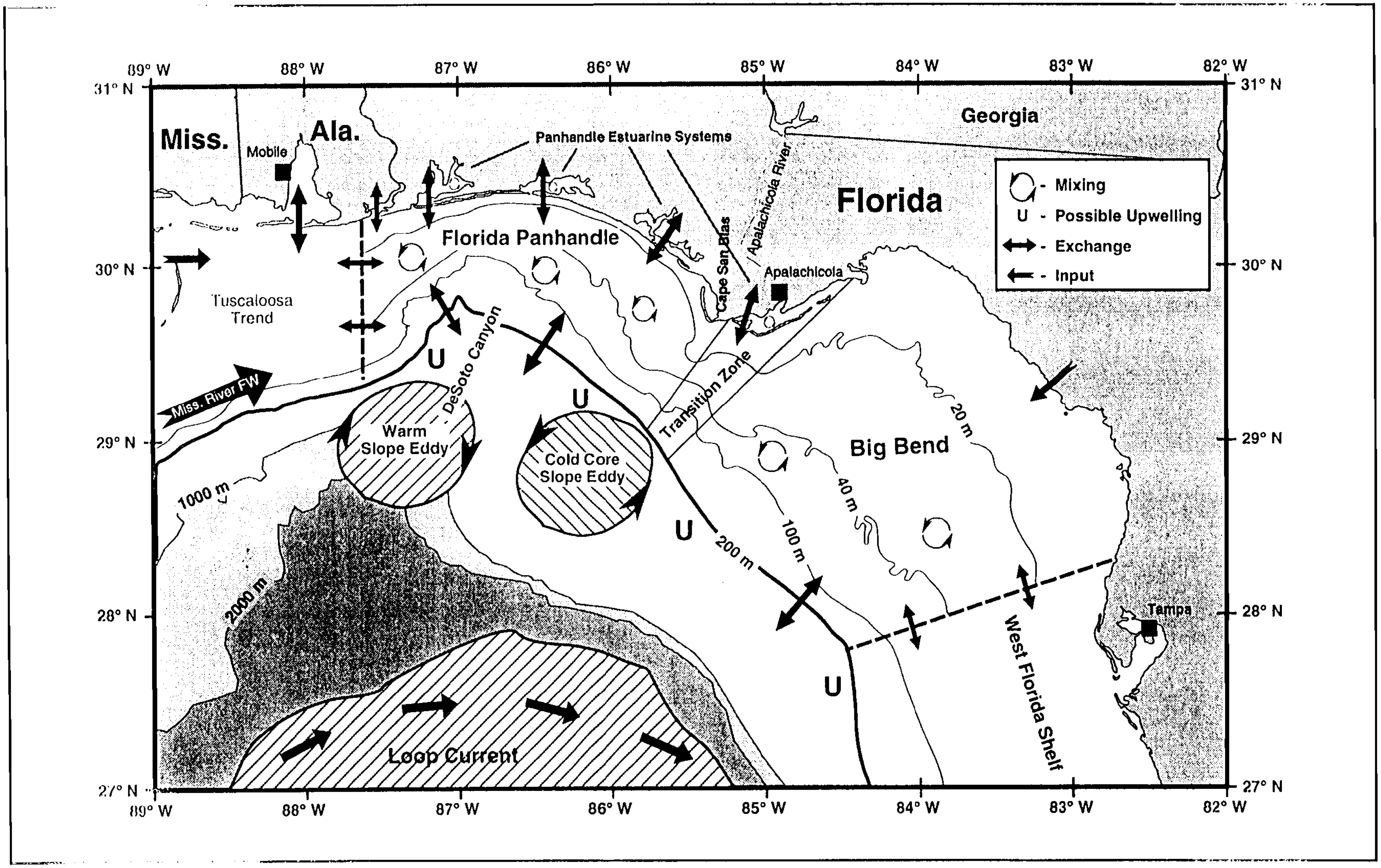


Figure 7-1. Map of the northeastern Gulf of Mexico showing the boundaries of the study area and ecosystem core regions. Major physical exchange paths and forcing mechanisms are indicated schematically.

Though input and output controlling factors were identified and modeled, they could not be calculated, because comprehensive quantitative data to support the movement of materials, energy or chemicals across the boundaries do not exist. Simple mass-balance models have not been provided to identify materials that may be imported into, accumulated or exported from the NEGOM study area.

7.2.2 Components and Model Representation

The NEGOM conceptual model comprises four components:

1) inputs and outputs;

2) compartments;

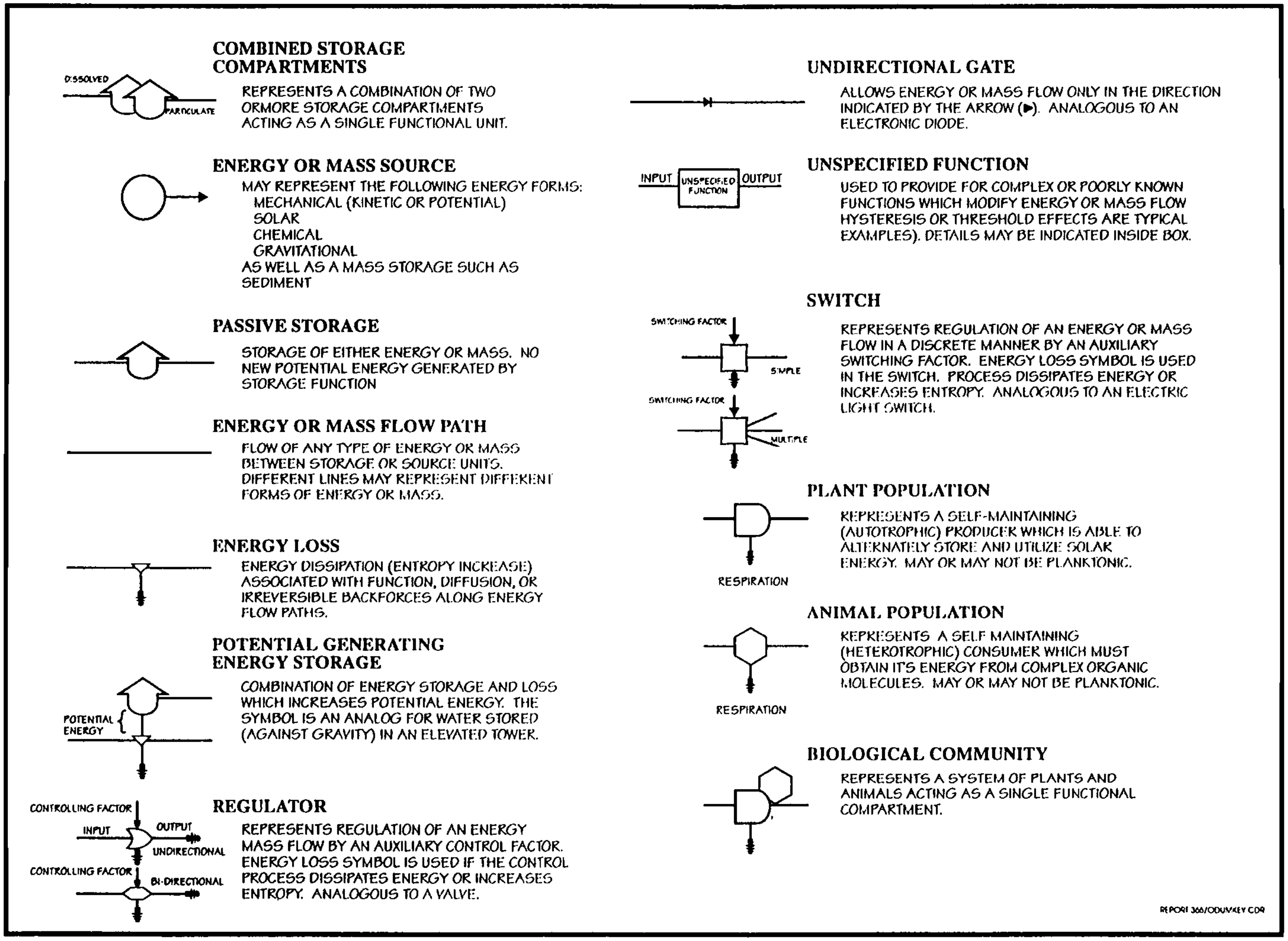
3) processes (physical, chemical, geological and ecological); and

4) regulators (salinity, temperature, advection, turbulence [non-steady flow having a very broad time and spatial scale] and others).

Inputs and outputs define relationships of the subject ecosystem to adjacent ecosystems. Compartments in the model are either biotic or abiotic functional entities. These compartments include producers, consumers, decomposers, particulate detritus, and organic and inorganic material dissolved in the water column. Functional relationships among these entities are represented by the flows connecting them, which are, in turn, controlled by environmental regulators. Ecosystem components are represented graphically by symbols developed for marine ecosystem modeling by Odum (1972). The flow "language" provides a way of representing basic structural and functional components of ecosystems so they can be related in a modeling context (Figure 7-2). Sources of energy and materials are represented by circles. Biotic compartments are defined by how they feed or fit into a trophic breakdown of the biological community. Producers (plants) are separated from consumers (animals). Abiotic storage compartments, such as particulate and dissolved material in the water column, and seafloor sediments, are represented by storage tanks. Energy or mass flow is represented by an arrow, defining the direction of flow. The flows represent physical, chemical, geological and ecological processes in the model and are controlled by regulators like advection and turbulence. The regulators are represented as unidirectional or bi-directional hollow arrows. The "grounding" symbol associated with the regulators represents energy loss associated with the work done by the flows.

7.3 System Level One – Comprehensive Model of the Northeastern Gulf of Mexico Ecosystems

The simplest conceptualization of the NEGOM ecosystems includes representations of both the physical and biogeochemical processes. As in Figure 7-3, the left-hand side presents the dominant physical oceanographic processes while the right-hand side shows important biogeochemical processes.



COMBINED STORAGE COMPARTMENTS

REPRESENTS A COMBINATION OF TWO ORMORE STORAGE COMPARTMENTS ACTING AS A SINGLE FUNCTIONAL UNIT.

ENERGY OR MASS SOURCE

MAY REPRESENT THE FOLLOWING ENERGY FORMS:
- MECHANICAL (KINETIC OR POTENTIAL)
- SOLAR
- CHEMICAL
- GRAVITATIONAL

AS WELL AS A MASS STORAGE SUCH AS SEDIMENT

PASSIVE STORAGE

STORAGE OF EITHER ENERGY OR MASS. NO NEW POTENTIAL ENERGY GENERATED BY STORAGE FUNCTION

ENERGY OR MASS FLOW PATH

FLOW OF ANY TYPE OF ENERGY OR MASS BETWEEN STORAGE OR SOURCE UNITS. DIFFERENT LINES MAY REPRESENT DIFFERENT FORMS OF ENERGY OR MASS.

ENERGY LOSS

ENERGY DISSIPATION (ENTROPY INCREASE) ASSOCIATED WITH FUNCTION, DIFFUSION, OR IRREVERSIBLE BACKFORCES ALONG ENERGY FLOW PATHS.

POTENTIAL GENERATING ENERGY STORAGE

COMBINATION OF ENERGY STORAGE AND LOSS WHICH INCREASES POTENTIAL ENERGY. THE SYMBOL IS AN ANALOG FOR WATER STORED (AGAINST GRAVITY) IN AN ELEVATED TOWER.

REGULATOR

REPRESENTS REGULATION OF AN ENERGY MASS FLOW BY AN AUXILIARY CONTROL FACTOR. ENERGY LOSS SYMBOL IS USED IF THE CONTROL PROCESS DISSIPATES ENERGY OR INCREASES ENTROPY. ANALOGOUS TO A VALVE.

UNDIRECTIONAL GATE

ALLOWS ENERGY OR MASS FLOW ONLY IN THE DIRECTION INDICATED BY THE ARROW (▶). ANALOGOUS TO AN ELECTRONIC DIODE.

UNSPECIFIED FUNCTION

USED TO PROVIDE FOR COMPLEX OR POORLY KNOWN FUNCTIONS WHICH MODIFY ENERGY OR MASS FLOW HYSTERESIS OR THRESHOLD EFFECTS ARE TYPICAL EXAMPLES). DETAILS MAY BE INDICATED INSIDE BOX.

SWITCH

REPRESENTS REGULATION OF AN ENERGY OR MASS FLOW IN A DISCRETE MANNER BY AN AUXILIARY SWITCHING FACTOR. ENERGY LOSS SYMBOL IS USED IN THE SWITCH. PROCESS DISSIPATES ENERGY OR INCREASES ENTROPY. ANALOGOUS TO AN ELECTRIC LIGHT SWITCH.

PLANT POPULATION

REPRESENTS A SELF-MAINTAINING (AUTOTROPHIC) PRODUCER WHICH IS ABLE TO ALTERNATELY STORE AND UTILIZE SOLAR ENERGY. MAY OR MAY NOT BE PLANKTONIC.

ANIMAL POPULATION

REPRESENTS A SELF MAINTAINING (HETEROTROPHIC) CONSUMER WHICH MUST OBTAIN IT'S ENERGY FROM COMPLEX ORGANIC MOLECULES. MAY OR MAY NOT BE PLANKTONIC.

BIOLOGICAL COMMUNITY

REPRESENTS A SYSTEM OF PLANTS AND ANIMALS ACTING AS A SINGLE FUNCTIONAL COMPARTMENT.

Figure 7-2. Odum energy-mass language symbols used in the northeastern Gulf of Mexico ecosystem conceptualization.

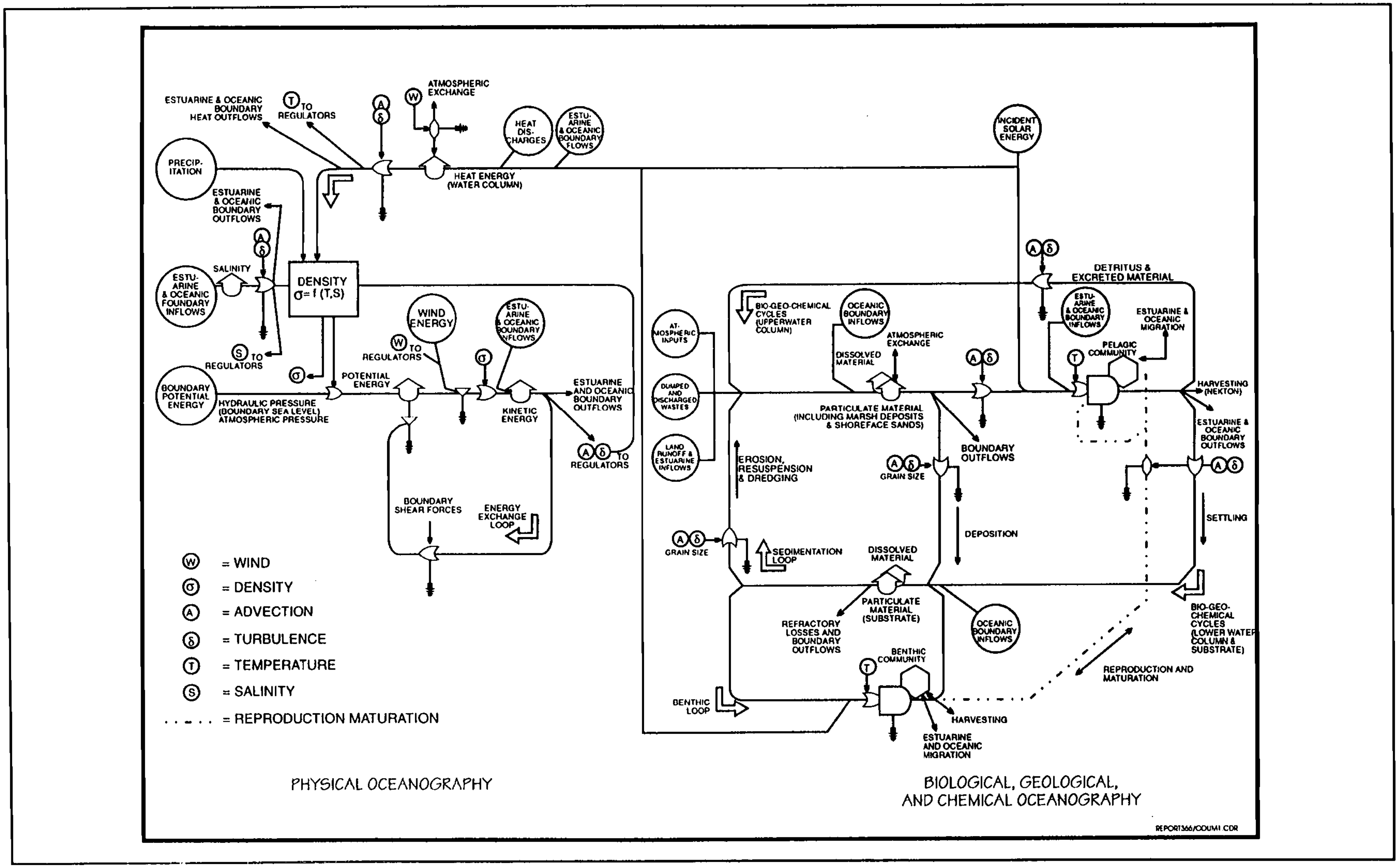


Figure 7-3. A comprehensive conceptual representation of the northeastern Gulf of Mexico ecosystem (modified from McLaughlin et al., 1975).

7.3.1 Physical Processes

As in the conceptual model developed for the adjacent Tuscaloosa Trend study area, physical processes in the NEGOM study area regulate many of the biogeochemical processes. Current advection (mean transport) and dispersion (mixing) provide the primary means by which biogeochemical components are transported and dispersed in the ecosystem, while water temperature and photoperiod regulate the rates of biological and geochemical processes (Figure 7-4). Temperature also influences advection and turbulence through its effect on density and stratification of the water column.

Physical processes in the NEGOM are dependent on energy exchanged across atmospheric and oceanic boundaries. Potential and kinetic energy flowing across the estuarine and oceanic boundaries of the study area are associated with tidal forces, winds, and riverine inputs. All of these are especially important for the estuaries and nearshore areas where mixing of brackish water by tidal and wind-driven currents generate pycnoclines (e.g., density gradients), and produce onshore-offshore, two-layer flow. Tidal currents and discharges of brackish water from small rivers and streams bordering the estuaries may form transient coastal fronts. Proximity of the Mississippi River inflow provides the largest addition of freshwater in the region, which can be entrained by the Loop Current in the western portion of the study area. Potential energy is also introduced to the ecosystem by way of barometric and gravitational pressure fields (baroclinic forcing and gravity flow). The combination of local and regional processes determines advection and turbulence, which in turn regulate the inputs and outputs of the ecosystem as well as the materials and energy within it

On the west Florida shelf portion of the study area, long-term circulation patterns of advective transport are determined by ocean boundary conditions and seasonal cross-shelf density gradients. Transient west Florida shelf currents driven by wind-forced shelf waves also contribute to overall advective transport, as do such episodic events as hurricanes and storms. In the western section of the NEGOM study area, Loop Current waters in the form of frontal eddies and filaments may intrude onto the shelf in the DeSoto Canyon region and other areas along the shelf break.

Dispersion in the study area is dominated by tide- and wind-induced mixing and storm events. Mixing in the upper layer of the water column is caused by wind stress while internal waves can provide mixing forces throughout the water column. Mixing between shelf waters and Gulf of Mexico waters results from Loop Current and eddy interactions with the shelf, storms, and hurricane events.

In the conceptual model of physical oceanic processes, heat energy is transported across estuarine and oceanic boundaries by advective and turbulent flows. Boundary conditions also exist at the air-sea interface where solar radiation seasonally warms the ocean's surface, and sea surface temperatures in turn warm the air, contributing to the generation of winter storm fronts in the NEGOM. Heat energy from the atmosphere can also affect

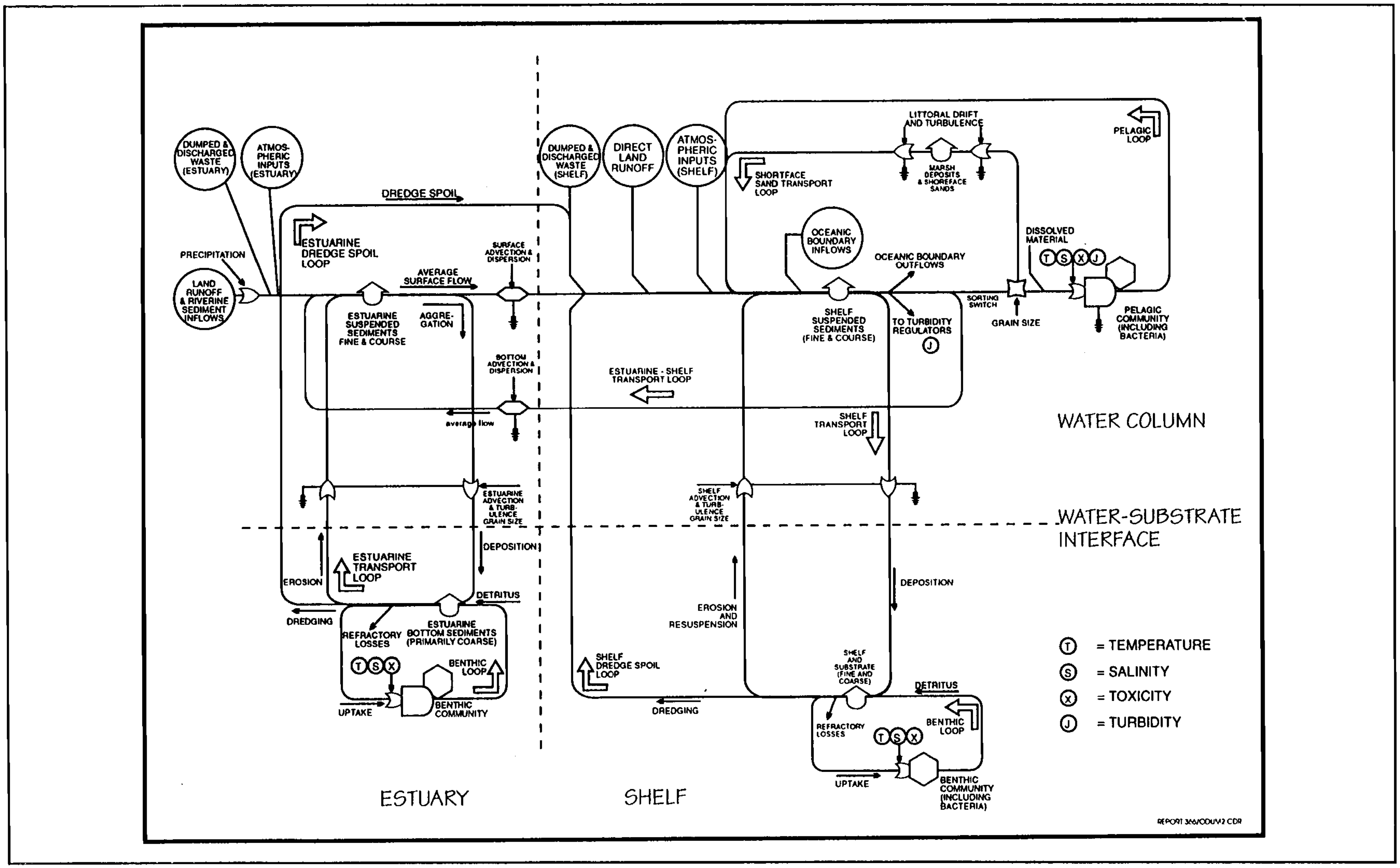


Figure 7-4. A conceptual representation of sedimentation processes in the region west of Cape San Blas in the northeastern Gulf of Mexico ecosystem. (from McLaughlin et al., 1975).

the structure of the water column by warming surface waters and creating a less-dense layer over a cooler, heavier layer.

Density differences in the water column, generated by heating/cooling and fresh water inputs, represent important regulators of flow patterns in the NEGOM. Water in the NEGOM is transported across estuarine and oceanic boundaries by both riverine discharge (fresh water) and incursions of the Loop Current (saline water). Salinity is influenced by seasonal precipitation and evaporation patterns. Salinity and temperature determine the density of a water mass and regulate advection and turbulent transport of materials and energy.

The energy exchange loop shown in the conceptual model represents the endless cycle of kinetic-to-potential-to-kinetic energy conversion, occurring in NEGOM. Kinetic energy moves water masses around and through the NEGOM study area by advection and turbulence, while the loop itself is regulated by the distribution of water mass densities.

7.3.2 Biogeochemical Processes

The right-hand side of the comprehensive model depicts the biological, chemical and geological processes in the NEGOM study area (Figure 7-4). The regulators of the processes are those previously described in Section 7.3.1. As in the Tuscaloosa Trend, the NEGOM model shows a pelagic and a benthic habitat. The separation and unique identity of each depends on such physical phenomena as density gradients. During mixing events, when wind mixing produces a homogeneous water column, pelagic and benthic functioning may be similar and the division between them poorly defined.

Both pelagic and benthic habitat types contain biological communities, dissolved chemicals and particulate sediment load. These habitats receive input from oceanic boundary inflow, dumping and discharging of wastes, land runoff, estuaries and the atmosphere. Both communities utilize the dissolved and particulate loads of the water column, which involve organic carbon, oxygen, inorganic nutrients (nitrogen, phosphorous and silica), toxicants (trace metals, hydrocarbons and pesticides) and trace organics.

Both habitat types exchange materials through the following processes: a sediment deposition or resuspension loop, detrital rain from the pelagic to the benthic habitat, movement of animals (fishes, portunid crabs, shrimp) from the water column to the bottom, and transport of living material from one habitat to the other during the reproduction and maturation processes. The sedimentation loop, which is routinely regulated by turbulence and advective transport in the western section of the NEGOM study area, does not function substantially in the Big Bend area, except when storm waves and surge erode marshland and estuarine deposits.

Both benthic and pelagic communities in the NEGOM study area contain primary production components, due to the availability of light for photosynthesis and solid substrate for attachment of macrophytes.

Components of both benthic and pelagic communities are "outputted" through harvesting by man or exported to estuarine or oceanic boundary outflows and migrations. Dissolved and particulate materials are also lost to the system through ocean boundary exchanges or are buried by sediment accretion within the system. Volatile materials, such as dissolved gasses and the lighter fractions of hydrocarbons, are also lost to the system through exchanges with the atmosphere.

7.4 System Level Two – Representation of Biochemical Processes

Level 2 representations of the biological processes within the NEGOM study area include separate models for sedimentation, chemical and ecological cycles. The sedimentation processes at work in the NEGOM are presented for both estuarine and shelf environments in two diagrams, while those depicting chemical processes are divided into three major categories (carbon-oxygen, nitrogen and a prototype toxicant). The ecological processes are illustrated by a generalized representation in the second level.

7.4.1 Sedimentation Processes

Dynamics of particulate material movement within the NEGOM study area are represented in Figures 7-4 and 7-5. Within the estuarine and shelf domains, the benthic and water column subsystems are separated by the sediment-water interface. The representations contain four to five sediment storages: a pair of suspended sediment and deposited sediment storages in each of the domains and a marsh and shorefast sand deposit in the shelf domain. Water columns in both domains receive inputs from land runoff and rivers, dumped and discharged wastes, ocean boundary inflows and the atmosphere. Suspended material export occurs through estuarine and oceanic boundary outflows.

Sedimentation processes within the western half of the NEGOM, with its many small rivers and shallow water embayments, are portrayed in Figure 7-4, while the processes within the Big Bend estuary are depicted in Figure 7-5. The difference between the two regions is reflected in the feedback loops, which represent the sediment transport processes in the model. The estuaries to the west of Cape San Blas depend on the shoreface sand transport loop to maintain barrier islands. The Big Bend estuary does not show substantial evidence of this component of sand transport. Instead, its banks are composed of marsh deposits which are not exposed to substantial littoral drift or erosion except during severe storms or hurricanes.

Other feedback loops involve erosion and deposition of sediments under non-storm conditions and are regulated by advection and turbulence, sediment grain size and bottom topography. They include the dredge material disposal loops and benthic loops in both estuarine and shelf domains, as well as individual estuarine and shelf transport loops and the estuarine-shelf transport loop. The estuarine-shelf loop linking exchange of sediment across a common boundary is regulated by advective and turbulent transport generated by tidal forces and local winds. Estuarine and shelf dredge material transport loops incorporate dredging material from both the estuaries and their entrances and disposal of this material in the water column and on the shelf seafloor. A majority of dredged material enters the shelf transportation loop through deposition, while turbulence and advection may transport a small fraction off-site.

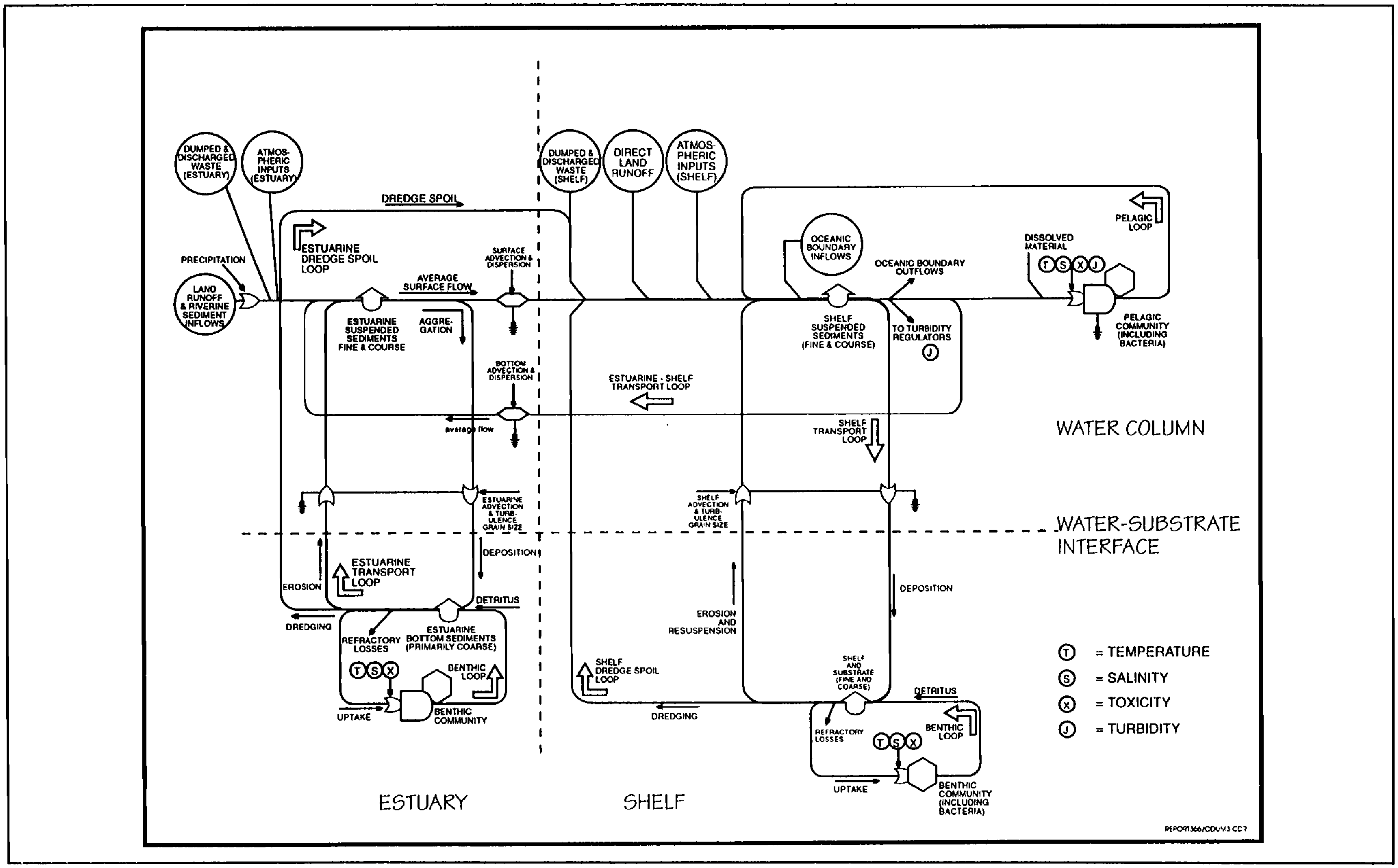


Figure 7-5. A conceptual representation of sedimentation processes in the Big Bend region of the northeastern Gulf of Mexico ecosystem. (from McLaughlin et al., 1975).

In the shelf and estuarine domains, both pelagic and benthic loops absorb and release particulate organic and inorganic materials. Most suspended particulate matter is transported to the shelf seafloor in the shelf transport loop or to estuaries through the estuarine-shelf loop or across oceanic boundaries in the pelagic loop. The pelagic loop contains shoreface sand and marsh deposit transport loops adjacent to the barrier island estuaries. The shoreface sand and marsh deposit loop is most active during storm conditions, when barrier island dunes can be eroded and the seafloor sediments of protected estuaries are resuspended and advected into shelf waters. The shoreface and marsh transport loop is regulated by littoral drift and turbulence driven by wave energy and storm surge.

7.4.2 Chemical Processes

Representations of chemical processes within the NEGOM study area include a well-mixed water column, and a two-layer water column with a pycnocline separating the warmer, less-dense upper layer from the cooler, denser lower layer. Within the estuaries, water column structure is also influenced by freshwater input from rivers. During the spring and summer wet seasons, stratified conditions predominate in the estuaries west of Cape San Blas. During the drier seasons the water column is well mixed in the estuaries, simplifying the model to a single layer. In the shelf domain solar warming creates density differences in the water column by heating well-mixed surface waters, effectively isolating the cooler, denser waters and their retinue of chemical constituents from exchange with the atmosphere. Solar heating and strong theroclines are of perhaps even greater importance in estuaries with respect to biological function. Even in shallow area, diffusion of oxygen through the thermocline may not be rapid enough to prevent near bottom hypoxia.

7.4.3 Carbon-Oxygen Cycling

The three storage compartments present in both single-layer and two-layer models of carbon-oxygen cycling are organic carbon, oxidizable inorganic material and dissolved oxygen (Figures 7-6 and 7-7). In both representations, dissolved oxygen is replenished from the atmosphere-water interface by wind mixing, by photosynthesis in either the phytoplankton or benthic epiflora, and by inputs across ocean boundaries.

Throughout the water column, dissolved oxygen is taken up during both biological respiration and organic and inorganic oxidation, while organic carbon resulting from excretion, egestion and death can, depending on size, fall to the bottom and be recycled there; be recycled in the water column and fall through the pycnocline; or be transported across oceanic boundaries. In the shelf domain, net flux of organic carbon is downward across the pycnocline to the detritus-based benthic food web. The presence of a strong pycnocline, combined with slow advection and much reduced vertical and horizontal mixing (dispersion), can adversely affect dissolved oxygen concentrations in the lower water column. Organic material may "rain" from the pelagic community, especially in embayments, in such quantity that the benthic community, which is stimulated to metabolize the detrital food source, depletes the dissolved oxygen levels to hypoxic conditions. Hypoxia at the water-seafloor interface would create anaerobic conditions in the sediments, which are not conducive to the survival of

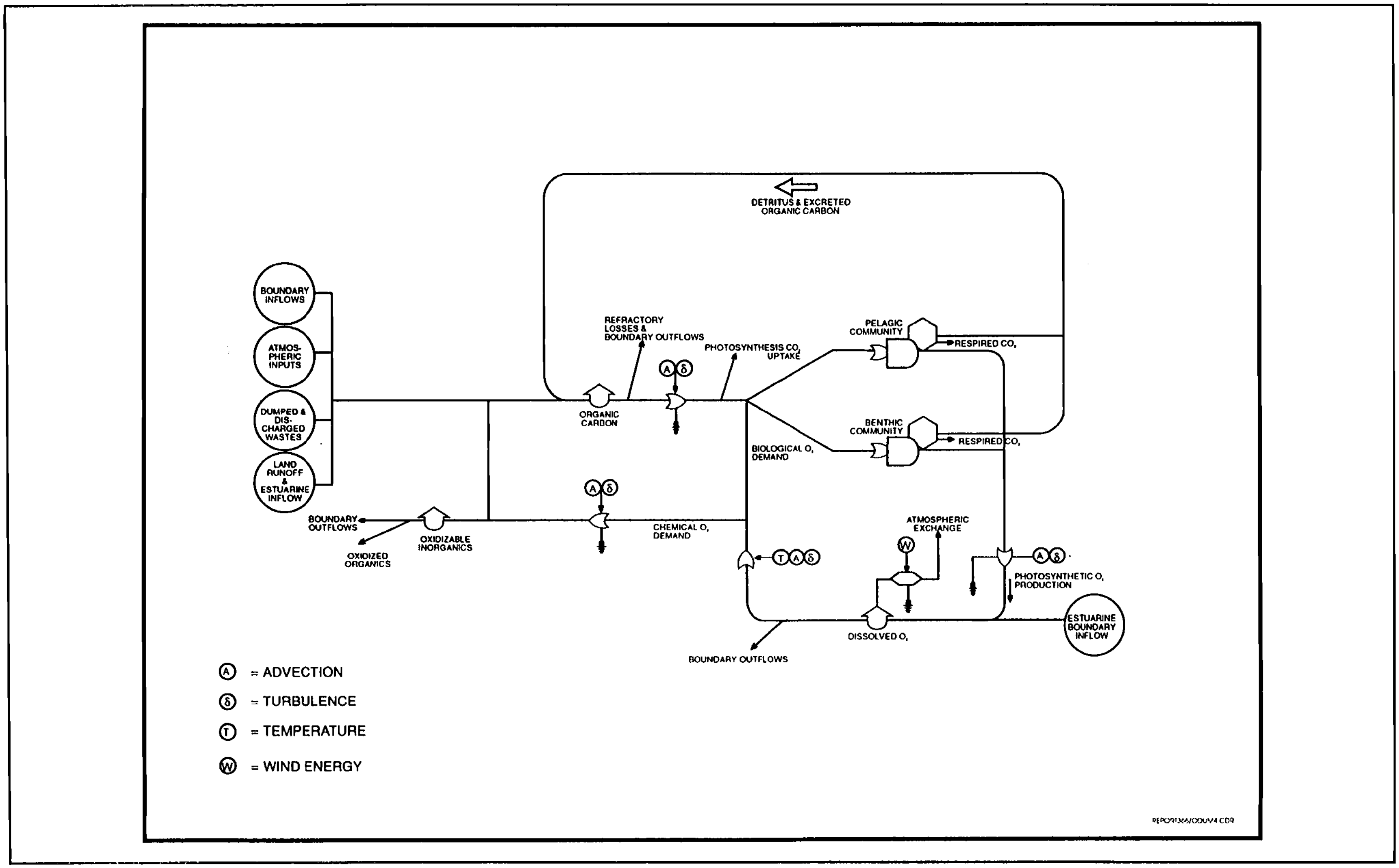


Figure 7-6. A conceptual representation of carbon-oxygen cycling for well-mixed water column conditions in the northeastern Gulf of Mexico ecosystem (from McLaughlin et al., 1975).

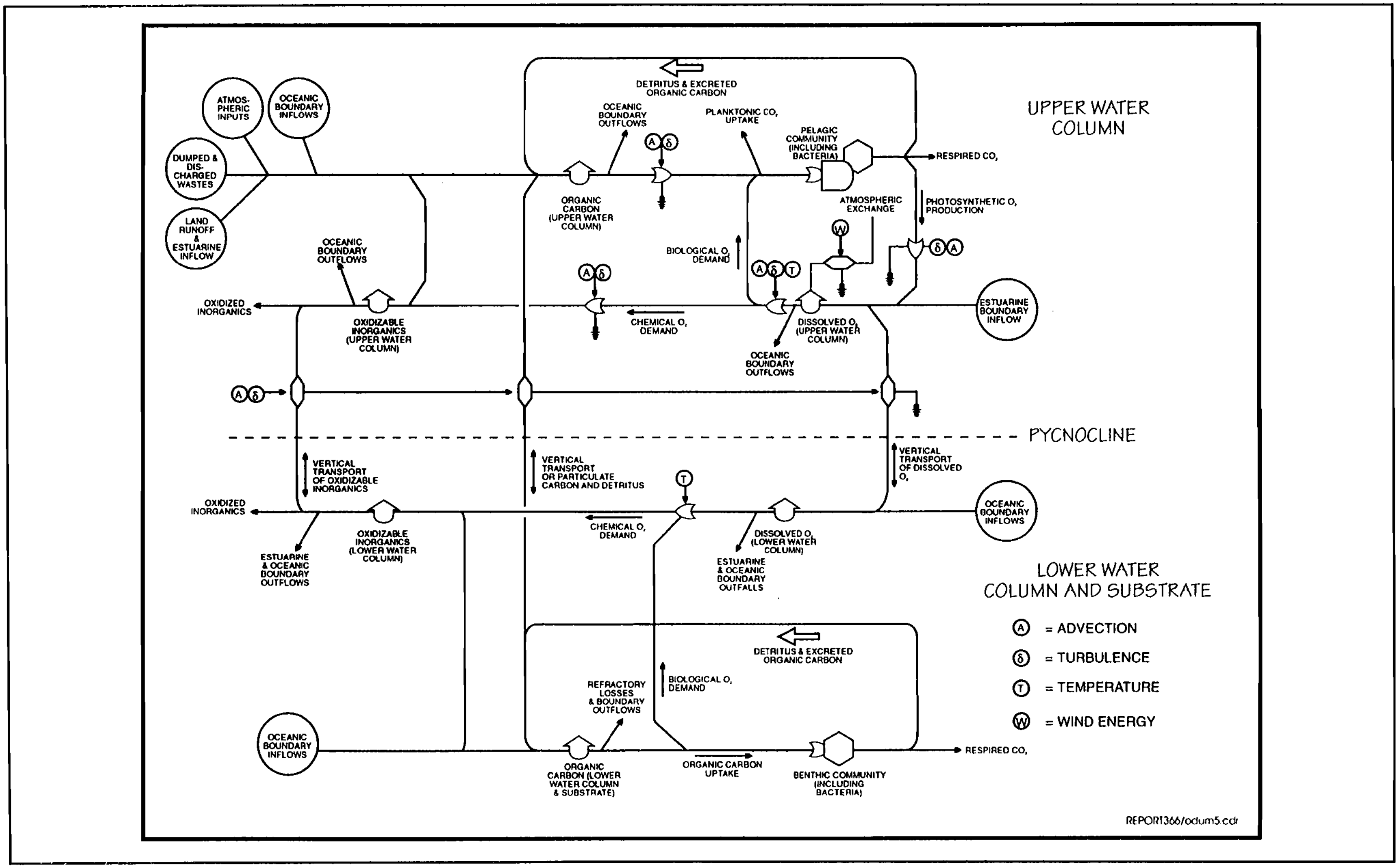


Figure 7-7. A conceptual representation of carbon-oxygen cycling for stratified water column conditions in the northeastern Gulf of Mexico ecosystem (from McLaughlin et al., 1975).

aerobes (virtually all benthic macrofauna and epifauna). Note, however, that many benthic animals have mechanisms (siphons, etc.) to obtain oxygen above a thin hypoxic or anoxic layer at the sediment water interface while some nematodes and meiofauna/microfauna are facultative anerobes. Sessile and motile benthic fauna, with the notable exception of the blue crab, tend to stay in the area affected and die, further increasing the detrital mass. Anaerobic conditions would change the chemical state to a reducing environment, releasing phosphorous from the sediments. Once aerobic conditions returned to the lower water column, the released phosphorous would restimulate primary production.

7.4.4 Nitrogen Cycling

Depictions of nitrogen cycling have two storage compartments, the particulate and dissolved nitrogen pools. These represent the processes in the single-layer and two-layer systems of the estuarine and shelf domains, respectively (Figures 7-8 and 7-9). These representations do not show ammonia, nitrite, nitrate or the dissolved organic species. Instead, both dissolved and particulate nitrogen are exchanged between the biological communities and the water column. Primary producers absorb dissolved nitrogen from the water column, while detritivores filter nitrogenous organic materials. A major source of nitrogen for benthic animals is ingestion of microbial biomass by direct and indirect deposit feeders. Both dissolved and particulate nitrogen are cycled back to the water column by biological communities.

7.4.5 Toxicant Cycling

Two storage compartments, ambient toxicant and biomass toxicant pools, are rendered for the single-layer and two-layer models of the estuarine and shelf domains (Figures 7-10 and 7-11). Representations include sources, transport mechanisms and fluxes of a typical prototype toxicant, as well as anthropogenic system inputs. Sources of toxicants are boundary inflows, toxic algal metabolites, atmospheric inputs, dumped and discharged wastes, land runoff, and riverine input. The relative importance of inputs will vary with the contaminant and environment. On the west Florida shelf, transport of atmospheric contaminants across the air-water interface could represent a major flux of trace metals, while in the estuarine domain the same input would be minor except in heavily industrialized regions where sources are close to the estuary (Pensacola Bay, for example) in comparison to riverine input and discharged wastes.

Chemical characteristics of contaminants are important in determining transport, fate and residence times in the ecosystem. The chemical state of a toxicant depends on its affinity for the surface of particles as well as the oxidation-reduction state of the medium, which determines the path that a toxicant cycles through the system. Trace salinities (<2ppt) and pH (from acid rivers to basic estuaries) can significantly alter solubility and ionic states of chemicals. Those with strong sorption characteristics will be accumulated by sediments, while dissolved forms are likely to be transported out of the ecosystem by turbulent and advective forces. The oxidation-reduction status of the water column and sediment also determines the availability of toxicants, as changes in the redox potential may

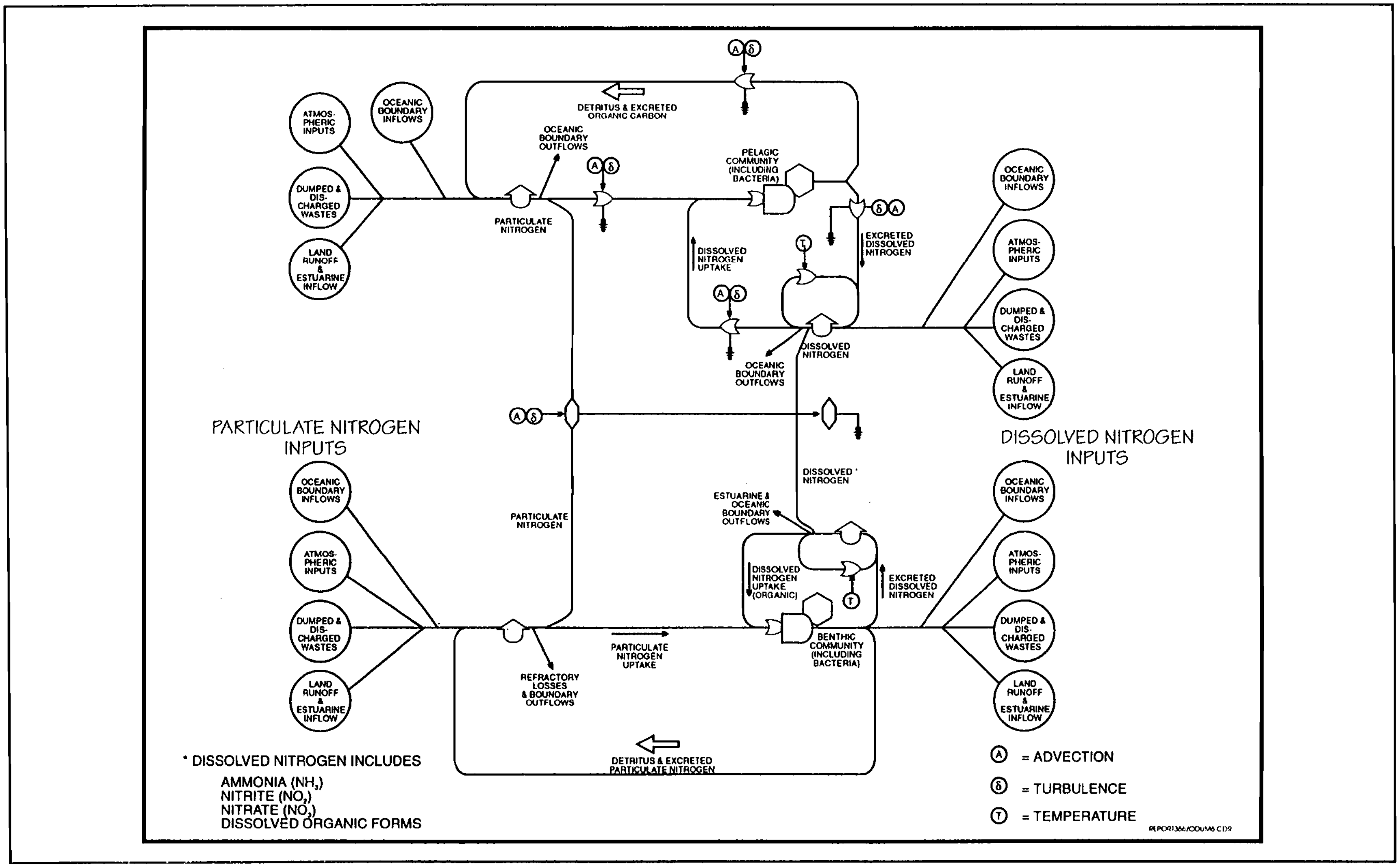


Figure 7-8. A conceptual representation of nitrogen cycling for well-mixed water column conditions in the northeastern Gulf of Mexico ecosystem. (from McLaughlin et al., 1975).

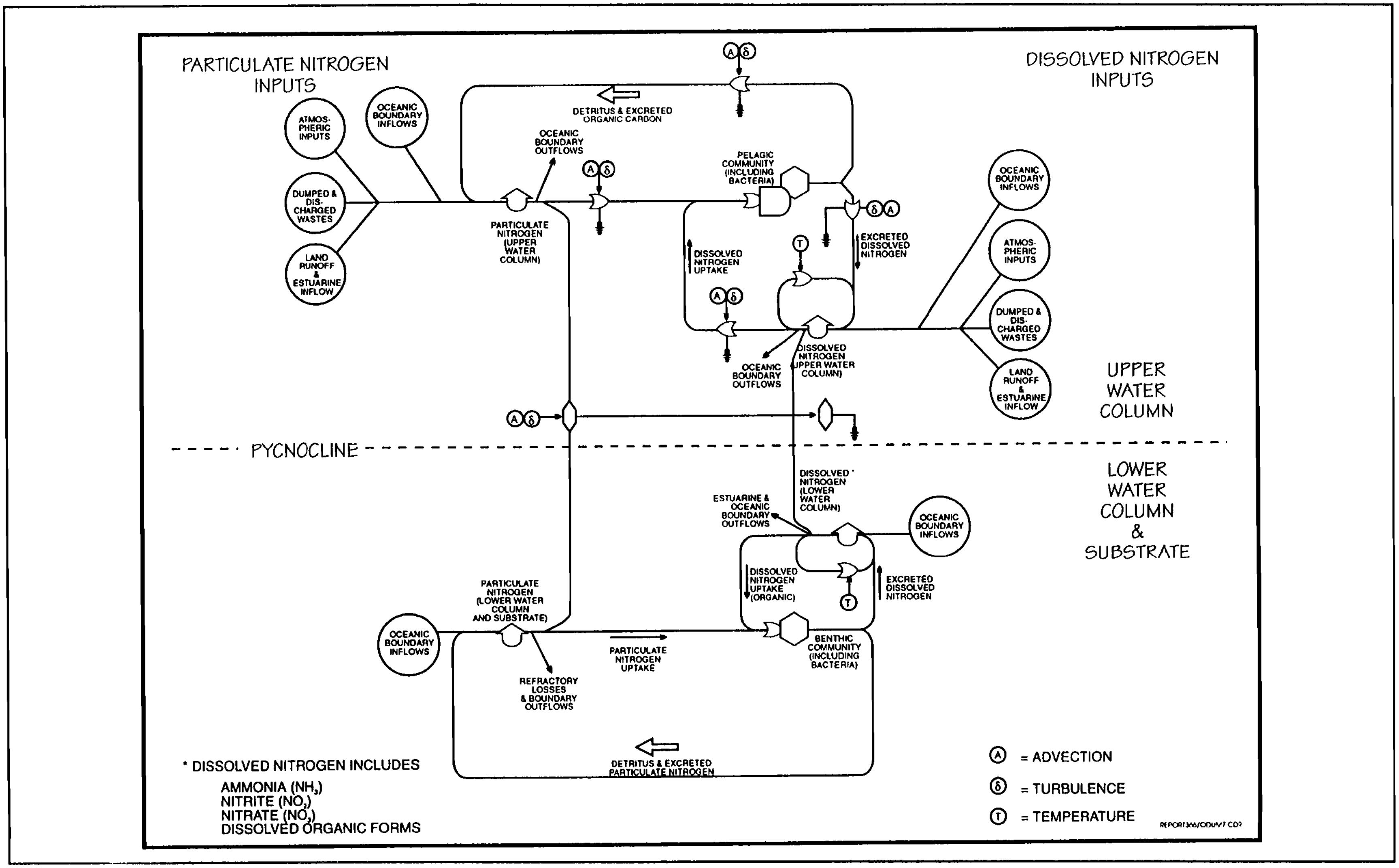


Figure 7-9. A conceptual representation of nitrogen cycling for stratified water column conditions in the northeastern Gulf of Mexico ecosystem. (from McLaughlin et al., 1975).

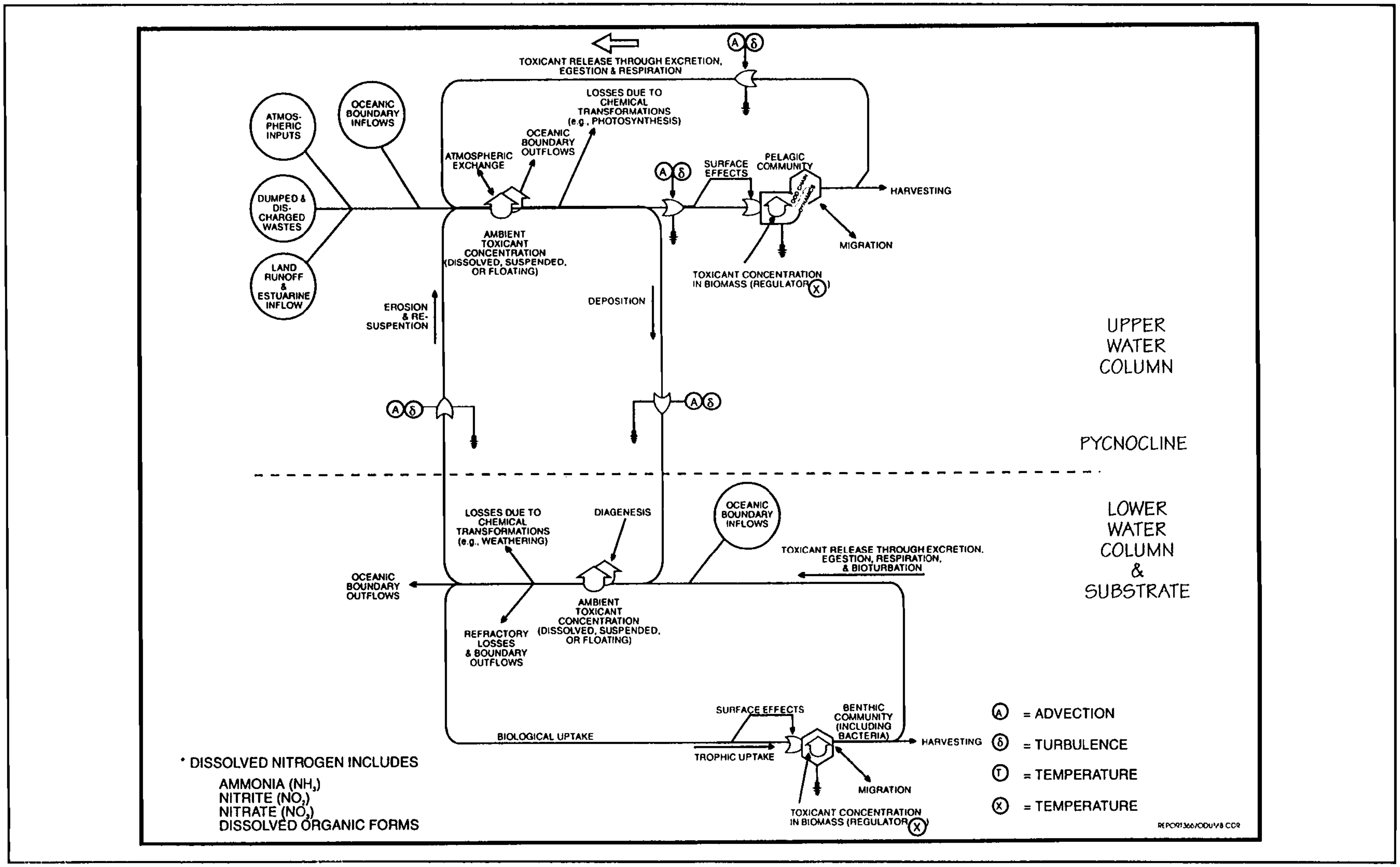


Figure 7-10. A conceptual representation of toxicant cycling for well-mixed water column conditions in the northeastern Gulf of Mexico ecosystem (modified from McLaughlin et al., 1975).

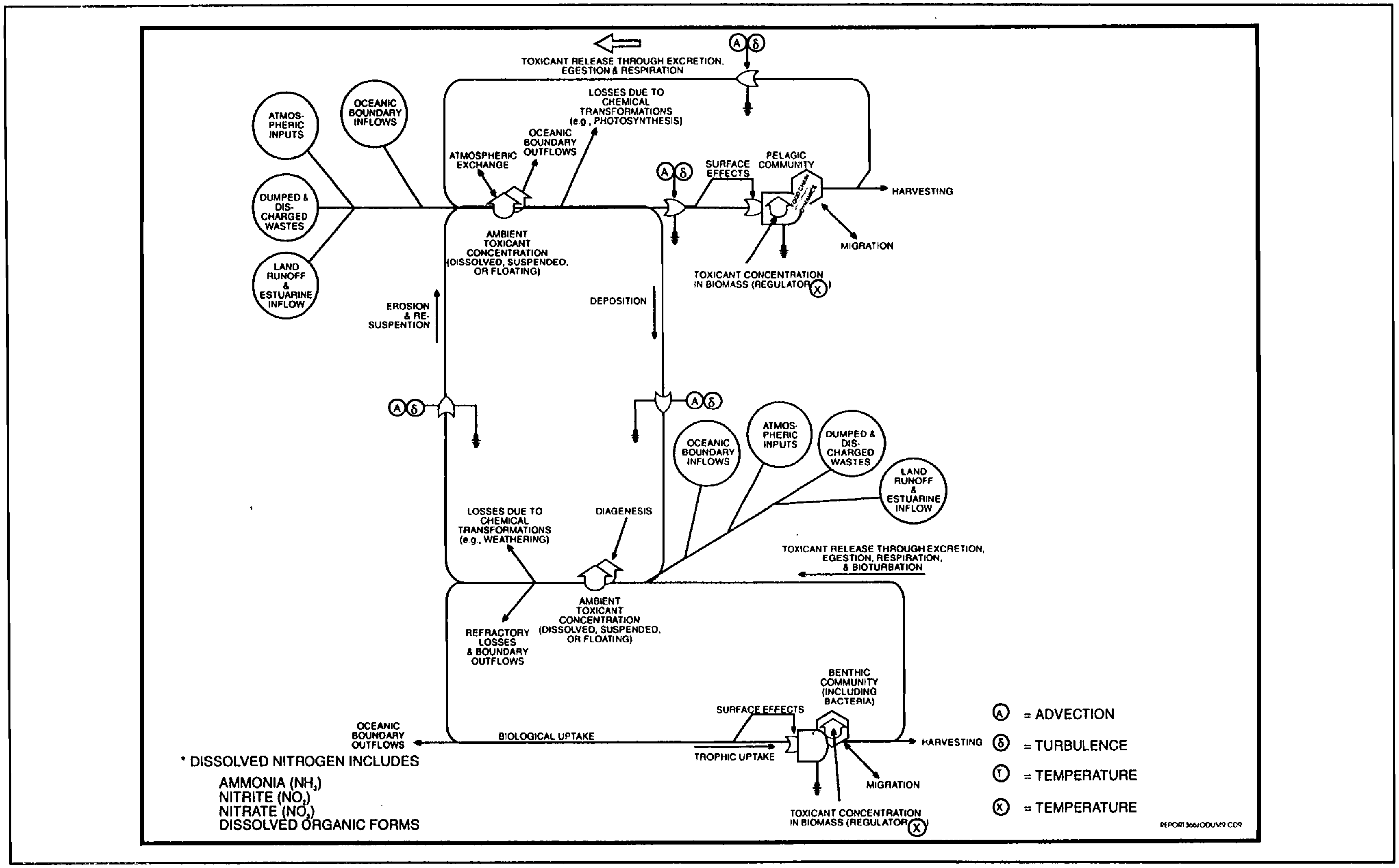


Figure 7-11. A conceptual representation of toxicant cycling for stratified water column conditions in the northeastern Gulf of Mexico ecosystem (modified from McLaughlin et al., 1975)

release those previously bound to particles in the water column ant sediments. The presence or absence of plants (algae and macrophytes) may have a large influence on what contaminants are found in the water column and sediments.

Toxicants find their way into living organisms through ingestion of food and respiration. They are returned to the water column and sediments through the metabolic processes of excretion, egestion and death. Toxic materials can become concentrated in consumers through food chain biomagnification. In the two-layer model (Figure 7-11) death or egestion of planktonic organisms make concentrated toxicants available to the benthic community once carcasses and fecal pellets fall through the pycnocline and are consumed by the detrital-based food web. In the single-layer model (Figure 7-10) of toxicant cycling, benthic filter feeders in the estuaries accumulate above ambient concentrations of toxic materials from their planktonic food sources and through sorption of dissolved materials.

Turbulence, diagenic reactions and redox state are among the processes determining the fate of adsorbed toxicants in the sediments. Storms may resuspend contaminated sediments and homogenize the distribution of toxicants throughout the water column and the sediment profile, making previously buried toxicants available to both plankton and benthic communities. In dynamic benthic communities, reworking of the sediments during feeding activities may mix the upper 10-20 centimeters. Both of these mixing mechanisms would tend to keep toxicants in surficial sediments where advective forces may disperse them to previously uncontaminated (pristine) areas. Toxicants are also lost from the ecosystem by transport across oceanic boundaries and across the air-water interface. Within the ecosystem, toxicants may degrade to non-toxic states through chemical transformation in biologically mediated water columns and sediments.

7.4.6 Ecological Processes

The ecological conceptualizations include both a single-layer model and a two-layer model (Figures 7-12 and 7-13). Light, turbulence and density stratification of the water column are critical factors in determining the distribution of primary productivity. Fluxes across the pycnocline are accomplished through settling of organic material; dispersal of eggs, ichthyoplankton and meroplankton; and migration of juveniles including the developmental migrations of meroplankters that make a habitat shift from the water column to benthic habitats. In the following section, several Level 3 representations of major ecological patterns are developed from the generalized models.

7.5 System Level Three - Ecological Process Representation

Detailed descriptions of trophic processes of pelagic and benthic subsystems in the NEGOM ecosystem are discussed in Chapter 5. In both conceptualizations, biological communities have been separated into several entities (Figures 7-14 and 7-15). A species may occupy several trophic levels during its lifetime as feeding relationships change with size and stage of development. Similarly, individuals such as members of the benthic community may occupy different trophic compartments based on their

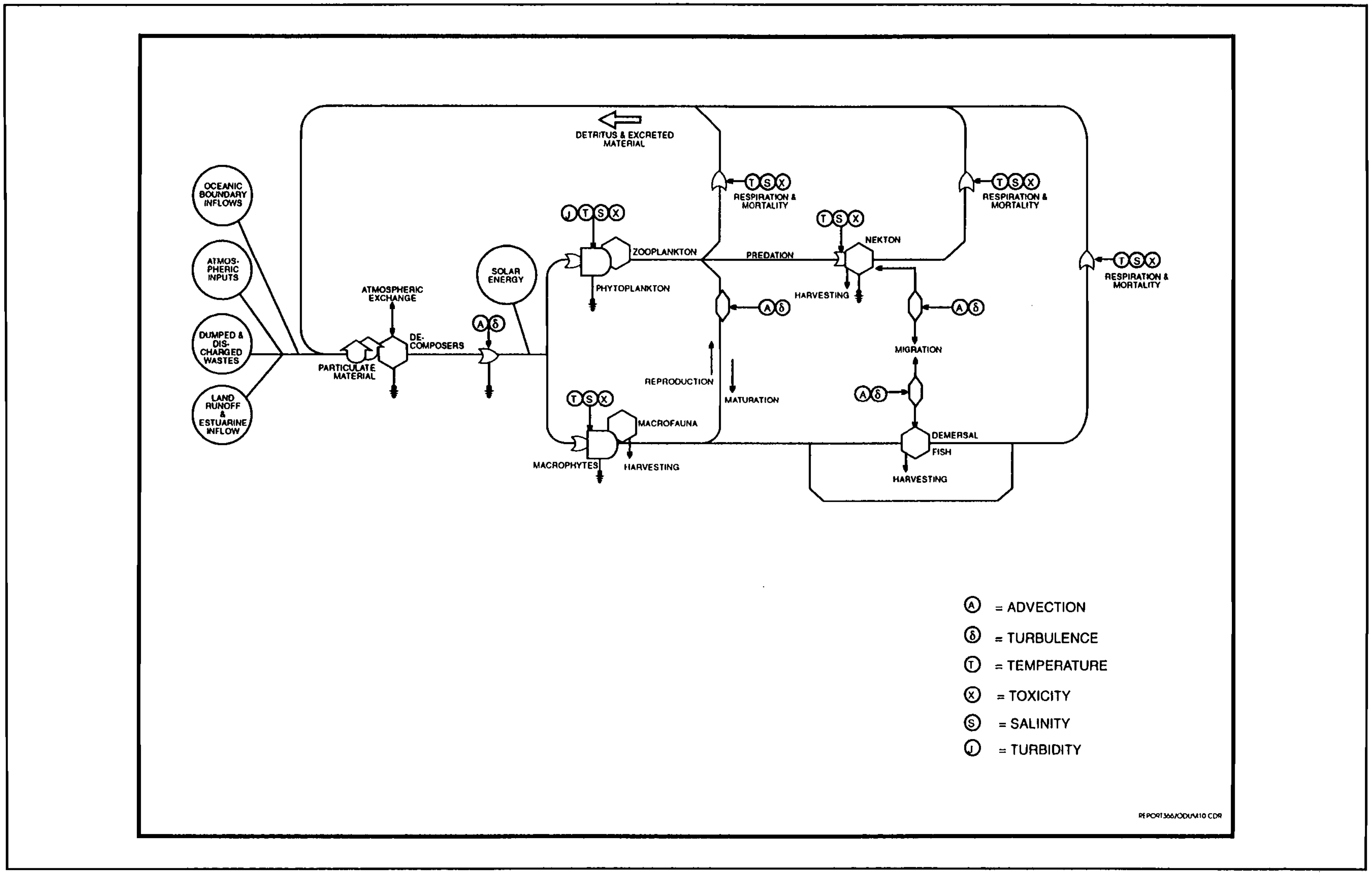


Figure 7-12. A conceptual representation of ecological processes for well-mixed water column conditions in the northeastern Gulf of Mexico ecosystem (from McLaughlin et al., 1975).

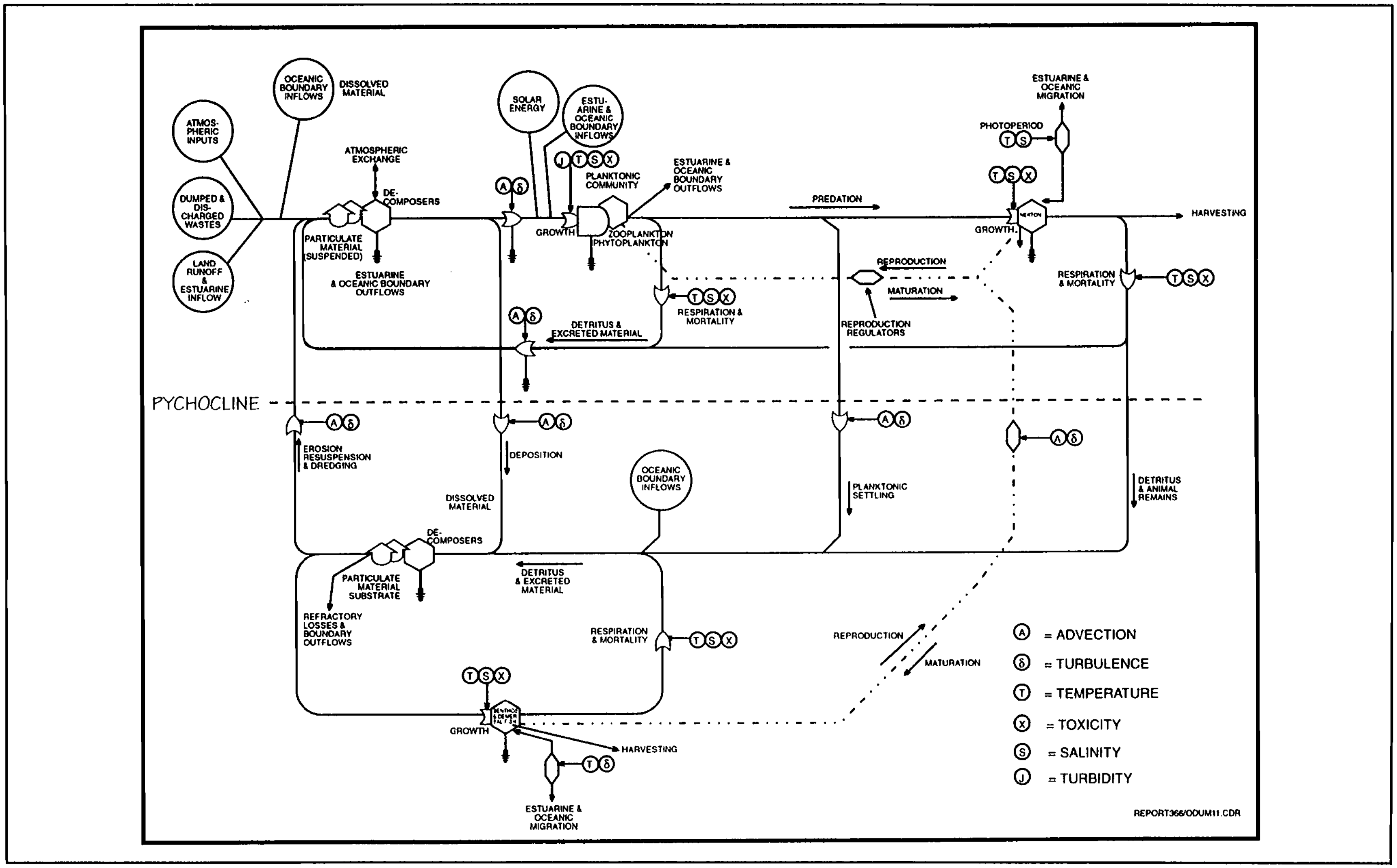


Figure 7-13. A conceptual representation of ecological processes for stratified water column conditions in the northeastern Gulf of Mexico ecosystem (from McLaughlin et al., 1975).

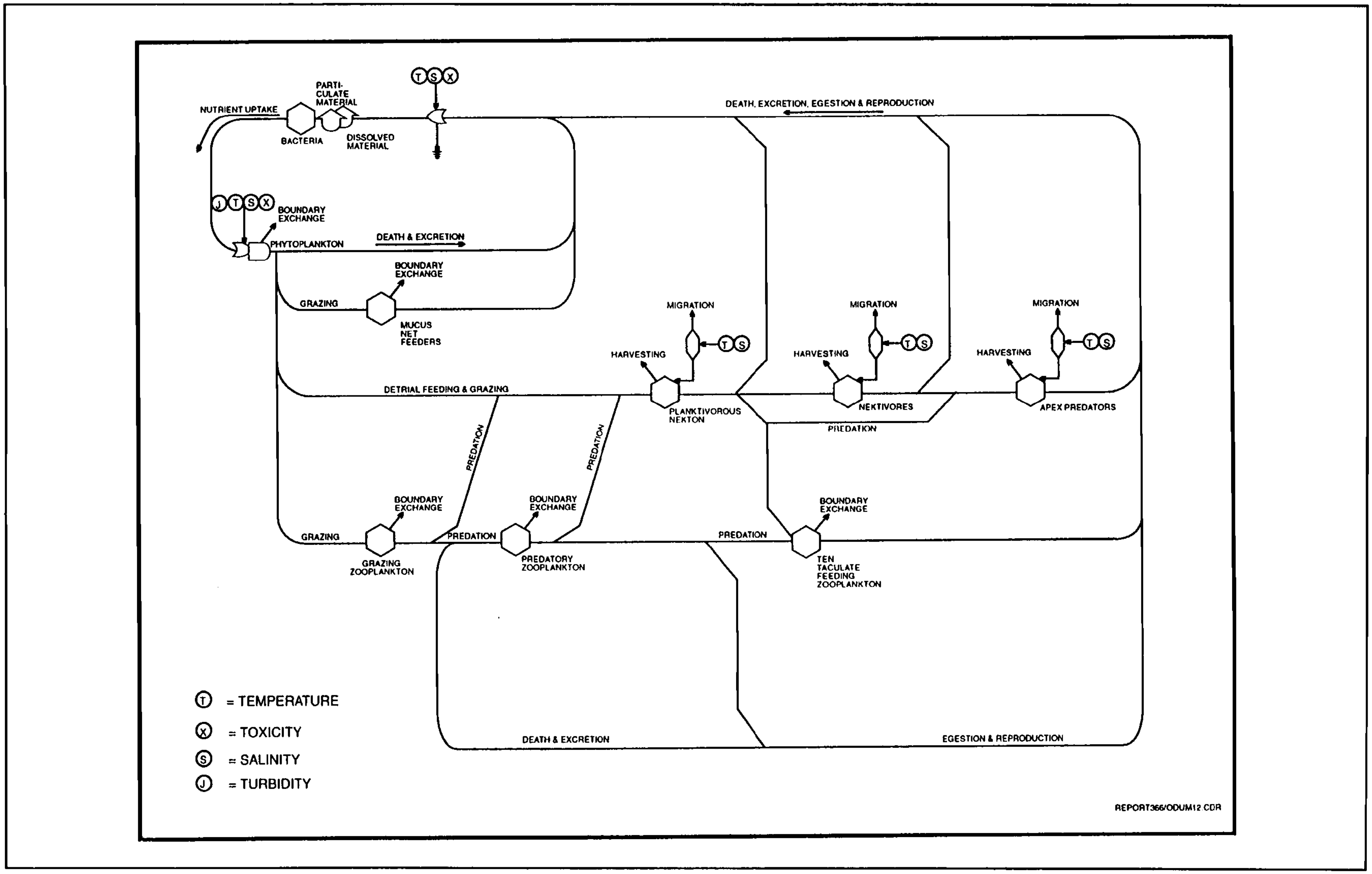


Figure 7-14. A conceptual representation of trophic processes in the pelagic subsystem for well-mixed water column conditions in the northeastern Gulf of Mexico ecosystem (from McLaughlin et al., 1975).

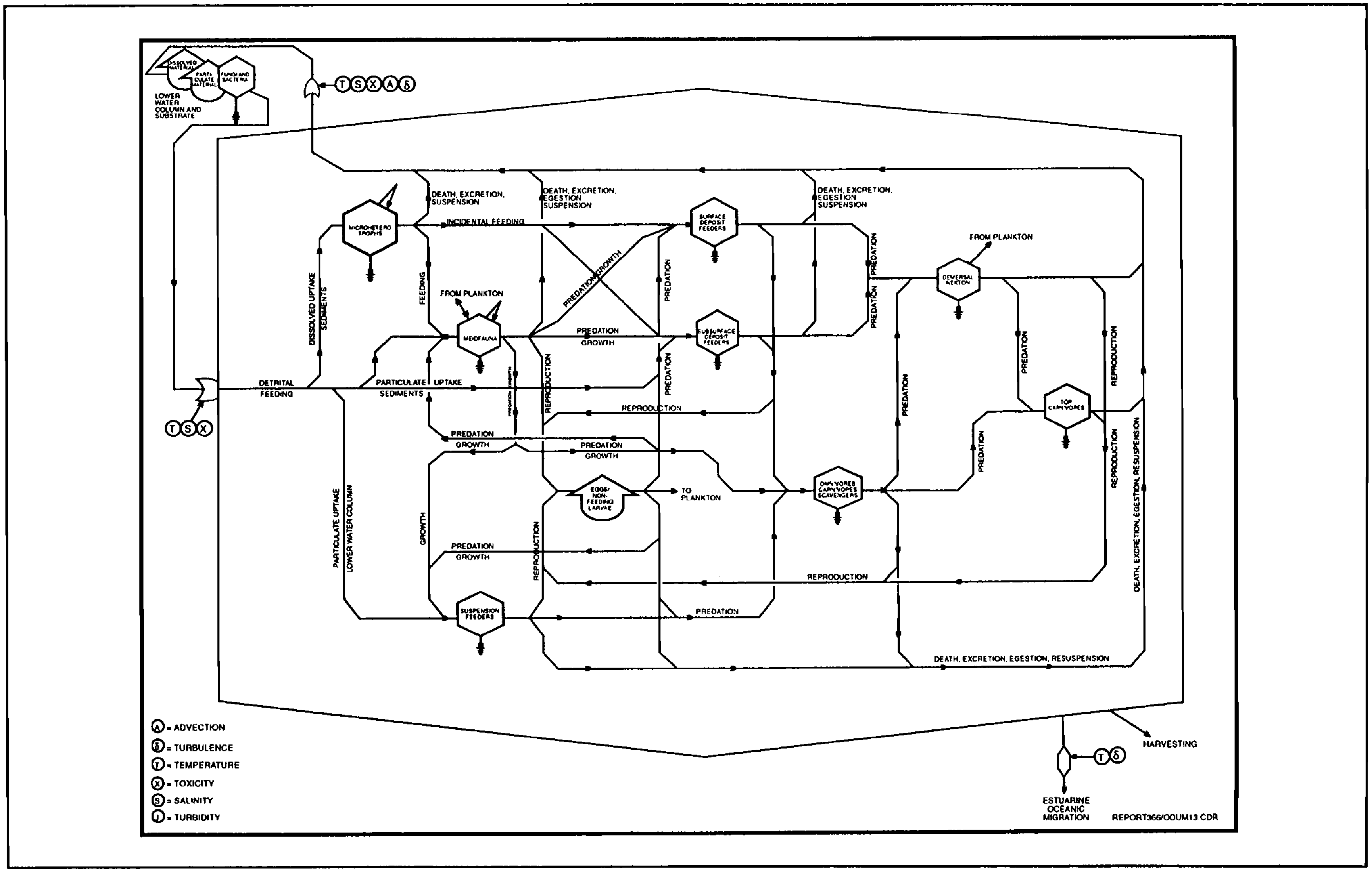


Figure 7-15. A conceptual representation of trophic processes in the benthic subsystem of the northeastern Gulf of Mexico ecosystem (from Vittor & Associates, 1985).

feeding behavior. The conceptual representations show growth and predation on the same path, even though they are different processes.

7.5.1 Pelagic Trophic Dynamics

The pelagic food chain is based on primary production, which occurs within estuaries and on the shelf. Phytoplankton production is controlled primarily by light, nutrients, density stratification, turbulence and temperature (Figure 7-14). Nutrient (nitrogen and phosphorous) availability within estuaries limits primary productivity, although panhandle estuaries do not appear to be nitrogen/phosphorus limited. Infusion of nutrients is linked with industrial, urban and agricultural runoffs; municipal and domestic wastewater discharges; and river input to the estuaries, which may form coastal frontal zones bounding the shelf domain. On the shelf domain, the availability of light and nutrients limits primary productivity. Photosynthesis decreases in proportion to decreased light intensity. The compensation depth (bottom of the euphotic zone) occurs where the rate of photosynthesis equals the rate of respiration, and depends also on the type of plant being considered. Correspondence between the upper water column and the euphotic zone depends upon the relative positions of pycnocline depth and compensation depth. During upwelling conditions at the shelf break of the DeSoto Canyon, primary production is rapidly stimulated by waters rich in nutrients reaching the photic zone. It is possible that an important, but patchy, regulator of primary production, especially near the shelf break, is the density of salps.

The pelagic food chain includes consumers – zooplankton which graze upon the photosynthetic phytoplankton. Grazing zooplankters are prey for predaceous zooplankton, planktivorous nekton and tentaculate-feeding macroplankton (Figure 7-14). Predatory plankton include cheatognaths, copepods, ctenophores and jellies as well as temporary plankton such as meroplankton (benthic forms) and ichthyoplankton (nektonic forms). The mucus net-feeding and tentaculate-feeding macroplankton are important in detritus production and as a habitat for microbial decomposers.

7.5.2 Benthic Trophic Dynamics

The benthic food web is primarily based on microbially-mediated (or processed) detrital sources of energy. Within the NEGOM the benthic community includes hardbottom (rock, oyster reef, wood), beach and nearshore sand, soft sediment and marsh habitats. All of these include substantial dependence on assimilation and recycling of detrital energy sources. For the purposes of this ecosystem model, "detritus" refers to the complex of organic and inorganic particulates including attached microorganisms (chief source of organic molecules) that enter the system. While the exact components of the energy sources in detritus are not clear, it is widely recognized that an influx of detritus is critical to the maintenance of benthic production in most ecosystems. The principle source of detrital particles is primary productivity (planktonic and shallow benthic). Some members of the benthic food web (clams, oysters, tunicates, etc.) feed directly on phytoplankton and may dominate in some estuaries. While in others this is a small fraction of the total flow and largely contributes to the maceration and breakdown of plant materials. Few species feed directly on seagrasses but many animals graze on organisms attached to the seagrasses. Much of the detritus which enters the NEGOM ecosystem is either transported across the pycnocline by gravitational settling or resuspended and advected from estuarine and shelf environments during storms. In general, detrital sources external to the ecosystem (land-derived) decrease in importance with increased distance from shore. As distance offshore increases, the benthic community becomes more dependent on production in the upper layers of the water column. On most continental shelves, benthic standing stock and productivity, decrease with distance offshore, presumably due to decreased food resource availability, while species diversity often increases (albeit with fewer individuals per species). In the western portion of the present study area (and associated material transport), this general cross-shelf pattern is modified by outflow of the Mississippi River to the mid to outer shelf.

In recent years, considerable attention has been paid to deducing the nutritional value of detritus. However, it is fair to say that "deposit feeders satisfy their nutritional requirements from the organic fraction of ingested sediment" (Levinton, 1989). This organic fraction includes a startling variety of forms, including dissolved and particulate non-living organic matter and microorganisms. The role that benthic deposit feeders (or detritivores) play in assimilation, breakdown and remineralization of organic matter is crucial in assessing the recycling or storage of ecosystem energy as well as contaminants. Deposit feeding activities (from microheterotrophic exudates to megafaunal irrigation) have profound consequences on physical and chemical properties of sediments, which in turn affect resuspension and transport of sediments and organic particulates. The nature and rate of supply of organic material to benthic environments and the density and metabolic efficiency of benthic deposit feeders are significant variables in determining trophic dynamics.

The detrital food web has two distinct loops, one external (sedimentation and advection of detritus) and one internal (recycled detritus). The external loop can develop complex coupling of trophic relationships between the pelagic trophic system and the benthic trophic system. The nature and specific dynamics of this coupling in the NEGOM are poorly understood. The internal loop can be described in general terms common to most shallow estuarine and shelf ecosystems (Figure 7-15).

Detrital particles are generally a complex combination of living and non-living organic matter and mineral components. They contain large numbers of microorganisms (bacteria, fungi, microheterotrophs) that can constitute a complete trophic cycle in themselves. Microorganisms decompose and remineralize organic matter and sorb dissolved organic matter, and exchange exudates and metabolic products freely. Large microheterotrophs ingest bacteria and fungi and are, in turn, ingested by larger meiofauna and macrofauna. In simple terms, microheterotrophs reside on detritus particles, meiofauna reside between particles, and macrofauna move the particles out of their way.

The particulates with their associated communities may be collected from the near-bottom water column by attached suspension feeders or ingested by surface and subsurface deposit feeders. As the eggs and larvae of macroinvertebrates grow, their functional role may change from meiofaunal to macrofaunal and from highly prized food source to detritivore to predator. Benthic macroinvertebrates are preyed upon by infaunal and epifaunal invertebrates, nekton and demersal fish. The larger epifauna, fish and nekton are in turn preyed upon by top carnivores or harvested.

7.5.3 Nekton Life Cycles

Types of nekton life cycles depicted for the NEGOM study area are based on their dependence on the estuary environment. Taxa which spend their entire life cycle in the marsh-estuary environment are classified as estuarine, while estuarine-dependent species spend at least part of their early life cycle in the estuary. Estuarine-related taxa are sometimes present, but estuarine-independent are exclusive to shelf waters. The estuarine life cycle is depicted on the left-hand side of Figure 7-16, while the remainder shows the estuarine-dependent type of life cycle. Figure 7-17 shows both the estuarine-related and estuarine-independent nekton life cycles.

Early larval stages of estuarine and estuarine-dependent species are both dependent on the marsh-estuary habitats. The post-larvae of estuarine species drift and swim to the marshes, where they are nurtured through their early life stages (Figure 7-16). The amount of habitat available to the post-larvae depends on the salinity and temperature of the water and the taxa's response to these regulators. The post-larvae and juveniles of menhaden, shrimp, seatrout and drums are estuarine-dependent species, which spawn on the shelf and advect into the estuarine environment as larval stages. These species depend on wind-driven and tidal currents to disperse and transport early larval stages from the shelf into the estuaries along the NEGOM study area. Providing that the seasonal cohorts are advected into the estuary, early life stages are similar to that of the estuarine species. Early life stages are spent in the marsh habitat, gradually migrating into the estuary and then the shelf through their phases of development.

Neither the estuarine-related nor the estuarine-independent nekton taxa require the support of estuaries to complete their life cycles. The estuarine-independent taxa have no relationship with the estuaries and spend their entire life cycle on the shelf, while the estuarine-related species make occasional use of the estuaries to feed (Figure 7-17). Estuarine-independent taxa include groupers, snappers, and billfish. Bluefish and mackerel are estuarine-related species which are prone to use the estuaries when high salinity conditions permit.

7.5.4 Marsh-Estuarine Dynamics

In the detailed representation of marsh-estuarine trophic processes, two major links exist between the habitats. One involves the two-way transport of dissolved and particulate materials between the marsh and estuary, while the other depicts the migration of juvenile shellfish and finfish (Figure 7-18). In the first, dissolved and suspended particulates are moved by advection and turbulence associated with the tidal exchange of brackish water. Flood tides inundate the marsh with estuarine water, suspending detritus which becomes the food base of the linked habitats. Ebb tides then transport suspended material from the marsh to the estuary, and may effect net flow of detritus into the estuary. The question of net flow

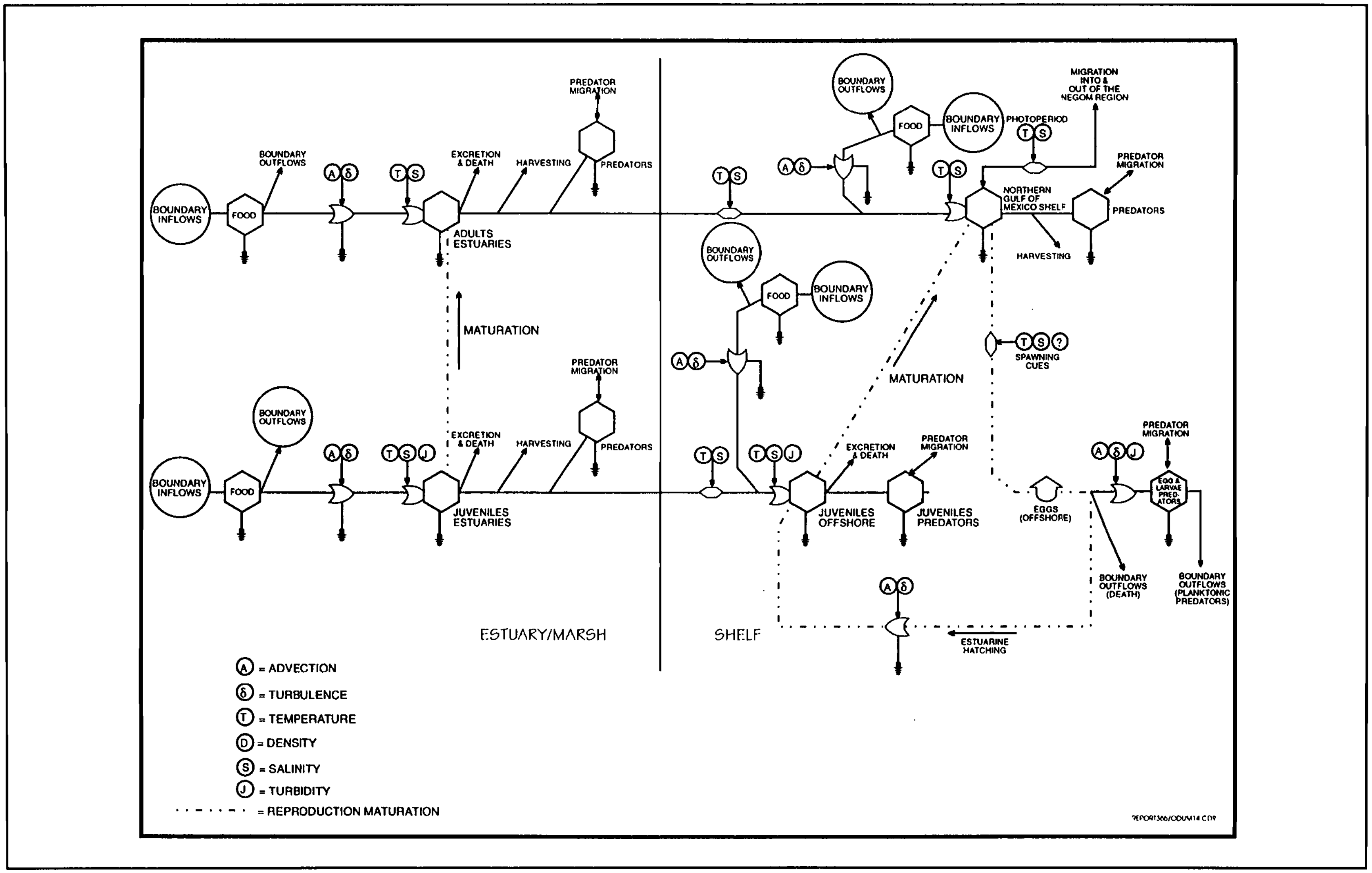


Figure 7-16. A conceptual representation of the life cycles of estuarine and estuarine-dependent nekton in the northeastern Gulf of Mexico ecosystem (from Vittor & Associates, 1985).

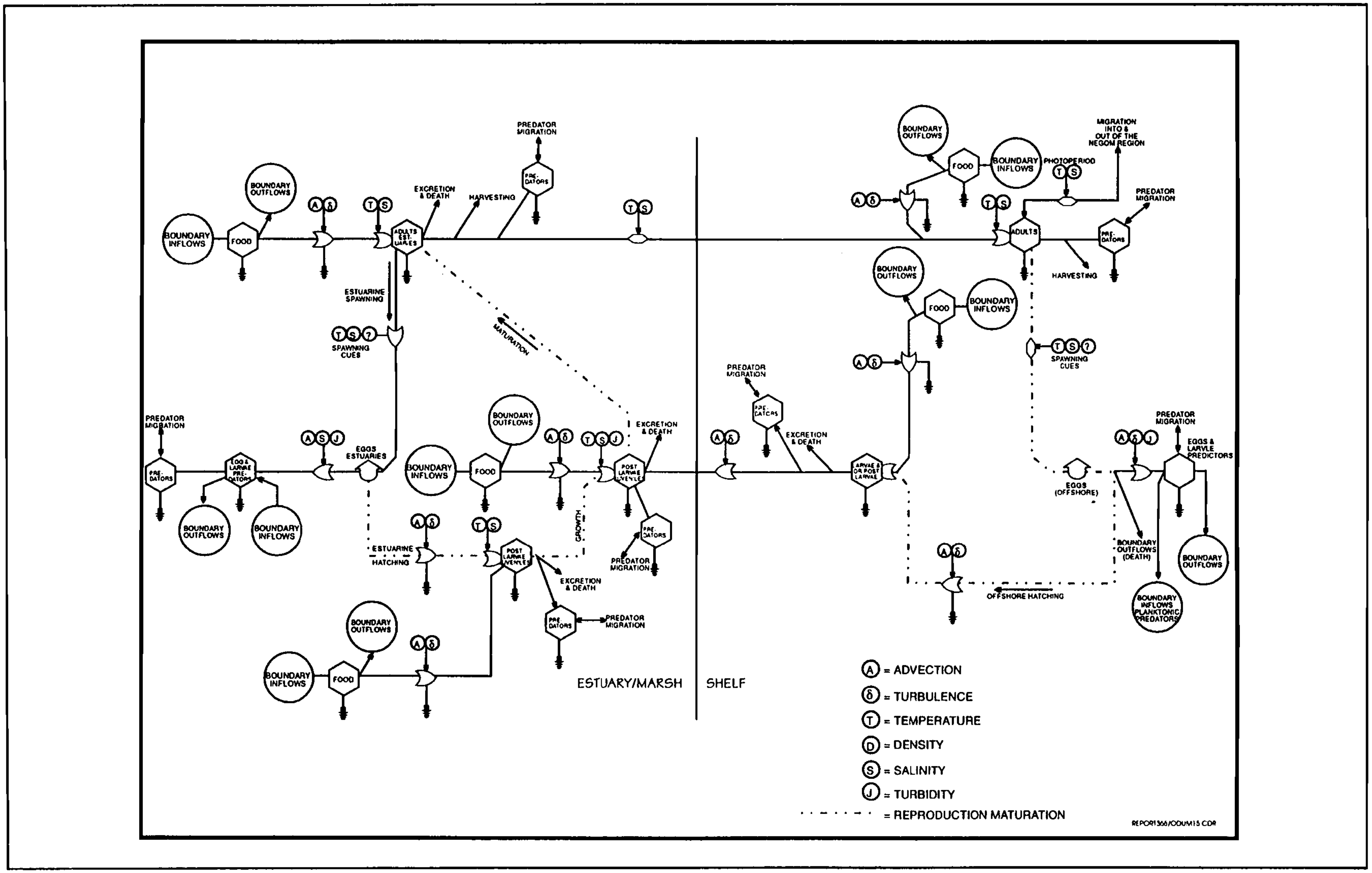


Figure 7-17. A conceptual representation of the life cycles of estuarine-related and estuarine-independent nekton in the northeastern Gulf of Mexico study area (from Vittor & Associates, 1985).

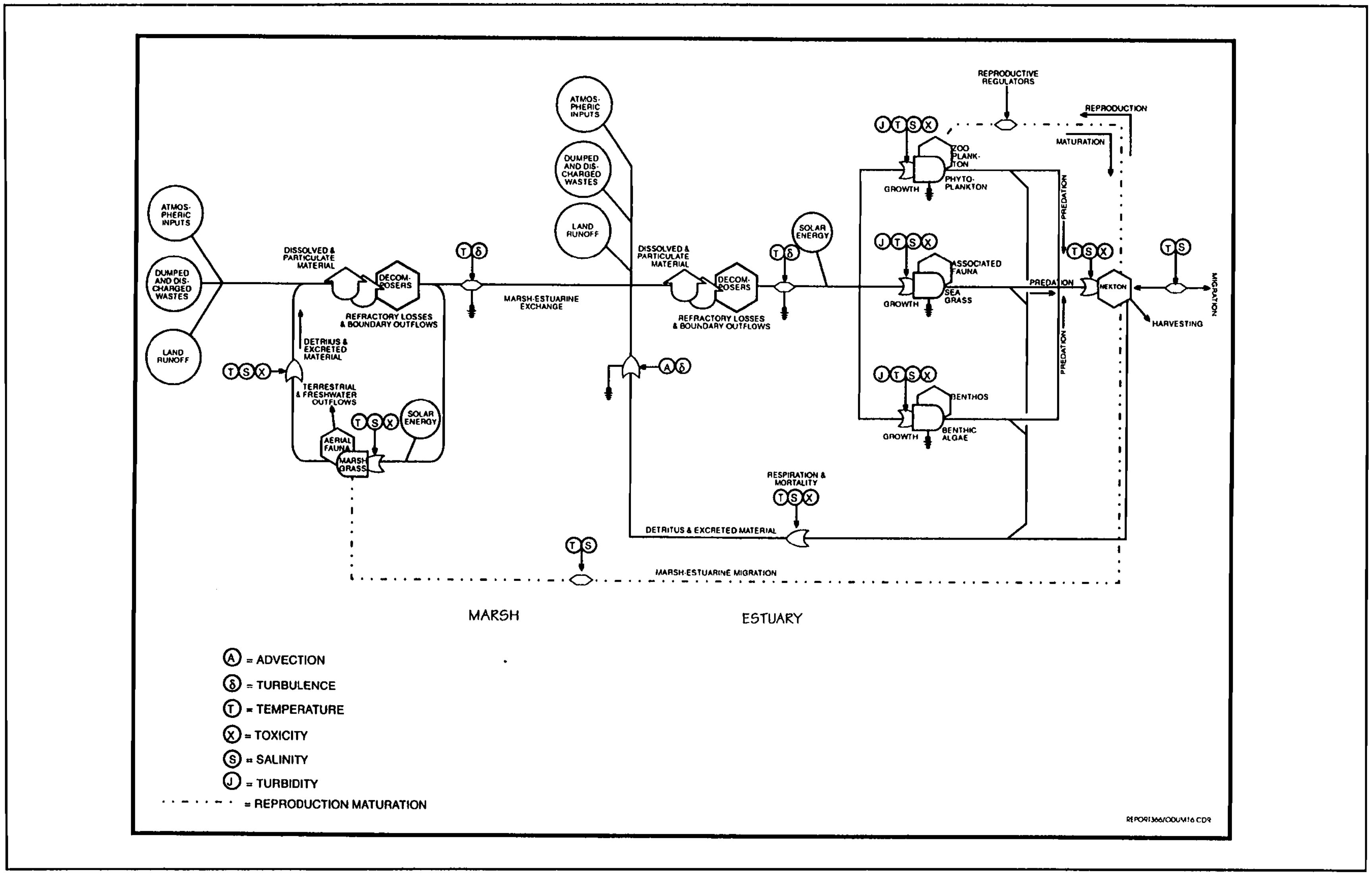


Figure 7-18. A conceptual representation of the important ecological features of Marsh-Estuarine dynamics in the northeastern Gulf of Mexico study area (from McLaughlin et al., 1975).

into the estuary is still being debated. The second transport mechanism between habitats shows the movement of post-larvae and juvenile forms into the marsh, and their subsequent migration into the estuary as subadults. Juveniles feed on particulate material while in the nurturing environment of the marsh, and move into the estuary as they make dietary shifts.

Among the several primary producers found in an estuary, seagrasses are an important link in the flow of detrital-based foods between the marsh and estuary. Seagrass beds pump oxygen into the sediments and function as sediment traps, which collect suspended detritus advected from the marsh. They also provide substrate for the microbial decomposition of detritus, and the production of dissolved organic material. In addition to contributing to the reduction of detritus advected from the marsh, and their own productivity, seagrass beds also produce photosynthate, and provide refugia for juvenile forms and habitat for macrofauna and fish.

7.6 Summary of Major Components of the Conceptual Model

Ecosystem models are mathematical or graphical depictions (maps) of energy sources, sinks, and (implied) trophodynamic processes of areas within arbitrarily or geographically defined boundaries. Unpopulated conceptual models are similar because *fundamental* trophodynamic processes in large ocean areas are similar. In contrast, quantitative (i.e., populated) models summarize and describe specific trophodynamic processes within specific ecosystems or regions. An effective means of assessing the depth and quality of information about a specific region involves (1) creating a conceptual ecological model of the area of interest (in the present case, the NEGOM), (2) gathering all reliable information available about the area, and (3) using this information, populating the conceptual model. Chapters 1-7 summarize the results of this approach. Major data gaps in knowledge of the NEGOM (discussed by discipline in Chapters 2-6) clearly show that population of the conceptual model (step 3) can not be accomplished based on present knowledge. The following paragraphs summarize, in a general way, what is known about the NEGOM, what kinds of information must be acquired in order to understand it within acceptable levels of confidence, and why the information needs to be gathered.

From shore to the continental shelf-slope boundary, geological, sedimentological, chemical, hydrological, physical oceanographic and biological features of the Florida panhandle (Perdido Key to Cape San Blas), and the Big Bend (Ochlockonee Bay to Cedar Key), are sufficiently different to be considered core subregions of the northeastern Gulf of Mexico. A transition zone located between Cape San Blas and Ochlockonee Bay with fuzzy physical and ecological boundaries lies between western and eastern core subregions. Based on limited information, it is expected that forcing functions (sediments, chemistry, circulation patterns), and the relative contributions of major biological players (producers, consumers, decomposers) differ between these NEGOM core subregions, and that some of the characteristics of the transitional zone between them may be unique to that area.

In general terms, nutrients (C, N, P, Si) and photoperiod drive levels and rates of primary production form the proximate or ultimate basis of food webs. Turbidity, toxic substances and other factors secondarily influence production. Primary nutrient inputs into the NEGOM are from rivers, estuaries and upwelling. Nutrient contributions are also made from land runoff, atmospheric fallout and basin-to-shelf water exchanges. Winds, water, and biological waste product fall-out transport nutrients from their sources to where they are used by producers (phytoplankton and benthic plants for the most part); and water movements also transport oxygen, producers and their corpses and by-products to areas where they are consumed by microbes and other consumers. Sediment composition and quality (the chief abiotic organizing determinants of benthic biological communities) depend upon circulation patterns, water chemistry and biogeochemical processes. Biotic characteristics (communities and species assemblages within them) are consequences of: (1) chemical, physical and geological-sedimentological conditions, events, and processes; and (2) recruitment patterns, competition, space availability, and highly variable factors that require measurement rather than conceptualization.

Water mass characteristics reflect the complex interaction of transport and mixing as well as the source and characteristics of those waters found on the shelf in this NEGOM study area. In the panhandle, fresher estuarine water is provided primarily by the Mississippi River (by volume) and other local sources such as Mobile Bay and the Apalachicola River and Bay. The net transport of fresh water from these is part of a two-way exchange that contributes to movement of material and organisms into and out of the area's estuaries. The freshwater contribution also changes over time, with the largest occurring in spring with high discharge from the Mississippi River from South Pass, Pass a Loutre (North Pass) and Main Pass. Discharges from other estuaries with more local drainage basins respond to local and generally higher frequency variations in precipitation. The other key source of shelf water results from exchange across the shelf break which, at the head of the DeSoto Canyon, can be as close as 30-50 km from the shoreline. Shelf break processes generally exchange consistently warmer and more saline water with the shelf. Linkage of the slope water to the Loop Current provides a pathway between this mid-latitude shelf and tropical waters of the Caribbean Sea. Shelf waters result from mixing of estuarine water and slope waters with in-place modification on the shelf by the overlying atmosphere, particularly by heat and wind energy. Circulation patterns on the shelf study area are affected by buoyancy (gravitational) forces, wind stress acting on the water surface, tides and exchanges due to slope circulation patterns, such as cyclonic and anticyclonic eddies.

In the Big Bend area, the shelf is considerably wider than on the panhandle, hence the body of warmer, more saline slope water is further offshore; in addition, the number and cumulative magnitude of freshwater sources is smaller. The breadth of the slope would seem to help isolate the mid- to inner shelf from shelf break exchange dynamics. At those times when the Loop Current (LC) is extended northward, LC-related eddies can affect the shelf break and result in the transport of material onto this broad, more gently sloping shelf. An example of the role that physical transport mechanisms can have occurs in the Big Bend area. It is known that DeSoto Canyon is an important spawning area for many commercially important fishes. The larvae of these fishes spend their early development stages in the seagrass beds of the Big Bend coast. The mechanisms and events that contribute to the transport of larvae across the wide west Florida Shelf are not at present understood.

Many key processes affecting the shelf conditions have consistent annual patterns. Wind stress and temperature patterns (the march of seasons) are relatively consistent from year-to-year. The Mississippi River flow can change interannually, however, with a large annual discharge generally occurring in late spring (March-May). Slope processes dependent on the proximity of the Loop Current do not exhibit an annual pattern, given that the eddy shedding cycle can vary from 6 to 14 months.

For this study area, little systematic, regional-scale information exists on water mass characteristics and hydrography as it changes annually and interannually. Clearly, information concerning the distribution of physical oceanographic conditions relative to other governing variables, such as the presence of soft or hard bottoms and seagrass beds, will be fundamental in understanding the range and distribution of various species throughout their life cycles.

To understand the presence and distribution of water mass characteristics requires as yet unavailable concurrent documentation of hydrography and currents. Currents reflect the dynamic processes that result in along- and across-shelf mixing. Concurrently, hydrography reflects the results of the dynamic mixing processes. These are interrelated and mutually dependent, since buoyancy forces are dependent on the changing spatial distribution of the density field (i.e. water mass distribution).

Considerable historical meteorological information is available for the study area, however, its importance in driving circulation patterns and modifying the underlying water column requires that it be documented concurrently with any measurement of currents, dynamics and hydrography. Processes controlling shelf-slope exchange are not well documented, although recent insights to slope dynamics have helped focus on eddies as likely features affecting the outer shelf circulation and transport patterns.

In summary, relatively few coordinated measurements are available concerning specific regional and subregional scale physical oceanographic conditions and processes occurring in this northeastern Gulf of Mexico shelf area. Although a conceptual basis exists for helping define processes of importance, little systematic information is presently available to allow observationally-based descriptions of ecologically significant physical oceanographic conditions and patterns/processes.

In the NEGOM biologically significant and often linked aspects of the geological setting for the panhandle and Big Bend regions include:

- Bottom type, composition and coverage
- Location and types of estuaries
- Sediment dynamics
- Bathymetry

A detailed description of bottom sediments is not possible based on presently available results of field sampling. However, based on spatially nonuniform sampling, coarse-scale generalizations are possible. The study area is composed of two major geologic regions each having a certain degree of internal consistency. They are the Florida panhandle and the Big Bend areas as shown in Figure 7-1. The separation or transition between these is in the general vicinity of Ochlockonee Bay. To the south or east is the more sediment starved carbonate region. To the west is the more terrigenous sediment rich region.

The panhandle coast consists of an almost continuous series of barrier islands forming relatively shallow estuaries which are receiving waters for local watersheds and the associated load of relatively fine grain material. In contrast, the Big Bend coast is generally marshy with small quantities of sediment being provided by smaller streams draining the adjacent carbonate platform. The exception to this is the Suwannee River which transits to the Gulf coast from the Okefenokee Swamp in Georgia.

On the shelf, in water depths of less than 60-80 meters, bottom sediments reflect the availability and type of coastal sediments. In the more gently sloping Big Bend area, sediments are generally characterized as being an intermittent veneer overlying an irregular carbonate platform. In the panhandle, shelf sediments reflect a mixture with components coming from relic, largely quartz sands, more recent fine terrigenous and organic sediments mixed with shell fragments.

With a more limited sediment supply, a broader, shallower shelf and thin sediment layers on the shelf, sediment dynamics are less of a factor affecting the ecosystem than in the panhandle where riverine and estuarine sources continue to discharge generally fine textured sediments to the estuaries, with some transiting out of the estuaries to the shelf. On the basis of occasional or anecdotal information, the presence of the relatively large Mississippi River outflow onto the Mississippi and Alabama shelves has been suggested as a possible explanation for nepheloid layers that are at least occasionally vertically extensive. These could inhibit the depth to which biologically important light can penetrate the water column.

Types of geological information which would enhance populating an ecosystem model for the present study area include:

- The depth at which combined waves and currents can expect to move or resuspend the actual sediment population. This information can be related to the intensity and track of storm events that might disrupt bottom communities in the study area.

- Finer scale resolution of the sediment thickness, composition and texture throughout the study area. Given the size of region, this information may be better established in conjunction with sampling schemes needed to characterize the biologically significant benthic and epibenthic communities.

Shelf water chemistry is a cumulative reflection of (1) the material being contributed to the shelf via rivers and estuaries and exported from the shelf over the shelf break or to adjacent shelf areas, (2) transport and mixing (dilution) of these materials by the shelf circulation patterns, and (3) chemical reactions and modifications with time and in reaction with other material on the shelf. This framework defines information needed if shelf chemistry is to be understood.

Material being contributed to the shelf should be well documented as to source, quantity and timing. Since estuaries are the primary pathway for non-ambient materials reaching the shelf, the location, quantity and type of material coming from the estuaries should be documented. As discussed in Chapter 4 of this document, a modest sampling program has or presently exists for some the estuaries in the panhandle. As this region becomes more developed and industrialized (see Chapter 6), the resulting type and quantities of material may change. Consequently, documentation of estuarine contributions should be maintained and adjusted to changing patterns of discharge.

Relative to an ecosystem model, the availability of nutrients is a key factor. The distribution of nutrient materials is governed by biochemical processes, and transport and mixing identified in the discussion of physical processes. If shelf water masses, and mixing and transport processes are documented and understood, it remains to understand the utilization and contributions of nutrients coming from geological and biological conditions on the shelf. Practically, this calls for documenting local nutrient levels in conjunction with water column and bottom/sub-bottom biological sampling.

Dissolved oxygen (DO) concentrations are basic to chemical and ecological conditions in the study area. There have been some suggestions that low DO levels may occur within or immediately adjacent to the present study area. However, the durability, vertical and horizontal locations and factors contributing to hypoxia have not been well documented. Limited and sometimes anecdotal information on low dissolved oxygen levels is primarily from the Florida panhandle, with little information from the Big Bend area. Since oxygen utilization by sediments and organisms is a continuing processes, oxygen replenishment is largely dependent on vertical and horizontal mixing processes and primary production which are highly variable at least on a seasonal basis. Again, knowledge of both mixing and transport processes along with patterns of primary production are basic to an understanding of this key chemical variable. Documenting the distribution and pattern of DO levels should be an integral part of any biological, physical, geological or chemical sampling conducted on the shelf.

Conceptually, the condition of an ecosystem at any given time reflects the cumulative influence of conditions prior to the time of sampling. The response or recovery time of the system determines the degree of dependence on prior conditions. Knowledge of water mass characteristics and mixing and transport processes, sources and sinks of constituents, and important forcing functions, such as light penetration for primary production, should provide a basis for estimating the range and expected chemical conditions that might occur at various locations in the study area.

Clearly, understanding the water chemistry in the region is intimately linked to understanding material sources and their movement, and biological and sediment utilization of these materials. These components are not well understood or well documented in the study area.

Species and trophic guilds comprising biological assemblages are consequences of the physical, chemical and geological attributes of the communities which they partially reflect and define. Communities are biological units that, by their existence, provide information about many of the abiotic features of regions or ecosystems, and can be used partially to characterize, compare, or discriminate between them. As discussed in Chapter 5 of this report, recent detailed knowledge of the structure, density, diversity and distribution of pelagic and benthic communities is relatively scanty in most estuarine-coastal areas of the NEGOM and, for all practical purposes, this information is not available for shelf areas. In order to gain the kind and depth of knowledge needed to understand the biology and trophodynamic structure of the NEGOM, coordinated, multidisciplinary studies of keystone sites within the region should be conducted.

Nutrient loads imported into estuaries and the fraction exported onto the shelf should be documented. Phytoplankton, salt marshes, benthic algae (including diatoms), microbes, and submerged aquatic vegetation capture and release nutrients in estuaries. This seasonal import-export variation should be determined. Nutrients in shelf waters are transported downstream or, through mixing processes, become available for assimilation in benthic food webs. Thus, currents and mixing patterns should be documented at the same time and locations as nutrient sampling. In order to determine background concentrations and assimilation rates of nutrients, phytoplankton samples (or chlorophyll surrogates) should also be collected with nutrient and water mass data, again on a seasonal (winter-summer) basis. The simultaneous collections of organisms which, at increasingly higher trophic levels participate in water column energy exchanges should include zooplankton and larger pelagic organisms, including crustaceans, cephalopods and fishes.

The structure of benthic communities depends upon substrate characteristics as well as water column processes. Thus, sediments (which are not uniformly distributed in the NEGOM) and benthos (microbes, meiofauna, macrofauna) should be sampled concurrently with water column variables.

The conceptual ecosystem model for the NEGOM study area is complex. Estuaries to the west of Cape San Blas are often stratified, while those to the east have good exchange with shelf waters and are typically well mixed. The shelf region west of the Southwest Cape (Alligator Harbor) have sufficient energy inputs and alluvial sources of sediment to form the barrier islands typical of the region. By contrast, blackwater sources of riverine input and sands of autochthonous origin are the dominant components in the nearshore region of the Big Bend estuary and the western Florida shelf.

Evidence supporting biological variability in the NEGOM ecosystem is missing. Data gaps exist for distribution and abundance information along the entire shelf region and in the estuaries east of Apalachicola Bay.

This is especially true for the Big Bend area where trends in species richness, community standing stocks, estuarine dependence and relationships, and benthic-pelagic coupling are not understood in the context of either longshore or onshore-offshore variability.

Major changes in ecosystem structure in an onshore-offshore direction typical of continental shelf regions are not known for this study area. In continental shelf systems, sediment grain size, hydrographic variability, tidal influences, nutrient concentrations, detrital input, community standing stocks and benthic-pelagic trophic coupling would all be expected to decrease with increasing water depth and distance from the shore, while depth of euphotic zone, and importance of biological interactions would increase with distance from shore. Classification analyses conducted on biological community data and sediment data collected in the Southern Texas OCS study area showed that habitat groupings were based on distance offshore and depth (Flint and Rabalais, 1981). Little information is available describing the nearshore and offshore biological communities in the NEGOM study area.

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U.S. Department of the Interior
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