SYMPOSIUM ON THE NATURAL RESOURCES OF THE MOBILE ESTUARY, ALABAMA

MAY, 1979

HAROLD A. LOYACANO, JR.
and
J. PAUL SMITH

Editors

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"The search for truth is in one way hard and in another easy. For it is evident that no one can master it fully or miss it wholly. But each adds a little to our knowledge about Nature, and from all the facts assembled there arises a certain grandeur."

Aristotle

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PREFACE

The importance of the Mobile estuary to the local population, the region and the nation is not questioned by many. In fact, the area and its resources have been in such demand that conflict between various user groups has developed and is becoming more severe. Various planning efforts seeking rational evaluation and regulation for land and water uses have been or are underway. The goals are, in part, to identify areas for preservation, areas for possible future development and the restrictions needed on some activities in order to maintain the quality of life. The factors that go into the evaluation must be well understood so that the cost of the alternatives, both to the environment and to the economy can be presented to the local public - the proper judge for these endeavors.

The Symposium on the Natural Resources of the Mobile Estuary was conceived as a vehicle to help make the natural resource information available to the general public and to various agencies. This volume has been edited by Harold A. Loyacano and J. Paul Smith. Hopefully, the information presented in this series of papers will be used to manage the natural resources, and to identify areas that require more detailed study. The ultimate goal is to use proceedings of this symposium to make the Mobile estuary an exception to the evaluation by Handler (1970)[1] ". . . in most of the world, environmental biology has not yet passed the stage of inventory and survey, and is far from ready to grapple with the galloping degradation of the human habitat."

Wolf-Dieter N. Busch

[1]Handler, P., ed. 1970. Biology and the future of man. Oxford Univ. Press, New York. 936 p.

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INTRODUCTION

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PHYSICAL

Mobile Bay is approximately 50 km (31 miles) long with a width of up to 38 km (24 miles) (Fig. 1). The highways, U.S. 90 (Battleship Causeway)

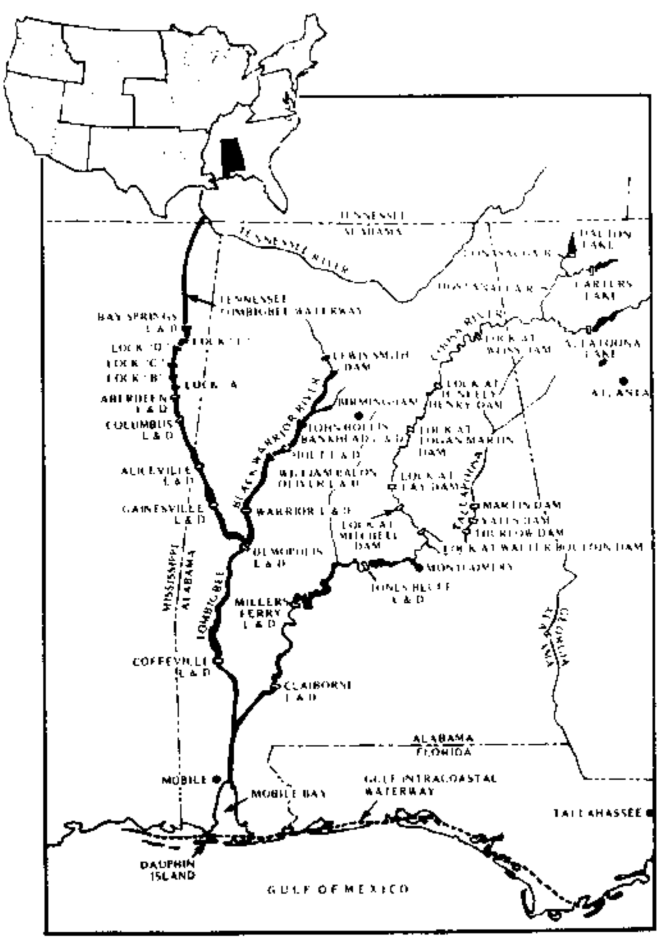

Figure 1. Mobile Bay Watershed.

and I-10 separate the Bay from the Mobile River delta to the north. The Bay is bordered on the west by industrial and urban areas of Mobile and the industrial area of Theodore and various rural communities; on the east by residential and farming communities of Daphne and Fairhope; on the southwest by Mississippi Sound and on the south by Dauphin Island, Fort Morgan Peninsula and the Gulf of Mexico. The surface area of this estuary is approximately 1,070 km^2 (413 square miles).

Mobile Bay receives freshwater inflow from several sources, but 95% comes through the Mobile River System, which carries the combined flows of the Alabama and Tombigbee Rivers (Fig. 2). The average discharge of the system into the Bay is approximately 1,750 $m^3\ sec^{-1}$ (62,500 $feet^3\ sec^{-1}$). The outflow of Bay water occurs at two passes. Approximately 15% of the Bay's discharge flows into Mississippi Sound through the pass located between Dauphin Island and Cedar Point. The remaining 85% flows directly into the Gulf of Mexico through the pass located between Dauphin Island and Fort Morgan Peninsula (Schroeder 1977).

The major portion of the Bay (590 km^2) has water depths ranging between 1.8 and 3.0 m (6 and 10 feet). Located primarily in the northern portion and around the Bay's periphery are approximately 246 km^2 (95.3 square miles) with depths less than 1.8 m (6 feet). The remaining 206 km^2 (79.7 square miles) have depths ranging between 3 m (10 feet) to over 9 m (30 feet) (Crance 1971).

Mobile Bay has gently sloping bottom contours with only minor natural irregularities. However, the disposal of dredged material in open water adjacent to the main ship channel (north-south) has altered the Bay's bottom contours. Bathymetric readings show that spoil banks have been created on both sides of the channel with the greatest relief on the west side ranging from an average of 0.6 m (2 feet) at midbay to 1.5 m (5 feet) in the northern section of the Bay. The water depth over these spoil banks ranges from 1.8 m at midbay to generally less than 0.6 m in the northern section where spoil mounds protrude above the water in various areas.

The overall circulation patterns within the Bay are controlled by river discharges, tides, winds and the bathymetric and geomorphic characteristics of the Bay. However, numerous studies have shown that alterations in the bottom contours caused by spoil disposal have modified and restricted water circulation patterns. Austin (1954) noted that spoil

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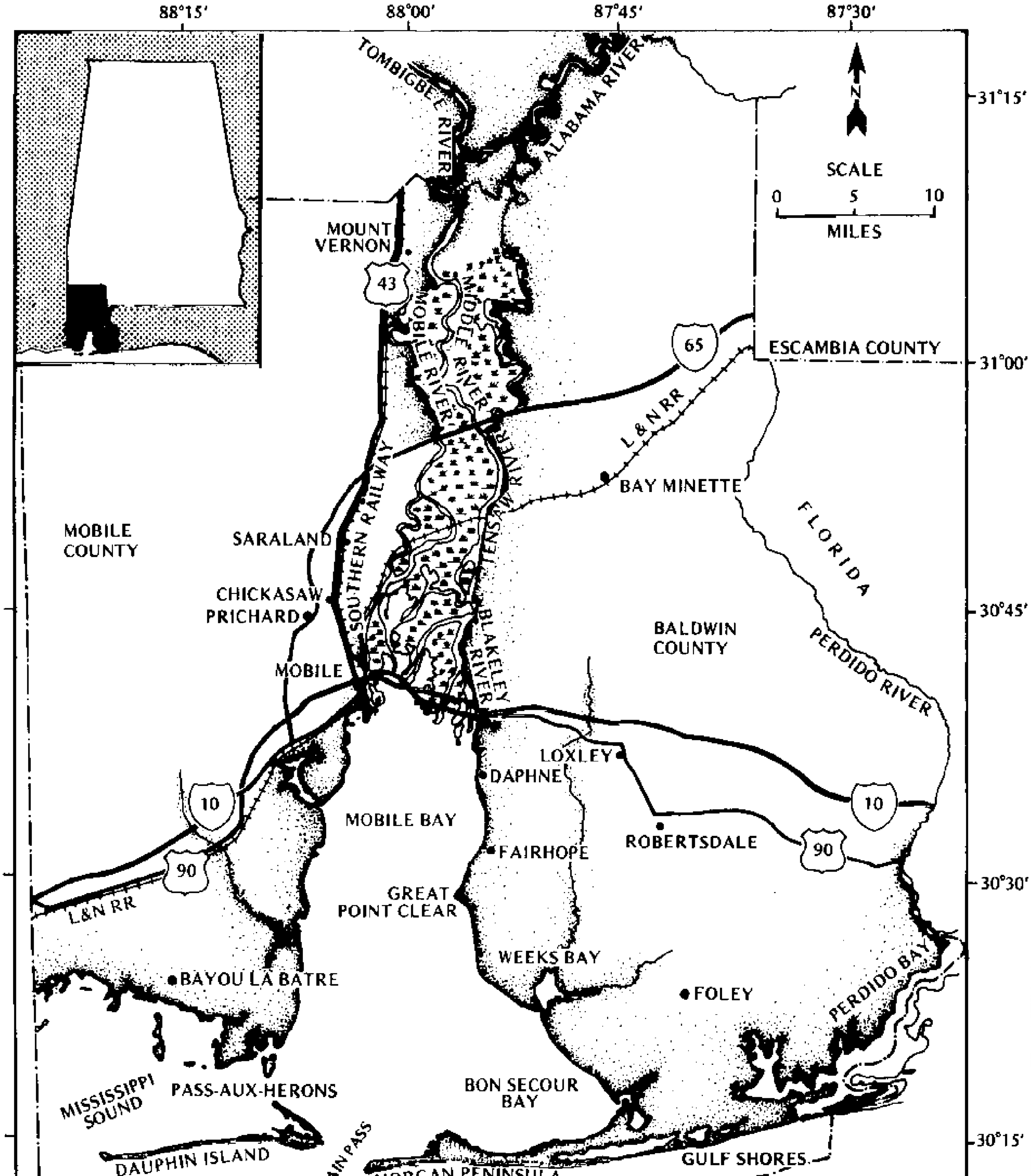

Figure 2. Mobile Estuary.

banks along the western side of the ship channel presented a physical barrier to the flow of bottom waters. Loesch (1960) made the same observation and both he and McPhearson (1970) showed that salinity stratification was more pronounced on the east side of the channel, indicating that the inflow of saline water from the Gulf of Mexico was restricted from flowing into the western side of the Bay. May (1973) observed that salinity stratification and restricted water circulation have caused depletion of oxygen in the bottom waters over large portions of the Bay during summer months. During the summer of 1971, such an event killed adult oysters and prevented spat setting on Point Clear Reef (May 1972). In a study performed almost 20 years after Austin's study and after an extensive accumulation of spoil material had occurred in the northern section of the Bay, Story et al. (1974) found that spoil banks in the northern section were not only altering bottom water circulation patterns, but were affecting surface circulation. They found that the spoil banks contained the freshwater flow from the Mobile River and prevented this flow from leaving the dredged channel for a distance of about 10 km (6 miles) south of the river's mouth. However, once leaving the channel, the flow proceeded along the western shore of the Bay as previous studies have indicated.

Water quality in the Bay is further stressed by the discharge of more than 121,000 kl (32 million gallons) of treated waste water per day from 19 municipal plants and 492,000 kl (130 million gallons) per day from industrial discharges. These discharges are in addition to non-point sources and miscellaneous point discharges such as sanitary wastes, cooling waters, and boiler blowdown.

BIOLOGICAL

Mobile Bay below Battleship Causeway contains only scattered areas of tidal marsh. The major areas are located in the tributaries, such as Dog and Fowl Rivers, and along the southeastern shore of the Bay. Chermock (1974) calculated that the Bay contained 1,160 ha (2,867 acres) of tidal marsh. The predominant marsh plants include smooth cordgrass (*Spartina alterniflora*), needlerush (*Juncus roemerianus*), giant cordgrass (*Spartina cynosuroides*), saltmarsh hay (*Spartina patens*), and roseau (*Phragmites communis*). Little information is available on the distribution of submerged vegetation in Mobile Bay. Baldwin (1957) estimated that the Bay contained approximately 2,024 ha (5,000 a) of submerged vegetation, composed primarily of bushy-pondweed (*Najas guadalupensis*) and eelgrass (*Vallisneria americana*). The majority of the subtidal vegetation is found in the northern portion of the Bay.

Fishery resources within Mobile Bay consist of numerous marine and freshwater species. Major marine fish species that are dependent upon the estuarine waters of Mobile Bay during some period of their life and are of commercial importance in Alabama include: seatrouts (*Cynoscion nebulosus, C. arenarius*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), striped mullet (*Mugil cephalus*) and southern flounder (*Paralichthys lethostigma*). Other important marine fishes that inhabit the estuarine waters of Mobile Bay and are utilized as forage by sport and commercial fishes include bay anchovy (*Anchoa mitchilli*), Gulf menhaden (*Brevoortia patronus*) and tidewater silverside (*Menidia beryllina*). In 1968, the commercial fishes listed above contributed approximately $470,000 to the economy of Mobile and Baldwin counties (Swingle 1971). In 1976, the reported value of these same estuarine-dependent species had increased threefold to $1,330,000 (U.S. Dept. of Commerce, National Marine Fisheries Service 1977).

Major shellfish species that are dependent upon the estuarine water of Mobile Bay and are of commercial importance in Alabama include blue crab (*Callinectes sapidus*), shrimps (*Penaeus* spp.) and oyster (*Crassostrea virginica*). Blue crab and shrimps occur throughout the estuarine waters of Alabama. The major oyster reefs are in the southwestern portion of Mobile Bay, primarily in the vicinity of Cedar Point. Currently, there are approximately 1,200 ha (3,000 acres) of public oyster reefs. Crab, shrimp and oyster resources provided $8,700,000 to the economy of Alabama in 1968 (Swingle 1971). In 1976, these same resources reportedly provided $31,800,000 to the state's economy (U.S. Dept. of Commerce, National Marine Fisheries Service 1977). Therefore, in 1976 the reported harvest of renewable natural resources in the form of commercially valuable estuarine-dependent fish and shellfish contributed approximately $33,100,000 to the local economies of Mobile and Baldwin Counties.

Recreational fishing in the coastal water of Alabama provides additional revenue to Mobile and Baldwin Counties. In 1975, an estimated 308,045 recreational saltwater fishing trips occurring in Alabama's coastal water resulted in the expenditure of an estimated $4,953,000 (Wade 1977). Approximately 73% of the trips occurred within the inshore waters of Mobile and Baldwin Counties. Major inshore sportfish species include spotted and sand seatrouts, red drum, Atlantic croaker, and striped mullet.

A 1964 sportfishing survey of the Mobile Delta by Swingle et al. (1966) showed that extensive sport fishing effort was placed on the lower section of the delta. Boat fishermen accounted for 68% of the fishing effort, bank fishermen represented 30%; and wading fishermen 2%. Dominant freshwater sportfish caught in the Mobile Delta included bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*) and largemouth bass (*Micropterus salmoides*). The most commonly caught saltwater species included spotted seatrout and mullet. A recent sport fishing survey of the Delta area has not been performed. However, fishing activity on the Delta has undoubtedly increased since 1964. Recent observations of fishermen along Battleship Causeway indicate the area is heavily fished and the species most frequently caught are apparently the same as in 1964.

Recreational shrimping is popular among Mobile and Baldwin County residents. In 1972, Swingle et al. (1976) determined that 30% of the people who owned boats less than 8 m (26 feet) long owned a 5-m (16-foot) shrimp trawl. During 1972, 1973, and 1974 the harvest by recreational fishermen was estimated to be between 15 and 25 percent of Alabama's total inshore catch of shrimp. Recreational trawling is generally well distributed throughout the Bay during the peak of the season, but is concentrated in the lower Bay during the spring months and in the upper Bay during the winter months. Estimates of annual monetary outlays of sportsmen for equipment, supplies, lodging, etc. have been placed as high as 1 billion dollars for the Mobile/Baldwin County area.

Some of the wildlife resources occurring in the coastal wetlands of Alabama and the Mobile Bay area include: raccoon (*Procyon lotor*), nutria (*Myocastor coypus*), rice rat (*Oryzomys palustris*), marsh rabbit (*Sylvilagus palustris*), white pelican (*Pelecanus erythrorhynchus*), the endangered brown pelican (*P. occidentalis*), and various species of wading birds and sea birds. Also found within the project area are several species of reptiles and amphibians.

The coastal waters of Alabama, especially the Mobile Delta, provide habitat for wintering waterfowl. The most commonly occurring ducks include mallard (*Anas platyrhynchos*), gadwall (*Anas strepera*), pintail (*Anas acuta*), green-winged teal (*Anas crecca*), American wigeon (*Anas americana*), canvasback (*Aythya valisineria*) and lesser scaup (*Aythya affinis*). Wintering populations are generally around 15,000 birds. Coots (*Fulica americana*) also heavily utilize the delta, with wintering populations around 30,000 birds (Beshears 1979 personal commun.). In 1975, over 1,800 migratory bird stamps were sold in Mobile and Baldwin Counites.

HISTORICAL

Since colonial time, Mobile Bay and the port at Mobile have played important roles in the development of the state of Alabama and have figured prominently in the history of the United States. Historic records of Mobile Bay occurred from the early 16th century on charts of navigators who entered the Gulf of Mexico (U.S. Army Corps of Engineers 1977). From its founding by Bienville in 1702 until Alabama entered the Union in 1819 Mobile was under the rule of France, England and Spain. During the War Between the States the strategic locations of Fort Gaines and Fort Morgan at the entrance to Mobile Bay and mines placed in the Bay prevented Union ships from entering the Bay and capturing Mobile until April 1865, after four years of siege (Delaney 1953).

From its beginning Mobile has served as an important port because of the safe harbor provided by Mobile Bay and the major river system that connects the port with the interior of the state. This connection with the interior caused the port to flourish during the era when cotton was "king," and in the 1850's, the Port of Mobile was the second ranking cotton port in the World (Delaney 1953). Today it ranks as third largest port on the Gulf Coast and in 1977, 35 million tons of cargo passed through the port.

In order to accommodate growth of the port and increases in the size of ships, the Mobile Estuary has been modified continually since the first Federal improvement of the harbor was authorized in 1826 (Weber 1968). Since that time the harbor channels have been repeatedly enlarged and extended. The total length of the ship channels in Mobile Bay is currently over 60 kilometers (40 mi). The channel through the bar at the mouth of Mobile Bay is 12.8 meters (42 ft) deep and 183 meters (600 ft) wide, and through the Bay to the mouth of Mobile River it is 12.2 meters (40 ft) deep and 122 meters (400 ft) wide. In addition to the major ship channels, small-craft harbors and entrance channels have been developed at six locations since 1925. Maintenance of the ship channel has required dredging about every two years while the smaller channels are dredged every 3-5 years. From 1960 to 1970 the average annual dredge spoil from the Port of Mobile has been 5 million m^3 (7 mil yd^3).

The Mobile Estuary Symposium was planned in order to bring together the physical/biological information that may affect the fish and wildlife resources of this area. The data obtained from this state-of-the-knowledge review were then used to formulate management alternatives, where possible, and to identify critical data gaps. Listing of data gaps may result in funding of key studies to gather information useful for scientific management of these natural resources.

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SEDIMENTATION IN MOBILE BAY

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ABSTRACT

Mobile Bay is the discharge point for a very large river system. The Bay was formed as the last of the Wisconsinan ice sheets melted and sea level rose and covered the flood plain of the ancestral river. Since that time, the Bay has been filling with sediments from a variety of terranes, although the rate of sedimentation has diminished through time.

Although there has been an acceleration in the rate that data on the various aspects of the Bay are accumulating, there is still a dearth of knowledge. Circulation within the Bay is of basic importance to many studies, but is very incompletely known, because of the complex variables involved. The relationship between circulation and sediment distribution is direct, so that as new data are collected from one study, they are applicable to the other.

Sediments within the Bay range from clean sands to relatively pure clays, with various admixtures of sand, silt and clay covering much of the area. The distribution of these sediments is an indication of the average pattern of circulation, and may provide valuable information about changes with time.

Modern methods of studying sediment dispersal rely more and more heavily upon remote sensing. This tool has not yet been thoroughly utilized in the study of sediments in Mobile Bay.

GENERAL SETTING

Mobile Bay constitutes the primary depositional basin for the sixth largest river system in the United States. The rivers that discharge into the Bay drain a watershed area of more than 111,370 km^2 (43,000 square miles) which includes more than two-thirds of the state of Alabama, and portions of neighboring Georgia and Mississippi. U.S. Army Corps of Engineers data from the gauging station on the Mobile River at Mount Vernon show a mean discharge of 16,990 m^3 (60,000 cubic feet) per second for the 25 years from 1940 through 1964. This ranks the contributary river system as the fourth largest in the United States in terms of discharge. This flow is exceeded only by the Mississippi, Columbia and Yukon. Unlike these other rivers, however, this large volume of water is funneled into a relatively small estuary, Mobile Bay, creating a unique site for the study of the interactions of a fluvial-estuarine system.

The rivers draining into Mobile Bay flow through a variety of terrain and rock types (Fig. 1).

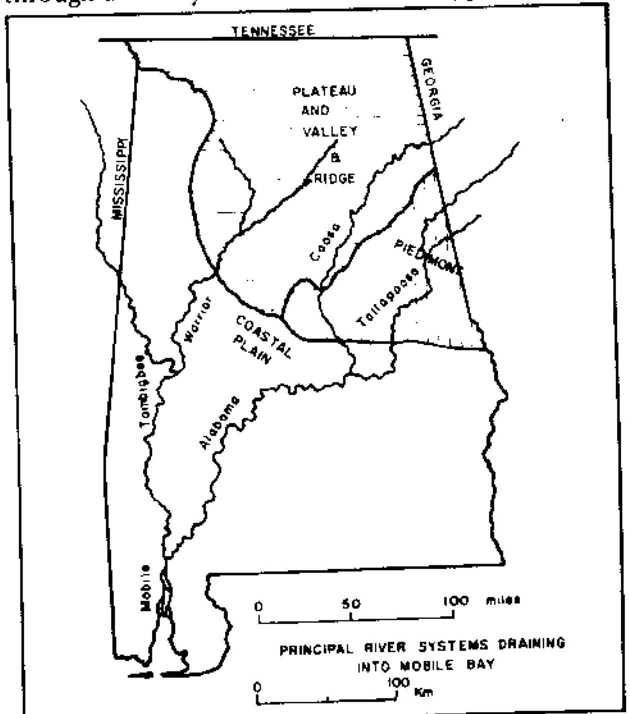

Figure 1. Principal River Systems Draining into Mobile Bay, Showing the Three Terrains in the Drainage Basin: (1) Piedmont, with igneous and metamorphic rocks; (2) Plateau and Valley & Ridge, with consolidated Paleozoic sedimentary rocks; and (3) Coastal Plain with Cretaceous and Cenozoic sedimentary rocks and unconsolidated sediments.

On the west, the Tombigbee flows through the sediments and sedimentary rocks of the Coastal Plain, following the outcrop of the Selma Group marls and chalks for much of its length. The principle tributary of the Tombigbee, the Black Warrior River, flows out the plateau area, generally through the Paleozoic sandstones and shales that make up the plateaus. The Alabama River is formed on the Coastal Plain by the confluence the Coosa and the Tallapoosa rivers, both of which have their headwaters in northwestern Georgia. The Coosa drains the area of the folded Appalachians, flowing largely down limestone valleys, between sandstone ridges. The Tallapoosa River drainage is largely in the older metamorphic and igneous rocks of the Piedmont, and brings a far different suite of heavy minerals into the Mobile basin.

The heavy mineral suite of the sediments in the Alabama River consists largely of four minerals: hornblende, ilmenite, garnet and kyanite, in order of abundance. This is in some contrast to the heavy mineral suite of the Tombigbee sediments, which consists of ilmenite, kyanite, staurolite and leuxocene. Possibly a more detailed study of the heavy mineral suites of these principal rivers, and the changes in heavy mineral percentages in the Bay sediments, as seen with depth, could afford some idea of the history of the drainage into Mobile Bay. Certainly there have been profound changes in the depositional regime during the past few thousand years, and even within the last century.

The longer term changes reflect the melting of the Wisconsin ice sheet, and the rise in sea level that accompanied that melting. Mobile Bay itself was formed as sea level rose and covered the flood plain of the ancestral Mobile River. Carlston (1950, p. 1128) points out that, "Opposite the mouth of the Bay and the western tip of Mobile Point is a submerged arcuate delta, which has a base about ten miles wide and extends four miles out into the Gulf. Because the top of this submerged delta is also about ten to eleven feet below mean low water, it is evident that it is a delta of the Mobile River and of the same age as the submerged valley of the river.

These features indicate that the most recent event in the Pleistocene history of coastal Alabama was the submergence up to the present sea level of a river valley and delta formed during post-Wisconsin time. This recent rise in sea level was ten to eleven feet." This eleven-foot rise, used by Carlston, is only the latest in a whole series of post-Wisconsin sea level rises. Poag (1973) reviews the data for late Quaternary sea levels in the Gulf of Mexico. He also points out that the present knowledge of these fluctuations is considered inadequate.

The sedimentation which formed the present-day Mobile delta accompanied this rise in sea level, and represents the infilling of a much longer bay that extended essentially to the present location of Mt. Vernon, Alabama. This infilling of the Bay is proceeding still but probably at a greatly reduced rate. The rate would gradually begin to decrease as sea level rose, and the original Bay began to fill. Two sets of events brought about by human activity in much more recent time have had a profound effect on bay sedimentation.

The first of the human factors was the introduction of agriculture on a large scale by European settlers. As they cleared away the forest and plowed the land, there was undoubtedly a marked increase in the runoff and erosion rates, and consequently in the amount of sediment being supplied to the Bay. However, in the present century there has been a trend toward less extensive farming, with much more of the land being in forests and pasture throughout the drainage basin. Although there are not the data to prove a reduction in the rate of sedimentation, it is logical to conclude that such a reduction has taken place.

An even more complete reduction in the amount of sediment being carried by the rivers has been brought about by the construction of dams along all of the major streams of the Mobile River system. There are over twenty dams on these streams now, with more planned. Each of these dams acts as a sediment trap. Since the southernmost of these dams are at Claiborne on the Alabama River, and Coffeeville on the Tombigbee, the area still actively supplying sediment to Mobile Bay has been reduced to a minute fraction of the drainage basin.

Other human activity, such as dredging and filling within the Bay has tended to rearrange the sediment distribution, and drastically affects some local areas of the Bay, but does not greatly change the overall sediment budget.

SEDIMENTATION

Previous Work

Before 1969, little had been published on the sediments of Mobile Bay. Certainly there had been no comprehensive study. In 1969, John Ryan published a paper entitled "A Sedimentologic Study of Mobile Bay, Alabama," in which he summarized the results of the most extensive and comprehensive study yet undertaken in the Bay itself. He took a total of 310 grab samples, using the upper 5-8 cm (2 or 3 inches) of sediment to produce the data and maps illustrating the distribution of sediments within the Bay and surrounding areas. Since that time, other studies have produced additional data on sediment transportation and deposition within the Bay. The most complete of these is entitled, "Shoreline and Bathymetric Changes in the Coastal Area of Alabama: A Remote-Sensing Approach," and was prepared by the Geological Survey of Alabama for the Alabama Development Office and the Alabama Coastal Area Board. Certainly, within the last decade more has been written concerning Mobile Bay, from the sedimentologic standpoint, than had been written in all previous times, and studies are continuing at an ever-increasing rate. The acceleration of interest has accompanied the growth in awareness of the value of the estuarine environment, and the understanding of the necessity of managing that environment for the greatest public benefit.

Studies of other factors closely related to sedimentation, such as circulation within the Bay, have also been undertaken at an accelerated rate, and will be invaluable to a more complete understanding of the ever-changing sedimentologic environment.

Circulation

The water currents that produce the circulation within the Bay are directly related to the sediment distribution. The direction and velocity of the currents determine the areas that are eroded, the transportation of the various sizes of sediment, and the sites of deposition of the various sizes and types of sediment. If the circulation were simple, then the distribution of the sediment could not only be easily understood, but could be predicted. However, the circulation patterns within the Bay are not simple, and while there are general circulation patterns, the details are most complex. There are several variables that affect the circulation, and these variables have wide ranges, in some cases almost infinitely wide ranges. Austin (1953, p. 35) summed this up nicely in his study of the circulation of Mobile Bay. "The circulation of any water body is probably the most important feature in the explanation of mixing and flushing for that water mass. At the same time it is certainly the most difficult feature to explain satisfactorily for any water body, partially enclosed in an irregular basin and complicated by many various and sundry natural effects. River flow, tides, wind, topography, density differences, evaporation, depth, bottom roughness, internal waves, and surges are but a few of the variables entering into the explanation of the circulation in an estuary."

Lawing et al. (1975) pointed out that "the surface water in Mobile Bay exhibits a net counterclockwise movement due to the interaction of the flood tides entering the Bay from Mississippi Sound and the Gulf of Mexico with the freshwater inflow entering from the Mobile River system. These conditions combined with the natural Coriolis effects, which influence currents in large estuaries, accentuate the movement of water flowing down the Bay in the direction of and along the western shore, where it returns to the Gulf and Mississippi Sound." Hill and April (1974) showed somewhat different results from their study of a hydrodynamic and salinity model for Mobile Bay. Their model, quite naturally, was somewhat idealized, and while it presents the general flow characteristics, did not show the almost infinite variations that are possible. Certainly the simplified flow that their model showed does not fit the pattern of sediment distribution shown by Ryan (1969, Fig. 17, p. 82).

Austin (1953) showed a much more complicated flow pattern, especially with the flood tide (Fig.

Figure 2. Streamlines of Velocity—Flood Tide Surface Currents. As shown by Austin (1953) for tides in October, 1952.

that he showed in this circulation pattern more closely correspond to the sediment distribution. Although Austin did show some of the complexities of the circulation, he realized that his study was only a beginning. In the first place, the study was conducted during a time of abnormally low stream flow (Austin, 1953, p. 14), and secondly, the short time period of the study produced only meager data (Austin, 1953, p. 49). To get a realistic picture of the circulation would take a study over many years, with both normal and abnormal weather conditions, and through all of the changing seasons.

As previously mentioned, studies of the circulation within the Bay are continuing. Hill and April, the Corps of Engineers and the personnel of the Dauphin Island Sea Lab are currently working on various aspects of the circulation patterns, and a great deal of data have been collected that are not yet generally available.

Sediment Distribution

Sediments in Mobile Bay include all sizes of clastic material from relatively clean sand to relatively pure clay, plus various admixtures of sand, silt and clay. This distribution, as mapped by Ryan (1969, p. 82), is shown in Figure 3. In this figure

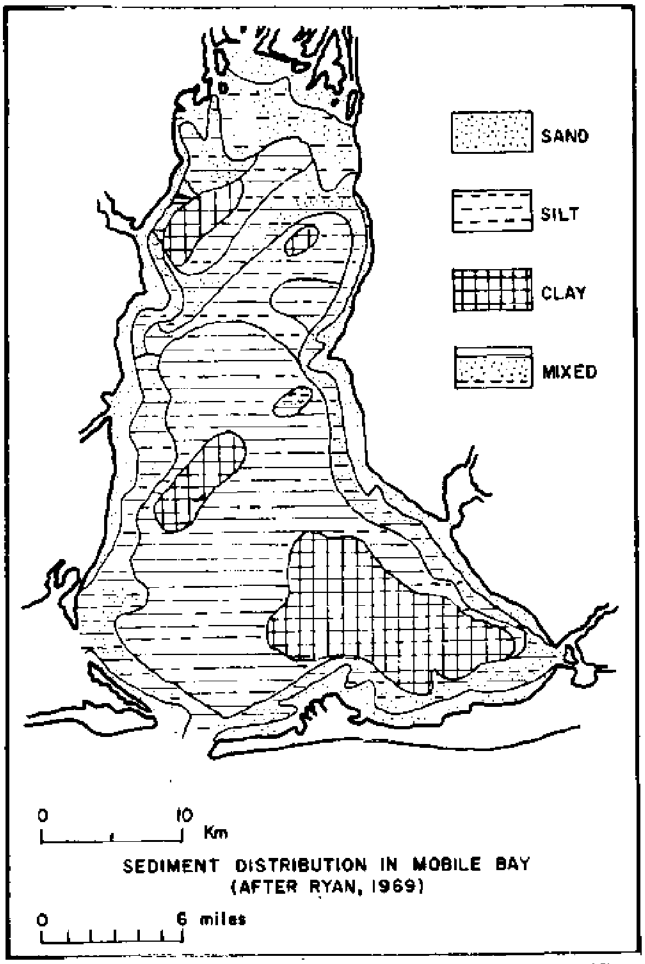

Figure 3. Sediment Distribution in Mobile Bay, Modified from a Map by Ryan (1969).

the admixtures are shown generally with silty sand being shown as more sand and less silt, etc. The sand in the upper reaches of the Bay, and around the periphery, is indicative of the relatively strong currents and shallow waters in those areas. The large areas of clay deposition show low energy areas, and would generally confirm the presence of eddy currents that cause these areas to be bypassed by the general sediment flow. The areas of mixed sediment sizes are taken to be areas in which the currents are variable, with the coarser sediment admixtures indicating stronger currents in those portions of the Bay. Since the circulation within the Bay is so variable, and the sediment distribution directly dependent upon the circulation, the sediment distribution will give a more complete picture of the average circulation over long periods than any other method of short-term sampling. It would not, of course, illustrate the range of variations, or deviation from the average. Preliminary data, from samples collected in May 1979 (Isphording and Lamb, unpublished data) indicate a significantly larger percentage of clay than Ryan (1969) reported. As this difference became apparent, core samples were taken to ascertain the possiblity of this reflecting a change in sedimentation over the intervening years. When samples from the top and bottom of a 0.5 meter core showed no change in grain size, another explanation was sought. At this time, the most plausible is that the difference reflects the different techniques used. Ryan (1969, p. 42) used Coulter Counter analysis for the finer sediments. As pointed out by Behrens (1978, p. 1215), "pipette means are finer than Coulter Counter means, and the finer the size, the greater the difference." It is predicted that the areas shown as clay will be expanded on future maps.

The pattern of sediment distribution, shown in Figure 3, closely parallels the pattern of distribution of the benthic molluscs as shown by Chermock et al. (1974, p. 109). Here, as in the sediment distribution map, there is a strong NE-SW trend across the middle of the Bay, reinforcing the evidence for a counterclockwise eddy flow in the lower part of the Bay.

Both Ryan (1969) and Hardin et al. (1975) presented bathymetric evidence which shows that the rate of sediment accumulation in the Bay is averaging approximately 0.5 meters (1.6 feet) per century. Hardin et al. divided the Bay into an upper and lower portion and showed that the rate of sediment accumulation in the two areas was different. They cite the rate of filling for the upper Bay as being 0.58 meters (1.9 feet)/100 years between 1852 and 1920, and showed that this rate has decreased to 0.30 meters (1 foot)/100 years between 1920 and 1973. In the lower Bay the rate of filling was 0.41 meters (1.3 feet)/100 years in the period from 1852 to 1920, and increased to 0.71 meters (2.3 feet)/100 years in the period from 1920 to 1973. The change may have resulted from diminished amounts of sediment being brought into the upper bay from the rivers, and some of the upper Bay sediment being redistributed by currents, and finally deposited in the lower Bay area.

With the development of more sophisticated remote sensing techniques, their use in studying the circulation and sedimentation within the Bay looms as a distinct possibility for future studies. Atwell and Thomann (1973) collected data that allowed a comparison of remote and conventional measurements of temperature, salinity and chlorophyll content of the water of Mississippi Sound. Although the agreement was not perfect, their analysis indicated that such measurements by remote-sensing methods are a real possibility. Moore (1978) discussed some of the problems in satellite surveillance of water bodies and the use of turbidity as an index of stream flow and other currents in circulation and sedimentation. Coker et al. (1978) offered the possibility of the use of multispectral imagery in measuring the amount and type of material in suspension in turbid waters.

The Landsat-1 imagery used by Hardin et al. (1975, p. 138-148) pointed out a major problem in the use of remote sensing techniques. No two of the eleven photographs that were used showed the same pattern of currents and suspended sediment. Vast amounts of data would have to be taken from the interpretation and sediment movement. As an example, Figure 4 shows a large amount of sediment in suspension in the lower portion of the Bay, with some sediment moving south from the northeast and northwest quadrants of the Bay. Figure 5 is a computer-enhanced density slice of the same image, which divides the image into eight classes of tonal quality, facilitating a more quantitative interpretation. These images represent the conditions in the Bay only at the time they were taken. Later in the same day, con-

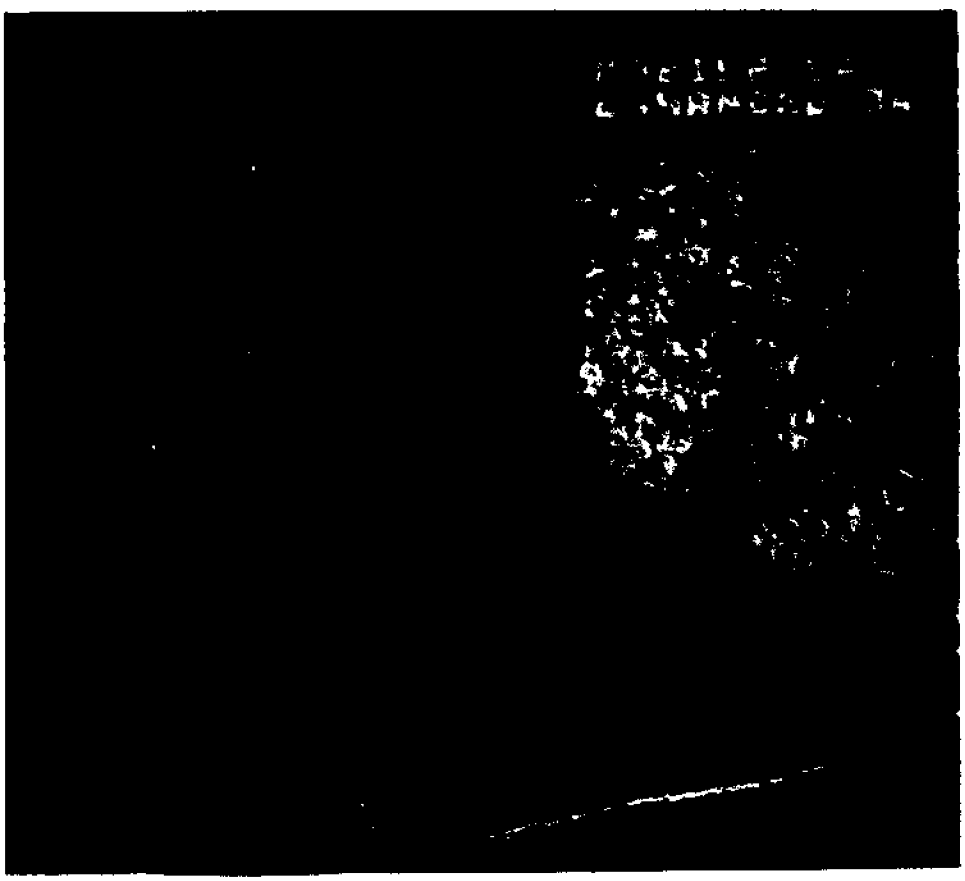

Figure 4. Landsat 1 Photograph, Enhanced to Show Color Contrast in Suspended Sediment in Mobile Bay, 17 November 1973.

Figure 5. Computer Enhancement, Density Slice of the Same Landsat I Photograph Used in Figure 4.

ditions of wind, tide, river flow, etc., would present a completely different situation. The number of images, and the data to be taken therefrom would be prohibitively large at the current level of technology and knowledge. The possibilities for the use of more remote sensing in the future are real, however.

SUMMARY AND CONCLUSIONS

Ryan (1969) presented the first comprehensive map of sediment distribution in Mobile Bay. There are currently few additional data to show whether this has changed within the last decade. Such a study would be useful in providing data for an understanding of the dynamics of the Bay environment. Studies of circulation and currents within the Bay are basic to this understanding, and are presently proceeding at an accelerated pace. As these data become available, they will supplement the surface sediment distribution data to show present conditions. A study of sediment changes with depth would be necessary to evaluate changes through a longer time period, and such a study could be used to ascertain the sedimentological setting before the advent of man and his various influences on inflow into the Bay.

Although there are some data on the geochemistry of the Bay sediments now being collected, most of the data are confined to rather small areas. From the standpoint of knowing the fate of some of the more exotic chemical elements which are being introduced into the Bay, a study of the geochemistry of the Bay sediments should be undertaken. In such a study, the affinity of these exotic elements for various types and sizes of sediments should be examined in detail, and changes in the abundance of such material at depth within a core sample would give a historical background to build upon.

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MINERALOGY AND CHEMISTRY OF MOBILE BAY SEDIMENTS

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ABSTRACT

Samples from 10 bottom cores obtained in the southwestern area of Mobile Bay were analyzed for particle size distribution, clay mineralogy, and major element and trace element chemistry. Pearson correlation coefficients were calculated to determine the degree of apparent inter-relationship between each of the mineralogical and textural variables versus the individual chemical elements. Multiple regression analysis was also used to calculate partial regression coefficients for the purpose of deriving equations that can be used to predict trace metal abundances using only textural and mineralogical data. Four successful equations resulted that permitted prediction of copper, lead, vanadium, and zinc in the bottom sediments of the study area.

INTRODUCTION

Mobile Bay is the primary depositional basin for the sixth largest river system in the United States. The rivers that discharge into the Bay drain a watershed of more than 110,000 km^2 (43,000 square miles), which includes over two-thirds of the State of Alabama, and portions of neighboring Georgia and Mississippi, as well. The mean discharge of some 2,000 m^3/sec (72,000 cubic feet/second) (Crance 1971) ranks the contributary river system as the fourth largest in the United States, in terms of discharge, exceeded only by the Mississippi, Columbia, and Yukon (Ryan 1969). Unlike these other river systems, however, this large volume of water is funneled into a relatively small estuary (Mobile Bay) where it annually contributes in excess of 7,250,000 mt (8,000,000 short tons) of suspended sediment to the Bay.

In spite of the Bay's unique setting, relatively little work has yet been carried out to define the mineralogy of the bottom sediments and to integrate this information with the mineral chemistry of these sediments. Previous investigations have been directed either toward textural and mineralogical studies of the sediments (Ryan 1969) or have involved trace metal studies of the water or sediments themselves (Brannon et al. 1977, May 1973). The purpose of this study was, therefore, to collect data on the texture, mineralogy, major element chemistry and trace element chemistry of Bay sediments and to determine the degree of inter-relationship among these variables.

LABORATORY ANALYSIS

A series of 10 box core samples was acquired from an area in the southwestern portion of the Bay (Figure 1) and returned to the lab where sieve and hydrometer analyses were carried out to determine the size frequency distribution. The actual sample locations were centered about the present Mobil Oil Corporation test well, with two one-quarter m box cores collected at each of five sites.

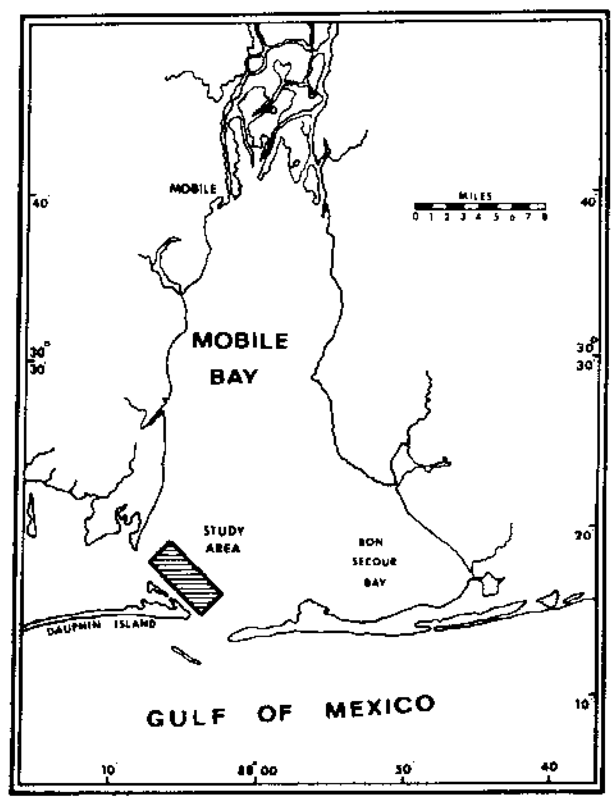

Figure 1. Map of Mobile Bay, Alabama Showing Location of Study Area.

Samples one and two were collected 500 m (1,640 feet) northeast of the drill site, samples three and four, 500 m due north of the site, samples five and six, 1,500 m (4,920 feet) due north of the site, samples seven and eight, 1,500 m northwest of the drill site, and samples nine and ten, 1,500 m southeast of the test well. X-ray diffraction analyses were run on the clay-size fraction (less than 4 micron) using a Philips X-ray Diffraction System equipped with nickel-filtered, copper k-alpha radiation. Estimates of mineral percentages were based on the "half height" peaks of each of the constituents corrected using a "mica factor" procedure developed by Lodding (unpublished, Rutgers University). The accuracy of this technique has been extensively tested by internal standard calibration curves and shown to yield a precision of, plus or minus, 10%. Whole rock (i.e., complete digestion) chemical analyses were carried out on the clay-size fraction by fusing each sample with lithium tetraborate and then analyzing for specific elements using a Perkin-Elmer, Model 460, Atomic Absorption Spectrophotometer. Analyses for the individual elements were based on standard Atomic Absorption procedures recommended by the instrument manufacturer. A baseline for each element was obtained by zeroing the instrument with a blank which was prepared by dissolving lithium tetraborate in distilled and deionized water. A minimum of 10 readings was obtained for each element and the average of these was used in calculating the elemental abundance.

RESULTS OF ANALYSES

Size Analysis

Representative size frequency gradation curves for samples used in this study are shown on Figure 2 and reflect the variability of sediment textures found in the Bay. Textures range from almost wholly sand-sized material down through fine, silty clays, and the texture of any one sample is largely a function of where in the Bay sampling was performed. Though Ryan's (1969) map shows several large areas for which the bottom sediments are designated "clay" and "silty clay," detailed examination of his raw data revealed that the sediment textures within these areas were far from homogeneous. Some idea of the overall textural variation observed within the Bay may be seen on the ternary diagram (Figure 3), which shows the sand, silt, and clay percentages plotted for the 215 Bay samples that were used in Ryan's study. It is interesting to note that from a statistical standpoint, and assuming that all the samples were collected using a randomized sampling procedure, the variability observed in the mean diameter of the

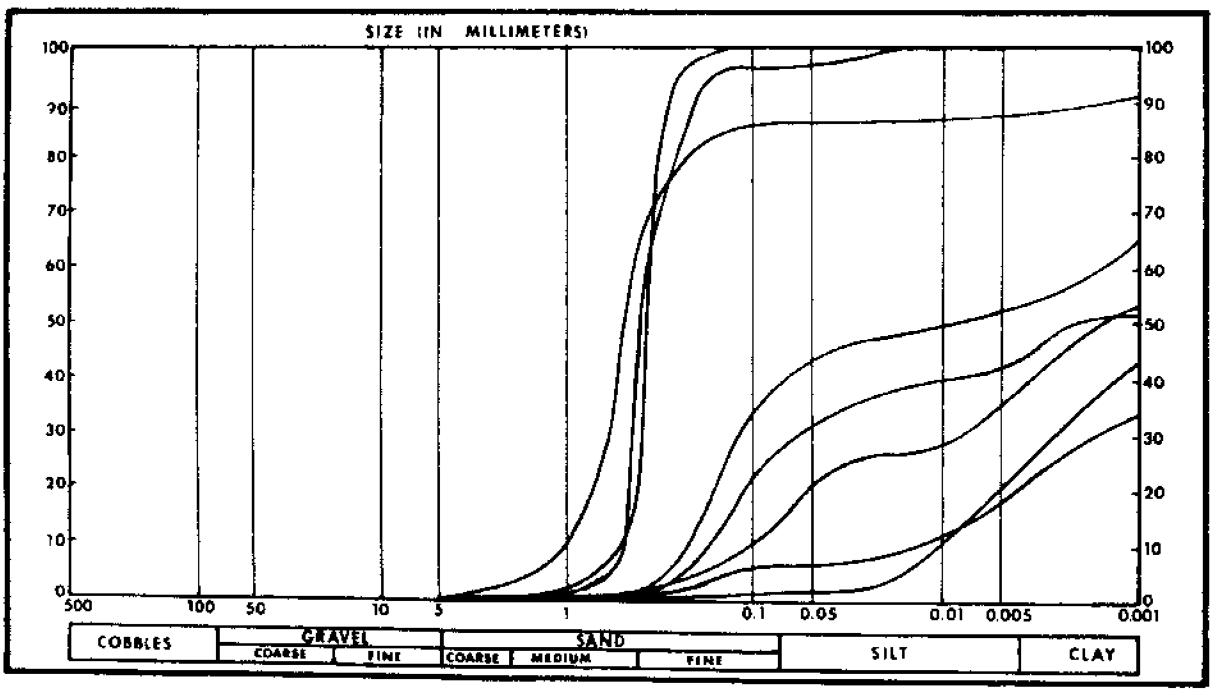

Figure 2. Cumulative Frequency (gradation) Curves of Bottom Sediments Collected in Study Area.

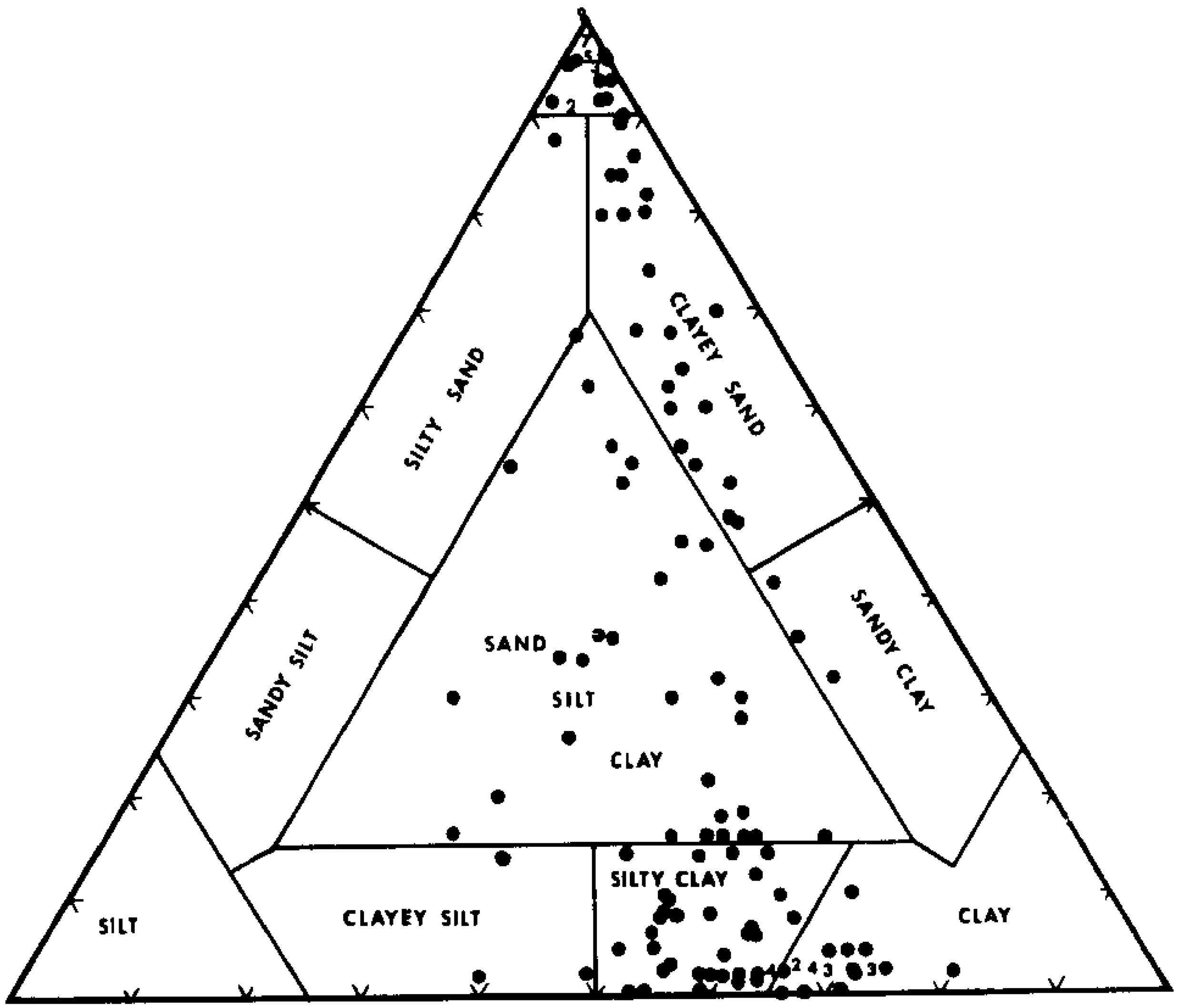

Figure 3. Sand-Silt-Clay Ratios of 215 Bottom Sediments from Mobile Bay (data from Ryan, 1969).

215 samples suggests that approximately 450 samples would be necessary to allow the mean diameter of any one sample collected in the Bay to be estimated to an accuracy of, plus or minus, one-half phi unit. Because less than half this number were used in Ryan's study, care should be used in the interpretation of his map and in drawing conclusions about sediment trends from the map.

Though no tendencies were observed for any specific clay minerals to be associated with samples containing different percentages of clay-, silt-, or sand-sized material, there was an expected strong tendency for certain metals to be found with samples having a greater percentage of fine silt and clay. The significance of this will be discussed in a later section of this paper.

Clay Mineral Analysis

The 10 samples were prepared for X-ray diffraction analysis by sedimenting approximately 90 mg of clay-sized material on glass slides so as to produce a thickness of between 0.07 and 0.12 mm. This thickness has been found to produce minimum background by X-ray scattering and to yield optimum diffraction patterns (Carroll 1969). Additional slides were also prepared so that the effects of heating and glycolation on the clay mineral species could be observed.

The analyses revealed that the bottom sediments are relatively homogeneous throughout the study area, with respect to mineral composition, and consist, almost wholly, of montmorillonite, kaolinite, and clay mica (illite). Though illite was eported by Ryan (1969) as present in the Bay edimcnts only in low concentrations, the mineral vas found in each of our 10 samples in amounts :xceeding 8% (Table 1). Other samples analyzed by .he authors, but not used in this study, indicated :hat the mineral may make up as much as 25% of :he clay mineral fraction. Halite and quartz were also observed in some samples as were also trace amounts of mixed layer clays.

The importance of the clay-sized fraction and the individual clay mineral species, themselves, lies in the fact that, with minor exception, these are the "sumps" that concentrate and remove many trace metals from solution. Most clay minerals have a crystal lattice consisting of repeating units of either two-layer or three-layer sheets (Grim 1953). Kaolinite is a two-layer clay and is made up of one sheet of silicon atoms tetrahedrally co-ordinated with oxygen (the "tetrahedral layer"), which is combined with a second sheet in which aluminum is octahedrally coordinated with both oxygen and hydroxyl ions (the "octahedral layer"). Hydrogen bonds and residual Van der Waals bonds between these repeating two-layer units hold the adjacent two-layer groups together and form a lattice characterized by a minimum of atomic substitution and, consequently, low cation exchange capacity of approximately 3 to 15 meq/100 g. Montmorillonite and clay mica (illite), in contrast, are three-layer clays having two tetrahedral layers sandwiched about one octahedral sheet. In both of these minerals, some of the silicon atoms in the tetrahedral layer are replaced by aluminum and, similarly, aluminum in the octahedral layer can be replaced by a number of different ions, such as iron, zinc, nickel, lithium, magnesium, etc. As a consequence of this substitution, the chemical neutrality of montmorillonite is disrupted, resulting in unbalanced charges on the three-layer sheet that are, in part, balanced off by the acquisition of ions such as calcium and sodium in inter-layer exchangeable ion sites. This provides montmorillonite with an extremely high cation exchange potential and values of 80 to 150 meq/100 g are commonly reported. Somewhat less substitution takes place in the octahedral and tetrahedral sites in the clay mica (illite) lattice and this, coupled with the stronger bonding of adjacent three-layer groups resulting from inter-layer potassium ions, forms a lattice that lacks the high cation exchange of montmorillonite. Values of approximately 10 to 40 meq/100 g are usually observed (Millot 1970). The range of cation exchange capacities (c.e.c.) from 40.7 to 49.8 obtained by Brannon et al. (1977) for eight Mobile Bay clay samples would, itself, suggest that the Bay sediments are dominated by montmorillonite, but with other clay species of lower exchange capacity also present. This conclusion is, therefore, in excellent agreement with the X-ray diffraction data presented in Table 1.

The combination of exchangeable ion sites, lattice defects, and broken-bond sites thus allows clay minerals to attract a large number of trace metal species and to remove these from solution. In addition, many other metals associated with the clay mineral fraction either adhere to the surface of the clay particles in the form of organo-metallic chelated compounds (Knezevic and Chen 1977) or are trapped at the time of deposition in pore waters between the clay mineral platelets. The environmental importance of metals partitioned in these

Table 1. Relative Mineral Percentages for Mobile Bay Samples as Determined by X-ray Diffraction Analysis for Clay-sized Fraction (-0.004 mm).

Sample Number	MONTMORILLONITE	ILLITE	KAOLINITE	QUARTZ	HALITE
1	56	13	22	1	8
2	58	13	23	2	5
3	52	10	20	1	17
4	42	8	15	1	34
5	55	12	19	1	14
6	54	14	20	1	14
7	43	10	16	Tr	12
8	40	11	15	1	30
9	52	9	17	1	32
10	61	12	19	1	21

various forms lies in the fact that not only do the clay minerals remove metals from solution but, in many cases, retain these ions in a manner such that subsequent release back into solution is also possible (Lee and Plumb 1974, Wakeman 1976, Lu and Chen 1977). A number of factors have been identified that may trigger such re-mobilization of the trace metals. Among these are dredging operations, which cause release by disruption of Eh (oxidation-reduction conditions), burial of the sediments, which squeezes out the pore waters, and a number of forms of biological activity. Thus, detailed environmental studies should contain information not only on the metal content of the water column, but also on those metals present in the form of adsorbed ions on clay mineral platelets, in exchangeable ion sites in the clays and as structurally coordinated ions within the clay mineral lattice itself (Brannon et al. 1977).

Chemical Analyses

A summary of the major element chemistry for the samples analyzed in this study is shown in Table 2. The abundances of the major elements, expressed as oxides, are consistent with the minerals observed on the X-ray diffractograms, except that no minerals were present that would account for the "excess" iron and titanium found. To account for these, the oxide analyses were submitted to a computerized sedimentary normative mineral analysis routine (Isphording and Kibler, manuscript in preparation) which "partitions" the oxides into a series of standard normative minerals and calculates the percentages of these minerals that would be consistent with the chemical analyses. All minerals observed on the diffractograms were calculated to be present in approximately the abundances observed but, in addition, two other minerals, rutile (TiO_2) and limonite ($HFeO_2$), not found on the diffractograms, were also predicted to be present. Limonite was calculated present in amounts of approximately 4% and rutile at somewhat less than 1%. Because X-ray diffraction analysis will generally not detect a mineral whose presence is less than 1%, neither of these minerals would be expected to appear on the diffractograms. Because the bottom sediments characteristically display a large negative Eh, the excess iron, rather than occurring in the form of the oxidized mineral limonite, probably exists largely in the ferrous state, either in the form of a fine-grained disseminated sulfide phase or as a constituent of the mineral ilmenite ($FeTiO_3$). The latter is the most abundant heavy mineral species present in most central Gulf Coast sediments and frequently makes up 50%, or more, of the heavy mineral fraction (Isphording and Flowers 1979). Heavy minerals ("black sands") are those minerals present in the sand-sized fraction in trace amounts (usually less than 1%) whose specific gravities exceed 2.85. The presence of this mineral would also account for the "excess" titanium observed in the sample analyses.

Table 2. Major Oxides (%) of Clay-sized Fraction of Mobile Bay Bottom Sediments.

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O^{-}*	H_2O^{+}**
1	50.23	20.55	6.85	1.49	1.08	0.48	1.52	0.57	3.78	12.93
2	48.15	22.52	6.99	1.50	0.72	0.41	1.46	0.45	4.01	12.40
3	50.68	21.65	6.81	1.49	1.14	0.50	1.48	0.47	5.14	12.28
4	52.92	19.32	6.75	1.50	1.44	0.47	1.46	0.45	3.86	11.88
5	47.31	21.28	6.55	1.52	0.48	0.46	1.42	0.42	5.16	12.15
6	45.92	20.43	7.21	1.49	0.54	0.44	1.46	0.45	5.15	11.72
7	46.20	22.19	7.59	1.53	0.60	0.38	1.39	0.43	5.69	12.20
8	48.00	20.01	7.32	1.52	0.60	0.56	1.42	0.44	4.56	11.61
9	46.96	17.70	7.12	1.52	1.26	0.82	1.38	0.50	4.28	12.31
10	49.23	18.42	7.59	1.41	1.26	0.55	1.37	0.50	3.25	12.08

* L.O.I. (Loss on ignition) @ 100°C (1 hour)

**L.O.I. @ 1,000°C (1 hour)

Trace elements in the clay-sized fraction (Table 3) were found in similar abundances as those reported in other studies dealing with Mobile Bay. Zinc was present in amounts averaging 101 ppm whereas samples collected near our sites by May (1973) were reported to contain 92 ppm. Similarly, manganese averaged 786 ppm in our 10 samples, whereas Brannon et al. (1977) reported an average of 837 ppm for surface samples collected in the Arlington Ship Channel in northern Mobile Bay. Chromium values in our 10 samples appear to be anomalously high, however, at 250 ppm when compared with the 50 ppm figure reported by May (1973). The most likely explanation for our higher values is that: (1) May's analyses were for the total sample (sand, silt, and clay fractions), whereas our values are for the clay-sized fraction only and (2) chromium, similar to a number of other heavy metals, has a greater affinity for the clay-sized fraction of sediments where it occurs in the octahedral sites in various clay mineral species and attached to the surface of the clay platelets as organo-metallic chelated compounds. The same argument would also explain the higher values of copper observed in our samples.

STATISTICAL ANALYSIS

Pearson correlation coefficients were calculated for each of the trace metals versus the percentages of the various clay mineral species present, the gravel, sand, silt, clay abundances, the median diameter and the organic content of the sediments (Table 4). As expected, strong, positive correlations were found between the heavy metals Cr, Cu, Pb, Hg, Ni, Va, and Zn and the percentage of clay in the samples. This is, in part, due to the ionic substitution of the metals for magnesium, aluminum, and silicon in the clay mineral lattices and also results from the reaction of some of the metals with organic material, which is more abundant in fine grained sediments (Krauskopf 1967). That a significant percentage of these metals may be occurring as metallic chelates attached to the clay platelets is suggested by the lack of strong correlation of these metals with any particular clay mineral species and their moderate to strong correlation with organic content. This supports the earlier conclusion of Brannon et al. (1977), where, in a careful study of the site partitioning of metals in bottom sediments from northern Mobile Bay, sizeable percentages of copper (29-42%) and zinc (38-72%) were identified as occurring as organically-bound phases.

The lack of strong correlation of Ti, Mn, Ba, and Sr with the elevated clay contents can be explained by the fact that titanium is not a common constituent in clay minerals and is more likely to be found in the form of an oxide mineral such as rutile, ilmenite, or leucoxene, occurring in the sand fraction. Manganese, similarly, occurs in the

Table 3. Trace Elements (ppm) of Clay-sized Fraction of Mobile Bay Bottom Sediments.

Sample No.	Mn	Cu	Ba*	Zn	Pb*	Hg*	Ni*	Sr*	Cr	V*
1	768	95	6	110	13	.24	3	69	289	25
2	590	115	6	85	12	.27	5	43	300	26
3	694	135	5	85	8	.11	5	26	264	19
4	752	85	7/120	80	7/11	.10/.26	4/14	28	281	12/12
5	519	70	12	70	15	.19	8	55	215	55
6	529	70	10	110	14	.23	7	64	260	64
7	564	70	10	90	16	.25	6	23	265	23
8	715	105	8	75	18	.28	7	26	240	26
9	1210	75	10	250	20	.47	7	39	230	39
10	1522	80	16	60	19	.27	8	39	160	39

*Partial extraction analyses carried out on entire sand-silt-clay sample.

Values shown after / represent amounts determined for complete dissolution of sample.

Table 4. Pearson Correlation Coefficients for All Trace Elements Versus Percentage of Major Clay Minerals, Percentage of Organics, Sand, Silt, and Clay and Median Diameter of Bottom Samples from Mobile Bay.

	ILLITE	KAOLINITE	MONTMOR.	ORGANICS	GRAVEL	SAND	SILT	CLAY	DIAMETER
TiO_2	0.1596	0.4020	0.4375	0.1625	-0.0765	-0.0520	0.1615	0.0166	-0.1005
MnO_2	-0.2275	-0.1282	0.3294	0.6771	-0.0429	-0.4073	0.5214	0.3379	-0.0938
Ba	0.1238	-0.2228	0.2883	0.6674	-0.2541	-0.6962	0.7624	0.6379	-0.4541
Cr	0.1391	-0.3349	0.0410	0.4930	-0.5494	-0.9024	0.8534	0.8928	-0.6615
Cu	0.1480	-0.2148	0.1746	0.7327	-0.6437	-0.9704	0.9451	0.9552	-0.7603
Pb	0.1690	-0.1914	0.1406	0.7516	-0.6786	-0.9765	0.9353	0.9693	-0.8216
Hg	0.0491	-0.0409	0.1674	0.5893	-0.5490	-0.7626	0.7785	0.7421	-0.6984
Ni	0.1691	-0.1989	0.2445	0.5144	-0.5327	-0.7639	0.7728	0.7442	-0.5158
Sr	0.7528	0.6502	0.6228	-0.1020	-0.02870	-0.1618	0.2597	0.1399	-0.4477
V	0.1620	-0.1213	0.2089	0.7021	-0.7316	-0.9420	0.9439	0.9275	-0.8056
Zn	0.2537	-0.2246	0.1213	0.5448	-0.6765	-0.9310	0.8788	0.9312	-0.7508

form of an oxide mineral and, in combination with barium, may be present as an amorphous equivalent of the mineral psilomelane, $(Ba, H_2O)Mn_5O_{10}$. Its strong, positive correlation with the organic content of the sediments, however, suggests that it is likely occurring in the form of organically-bound, metallic chelate compounds. The very low correlation of strontium with the clay-sized fraction undoubtedly reflects the fact that strontium, when present, has a strong tendency to substitute for calcium in the lattice of carbonate minerals. Because no calcite, aragonite, or other carbonate phases were observed on the X-ray diffractograms, and because the strontium shown on Table 4 represents a partial extraction from the entire sample, rather than from the clay-sized fraction alone, it is probable that the strontium reported is locked up in silt and sand-sized shell fragments.

Finally, the strength of inter-relationships of the trace metals versus the texture, clay mineralogy, and percentage of organics present in the sediments was tested by multiple regression analysis. Each of the trace metals was chosen as the dependent variable (Y) and the remaining variables were considered as independent variables (X_1, X_2, X_3, etc.) that control the magnitude of the dependent variable. A mathematical analysis of the entire data matrix was then carried out in order to solve for the partial regression coefficients (a_1, a_2, a_3, etc.) that allow predicitve equations to be obtained in the form: $Y = a_1X_1 + a_2X_2 + \ldots + a_nX_n$. Each of the metals was individually inserted as the dependent variable to determine if some combination of the mineral percentages, organic content, and percentages of gravel, sand, silt, and clay could be used to predict its abundance in the bottom sediments. A stepwise regression procedure was used in order to exclude from the equation any independent variable whose contribution did not reach a specified significance level. Of the 11 metals tested by the regression routine, successful equations resulted for copper, lead, vanadium, and zinc (Table 5). Each of the four equations possessed high F values for significance, high R^2 values and a small standard error. By way of application, the regression equation would permit the amount of copper (in ppm) to be determined anywhere within the study area by simply multiplying the percent sand by its regression coefficient (-0.115), adding to that the median diameter of the sample, multiplied by its regression coefficient (14.349), plus the percentage of kaolinite multiplied by 0.210, and so forth for the remaining 5 variables, and then adding the "constant" term (5.565). The percentages of lead, vanadium, and zinc could be similarly calculated by multiplying the raw data obtained for each of the variables by their associated partial regression coefficients, plus the addition of the constant. Because only 10 samples were used in this study and the effect of possible inter-relationships among the independent variables was not tested, no functional significance should be placed on the equations given in Table 5. The regression analysis does suggest that various combinations of more easily measured sediment

Table 5. Regression Equations Showing Partial Regression Coefficients and Variables Included by Stepwise Multiple Regression Procedure. Variables are: Percent Organics (Orgs.), Median Diameter (Med. Dia.), Percent Montmorillonite (Montm.), Percent Gravel (Pct. Grav.), Etc.

Y	COPPER	LEAD	VANADIUM	ZINC
a_1	-0.115 (Pct. Sand)	-0.006 (Pct. Sand)	0.111 (Pct. Silt)	-0.297 (Pct. Clay)
a_2	14.349 (Med. Dia.)	0.056 (Pct. Orgs.)	-1.926 (Pct. Grav.)	-2.954 (Pct. Qtz.)
a_3	0.210 (Pct. Kaol.)	-0.111 (Pct. Grav.)	-2.274 (Pct. Illite)	-6.785 (Pct. Grav.)
a_4	-0.182 (Pct. Grav.)	-0.728 (Pct. Illite)	0.345 (Pct. Sand)	-179.793 (Med. Dia.)
a_5	0.020 (Pct. Orgs.)	0.693 (Pct. Qtz.)	3.905 (Pct. Qtz.)	-1.331 (Pct. Silt)
a_6	-0.140 (Pct. Illite)	9.703 (Med. Dia.)	-0.210 (Pct. Orgs.)	-0.859 (Pct. Orgs.)
a_7	0.237 (Pct. Qtz.)	0.534 (Pct. Kaol.)	0.284 (Pct. Montm.)	-0.859 (Pct. Orgs.)
a_8	0.286 (Pct. Clay)	0.282 (Pct. Clay)	-2.028 (Med. Dia.)	3.530 (Pct. Montm.)
constant	5.565	-5.413	47.288	176.271
Standard Error	0.004	0.116	0.380	0.457
R^2	0.999	0.999	0.998	0.998
Tabulated F Statistic ($F_{.05,8,1}$)	238.88	238.88	238.88	238.88
Computed F Statistic	366,251	1,576	671	1,340

properties may exist that would allow those concerned with the distribution of trace metals in bottom sediments to predict such values without resorting to more expensive chemical analyses.

CONCLUSIONS

Analyses carried out on bottom sediments from Mobile Bay indicated that the chief clay minerals present were montmorillonite, kaolinite, and illite. These clays have acted as "traps" for a number of trace elements and have incorporated the metals in inter-layer sites, as organo-metallic chelated compounds and, by substitution for magnesium, silicon, and aluminum, in the octahedral and tetrahedral sites in the clay mineral lattices.

Correlation analyses were used to identify strong apparent relationships between some of the metals and high clay and organic content of the sediments (Cr, Cu, Pb, Hg, Ni, Va, and Zn) and to show that others (Ti, Mn, and Sr) appear to have greater affinities for the sand fraction. Though a complete sampling program for the entire Bay would be necessary to support the conclusion, the data does strongly suggest that potential sites of heavy metal contamination and locations where remobilization of heavy metals might occur during dredging operations can be identified in estuaries such as Mobile Bay by simple reference to a bottom sediment texture map.

Regression analyses were also carried out on the data matrix to determine if combinations of the organic content, percentages of gravel, sand, silt, and clay and percentages of various clay mineral species could be used to estimate concentrations of trace metals in Bay sediments. Though too few samples were available for rigorous statistical testing, the analyses did suggest that the hypothesis was viable, at least for certain trace metals in the study area (Cu, Pb, Va, and Zn).

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THE DISSOLVED OXYGEN PUZZLE OF THE MOBILE ESTUARY

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ABSTRACT

The dissolved oxygen system in the Mobile Estuary remains essentially unknown. Some information is available on the quantitative annual cycle and macro-scale distribution patterns during oxygen depletion periods. Recent unpublished research has provided the first look at oxygen-consuming processes. Virtually nothing is known about oxygen-producing processes, environmental factors responsible for the on-set, maintenance and termination of oxygen depletion periods or meso- to micro-scale distribution patterns during oxygen depletion periods.

BACKGROUND

Little specific information is available concerning the dissolved oxygen (DO) system in the Mobile Estuary (Fig. 1). The small amount of historical data (pre-1970) that can be found in the literature (Loesch, 1960 and Bault 1972) were collected so randomly, either spatially or temporally, that they are of minimal value. Results presented by May (1973) consisted of one figure generalizing the distribution pattern of the lowest DO observations made over the period June through September, 1971. Unfortunately, no field data were presented in May's paper nor was there any reference made to where the data may be archived.

There are three sources of contemporary data that can serve as a first step in understanding parts of the dissolved oxygen system. They are: (1) the reports associated with the 208 wastewater management plan study carried out by the South Alabama Regional Planning Commission (1977); (2) the Physical Environmental Atlas of Coastal Alabama (Schroeder 1976 and 1977); and (3) the final report of the U.S. Army Corps of Engineers sponsored "Theodore Ship Channel Project - Baseline Data Collection" (U.S. Army Corps of Engineers 1979). Drawing primarily from the latter two sources an attempt is made herein to define what is known about the DO system in the Mobile Estuary.

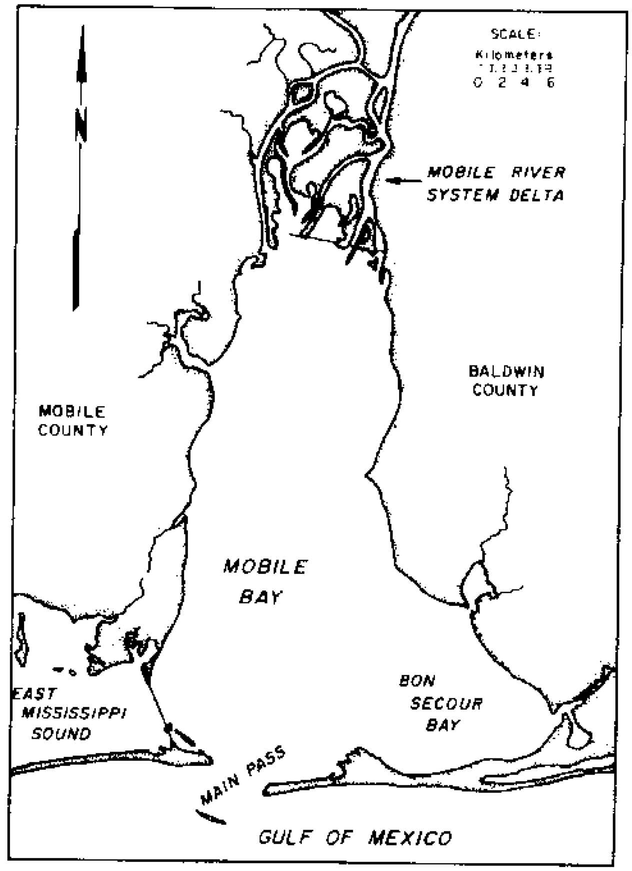

Figure 1. The Mobile Estuary

WHAT WE KNOW SOMETHING ABOUT

Quantitative Annual Cycle

Dissolved oxygen data from East Main Pass and the upper Bay are presented in Figures 2 and 3, respectively. In part (a) of each figure measured concentrations of dissolved oxygen, in mg/l, are plotted versus months of the year while in part (b) of each figure calculated percent saturation values are also plotted versus months of the year. The measured concentrations of DO at both East Main Pass (Fig. 2a) and the upper Bay (Fig. 3a) showed a

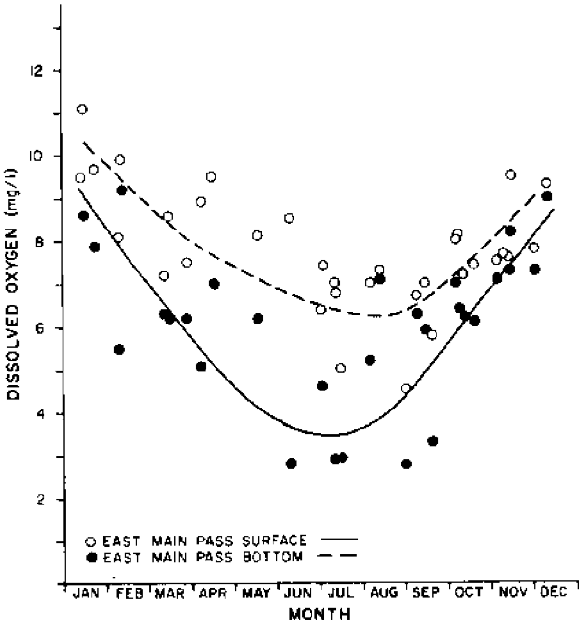

Figure 2a. Measured Concentrations of Dissolved Oxygen at East Main Pass.

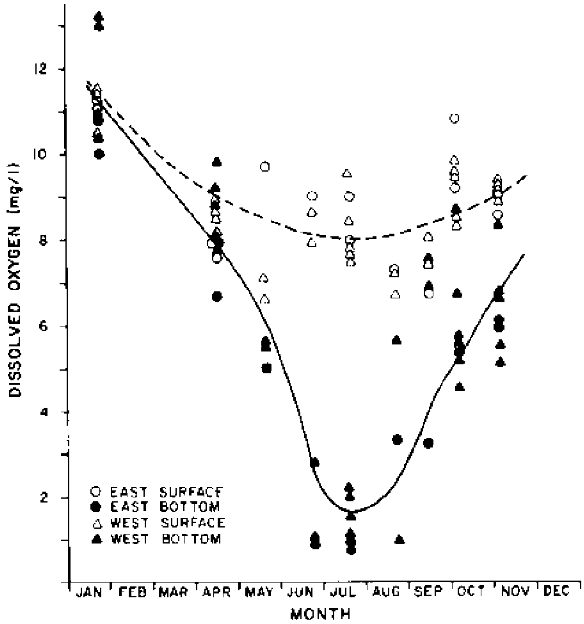

Figure 3a. Measured Concentrations of Dissolved Oxygen at the Upper Bay.

similar annual cycle. Values were generally highest during the period October through March (late fall, winter and early spring) and generally lowest during the period April through September (late spring, summer and early fall).

The surface values at both locations were nearly always a higher measured concentration than the corresponding bottom values. Surface and bottom values tended to be similar during the periods of highest measured concentrations while during the periods of lowest measured concentrations they became widely separated. This latter consideration was particularly true during the months of June, July and August. No apparent east-west differences were observed in the upper Bay data (Fig. 3a).

Calculated values of percent saturation for the two locations (Figs. 2b and 3b) presented a slightly different annual cycle. Seasonal trends for the bottom percent saturation values approximated the measured values depicted in Figures 2a and 3a. However, the surface percent saturation values did not decrease during the late spring, summer and early fall as did the surface measured values (Figs. 2a and 3a) but rather they increased (Figs. 2b and 3b). In fact, in nearly all cases they were the highest values of the year.

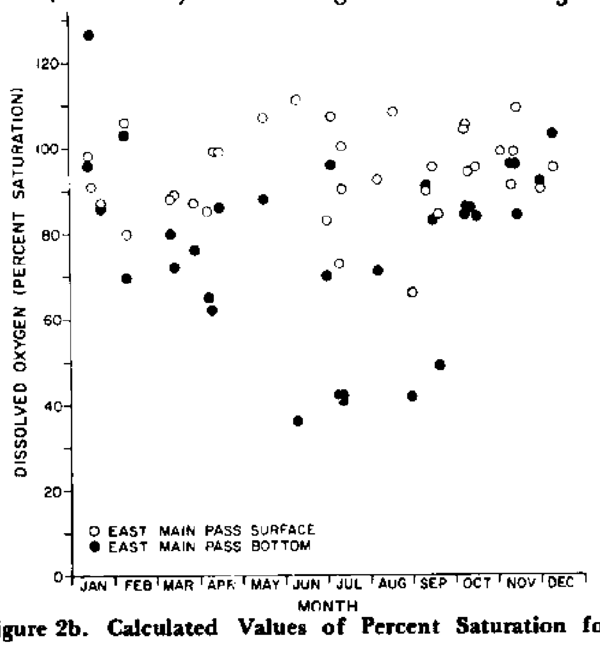

Figure 2b. Calculated Values of Percent Saturation for East Main Pass.

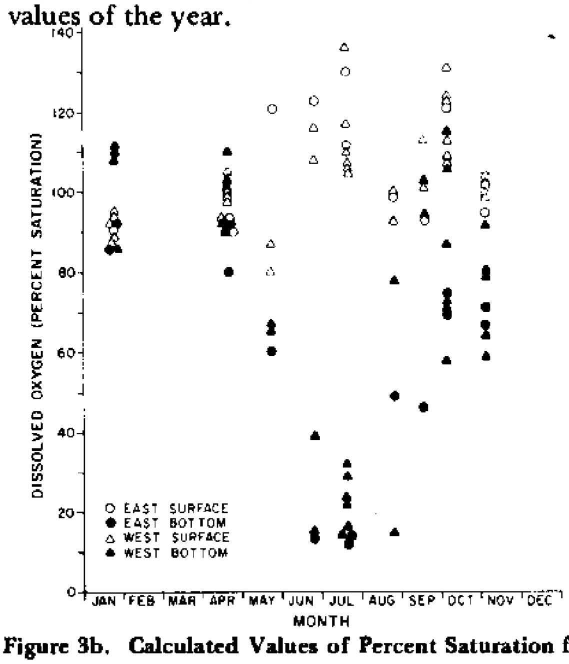

Figure 3b. Calculated Values of Percent Saturation for the Upper Bay.

The difference between measured concentrations of DO and calculated percent saturation values was partially a function of the temperature cycle and differences in salinity concentrations over the annual period. For example, the lower measured values during the summer occurred in waters with high temperatures and likely high salinities and therefore had low solubility capacities for dissolved gases. This means that a low measured concentration of DO during the summer could in fact have had a high percent saturation value. This is very important because low measured concentrations of DO do not automatically suggest stress on the environment.

Macro-Scale Distribution Patterns During Oxygen Depletion

Because of the impact to the local fisheries and the link to the "Jubilee" phenomenon much more interest has been generated towards the structure and behavior of the DO system during periods of oxygen depletion than during any other time. This has resulted in some field data and therefore a little insight into the distribution patterns during these periods.

Bottom DO and bottom salinity fields during and immediately after a very depressed DO period are presented in Figures 4, 5 and 6. The conditions that existed during the depressed period are illustrated in Figures 4 and 5. Both of these figures are presented because Figure 4 has stations which depict the upper two thirds of the Bay including the delta interface while Figure 5 covers the entire Bay except the southwest portion and the delta-upper Bay interface.

Figures 4a and 5a show a large area of depressed DO (< 1.0 mg/l) over most of the middle and upper Bay bottom. This area did not extend into the delta (Fig. 4a) or into the far western side of the Bay (Fig. 4a and 5a), but it did appear to extend very close to or even up to the eastern shore. Two smaller areas of > 1.0 but < 2.0 mg/l concentrations were observed, one extending southeast from the < 1.0 mg/l area into Bon Secour Bay and the other in the very southwest corner of Bon Secour Bay (Fig. 5a).

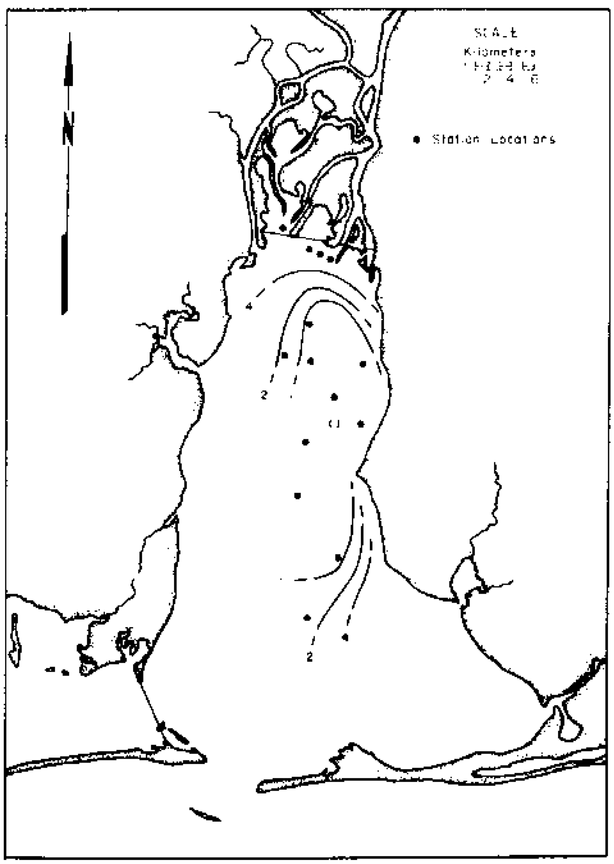

Figure 4a. Stations Showing Dissolved Oxygen Over the Upper Two-Thirds of the Bay.

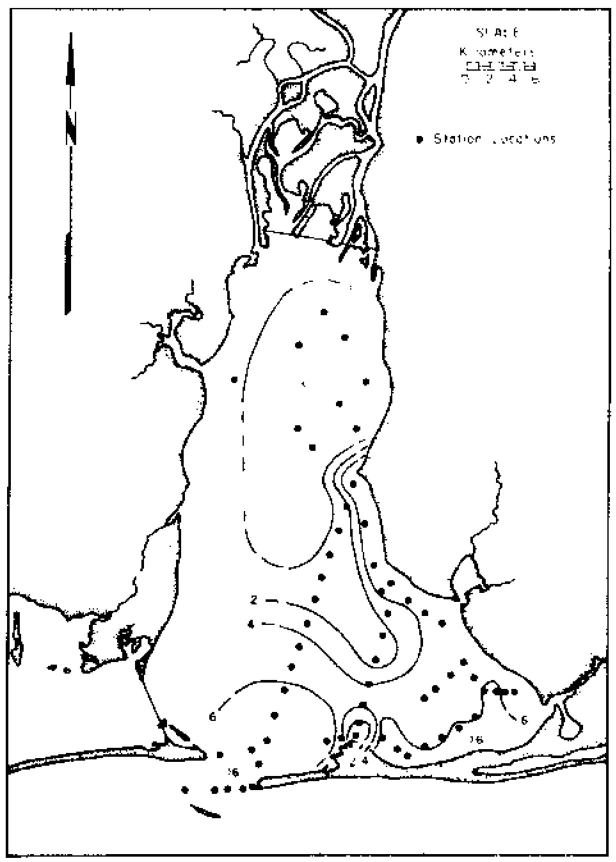

Figure 5a. Stations Showing Dissolved Oxygen Over the Entire Bay.

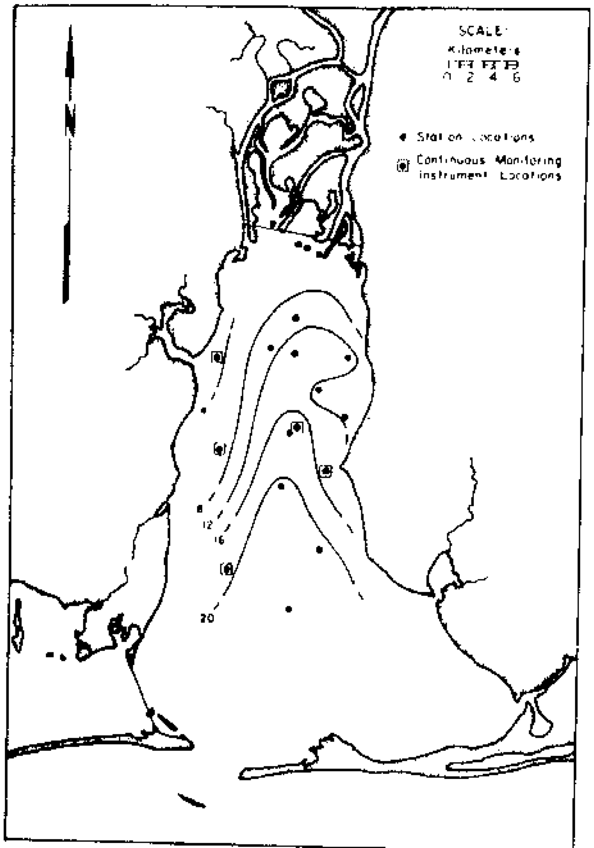

Figure 4b. Stations Showing an Intruding Tongue of High Salinity Water Over the Upper Two-Thirds of the Bay.

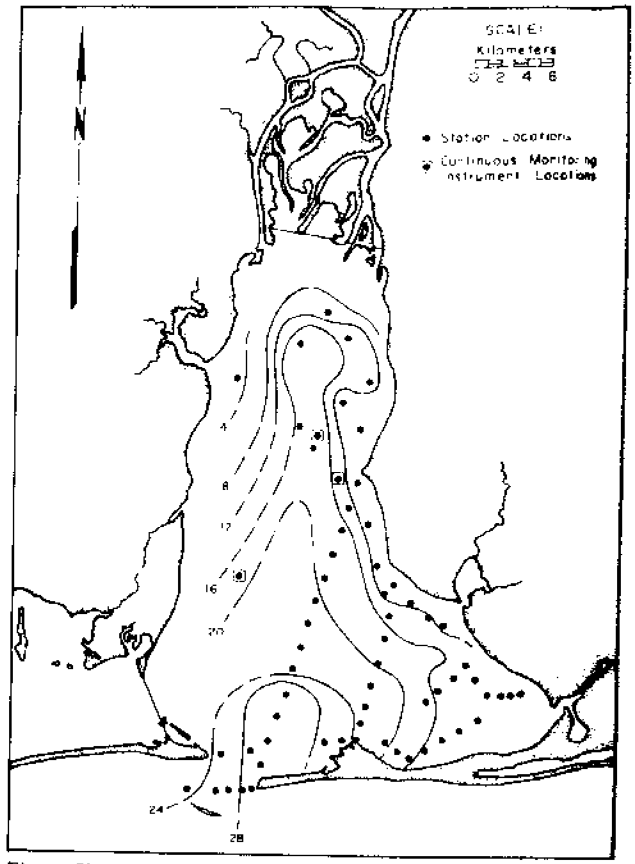

Figure 5b. Stations Showing an Intruding Tongue of High Salinity Water Over the Entire Bay.

Both figures 4b and 5b depict an intruding tongue of high salinity water situated slightly east of the central axis of the Bay. The isohalines of these two bottom salinity fields did not seem to have any relationship to their corresponding bottom DO fields.

Surface salinity data (not illustrated) compared to the bottom salinity data showed that there was weak to moderate positive vertical stratification in the upper Bay and East Bon Secour Bay and strong positive vertical stratification in the middle and lower Bay and west Bon Secour Bay. Temperature data for all stations ranged between 28.0 and 32.0°C and had a moderate positive stratification. Surveys taken during the low tides of these two days (July 17 and 18, 1978) revealed no significant change in the overall structure and only a 3 to 5 km north-south shift.

Ten days later a follow up survey revealed that the bottom DO field had significantly recovered from the depressed conditions of < 1.0 mg/l to levels around 4.0 mg/l (Fig. 6a). The corresponding bottom salinity field (Fig. 6b) again did not seem to have any relationship to the DO field (Fig. 6a).

WHAT WE KNOW A LITTLE ABOUT

Oxygen-Consuming Processes

Results of research performed by Dr. Mario Pomatmat of Auburn University as part of the "Theodore Ship Channel-Baseline Data Collection" (U.S. Army Corps of Engineers 1979) are used in this section. Dr. Pamatmat investigated the rates of oxygen-consuming processes in the bottom sediment of the Bay. His position was that compared to the water column and the total biological activity of plankton and nekton, the bottom and the benthos become relatively more important as water depth decreases. Therefore, because Mobile Bay is a very shallow estuary (average depth at mean low water - 2.6 m) bottom related oxygen-consuming processes were the logical place to start.

Because of the limited number of samples he had to work with, Dr. Pamatmat cautioned that the results provided at best only an initial assessment. Sediment cores from the Bay bottom showed total oxygen uptake ranged between 12.9 to 41.7

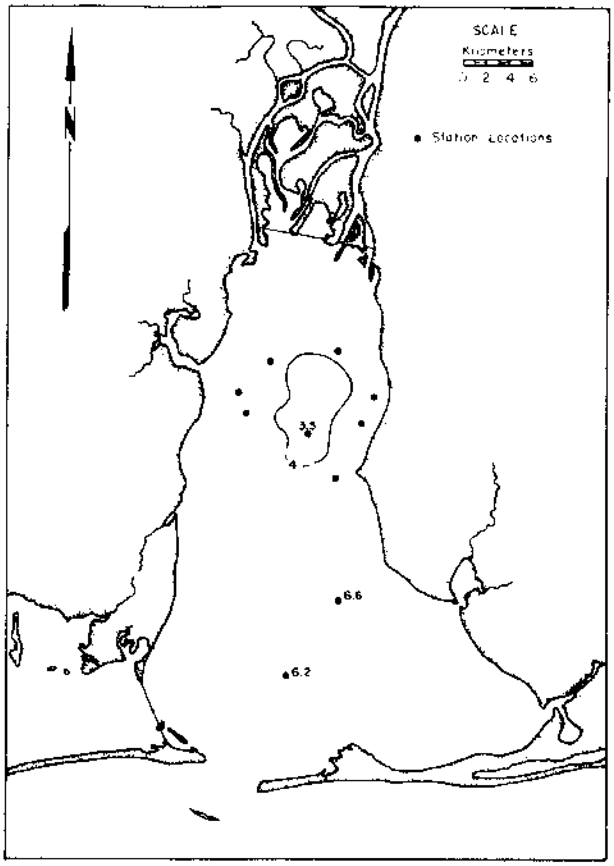

Figure 6a. Conditions in the Upper Two-Thirds of the Bay After Ten Days.

Figure 6b. Conditions in the Entire Bay After Ten Days.

ml $O_2 m^{-2} h^{-1}$ and chemical oxygen uptake ranged between 4.8 to 18.1 ml O_2 m^{-2} h^{-1}. Interfering chemical reactions prevented reliable measurements of ATP concentrations to determine living biomass, which in turn should be related to total metabolic activity, and measurements of heat flux to determine the anaerobic component of the total metabolic activity.

Municipal and Industrial Waste Information

The reader is referred to the 208 wastewater management plan reports prepared for Mobile and Baldwin Counties by the South Alabama Regional Planning Commission (1977).

History of Low Concentration Periods

By using the occurrence of the "Jubilee" phenomenon as a signature for oxygen depletion periods it is then possible to go back through newspaper records for historical documentation purposes. The earliest report of a "Jubilee" and therefore an implied low dissolved oxygen period was in 1821, according to newspapers in files of the Fairhope Single Tax Corporation. From that date forward numerous accounts of "Jubilee" have been published in various newspapers throughout the area. Historical reviews were presented by Loesch, 1960 and May, 1973.

The important implication here is that low dissolved oxygen periods have occurred in the Bay for over 150 years and, therefore, prior to major man-made alterations to the Bay bottom or municipal - industrial waste stresses. With this in mind a concerted effort must be made, during the designing of future studies, to consider both natural as well as man-made consequences with respect to the dissolved oxygen system.

WHAT WE KNOW NOTHING ABOUT

1. Oxygen-Producing Processes.

2. Environmental Factors Responsible for the

On-Set, Maintenance and Termination of Oxygen Depletion Periods.

3. Meso-to Micro-Scale Distribution Patterns During Oxygen Depletion Periods.

DATA GAPS AND RECOMMENDATIONS

No aspect of the DO system of the Mobile estuary is understood well enough that it can be removed from a data gap list. Therefore, all of the elements mentioned in this paper and undoubtedly others, must be considered, to some degree, data gaps. A definitive study of the DO system is years overdue and each additional year that goes by further complicates the task of properly and adequately piecing the puzzle together. What is needed is an extensive and intensive study, covering no less than a 3-year period, to commence as soon as possible, because to do otherwise may ultimately result in irreparable harm to the Mobile estuary.

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WATER RESOURCE MANAGEMENT THROUGH CONTROL OF POINT AND NONPOINT POLLUTION SOURCES IN MOBILE BAY

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ABSTRACT

Traditional development in the Mobile Bay area has, in some instances, resulted in undesirable degradation of water quality caused directly by point source discharges and indirectly by nonpoint source runoff. The study partially described in this paper was undertaken to provide recommended guidelines and management schemes for control of point and nonpoint sources of pollution affecting Mobile Bay and its tributary streams. The study area consists of approximately 7,500 km^2 (2,900 sq. miles) of land area and an estuarine bay and delta of approximately 1,070 km^2 (413 sq. miles).

A sampling program was used to determine existing water quality and to identify where violations of quality criteria were occurring. Data from the sampling program were also used as input to the water quality model which was used to project future receiving water quality and to assess nonpoint source impacts on water quality. Major study recommendations relate to total maximum daily loads, stream standards, treatment levels, discharge locations, and non-structural controls for surface runoff. Authorities are recommended for designation to fulfill specific management responsibilities to assure proper use of local water resources.

INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) set two major national water quality goals: 1) to obtain, wherever possible, fishable and swimmable waters by 1983; and 2) to eliminate the discharge of pollutants into navigable waters by 1985. Three basic approaches to achieve these goals are also outlined in the Act: 1) the issuance of permits to discharge under the National Pollutant Discharge Elimination System (NPDES) as required in Section 402; 2) planning for water quality management as described in Sections 201, 208, and 303e; and 3) the awarding of construction grants for publicly owned waste treatment systems as stipulated in Sections 201, 202, and 204. The significance of this legislation and the 1977 Amendments to it should not be underestimated, especially as it regards Section 208 planning.

The South Alabama Regional Planning Commission (SARPC) was charged by the Governor in 1975 to plan for water resource management through the control of point and nonpoint pollution sources in Mobile Bay and its major tributary streams. This paper presents a summary of the Commission's approach, methodology, findings, and recommendations concerning water quality management in the Mobile Bay area.

There are two primary objectives in the practice of water resource management: 1) the satisfactory disposal of waste products and the protection of health; and 2) the maintenance of water quality for the intended or desired uses. The Section 208 planning for the Mobile Bay area was designed to investigate existing water quality, to compare it with existing State use classifications and the criteria for each, to identify where violations occur, to project future waste loads, and to recommend a water resource management program with necessary controls for point and nonpoint sources that will assure attainment of water quality goals. Time and money were the limiting factors in the final study design. Due to these limitations, desired levels of detail were eliminated from the water quality sampling and modeling elements, resulting in a minimally acceptable study design.

STUDY DESIGN

The two major components of the Mobile 208 study design from a water quality perspective are the water quality assessment and the water quality modeling. The water quality assessment is made by comparing the results of a sampling program with accepted water quality criteria. This determines where violations are in fact occurring, and what improvements in water quality must be achieved to meet the criteria. The sampling data is also used as input to the water quality model which is a set of equations representing the relationships among the various pollutant parameters. Through the use of these equations, the effects of changing the quantity or the quality of both point and nonpoint discharges upon various parameters can be estimated and examined. Such simulations make it possible to evaluate various discharge alternatives in terms of their impacts on the water quality of a given stream. These evaluations are used to determine the maximum daily waste loads for a particular receiving water body. The maximum daily waste loads are those quantities of waste materials that can be discharged into the receiving water and assimilated therein without violating applicable water quality criteria. The simulations to determine maximum daily waste loads are usually made under the most critical environmental conditions, the assumption here being that if water quality standards are met under the most critical conditions, they will be met under any conditions. Waste load allocations for point source dischargers are defined on the basis of the maximum daily loads. These, in turn, are used by the appropriate State and Federal permitting authorities to determine required treatment levels and waste permit conditions.

METHODOLOGY

Stream Sampling Program

Initially, a monthly sampling program was proposed over a 12-month period; however, the U.S. Environmental Protection Agency (EPA) officials felt this required too large a percentage of the total budget so the effort was reduced in scope to five routine and one comprehensive sampling periods. Thirty-three sites were located and samples were collected during three seasons of the year (spring, summer, and fall). These three seasons also represented the three hydrological periods of the year (high stream flow, high local rainfall, and low stream flow). Figure 1 identifies the monitoring stations used for the water quality assessment and modeling, including those in Perdido Bay which were a part of the Pensacola 208 study, the Alabama Water Improvement Commission (AWIC) trend monitoring stations, and the U.S. Geological Survey (USGS) water quality monitoring stations. Table 1 further defines the locations of the sites. Numbers in Table 1 are keyed to the corresponding numbers on Figure 1. Table 2 lists the stations used in the comprehensive sampling for the hydrodynamic calibration of the water quality model. Station numbers in Table 2 are also keyed to the corresponding numbers on Figure 1.

Table 1. Routine Sampling Program Station Locations. (Reference Figure 1)

Boundary Sites

1. Mobile River opposite David Lake (RM 42)
2. Mouth of Mobile River @ Choctaw Point
3. Mouth of Spanish River and Delvan Bay
4. Mouth of Tensaw River
5. Mouth of Apalachee River @ Causeway
6. Mouth of Blakely River (West of D'Olive Bay)
7. Dauphin Island Bridge (Grant's Pass)
8. Mouth of Mobile Bay, between Ft. Gaines and Ft. Morgan

Bay Sites

9. Mobile Bay @ approximately 1.5 miles east of Dog River
10. Mobile Bay @ approximately 2 miles northwest of Montrose
11. Mobile Bay @ approximately 1.5 miles east of Fowl River.
12. Mobile Bay @ approximately 5 miles east of Fowl River.
13. Mobile Bay @ approximately 3 miles southwest of Point Clear

Stream Sites

14. Mouth of Three Mile Creek
15. Three Mile Creek @ St. Stephens Rd.
16. Mobile River @ Pinto Pass (RM 5)
17. Intersection of Mobile and Spanish Rivers (RM 6.0)
18. Mouth of Eight Mile Creek
19. Eight Mile Creek @ Highway 45
20. Mouth of Dog River
21. Mouth of Theodore Ship Channel (Deer River)
22. Mouth of Fowl River
23. Mouth of Intracoastal Waterway
24. Mouth of Bon Secour River
25. Mouth of Weeks Bay (Fish River Point)
26. Magnolia River @ Highway 49
27. Mouth of Polecat Creek
28. Corn Branch near Camp Loxley
29. Mouth of Styx River
30. Styx River @ Hollinger's Creek
31. Tensaw River @ Big Lizard Creek (North of Gravine Island)
32. Tensaw River @ Middle Creek
33. Bayou Sara @ Norton Creek

AWIC Trend Stations

42. Dog River @ Luscher Park
43. Mobile River @ I-65
44. Mobile River @ L&N Railroad Bridge
45. Mobile River @ Alabama State Docks
46. Bayou La Batre @ Alabama Highway 188
47. Three Mile Creek between U.S. 43 and Southern RR
48. Chickasaw Creek @ Highway 43

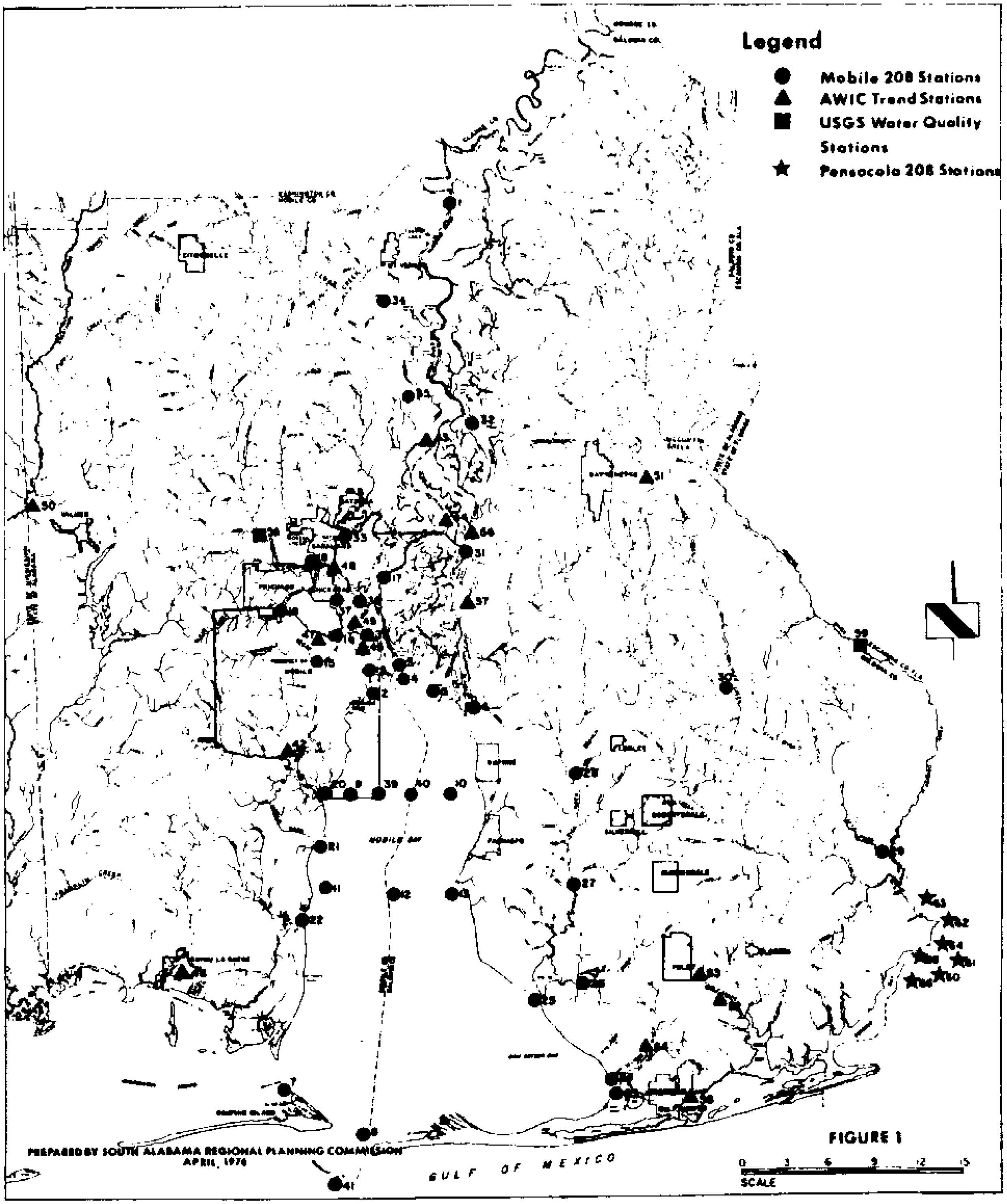

Figure 1. Water Quality Monitoring Stations.

Table 1. - Continued

49. Chickasaw Creek @ L&N RR Bridge
50. Escatawpa River @ Highway 98
51. Hollinger Creek southeast of Bay Minette
52. Wolf Creek @ County Road 12
53. Wolf Creek 0.25 mile upstream of County Road 12 Bridge
54. Bon Secour River near Bon Secour, Alabama
55. Intracoastal Canal east of Gulf Shores
56. Tensaw River @ L&N RR Bridge
57. Tensaw River just below Gravine Island

USGS Stations

58. Chickasaw Creek
59. Perdido River

Table 2. Comprehensive Sampling Program Station Locations. (Reference Figure 1)

Boundary Sites

34. Mobile River near Grog Hill Crk (RM35.3)
35. Mobile River below Shell Chemical (RM 24)
2. Mobile River @ Choctaw Point
4. Mouth of Tensaw and Spanish Rivers @ Delvan Bay
5. Mouth of Apalachee River (@ Causeway)
6. Mouth of Blakeley River (West of D'Olive Bay)
7. Dauphin Island Bridge (Grant's Pass)
8. Mouth of Mobile Bay between Ft. Gaines and Ft. Morgan
41. Gulf of Mexico approx. 1 mile south of Sand Island

Bay Sites

9. Mobile Bay @ approx. 1.5 miles east of Dog River
39. Mobile Bay @ approx. 3 miles east of Dog River @ Mobile Ship Channel
40. Mobile Bay @ Approx. 8 miles east of Dog River

Stream Sites

17. Intersection of Mobile and Spanish Rivers (RM 6.0)
36. Mobile River above Chickasaw Creek (RM 3.5)
37. Mouth of Chickasaw Creek
14. Mouth of Three Mile Creek
38. Mobile River below Three Mile Creek (RM 0.5)

Sampling Frequency and Parameter Coverage

For the routine sampling program, one sample was collected from each of the 33 sites on April 8, April 20, and May 13, representing high stream flow period of 1976. The Mobile and Tensaw Rivers were at flood stage during the April 8, 1976 sampling. Another sample was collected at each site on August 15, 1976, representing the period of local thunderstorm activity which produces high surface runoff into area streams. The last sample was collected on October 22, 1976, representing the low stream flow period of the year. In the Mobile River, the lowest flow of the year occurred on October 17, 1976, and was about 255 m^3/s (9,000 cubic feet per second). Sampling was coordinated so that four of the sampling dates corresponded to sampling dates for the AWIC trend stations. Samples were collected at mid-depth or at a maximum of five feet below the surface. All stations were sampled within an eight-hour time frame. Parameter coverage for the routine sampling is shown in Table 3. Samples from the comprehensive stations were collected at 17 sites (Table 2) at specified intervals over one tidal cycle to provide data for water quality and for hydrodynamic verification of the water quality model. Sampling began at 6:00 p.m. local time on October 12, 1976, and ended with the 6:00 p.m. sampling on October 13, 1976. Conditions were ideal–winds were calm, there was no rainfall, and stream flow was low. Parameter coverage and sampling frequency for the comprehensive sampling are indicated in Table 4.

Nonpoint Sampling Program

A second part of the sampling program was designed to assess the contributions of storm water runoff and other nonpoint sources from various land use categories. The selection of an appropriate level of detail in the definition of storm loads is best dictated in assessment studies by receiving water impacts. Pollutants discharged to receiving waters have characteristic time and space scales associated with the impacts they cause. These scales are illustrated in Figures 2 and 3, and can be used to provide guidance in determining the time scale of the averaging which is appropriate. Thus, while suspended solids loads may, in most cases, be characterized on an annual basis, more reactive contaminants such as coliform organisms and oxygen consuming materials, will usually require definition on a scale in the range of hours. Waste load definition on a scale finer in detail than one to several hours (approximately the scale of storm events) is not necessary for the evaluation of transient water quality impacts.

A sampling program was outlined for selected catchment basins representing the identified land use categories that were included in the nonpoint

Table 3. Routine Sampling Program Parameter Coverage.

WEATHER DATA	UNITS	CHEMICAL DATA	
Wind Speed	Miles Per Hour (MPH)	Biochemical Oxygen Demand-five day (BOD_5)	Milligrams per liter (mg/l)
Wind Direction	From North (N)	Nitrite (NO_2 - N)	"
Air Temperature	Degrees Celcius (°C)	Nitrate (NO_3 - N)	"
Cloud Cover	General Descriptors	Ammonia (NH_3 - N)	"
	Cloudy (Cldy)	Organic Nitrogen (ORgN - N)	"
	Partly Cloudy (Ptl Cldy)	Total Phosphorus (PO_4 - P)	"
	Clear		
	Fog	Total Dissolved Solids (TDS)	"
PHYSICAL DATA			
Water Depth	Feet	Oil and Grease (O & G)	"
Sample Depth	Feet	Total Mercury (Hg)	"
ph	Unitless	Total Zinc (Zn)	"
Water Temperature	Degrees Celcius (°C)	Total Lead (Pb)	"
Dissolved Oxygen	Milligrams Per Liter (mg/l)	Fecal Coliform (Fec Col.)	counts/100 milliliters as determined by the membrane filter technique
Specific Conductance	Micromhos/Centimeter (mmho/cm)	Chlorophyll "a" (chl "a")	micrograms per liter
		Pesticides: Organochlorine	namograms per liter
		Organophosphorus	namograms per liter

Table 4. Comprehensive Sampling Program Parameter Coverage and Sampling Frequency.

Parameter Coverage	Sampling Frequency			
Physical Data	Every 3 hours at 3 depths (1 ft. below surface, 5 ft. or mid-depth, 1 ft. above bottom)	Every 6 hours at 5 ft. or mid-depth	Twice Only once a.m. once p.m.	Once only at Peak Flood
Water Depth	X			X
Temperature	X			X
Specific Conductance	X			X
Dissolved Oxygen	X			X
Chemical Data				
5 day BOD		X		X
Ultimate BOD		X		X
Ammonia Nitrogen		X		X
Organic Nitrogen		X		X
Nitrate Nitrogen		X		X
TKN		X		X
Total Phosphorus		X		X
Fecal Coliform		X		X
Chlorophyll "a"			X	X

source assessment. Figure 4 shows the selected catchment basins and Table 5 briefly describes each. The sampling frequency and parameter coverage proposed for the nonpoint assessment are presented in Table 6. However, problems encountered in the nonpoint sampling program related either to no rainfall at all over some catchments or to insufficient rainfall or insufficient runoff from some catchments, resulted in no samples being obtained at three of the original

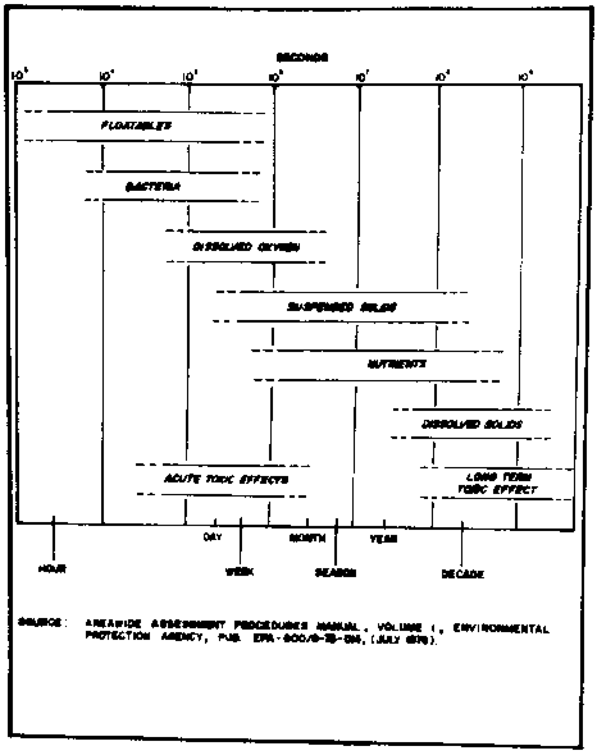

Figure 2. Time Scales
Storm Runoff Water Quality Problems.

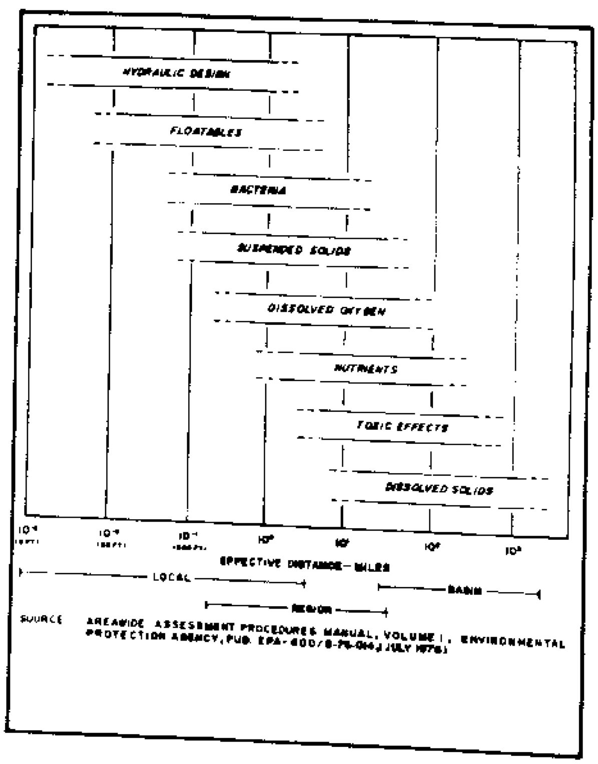

Figure 3. Space Scales
Storm Runoff Water Quality Problems.

Table 5. Nonpoint Sampling Sites.

Residential (5R) (180 acres)	- Samples were taken from paved ditch at south end of culvert under Government Boulevard on the east side of Skyline Country Club; 100% single family residential.
Commercial (5C) (272 acres)	- Samples were taken from paved ditch at the east end of culvert under National Jewelers building on Bel Air Blvd.; 70% commercial, 5% single family residential, 25% open.
Industrial (6) (42 acres)	- Samples were to have been taken from storm-water drainage system of Alcoa Aluminum Plant at the north end of Alabama State Docks; 100% industrial. No samples obtained.
Septic Tank Installations (3) (35 acres)	- Samples were to have been taken from west drainage ditch at north end of culvert under first street south of Bear Point Marina; 100% single family residential. No samples obtained.
Agricultural (1A) (82 acres)	- Samples were taken from south end of corrugated metal culvert under Highway 64 approximately 1 mile west of Wilcox Road and I-10 intersection in Baldwin County; 100% agricultural pastureland.
Agricultural (1B) (196 acres)	- Samples were taken from south end of corrugated metal culvert under Baldwin County Road 24 approximately 0.75 mile west of intersection of County Road 55; 100% agricultural land under cultivation.
Silvicultural (2) (1664 acres)	- Samples were taken from south end of culvert under road approximately one mile west of Wilcox Road and five miles north of I-10; 100% managed forest land.
Theodore Industrial Park (4I) (1569 acres)	- Samples were taken from middle Deer River at the west end of culvert under road on the south side of Kerr McGee plant site; 60% developed/developing industrial, 40% undeveloped.
Theodore Industrial Park, Background Area (4B) (356 acres)	- Samples were taken at twin culvert located at west end of drainage ditch under new spur track to DeGussa; 100% totally undeveloped land.
Fairhope Landfill (7) (14 acres)	- Samples were taken at the end of a five foot metal culvert located under Section Street in Fairhope; 100% sanitary landfill.

NOTE: Numeric and/or alpha numeric designations refer to identifiers shown on Figure 4.

sites. These were the original agricultural site, Figure 4 (1), the resort site, Figure 4 (3), and the industrial site, Figure 4 (6). Two alternate agricultural sites were identified, Figure 4 (1A) and (1B), from which samples were finally collected. Sixty-six field trips were made to the nonpoint sampling

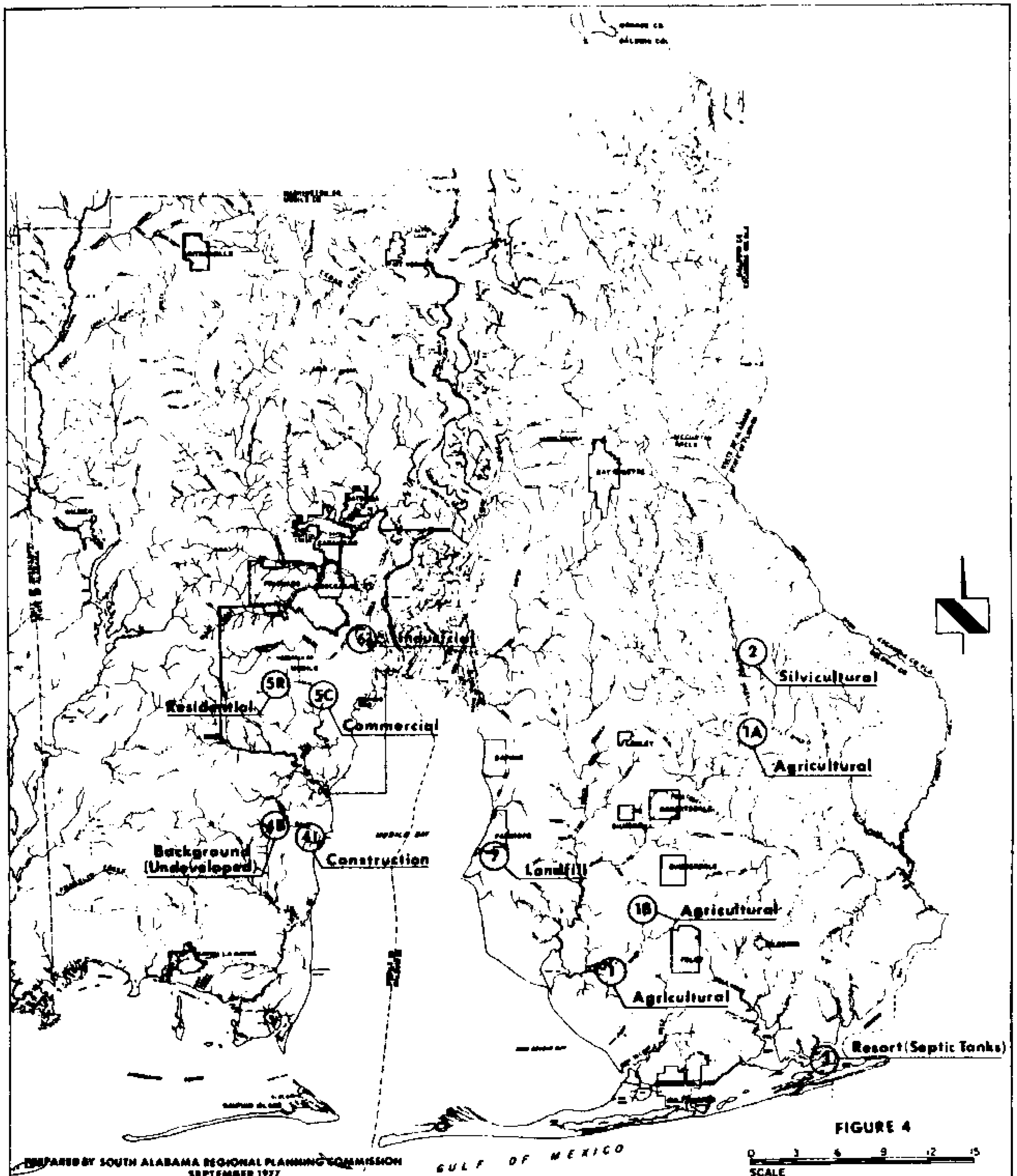

Figure 4. Water Quality Sampling Stations for Nonpoint Source Assessment.

Table 6. Nonpoint Sampling Frequency and Parameter Coverage.

LAND USE	PROGRAM	NUMBER OF SAMPLES																			
		BOD	COD	TKN	Nitrate N	Nitrite N	Ammonia	Organic N	TSS	TDS	Total P	Fecal Coliform	Mercury	Arsenic	Cyanide	Iron	Lead	Manganese	Zinc	Pesticides	Oil & Grease
Agriculture (1A & 1B)	Scheduled	16	8		16	16	16	16	16	8	16	16		8						16	
	Completed	32	19		32	32	32	32	32	19	32	32		19						32	
Silviculture (2)	Scheduled	16	8		16	16	16	16	16	8	16	16		8						16	
	Completed	19	12		19	19	19	19	19	12	19	19		12						19	
Construction (4I)	Scheduled	27	10	27	27	27			27	15	27	27				5	5				
	Completed	28	10	28	28	28			28	15	28	28				10	10				
Landfill (7)	Scheduled	8	4		8	8	8	8	8	4	8	8									
	Completed	8	4		8	8	8	8	8	4	8	8									
Septic Tank Installations (3)	Scheduled	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	Completed	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Residential (5R)	Scheduled	24	8	8	27	24	16	16	24	12	24	24	4	4	4	4	4	4	4	4	24
	Completed	24	12	9	28	28	19	19	28	21	28	28	5	5	5	5	5	5	5	11	19
Commercial (5C)	Scheduled	18	10	9	27	27	18	18	27	11	27	27	10	10	10	10	10	10	10	10	27
	Completed	24	11	10	28	28	18	18	28	21	28	28	11	11	11	11	11	11	11	12	28
Industrial (6)	Scheduled	24	8	8	24	24	16	16	24	12	24	24	4	4	4	4	4	4	4	8	24
	Completed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undeveloped (4B)	Scheduled	27	10	27	27	27			27	15	27	27				5		5			
	Completed	18	10	18	18	18			18	10	18	18				4		4			
Totals	Scheduled	161	67	79	170	170	91	91	170	86	170	170	19	35	19	24	24	28	19	55	75
	Completed	153	78	73	161	161	96	96	161	103	161	161	16	47	16	30	16	30	16	74	43

sites. Only 18 of these resulted in representative samples from the sites.

EXISTING CONDITONS

The results of the water quality sampling program indicate that overall the streams in the area experience a great range of parameter values. Based upon the AWIC water quality criteria and stream use classifications, the most frequently occurring violations are dissolved oxygen, pH, and fecal coliform. These violations are scattered throughout the Mobile River Basin, but more specifically affect Mobile Bay, Three Mile Creek, Chickasaw Creek, Fowl River, Magnolia River, Bayou Sara, Bayou La Batre, Hollinger Creek, and Wolf Creek. Table 7 presents a summary of the streams sampled, their use classifications, and the existing criteria that were violated, if any.

The storage-treatment-overflow-runoff model (STORM) was used to estimate the frequency and magnitude of pollutant loads from nonpoint sources. STORM is a continuous storm water model that simulates both quality and quantity of runoff. It accepts land use classification by area disaggregated according to soil properties and a measured rainfall record as a direct input. The model also takes into account the capacity of the watershed to intercept and retain water (depression storage) as well as infiltration and percolation of pervious surfaces. STORM produced mass emissions for the nonpoint catchment basins as indicated in Table 8. Table 9 describes the range of constituent concentrations observed at several of the catchments. Maximum concentrations were exclusively observed in a first flush immediately following the start of runoff. Minimum concentrations occurred near the end of the storm.

In order to generate storm water loadings to receiving waters, the STORM model was individually applied using both current (1977) and projected (2000) land uses to each of 38 drainage subbasins in the area, and the 2.54 cm (1 inch) storm falling in 1 hour as the critical storm. Based on these considerations, simulated current and projected storm water loads were compared with current (1977–Best Practicable Treatment) and projected (2000–Best Available Treatment) municipal and

Table 7. Water Quality Criteria Assessment at 208 and AWIC Sampling Station Locations.

Sampling Station	Stream	Stream Use Classification[1]	Water Quality Criteria[2] Violations,[3] 1977	Sampling Station	Stream	Stream Use Classification[1]	Water Quality Criteria[2] Violations,[3] 1977
01	Mobile River	F&W	–	29	Styx River	F&W	pH
02	Mobile River	A&I	–	30	Holligner		–
03	Spanish River	F&W	–		Creek	F&W	pH
04	Tensaw River	F&W	–	31	Tensaw River	SWM, F&W	–
05	Appalachee			32	Tensaw River	SWM, F&W	–
	River	F&W	–	33	Bayou Sara	F&W	DO, FC
06	Blakeley			34[4]	Mobile River	PWS, F&W	–
	River	F&W		35[4]	Mobile River	F&W	–
07	Mobile Bay	SWM, F&W, SHLL	DO, FC	36[4]	Mobile River	A&I	–
08	Mobile Bay	SWM, F&W, SHLL	FC	37[4]	Chickasaw		
09	Mobile Bay	F&W	–		Creek	NAV	DO
10	Mobile Bay	SWM, F&W	–	38[4]	Mobile River	A&I	–
11	Mobile Bay	SWM, F&W, SHLL	FC	39[4]	Mobile Bay	F&W	–
12	Mobile Bay	SWM, F&W, SHLL	FC	40[4]	Mobile Bay	F&W	–
13	Mobile Bay	SWM, F&W, SHLL	FC	41[4]	Gulf of		
14	Three Mile				Mexico	SWM, F&W, SHLL	–
	Creek	A&I	–	42	Dog River	F&W	–
15	Three Mile			43	Mobile River	F&W	–
	Creek	A&I	DO	44	Mobile River	F&W	pH
16	Mobile River	A&I	–	45	Mobile River	A&I	–
17	Mobile River	F&W	–	46	Bayou La Batre	F&W	DO, FC
18	Eight Mile			47	Three Mile Creek	A&I	DO
	Creek	F&W	–	48	Chickasaw		
19	Eight Mile				Creek	F&W	DO, pH, FC
	Creek	F&W	–	49	Chickasaw		
20	Dog River	SWM, F&W	–		Creek	NAV	DO, pH, T
21	Deer River			50	Escatawpa		
	(Middle Fork)	F&W	–		River	SWM, F&W	pH, FC
22	Fowl River	SWM, F&W	DO	51	Hollinger		
23	Intracoastal				Creek	A&I	DO
	Waterway	SWM, F&W	–	52	Wolf Creek	F&W	DO, pH
24	Bon Secour			53	Wolf Creek	F&W	–
	River	SWM, F&W	–	54	Bon Secour		
25	Weeks Bay	SWM, F&W	–		River	SWM, F&W	–
26	Magnolia			55	Intracoastal		
	River	SWM, F&W	pH, DO		Waterway	F&W	–
27	Polecat Creek	SWM, F&W	pH, FC	56	Tensaw River	SWM, F&W	FC
28	Corn Branch	F&W	pH	57	Tensaw River	SWM, F&W	FC

[1] Presented in Chapter 11
[2] AWIC Criteria, Table 8-1
[3] FC = Fecal Coliform; DO = Dissolved Oxygen; T = Temperature
[4] Station not sampled for pH

industrial point source loads. Table 10 presents a summary comparison of these simulated loads. In interpreting this table, it should be kept in mind that the point source loads and the average summer storm water loads are continuous as opposed to the critical storm runoff loads, which are introduced over a matter of hours. Hence, the units for the critical storm runoff loads are more appropriately pounds per critical storm rather than pounds per day.

The relative magnitudes of point source and critical storm loads vary with location. Chickasaw Creek, with its present concentration of industries, is dominated by point source discharges although storm water loads are substantial. Point source and storm water loads to the lower Mobile River are approximately the same magnitude. Loads from the critical storm are much larger than current point source loads to Three Mile Creek and Dog River and will be even larger in the future as Best Avail-

Table 8. Mobile 208 Measured Storm Event Mass Emissions Summary.

Catchment Name*	Event Date	Measured Stormwater Pollutant Mass Emissions[1] BOD$_5$ lbs	BOD$_5$ lbs/acre	Total N lbs	Total N lbs/acre	Total P lbs	Total P lbs/acre	TSS lbs	TSS lbs/acre	Fecal Coliform lbs	Fecal Coliform lbs/acre
Residential[2] (5R)	06/18/76	60.2	0.334	16.3	0.091	2.55	0.014	7570	42.1	230	1.28
Residential (5R)	12/06/76	21.8	0.121	2.3	0.0128	0.31	0.0017	135	0.75	12.6	0.07
Residential (5R)	01/13/77	3.0	0.0167	0.7	0.0039	0.06	0.00033	10	0.055	0.0276	0.00015
Commercial (5C)	06/18/76	226	0.830	40.8	0.15	5.32	0.020	11500	42.3	168	0.61
Commercial[3] (5C)	12/06/76	134	0.493	15.1	0.056	1.83	0.0067	643	2.36	40.7	0.15
Commercial[3] (5C)	01/13/77	87.9	0.323	7.4	0.027	0.80	0.0029	186	0.68	3.31	0.012
Agricultural (1A)	10/30/76	11.2	0.137	2.4	0.029	0.61	0.0074	303	3.70	32.6	0.40
Agricultural (1A)	12/11/76	0.2	0.002	0.1	0.001	0.02	0.00024	8	0.097	0.767	0.0093
Silvicultural (2)	10/30/76	4.0	0.002	0.5	0.0003	0.12	0.000072	182	0.11	13.8	0.008
Silvicultural[2] (2)	12/11/76	---	---	---	---	---	---	---	---	0.0518	0.000031
Theodore Background[2] (4B)	08/02/76	1.0	0.0028	0.7	0.0020	0.02	0.000056	17	0.0478	0.0987	0.00027
Theodore Background[3] (4B)	12/19/76	---	---	0.1	0.0002	0.01	0.0030	17	0.0478	0.202	0.00057
Theodore Construction[2] (4I)	08/02/76	11.3	0.0072	3.4	0.0021	0.25	0.00016	378	0.241	3.36	0.00214
Theodore Construction[2] (4I)	09/02/76	37.3	0.024	11.4	0.0073	0.80	0.00051	3950	2.52	20.5	0.0131
Theodore Construction[3] (4I)	12/19/76	8.3	0.0053	1.7	0.0011	0.27	0.00017	258	0.165	6.69	0.00426
Fairhope Landfill (7)	09/07/76	16.0	1.14	11.2	0.80	1.58	0.113	12170	870.0	9.93	0.709

[1] Applies only to the period over which measurements were taken. In almost all cases, storm water discharge continued after the last measurement.

[2] Runoff had started prior to initial sampling. Mass emissions not corrected for base flow, if any.

[3] Mass emissions corrected for base flow loads

*Numeric and/or alpha numeric designators refer to identifiers shown on Figure 4 and in Table 5.

NOTE: This table does not list the measured mass emissions for Agricultural Site 1B. Although many "dry runs" were made, samples were not collected at this site until 6 to 9 months after sampling at all the other sites except the industrial and resort (septic tank) sites had been completed. Samples at the latter two sites were never obtained. It was not known when sufficient rainfall at these sites would result in representative samples being taken, and the computer modeling tasks could not be delayed indefinitely without seriously affecting the entire project schedule; therefore, the model runs were made without the sample results that were eventually taken from Site 1B.

Table 9. Range of Pollutant Concentrations Observed During the Storm Water Sampling Program.

Land Use	TSS mg/l Max	TSS mg/l Min	COD mg/l Max	COD mg/l Min	BOD$_5$ mg/l Max	BOD$_5$ mg/l Min	Oil and Grease mg/l Max	Oil and Grease mg/l Min
Residential	1,270	10	199	30	19	3.4	5.7	<1
Commercial	1,350	16	466	19	49	2.8	6.3	<1
Sanitary Landfill	5,360	46	121	57	4.6	3.6	-	-
Agricultural	2,200	11	178	27	9.4	0.7	-	-
Silvicultural	1,000	3	39	8	2.4	0.1	-	-
Open, Marshy	131	13	84	20	2.4	0.1	-	-

Table 9. continued on next page.

Table 9. Range of Pollutant Concentrations Observed During the Storm Water Sampling Program (Concluded).

Land Use	TKN mg/l Max	TKN mg/l Min	NO_3-N mg/l Max	NO_3-N mg/l Min	TOTAL P mg/l Max	TOTAL P mg/l Min	F. Coli MPN/100ML Max	F. Coli MPN/100ML Min
Residential	3.4	0.55	0.80	0.11	0.28	0.09	93,600	78
Commercial	4.3	0.42	0.94	0.09	0.44	0.06	35,400	38
Landfill	3.0	1.0	0.65	0.41	0.65	0.21	3,000	325
Agricultural	7.4	0.13	3.0	0.04	2.4	0.03	3,500	810
Silvicultural	0.75	0.07	0.27	0.04	0.14	0.02	2,200	38
Open, Marshy	0.95	0.20	0.65	0.10	0.05	0.02	163	26

Table 10. Comparison of Loadings from Urban Storm Water and Point Source Discharges.
(lbs/day)

Source	Chickasaw Creek	Dog River	Mobile River	Three Mile Creek
BOD_5				
Point Sources				
BPT (1977)	39,200	640	3,730	2,210
BAT (2000)	20,700	380	1,590	750
Critical Storm				
1977	10,000	28,300	3,020	16,000
2000	11,500	37,700	3,030	17,100
Average Summer Storm Water (1977)	640	1,200	110	600
Total Nitrogen				
Point Sources				
BPT (1977)	6,300	470	3,330	2,140
Critical Storm Runoff				
1977	1,230	2,700	440	1,600
2000	1,420	3,700	440	1,680
Average Summer Storm Water (1977)	120	160	20	80
Total Phosphorus				
Point Sources				
BPT (1977)	660	150	1,110	710
Critical Storm Runoff				
1977	150	290	50	160
2000	150	360	50	160
Average Summer Storm Water (1977)	19	22	3	10

able Technology (BAT) is applied to point sources and as storm water loads increase with urban development.

Samples collected for the nonpoint source modeling were analyzed for parameters other than those addressed by STORM. Pesticides were present above the limits of detection in runoff from the residential, commercial, and agricultural catchments. Mercury was detected in a runoff sample from the commercial catchment, and small amounts of iron, lead, manganese, and zinc were found in both the commercial and residential catchment samples.

In summary:

- The upper reaches of the Mobile River exhibit good water quality with two significant exceptions. Thermal violations occur as a result of the large volumes of cooling water discharged from the Barry Steam Generating Plant, and the fecal coliform concentrations contributed from nonpoint source runoff in this area heavily impact the shellfish harvesting during low temperature, high stream flow periods.
- Chickasaw Creek is heavily impacted by point source dischargers of both industrial and municipal origins. The water quality of this stream is worsened by heated discharge from the Chickasaw Steam Plant. Water quality is poor and made worse by heavy benthic oxygen demand and the intrusion of a salt water wedge. Storm water runoff has little or no impact on the in-stream water quality.
- Three Mile Creek has poor water quality largely due to the discharge from two municipal sewage treatment plants and to the poor reaeration of the stream resulting from strong tidal influence. Nonpoint sources also severely impact the stream.
- The lower segment of the Mobile River has poor water quality as a result of the point source discharges contributed from Three Mile and Chickasaw Creeks and the tidal influence of the Bay.

Table 11. Existing Municipal Sewage Plants.
(December 31, 1977)

Plant	Treatment Description	Design Flow (mgd)	Receiving Water
-Mobile County-			
McDuffie Island/Mobile[1]	High rate Activated Sludge	16.00	Mobile Bay
Halls Mill Creek/Mobile[2]	High rate Trickling Filter	1.50	Halls Mill Creek
Three Mile Creek/Mobile	High rate Trickling Filter	10.00	Spring Branch
Hog Bayou/Mobile	Package plant	0.35	Hog Bayou
Bill Ziebach/Mobile	High rate Trickling Filter	2.00	Mobile Bay
Grover Street/Prichard	2 Stage Trickling Filter	4.00	Three Mile Creek
Eight Mile/Prichard	High rate Trickling Filter	1.50	Eight Mile Creek
Chickasaw Lagoon	2 Single stage lagoons	1.50	Chickasaw Creek
Saraland	Conventional Activated Sludge	0.59	Norton Creek
Dauphin Island	Standard rate Trickling	0.25	Aloe Bay
Bayou La Batre	Conventional Activated Sludge	1.00	Portersville Bay
Citronelle	Single stage Lagoon	0.22	Puppy Creek
-Baldwin County-			
Gulf Shores	3 Stage lagoon	0.33	Intracoastal Waterway
Robertsdale	Extended aeration Activated Sludge	0.25	Rock Creek
Bay Minette	Primary clarification	1.00	Hollingers Creek
Westside Lagoon/Bay Minette	2 Stage lagoon	0.225	Martin Branch
Loxley Lagoon	3 Stage lagoon	0.16	Corn Branch
Foley Lagoon	Single Stage lagoon	0.27	Wolf Creek
Fairhope	Step aeration Activated Sludge	2.00	Mobile Bay

[1] Currently being converted to a 28 MGD pure oxygen A.S. process
[2] Will be closed in 1978

- Deer River has poor hydraulic flushing and is impacted by storm water runoff. This limits its assimilative capacity for direct discharges.
- Mobile Bay has relatively good water quality. It experiences occasional water quality problems on its western shores due to poor circulation and to heavy bacterial contamination from high fresh water inflows.
- Bayou Coden and Bayou La Batre experience poor water quality due to waste disposal from seafood industries operating in the area.
- Norton Creek and Bayou Sara have poor water quality resulting from the overloaded Saraland sewage treatment plant and low dry weather flows.
- Hollinger Creek has poor water quality resulting from the discharge of primary effluent from the Bay Minette sewage treatment plant.
- Dog River is impacted by high sediment loads in urban storm water runoff.
- Improperly installed and/or improperly operating septic drainfields deteriorate water quality in low lying areas and coastal waters of resort areas such as Gulf Shores and Dauphin Island, and in streams discharging directly into Mobile Bay, such as Fish River, Fowl River, and Magnolia River.

SOURCES OF POLLUTANTS

Point Sources

Major point sources of pollution in the area include 19 municipal wastewater dischargers with an aggregate flow of 250,000 m^3/day (55 MGD) and 38 industrial process wastewater dischargers with NPDES permits having an aggregate flow of approximately 609,000 m^3/day (134 MGD). In addition there are 49 semi-public and private dischargers and other miscellaneous dischargers of sanitary waste, cooling water, boiler blowdown, rain water runoff, and other nonpermitted effluents.

Municipal sewage treatment plants generally accept only domestic wastewater. Because of this the plant capacities and the gross pollutant loads which they receive are in direct proportion to the populations they serve. Table 11 lists the municipal sewage treatment plants in the area, their treatment processes, design flows, and receiving waters for the treated effluent. Table 12 summarizes the typical concentrations of constituents found in domestic wastewater. Pollutant concentrations and average flows may both vary if industrial wastewater is also treated and/or if extraneous water is received via flow from surface water or infiltration from ground water.

Table 12. Typical Composition of Domestic Sewage.

Constituent	Concentration- mg/liter Strong	Medium	Weak
Solids, total	1,200	700	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	200	100
Fixed	75	50	30
Volatile	275	150	70
Settleable solids, (ml/liter)	20	10	5
Biochemical oxygen demand, 5-day	300	200	100
Total organic carbon (TOC)	300	200	100
Chemical oxygen demand (COD)	1,000	500	250
Nitrogen, (total as N)	85	40	20
Organic	35	15	8
Free ammonia	50	25	12
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	20	10	6
Organic	5	3	2
Inorganic	15	7	4
Chlorides	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50

Source: Wastewater Engineering: Collection, Treatment, Disposal by Metcalf & Eddy, Inc. Copyright (c) 1972 by McGraw-Hill, Inc. Used with permission of McGraw-Hill Book Company.

Industrial point sources in the area are principally located in the Mobile metropolitan area with discharges to the Mobile River and Chickasaw Creek. Table 13 lists the major industrial point sources and categorizes them by their 1977 discharge volumes. The largest volume dischargers are paper mills and electricity generating plants with most of the latter's flow being cooling water and steam condensate. The bulk of the pollution load is contributed by the paper mills and the chemical plants which discharge into Chickasaw Creek and the Mobile River. These loads are strictly controlled by NPDES permit conditions which limit the concentrations of pollutant parameters to assure compliance with applicable stream standards. At the time of the 208 assessment of industrial dischargers in 1977, only four industries in the area had not met the 1977 BPT requirements of law. These were all under compliance schedules for 1978 satisfaction of the requirements.

Nonpoint Sources

Major nonpoint sources of pollution in the area are urban storm water carrying sediment loads from construction and new development sites, hydrologic modification which affects movement of the salt water wedge up the delta causing some salt water intrusion into ground water, and surface runoff upstream coming into the area and carrying bacterial contamination. Another source is improperly operating septic drainfields in low lying coastal areas.

Most pollutant parameters from nonpoint sources have their greatest impacts during the high temperature, low flow periods of the year. However, the converse is true for fecal coliform bacteria. Since their impacts force annual closure of the oyster beds in the lower Mobile Bay, the 208 modeling assessment was expanded to include the higher flows and colder water temperatures. Using observed fecal coliform concentrations of 50 MPN/100 ml, projected year 2000 flows for point source discharges, generated fecal coliform loadings for urban storm water runoff, and freshwater inflows identical to summer simulations except temperature which was set at 10°C (50°F), the model was operated with the Mobile River flow at 4,250 m^3/s (150,000 cfs) to assess the effects of fecal coliform concentrations in the winter storm water runoff from the 2.54 cm (1 inch), 1 hour storm. The results of the simulations showed that a marked increase occurred in the fecal coliform concentrations reaching the Bay in the winter as compared to the summer. The winter simulations were rerun for the same storm with the fecal coliform loadings from urban storm water runoff increased by 10 times. There was no detectable increase in fecal coliform concentrations in the lower

Table 13. Flow Summary of Industrial Process Waste Water Dischargers.

SIC	Company	MGD	Average Discharge (MGD) <0.01	0.01-0.1	0.1-1.0	1.0-10	10-100
2026	Barber Pure Milk	.05		X			
2077	SARS	.02		X			
2091	Aquila Seafood	.001	X				
2092	Plashes Seafood	.003	X				
	Grass Seafood	.001	X				
	Gulf Shrimp	.010		X			
	Mallon Seafood	.0005	X				
	Oyster Bay Seafood	.001	X				
	Star Fish & Oyster	.288			X		
	Patronas Seafood	.001	X				
	Causeway Seafood	.001	X				
	Gulf Coast Knight Seafood	.013		X			
	Bon Secour Fisheries	.014		X			
2491	Crown Zellerbach	.010		X			
2621	International Paper	33.2					X
	Scott Paper	42.43					X
2631	Stone Container	0.02		X			
2812	Stauffer Chemical-LaMoyne	1.10				X	
	Diamond Shamrock	.06		X			
2819	Union Carbide-Chickasaw	3.634				X	
	Halby	.0025	X				
	American Cyanamid	.0600		X			
	ALCOA	.8000			X		
	Virginia Chemical	.2000			X		
	Eagle Chemical	.2250			X		
2823	Courtaulds of N.A.	8.80				X	
2861	Reichhold Chemical	.1900			X		
2869	Degussa	.3710			X		
2879	Shell Chemical	1.044				X	
	Stauffer Chemical Cold Creek	.400			X		
2911	Marion Refinery	.0453		X			
	Louisiana Land & Exploration	.110			X		
2951	Chevron Asphalt	.350			X		
3313	Airco Alloys	.354			X		
4011	Frisco Railroad	.000325	X				
	I.C.G. Railroad	.0115		X			
4911	Alabama Power-Barry	40.0					X
5161	Thompson-Hayward	.0041	X				
	Totals		10	11	10	4	3

Bay with the higher urban runoff loadings. Thus, it appears that the urban storm water loadings from the Mobile area are not a significant contributing factor to the concentrations in the lower Bay. It does appear that high river flows and low water temperatures will allow the transport of bacteriological contaminants from the upper limits of the delta to the oyster reefs in sufficient concentrations to cause closure of the reefs.

Table 14 presents a summary of the nonpoint source assessment including the streams affected, the types and seriousness of the problems, and the contributing nonpoint sources.

Table 14. Nonpoint Source Problem Assessment Summary.

Waters Affected	Type of Problem[a]	Seriousness of Problem[b]	Contributing Source[c]
Chickasaw Creek	DO	M	US
	N	L	US
	P	L	US
	CL	M	HM/SI
	CB	M	US
Three Mile Creek	DO	H	US
	N	L	US
	P	L	US
	SED	H	CON/ND
	CL	M	HM/SI
	CB	M	US
Mobile River	DO	L	US
	N	L	US
	P	L	US
	SED	H	SE/CON/ND
	CL	M	HM/SI
	CB	L/H[d]	UR[e]
Dog River	DO	H	US
	N	H	US
	P	M	US
	SED	H	CON/ND
	CB	M	US
Hall's Mill Creek	DO	H	US
	N	H	US
	P	M	US
	SED	H	CON/ND
	CB	M	US
Deer River	DO	H	US
	N	L	US
	P	L	US
	SED	M	CON/ND
	CL	M	HM/SI
	CB	L	US
Bayou Sara	DO	H	US
	N	H	US
	P	M	US
	SED	H	CON/ND
	CB	M	US
Eight Mile Creek	DO	M	US
	N	L	US
	P	L	US
	CL	L	HM/SI
	CB	H	US
Mobile Bay	DO	L	US
	N	L	US
	P	L	US
	SED	L/H[f]	US/HM
	CL	M	HM/SI
	CB	L/H[g]	UR[h]
Wolf Creek	N	L	AG[i]
	P	L	AG[i]
	CB	M	LSD[j]
Magnolia River	N	L	AG[i]
	P	L	AG[i]
	CB	M	LSD[j]
Fish River	CB	M	LSD[j]
Fowl River	CB	M	LSD[j]
Coastal Waters around Dauphin Island and Gulf Shores	CB	M	LSD[j]

Notes

[a] DO: Dissolved Oxygen
N: Nitrogen
P: Phosphorus
CL: Coliform Bacteria
SED: Sediment

[b] L: Low
M: Medium
H: High

[c] US: Urban Stormwater
HM: Hydrologic Modification
SI: Saltwater Intrusion
CON: Construction
ND: New Development
SE: Stream Erosion
UR: Upstream Runoff
AG: Agriculture/Pastureland
LSD: Land and Subsurface Disposal

[d] Not serious most of the year; however, during the winter low temperature, high flow period bacterial contamination in the River and Bay becomes serious enough to cause closure of the oyster reefs.

[e] Upstream runoff is probably a combination of urban stormwater from developed areas and runoff from agriculture/pastureland uses in areas drained by the River.

[f] Not serious most of the year with normal deposition of sediment occurring from stream flow; however, during peak flow periods and during dredging and spoil disposal

Notes continued on next page.

Notes continued from Table 14.

activities, deposition of sediment becomes a serious non-point source problem.

[g]Not serious most of the year; however, during the winter low temperature, high flow period, bacterial contamination in the River and Bay becomes serious enough to cause closure of the oyster reefs.

[h]Upstream runoff is probably a combination of urban stormwater from developed areas and runoff from agriculture/pastureland uses in areas drained by the Mobile River Delta and its tributary streams. Model simulations showed conclusively that elevated bacterial counts causing closure of the oyster reefs did not come from municipal point sources.

[i]These nutrients were detected above background levels during the course of the sampling program; however, they were not in amounts sufficient to cause any violation of stream standards. Since they could not be traced to any point sources, it was assumed that they were non-point source contributions from the agriculture/pastureland activities carried on in the area.

[j]Problems associated with bacterial contamination of coastal waters and resort areas were documented in recent EPA studies to emanate from overloaded and/or improperly functioning septic tank systems in these low-lying areas. It is also believed that such problems may contribute to the fecal coliform loadings that annually close the oyster reefs.

POLLUTION LIMITS

The water quality pollution limits are defined as the quantities of waste materials that can be discharged to a receiving water body and assimilated therein without violation of applicable water quality standards. Total maximum daily loads for an estuarine receiving water body are influenced by a number of factors including: 1) ambient temperatures; 2) hydraulics; 3) discharge locations; 4) pollutant concentrations; and 5) water quality standards. Of these, none is probably of more critical importance to the determination of total maximum daily loads in the Mobile Bay area than discharge locations. Because of the interconnected maze of channels, small creeks, and backwater areas in the system, there is an almost unlimited number of point source discharge combinations that could have been investigated for purposes of establishing optimum allowable waste loadings. To cope with this problem, a number of simplifying assumptions were made pertaining to the purpose of and the procedures used in assessing the total maximum daily loads.

First of all, it was decided that the total maximum daily loads would be determined to provide only a general indication of the level of pollutant loadings that could be discharged without violating existing standards. The resulting loads were not intended to be absolute values with regard to the allocation of the total loadings to individual point sources; rather, the purpose of the total maximum daily loads was to serve as a general guideline for identifying the most practical and feasible discharge location alternatives for further consideration in the waste load allocation process. This later would result in a refinement of the total maximum daily loads considering specific and alternative discharge configurations and treatment levels. In this regard, only the presently existing point source discharge locations were used in the total maximum daily loads determination.

The purpose of this section is to describe the procedure used to develop the total maximum daily loads, to define the critical hydrologic, tidal, and meteorologic conditions for which the total maximum daily loads were obtained, and to summarize the maximum daily waste loads obtained for specific streams in the area.

Procedure

Maximum daily waste loads for specific point source and urban storm water discharges were developed through application and calibration of the EPA Dynamic Estuary Model (DEM) to simulate the tidal hydraulics and water quality of Mobile Bay and its tidal tributaries. Following application and calibration of the model, a series of trial and error simulations was completed to determine maximum daily waste loads for waste sources discharging to those segments that the model indicated were water quality limited using 1977 Best Practicable Treatment (BPT) waste loads. Maximum daily waste loads were determined only for those constituents directly related to violation of a specific numerical water quality standard. Maximum allowable carbonaceous and nitrogenous oxygen demanding loads were determined for those segments with dissolved oxygen concentrations below applicable standards. Maximum allowable discharge temperatures were developed for those discharges causing thermal water quality standard violations. Maximum allowable fecal coliform loads were not developed because neither point sources, assuming proper disinfection, nor urban storm water runoff were responsible for violations of ambient water quality standards. Such violations, as indicated earlier, are caused by high fresh water inflows into the area. Neither were maximum allowable nutrient loads developed because water quality standards for nutrients do not exist.

Dynamic Estuary Model

Application of the DEM to simulate the hydrodynamic and water quality response of a particular estuary requires development of a segmentation network to which the equations comprising the DEM can be applied and solved by a computer. The network together with the DEM computer code constitute the model of the estuary.

Two segmentation networks were required to represent receiving waters in the vicinity of urban Mobile with the degree of spatial resolution desired. A coarse grid network as depicted in Figures 5 and 6 represented the entire Mobile Bay and Mobile River Delta, respectively, with a system of 149 nodes (junctions) interconnected by 267 channels (links). Because it was not feasible to obtain the desired spatial resolution for the lower Mobile River, Three Mile Creek, and Chickasaw Creek with the coarse grid network, a fine grid network for these areas was also developed as shown in Figure 7, with 47 nodes and 49 channels as opposed to the 8 nodes and 7 channels used to represent the same area on the coarse grid network. Additionally, a fine grid network was developed for that part of the Bay in the vicinity of the Theodore Industrial Park in order to more effectively evaluate alternative discharge locations for effluent from the Theodore area. This fine grid network, as illustrated in Figure 8, was superimposed over a portion of Mobile Bay as defined by several of the link-node boundaries of the coarse grid network.

Since storm water runoff loadings were also to be evaluated, the DEM was modified to accept temporally variable storm water loadings. Using wet weather conditions, a prestorm steady-state water quality simulation was first obtained. Using these wet weather prestorm equilibrium conditions as a starting point, storm water runoff from an intense, short duration storm was introduced into the model. The simulation continued until the transient water quality effects caused by the storm water loads had dissipated.

Critical Conditions for Simulations

Receiving water quality effects of pollutant discharges are greatly influenced by environmental conditions—tidal range, fresh water discharges, and meteorology—prevailing at the time of discharge. The mean annual tide at the Main Pass with a 0.39 m (1.3 foot) range was used to drive both the dry and wet weather hydraulic simulations. Ambient temperature simulations for both the dry and wet weather cases were based on average meteorological conditions observed during July 1976 at the Mobile airport. Since the Alabama State water quality criteria require use of the minimum 7-day low flow that occurs once in ten years as the basis for design criteria, inflows from fresh water tributaries to Mobile Bay were set at their 7-day 10-year low flow ($Q_{7,10}$) values for the dry weather simulations. Use of $Q_{7,10}$ flows for the wet weather simulations were considered inappropriately severe; therefore, these inflows were doubled for the wet weather simulations.

Baseline Simulations

A series of baseline or no-action simulations was completed to project water quality assuming that Best Practicable Treatment (BPT) for industrial discharges and secondary treatment for municipal discharges would be attained, but that no additional water quality regulatory action would be taken. The baseline wet weather simulations also assumed no action would be taken to control urban storm water runoff loadings. Two sets of dry and wet weather baseline simulations were completed, one for 1977 and the other for projected year 2000 conditions. From the results of the 2000 baseline simulations, estuarine segments with simulated water quality in violation of applicable water quality standards were identified and used for further analysis.

Dry Weather Conditions

The dry weather baseline simulations indicated that violations of water quality standards due to point source discharges were limited with one exception to the vicinity of the urban Mobile area covered by the lower Mobile River fine grid model segmentation. Figure 9 illustrates that simulated BOD_5 concentrations exceeding 0.2 mg/l are found only in the vicinity of urban Mobile and near the ocean boundaries, while BOD_5 concentrations over most of the Bay are quite low. This is interpreted as meaning that direct impacts of point sources on Mobile Bay water quality and, in particular, on dissolved oxygen concentrations, are negligible except in the northwest corner of the Bay where poorer water quality from the Mobile River entered the Bay. The area of direct influence of point source discharges simply does not extend much beyond the mouth of the Mobile River.

Violations of applicable dissolved oxygen standards due to point sources were simulated

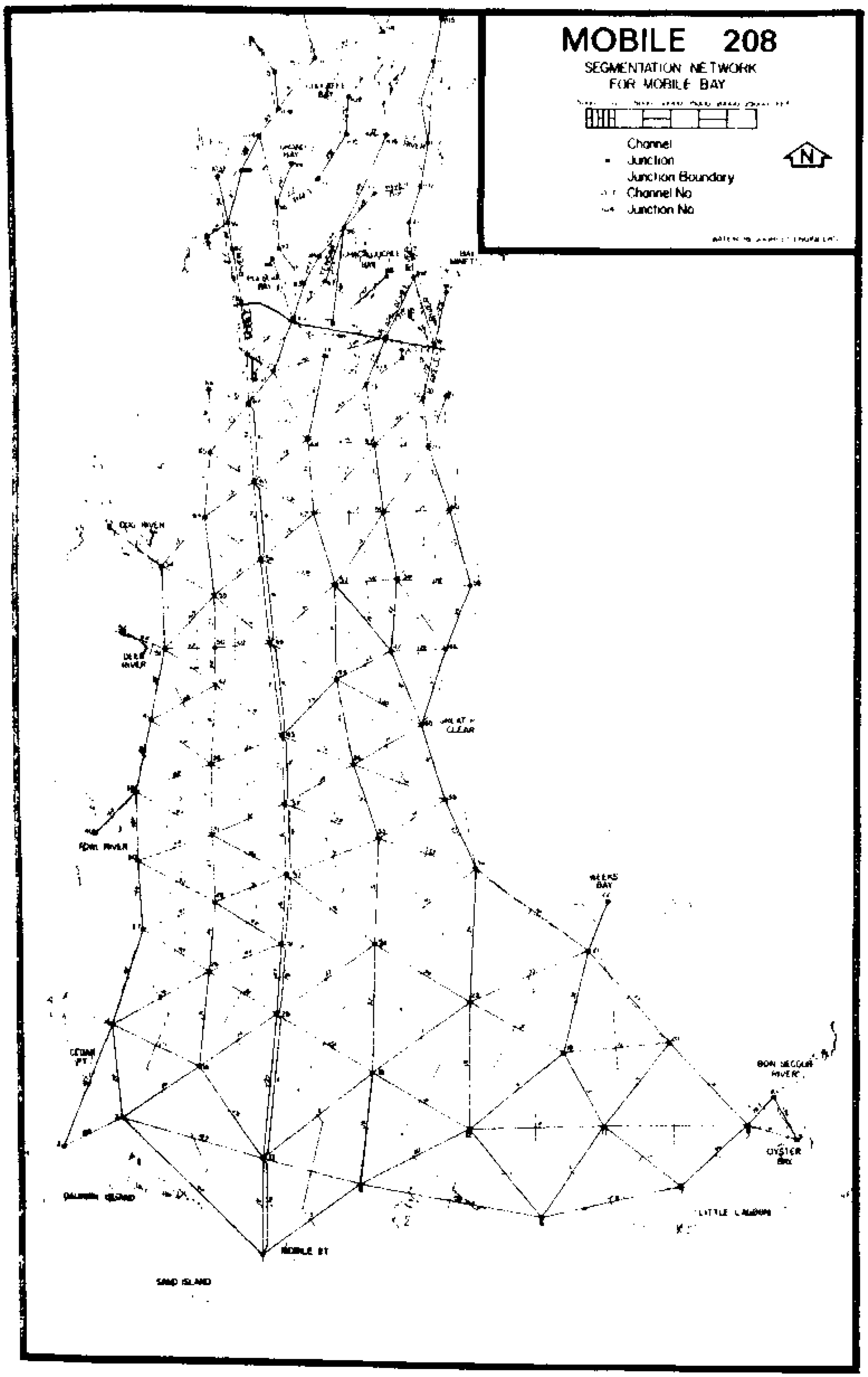

Figure 5. Coarse Grid Segmentation Network of Mobile Bay

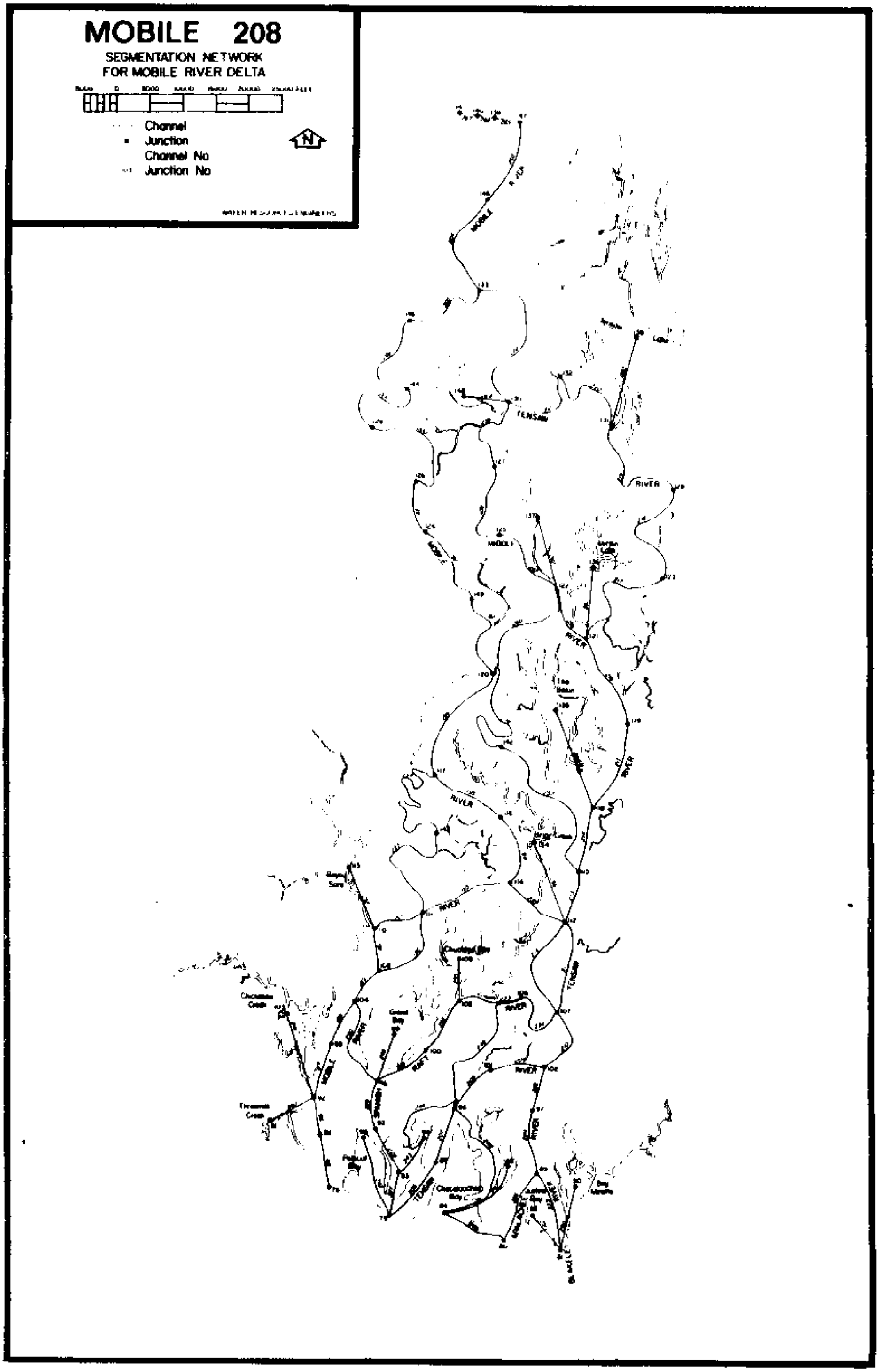

Figure 6. Coarse Grid Segmentation Network of Mobile River Delta.

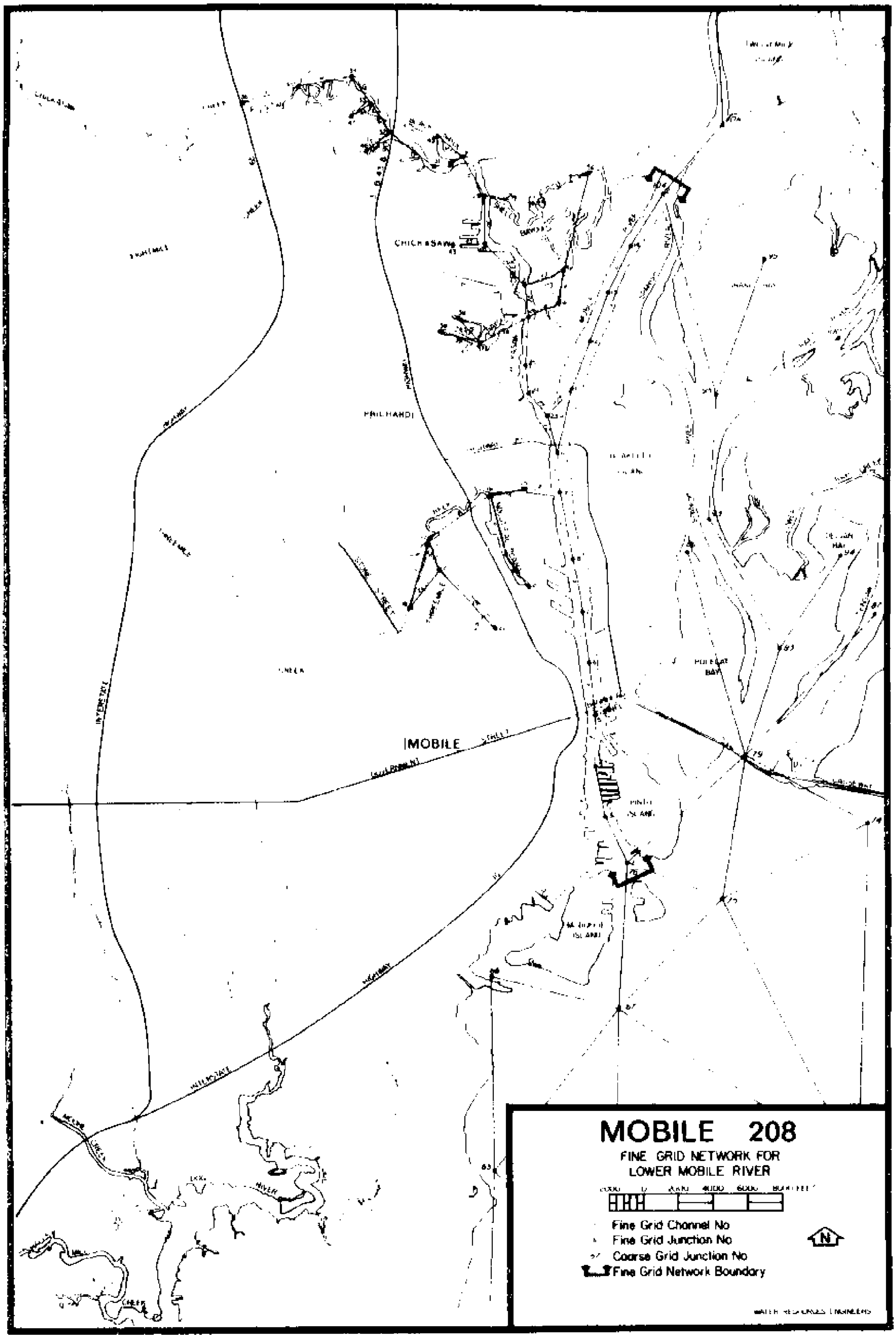

Figure 7. Lower Mobile River Fine Grid Network.

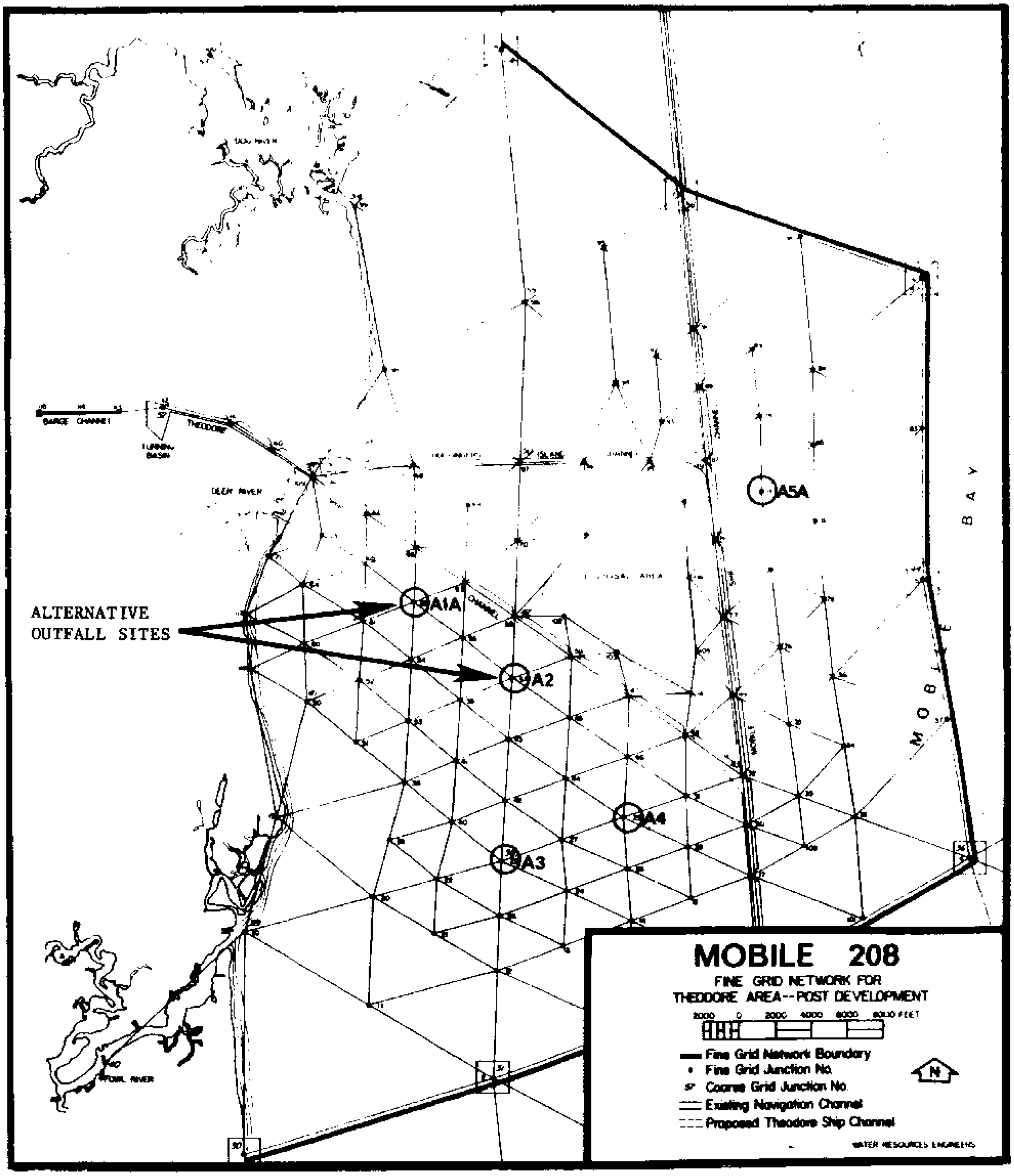

Figure 8. Theodore Area Fine Grid Network.

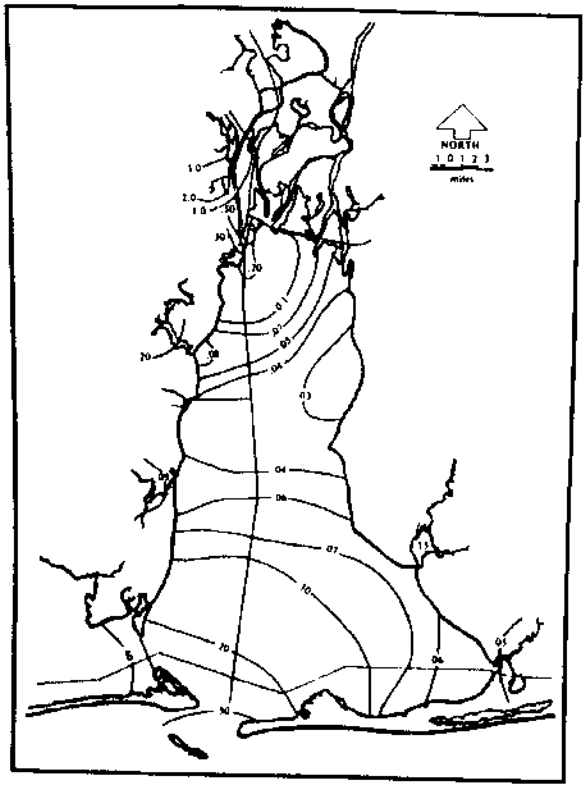

Figure 9. Simulated Distribution of BOD, Originating from Point Sources and Boundaries--mg/l.

in Three Mile Creek, Chickasaw Creek, and in the northwest corner of Mobile Bay just below the mouth of the Mobile River. Figure 10 illustrates

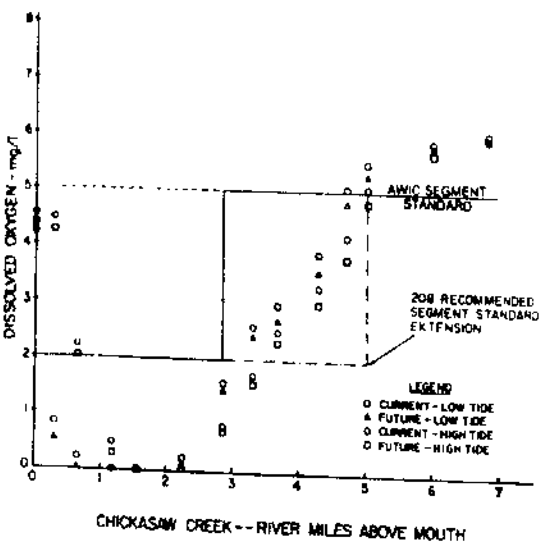

Figure 10. Simulated Current and No-action Future Dissolved Oxygen. Profiles in Chickasaw Creek–Dry Weather.

simulated dissolved oxygen concentrations in Chickasaw Creek at low and high tide in response to current (1977) and future (2000) baseline loadings. The 2.0 mg/l dissolved oxygen standard applicable downstream from Shell Bayou (River Mile 2.8) is violated as is the 5.0 mg/l standard applicable upstream from Shell Bayou. Clearly very poor water quality in Chickasaw Creek currently occurs and will continue to occur if point sources receive only BPT.

In Three Mile Creek, simulated dissolved oxygen concentrations with the baseline loadings were also in violation of water quality standards. Complete depletion of dissolved oxygen was simulated over most of the creek. The maximum dissolved oxygen concentration simulated was less than 2.0 mg/l, considerably below the 3.0 mg/l standard.

The 3.0 mg/l dissolved oxygen standard in the lower Mobile River was not violated using BPT loadings as indicated in Figure 11. However, results from the coarse grid model did indicate that the

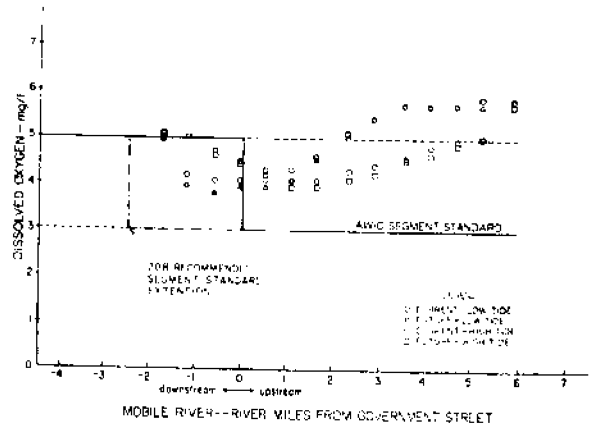

Figure 11. Simulated Current and No-action Future Dissolved Oxygen. Profiles in the Mobile River–Dry Weather.

5.0 mg/l standard applicable in Mobile Bay was violated over a short reach immediately below the mouth of the Mobile River.

In all other locations, no dissolved oxygen standards violations due to point source discharges were simulated. However, the simulations did indicate that in some areas natural processes will, under critical conditions, lower ambient dissolved oxygen concentrations below 5.0 mg/l.

Violations of thermal water quality standards using the baseline loadings were simulated due to cooling water discharges from two electrical generating facilities, the Chickasaw Steam Plant located on Chickasaw Creek, and the Barry Steam Plant located on the upper Mobile River. Simulated temperatures in each case violated both aspects of the temperature standard allowing maximum temperatures of 32.2°C (90°F) and maximum temperature increases of 2.8°C (5.0°F) above natural background.

Wet Weather Conditions

The wet weather baseline simulations were intended to demonstrate the effects of urban storm water runoff from the critical 1-inch, 1-hour storm on estuarine water quality. Water quality effects of the urban storm water loadings generated with the STORM model previously discussed were analyzed using the DEM for current (1977) and projected (2000) land use conditions. Results of simulations indicate that urban storm water loads are not responsible for violations of water quality standards in areas where water quality standards were attained during dry weather. However, the wet weather loadings increased water quality problems caused by dry weather baseline waste loads. Dissolved oxygen concentrations are depressed in Chickasaw Creek due to the storm water loads. Dissolved oxygen concentrations in the Mobile River are almost unaffected by the storm water loads. Figure 12 illustrates dissolved oxygen responses in Three Mile Creek to the critical storm loads. At

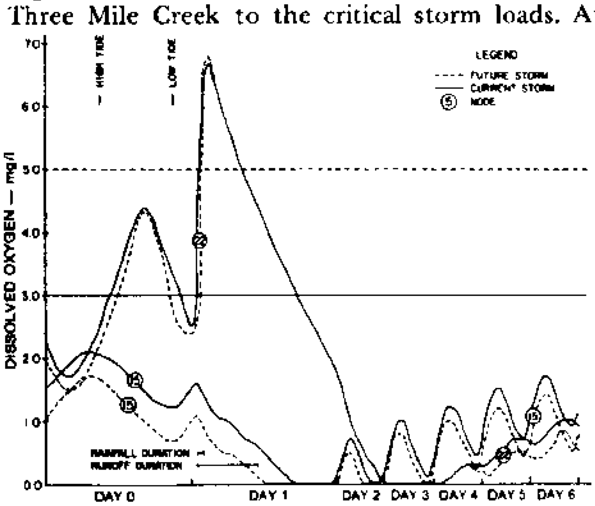

Figure 12. Three-Mile Creek Simulated Current and No-action Future Dissolved Oxygen Responses to One Inch, One Hour Storm.

node 15, located at the mouth of Three Mile Creek, the storm causes anaerobic conditions to develop within hours after the storm. Upstream at node 22, dissolved oxygen concentrations temporarily increase to almost 7.0 mg/l due to the oxygenated runoff entering the Estuary. Development of anaerobic conditions rapidly follows.

The winter wet weather baseline simulations indicated that urban storm water discharges would elevate fecal coliform concentrations to 170 MPN/100 ml in Chickasaw Creek, 810 MPN/100 ml in Three Mile Creek, and 220 MPN/100 ml in Dog River. Only the Dog River concentration is in violation of present standards. It should be noted again that the simulations indicate that neither urban storm water nor adequately disinfected point source discharges are responsible for the relatively high levels of fecal coliform bacteria. Both of these sources are relatively small compared to the loadings from upstream runoff.

Maximum Allowable Waste Loads

Following identification of those areas where secondary and BPT point source discharges or urban stormwater runoff loadings were responsible for violations of water quality standards, a series of simulations was performed to determine the levels of point source and urban stormwater loadings that would provide for the attainment of ambient water quality standards under critical conditions. It should be emphasized that these pollution limits were derived for the existing outfall configuration. Alternative outfall configurations and treatment levels were evaluated later in the modeling process.

Three Mile Creek

During dry weather, the water quality in Three Mile Creek is principally affected by discharges from the Grover Street and Three Mile Creek sewage treatment plants. The simulations indicated that the 3.0 mg/l dissolved oxygen standard for the Creek could be met if the combined total oxygen demand from these two plants was limited to 526 kg/day (1160 lbs/day) at their projected year 2000 flow rates. This total includes both ultimate carbonaceous and nitrogenous biochemical oxygen demand.

Even if point source loads are constrained to these limits, urban storm water runoff would still create anaerobic conditions in Three Mile Creek annually or more frequently. Reduction of storm water oxygen demanding loads from the critical storm to approximately 65 percent of uncontrolled loads would be required to maintain the 3.0 mg/l dissolved oxygen standard at all locations in the Creek. This corresponds to a total ultimate carbonaceous and nitrogenous oxygen demand of 3000 kg (6600 lbs) per critical storm event.

Chickasaw Creek

Water quality in Chickasaw Creek is primarily affected by waste water discharges from the Eight Mile Creek sewage treatment plant and the Chickasaw Lagoon, and from International Paper Company which discharges into Hog Bayou. The maximum daily load simulations indicated that the two municipal treatment plants must be constrained to a maximum carbonaceous and nitrogenous oxygen demanding load of 159 kg/day (350 lbs/day) at their projected flow rates to meet the applicable 5.0 mg/l dissolved oxygen standard for the reaches of the Creek where these discharges are located.

The total maximum daily oxygen demanding load required to attain the 2.0 mg/l dissolved oxygen standard in Hog Bayou is approximately 249 kg/day (550 lbs/day). With point sources constrained to these limits, no allocation for urban storm water loads is necessary, since projected storm water loads do not cause violations of water quality standards in Chickasaw Creek.

Mobile River

Maximum allowable daily loads to the Mobile River are not constrained by the dissolved oxygen standards designated for the various reaches of the River. The only simulated water quality violation along the upper River resulted from the Barry Steam Plant cooling water discharge. The maximum daily load simulations indicated that the temperature increase in the cooling water must be limited to 7.5°C (45.5°F) under critical conditions if the thermal water quality standards for the River are to be attained.

Mobile Bay

Two areas in Mobile Bay were of direct concern in the analysis of the total maximum daily loads: 1) the area immediately south of the Mobile River mouth; and 2) the area adjacent to the proposed outfall from the Theodore Industrial Park. Violations of the 5.0 mg/l dissolved oxygen standard were indicated at the point where the Mobile River, with a DO standard of 3.0 mg/l, enters Mobile Bay. The violations did not exceed 0.5 mg/l and were attributed to the abrupt change in standard at the point of definition of the mouth of Mobile River—the foot of Government Street. The violation occurred only along this reach from the foot of Government Street to Choctaw Point, which is really a part of the River rather than a part of the Bay. No waste load was developed for this small affected area. Rather, it was recommended that the mouth of the River be defined as Choctaw Point.

Analysis of the proposed Theodore Industrial Park outfall was conducted in two phases. First, alternative outfall locations were evaluated using the mathematical model, and then further evaluated using the Corps of Engineers' physical model.

Evaluation of the five alternative discharge sites selected was accomplished with the Dynamic Estuary Model (DEM) using the segmentation networks previously described in Figures 5 and 8. The coarse grid network was altered slightly to reflect the addition of a spoil island and the dredged Theodore Ship Channel.

The water quality (mass transport) module of the DEM was applied to simulate the dispersion of conservative (tracer) constituents discharged from the five sites. Initial concentrations of the conservative tracers in all junctions were set at zero. Two mass transport simulation runs were made, one showing the effects of initial release of the tracer constituents at low slack water and the other showing the effects of initial tracer release at high slack water. The simulated tracer discharge to each site was .142 m^3/sec (5.0 cfs) with a concentration of 30,000 mg/l, corresponding to a mass emission rate of approximately 366,000 kg/day (807,000 lbs/day). The sites were also evaluated on the physical model of Mobile Bay maintained by the Corps of Engineers at the Waterways Experiment Station in Vicksburg, Mississippi. Dye releases were made at each outfall location and resulting dispersion patterns were observed under the same ambient conditions as those used in the mathematical modeling. Based on the results of these two modeling efforts and considering the ultimate fate of the plumes with regard to known existing oyster reefs, the A-3 outfall was recommended as the optimum discharge location. Simulations of the water quality effects of this recommended outfall did not reveal any significant effects, and changes in constituent concentrations as a result of the proposed discharge were negligible. Calculations were performed for both conservative and reactive parameters in order to determine the range of concentrations that would result from the initial anticipated users of the pipeline. This analysis was further extended in the mathematical and physical modeling to determine the maximum allowable daily loads that would achieve water quality standards for protection of shellfishing waters. The simulations indicated that the maximum carbonaceous and nitrogenous oxygen demanding load at the point of discharge to attain the 5.0 mg/l dissolved oxygen standard would be approximately

4535 kg/day (10,000 lbs/day). In addition, a total coliform count of 1000 MPN/100 ml and a fecal coliform count of 200 MPN/100 ml would be the constraining loads necessary to meet the shellfish harvesting standard.

Deer River

The baseline simulations previously described did not include water quality projections for Deer River after construction of the Theodore Industrial Park and Ship Channel. However, a series of simulations was conducted to project water quality in the ship channel following project construction and to develop maximum allowable waste loads. The waste load allocation was structured in four parts: 1) development of a segmentation network for the DEM to represent the land cut portion of the Theodore Ship Channel and barge canal extension; 2) development of average annual and critical event storm water runoff loadings to the channel; 3) selection of values for key dissolved oxygen budget parameters; and 4) simulation of storm water runoff effects.

The segmentation network used to represent the ship channel is schematically shown in Figure 13. Average annual and critical storm water runoff loadings were developed using the storm water load generation model (STORM). The hydraulic and water quality modules of the DEM were operated to simulate ambient dissolved oxygen levels in the ship channel under three conditions: 1) without either point source or storm water runoff loadings; 2) with average annual storm water loadings treated as a continuous point source; and 3) with time variant loadings generated for the critical storm. Table 15 presents the results of the waste load allocation for the inland portion of the ship channel. In summary, the simulations indicated that even if point and nonpoint source loads are excluded from the land cut portion of the ship channel, dissolved oxygen concentrations below the 5.0 mg/l standard are expected due to benthic uptake of dissolved oxygen and the extremely low mixing, flushing and reaeration that can be expected.

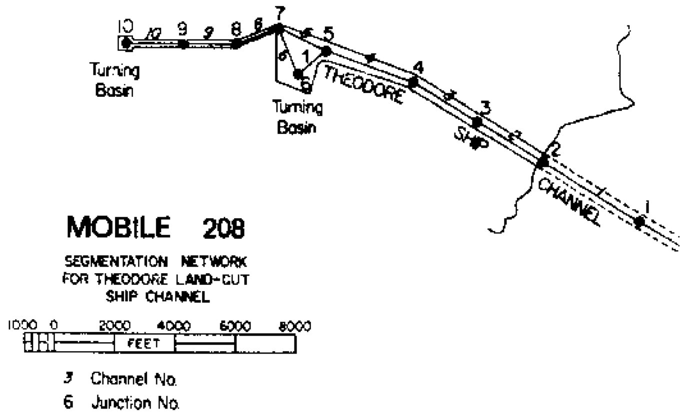

Figure 13. Segmentation Network for the Theodore Land-cut Ship Channel.

DATA GAPS AND LIMITATIONS

Several significant data gaps and limitations should be recognized in connection with the water quality assessment and mathematical modeling performed in this study.

1) The analyses, evaluations and recommendations of the study are based strictly on sampling in the water column. No account was taken of waste deposits in bottom samples, especially the

Table 15. Theodore Ship Channel Waste Load Allocation Summary

Node	Reaeration Coefficient day^{-1}	Dissolved Oxygen Reaeration Rate mg/l-day	Reaeration Rate lbs/day	Benthic Uptake g/m^2-day	Benthic Uptake lbs/day	Reaeration Deficit* lbs/day	Equivalent Excess Demands† BOD_5 lbs/day	NH_3 lbs/day
3	0.06	0.15	407	1.6	659	252	169	55
4	0.06	0.15	463	1.6	752	289	194	63
5	0.06	0.15	585	1.6	951	366	245	80
6	0.05	0.13	374	1.6	610	236	158	52
7	0.06	0.15	232	1.6	377	145	97	32
8	0.17	0.48	100	1.6	159	59	39	13
9	0.17	0.48	110	1.6	175	65	44	14
10	0.17	0.48	97	1.6	154	57	38	13

*Benthic uptake less reaeration rate. External dissolved oxygen demands not considered.

†Reaeration deficit expressed as an equivalent amount of 5-day BOD exertion or ammonia nitrification.

potential deposition of heavy metals.

2) Water quality stress limits are assessed only in terms of meeting the State water quality standards.

3) The methodology employed in the nonpoint source assessment resulted in the application of nonpoint source loadings from the "typical" catchments actually sampled to similar land use types throughout the Mobile/Baldwin area. A more accurate assessment of the nonpoint source impacts from a particular area would require site specific sampling.

4) There is a paucity of data available on the benthic oxygen uptake rates in the Mobile Bay and Mobile Delta area. Further study should be done in this regard.

5) No biological sampling and analysis was done in this study, and, to our knowledge, very little biological data exists on a wide-scale basis for the Bay area.

6) There are definite limitations that should be taken into account in the interpretation and application of the mathematical model simulation results. It should be noted that the model represents the prototype as a series of well-mixed reactors between which both water and constituent mass are transferred as a function of concentration gradients and relative heads. However, the well-mixed assumption does not hold along the lower Mobile River and dredged portions of Chickasaw Creek and Three Mile Creek due to strong stratification associated with the salt water wedge up the Mobile Ship Channel. The water quality simulation results in these areas are at best an average of the sharply different levels of water quality above and below the halocline. It should be recognized that poor water quality in the salt water wedge will persist regardless of the point source pollution control strategy applied.

7) A more spatially detailed segmentation network for the model, especially in the vicinity of potentially serious point source impacts, could reveal water quality effects that are impossible to simulate with the coarse grid segmentation used as the basis for the modeling work done in this study.

8) Pollutant accumulation rates and, therefore, storm water runoff loads used to accurately calibrate the STORM model for commercial and residential land uses were smaller than reported values in the literature for other urban areas.

9) The behavior of effluent plumes under varying hydrographic conditions in the Bay and Delta has not been studied in great detail. Because the hydrography of the area waters is dynamic and complex, and effluent plumes could behave in a number of different ways, the specific impacts of wastes discharged at any given point cannot be stated with certainty. Our study was limited in its analysis to an evaluation of only one hydrodynamic regime based on a non-stratified water condition and a surfacing plume. Actual field studies should be performed under all possible hydrodynamic regimes in order to more completely assess the impacts of effluent wastes on the receiving waters.

10) Application of dispersion formulation requires the determination of many equation parameters. At present, for Mobile Bay, there are no determined values for these parameters and estimates based on assumptions and literature values must be utilized in calculating dispersion effects of wastes in receiving waters.

MANAGEMENT RECOMMENDATIONS

The following quantitative and qualitative site specific management recommendations are based on the findings of this study.

1) The management of sanitary point source discharges should continue to be the responsibility of the local municipal authorities presently permitted for such discharges. All sanitary waste treatment plants in the area should meet secondary or better levels of treatment, and future permit conditions for each facility should be based on the waste load allocation required to meet water quality standards for discharge to receiving streams as determined in this study or in the AWIC Basin Plans and summarized in Table 16.

2) The management of industrial point source discharges should continue to be the responsibility of the industries presently permitted for such discharges. All industrial waste treatment plants should meet BPT levels of treatment immediately. Permit conditions for each industrial discharge after 1983 should be based on the waste load allocation required to meet water quality standards for discharge to receiving streams as determined in this study or in the AWIC Basin Plans and summarized in Table 16.

* 3) International Paper Company should relocate its discharge to the Mobile River by 1983, and discharge should be permitted at present treatment levels since water quality in the River is insensitive to higher levels of treatment. Other industrial point sources discharging to Chickasaw Creek and Three Mile Creek must either connect to sanitary sewer systems or meet BPT treatment by 1983.

4) No point sources containing process waste water should be permitted to discharge to Bayou

Table 16. Waste Load Allocations for Area Dischargers, Year 2000.

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
				STREAM SEGMENT: MOBILE BAY (MS-125)					
Causeway Seafood	N/A	0.001	(d)[2]	(d)[2]	(d)[2]	(d)[2]	(d)[2]	(d)[2]	Based on sewer service being provided to the causeway by 1983. Must connect to McDuffie Island STP.
McDuffie Island STP	141,653	28.0[k]	30	45	90	135[b]	20	3	NPDES Permit is basis of allocation shown—upon completion of expansion in Feb. 1978 facility adequate "as is."
International Paper Bag Pk. (Discharge 001)	N/A	0.001	(d)[2]	(d)[2]	(d)[2]	(d)[2]	(d)[2]	(d)[2]	NPDES Permit is basis of allocation shown—discharge to McDuffie Island STP.
Fairhope STP	12,285	2.00[k]	30	45	90	133[b]	20	2	Mechanical system—treatment level 1 required—facility satisfactory "as is." (p)
Grand Hotel	N/A	0.10	30	45	90	133[b]	20	2	Private mechanical system—treatment level 1 required. (p)
Bill Ziebach STP	9,270	2.00[k]	30	45	90	133[b]	20	3	NPDES Permit is basis of allocation shown. Mechanical system—treatment level 1 required—facility satisfactory "as is." (p)
Bayou La Batre STP (Discharge is to Portersville Bay)	7,606	1.00[k]	30	45	90	133[b]	20	2	NPDES Permit is basis of allocation shown—design capacity adequate to 1983 when upgrade to level 4-a should be accomplished.
Patronnas Seafood (Discharge is to Aloe Bay)	N/A	0.001	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown. BAT treatment required in 1983 or connection to Dauphin Island STP.
Dauphin Island STP (Discharge is to Aloe Bay)	1,280[l]	0.487	30	45	90	133[b]	20	5	NPDES Permit effluent limits not established yet—treatment level 1 required. Any future treatment would require upgrade to treatment level 4-a. (p)

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Mallon Seafood (Discharge is to Aloe Bay)	N/A	0.001	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to Dauphin Island STP.
Water Front Seafood	N/A	0.110	- None -Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
LaForce Seafood	N/A	0.01	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Seafood Haven	N/A	0.005	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Ramos Shrimp Co.	N/A	0.03	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Blue Gulf Seafood	N/A	0.004	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Henry Johnson Seafood	N/A	0.008	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Mexican Gulf Fisheries	N/A	0.01	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Waters Seafood	N/A	(f)	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Steiner Shrimp	N/A	0.046	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Lyon Seafood Co.	N/A	0.01	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Gulf's Best Seafood	N/A	0.01	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Stork Seafood	N/A	0.001	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Quality Foods, Inc.	N/A	0.432	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Joes Seafood Co.	N/A	0.007	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Independent Seafood	N/A	0.01	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Steeles Seafood	N/A	0.001	- None—Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Seaman Fisheries	N/A	0.025	- None Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Sea Pearl Seafood	N/A	0.01	- None - Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
Bryant Seafood	N/A	0.01	- None--Must connect to New Bayou La Batre STP.						NPDES Permit is basis for allocation shown. (o)
				STREAM SEGMENT: MOBILE RIVER (MS-1)					
Scott Paper, Sawmill Sawmill "D"	N/A	0.787	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown--cooling water. (o)
Searcy Hospital	N/A	0.360	30	45	18	63[c]	4	2	NPDES Permit effluent limits not established yet treatment level 1 required - private lagoon system discharge to Cedar Creek. (p)
Barry Steam Plant—Alabama Power Co. (Disch. 001)	N/A	1,156.0	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—cooling water.
Barry Steam Plant—Alabama Power Co. (Disch. 002)	N/A	27.8	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—ash pond discharge.
Georgia Pacific	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown - cooling water discharge to Cedar Creek.
				STREAM SEGMENT: MOBILE RIVER (MS-2)					
Virginia Chemicals (Disch. 001)	N/A	0.13	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown cooling water (o)
Virginia Chemicals (Disch. 002)	N/A	0.278	200#/day	(e)	(e)	(e)	170#/day	(e)	NPDES Permit is basis of allocation shown with relocation of discharge to Mobile River by August 24, 1978. (o)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Stauffer Chemical Co.–Bucks (Disch. 001)	N/A	0.196	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown-BAT treatment required in 1983.
Stauffer Chemical Co.–Axis (Disch. 001)	N/A	1.40	300#/day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983.
Halby Chemical (Disch. 001)	N/A	0.02	(e)	(e)	(e)	(e)	0.33#/day	(e)	NPDES Permit is basis of allocation shown-BAT treatment required in 1983. (o)
Courtaulds North America	N/A	8.20	2475#/day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983.
Shell Chemical Company	N/A	0.113	43.8#/day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983.
STREAM SEGMENT: THREE MILE CREEK (MS-3)									
Aluminum Company of America (Disch. 001)	N/A	0.826	(m)	(m)	(m)	(m)	(m)	(m)	Allocation for this discharger based on elimination of process wastewater discharge after July 1, 1977 cooling water only.
Miller Transporters	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown-BAT treatment required in 1983 or connection to STP.
Chevron Asphalt	N/A	0.325	(m)	(m)	(m)	(m)	(m)	(m)	Allocation for this discharger based on BPT Guidelines.
Shell Oil Company (Disch. 001 & 002)	N/A	0.017	(e)	(e)	(e)	(e)	(e)	(e)	Based on NPDES Permit-BAT treatment required in 1983. Disch. 001 is stormwater discharge.
Texaco (Disch. 001)	N/A	0.002	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown. Stormwater discharge.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Union Chemical Div. Union Oil (Disch. 001)	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown. Stormwater discharge.
Kaiser Aluminum & Chemical (Disch. 001)	N/A	2.254	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown - discharge is from tank fabrication and occurs once per month.
Gulf Oil Company	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown. Stormwater discharge.
Amerada Hess (Disch. 001 & 002)	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown. Discharge 001 is storm water.
Ideal Cement Company (Disch. 001 & 002)	N/A	0.980	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—Cooling water and stormwater discharge.
Triangle Refinery—Choctaw Pt. (Disch. 001)	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—Stormwater discharge.
Triangle Refinery—Blakely Is. (Disch. 001)	N/A	0.001	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—Stormwater discharge.
American Oil (Disch. 001)	N/A	0.0002	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—Stormwater discharge.
Alabama Dry Docks	N/A	0.42	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—cooling water discharge.
Southern Railway System	N/A	(f)	30	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to STP.
Alabama Wood Treating Corp.	N/A	0.12	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000, (Continued)

Discharger	2000 Population	2000[(a)] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Scott Paper Company	N/A	76.40	22,177#/ day	(e)	(e)	(e)	(e)	(e)	Based on NPDES Permit for discharge to the Mobile River. BAT treatment required in 1983.
North Mobile Industrial WWTP	N/A	34.63[(k)]	15,862#/ day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983 for relocated discharge.
North Mobile Regional STP (combines Prichard Eight Mile STP, Saraland STP and Satsuma Sewer Service Areas)	N/A	8.5[(k)]	30	45	90	133[(b)]	20	3	Allocation based on discharge to Mobile River Segment classified A&I (MS-3) (i).
Prichard Grover Street STP	27,443	4.0[(k)]	30	45	90	133[(b)]	20	3	Allocation based on meeting A & I standard in Mobile River (i).
Three Mile Creek STP	82,530	10.0[(k)]	30	45	90	133[(b)]	20	3	Allocation based on meeting A & I standard in Mobile River (i).
STREAM SEGMENT: THREE MILE CREEK (MS-4)									
Star Fish & Oyster	N/A	0.288	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983 or connection to STP.
Illinois Gulf Central RR	N/A	0.007	30	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983 or connection to STP.
Frisco RR	N/A	0.002	30	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983 or connection to STP.
Crown Zellerbach	N/A	0.001	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown–BAT treatment required in 1983.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Stone Container Corp. (Disch. 001)	N/A	0.02	50#/day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983.
Stone Container Corp. (Disch. 002)	N/A	0.15[k]	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—cooling water discharge.
Prichard Grover Street STP	27,443	4.0[k]	5	7.5	4.5	7[b]	1	3	Based on meeting A & I standard in Threemile Creek see allocation for relocation to Mobile River.
Three Mile Creek STP	82,530	10.0[k]	5	7.5	4.5	7	1	3	Based on meeting A & I standard in Threemile Creek - see allocation for relocation to Mobile River.
Mobile Rosin Oil Co. (Disch. 001)	N/A	0.01[k]	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	Allocation based on AWIC approval for discharge to Threemile Creek STP.
Alabama Dept. of Conservation	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown - discharge is from experimental fish ponds.
Gulf Lumber Company	N/A	0.005	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—cooling water discharge.
STREAM SEGMENT: CHICKASAW CREEK (MS-5)									
Alabama Power—Chickasaw Plant (Disch. 001)	N/A	213.0	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—this plant is used only for emergency power generation.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[(a)] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Alabama Power–Chickasaw Plant (Disch. 002)	N/A	0.33	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—this plant is used only for emergency power generation.
Union Carbide (Disch. 003)	N/A	1.817	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to No. Mobile Industrial WWTP.
Diamond Shamrock (Disch. 001)	N/A	0.135	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to No. Mobile Industrial WWTP.
Diamond Shamrock (Disch. 002)	N/A	1.008	(e)	(e)	(e)	(e)	(e)	(c)	NPDES Permit is basis of allocation shown—cooling water.
Eagle Chemical Company	N/A	0.21	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to No. Mobile Industrial WWTP.
International Paper Company (Disch. 012)	N/A	33.2	(d)[1]	(d)[1]	(d)[1]	(d)[1]	(d)[1]	(d)[1]	NPDES Permit is basis of allocation shown.
International Paper Company (Disch. 018)	N/A	25.0	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—cooling water.
North Mobile Industrial WWTP	N/A	34.63[(k)]	250#/day	(e)	(e)	(e)	(e)	(e)	Based on meeting Navigation Standard in Hog Bayou—see allocation for relocation to Mobile River.
American Cyanamid (Disch. 001)	N/A	0.63	(e)	(e)	(e)	(e)	(c)	(e)	NPDES Permit is basis of allocation shown—cooling water.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
American Cyanamid (Disch. 002)	N/A	0.30	(d)[1]	(d)[1]	(d)[1]	(d)[1]	(d)[1]	(d)[1]	Based on AWIC approval for discharge into No. Mobile Industrial WWTP.
Thompson Hayward Chemical (Disch. 001)	N/A	0.006	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to No. Mobile Industrial WWTP.
Thompson Hayward Chemical (Disch. 002)	N/A	0.001	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to No. Mobile Industrial WWTP.
Thompson Hayward Chemical (Disch. 003)	N/A	0.001	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 or connection to No. Mobile Industrial WWTP.
Hog Bayou STP	3,500	0.35[k]	30	45	90	133[b]	20	2	Based on Nav. Standard with discharge to Hog Bayou at treatment level 1. (p)
Chickasaw Lagoon	9,000	1.50[k]	30	45	18	61[b]	4	2	Based on meeting Nav. standard with discharge relocated below Shell Bayou in Chickasaw Creek or with discharge at present location and Nav. standard extended to HWY. 43 Bridge as recommended.
STREAM SEGMENT: EIGHTMILE CREEK (MS-39)									
Prichard Eightmile Creek STP	22,188	2.22	3	4.5	4.5	4[b]	1	5	Allocation for this discharger based on meeting F & WL standard in Eightmile Creek (i).

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[(a)] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Barber Pure Milk Co. (Disch. 001)	N/A	0.05	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	NPDES Permit is basis of allocation shown—discharge is to Prichard-Eightmile STP. (o)
STREAM SEGMENT: DOG RIVER (MS-47)									
Mobile Paint Mfg. Co.-- Theodore (Disch. 001)	N/A	(f)	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	Allocation for this discharger based on AWIC approval for discharge to Halls Mill STP.
Halls Mill Creek STP	38,491	1.50[(k)]	(m)	(m)	(m)	(m)	(m)	(m)	Allocation for this discharger based on this facility being abandoned by April, 1979 with flow going to McDuffie Is. STP.
GAF Corp. (Disch. 001)	N/A	1.67	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—cooling water discharge.
Union Carbide-- Theodore (Disch. 001 & 002)	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—discharge is to Alligator Bayou—001 is hydrostatic test water, 002 is drum and storage tank wash water.
STREAM SEGMENT: BAYOU SARA (MS-87)									
Saraland STP	12,500	1.22	3	4.5	4.5	4[(b)]	1	5	Allocation for this discharger based on meeting F & WL standard in Norton Creek (i).
Jacintoport Lagoon	N/A	0.007[(k)]	19.3#/day(e)		(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—discharge is to Black Creek.
STREAM SEGMENT: DEER RIVER (MS-116 & 119)									
Airco Alloys & Carbide	N/A	0.101	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	$(d)^2$	Allocation for this discharger based on connecting sanitary waste to Halls Mill STP by July, 1979 and reuse of cooling water.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Marion Refining Co. (Disch. 001 & 002)	N/A	0.072 (001 only)	44.9#/day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983. Discharge 002 is stormwater.
Kerr-McGee	N/A	0.026	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—cooling water and storm-water discharge.
Degussa	N/A	2.773	6	9	13	20	2.9	2	Allocation for this discharge based on discharge to A-3 site in Mobile Bay. (q)
STREAM SEGMENT: TENSAW RIVER (MS-54)									
Alpine Laboratories	N/A	0.018	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown. (o)
Bay Minette Westside Lagoon	1,233	0.225[k]	30	45	18	63[c]	4	2	Lagoon system treatment level 1 required - facility satisfactory "as is." (o) (p)
Tensaw Fertilizer	N/A	(f)	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit effluent limits not established yet.
STREAM SEGMENT: BLAKELY RIVER (MS-94)									
Spanish Fort Estates	3,400	0.54[k]	30	45	18	61[b]	4	2	Private lagoon system. NPDES Permit effluent limits not established yet. Treatment level I required. (p)
Lake Forest Development	3,100	1.25[k]	30	45	90	133[b]	20	2	Private mechanical system. NPDES Permit effluent limits not established yet. Treatment level 1 required.[p]
STREAM SEGMENT: BON SECOUR RIVER (MS-114)									
Aquila Seafood	N/A	0.001	(n)	(n)	(n)	(n)	(n)	(n)	Allocation will be made after further study.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[a] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
Grass Seafood	N/A	0.001	(n)	(n)	(n)	(n)	(n)	(n)	Allocation will be made after further study.
Plash's Seafood	N/A	0.003	(n)	(n)	(n)	(n)	(n)	(n)	Allocation will be made after further study.
Oyster Bay Seafood	N/A	0.001	(n)	(n)	(n)	(n)	(n)	(n)	Allocation will be made after further study.
Bon Secour Fisheries	N/A	0.014	(n)	(n)	(n)	(n)	(n)	(n)	Allocation will be made after further study.
Gulf Shrimp Company	N/A	0.01	(n)	(n)	(n)	(n)	(n)	(n)	Allocation will be made after further study.
STREAM SEGMENT: FISH RIVER (MS-103)									
Sars, Inc.	N/A	0.21	13.26#/day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983. (o) (p)
Loxley Lagoon	1,114	0.16	30	45	18	63[c]	4	2	Lagoon system treatment level 1 required—facility satisfactory "as is." (o) (p)
STREAM SEGMENT: TRIBUTARY TO McCURTIN CREEK (PS-20)									
Baldwin Pole Piling Company	N/A	0.005	----No discharge allowed----						NPDES Permit is basis of allocation shown. (g)
STREAM SEGMENT: HOLLINGER CREEK (PS-33)									
Bay Minette STP	7,767	1.000	20	30	36	63[b]	8	3	Mechanical system—treatment level based on meeting A & I standard in Hollinger Creek.
Reichold Chemical, Inc. (Disch. 001)	N/A	0.250	250#/day	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown—BAT treatment required in 1983 for discharge to Hollinger Creek—Present treatment is adequate for discharge to Bay Minette STP.

Table 16. Waste Load Allocations for Area Dischargers, Year 2000. (Continued)

Discharger	2000 Population	2000[(a)] Flow (mgd)	BOD_5	$CBOD_u$	$NBOD_u$	UOD	Ammonia	Effluent DO	Remarks
STREAM SEGMENT: TRIBUTARY TO STYX RIVER (PS-3)									
Kaiser Aluminum	N/A	0.003	(e)	(e)	(e)	(e)	(e)	(e)	NPDES Permit is basis of allocation shown. (g)
STREAM SEGMENT: ROCK CREEK (PS-26)									
Robertsdale STP	3,800	0.550 (proposed design flow)	30	45	81	121[(b)]	20	5	NPDES Permit is basis of allocation shown. (g)
STREAM SEGMENT: WOLF CREEK (PS-37)									
Foley STP	4,800	1.000 (proposed design flow	20	30	36	61[(b)]	8	5	NPDES Permit is basis of allocation shown. (g)
STREAM SEGMENT: INTRACOASTAL WATERWAY (MS-115)									
Gulf Shores STP	5,500[(i)]	1.6 (proposed) design capacity)	20	30	36	61[(b)]	8	5	NPDES Permit is basis of allocation shown for discharge to Intracoastal Waterway.
Gulf Coast White Knight Seafood (Gulf Shores)	N/A	0.013	(n)	(n)	(n)	(n)	(n)	(n)	NPDES Permit effluent limits not established yet—BAT treatment required in 1983 or connection to Gulf Shores STP.
Ala. Dept. of Conservation (Gulf Shores)	N/A	(f)	(n)	(n)	(n)	(n)	(n)	(n)	NPDES Permit effluent limits not established yet—discharge is from experimental fish ponds.
STREAM SEGMENT: PUPPY CREEK (ES-3)									
Citronelle Lagoon	2,761	0.268	30	45	18	63[(c)]	4	2	Lagoon system—treatment level 1 required—facility will need to be expanded and upgraded in 1983. (p)

(a) 2000 flows shown for municipal dischargers are either the listed design flow of the existing treatment facility or the flow anticipated from 95 percent of the 2000 projected population of the plant's service area (@100 gpcd), whichever is greater, unless otherwise noted. 2000 flows shown for industrial and semi-public dischargers are the listed design flow of the treatment facility unless otherwise noted.

(b) UOD = 1.5 BOD_5 (or $CBOD_u$) + 4.50 Ammonia (or $NBOD_u$)–Effluent DO.
(c) UOD = 1.5 BOD_5 (or $CBOD_u$) + 4.57 Ammonia (or $NBOD_u$)--rounded off to nearest whole number.
(d) Discharge to North Mobile Industrial Facility (d)[1] or STP (d)[2].
(e) NPDES Permit does not indicate allocations for these parameters.
(f) No flow data available.
(g) No population data available.
(h) Allocation shown reflects NPDES interim limits which expire 6/30/77.
(i) See North Mobile Municipal Allocation.
(j) Projected population data for plant service area deferred–will be developed by the South Alabama Regional Planning Commission.
(k) Listed design flow of facility.
(l) Both 2000 population and flow vary considerably throughout year due to tourist influx and departures (see completed Facilities Plan for details).
(m) Elimination of discharge.
(n) Allocation for these parameters to be made at a later date.
(o) Allocation developed by Alabama Water Improvement Commission in Basin Plan.
(p) The level of treatment may be defined by the expected effluent quality discharged from a well operated lagoon system or mechanical sewage treatment plant. The effluent characteristics for each are somewhat different. The primary element of a lagoon system is a stabilization pond at Level 1. It would be expected to discharge an effluent with the following characteristics: BOD_u = 45 mg/l, BOD_5 = 30 mg/l, NH_3 - N = 4 mg/l, and DO = 2 mg/l. The primary elements of a mechanical system are pretreatment, sedimentation, aeration, and chlorination. At Level 1 such an activated sludge plant would be expected to discharge an effluent with the following characteristics: BOD_u = 45 mg/l, BOD_5 = 30 mg/l, NH_3 - N = 20 mg/l, and DO = 2 mg/l. As the level of treatment increases, the quality of the effluent improves. (Source: Water Quality Management Plan-Mobile River Basin, Alabama Water Improvement Commission, August, 1976, IX-9 through IX-12).
(q) Tentative allocation pending completion of the Theodore EIS.

Sara, Norton Creek, Eight Mile Creek, Halls Mill Creek, Eslava Creek or Dog River.

* 5) The discharge of contaminants into the Theodore Ship Channel and Barge Canal Extension should not be permitted. The collection, proper treatment and disposal of wastes generated in the area should be the responsibility of a single authority. Disposal of wastes should be by outfall to the A-3 site in Mobile Bay with permit conditions for each individual user of the outfall based on the waste load allocation required to meet water quality standards for discharge to the Bay and the waste control concept illustrated in Figure 14.

6) All semi-public and private point source discharges along Battleship Parkway should be eliminated. To accomplish this, it is recommended that an interceptor be constructed to connect the Parkway, including Pinto Island and Blakely Island to the McDuffie Island STP.

* 7) The Grover Street and Three Mile Creek sewage treatment plants should discharge their wastes through a single outfall to the Mobile River by 1983.

*These recommendations are under further study at the request of EPA and AWIC. Any implementing actions will depend upon the results of the study which may confirm these recommendations or may recommend other alternatives.

8) Sanitary landfill sites and other necessary waste disposal sites should be identified for evaluation by appropriate local and state authorities as potential locations for disposal of municipal and industrial residual wastes, including toxic and hazardous materials.

9) Each county and local government in the Mobile Bay area should adopt and enforce a sediment and erosion control ordinance, and require that drainage plans be submitted for construction sites and new development activities. These drainage plans should identify the magnitude of the storm water runoff before development begins, and should specify the management practices that will be utilized during and after construction to maintain the same storm water rate of flow as existed before development began.

10) A monitoring program should be developed for Three Mile Creek to assess the effectiveness of existing and proposed drainage projects and the implementation of management practices for the control of urban storm water runoff.

11) No further development should be approved in the 100 year flood plain or in areas with severe septic tank limitations unless properly operating sewer collection and treatment systems are available.

The following recommendations are based on data gaps and limitations identified during the course of this study.

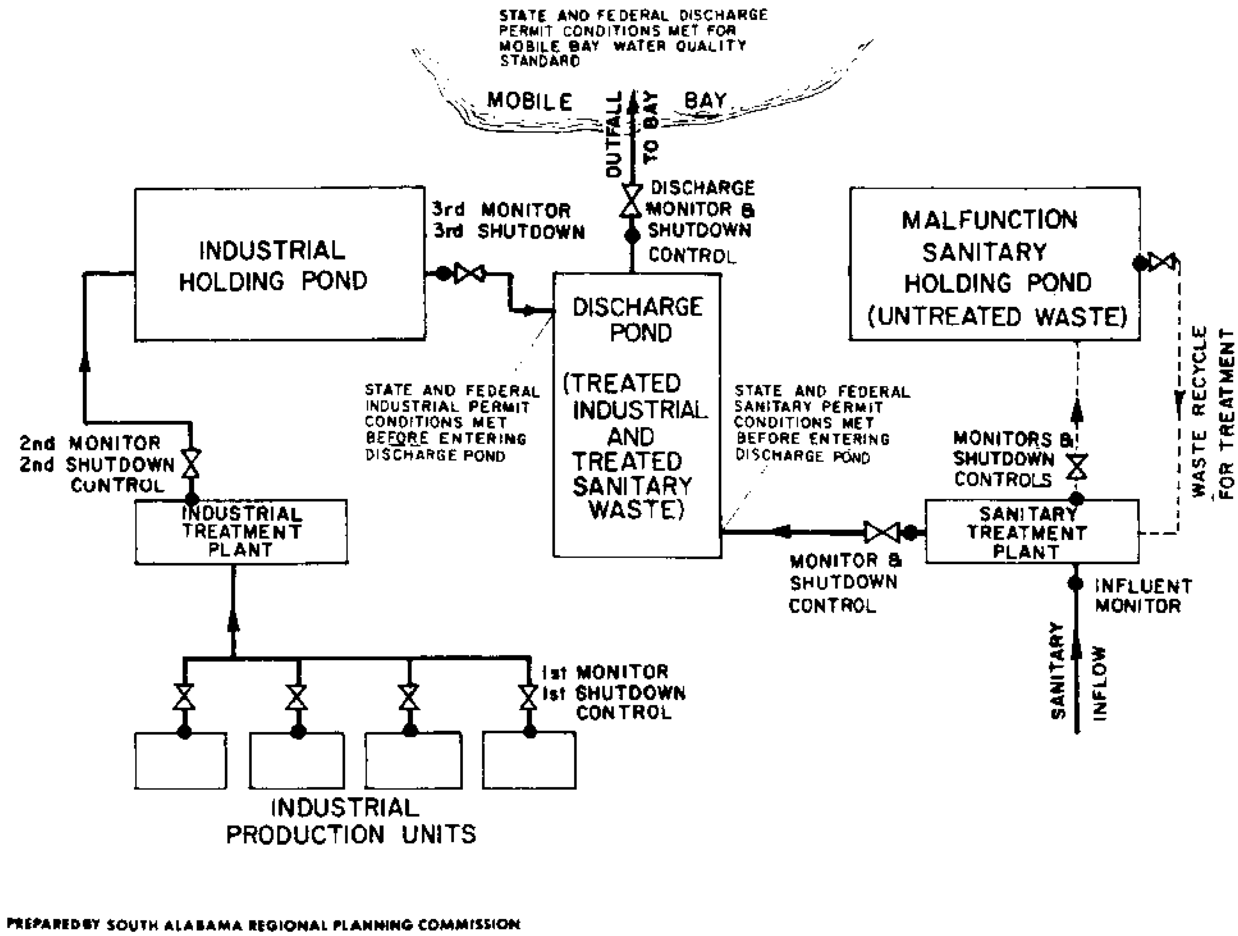

Figure 14. Theodore Waste Control Concept.

1) A closely coordinated "total" study design of Mobile Bay and Delta should be organized and implemented. This study should involve technical and financial input at the federal, state and local levels, and cover the full range of physical, chemical, biological, and climatological data necessary to provide the basis for informed decisions that can be made with a high degree of certainty.

2) In order to assist in the decision-making process, an adequate predictive tool in the form of a stratified computer model should be developed. The model should be calibrated and verified on the basis of data collected and made available for use at the local, state, and federal levels to all who would benefit from it.

3) All existing data and all data collected during the proposed "total" study should be computerized and made available for use to all who would benefit from it. The data base should be periodically updated so that fairly current information is always available to researchers, decision-makers, industrialists, environmentalists, developers, and others.

4) As technology becomes available, all treatment systems should be required to upgrade to eventually achieve zero discharge from point sources so that Bay and Delta water quality may also be upgraded.

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HYDROGRAPHY AND CIRCULATION OF MOBILE BAY

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ABSTRACT

Mobile Bay's salinity regime ranges from Bay wide influence of high salinity Gulf of Mexico waters during extended periods of low river discharge to dominance by freshwater under flooding river conditions. However, no set seasonal salinity pattern exists because of the river system's high degree of variability on day-to-day, month-to-month and year-to-year time scales. On the other hand the Bays thermal regime has a well defined seasonal structure directly linked to atmospheric temperatures. Circulation is poorly understood. It appears to be a two layer system even though the Bay is very shallow. Surface drogue studies suggest a highly variable system in the lower Bay.

BACKGROUND

The environmental components that produce the hydrography[1] and circulation of Mobile Bay are presented in Table 1. The components are grouped into five categories: (1) Mobile Bay Basin; (2) Oceanic; (3) Continental; (4) Atmospheric; and (5) other. Each component is divided in the Table into its: (1) Function; (2) Time Rate of Change; (3) Relative Importance to Salinity, Temperature and Circulation; and (4) Sensitivity to Impact from Man. The description of the hydrography and circulation of Mobile Bay generally will follow the structure of Table 1.

In a simple form the fundamental requirements of an estuary may be expressed as:

Semi-enclosed Coastal Basin + ("Salt waters" measurably diluted by "Freshwater") = Estuary.

Table 1 lists the above components as "Basic Constituents."

[1]For the purpose of the Mobile Estuary Symposium the term "Hydrography" is defined to include only the parameters salinity and temperature.

The Mobile Bay basin has been described in the introduction to these proceedings and is illustrated here in Figure 1. Important features to keep in mind are (1) triangular shape with the long axis running north-south; (2) relatively shallow overall but with significant exceptions (i.e. East Main Pass and the eastern side of the middle and upper Bay);

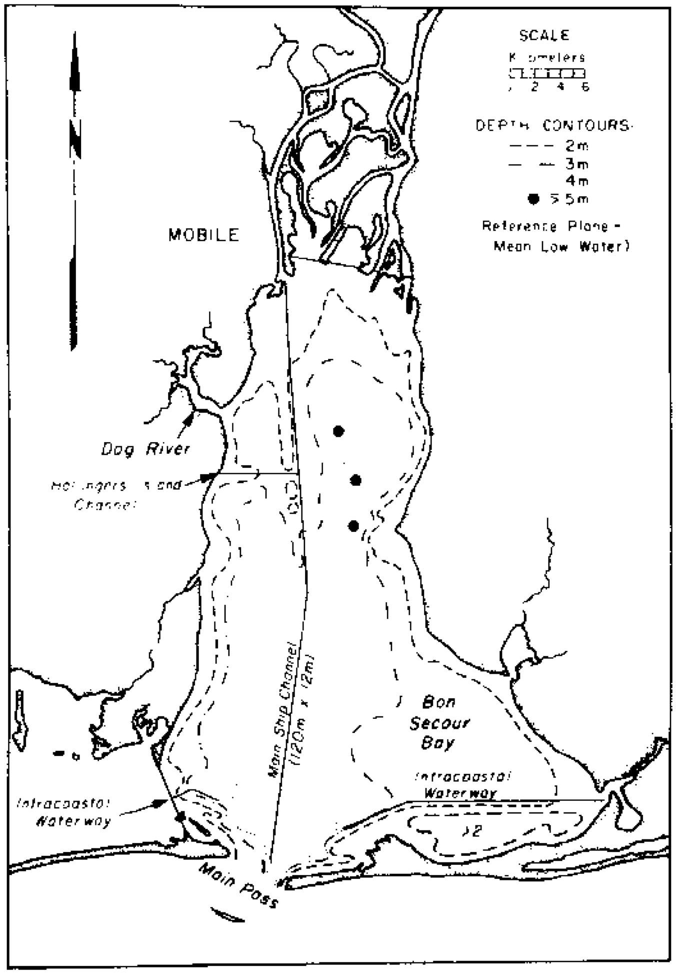

Figure 1. Mobile Bay, Alabama, Constructed of data obtained from National Ocean Survey Chart No. 11376 (31st Ed. November 5, 1977) and unpublished U.S. Army COE sources.

Table 1. The Components of the Hydrographic and Circulation Regimes of Mobile Bay.

COMPONENTS	FUNCTION: Basic Constituent	FUNCTION: Major Input (Dynamic)	FUNCTION: Minor Input (Dynamic)	FUNCTION: Modifying Role (Static)	FUNCTION: Modifying Role (Dynamic)	NATURAL TIME RATE OF CHANGE (Hours, Days, Weeks, Months, Years, Decades)	RELATIVE IMPORTANCE[c/] TO: Salinity	RELATIVE IMPORTANCE[c/] TO: Temperature	RELATIVE IMPORTANCE[c/] TO: Circulation	SENSITIVITY TO IMPACT FROM MAN: Great	SENSITIVITY TO IMPACT FROM MAN: Moderate	SENSITIVITY TO IMPACT FROM MAN: Little	SENSITIVITY TO IMPACT FROM MAN: None
I) Mobile Bay Basin													
A) Areal Shape	X			X		- -→	7	5	10		X	X	
B) Bathymetry	X			X		- -→	9	7	10	X			
II) Ocean (exchanges through Main Pass)													
A) Northeast Gulf of Mexico Water (salinities > 28.0 ppt)	X					- - ——	10	6					X
B) Astronomical Tides		X[a/]				—— -			10				X
III) Continental													
A) "Fresh Water" (salinities < 1.0 ppt)	X						10	6					X
B) Mobile River System Discharge		X[a/]				- —— -			10		X	X	
C) Flows from small rivers & streams			X[a/]			—— ?			5	X			
D) Unchanneled Land Runoff					X	—— ?			2	X			
IV) Other													
A) Winds		X[a/]				—— -			10				X
B) Air Temperature		X[b/]				—— -		10					X
C) Precipitation (directly on the Bay)					X	—— -	2						X
D) Evaporation					X	——→ ?	3						X
V) Other													
A) Exchanges Water with East Mississippi Sound			X[a/]			——→ ?	6	2	7		X		
B) Exchanges of Water with intracoastal channel on Baldwin County					X	——	1		1	X			

[a/]Vectory quantity: having both direction and magnitude.

[b/]Scalar quantity: having magnitude only.

[c/]Blank to 10 scale is equivalent to no importance to very important.

(3) major openings to the Gulf of Mexico and East Mississippi Sound in the southwest corner; (4) a major river system delta at the northern end; (5) a large, relatively isolated area in the southeast corner, Bon Secour Bay; and (6) numerous man-made channels, the principal one being the Main Shipping Channel (120 m x 12 m) running from Main Pass to the Port of Mobile.

Oceanic conditions for the Mobile Bay Estuary are defined as waters with salinities > 28.0 ppt, which occurred 94% of the time during 35 26-hour sampling periods at East Main Pass (Schroeder 1976 and 1977c) and have been given the name "Northeast Gulf of Mexico Coastal Waters" (Shroeder 1979). The exchange of these waters between the Gulf of Mexico and Mobile Bay occurs almost exclusively through Main Pass. There is some evidence (Schroeder 1976 and 1977c) that suggests that occasionally waters with salinities > 28.0 ppt are exchanged through Pass aux Herons but the route these waters are traveling is not clear because their immediate past history is unknown.

The driving force for the "Oceanic" constituent are the astronomical tides. For coastal Alabama these tides are principally daily with an average range of < 0.5 m. During the period of greatest tides, known as "tropic tides," the range can reach 0.8 m, while during the smallest tides, known as "equatorial tides," the range can be < 0.1 m. Periods of semi-daily tides usually occur twice a month for one to three days at a time. Additional information on tides can be found in Marmer (1954) and McPhearson (1970).

The Mobile River System provides approximately 95% of the freshwater received by Mobile Bay (Schroeder 1978). Pertinent statistics of the Mobile River System relative to it discharging into Mobile Bay are presented in Table 2. Average dis-

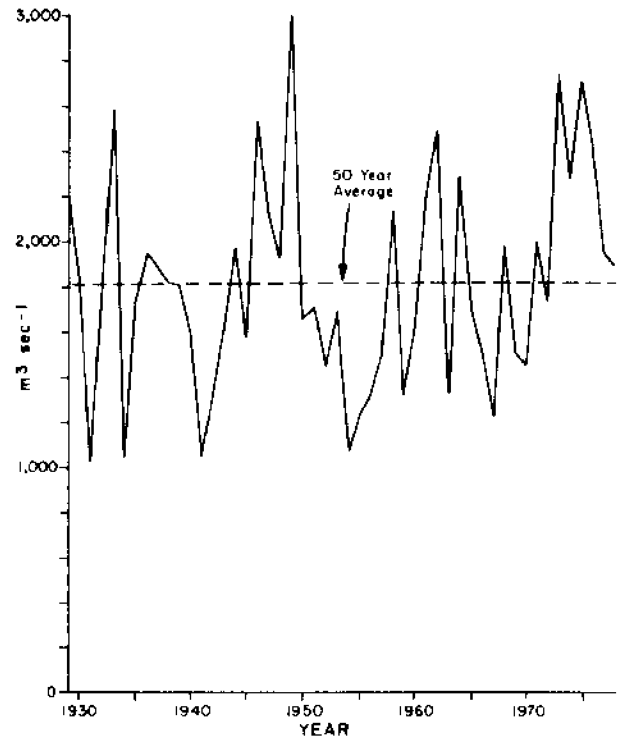

Figure 2. Mobile River System Average Discharge into Mobile Bay for Each Water Year Over the Period 1929-1978.

charges into Mobile Bay for each water year over the period 1929 to 1978 are compared to the 50 year average discharge in Figure 2. Monthly average discharges for water years 1973 and 1978 are presented in Figures 3 and 4 while daily average discharges for water years 1974 and 1977 appear as Figures 5 and 6. Table 2 and Figures 2 through 6 clearly show that the river system in highly variable on day-to-day, month-to-month and year-to-year time scales.

Specifically, Figure 2 shows that over the past six water years (1973 to 1978) the average discharge of the system has been above the 50 year average and therefore the Bay has been under heavy riverine influence. Conversely, during 1950 to 1957 the average discharges were below the 50 year average and, therefore, the Bay was influenced more by the Gulf of Mexico. For the remainder of the record period the average discharges fluctuated up and down across the 50 year average every one to four years.

Winds are an important driving and modifying force for Bay processes. The dominant wind fields

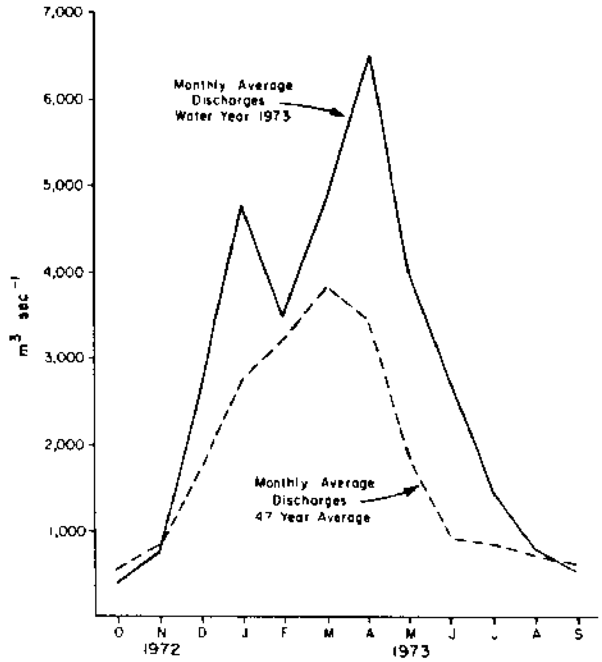

Figure 3. Mobile River System Monthly Average Discharge into Mobile Bay for Water Year 1973 Compared to the 47-Year Average Monthly Discharge (1929-1978).

are a northwest to northeast system during the fall and winter and a southeast to southwest system in the spring and summer. A land-sea breeze system often prevails during the summer, and multiple day periods of light variable winds to calm may occur during any season. Detailed meteorological observations, made at the Dauphin Island Sea Lab, are presented in Schroeder (1976 and 1977c).

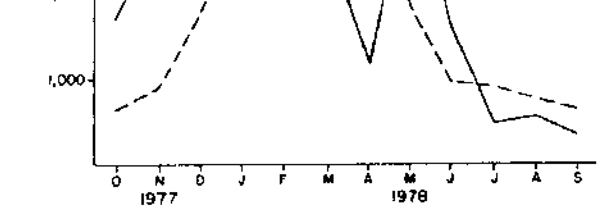

Figure 4. Mobile River System Monthly Average Discharge into Mobile Bay for Water Year 1978 Compared to the 50-Year Average Monthly Discharges (1929-1978).

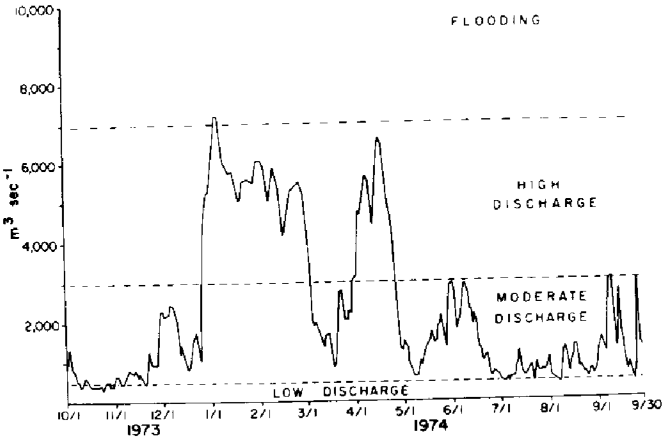

Figure 5. Mobile River System Daily Average Discharge into Mobile Bay for Water Year 1974.

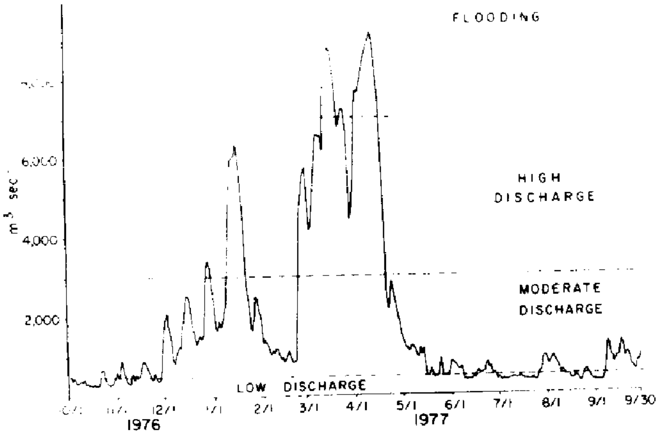

Figure 6. Mobile River System Daily Average Discharge into Mobile Bay for Water Year 1977.

Salinity

Mobile Bay's salinity regime encompasses direct, Bay wide influence of high salinity Gulf of Mexico waters during extended periods of low river discharge at one extreme to near dominance by freshwater under flooding conditions at the other extreme. Salinity[2] values ranging from 0 to ~36.0 ppt have been observed in the lower Bay (Schroeder 1976 and 1977c) while in the upper Bay the range is 0 to ~24.0 ppt (Schroeder 1978).

Because the salinity regime varies principally as a function of the discharge rate of the Mobile River System (McPhearson 1970 and Schroeder 1978 and 1979), which has been shown to be highly variable (Table 2 and Figures 2 thru 6), no set seasonal salinity pattern exists. What can be said is that the lowest salinities are present normally sometime between February and May when high river discharge and flooding ordinarily occur and

[2] Salinity values in any of the dredged channels, because of their depths (up to 12 m), are artificially higher than adjacent undredged Bay bottom. Therefore, the bottom salinity fields considered in this paper, unless specifically stated, will not utilize dredged channel data but rather will consider, for channel stations, the one-to four-meter water column values depending on the depth of the adjacent bottom plane. This procedure is not meant to suggest that these channels do not play a role in the hydrography of Mobile Bay, for they certainly provide avenues for high salinity waters to move around in the Bay.

Table 2. Mobile River System Statistics (Modified From Schroeder 1978).

1) Average discharge[a] into Mobile Bay - 1929 to 1978:	1,815 m^3 sec^{-1}
2) 10 and 90 percentile discharges[a] into Mobile Bay - 1929 to 1978:	4,250 m^3 sec^{-1} and 370 m^3 sec^{-1}
3) Maximum time rate of change:	
8-10 Day Period	± 4,000 to 6,000 m^3 sec^{-1}
15-20 Day Period	± 8,000 to 10,000 m^3 sec^{-1}
4) River Discharge categories:	
Low	$<$500 m^3 sec^{-1}
Moderate	500 to 3,000 m^3 sec^{-1}
High	3,000 to 7,000 m^3 sec^{-1}
Flooding	$>$7,000 m^3 sec^{-1}

[a] Calculated from data collected at the USCG gauging stations at Coffeeville (Tombigbee R.) and Claiborne (Alabama R.), Alabama.

the highest salinities are present normally sometime between August and November when low river discharges ordinarily occur.

Selected field surveys and sets of time series data will be utilized to illustrate the wide degree of variability found in the salinity regime. Bathymetric features can play a controlling role in salinity distribution patterns. For example, the bathymetry of the eastern and western sides of the upper-middle Bay are significantly different (Figure 1). The eastern side has an average depth of -4 m at mean low water (MLW) and numerous depressions (diameters ≤ 1 km) with maximum depths of -7 m at MLW while the western side has an average depth of -3 m at MLW and is generally uniformly flat with maximum depths of -4 m at MLW (Schroeder 1979). The bottom salinity field depicted in Figure 7, when compared to Figure 1, shows the higher

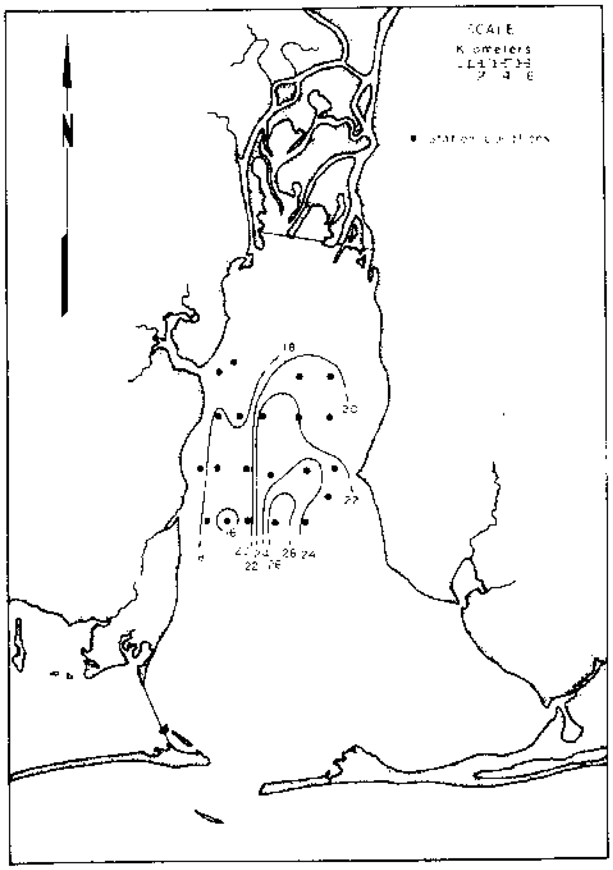

Figure 7. Bottom Salinity (ppt) Field in Mobile Bay During November 1, 1978. Low river discharge, high tropic tide and winds calm.

salinity waters (i.e. higher density waters) outlining the deeper areas of the eastern bay and the lower salinity waters (i.e. lower density waters) outlining the shallow areas of the western bay.

The only major barrier to east-west movement of water is the north-south running spoil bank located on the western side of the main shipping channel east and south of the Dog River area (Figure 1). The spoil bank system rises 0.5 to 1.5 m above the 2.5 to 2.9 m bottom plane, thus, interfering with the bottom water movements but not surface water movements. The impact of this man-made bathymetric feature is illustrated in Figure 8.

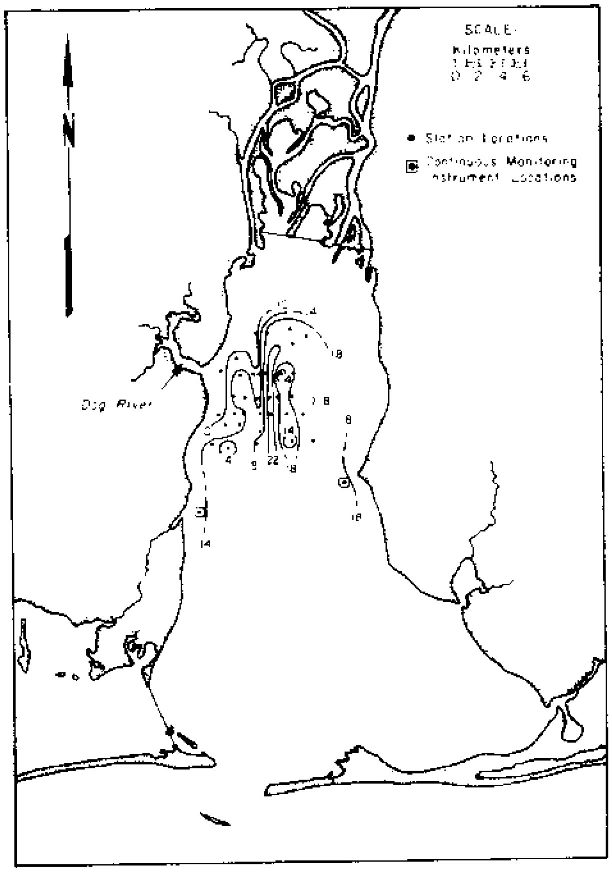

Figure 8. Bottom Salinity (ppt) Field in Mobile Bay During September 5, 1978. Low river discharge, equatorial tide and winds variable < 10 k.

The 14 and 10 ppt isohalines on the western side of the Bay outline the shallow depths depicted in Figure 1 and show that east-west exchange of bottom waters is restricted in this region. The surface salinities during the same survey (not illustrated) ranged from 7.0 to 10.7 ppt and had an areal distribution pattern totally independent of bottom features. In the southern half of the Bay the old spoil bank system associated with the main shipping channel is essentially non-existent today (Schroeder and Lysinger, unpublished data). There are no major barriers to north-south water movements, however, the east-west running spoil banks associated with the Hollingers Island Channel contribute to some degree to the isolation of bottom waters in the area east of Dog River (Figure 8). The spoil bank associated with the Gulf Intracoastal Waterway in south Bon Secour Bay partially isolate the bottom waters in that area.

The interaction of the local winds is best summarized by Schroeder (1978):

> Because of the Bay's large surface area and shallow depth the wind can be both an important driving force and a modifying force. Winds with a northerly component compliment river flow and move river influence toward the lower Bay. The opposite condition occurs with southerly winds that move offshore waters into the Bay and, therefore, move river influence up the Bay. Winds with east or west components tend to push the surface waters to the opposite side of the Bay and consequently there is often a complimentary shift of the bottom waters to the windward side of the Bay. Westerly winds are certain to play a role during some of the periods when river waters are moving south along the eastern shore. Multi-day periods of strong sustained winds can mix the entire Bay vertically, except for the deeper areas.

Astronomical tidal action from the Gulf of Mexico can result in north-south shifting of salinity fields on a daily time scale. During maximum amplitude tropic tides north-south changes of 6 to 10 km have been observed (Schroeder 1979). On the other hand, during minimum amplitude equatorial tides, little or no movement is observed.

Figures 9, 10 and 11 are presented to illustrate the wide variability that has been observed in the structure of the salinity regime in Mobile Bay. In all three examples significant longitudinal, lateral and vertical variations predominate. The salinity regime across Main Pass during periods of oceanic dominance and river system dominance are depicted in Figures 12 and 13, respectively.

Time series data can be used to delineate the changes that take place at a fixed location over

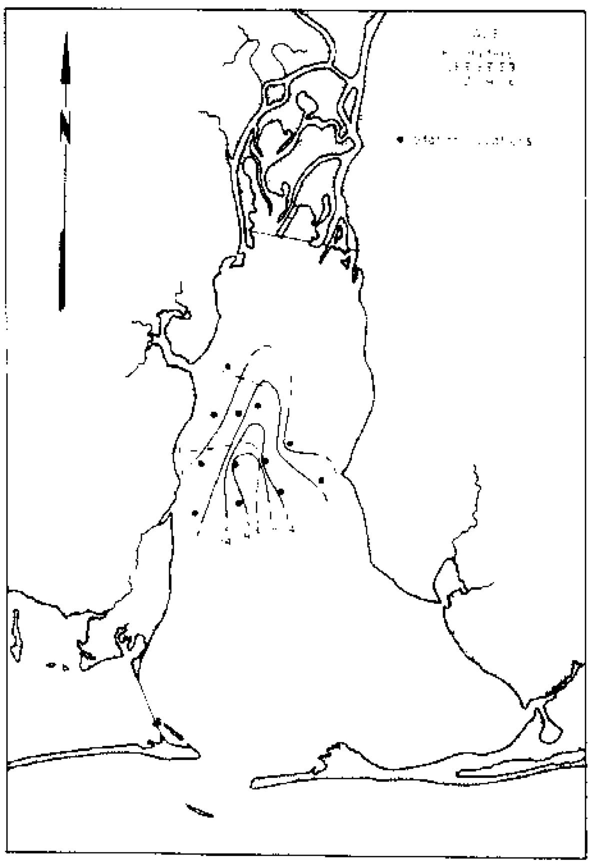

Figure 9. Surface (dashed) and Bottom (solid) Salinity (ppt) Fields in Mobile Bay During January 16, 1978. Moderate river discharge, low tropic tide and winds east southeast < 10 k.

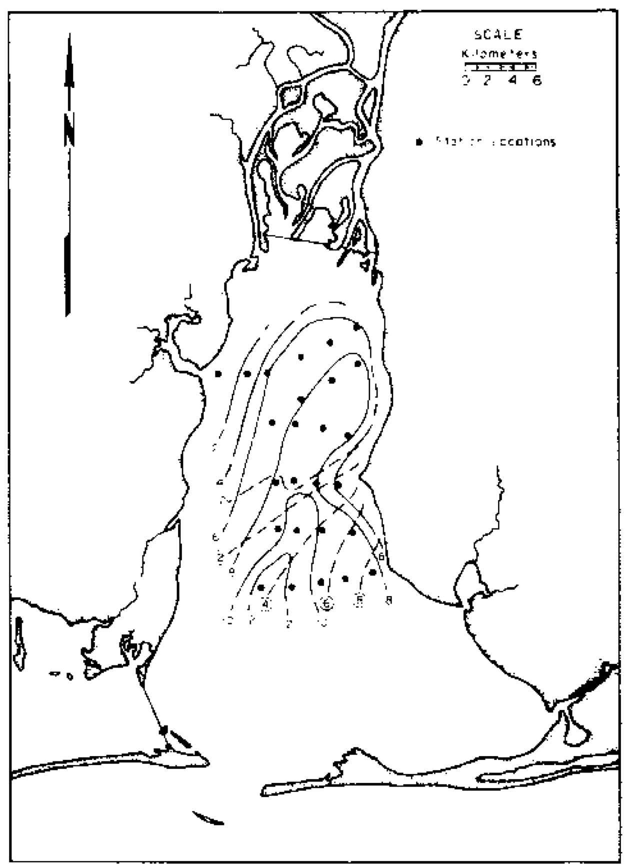

Figure 10. Surface (dashed) and Bottom (solid) Salinity (ppt) Fields in Mobile Bay During December 2, 1978. Moderate to high river discharge, low tropic tide and winds northwest to northeast at 10 k.

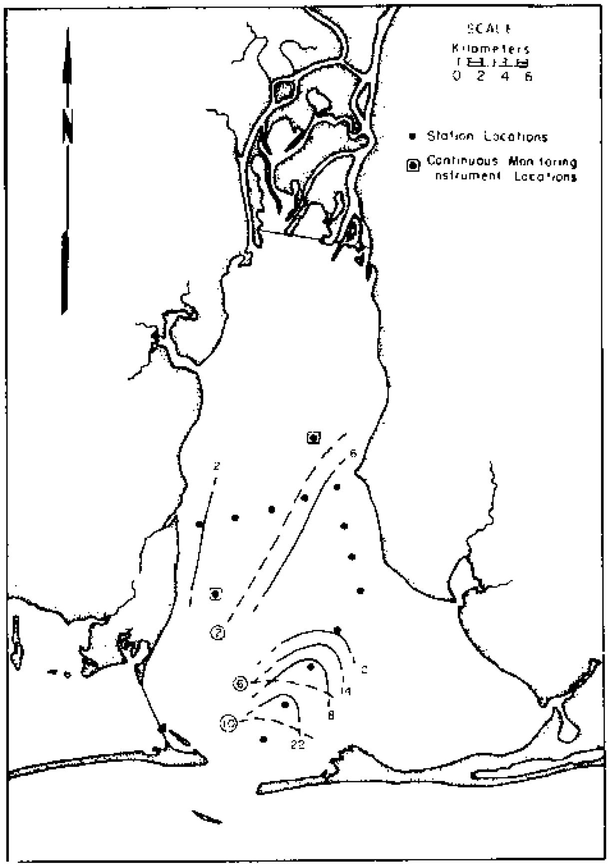

Figure 11. Surface (dashed) and Bottom (solid) Salinity (ppt) Fields in Mobile Bay During June 19, 1978. Moderate to high river discharge, high tropic tide and winds variable <10 k.

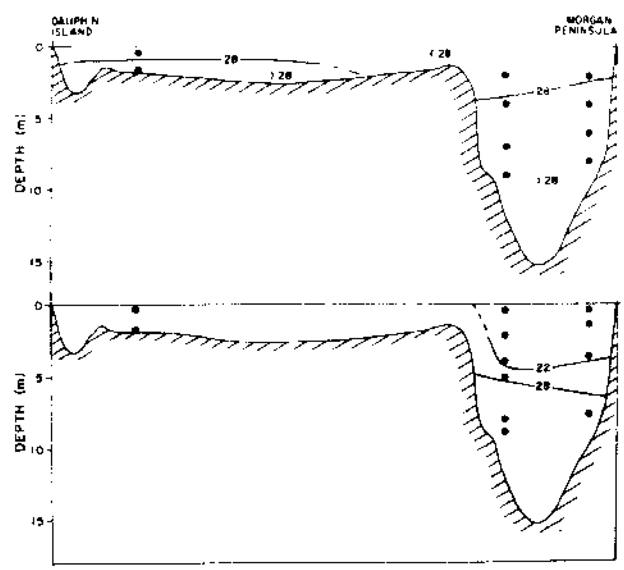

Figure 12. Vertical Cross Section of Salinity (ppt) through Main Pass, Mobile Bay During October 11, 1976. Low river discharge.

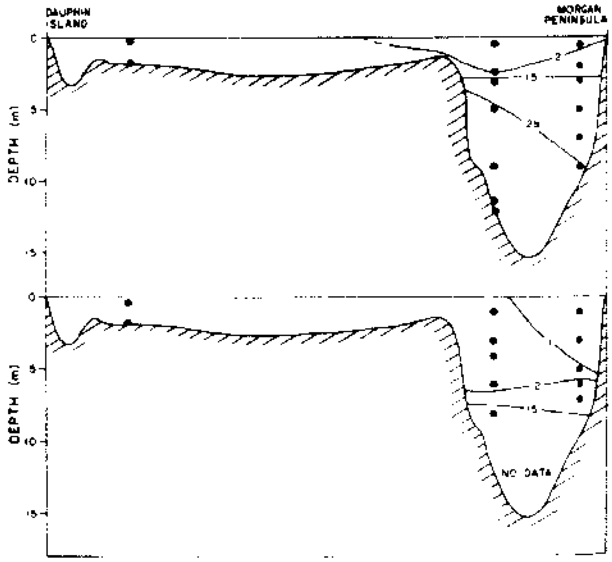

Figure 13. Vertical Cross Section of Salinity (ppt) through Main Pass, Mobile Bay During April 8, 1977. Flooding river discharge.

time. During portions of 1978 a network of continuously recording refractometer-thermograph instruments (ENDECO 101 units) were deployed in Mobile Bay (Figure 14). Results from this

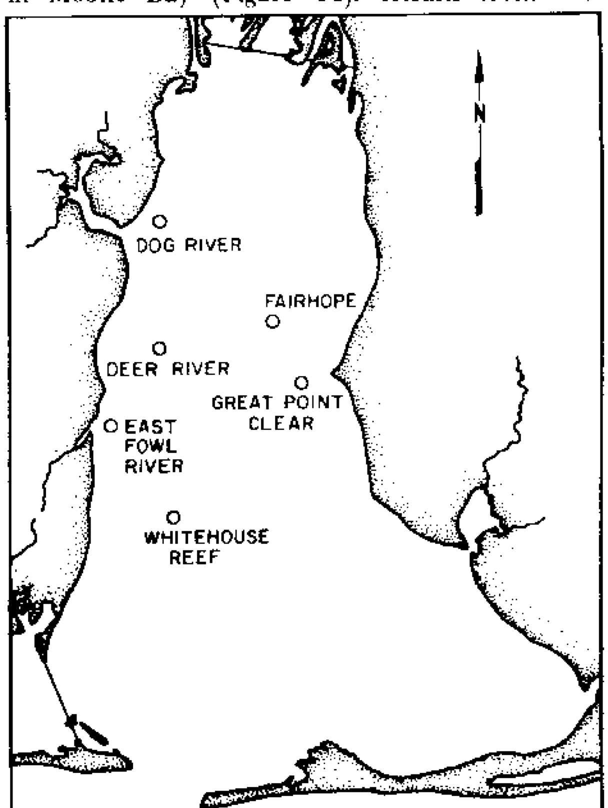

Figure 14. Locations of Continuous Recording Refractometer/Thermograph Instrumentation in Mobile Bay.

project are utilized here to illustrate the dynamic nature of the salinity regime over time periods of days to weeks. Figures 15 and 16 present selected

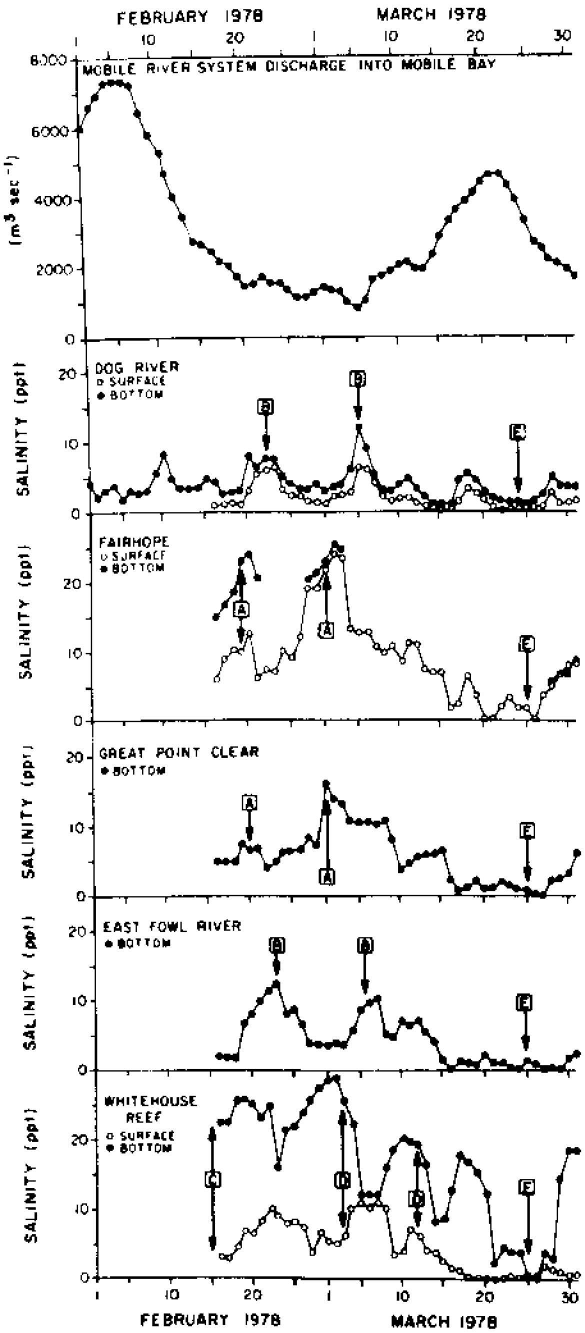

Figure 15. Time-Series Salinity (ppt) Data for Mobile Bay, February and March, 1978. See Figure 14 for station locations.

time series data sets of salinity during a flooding and high river discharge period and a high to low river discharge period, respectively.

In Figure 15 all but one of the data sets begin

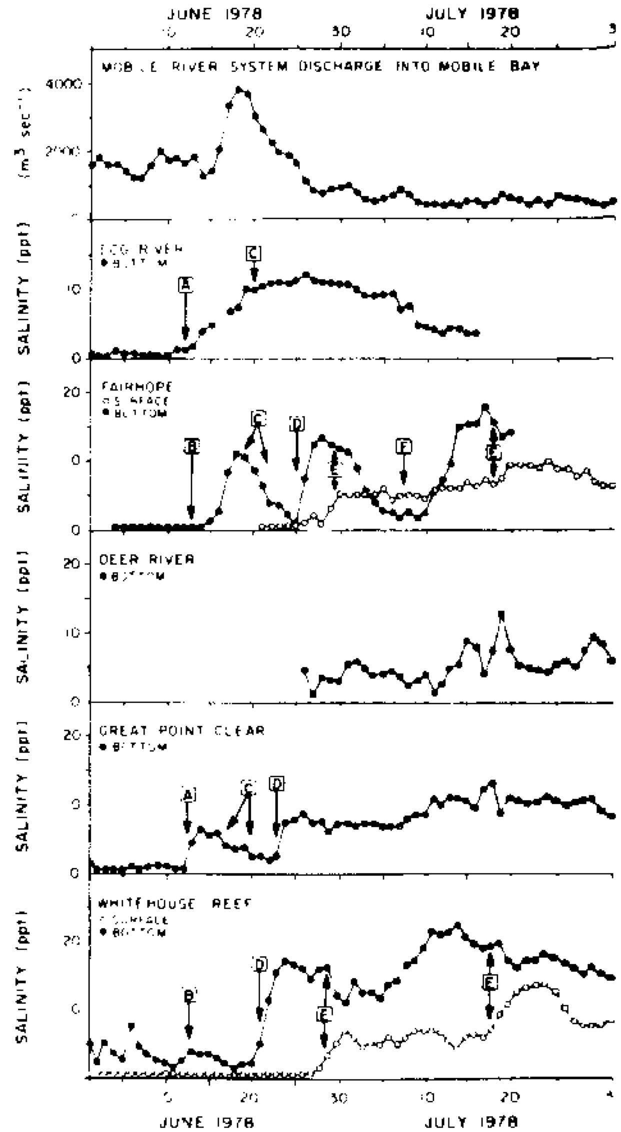

Figure 16. Time-Series Salinity (ppt) Data for Mobile Bay, June and July, 1978. See Figure 14 for station locations.

during the post flooding period. All stations show an increasing salinity trend as river discharge decreases. As the Bay recovered from the flooding event a 5 to 8-day pattern of higher salinities on the east side of the Bay (points marked A) alternating with higher salinities on the west side of the Bay (points marked B) occurred. At Whitehouse Reef the data indicate that 10 days after the peak of the flood the surface waters were still under the influence of river water while the bottom waters showed no river water impact whatsoever (point C). Vertical salinity gradients were >

20.0 ppt. Also the Whitehouse Reef record shows the effect of strong wind mixing (points marked D). Low-salinity surface waters were mixed with high salinity bottom waters to form intermediate salinities. In one case near homogenous conditions were reached in the water column. All of the stations were impacted by the high river discharge period in late March as indicated by the very low salinities (points marked E) and all showed some degree of recovery from the low salinity period with the increased salinities at the end of March.

In Figure 16 those stations with data for the first two weeks of June all show a dominance of river water influence. River discharge during the month of May (not illustrated) was highlighted by 20 days of high flow (> 2,000 m^3 sec^{-1}) with the maximum discharges approaching flooding levels. This, plus the previous flooding and high flows in February and March (Figure 15) resulted in the Bay becoming a near limnetic system. However, by mid-June salinities began to increase. The first two stations to show any recovery were Great Point Clear and Dog River (points marked A). The increased salinity at Great Point Clear is understandable because high salinity waters entering Main Pass can readily move up the eastern side of the Bay (Figures 10 and 11). But the increased salinity at Dog River is not easily explained in that there wasn't any corresponding increase at either Whitehouse Reef or Fairhope (points marked B).

An increase in the bottom salinities at Fairhope finally occurred between June 15-18. The initial increases at both Great Point Clear and Fairhope lasted only a few days before the increase in river discharge around June 15 to 18 brought about a decreasing salinity trend (points marked C). Note that no corresponding salinity decrease was measured at Dog River (Point C). During the latter part of June as river discharge decreased there was a rapid increase in salinities at Whitehouse Reef, Great Point Clear and Fairhope (points marked D). Periods when wind and tidal action mix surface and bottom waters together are clearly evident at Whitehouse Reef and Fairhope (points marked E).

The salinity inversion at Fairhope in early July (point F) is a very unusual occurrence. Except for the first and last day of this phenomenon the water column was unstable even though the less saline bottom waters were cooler than the more saline surface waters. An explanation for this situation is not apparent, therefore, the data should be viewed with some suspicion.

Temperature

Water temperatures in Mobile Bay range from highs of 30.0 to 33.0° C to a low of 0° C (ice). The thermal regime for the Bay is summarized in Tables 3 and 4 and Figures 17 and 18. Water temperatures

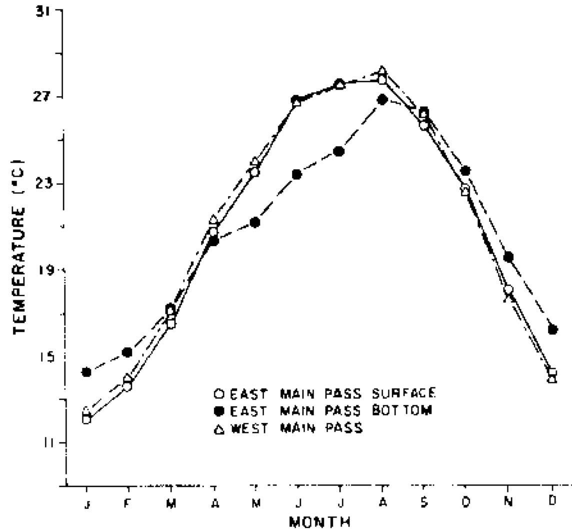

Figure 17. Thermal Regime of Upper Mobile Bay. Values are three-month running averages.

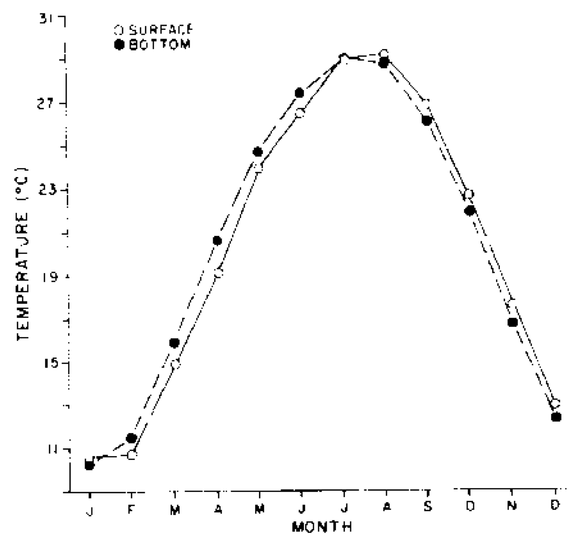

Figure 18. Thermal Regime of Main Pass, Mobile Bay. Values are three-month running averages.

are directly linked to air temperatures (Table 3). Seasonal periods are well defined except for the bottom waters at Main Pass which have a four-month spring warming season, a summer that lags one month behind the remainder of the Bay and only a two month fall cooling season (Table 4). On the average the upper Bay tends to be colder in the winter and hotter in the summer than the Main Pass area. This is particularly true if the upper Bay is compared to the bottom waters at Main Pass (Table 4).

Table 3. Temperature (°C) data for Mobile Bay. Water temperatures are three-month running averages and air temperature are monthly averages.

	UPPER BAY		EAST MAIN PASS		WEST MAIN PASS	AIR TEMP.
	Surface 0.5 m	Bottom -2.0 m	Surface 0.5-1.0 m	Bottom 8.0-9.0 m	Water Column 0-3.0 m	Mobile (Bates Field NWS)
J	10.6	10.3	12.0	14.2	12.4	10.7
F	10.7	11.5	13.5	15.1	13.9	12.2
M	14.9	15.9	16.4	16.9	17.0	15.2
A	19.1	20.6	20.6	20.3	21.2	19.9
M	23.9	24.7	23.4	21.1	23.9	23.7
J	26.5	27.4	26.6	23.3	26.6	26.8
J	28.9	28.9	27.4	24.4	27.4	27.6
A	29.2	28.8	27.7	26.8	28.1	27.5
S	26.9	26.1	25.6	26.2	26.1	25.2
O	22.7	21.9	22.7	23.5	22.5	20.5
N	17.6	16.6	18.0	19.5	17.5	14.7
D	13.0	12.3	14.1	16.1	13.8	11.6

Table 4. Seasonal Temperature (°C) Data for Mobile Bay. Derived from Table 3.

		WATER TEMPERATURE RANGE			AIR TEMPERATURE RANGE
Season	Months	Upper Bay	Main Pass[a]		Mobile (Bates Field NWS)
			Surface	Bottom	
Winter	D J F	<13.0	<14.0	<16.0	<13.0
Spring	M A M	13.0-27.0	14.0-26.0	16.0-24.0 (M A M J)	13.0-26.0
Summer	J J A	>27.0	>26.0	>24.0 (J A S)	>26.0
Fall	S O N	27.0-13.0	26.0-14.0	24.0-16.0 (O N)	26.0-13.0

[a]Because of the bathymetric differences between East and West Main Pass (Fig. 1) the surface observations at East Main Pass are combined with the water column observations at West Main Pass and are treated as the surface zone of Main Pass. The bottom zone of Main Pass is characterized by bottom East Main Pass data exclusively.

Surface and bottom temperature data for the upper Bay presented in Table 3 are depicted in Figure 17. The average difference between surface and bottom waters was ≤ 1.0° C except during April when the bottom was 1.5° C warmer than the surface. The thermal vertical structure undergoes a reversal during the year. From February through June bottom waters are warmer than surface waters while from August through January surface waters are warmer than bottom waters. During July the water column is homogeneous.

Surface and bottom temperature data for Main Pass presented in Table 3 are depicted in Figure 18. The thermal vertical structure is much more complex at Main Pass than in the upper bay. First, the differences between the surface values of East Main Pass and the water column values of West Main Pass were $\leq 0.6°$ C and therefore these two areas were treated as representing the surface zone of Main Pass. The thermal vertical structure undergoes a reversal just as in the upper bay but the chronology is very different. From October through February bottom waters are warmer than surface waters while from April through August surface waters are warmer than bottom waters. During the months of March and September the water column is nearly homogeneous. This annual vertical structure is accounted for by the fact that the bottom waters are linked with the Gulf of Mexico which, because of the greater volumn, do not warm up as fast nor get as hot as bay waters or cool down as fast nor get as cold as bay waters. Therefore, the surface waters become warmer than bottom waters during the spring warming season and remain hotter through the early fall and then become cooler than bottom waters during the late fall cooling season and remain colder through the winter.

Maximum stable vertical temperature gradients observed in Main Pass were 8.0 to 10.0° C during the summer season when surface waters were hotter than bottom waters while the maximum observed temperature inversions were 4.0 to 6.0° C during the winter season when surface waters were colder than bottom waters. In the upper bay the maximum stable vertical gradients observed were 5.0 to 7.0° C during the summer and early fall while the maximum temperature inversions were 3.0 to 4.0° C during the late winter and spring.

CIRCULATION

No definitive studies on the circulation of Mobile Bay have been undertaken. Numerous small and medium scale investigations have approached the circulation question both directly and indirectly. The following is a summary of what has been learned through these various projects.

Current Measurements

Over the period July, 1973 to December 1975, seventeen 26 hour anchor stations were carried out in Main Pass during which hourly current profiles of the water column were taken (Schroeder 1976). Ten of these anchor stations were made in East Main Pass and seven were made in West Main Pass. The station positions were located just inside the Bay. Composite current roses of surface (0.5 to 1.0 m) observations at West Main Pass and surface (0.5 to 1.0 m) and bottom (7.0 to 9.0 m) observations at East Main Pass are presented in Figure 19. Only the surface observations are presented for West Main Pass because they are representative of the current structure throughout the 2.5 to 3.0 m water column.

The current rose for West Main Pass shows that on the west side of Main Pass more water flowed out of the Bay than into the Bay. It is estimated here that the ratio is between 2:1 and 3:1. Currents out of the Bay moved southwest to southeast with a dominant flow due south ± 22.5°. The greatest current speeds occurred during flow out of the Bay (falling tides) and reached absolute values of 1.6 to 2.1 knots.

The current rose for the surface at East Main Pass shows that on this side of Main Pass nearly equal amounts of water moved into and out of the Bay at the surface. Surface currents into the Bay moved mostly north to northeast with a dominant flow to the northeast ± 22.5° and they attained speeds of 2.1 to 2.5 k. Surface currents out of the Bay moved south to southeast with a dominant flow due south ± 22.5° and attained speeds of 1.6 to 2.0 k. The current rose for the bottom of East Main Pass also shows that nearly equal amounts of water moved into and out of the Bay. Bottom currents into the Bay moved north to northeast at speeds up to 1.6 to 2.0 k. Bottom currents out of the Bay moved south to southeast at speeds up to 1.6 to 2.0 k.

Two 26 hour stations were carried out on the Dauphin Island Bridge in Grant's Pass during 1975 (Schroeder 1976). Current measurements made on July 1 and 2, 1975 indicate that the flow was from Mobile Bay into Mississippi Sound throughout the 26 hours. An explanation for this is that the circulation of this portion of the Bay was dominated, at the time, by a sustained southeast to east wind at 6 k gusting 15 k. Tidal height differences were only 0.2 m and river discharge was moderate.

During the second survey, August 5 and 6, 1975, current directions changed with the tidal cycle. During the falling tide water moved out of Mobile Bay in a south to southwest direction at speeds up to 0.7 k. During the rising tide water moved into Mobile Bay in a northeast direction at speeds up to 1.9 k. Tidal height differences were 0.5 m, river discharge was moderate to high and the winds were south-southwest to west at 6 k gusting to 20 k.

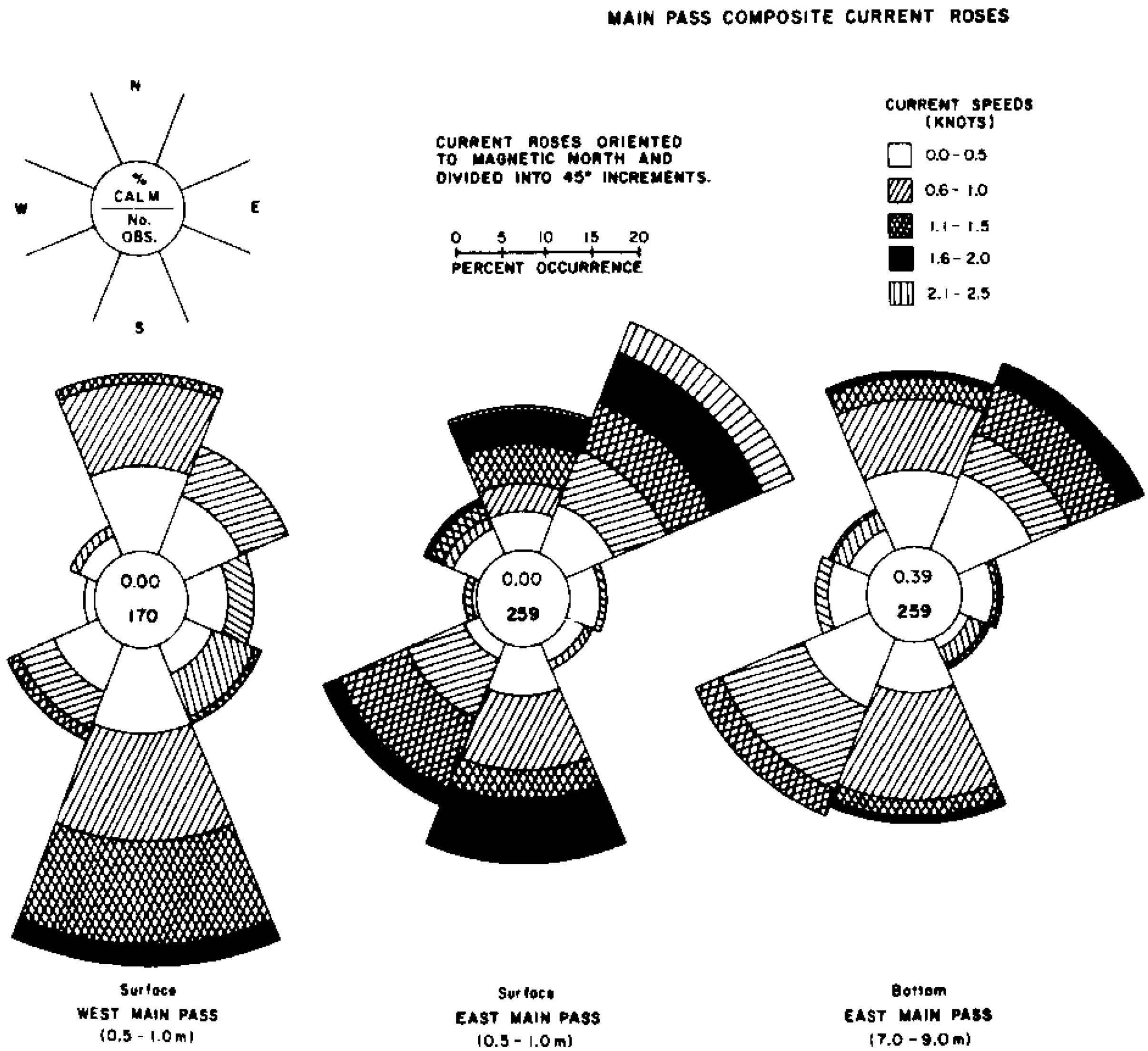

Figure 19. Main Pass Composite Current Roses. (From Schroeder 1976.)

Drogue Studies

Twenty drogue tracking exercises, consisting of single and multiple drogue releases in the southern half of the Bay, were made between August, 1975 and November, 1977 (Schroeder 1976 and 1977c). The drogues were constructed to respond to water movements associated with the upper 1.2 m of the water column. Pertinent information on eleven of the exercises is summarized in Table 5. Exercises 1 thru 8 were carried out during periods of low to high river discharge and a composite of their tracks is presented in Figure 20. Exercises 9 thru 11 were carried out during periods of very high to flooding river discharges and a composite of their tracks is presented in Figure 21.

From the tracks depicted in Figure 20 the following observations were made: (1) the surface circulation pattern of lower Mobile Bay was highly variable; (2) the maximum displacement of drogues released in or near Main Pass over one half of a daily tidal cycle (12 hours) ranged between 10 and 12 km (5 to 6.5 nm); (3) many individual drogue tracks (i.e., 1, 3a, 4a, 4b, 6 and 7) reflected a tendency for an "excursion type pattern" within the Bay (e.g. a trip with the same departure and return point); and (4) sustained winds could override astronomical tidal forces preventing direction reversals during the daily tides (i.e., track 8).

Table 5. Summary of Selected Drogue Tracking Exercises in Mobile Bay (Modified from Schroeder 1976 and 1977c).

Date	Drogues	Tracking Time (Hours)	Predicted Tidal State at Release	Predicted Tidal Height Differences (m)	Mobile River System Discharge ($m^3\ sec^{-1}$)	Winds
1. 4/20/76	1	14	Low + 2 hrs.	.5	2,000 - 4,000	Variable < 10 k
2. 5/1/76	1	9	Low + 2 hrs.	.5	2,000 - 4,000	SW to NW < 10 k
3. 9/15 & 16/76	2[a]	a. 16 b. 13.5	Low + 2 hrs. Low + 4.5 hrs.	.2	700 - 1,000	Variable < 10 k
4. 17/21 & 22/76	2[b]	a. 11 b. 10	Low + 3 hrs.	.7	700 - 1,000	N to NW < 10 k & gusts > 20 k
5. 5/5/77	1	14	Low + 2 hrs.	.6	1,300 - 2,000	S to SE < 10 k
6. 6/1 & 2/77	1	15	Low + 0.5 hrs.	.7	400 - 1,000	Variable < 10 k to N < 10 k & gusts > 10 k
7. 7/1/77	1	7	High - 1.0 hr.	.7	< 800	S to SW < 10 k
8. 11/8 & 9/77	2[b]	a. 23.5	Low + 6 hrs.	.3	2,000 - 4,000	SE to SW < 10 k & gusts > 20 k
9. 3/30/76	3[c]	a. 1 b. 3 c. 1	Low + 2 hrs. Low + 4 hrs High + 1 hr.	.1 (semi-daily tides)	> 8,000	SE < 10 k
10. 3/13/77	1	8	Low + 7 hrs.	.5	5,000 - 6,500	SSW < 10 k
11. 4/8/77	1	13	Low + 1 hr.	.5	5,000 - 8,000	Variable < 10 k

[a]Drogue release points at different locations.

[b]Drogue release points at the same location.

[c]A single drogue was released three different times at three different locations.

The tracks on Figure 21 illustrate the degree of influence the river system can exert on the surface waters of the lower Bay during very high to flooding discharges. This was particularly evident during exercise 9 when flooding river water continuously flowed out of the Bay at West Main Pass.

Inferred From Salinity Distribution Patterns

The use of salinity distribution patterns to infer circulation is a common practice. Macro- to meso- scale trends and in some cases meso- to micro- scale structure can be defined by the use of this technique. However, care should be taken not to allow these results to be treated as detailed circulation data in the absence of supporting current meter or drogue track data for quantification and verification purposes.

From Figures 9, 10 and 11 two surface circulation trends were identified. In Figure 9 the lower salinity water from the upper bay appeared to be moving down the eastern side of the Bay while slightly higher salinities from the lower bay occupied the western side of the Bay. In Figures 10 and 11 just the opposite situation existed where the low salinity upper bay waters appeared to be moving down the western side of the Bay. Schroeder (1979) concluded that: (1) during low river discharges river water (salinities < 1.0 ppt) and transitional water (salinities of 1.0 to 7.9 ppt) in the upper and middle Bay form a surface lens over the more saline bottom waters and move to the south

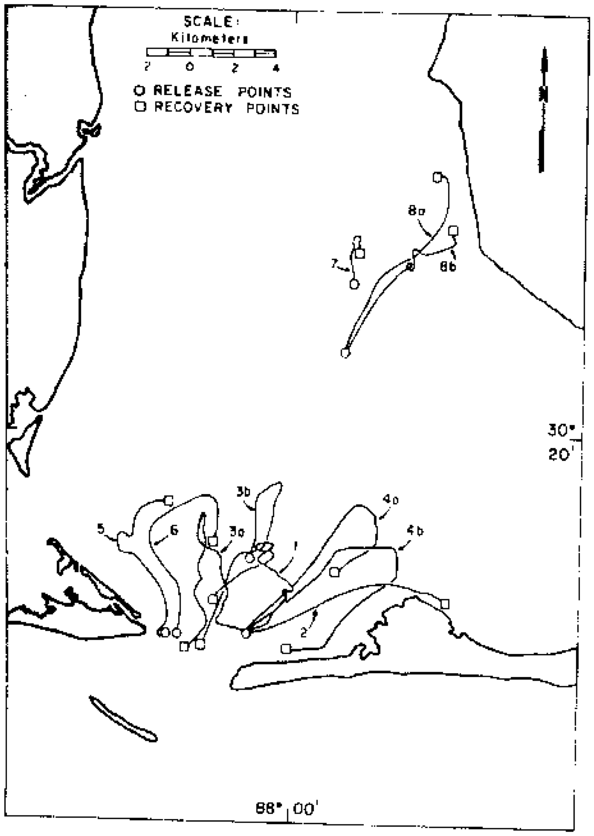

Figure 20. Drogue Track Composite for Releases Made in Mobile Bay During Low to High River Discharge. (For supportive data see Table 5.)

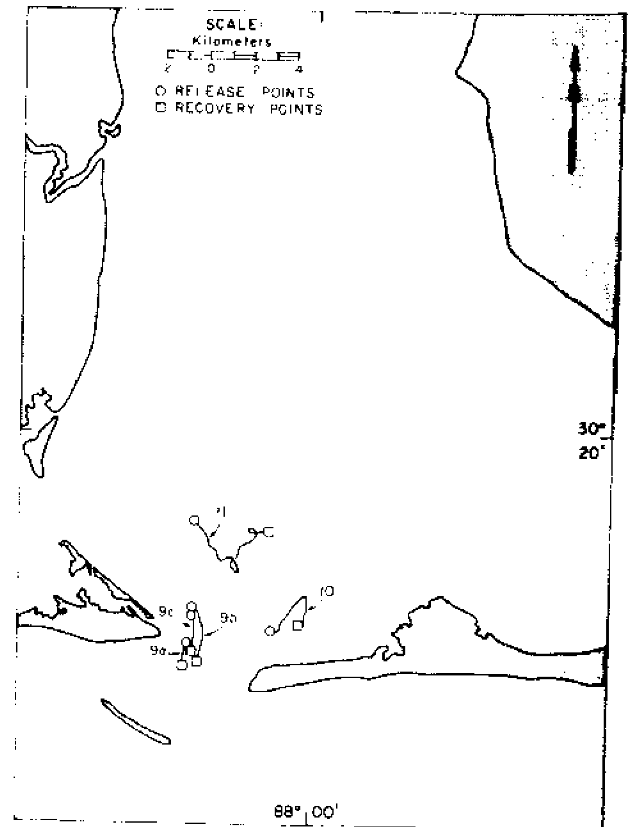

Figure 21. Drogue Track Composite for Releases Made in Mobile Bay During Very High to Flooding River Discharges. (For supportive data see Table 5.)

under no particular east to west pattern; (2) as river discharge increases into the moderate range, river and transitional waters at the surface and the bottom of the water column favor the western side of the Bay as they move to the south; and (3) at higher river discharges the down-bay patterns of river and transitional water become less obvious at the surface because they tend to dominate the entire surface field, while at the bottom they still favor the western side of the Bay.

High salinity water from the Gulf of Mexico can move northward into the Bay as a broad bottom intrusion, as overflow from the Main Shipping Channel or as a combination of the two. The bottom salinity field of Figures 7 thru 11 indicate that the broad bottom intrusion of higher salinity water favors the eastern side of the Bay as it moves northward in the Bay but that there is no single bottom salinity pattern associated with this northward movement.

Inferred From LANDSAT Satellite Imagery

Surface circulation can be inferred from the distribution patterns of suspended particulate material (SPM) observed on imagery produced by LANDSAT satellites (Schroeder 1977a). Four LANDSAT images (Figures 22 to 25) were chosen to illustrate the complex nature of the surface circulation of Mobile Bay.

Moderate river discharges and winds from the north at < 10 k were occurring at the time the images in Figures 22, 23 and 24 were taken. Note that the distribution patterns of SPM (light shaded areas of the Bay) were totally different. In Figure 22 a complex SPM pattern was present in the upper and eastern middle Bay. A less structured area of SPM occurred in Bon Secour Bay. In Figure 23 very high concentrations of river water borne SPM dominated the entire western Bay while in Figure 24 the exact opposite condition existed. A high degree of complexity was apparent in Figure 24.

High river discharge and calm wind conditions were depicted in Figure 25. Over 90% of the surface area of the Bay was impacted by river borne SPM. Only the very eastern and southern portions of Bon Secour Bay were unaffected. Very complex patterns along the western shore and at Great Point

Figure 22. LANDSAT MSS Band 5 Image of Mobile Bay Taken on August 18, 1975 (I.D. 2208-15435). Moderate river discharge, high tropic tide and winds northwest <10 k.

Figure 23. LANDSAT MSS Band 5 Image of Mobile Bay Taken October 11, 1975 (I.D. 2262-15433). Moderate river discharge, falling tropic tide and winds north <10 k.

Figure 24. LANDSAT MSS Band 5 Image of Mobile Bay Taken March 29, 1978 (I.D. 2116-215183). Moderate river discharge, rising tropic tide and winds north <10 k.

Figure 25. LANDSAT MSS Band 5 Image of Mobile Bay Taken May 22, 1978 (I.D. 2121-615212). High river discharge, high tropic tide and winds calm.

Clear and Mullet Point on the eastern shore are revealed by close examination of the image. Also, the exchange of waters from Mobile Bay to coastal waters is clearly seen in Figure 25.

ADDITIONAL INFORMATION

For additional information on the following subjects, as they relate to Mobile Bay, the reader is referred to references cited below.

General hydrography: Austin 1954, McPhearson 1970, Crance 1971, Bault 1972, and Schroeder 1978 and 1979.

Riverine influence: Schroeder 1978 and 1979.

Flooding: Schroeder 1977b.

Circulation: Austin 1954, Ryan 1969, McPhearson 1970, Ryan and Goodell 1972, and Story et al. 1974.

Remote sensing & event monitoring: Hardin et al. 1976 and Schroeder 1977a.

Bathymetry: Bisbort 1958, Ryan 1969, Crance 1971, Ryan and Goodell 1972, Hardin et al. 1976.

Physical environment atlas: Schroeder 1976 and 1977c.

HISTORICAL REVIEW

The data presented in the hydrography section were all collected over the period 1973 to 1979. When these data were compared to the data collected in previous years (Austin 1954, McPhearson 1970, Crance 1971, and Bault 1972) no significant differences were detected. The data presented in the circulation section were also collected over the period 1973 to 1979. The only historical measurements of circulation were made by Austin 1954 and Story et al. 1974. The conclusions that Austin presented should be viewed with caution because they were based on an analysis in which data from different days were combined and treated synoptically. No attempt was made to compare Austin's results to the present data. Story et al. (1974) carried out a short term dye study on the western side of Mobile Bay. There have been no comparable studies.

DATA GAPS

The percentage values indicate the extent of the data gap.

HYDROGRAPHY (salinity and temperature)

1. Bon Secour Bay 100%
2. Bay areas immediately adjacent to Dog River, Deer River, East Fowl River, Bon Secour River, Weeks Bay and Fly Creek 100%
3. Bay wide synoptic coverage 100%
4. Mobile River System distributaries in the lower delta 75% to 100%
5. Pass aux Herons 50%

CIRCULATION

1. Current meter measurements
   a. Bay wide (excluding Main Pass) 100%
2. Drogue Studies
   a. Bay wide (excluding releases from Main Pass) 100%
   b. Main Pass releases 50% to 75%

RECOMMENDATIONS

The greatest threat to the hydrographic and circulation regimes of Mobile Bay is alteration of its natural bathymetry. The following recommendations fall into two categories: one dealing with the evaluation of the environmental consequences associated with both existing and future alterations and the other being a list of "DON'TS."

1. Evaluate the environmental consequences of the following:

   A. spoil bank systems associated with the northern third of the Main shipping Channel;
   B. spoil bank systems associated with the intracoastal waterways;
   C. the spoil island associated with the proposed Theodore Channel (scheduled to be carried out); and
   D. all projects that involve any type of alteration to the bathymetry of the Bay.
2. Do not permit the following activities:
   A. spoil deposition along the southern two thirds of Main Ship Channel;
   B. spoil deposition along the Hollingers Island Channel;
   C. alterations to the configurations of the Mobile River System distributaries in the Delta;

D. alterations to Main Pass;
E. additional alterations to Pass aux Herons (Cedar Point to Peavy Island); and
F. dredging operations that result in the creation of either nonspecific depressions or shoals.

ACKNOWLEDGEMENT

We wish to thank Ms. R. Horton for data processing support, Ms. L. Lutz for producing all of the graphics and Ms. P. Barbour and Ms. L. Bryant for typing the manuscript. Data utilized in this publication have been obtained by the Dauphin Island Sea Lab and the Marine Science Program of The University of Alabama System through research support from: Alabama's Water Resources Research Institute of Auburn University (Project A-058-44060), the USDC-NOAA office of Sea Grant through the Mississippi-Alabama Sea Grant Program (Grants 04-5-158-54 and 04-6-158-44060), the National Aeronautics and Space Administration (Contracts NAS5-21876 and NAS8-30810), the U.S. Army Corps of Engineers, Mobile District (Contract DACW01-78-0010), and Marine Environmental Sciences Consortium Contribution No. 35 and Contribution No. 29 from the Aquatic Biology Program of The University of Alabama.

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MATHEMATICAL MODELING OF MOBILE BAY: AN ALTERNATE SOURCE OF DATA FOR MANAGERS AND RESEARCHERS

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ABSTRACT

This paper reviews the results derived from mathematical models used in the description of hydrodynamic and material transport behavior in Mobile Bay. Results of parametric studies are reported as within tide and tidal cycle average current and salinity patterns, and monthly average coliform bacteria patterns, for periods subject to normal and severe hydrologic and meterologic conditions in the Bay area. The parameters included are wind direction and speed, river flow rates, coliform bacteria concentrations at the river inlets, bay water temperature, and tidal stage at the Bay/Gulf exchange.

Of primary importance are the relationships of the data base used to calibrate and verify the various models and the form of the corresponding model results derived from the study. These comparisons provide a way of integrating mathematical modeling methods with field and remote sensed data collection programs. A recommendation for the development of a statewide, coordinated data collection program providing better support of mathematical modeling efforts is also made.

INTRODUCTION

Formulation, development and application of mathematical modeling in describing natural water systems have been completed for a number of coastal bays. These models have been applied successfully to San Francisco, Chesapeake, Galveston, Narragansett, and Tampa Bays, among others.

Since 1972, The University of Alabama has been engaged in studies related to the mathematical description of behavior in Mobile Bay. These studies include the hydrodynamic, salinity, and coliform bacteria distribution and transport within the Bay. This paper is intended to summarize the results of those studies, and, to relate the interdependence of modeling activities with the type and kind of data collection plan used to provide basic information about the system.

The Necessity of Mathematical Models

There are several reasons for using mathematical modeling methods to describe bay behavior. The first is the need to be able to assess the effects on bay behavior resulting from rapid, and often unpredictable changes in system variables. This dynamic nature of the system produces conditions that are seldom duplicative from day to day or season to season since the forces acting on the system are truly random. These variables include wind, rain, runoff, river flow, tidal condition and material transport by various mechanisms. In order to assess the interactive effects resulting from these variables, a rapid, accurate model is necessary.

A second reason for using modeling methods for description of bay behavior is the predictive capability it can provide. Forecasting of impacts that could result from variable changes and system modifications (i.e., construction and/or maintenance of channels, etc.) is important to planners and engineers concerned with water resource management. Such information can be used to compare alternative plans before they are introduced into the system. In so doing, policies can be arranged in order of decreasing adverse impact on the environment. Model-predicted results are also useful in directing field data collection programs aimed at the improved assessment of physical, biological and chemical processes existing in the bay.

A third use of model results is in extending field data and remotely sensed data capabilities to time frames when this information is unavailable or impossible to collect. Because these data are collected on a non-continuous basis, a method that provides interpolation between data collection periods is essential to assess changes in this dynamic system. Unless such methods can be applied, events that occur between data collection periods may be misinterpreted. Properly used, it can produce information that is otherwise too costly or impossible to retrieve. It is a reasonable method to link discrete data collection programs—either field oriented or remotely sensed—in a manner to permit accurate assessment of the dynamic behavior of the Bay.

To provide such capabilities requires that the person formulating the model be thoroughly familiar (1) with the system, (2) with the data available for calibration and verification, and (3) with the intended end use of the model results. Of these three, specification of the data base to support mathematical modeling efforts is the most important.

The Relationship of Mathematical Models to Data Collection Plans

All data used in the calibration, verification and implementation phases of a mathematical model description of a bay must be statistically sound. Obviously, the accuracy, precision and sensitivity of model results are never any better than the accuracy, precision, and sensitivity of the data used in its formulation and application. However, there is another important factor to be considered–data frequency.

Obviously, the best data plan would be one providing continuous sampling at all points within a system, simultaneously. This would be the most costly plan and, more realistically, impossible to implement. Therefore, discrete sampling methods are used. Some plans are classified as follows:

1) within tidal cycle
2) tidal cycle
3) daily
4) weekly
5) monthly
6) seasonally
7) yearly (or longer)

These plans may be subgrouped either as random taking samples at different locations at different periods of time, or synoptic–taking samples at different locations at the same time. From a modeling point of view, synoptic plans are needed for calibration and desired for verification. Random plans are useful in checking the verified model results for accuracy and precision.

A further fact is that no data collected on a plan shown in the above list can be reasonably, and accurately used to generate model results in a classification listed above it. (There are some cases where this is not the case–one such being trend analyses within a bay.) Therefore, the plan having the greatest frequency, and the highest cost, also provides the greatest flexibility. Data collection plans must therefore be formulated to provide useable information at economically feasible levels. This requires knowledge of the kind of results desired to do a job, and more importantly, knowledge of the kinds of models available to provide the end results needed.

Because of the complex nature of Mobile Bay (Fig. 1) and the environmental impacts that are created by the industrial, municipal, recreational and natural communities that surround its waters, rapid predictive methods could result in substantial savings of time and effort in analyzing bay behavior. The method could also provide answers related to the abatement and prevention of serious disturbances to the system.

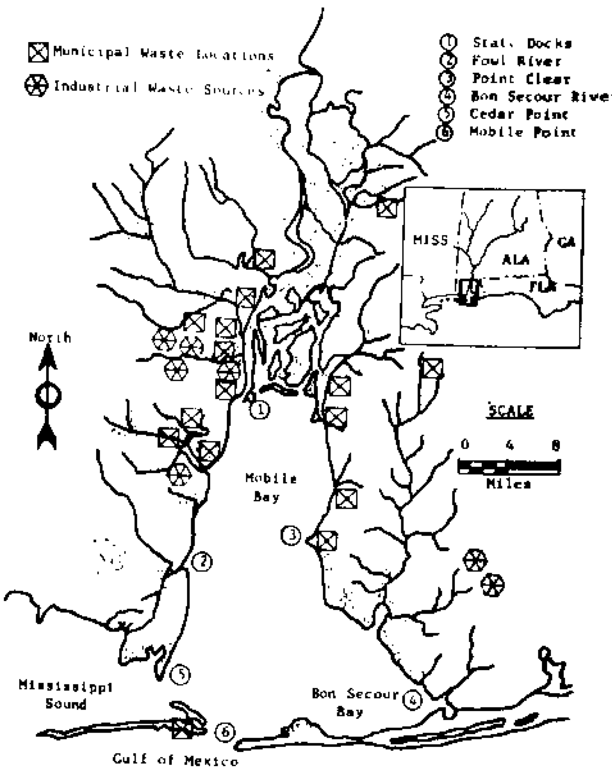

Figure 1. Mobile Bay System with Approximate Locations of Industrial and Municipal Waste Waters Discharges.

This study provides such a method which has as a basis the application of conservation of mass and species equations subject to the bay ecosystem constraints. For this purpose, a two dimensional (surface), non-conservative species transport model is developed for Mobile Bay. The model is solved with a finite difference method and implemented by computer solution using a UNIVAC 1110 system. The hydrodynamic model for Mobile Bay developed by Hill and April (1974a) is used to provide basic current and dispersion coefficient data required by the nonconservative species transport model. The resultant package, referred to as the Non-conservative Species Transport Model (NCSTM) is verified with available total coliform bacteria data obtained from the State Department of Health and with related historical data provided in the literature (Ryan 1969). In addition, work extending the model capabilities to severe weather conditions (i.e., river flooding and storm surges) is also presented. These examples illustrate the interactive nature of the data base with model output. Typical output will be presented for each case illustrating the form of the results produced.

MATHEMATICAL MODELS OF THE MOBILE BAY SYSTEM

In order to better understand the complex, interactive effects influencing water movement in the Bay, several mathematical models based on the laws of conservation of mass and momentum have been formulated. These include models describing the hydrodynamics, conservative and non-conservative species transport within the Bay (Table 1).

The mathematical model (Hill and April 1974a) describing water movement and tidal elevation within Mobile Bay is based on a two-dimensional unsteady flow equation and is referred to as a hydrodynamic model. The water mass is considered to be reasonably mixed such that integration of the general three-dimensional equation in the depth direction is a valid, simplifying assumption. Because of the specific nature of Mobile Bay, convective acceleration and the Coriolis force make significant contributions in the momentum equations. Results can be generated for non-steady flow when boundary conditions are available as a function of time, or for quasi-steady flow when boundary conditions are stable for a time period encompassing several tidal cycles.

The material transport model for Mobile Bay (Liu and April 1975) is based on the two-dimensional form of the species-continuity equa-

Table 1. Mathematical Representation and Operational Modes of the Mobile Bay Mathematical Models

Name	Equation Form	Results	Modes
Continuity	$\frac{\partial Qx}{\partial x} + \frac{\partial Qy}{\partial y} + \frac{\partial H}{\partial t} = -(R + E)$	Tidal Height	Tidal Cycle Daily Avg. Monthly Avg. Seasonal
Momentum x-Component	$\frac{\partial Qx}{\partial t} + gD\frac{\partial H}{\partial x} = K\eta^2\cos\psi - fQQ_xD^{-2} + Qx(2W\sin\varphi) + D^{-1}(\frac{\partial(V_x^2)}{\partial x} + \frac{\partial(V_xV_y)}{\partial y})$	x-Component of System Current	Tidal Cycle Daily Avg. Monthly Avg. Seasonal
y-Component	$\frac{\partial Qy}{\partial t} + gD\frac{\partial H}{\partial y} = K\eta^2\sin\psi - fQQ_yD^{-2} + Q_y(2W\sin\varphi) + D^{-1}(\frac{\partial(V_y^2)}{\partial y} + \frac{\partial(V_xV_y)}{\partial x})$	y-Component of System Current	Tidal Cycle Daily Avg. Monthly Avg. Seasonal
Species Continuity	$\frac{\partial C}{\partial t} + Vx\frac{\partial C}{\partial x} + Vy\frac{\partial C}{\partial y} = E(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}) + \frac{E}{D}(\frac{\partial C}{\partial z}(z_s) - \frac{\partial C}{\partial z}(z_b)) - \frac{1}{D}(CV_z(z_s) - CV_z(z_b)) + R_o$	Concentration of Species	
Salinity	$R_o = 0$	Salinity Concentration	Daily Avg. Seasonal
Coliform	$R_o = K_r$; where $K_r = f(\theta)$	Coliform Bacteria Concentration	Monthly Avg. Seasonal

tion. This model is driven by tidal average velocities and dispersion coefficients generated by the hydrodynamic model. The results thus produced are average concentration distributions throughout the Bay. Modification of the bottom boundary in areas where salt wedge (stratification or unmixed region) effects have been observed, has been used successfully to simulate three-dimensional characteristics. Similarly, coliform die-off rate constants are introduced when these elements are being studied with the model.

The model used to develop the storm surge hydrograph is adapted from Wanstrath's (1978) open coast model. A form of the Reid-Bodine hydrodynamic model, including cell flooding/draining capabilities, was used to evaluate the impact of surge conditions on Bay water level and studied with the model.

VERIFICATION DATA BASES FOR THE MOBILE BAY MODELS

Hydrodynamic Model

Synoptic hydrodynamic data at locations within the Mobile Bay system were received from the U.S. Army Corps of Engineers, Mobile, Alabama, for May 15 and 16, 1972. That information consisted of tide charts and discharge rates experimentally determined over a 34-hour period.

Tide heights were taken from the appropriate charts and converted to read from the model reference plane (mean sea level). Fourier series were fit to data by least squares. Equations used for the Dauphin Island-Gulf boundary and the Cedar Point boundary are given as:

$$HDI = 1.090 + 1.295 * \cos(.004188 * t + .0567114)$$
$$HCP = 1.089 + 1.177 * \cos(.004188 * t - .0032453)$$

A minimum correlation coefficient of 0.99 was obtained in each case.

Manning coefficients varied from 0.010 to 0.050. A coefficient of 0.050 was used in the marsh area to simulate the low flow rates expected in that area. Values within the Bay proper ranged from 0.010 to 0.018. Initially, efforts were made to account for variations in roughness created by oyster beds, channels and spoil banks. However, large changes in the Manning coefficient caused only minor changes in flow on the scale of the model used.

The hydrodynamic model was exercised over two tide cycles beginning with estimates from a previous run. The first step in the verification process was a check of the tidal heights at Mobile State Docks, Great Point Clear, Fowl River, and Bon Secour. Both tidal amplitudes and phases checked closely with the actual data (Fig. 2).

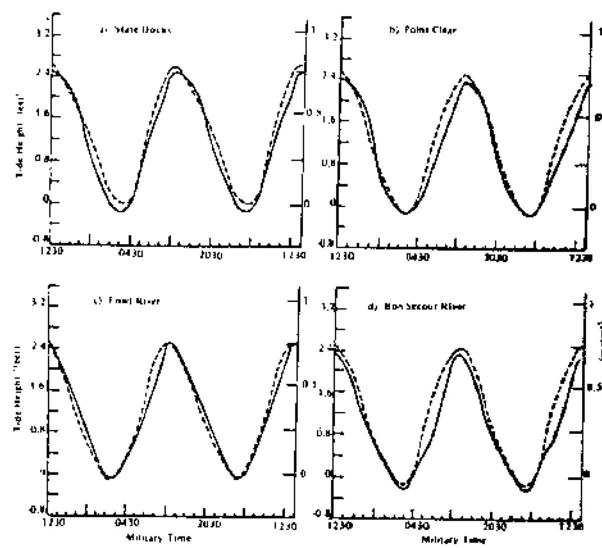

Figure 2. Tidal Cycles at Four Locations in Mobile Bay for Model (dashed lines) and Field (solid lines) results.

That was significant in view of the fact that the forcing function in the Gulf of Mexico and at Clear Point are smoothed data derived from storage equations as previously discussed in relation to boundary conditions. Other factors that may have influenced somewhat the exactness of the fit were localized winds and adjacent marsh areas that may have flooded at high tide. Details of the calibration and verification phases of this study can be found in reference works by Hill and April (1974a,b).

The second verification step consisted of a comparison of discharges at Main Pass and Cedar Point with field measurements taken by the Corps of Engineers. Discharges were calculated by the Corps from periodic measurements at various locations in those passes at a depth of 0.2 and 0.8 times the depth of flow. An arithmetic average of those values was considered to be the average value for that location in the vertical direction. Horizontally, the area covered was half the distance to the adjacent measurement location on either side.

The correlation between actual data and model-predicted data at Main Pass was excellent (Fig. 3). This was expected because flows were well behaved and represented the major discharge route from the Bay; the other being at Cedar Point. There was a deviation at Cedar Point between model-predicted and field results (Fig. 3).

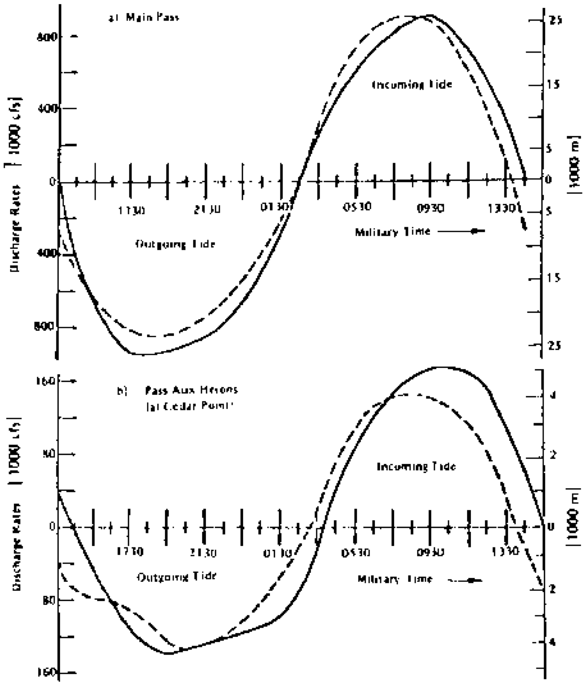

Figure 3. Discharge Rates at 2 Locations in Mobile Bay for Model (dashed lines) and Field (solid lines) Results.

During the course of this study, flows through Main Pass evidently had a direct influence on the flows through Cedar Point. At one point discharge rates for the Cedar Point boundary were used by necessity to define precisely the tide delay between the Gulf and Cedar Point. This aspect points out the interactive effects between Mobile Bay and Mississippi Sound and the desirability of ultimately linking model descriptions of the Sound with the Mobile Bay model (Hill and April 1974b). Such a study is currently underway.

In subsequent studies, river flow rates in excess of those defining flood stage conditions were also made. Results, as in the case of the earlier investigations, are expressed in terms of water elevation and movement at locations within the Bay.

Salinity Model

Some salinity data were received from the Corps of Engineers, Mobile, Alabama, for the period of May 15 and 16, 1972. The number of locations sampled in this effort was judged to be insufficient for verification purposes. This was particularly true since all locations were within the ship channel. Considerable salt concentration data were located in the literature for the month of October, 1952. Average river flows obtained from the U.S. Geological Survey for that time period indicated a fresh water input of 340 m^3 sec^{-1} (12,000 ft^3 sec^{-1}). The hydrodynamic model was exercised using the modified river flows to compute the pertinent data for the salinity model.

Dispersion coefficients and net velocities, calculated in the hydrodynamic model for each grid location, were used as input data for the salinity model. The Gulf boundary saline concentration was set at 35 parts per thousand (ppt). The concentration at Cedar Point for October, 1952, was elucidated from the literature (Hill and April, 1974b) and set at 25 ppt. Dog and Mobile Rivers were set at zero concentrations.

The salinity wedge was accounted for in the Bon Secour area. This area was chosen rather than the ship channel for several reasons. First of all, data available indicated that effects in the ship channel were minimal. That may be attributable to the low comparative surface area involved on the scale of the model studied. Secondly, the literature (Barlow et al. 1955) indicated that a large area in Bon Secour was influenced by the wedge. This is expected as a result of the flow patterns in the area. Finally, the model indicated that the salinity wedge in Bon Secour significantly contributed to the overall salinity patterns. This was achieved in the model using a first order equation for the rate of mass transfer from the salt wedge to upper water layers. The value of the mass transfer coefficient, K_{jf}, used in this rate equation was taken as 0.000002 $*E_{max}$. Simulating the three-dimensional salt wedge effect in this manner gave model results in closer agreement with reported field data.

The salinity model was exercised for 16 tidal cycles beginning with estimates from a previous run. Data from the literature (Barlow et al. 1955) were averaged for ebb and flood tides as well as in the vertical direction and compared with model trends.

Model results were in general agreement with the field data. A deviation along the western side of the Bay may have been the result of unidentified fresh water flows in that area, as in the case of Dog River at the outset of this study. This was surmised from several pieces of information. Profiles from the literature indicated a rather strong net outflow along the extreme western shore even for low fresh water flows (Barlow et al. 1955). This was in contrast to Earth Resources Technological Satellite photography and coliform profiles, which indicated the main thrust of net outflow was down the ship channel and minimum flows adjacent to the western land boundary. Even with the possibility of additional fresh water flows, the model-predicted isohalines appeared reasonable and led to a study of natural phenomena expected in Mobile Bay as a function of various wind and river conditions.

Coliform Model

Total coliform group concentration data for various locations in Mobile Bay were collected by the Alabama State Department of Health for the period from January 1962 to August 1962. Coliform concentrations were obtained by analysis according to "The Significance of EC Positive Organisms in Gulf Shellfish Growing Waters" (Hosty 1974).

The model was verified on a monthly basis, i.e., monthly average conditions were used, and the model results were tabulated and compared to the monthly average values of actual data. The 70% confidence ranges of the actual data were also tabulated to indicate the range in the monthly field data averages. Model verification was based on how well model-predicted results fell within the field data range at the several locations within the Bay for any given monthly period.

Because of the dependence of the species-continuity equation on the hydrodynamic model of Mobile Bay for current distributions and dispersion coefficients, the first step in the verification procedure involved specification of data necessary for the proper description of the hydrodynamic behavior of this bay. This included the calculation of monthly average river flow rates, wind conditions and tidal conditions for the period for which total coliform group concentrations were available.

Additionally, the total coliform die-off rate constant, K_F, used in the model was calculated as a function of monthly average water temperature of the Bay. These temperatures were estimated from the bimonthly average water temperatures of Mobile Bay compiled by Bault (1972). Water temperatures are not uniform in the Bay and the degree of mixing that occurs between sea water and river water within the Bay will affect the temperature distribution. In this study, temperatures were considered homogeneous throughout the Bay. Temperatures can be adjusted linearly between the values corresponding to Gulf of Mexico water temperature and river water temperature to approximate real system behavior. In this study, where monthly average values were investigated, the sea water intrusion effect was neglected.

Total coliform group concentration data for locations having severe pollutant input into the Bay were used as loading concentrations at each relevant grid cell. They were held constant throughout each computation. Loading at Mobile River has been found to be the main source of pollution of Mobile Bay (Liu and April 1975).

Results are presented as model-calculated total coliform profiles within Mobile Bay. Similar results were tabulated for each month from January to August, 1962, during which the verification phase was performed. Total coliform concentration vs. time (month) curves are also presented to indicate the trend of concentration changes with season (Liu and April 1975).

Storm Surge Model

Adaptation of Wanstrath's (1978) open coast model to the Northeastern Gulf of Mexico provided storm surge hydrographs at the Mobile Bay entrance. Sufficient data for Hurricane Camille, 1969, were used to specify the hydrographs along coastal Alabama. Once achieved, these results are linked to the Mobile Bay hydrodynamic model. Results were then obtained as increases in water elevations, velocities and salt concentration as the storm surge approached the coastline. Both within tide and tidal cycle averaged modes were used in this analysis.

THE INFLUENCE OF SYSTEM CHANGES ON MOBILE BAY BEHAVIOR

In order to assess the impact that changing river flow rates, wind conditions, coliform loading concentration and water temperature have on the hydrodynamic and material transport properties of Mobile Bay, a parametric study was conducted using the developed and verified mathematical models. The results of this study are discussed in the following sections, subdivided for clearer presentation of the material.

Normal River Flows and Wind Conditions

Three river flow rate conditions were investigated (340 m^3 sec^{-1}, 1246 m^3 sec^{-1} and 6938 m^3 sec^{-1}). Also wind conditions were studied at 0, 8 and 13 m sec^{-1} speeds blowing from the prevailing direction (southwest). The effect of these system changes on extreme (high and low) tidal elevations at four locations in the Bay are shown in Table 2. In each case there was a pronounced influence of wind speed on tidal elevation, especially toward the northern Bay. This was caused by the retention of water because of wind stress conditions and the decrease of Bay width from 39 km in the south to 13 km in the north.

Table 2. Extreme Tidal Elevations (Feet) from Mean Sea Level for Varying River Flow Conditions.

River Flow Rate, cfs ($m^3 sec^{-1}$)	12,000 (340)			44,000 (1246)			245,000 (6938)		
Wind Condition									
Speed, knots[a]	0	15	25	0	15	25	0	15	25
Direction	SW	SW	SW	SW	SW	SW	SW	SW	SW
State Docks									
High Tide[b]	2.57	2.78	3.77	2.60	2.84	3.87	3.06	3.29	4.28
Low Tide	-0.24	0.30	1.67	0.05	0.57	1.87	1.97	2.20	2.77
Point Clear									
High Tide	2.53	2.66	3.21	2.50	2.67	3.23	2.55	2.70	3.33
Low Tide	-0.27	-0.02	0.80	-0.19	0.01	0.83	0.05	0.26	1.09
Fow River									
High Tide	2.51	2.61	3.05	2.49	2.62	3.07	2.58	2.70	3.21
Low Tide	-0.23	-0.01	0.67	-0.14	0.02	0.72	0.14	0.31	1.01
Bon Secour River									
High Tide	2.45	2.51	2.74	2.41	2.50	2.75	2.47	2.48	2.81
Low Tide	-0.20	-0.12	0.29	-0.14	-0.11	0.31	-0.04	0.07	0.47

[a]To obtain $m\ sec^{-1}$ multiply speed in knots by 0.5148.
[b]To obtain m multiply elevations in feet by 0.3048.

Similarly, significant variations in tidal elevation were observed at high river flows in the north with a rapid dissipation to nearly normal levels at the mid-Bay locations. The influence of these system changes on current direction and speed was likewise discussed in the original study document (Hill and April 1974b).

The influence of river flow rate on Bay salinity is illustrated in Figure 4. Suppression of the salinity content of intruding Gulf waters was observed during high riverine inflow conditions. The Bay approached river-dominant characteristics in the upper one half of the Bay when flows exceeded 4248 $m^3\ sec^{-1}$.

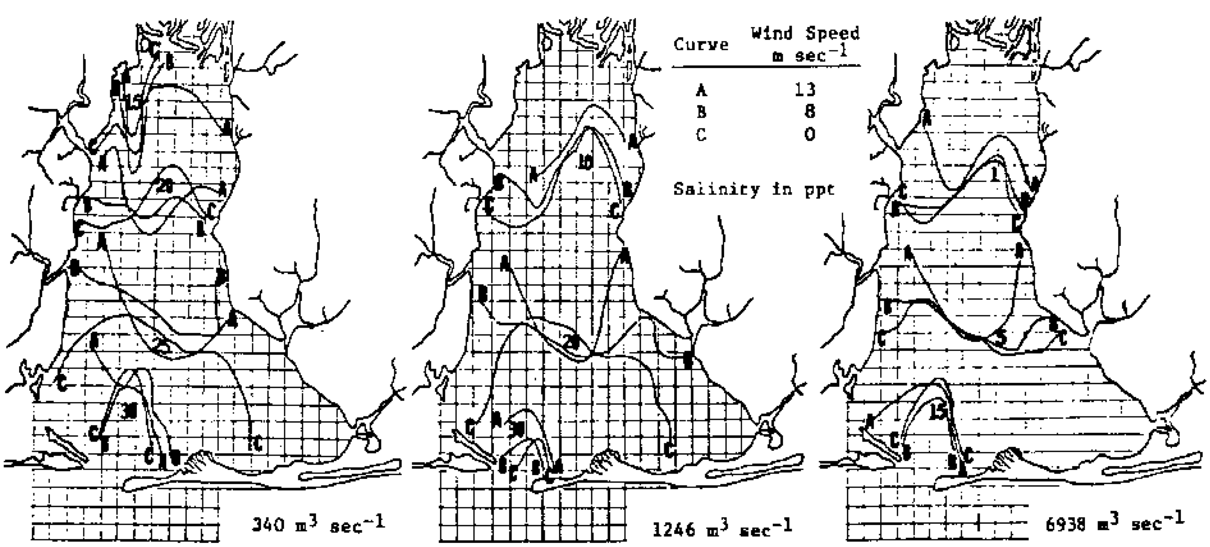

Figure 4. Southwest Wind Effect on the Salinity Distribution Patterns in Mobile Bay for Three River Flow Rates.

Wind speeds above 8 m sec^{-1} influenced salinity distribution in the Bay. Characteristic shifts in freshwater flow patterns can be traced by following salinity profile trends from 0 to 13 m sec^{-1} wind conditions (Fig. 4). Downward profiles gradually oscillated as the wind speed approached 8 m sec^{-1} followed by a reversal in the profile at 13 m sec^{-1}. These shifts were directly related to wind stress conditions imposed by the prevailing and constant southwest wind.

Similarly, total coliform bacteria group counts shifted south-eastward when river flow rates increased (Fig. 5). This was caused by lower retention times needed for the coliform bacteria to die off resulting in higher residual coliform concentrations in all parts of the Bay. The results in Figure 5 are for conditions of constant coliform loading that, in most cases, did not exist during high river flow conditions. A more realistic way of assessing the effect of changing coliform loads independent of river flow rates is discussed in the following section.

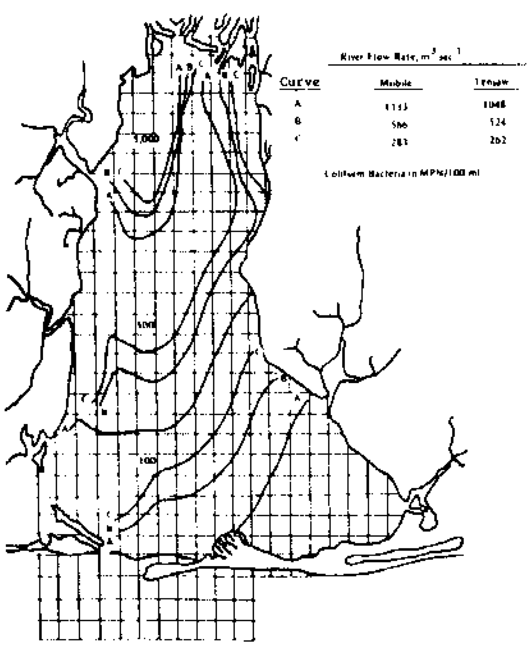

Figure 5. Effect of River Flow Rate on Coliform Bacteria Distribution in Mobile Bay.

Effect of Varying Coliform Loadings

Cell-loading concentration of total coliform at the mouth of a river reflects the pathogenic pollution potential of the river relative to the Bay. This concentration is attributed to waste loadings from sources such as municipal, industrial, and rural areas. After periods of heavy rainfall and runoff, the river flow rates stabilize. However, coliform loading along the river course usually peaks and begins decreasing at rates greater than river flow decreases. In this discussion river flow rates, wind conditions, and temperature are held constant. The only changes made were on the loading concentrations of total coliform bacteria at the mouths of Mobile and Tensaw Rivers. The resulting total coliform concentration profiles are shown in Figure 6. Comparisons were made at two concentrations of 70 and 1000 MPN/100 ml. Each of the shifts of the coliform concentration profile was in the order of 2 grid widths (4 km). Note that the 70 MPN/100 ml contour shifted as many as 6 grid widths from one extreme to the other as 7/8 of the original total coliform bacteria was removed or reduced. These changes in total coliform loading were also more representative of conditions that might be achievable for varying degrees of treatment of municipal and industrial waste sources.

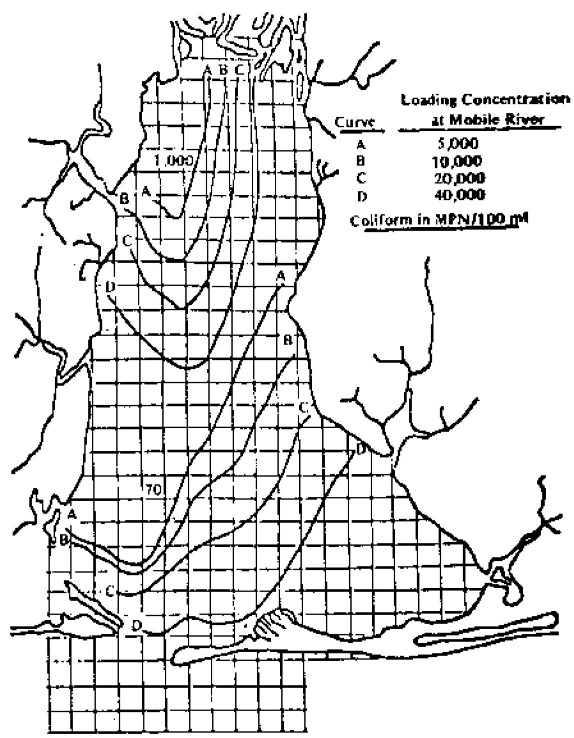

Figure 6. Coliform Bacteria Distribution in Mobile Bay as a Function of Loading Concentration in the River System.

Temperature

Effects of changing temperatures on total coliform distribution are shown in Figure 7. The shifts of the 100 and the 500 MPN/100 ml total coliform concentration isolines were in the order of 2 to 4 grid widths (4 to 8 km) from run to run. Shifts of that magnitude can seriously affect shellfish harvesting activities in the Bay, especially in the Bon Secour Bay areas. This simulates what can happen to the coliform distribution in case of sharp temperature variations when all the other system variables, i.e., river flow rates, wind conditions, and waste loadings remain unchanged. The reason for such pronounced shifts of coliform concentration profiles was the temperature induced change in dieoff rate constant, K_T. When water temperature in the Bay was higher, total coliform bacteria dissipated at a higher rate, and the coliform concentration in the Bay decreased. When water temperature was lower, K_T was smaller, the total coliform bacteria died at a slower rate, and the coliform concentration in the Bay increased. This effect also partly accounts for observed seasonal variation of total coliform concentration within Mobile Bay (Gallagher 1969).

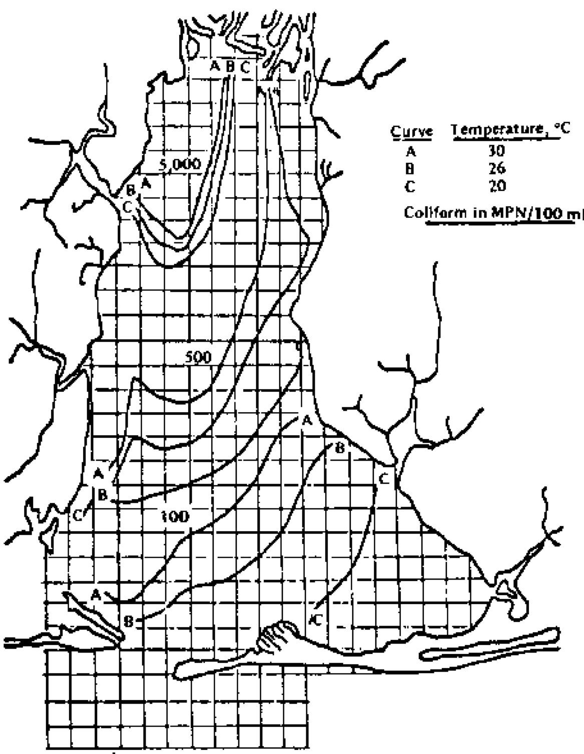

Figure 7. Coliform Bacteria Distribution in Mobile Bay as a Function of Water Temperature.

Abnormal River Flows and Storm Surge Conditions

When severe weather conditions are encountered by the Bay area, the normal patterns of water flow, water elevation and salinity are greatly altered. In a study by Hu (1979) river flow rate conditions in excess of flooding state (7000 m^3 sec^{-1}) and storm surge conditions were investigated with results compared with normal conditions.

River stages in excess of 7000 m^3 sec^{-1} introduced a large amount of fresh water into the Bay at the rivers in the north. These flood stages usually occurred between March and May. The overall impact on bay behavior was total dominance in the upper 2/3 of the Bay by fresh water. This is shown in Figure 8 in which the tidal cycle average salinity profiles are plotted for varying river flow rate up to and beyond flood stage values. Note the

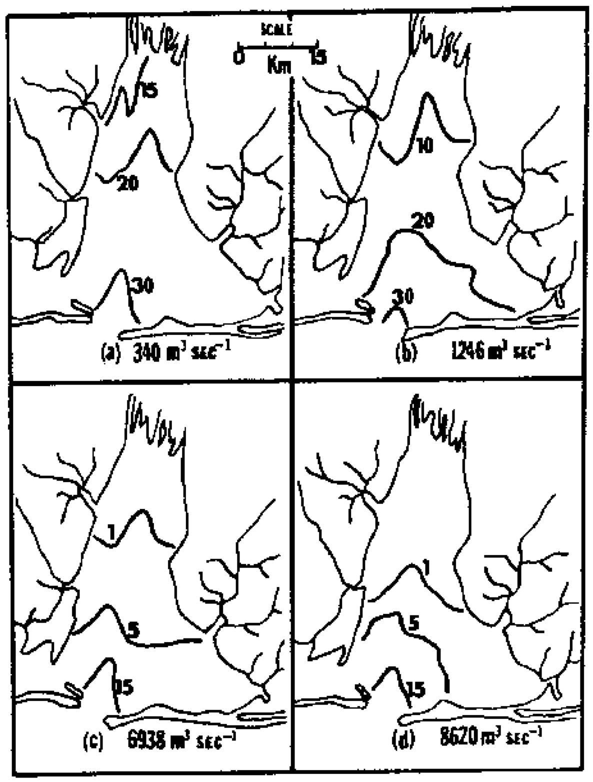

Figure 8. Tidal Cycle Averaged Salinity Profiles (in ppt) in Mobile Bay for Four River Flow Conditions.

effective blocking of Gulf water at the 7000 m^3 sec^{-1} flow in which only 5 ppt salinity reached a point 15 km from Main Pass. The entire Bon Secour Bay area was likewise at or below 5 ppt when flows approached 8500 m^3 sec^{-1}. Additionally, at a level greater than 8500 m^3 sec^{-1} there appeared to be little change in the overall salinity pattern over the tidal cycle. Excellent agreement with field data collected by Schroeder (1977) can be seen in Figure 9 for the lower Bay at Main Pass. Field data, depth averaged over the sampling period, were compared with model isohalines for the same periods during each tidal stage encountered during the survey. Agreement in all cases was within experimentally accepted limits. Likewise, water elevations increased with increasing river flow rate (Fig. 10). The greatest increase occurred in the State Docks area where the fresh water

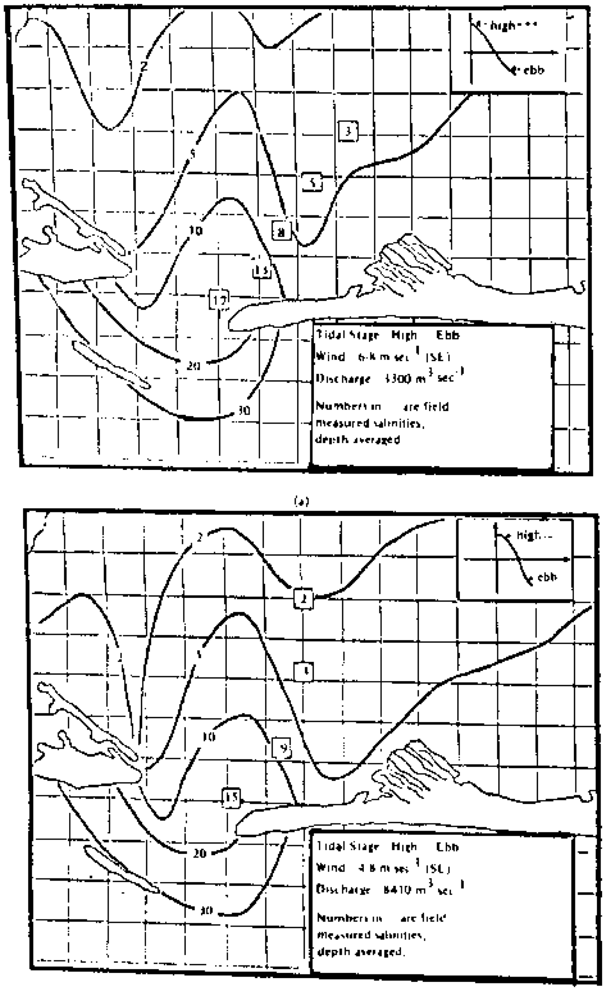

Figure 9. Isohalines for the Lower Mobile Bay Under River Flood Stage Conditions; (a) 3300 m^3 sec^{-1} and (b) 8410 m^3 sec^{-1}.

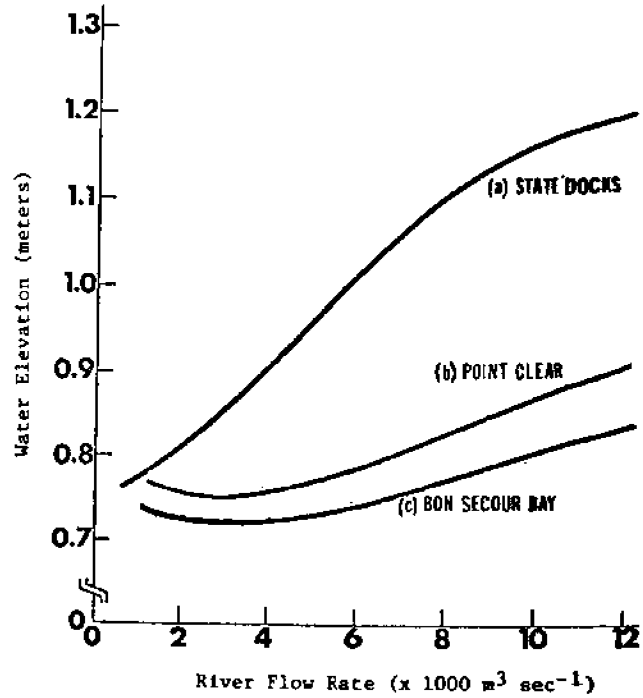

Figure 10. Maximum Water Elevations Vs. River Flow Rate for Three Locations in Mobile Bay.

enters the converging section of the Bay. Less noticeable increases occurred in Bon Secour Bay and at Point Clear. Water velocities likewise increased everywhere in the Bay with net water movement into the Gulf through Main Pass and Cedar Point (Table 3).

Conversely, during storm surges, the Bay water behavior is dominated by the intrusion of saline Gulf water. Conditions typical of storms in this area of the Gulf (Camille, August 1969) were used in the analysis.

Table 3. Velocity Distribution of Mobile Bay Waters under River Flood Stage Conditions.

Tidal Stage[a] / River Flow Rates, m^3 sec^{-1} / Velocity Components[b]	Flooding 3000		High–Ebbing 5000		Flooding–High 7000		High–Ebbing 8000	
	Mag.	Dir.	Mag.	Dir.	Mag.	Dir.	Mag.	Dir.
Bay Location:								
Main Pass	1.33	267.8	1.36	269.0	1.41	269.0	1.46	268.0
Cedar Point	0.24	240.9	0.20	246.0	0.21	242.0	0.25	244.0
State Docks	0.29	270.0	0.39	270.0	0.51	270.0	0.60	270.0
Point Clear	0.06	310.0	0.10	324.0	0.10	324.0	0.12	322.0
Bon Secour Bay	0.06	216.0	0.09	199.5	0.07	189.0	0.07	220.0

[a] Flood stages represent the periods over which field data were available for comparison purposes. The complete tidal cycle was broken down into fourths; flooding, high, ebbing and low, see Figure 9 for illustrations.
[b] The velocity components include the magnitude (Mag.) measured in m sec^{-1} and the direction (Dir.) measured in degrees, where 270° represents flow to the south.

The impact on Bay behavior can best be seen by comparing the tidal cycle averaged salinity pattern (Fig. 11) with previous patterns (Fig. 8). The entire Bay was subject to salt water intrusion with a level of 26 ppt at the State Docks in the northern Bay. This can likewise be seen in Table 4 in which the extreme variation between river flooding conditions and storm surge conditions were compared with normal conditions. The fresh water/saline water dominance is clearly illustrated.

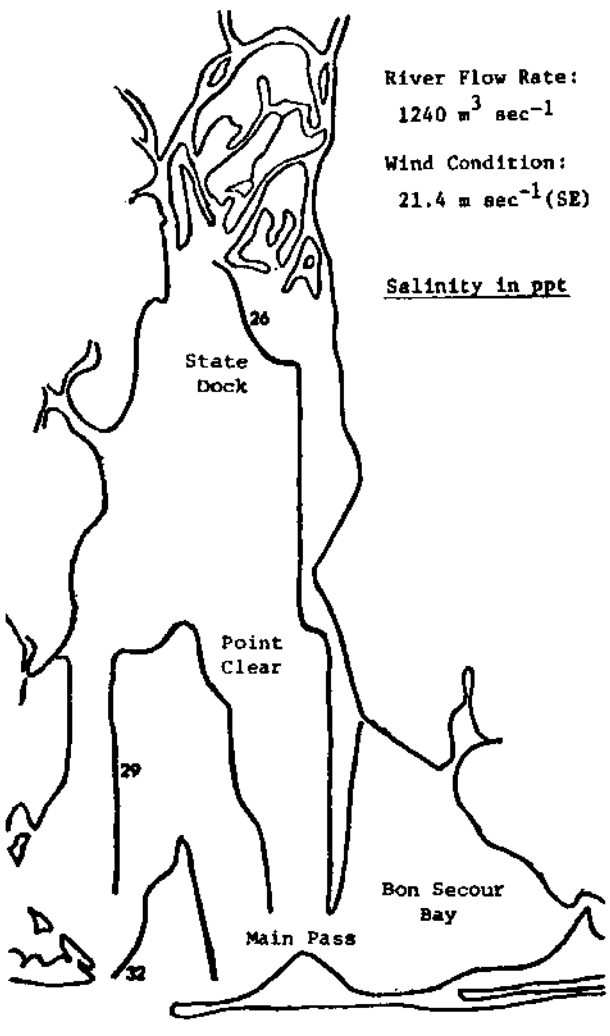

Figure 11. Salinity Profile in Mobile Bay Under a Storm Surge Condition.

Likewise, water elevations increased in all areas of the Bay. The greatest change occurred at Bon Secour Bay (Table 5) under storm surge conditions. Values for different river flow rates up to flooding stage are also shown. Such large changes, as illustrated during these periods of upset, resulted in alterations in all aspects of Bay behavior; physical, chemical and biological. More importantly, the manner and period required for the Bay to return to normal state is important in water quality planning and decision making.

CONCLUSIONS

The methods and corresponding results illustrated in this paper are intended to be examples of the many ways in which mathematical descriptions of natural systems can be used to assist in water quality management functions. Of equal importance was the emphasis placed throughout the discussions on the data base used to support the mathematical simulations.

Often models are used without a data base, or with a data base that does not correspond to the time frame over which model information is being sought. This results in gross errors, false interpretations and inaccurate policy decisions about the water system being modeled. However, when the analysis using modeling methods is paired with reliable data, trend behavior and, in many cases, predictive behavior can be obtained and used effectively. Therefore, the design of a data collection system to produce accurate model results of the kind desired, or, the adaptation of the proper model to fit the data already assembled is a necessary first step in any numerical simulation effort. Recognition of this essential step often dictates the fate of a modeling effort as a benefit or curse to the user.

ACKNOWLEDGEMENT

The research reported in this paper was accomplished under the sponsorship of a National Aeronautics and Space Administration contract (NAS8-29100), Research Grants Committee Project #921 at The University of Alabama, a Water Resources Research Institute contract (Project A-061-A) at Auburn University and a Sea Grant project (R/ES-4) of the Alabama-Mississippi Sea Grant Consortium. In addition the authors would like to recognize the efforts of the following students who contributed significantly to the projects: Donald O. Hill, Hua-An Liu, Samuel Ng, and Stephen Hu.

Table 4. Comparison of Salinity Values (ppt) at Five Locations in Mobile Bay as a Function of River Flow and Storm Surge Condition.

River Flow Rate, m^3 sec^{-1} / Condition	1250 Normal	11300 River Flooding	17000 River Flooding	1250 Storm Surge
Bay Location:				
Main Pass	30	14	13	34
Cedar Point	18	5	3	23
State Docks	5	1	1	27
Point Cedar	15	1	1	26
Bon Secour Bay	16	3	2	20

Table 5. Comparison of Maximum Water Elevations (Meters) for Three Mobile Bay Locations at Varying River Flow Rates or under Storm Surge Conditions.

River Flow Rate, m^3 sec^{-1} / Condition	340 Low Flow	1250 Medium Flow	6960 High Flow	1250 Storm Surge
Location:				
State Docks	0.78	0.79	1.10	1.19
Point Clear	0.77	0.76	0.78	1.48
Bon Secour Bay	0.75	0.74	0.75	1.65

NOMENCLATURE

- C Concentration of Species in the Water Column, M/L^3
- D Depth of Water in the Bay, L
- E Rate of Mass Transfer by Evaporation, L/T
  Dispersion Coefficient, L^2/T
- f Bay Bottom Friction Factor
- g Gravitational Acceleration, L/T^2
- H Height of Water above a Cell Datum, L
- K Constants
- Q Discharge Rate, Per Unit Cell Depth, L^2/T
- R Rate of Mass Transfer by Rainfall, L/T
  Rate of Disappearance or Appearance of Mass, M/L^3T
- t Time, T
- V Resultant of the Velocity Vector, L/T
- v Local Grid Velocity, L/T
- W Angular Velocity of Earth, L/T
- x Distance (East-West), L
- y Distance (North-South), L
- z Distance (Depth Direction), L
- η Wind Speed, L/T
- θ Temperature
  Wind Direction
- Ψ Angle Measurement in the Coriolis Term
- ∂ Differential Operator

SUBSCRIPTS

- b Bottom
- o Source or Sink Term
- r Resuspension
- s Settling
  Surface
- x East-West Direction
- y North-South Direction

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PANEL DISCUSSION - MODERATOR, DR. BRUCE TRICKEY, EXECUTIVE DIRECTOR, ALABAMA COASTAL AREA BOARD

MEMBERS

Dr. Gary April, University of Alabama
Mr. Donald Brady, South Alabama Regional Planning Commission
Dr. Wayne Isphording, University of South Alabama
Dr. George Lamb, University of South Alabama
Dr. Hugh McLellan, U.S. Army, Corps of Engineers
Dr. Will Schroeder, Marine Environmental Science Consortium

TRICKEY: I'd like to be forgiven for the viewpoint I am going to take. I'd like to stimulate the maximum amount of discussion. This means that I have to take a somewhat adversary position, perhaps, with some of the panel, at least, to stimulate some discussion. We have all these experts here, and this is our chance to get some input into some tough questions that some of us may want to ask. One of the first questions is, "How do we measure success?" I am not so sure that success is being able to predict wind going up and down the bay or the tide. Everybody knows that as the moon goes around the world, the tides go up and down. But, at the same time, what is this doing to the ecology. I don't think we quite tied that one in yet. So we have to somehow find out what they are trying to do when they do all this modeling. We seem to know a great deal about Mobile Bay, but is it relevant to the problems? Do we know a lot that doesn't help very much in decisionmaking and not enough about what we need to do when it comes to making decisions that are very important for the future? We have to also try to achieve a discussion with considerable candor in it because if we make it simply bland, we all go away without having used this opportunity to bring out facts that we need to know in order to come to better decisions. I'd like to ask the panel, to begin with, is the Bay getting better or worse? Is it lightly stressed, moderately stressed, or heavily stressed? Will, would you take off on that one?

SCHROEDER: Bruce, I'm all for approaching a problem with all the candor that we can. But I am afraid that I have to respond with a question before I can answer, and that is: Do you want us to look at individual processes or are we answering this question with regard to the synergistic effects in our fields?

TRICKEY: All of the people here are interested in the problems of Mobile Bay, and everything they do is related to that in some way or another. The problems in the Bay are of a kind that many people here are very concerned about. Is what we are doing relevant to those questions and those problems?

SCHROEDER: If you are asking about stressing, I would say that the upper Bay from Hollinger's Island, on the Delta and particularly the western side is certainly impacted. The eastern side is in fact under a stress situation with regard to bottom circulation because of the shoaling resulting from the deposit of material from the ship channel. Regarding the lower end of the Bay, we were out recently to verify for our own minds whether or not the shoal banks still existed, and we really couldn't find any. In the absence of many of the old time shoal banks, whatever they may have been, (we seem to lack any real documentation of the exact positions of those) the lower Bay is not under the stress the upper Bay is with respect to bottom circulation.

TRICKEY: With respect to bottom circulation, is this a significant factor? What does that do to the plants and animals in the Bay?

SCHROEDER: Well, I am not a biologist, but certainly the biological system responds to the physical and chemical systems within the Bay.

TRICKEY: That's the tie-in. They tie together that way.

SCHROEDER: Certainly, I think all of us here would feel that what we are trying to do is characterize certain aspects of the physical, chemical, and geological environment in a manner that gives us a point from which to depart in saying whether or not the Bay is stressed relative to some of what we have studied. We are probably, individually, a long way from coupling up one on one to biological work, simply because we are still trying to do the work in our own house. We are not ready to move out yet.

TRICKEY: You had some pretty strong recommendations in your discussion, Will. I guess your recommendations were related to your concern about how things should be done out there.

SCHROEDER: In my opinion it is very important to protect the natural circulation regimes within the Bay as best as possible if, in fact, we want the Bay to continue along a natural course of events. On the other hand, if we feel, somewhere down the line, that we know how to manage the Bay in a manner that we can alter it physically and still get from it everything we want, perhaps I will change my mind. I don't feel we have the ability to manage the Bay apart from its natural setting; therefore, we'd best leave it alone and work within that framework. I am willing to accept a middle-ground position with respect to ship channels or cuts in the Bay, providing that we have done as much homework as we can to understand the consequences that may result.

TRICKEY: Dr. April, you have obviously a very long and deep and tremendous background in modeling. If you were forced to answer, what sort of relevance do you see? How much accuracy or how much credence can we give to modeling efforts for the Bay for the decisionmakers?

APRIL: I'd like to go back to the first question, namely, is the Bay stressed? Yes, the Bay is stressed. Any time you have large population densities where you have municipal impacts, industrial impacts, any system is going to be stressed. The ideal situation is that every natural body has its own limit of assimilative capacity to handle the input, the pollution, that it can take. Up until about 1960, people were not concerned about the assimilative capacity of certain natural water bodies. As a result, there wasn't a large outcry. As our technology developed, as we sent man into space, we became more aware of looking at things on a very minute scale, very accurately. We decided that we had overstepped our limit. We can unstress Mobile Bay from man-made type activities. That is a very possible and a very realistic kind of thing to do. To do that, we first have to understnad what the impacts are, and to do that we need to know the physical, the hydrologic, the biologic, and the chemical effects that are impacting on the Bay. The second thing is we have to realize that, and I quote my father on this, "you don't get nothing for nothing." If you want a clean bay, you have to pay for it. I got into the business as a chemical engineer because I have an interest in chemical engineering impacts on natural systems. My industry, my profession, any current course in chemical engineering, does not overlook environment. Any process which any engineer develops, in my profession, always considers that. And processes are now going from very large discharges of pollutants to what we refer to as total recycle. When we get to total recycle, the industrial impact is going to be nil. Then we are back to the old thing that Will said; we still have the natural system. What we choose to do from that point I don't know. Can we improve it beyond the natural behavior of the Bay? We are too far away from that to be able to say, but in terms of the short run, the management aspects, I think what we need to look for is how to optimize. How do we keep within a reasonable level of things that we can do? The only answer I see is good, accurate information to predict the effects before we rush out and do something that has no scientific basis. Emotion won't solve all these problems, but facts and data will, and mathematical modeling is a way of getting at the facts and data.

TRICKEY: Dr. Isphording, would you let us have your opinion on whether you think the Bay is stressed and to what extent and so on.

ISPHORDING: My study involved simply determination of some of the chemistry of the Bay. It is hard for me to tell whether it is stressed or not. I am not a chemical engineer. What I was doing was gathering baseline data. I would have to go along with Dr. April in that until we have an accurate modeling of the bay, it is going to be very difficult for us to assess the influences that industrial contamination and any other source of natural deposition taking place in the Bay will have on it. There is no doubt that the Bay itself has a stress put on it. The Bay is stressed. It is stressed by both natural systems where you're depositing and filling in the Bay in certain areas. It's being stressed, we can see from our preliminary chemical data, by the effluent being deposited in the Bay. The effects on this are hard to assess except from the standpoint that our preliminary data indicate that many of the heavy metals that are being dumped into the Bay are being locked up in the sediments in such a way that these are not permanently partitioned and that these can be remobilized. I don't think people understand enough about remobilization of heavy metals. Once you get something deposited in the bottom Bay sediments, that doesn't mean it is there forever. There are a number of things that can act to remobilize these. We are able to observe this high concentration of the heavy metals with silt, clay size materials, when we look at these oyster reefs. Fortunately for us, the oysters don't like the clay substrate. If they liked the clay substrate, we'd be in bad trouble, because they are filter feeders, and they would act upon these heavy, metal-loaded sediments and extract the heavy metals from them. But we don't know what the effect is on other animals, and I think we need baseline studies on these in order to establish this.

TRICKEY: Thank you sir. I wonder if the panel has some questions that they would like to discuss, or do you have any answers, for instance, to the dilemma that the area is in, at the moment, between the modeling studies done for the 208 by Don Brady and the EIS brought out by the Corps. These two opinions which the Corps now has, in its own shop need somehow to be reconciled. One model study says do it, and the other study says don't do it. How is this going to come out, Mr. McLellan?

McLELLAN: I certainly don't know how it is going to come out. I was talking to Don a little earlier. We need to get together, obviously, and perhaps put together the technical committee we had together in the scoping meeting on the EIS. The EIS's primary point of divergence from the 208 plan lies in the domestic wastes aspect of the culture.

TRICKEY: Mr. Lamb, do you have something to add to that question? Have you studied the EIS and the Corps efforts in this area?

LAMB: No, I haven't, really. But, I have been interested in this sediment distribution, and I think there is one interesting point that a number of people have brought out here. Earlier in the discussion, somebody said that as soon as an estuary is born it starts to be destroyed in that it is filling in with sediment. Another was that we are just beginning to accumulate data on the Bay. I wish my ancestors, some of the Creek Indians that used to roam around here, had kept some data, had gathered some data, so that we would really know what the Bay was like before there was any impact by man. One of the big stumbling blocks is the lack of data. What was it really like? How much sediment was coming into the Bay? What kind of sediment? Are some of these heavy metals that we see natural? Were they coming down the rivers before there was any industry? That has been suggested by various people. I don't usually believe it, but it is a possibility; nobody knows. That is one of our big stumbling blocks and we are still at that first step, unfortunately. I wish somebody had collected data years ago so that we could come along now and have something to compare it to and show what changes have been made. If you could see what changes had been made, then you could see what direction you were going in and maybe predict something, but if you don't have anything to compare to, if you are the first person that goes out into the Bay and starts to look at it, then there is no basis for comparison. You can't see how it's changed. We are just stumbling through this. I think in the last decade there has been more information gathered in the Bay than all previous time. We really are just beginning to accumulate enough data so that we can come up with any sort of predictive devices.

TRICKEY: I'm with you there. I think this effort today and tommorrow, this symposium, is one of the more important things that is happening in the Mobile area. It ought to set a tone or base for the direction we take in the future in an excellent way. I'm going to give Don Brady a break and see what he has to say about the same question I raised with Hugh McLellan.

BRADY: First of all, Dr. Trickey, I don't exactly agree with the statement that one model showed that the discharge should be allowed and another showed that it shouldn't. I don't believe there were two models in this regard. The EIS didn't do any modeling. All they did was an evaluation of the modeling. I do believe that from my reading of the EIS it indicated that under normal operating conditions, there wouldn't be any significant impacts on the oysterbed, which is the main concern here. It was the possibility of the breakdown or failure of the system which would cause the concern. I believe this is true. Their evaluation did not take into consideration the second holding pond that was recommended in the 208 study. This holding pond would be somewhat of a fail safe holding pond, if you will, into which, in case of a breakdown of the sanitary facility, untreated municipal waste would be diverted, and it would have a 5 to 7 day capacity and would contain those untreated wastes until such time as the malfunction could be corrected. Then that raw, untreated waste would be recycled back through the plant for treatment before it was discharged to the holding pond, and then from the holding pond into the pipeline. I think that this concept of the waste treatment process that we defined in the 208 plan was not fully or adequately treated in the EIS. I don't believe from our evaluation, as far as water quality is concerned in comparison with the Alabama Water Improvement Commission standards, that the Bay itself is constrained in any way by point source discharges existing. The lower Mobile River is, Chickasaw Creek is, Three Mile Creek is, but the Bay itself is insignificantly affected. Only in the northwest corner of the Bay where the river mouth enters, is there any significant water quality impact from the existing point source discharges. In fact, our analysis really showed that the greatest stress comes from the high freshwater inflows and the urban storm runoff especially in the delta area. I don't know whether that answers your question directly or indirectly, or at all, but I think that perhaps brings a little more light on what our modeling effort does recommend.

McLELLAN: The EIS was written according to the plan that the Mobile Water and Sewer Board told us that they were going to do and what the contractor told us they were going to do. I think there has been a misunderstanding as to whether there would be a holding basin or not for the domestic waste. As Don said, we did not do any modeling. The primary point of divergence in the analyses relates to the diffusion system in the Bay in that our contractor, who prepared the EIS for us, says the diffusion system will give us about 1 to 4 dilution. South Alabama Regional Planning Commission expects a 1 to 20. Our contractor tells us, 1 to 9 would be the maximum for redesign of the diffuser.

MARSHES OF THE MOBILE BAY ESTUARY: STATUS AND EVALUATION

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Dauphin Island Alabama 36528

ABSTRACT

Approximately 5,651 ha (13,955 acres) of marshland are currently found in the Mobile Bay Estuary. Of these, 1,333 ha (3,291 acres) are salt and brackish environments and 4,319 ha (10,664 acres) are freshwater. Distribution in the Estuary is described. Pressures resulting in destruction or alteration of marshes within the Estuary include dredging and consequent spoil disposal, erosion, marsh filling, petroleum pollution and industrial pollution.

The data base for evaluating the marsh resources of the Estuary is poor and specific needs are enumerated. Management recommendations are made based upon local information and that available from other areas because of the scarcity of local data.

INTRODUCTION

The roles played by marsh ecosystems are many and varied, whether tidal or inland fresh marshes. Of primary importance is their role as primary producers for the detritus-based food chain. High levels of productivity, low grazing pressure, enrichment by microbes of detrital material and tidal transport to estuaries and coastal waters may combine to provide a rich and abundant food source (Cruz 1973, Valiela et al. 1978). Marshes provide habitat for young and juveniles, especially of commercially important species, and breeding and spawning areas for others. A positive correlation between commercial yields of penaeid shrimp per unit area of intertidal marsh and latitude has been demonstrated for 27 locations worldwide (Turner 1977). Additionally, marshes play important roles in water quality and quantity, removing nutrients and toxic materials from the water and regulating flow (Banus et al. 1974, Pomeroy et al. 1966). These densely vegetated areas are also quite successful at sediment binding and erosion control.

To assure continued performance of these and other roles, marshes must be protected from destruction or deterioration by wise management policies based upon an adequate, sound data base. The effects of each potential activity on marsh tracts must be understood. In the event that natural conditions must be allowed to deteriorate, plans must exist to ameliorate the situation or restore previous values to the system.

CURRENT STATUS OF THE RESOURCE

Description and Distribution

The distribution, aerial coverage and species composition of marshlands is dependent on several environmental variables, the more important of which are tidal range, shoreline elevation, topography and salinity of flooding water. Within the Mobile Bay and Delta, only the area of the Mobile Delta provides conditions suitable for extensive marsh development. Along the western shore of the Bay, marshes are limited to the low elevation mouths and margins of bay tributaries. In other shoreline areas elevation is too great, the slope is too great, or both.

The influence of freshwater discharges into the Mobile Bay Estuary is significant (Schroeder 1979) and is demonstrated in the marsh types present. True salt marshes, dominated by *Spartina alterniflora* and *Juncus roemerianus* occur only in lower Mobile Bay nearest Main Pass.

The marshes of Little Dauphin Island, the east end of Dauphin Island, Fort Morgan Peninsula and Oyster Bay have broad borders of *S. alterniflora* with interior, higher elevations covered by dense stands of *J. roemerianus*. However, the remainder of the marsh areas of the Bay and its minor tributaries are brackish in nature, composed of one of the typical plant communities in Table 1, depending upon the relative contributions of fresh and saline waters.

Table 1. Dominant vegetation of the marsh types represented in Mobile Bay and the Mobile Delta. Brackish I is more saline than Brackish Marsh II.

Marsh Type	Dominant Vegetation	
	Scientific Name	Common Name
Salt Marsh	*Spartina alterniflora*	Saltmarsh Cordgrass
	Juncus roemerianus	Black Needlerush
	Distichlis spicata	Salt grass
	Spartina patens	Saltmeadow Cordgrass
Brackish Marsh I	*Juncus roemerianus*	
	Spartina cynosuroides	
	Spartina patens	
Brackish Marsh II	*Juncus roemerianus*	
	Spartina patens	
	Cladium jamaicense	Sawgrass
	Phragmites australis	Roseau Cane
	Sagittaria falcata	Duck Potato
Fresh Marshes	*Alternanthera philoxeroides*	Alligator grass
	Sagittaria falcatta	
	Zizania aquatica	Wild Rice
	Zizaniopsis miliacea	Cutgrass
	Scirpus validus	Giant Bullwhip
	Typha spp.	Cattails
	Phragmites australis	

Approximately 5,651 ha (13,955 acres) of the Mobile Bay Estuary support marsh systems, 1,333 ha (3,291 acres) within salt/brackish environments and 4,319 ha (10,664 acres) in freshwater (Table 2).

On the eastern bay shore, from the mouth of Bon Secour River to St. Andrews Bay, large salt marsh expanses comprise the largest portion of this type within the estuary. Oyster Bay and the Bon Secour River mouth (Number 8, Figure 1) are bordered by *S. alterniflora/Juncus* marshes, *Spartina* forming a broad zone within the intertidal zone (Sapp et al. 1976). Of the two areas Oyster Bay is more protected from wave action and is also less accessible to man. Shallow depths combined with oyster beds make even boat access difficult. Consequently, the marsh is stable and relatively undisturbed. At the mouth of the Bon Secour River, erosion is a problem on the bay side of the marsh and illegal canal dredging within the marsh has affected the system. Though efforts were made to restore the marsh by filling the canals, it has not fully recovered, particularly from changes in elevation caused by spoil piles.

Approximately 380 ha (939 acres) of salt marsh are located along the north side of the Fort Morgan Peninsula (Stout 1977). The largest expanses are in the area from St. Andrews Bay east to Three Rivers (Number 9, Figure 1). Marshes occur along the shores and between ancient sand spits extending northwestward toward Mobile Bay. All exhibit broad borders and large stands of *S. alterniflora* with higher areas of *J. roemerianus*. Between the sand spits a sequence of shallow tidal creeks with *S. alterniflora* borders, *J. roemerianus* high marsh, pinescrub and ridge sloping off to the next high marsh-to-creek arrangement occurs repeatedly. This entire shoreline is subject to heavy erosion with subsequent deposition of eroded materials in protected areas such as St. Andrews Bay (Hardin et al. 1976). Consequently, the area is naturally undergoing constant changes in the shoreline and accompanying plant communities. Off-road vehicles regularly travel the tops of the ridges, but the marshes show no evidence of impact by man.

Little Dauphin Island, on the western shore (Number 6, Figure 1), is almost entirely marshland consisting of a dendritic pattern of tidal creeks with *S. alterniflora* meadows adjacent to them and higher areas of *J. roemerianus* and *Spartina patens*. Frequent fires result from careless campers and cause the greatests impact upon the marsh flora and fauna. The construction of the Dauphin Island bridge and causeway along the northwestern edge has practically eliminated tidal recharge into the marsh from Mississippi Sound and likely has caused gradual changes to occur in the marsh.

Brackish I Type marshes (Table 1) are found in Weeks Bay, along southwest Mobile Bay, the mouth of East Fowl River and the bayshore portions of the Deer River Complex (Numbers 7, 5, 4 and 3, respectively, Figure 1). *Spartina cynosuroides* is a good indicator species along the margins of this marsh type. Little marsh surface is regularly flooded and consequently *S. alterniflora* is sparse or absent.

Preceding northward up the Bay and into each of the rivers, less influence of tidal saline water is evident. A progression of marsh types from Brackish I to intermediate Brackish II to Freshwater communities is observed. Transitional conditions occur so there is a continuum and no distinct break between the community types. The East Fowl River system best represents this continuum.

Table 2. Estimates of marsh area by type and geographic area for Mobile Bay and the Mobile Delta[a].

Geographic Area	Marsh Area Salt/Brackish[b]	Fresh[c]	Total
Mobile Bay	1,333 (3,291)[d]	86 (214)	1,419 (3,505)
1 Dog River		75 (186)	
2 Northwest Mobile Bay, Dog River to Deer River	8 (20)		
3 Deer River Complex	87 (215)		
4 East Fowl River	145 (358)		
5 Southwest Mobile Bay, East Fowl River to Cedar Point	122 (300)		
6 East Dauphin Island/Little Dauphin Island	74 (182)	11 (28)	
7 Weeks Bay	77 (191)		
8 Oyster Bay/Bon Secour River	440 (1,086)		
9 Fort Morgan Peninsula	380 (939)		
Mobile Delta (Hwy. 90 North to Mobile & Baldwin County Lines)		4,232 (10,450)	4,232 (10,450)
	1,333 (3,291)	4,318 (10,664)	5,651 (13,955)

[a] Geographic areas are designated in Figure 1.

[b] From Stout, 1977

[c] From Vittor & Stout, 1975

[d] First figure is hectares, figure in parentheses in equivalent acres

With increasing distance from the mouth and increasing influence of freshwater run-off, *S. alterniflora* is absent and *S. cynosuroides* appears to replace it. *Juncus* continues as the dominant species with a significant contribution to the community being made by *Sagittaria falcata*. In the marshes connecting East and West Fowl Rivers, *S. alterniflora* and *S. cynosuroides* are absent and *Juncus* is co-dominant with *Cladium jamaicense* and *S. falcata*. Portions of this stretch of river are bordered by freshwater swamps and marshes are absent. *Juncus roemerianus* disappears entirely from upper East Fowl River and fresh marshes, comprised of *Sagittaria falcata, Cladium jamaicense, Typha* spp. *Zizania aquatica* and other fresh water species, border the undeveloped river banks (Sapp et al. 1976). Similar continua may be observed in the Deer Rivers and Weeks Bay (Fish and Magnolia rivers).

Private access canals, boat slips and other man-made alterations occur all along the river's marsh fringe. Additional distrubance is found near and at the mouth of East Fowl River. Two tracts have been utilized for spoil disposal during canal maintenance dredging. Marsh vegetation has been destroyed and water flow across the marshes altered by diking. Dog River (Number 1, Figure 1) is the most highly developed of the rivers with residential areas lining its shores. The few marsh areas remaining are fresh in nature.

The Mobile Delta contains over 4,232 ha (10,450 acres) of freshwater marshes, primarily in its lower one-quarter. It is considered one of the finest natural marshes in the country (Goodwin and Niering 1971). The marshes are typically diverse in species with no one species dominating over large expanses. The most abundant marsh plant species are *Alternanthera philoxeroides, Phragmites australis, Typha* spp., *Zizaniopsis miliacea, Scirpus validus, Sagittaria falcata* and *Cladium jamaicense* (Lueth 1963).

Health and Productivity

No investigation has been undertaken to evaluate the current well-being or health of the estuarine marshes of Mobile Bay and only little has

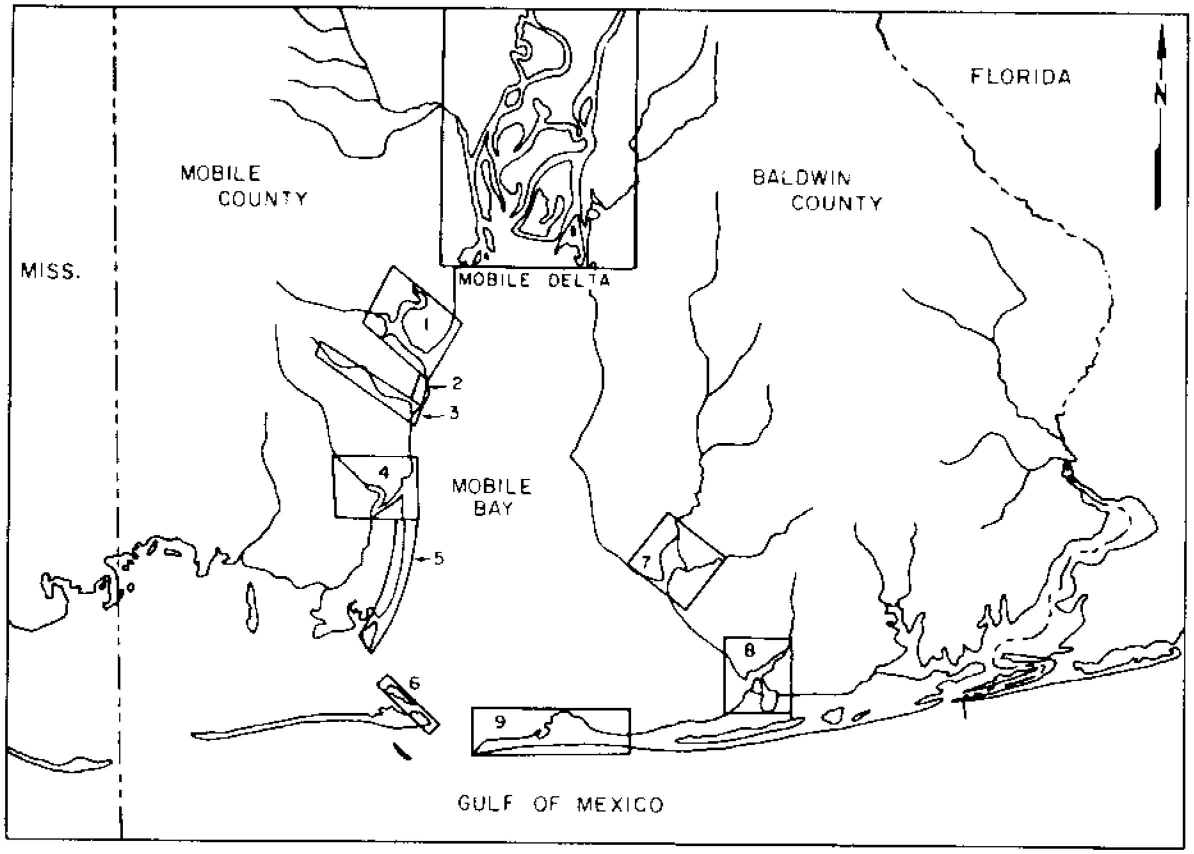

Figure 1. Marsh Units of the Mobile Estuary. Numbers Indicate Geographic Areas of Table 2.

been done to determine levels of productivity. Existing information on Alabama marsh productivity, limited to completed investigations with only salt marsh species is summarized in Table 3. When compared to productivity levels in other geographic areas, Alabama *S. alterniflora* and *Juncus roemerianus* marshes produce similar or greater quantities of biomass (Stout 1978). No data are available on other salt marsh species or on any of the fresh species.

Productivity is only one indication of relative health or vigor of a marsh system. One can make visual observations of the apparent condition of any given area. However, quantitative criteria have greater validity and comparability, but are lacking for Alabama marshes.

PRESSURES AND IMPACTS

Dredging

Historically, the most significant human impact on marshes in Alabama has been the result of dredging activities, either directly or indirectly through spoil disposal practices. It is impossible to estimate the impact from small private projects because of the lack of complete documentation through permitting programs and the absence of information on historical natural conditions. The results of larger projects, primarily transportation and construction canal dredging, are presented in Table 4.

Spoil disposal has a negative impact when marshes are destroyed, as is the case for approximately 2,427 ha (6,002 acres). However, it may also result in the creation of new marsh habitats which may or may not be comparable to similar natural marshes. Approximately 888 ha (2,194 acres) within the Estuary have been altered by spoil disposal in such manner as to create new marsh habitat. Assuming that man-made marsh is equivalent to natural marshland (not necessarily true), the Estuary has then lost a minimum of 1,539 ha (3,803 acres) of marshes to spoil disposal.

Table 3. Summary of net annual primary productivity (NPP) levels of marsh plant species in Alabama. Levels represent mean monthly dry weight biomass.

Species	Reference	NPP g/m^2
Spartina alterniflora		
	Stout 1977[a]	648
	Stout 1978[b]	1,030
	Stout, de la Cruz, and Hackney 1978	562
Juncus roemerianus		
	Stout 1977	1,138
	Stout 1978	1,449
	Stout, de la Cruz, and Hackney 1978	1,387
Distichlis spicata		
	Stout 1977	658
	Stout, de la Cruz, and Hackney 1978	537

[a]Mean of samples taken throughout species range in state.

[b]Mean of samples taken in one marsh representing best conditions for species within state.

Table 4. Impact of dredging activities on Mobile Bay estuarine marshes.

	Location	Hectares	Acres
I	Loss to Spoil Deposition		
	Bon Secour River	38	95
	Blakeley Island	1,214	3,000
	East Fowl River	69	172
	Little Dauphin Island	4	10
	Dog River	33	81
	I-10 Highway	73	180
	I-10 Twin Tunnels	5	13
	Alcoa–Blakeley Island	121	300
	Scott Paper Company–3 Mile Creek	61	150
	Private Projects	809	1,000
	Total	2,427	6,002
II	Loss to Canal Dredging		
	I-10	14	34
	I-65	3	8
	Theodore Industrial	20	50
	Private Projects	20	46
	Total	57	138
III	Creation by Spoil Deposition		
	Blakeley Island	364	900
	Polecat Bay	364	900
	Pinto Island	157	387
	Theodore Spoil Island	3	7
	Total	888	2,194

Total Loss 2,484 ha -Total Creation 888 ha =
Net Loss 1,596 ha = 22% Total Marshlands

Dredging activity itself will result in marsh destruction whenever it traverses a marsh system. The degree of destruction and alteration caused by small private canals is difficult to determine. Three large projects which are in various stages of construction will, however, have significant impact. The work canal for the construction of Interstate Highway 10 across the lower edge of the Delta resulted in the loss of 14 ha (34 acres) of fresh marsh. As the canal was relatively shallow (2.4 meters), and siltation and filling of the upper portion of Mobile Bay is continuous process, this loss is probably temporary and the area will be naturally restored in time. Construction of Interstate Highway 65, further north in the Delta, will destroy 3 ha (8 acres) of delta marshland, primarily crossing riverine swamps. Though this area may recover also, it probably will be at a much slower rate than the I-10 canal. Permanent destruction of approximately 20 ha (50 acres) of brackish marsh will result from the construction and widening of the inland portion of the Theodore Industrial Canal.

Total loss from these three projects is 37 ha (92 acres). Adding 50% of that for private projects (20 ha), the total loss directly attributable to dredging is 57 ha (138 acres). Net loss from dredging to the Estuary is 1,596 ha (3,946 acres), 22% of natural marshes (Table 4).

Shoreline Erosion/Accretion

The Mobile Delta is a prograding delta filling over 64 km (40 miles) of the original estuary over some 3,000 years. The Delta shoreline has shown a net erosional trend between 1917 and 1967 for a loss of 8.92 ha (22.04 acres). The western bank of Blakeley River, the eastern bank of Apalachee River and both banks of Tensaw and Spanish rivers are principal erosional areas. Accretion has occurred along remaining banks and within interdistributary bays. The relatively small net accretion may indicate that the Delta's progradation has decelerated. This may be due to reduced sediment loads, increased water velocities or both (Hardin et al. 1976).

Severe erosion is altering bay shorelines significantly between the Brookley Aerospace Complex and Cedar Point on the western shore. Trends are from less than 1.5 m (5 feet) to as much as 2.6 m (8.6 feet) per year at Cedar Point. The only net accretion within this area is from spoil deposition north of the planned Theodore Channel at Deer River (Hardin et al. 1976). Total marsh loss is not known.

Along the southern shore of Bon Secour Bay, from Three Rivers to the eastern seawall of Fort Morgan, much erosion has occurred. Loss of from 61 to 244 m (200-800 feet) has been measured between 1917, and 1974 (Hardin et al. 1976). Land lost is primarily marsh and broad expanses of eroded marsh peat can be observed in the water's edge. Bathymetric data may indicate that some eroded material is contributing to shoaling in protected areas such as St. Andrews Bay and may result in new marsh habitat.

No net figures are available on impact of erosion and accretion on bay marshes. Obviously the negative impact is significant.

Filling

A tradition of filling low cost marsh real estate for residential or industrial development has had an unmeasured impact upon Mobile Bay marshes. Residential development is intense along Dog River and portions of Fowl, Fish, Magnolia, and Bon Secour Rivers, Bon Secour Bay and both shorelines of Mobile Bay. Much of the residential development is protected by bulkheading to retain the fill material against erosional forces.

Extensive areas of shoreline have been filled in the last 75 years in the area of the Brookley Industrial Complex (83.4 ha; 206 acres), McDuffie Island (93.1 ha; 230 acres), Battleship Park (73.2 ha; 181 acres), and Mobile Harbor (668.75 ha; 1,650.7 acres) (Hardin et al. 1976). Many of these areas were previously bay bottom but a good portion was previously marsh. Information is inadequate to determine the specific impact on wetlands alone.

Petroleum and Petroleum Products

The presence of the Gulf Intracoastal Waterway and the Port of Mobile within the Mobile Bay Estuary provides for the transport of petroleum products by tanker and barge into and through the Estuary. The Port and various industrial facilities also conduct transfers of petroleum and petroleum products. Accidents, of even minor proportions, introduce oil to the Estuary and create stress on marsh communities. There is evidence that marshes can recover from a single large spill or repeated spills if they are separated enough in time. The use of emulsifiers in clean-up operations aids in penetration of oil and increases the toxic results on the marsh (Cowell et al. 1970). Marsh vegetation may show reduction in biomass production, stem heights and stem densities. Impact on annuals is greater than on perennial species and may result in complete loss of some species (Hampson and Moul 1978). Deterioration of marsh vegetation will reduce its value to the estuarine food chain and may diminish its erosion control function (St. Amant 1972).

With completion of the Tennessee-Tombigbee Waterway and increased exploitation of coastal petroleum reserves the potential for accidental discharge and accumulation in marshes increases. The possibility of a larger petroleum refining industry in the area also increases the likelihood of oiling of marsh biota. The health of marshes subjected to chronic oiling must be monitored and continually evaluated.

DATA BASE AND GAPS

Information is scanty on all aspects of marshes in Alabama. The greatest needs in information are as follows:

1. Inventory of marsh resources of the Mobile Delta. Last published original information was by Leuth (1963) who reported data from a study completed in 1950.

2. Inventory of fresh marshes of the Mobile Bay Estuary exclusive of the Delta. Partial mapping is provided in Sapp et al. (1976), but many areas were not mapped as the major thrust was salt and brackish marshes.

3. Health indices for dominant marsh species. Local data on biomass production, growth parameters and population dynamics of only *Spartina alterniflora, Juncus roemerianus* and *Distichlis spicata* are available (Stout 1978; Stout et al. 1978). Information on additional species would provide a baseline to evaluate the relative health or vigor of specific marsh tracts and the impact of perturbations.

4. Faunal dynamics of marsh types. The only information available for Alabama marshes is Ivester (1978) and is limited to benthic meiofauna and macrofauna of salt marshes. All of the biota of an ecosystem are interrelated and must be considered when judging "health," "impact" and other evaluations.

5. Utilization of Alabama marshes by estuarine species, especially commercial species. As reported in the introduction, this is considered an important role played by estuarine marshes. However, quantitative documentation is needed to assure that marshes are maintained to fulfill this role.

6. Evaluation of marsh size-to-edge ratio value in Alabama. Gucinski (1978) has shown for some marshes in Maryland that smaller marsh parcels less than 2 ha (5 acres) may be of more value than larger marshes because of greater edge (exchange interface) to area ratio. This is a critical question for any geographic area as there is often less protection or support for preservation of very small marsh tracts.

7. Inter-relationships of freshwater wetlands and estuarine wetlands. Alteration or destruction of inland freshwater marshes may have deleterious impacts on the optimum functioning of estuarine marsh ecosystems. Freshwater recharge, nutrient and sediment input and toxic materials sources to the estuarine ecosystem from freshwater wetlands needs to be determined. The quantitative nature of these relationships and dependencies of the estuary on inland areas needs to be examined.

8. Utilization of Alabama marshes by waterfowl, wading birds and fur bearing mammals. The critical role of wetlands in support of birdlife, both permanent residents and migratory, is well documented, but needs to be elucidated for coastal Alabama. Support of game birds by the Mobile Delta alone is significant and should be monitored. Though the fur industry is small in coastal Alabama this aspect of wetland value is also important.

MANAGEMENT RECOMMENDATIONS

The following are recommended to reduce, if not curtail, destruction and deterioration of vital estuarine marshes and attempt to ameliorate conditions from such activities.

1. Activities which cause direct, irreversible loss of estuarine marshes should be prohibited. Exception may be made for activities of critical local, regional or national need, but not for private gain.

2. Small size of marshes should not act to the disadvantage of marsh preservation. Cumulative loss of area and edge through repeated destruction or alteration of small tracts may have greater impact than equal areas lost in single large tracts.

3. When destructive or detrimental activities are necessary, best technology available should be required to minimize impacts of the activity throughout the project life. Cost effectiveness should take into consideration the unquantified natural values of the tract.

4. When destructive or detrimental activities are unavoidable, attempts to ameliorate effects should be required in the project design and financial arrangements. Amelioration may include, but not be limited to the following, where applicable.

   a. Revegetation of portions of site.

   b. Restoration following project site abandonment.

   c. Creation of similar habitat through use of spoil disposal sites, new canals etc.

   d. Increase estuarine edge or interface through canal design.

5. Conduct a program of restoration of marsh tracts altered, but not destroyed by past activities.

6. Set aside specific marsh tracts to be preserved from any detrimental activity, regardless of need. Tracts may be designated for the following and other reasons.

   a. Uniqueness either locally, regionally or nationally.

   b. Particularly useful for educational purposes.

   c. Exceptional recreational values.

   d. Natural buffer between development and estuary.

   e. Specific and limited habitat of designated Endangered Species (state or federal).

f. Value in research.

g. Unusual contribution to maintaining water quality due to location.

7. Design multiple-use projects for marsh tracts that may enhance their economic value while still preserving their natural roles (i.e. mariculture, water treatment, restoration of endangered species populations, etc.)

8. Design study plans to:

   a. Determine the status of the marsh resources where not known.

   b. Evaluate utilization by itinerant species.

   c. Examine edge-effect and critical edge-to-area ratios for Alabama.

   d. Evaluate the relative roles played by inland delta and river marshes and estuarine coastal marshes.

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SUBMERGED GRASSBED COMMUNITIES IN MOBILE BAY, ALABAMA

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ABSTRACT

Ten species of submerged aquatic angiosperms and at least one species of macrophytic algae occur in the shallow shoreline areas of Mobile Bay. Documentation of historic distribution of submerged aquatic plants within Mobile Bay remained sparse until the late 1950's when the first comprehensive survey was initiated. Since that time other surveys have been conducted. Based on the results of these surveys and personal observations, the conclusion was reached that submerged grassbed communities have not only declined but changed in species density, diversity and distribution.

This paper represents an effort to collect and organize available information relating to submerged aquatic plants in Mobile Bay and to determine what environmental factors may be causing their recently noted decline. In order to determine the probable cause or causes for the changing patterns of grassbed communities, the various factors that are known to affect them have been discussed.

HISTORICAL CHANGES AND PRESENT CONDITION OF SUBMERGED GRASSBED COMMUNITIES IN MOBILE BAY

Documentation of the historic distribution and abundance of submerged aquatic vegetation (SAV) within the Mobile Estuary remained sparse until the late 1950's. Baldwin (1957) estimated there were about 2,024 hectares (5,000 acres) of SAV in Mobile Bay and 3,036 hectares (7,500 acres) in the lower Delta. Lueth (1963) conducted a study of the flora of the Mobile Delta and found a variety of SAV. *Vallisneria americana* was found to be an abundant species with small to large patches occurring in every bay of the Delta and extensive beds extending southward in Mobile Bay to Fairhope.

Extensive patches of SAV once grew along the eastern shore of Mobile Bay between Daphne and Point Clear. From 1940 through the early 1960's it was not uncommon to see cut leaves of *Vallisneria americana* floating on the surface after a motorboat had run through a submerged grassbed (verified by personal communication with residents of the eastern shore and previous personal observation). These submerged grassbeds were much reduced in the late 1960's and almost completely gone in the 1970's. In a study of the seasonal fluctuations of macroscopic fauna in the submerged grassbeds in Mobile Bay, Borom (1975) found that SAV had completely disappeared from certain areas in the Bay where it was formerly abundant. It was concluded that SAV provided protective habitats for a large number of aquatic organisms and is probably essential for certain species. Areas where growths of SAV were the thickest produced a greater abundance and diversity of animal species than areas where SAV was sparsely scattered. The fewest specimens were encountered where SAV was absent. The productivity of those portions of the Bay where SAV has disappeared has undoubtedly been adversely affected by this loss of available habitat.

Submerged aquatic plants provide the principal food source for waterfowl and some fish. They provide direct or indirect food and shelter for many of the small host organisms that are eaten by fish and other predators. The spawning activities of certain organisms require SAV. They purify the water by removing various noxious substances and returning oxygen. They shade the underlying waters and sediments from solar heating, and they provide an important source of detritus. The ability to assimilate inorganic substances into organic compounds usable by other organisms enhances the importance of these plants as vital links in food chains. Functioning as prime areas for hiding and breeding, SAV provides surfaces for the attachment of eggs. Also, an abundance of animal life (e.g. crustaceans, insects, and mollusks) provide fish with excellent feeding grounds.

Submerged aquatic vegetation helps stabilize sediments and reduces shoreline erosion. Bays with a healthy benthic flora have been shown to have relatively stable metabolism with less fluctuation in comparison to plankton dominated bays. Submerged plants function as a trap for dissolved inorganic phosphorus and nitrogen. Although not commonly viewed as indicators of biological conditions, SAV is considered to be potentially useful as an indicator of pollution trends (Stevenson and Confer 1978). In view of the functions listed above, submerged grassbed communities play an important role in the Mobile Estuary.

Knowledge of SAV in Alabama estuarine waters is limited and more work is needed to determine the extent of the beds and their role in the estuary. Over the years, there have been indications of changes in species diversity and abundance; but the present populations are dominated by ten angiosperms. Species of macrophytic algae that are known as muskgrasses and belong to the genus *Nitella* are found in the clear waters of the upper Bay and lower Delta.

These species of SAV inhabit the shallow shoreline areas of the Bay and are primarily limited to depths of two meters or less. Submerged aquatic plants known to occur in Mobile Bay are presented in Table 1.

Table 1. Submerged aquatic plants known to occur in Mobile Bay.[a]

ANGIOSPERMS	
Vallisneria americana	tape grass
Potamogeton perfoliatus	redhead grass
Ceratophyllum demersum	coontail
Heteranthera dubia	water stargrass
Zannichellia palustris	horned pondweed
Najas quadalupensis	bushy pondweed
Myriophyllum spicatum	Eurasian watermilfoil
Egeria sp.	elodea
Ruppia maritima	widgeon grass
Halodule beaudettei	shoal grass
ALGAE	
Nitella spp.	muskgrass

[a]Leuth 1963 and Borom 1975.

The most convenient classification system for these species is according to salinity tolerance. Other factors that affect distribution include morphology, preferred bottom substrate, temperature tolerances, and susceptibility to chemical pollutants. All species except *Ruppia maritima* and *Halodule beaudettei* are fresh to slightly brackish water species found in the upper reaches of Mobile Bay and the lower Delta. These species form rather extensive submerged grassbed communities. Although the submerged aquatic plants are most abundant in the extreme upper portion of Mobile Bay, SAV consisting of *Vallisneria americana* does extend southward along the eastern shore just south of Point Clear but only as small isolated patches. As previously mentioned, these submerged grassbed communities have become greatly reduced over the last 30 years. Local residents along the western shore (personal communication) stated that *V. americana* once occurred as extensive patches to a point south of Fowl River. Today they are absent except for small patches that exist around the mouths of tidal branches, creeks, and rivers that empty into the Bay.

Ruppia maritima and *Halodule beaudettei* are capable of tolerating higher salinities and occur in the lower portions of the Bay in scattered shallow areas. These species form grassbed communities on the north side of Dauphin Island. Local residents (personal communications) stated that SAV was once more abundant around Dauphin Island and the lower portion of the Bay than it is today. There is a need to map and identify the SAV in Mobile Bay, especially in the lower portion since little data are available.

Although there is evidence indicating a decline of SAV in some portions of Mobile Bay, just the opposite is true of *Myriophyllum spicatum*. There has been a spectacular invasion of this species in the lower Delta and upper Bay since 1975. In Chocalata Bay for example, milfoil is so thick that it restricts navigation. Milfoil reproduces most effectively by way of vegetative reproduction through fragmentation, rhizomes, and axillary buds (Patten 1956). The species has become a nuisance and contributes to a more rapid build up of the bottom through deposition of organic material and facilitation of silting. Milfoil beds appear to provide conditions suitable for mosquitoes (*Anopheles quadrimacularus* and possible certain *Culex* spp.). Undesirable odors are created by windrows of decomposing vegetation deposited by wind and tide on shoreline (Stevenson and Confer 1978).

Annual fluctuations in SAV density is natural in Mobile Bay and presents a continually changing picture. Some species, such as *Myriophyllum* *spicatum*, seem to be more subject to changes in their range and density than other species. In most areas, milfoil has two growth-surge periods during the growing season. To keep abreast of such changes, two or three surveys of vegetation beds should be made annually (Rawls 1971a).

Eurasian watermilfoil has a history of spreading rapidly when it is introduced into new areas with suitable habitat. It may decline just as rapidly as it spreads and eventually reach a new equilibrium with native species of SAV (Stevenson and Confer 1978). In theory, an area is most susceptible to a dramatic population explosion when the natural ecosystems are disturbed, particularly those disturbed by man.

The extravagant growth of milfoil has caused some concern among waterfowl enthusiasts as to milfoil's acceptability as a waterfowl food source. Based on information available at the time, Martin and Uhler (1939) determined that milfoil was a less thas satisfactory food for ducks. Florschutz (1969) indicated that the availability of higher quality waterfowl food was reduced by a milfoil invasion. In the 1960's, waterfowl populations in the Chesapeake Bay showed marked declines. During this time, milfoil displaced more than a dozen native rooted aquatic species. During early infestation of milfoil (1958-1961), January populations of waterfowl on the flats averaged 4,900 birds. During the milfoil peak, January waterfowl counts on the flats averaged only 390 birds. By 1965, when *Vallisneria americana* returned to about 50 percent its level sustained prior to milfoil invasion, an average of 4,860 birds wintered on the flats (Bayley et al. 1968). There seems to have been a reduced wintering population of waterfowl in Mobile Bay in recent years.

Apparently, a decrease of a traditionally desired food source such as SAV results in several options for waterfowl. They can either compete for the diminishing food source or seek an alternative food source. Either choice could result in population reductions and locale changes. Changes in species of SAV must also have an effect upon aquatic faunal associations.

Submerged aquatic vegetation in Mobile Bay has changed in species density, diversity, and distribution over the past 30 years. The basic questions which require consideration are whether Bay vegetation is (1) experiencing a normal population fluctuation, (2) responding to man oriented impacts such as pollution or (3) both. A normal cycle situation for SAV requires historical documentation of similar events in the past, but no data are available to support this hypothesis for Mobile Bay.

The variety and degree of human impacts, including a wide range of suspected or known pollutants, appear to be of greater relevance to recent declines in SAV than a naturally occurring cyclic event. If the Bay is experiencing a normal population fluctuation, such a hypothesis would still require consideration of human impacts on such a cycle.

Historical documentation of sufficient intensity and coverage necessary to support a cyclic phenomenon hypothesis is lacking. It is likely that SAV declines have resulted from no single factor but from a multitude of factors or synergisms.

ASSESSMENT OF ENVIRONMENTAL FACTORS PRESENTLY AFFECTING SUBMERGED AQUATIC VEGETATION IN MOBILE BAY

There are various environmental and human related factors that affect the establishment, growth, and reproduction of submerged aquatic vegetation (SAV) in Mobile Bay. Included among these are agrochemicals, salinity, turbidity, light, bottom substrate, nutrients, fauna, epiphytes, pH, temperature, heavy metals, petroleum products, and water movement. Although there have been gradual changes in many of the environmental factors over the years, others, especially the human related factors, have changed more rapidly.

The dynamic nature of an estuary results in gradual changes in such parameters as salinity, bottom substrate, and fauna. However, the changes that have resulted from increasing human activities have been much more rapid.

In order to assess the causes for the declines of certain species of SAV and the increases of others, the various factors that have changed within the Bay area must be analyzed. This section discusses these factors and attempts to consider selectively each one in order to determine the probable causes for change.

Agrochemicals

An increasing human population in the Bay area has directly affected the land-use patterns. These patterns in south Alabama have changed drastically since the turn of the century. One of the most obvious changes has been a decline in the agricultural use of land. To compensate for the decline in land available for agricultural use, more efficient methods have been developed. These changes have brought about increased usage of fertilizers and herbicides.

The use of chemical fertilizers is now standard practice for increasing crop yields. However, when highly soluble fertilizer is used, 10 to 25 percent is leached away into surface runoff (Wagner, 1974). Increased levels of organic material in the water column, plus nitrogen and phosphorus, can give rise to eutrophic conditions where an aquatic ecosystem is enriched beyond its assimilation and flushing capabilities. Under such enriched conditions, phytoplanktonic algae tends to thrive causing decreased light penetration. This shading effect can be sufficient to decrease SAV. The increased use of fertilizers around Mobile Bay must be a negative factor as far as SAV is concerned.

The presence of herbicides in agricultural runoff and the impact of herbicides to aquatic fauna and flora have recently become an issue for environmental concern, especially in estuaries. Increases in herbicide usage have been implicated in the recent SAV declines of the 1970's (Stevenson and Confer 1978). The extent to which increases in herbicide runoff have affected the SAV in Mobile Bay has yet to be determined.

Chlorine

The ecological impact of chlorine and its byproducts on the marine environment is extremely complex. It was verified several years ago that organochlorines such as DDT and DDE, dieldrin, and PCB's which enter seawaters from land runoff, sewage outfalls, and the atmosphere were extremely harmful to marine flora and fauna (Goldberg et al. 1971).

Experimental data show that chlorine acts differently in marine waters than in fresh waters. The fate of chlorine in estuarine ecosystems is largely unknown and laboratory chemistry techniques for chlorine are not yet dependable (Davis et al. 1977). In Mobile Bay, chlorine and chlorine by-products enter the estuary from sewage treatment plants, water treatment, runoff from agricultural pesticide application, and industrial effluents. There is currently no direct evidence relating the decline in SAV in Mobile Bay to levels of chlorination. Any impact to SAV from chlorine can be only speculative at this point.

Municipal and industrial use of chlorine has escalated. This has resulted in increased usage of Bay waters as a repository for chlorinated effluent. If chlorine is considered as a negative factor in relation to SAV declines in the Bay, it is probable that it is at least of local importance in areas receiving excessive municipal and industrial effluents.

Turbidity

Turbidity may result from suspended organic and inorganic particulates, plankton, and coloring or staining from dissolved organic matter. SAV can be affected by turbidity in different ways. Particulates can physically block the penetration of light through the water column. Stained waters differently absorb various wavelengths for photosynthesis. The dissolved and particulate matter entering the water column can serve as a means of transportation for the introduction of soluble pollutants into an estuary. Turbidity also varies with the seasons. Winter is usually the period of lowest turbidity. Spring rains increase suspended solids and warming temperatures in summer promote plankton blooms. In addition, wind action throughout the year can resuspend bottom sediments causing short periods of high turbidity.

Sources of suspended particulates in Mobile Bay include freshwater runoff, shoreline erosion, hydraulic dredging, industrial effluent, and biological production.

The deposition of silt and clay particles can aid in building up suitable bottom substrates in barren areas or add nutrients to existing substrate (Odum and Wilson 1962). Therefore, the impact of suspended solids on SAV is not wholly negative. SAV, in turn, aids in the precipitation of suspended solids.

Turbidity has been implicated as a prime cause for the decline of submerged aqautic vegetation (Martin and Uhler 1939). However, Mobile Bay has always been turbid from natural causes, due to the dynamic nature of a wind-driven estuary. Many local residents knowledgeable about the Bay feel that turbidity has increased dramatically over the last 30 years (personal communication). Logically, this would seem to be valid. Increased boat traffic, hydraulic dredging, and shoreline construction would appear to have influenced turbidity levels.

Investigations into the effects of turbidity on SAV include field determinations and laboratory experiments that showed that turbidity was the chief factor responsible for SAV destruction along the Atlantic Coast (Bourn 1932). Turbidity was determined to be detrimental due to the lessening of light penetration and silting of plant leaves. Experimental evidence relating directly to the effects of increased turbidity in Mobile Bay on SAV is lacking.

Sediments

The importance of sediments (i.e. particle size and chemical composition) in influencing the distribution of submerged aquatic plants has been recognized for a long time. Sediments play a twofold role in supporting submerged rooted plants. The substrate serves as a medium for anchorage of the plant and as a nutrient reservoir for the mineral nutrition of the plant species.

In addition to providing firmer root support, finer sediments possess a greater surface area than coarse sediments. This greater surface area influences the adsorption of various compounds and allows a high cation exchange capacity. The leaves may represent a major uptake site for some nutrients. Once adsorbed onto sediment particles, nutrients may then be available to rooted aquatic plants. Many pesticides and herbicides also bind readily to fine particles and may reach greater concentrations in sediments composed of these particles (Stevenson and Confer 1978).

SAV is generally absent in areas of high turbulence (Sculthrope 1967). Soils which are potentially the most productive are in actuality the least productive due to turbulence which tends to resuspend fine sediments. SAV may be absent due to an unstable, shifting sediment caused by siltation from natural or man-made causes. However, submerged plant communities tend to persist in spite of shifting sediments by the stabilizing action of roots, stems, and leaves. A change in bottom sediments from soft to hard may also affect vegetation patterns (Cronin 1976).

Stabilized fine sediments such as sand and clay seem to be the best substrate for submerged aquatic plants. Martin and Uhler (1939) found that firm sand would support the growth of *Potamogeton, Vallisneria* and *Ruppia*, but that it was not the optimum substrate.

Sediments appear to be important in the distribution of SAV. The effect of the sediments on Mobile Bay SAV may not be direct, but it may be extremely important in the adsorption and trapping of toxic substances. Reduced light penetration also results from sediment disturbance.

Light

Light transmission is affected by both turbidity and water color. It can be a limiting factor to SAV by determining the depth of the photic zone. Sculthrope (1967) found that SAV can inhabit suitable areas with as little as 1 to 4 percent of the surface light intensity. Light can also have an effect on seed germination. *Potamogeton* spp. tend to require light for proper seed germination, while light tends to be inhibitory to *Najas* spp. seeds (Hutchinson 1975).

It is not improbable that declines of some species of SAV may be related to fluctuations in light intensity reaching the grass beds and its effect on seed germination potential. Further experimental studies into the relationships of light and turbidity would be helpful in evaluating their importance in the declines of SAV in Mobile Bay.

Salinity

Species of SAV tend to be distributed within the Bay according to salinity. Species diversity is greatest at lower salinities and reduced at higher salinities.

Increases in salt content generally result in an overall growth reduction, since the plant is required to spend energy in salt absorption at the expense of growth. A further reduction in growth rate results from the effects of sodium and calcium as they relate to cell wall structure. It has been determined that seed germination of saltwater plants occurs optimally in freshwater because saltwater inhibits water uptake by the seeds (Chapman 1960).

Photosynthesis and respiration in relation to salinity were studied by McGahee and Davis (1971). Eurasian watermilfoil (*Myriophyllum spicatum*) was utilized. It was found that photosynthetic rates were reduced at high salinities. Respiration at all tested salinity concentrations showed no effects. It has been determined that a salinity of 6.7 parts per thousand or higher is toxic to tape grass (*Vallisneria americana*) (Haller et al. 1974).

There has been speculation that rapid salinity changes in the Bay might be a factor in SAV declines. Lowered salinity really reduces the growth of offshore seagrasses such as *Thalassia testidinum, Syringodium filiforme* and *Halodule beaudettei*. However, most species of SAV in Mobile Bay have little or no problem in tolerating decreased salinity changes. In fact, with a reduction in salinity, enhancement of growth and germination often occurs. Therefore, the assertion that the decline of the SAV is due to lowered salinities commonly associated with hurricanes is difficult to substantiate with scientific evidence (Stevenson and Confer 1978).

Temperature

Water serves as a buffer for temperature. The extent to which temperature in an aquatic environment influences the distribution of submerged vegetation is limited because temperature fluctuations are much less than those in an aerial habitat.

As temperature increases, dissolved oxygen content decreases but respiration and oxidation rates double for every 10°C temperature increase. The presence of dissolved oxygen is probably the most important factor in the biology of aquatic systems, and a great variety of physical and biological interactions stem from it (Wagner 1974). Temperature governs numerous interdependent factors such as dissolved oxygen concentration, carbon dioxide concentration, pH, toxicity and biochemical reactions (Hoak 1961).

Seasonal temperature fluctuations have an impact on the growth of SAV in Mobile Bay. SAV dies back to rhizomes during the winter months. It usually begins to grow back in March. Growth is rapid in the spring and summer and reduced during the fall. Submerged aquatic plants may completely die back during January and February. Various species show different tolerance levels to temperature changes (Borom 1975). Although seasonal temperature changes affect the annual growth cycle of submerged plants in Mobile Bay, there is presently no evidence linking the population declines over the past 30 years to dramatic changes in temperatures.

Water Movement

Submerged aquatic plants in Mobile Bay do not normally colonize areas subject to continuous strong currents and tides. Such water movement resuspends fine sediment particles which contribute towards increased turbidity. Excessive water movement tends to scour the bottom to the extent that submerged plants are physically prohibited from colonizing (Stevenson and Confer 1978). Extreme high tides can increase water depth and decrease light penetration. Extreme low tides can cause exposure resulting in desiccation.

Extreme water movement that results from storms or hurricanes often fractures submerged aquatic plants. The resulting detached plant fragments may not be capable of survival. It is unlikely that vegetation losses in Mobile Bay have resulted from storm damage alone. A scan of tide records from the U.S. Weather Bureau Station in Mobile does not show any abnormal tide events over the last 30 years which did not also occur in previous decades. Therefore, abnormal tide events can safely be ruled out as a major factor in the declines of SAV in Mobile Bay.

pH

Plant enzyme activity, seed germination, and a variety of other responses are affected by pH. Drastic fluctuations could cause damage to SAV. Extreme pH fluctuations resulting from industrial effluent input probably can be found in Mobile Bay as a localized condition. No documentation has been found confirming that pH fluctuations have affected SAV in Mobile Bay.

Carbon

One of the most crucial raw materials for photosynthesis in the estuarine environment is carbon. Any limitation in the carbon availability would be reflected in a decline of SAV productivity. Aquatic plants are capable of utilizing dissolved carbon dioxide in the water column through leaf uptake. They are also able to take up bicarbonate ions; and finally, carbon dioxide possibly may be taken up from the sediments by the roots and transported to the leaves. The bicarbonate ion as a carbon source may be a factor in plant declines in areas of lower salinities, but it is probably irrelevant where higher salinities are found (Stevenson and Confer 1978). More research involving this raw material needs to be done to determine the relative importance in assessing SAV declines.

Heavy Metals

Heavy metals occur naturally in marine, brackish, and fresh waters. Generally, the occurrence is in increasing concentrations with decreasing salinity (Bureau of Land Management 1976). There is a lack of data concerning the biological impacts of excessive levels of heavy metals on SAV and the extent of heavy metal pollution in Mobile Bay. Therefore, it is presently impossible to correlate SAV declines with heavy metal inputs.

Bottom sediments in the vicinity of heavy metal input can become a metal sink of sufficient toxicity to be unable to support any life (Davey and Phelps 1975). It is possible that Bay grasses may now be accumulating heavy metals; however, no data are available to support or refute such a hypothesis.

Petrochemicals

Petrochemicals enter the aquatic environment from tankers, refineries, municipal and industrial effluents, pleasure boats, drilling, and urban and river runoff. Increasing oil exploration, imports of petrochemicals, and transportation of petrochemical products in Mobile Bay have become a cause for concern. According to the Alabama Water Improvement Commission (personal communication) at least 14 major oil spills were investigated in the Mobile Bay area in 1978.

The impact of oil contaminated sediments on SAV appears to be largely unknown, and there is little information available concerning possible toxic effects. Extensive laboratory and field analysis would be required before a correlation can be made between a decline of Bay grasses and petrochemical pollution.

Fauna

A number of resident and migratory species feed on or around SAV. The cownose ray (*Rhinoptera bonasus*) feeds on the clam (*Rangia cuneata*) which lives in the substrate at the base of aquatic vegetation. The rays uncover their prey by vigorous digging with their pectoral fins and crush their food with dental plates. This species is known to uproot submerged vegetation in the Chesapeake Bay (Orth 1976). Due to its ability to dig for food in sparsely vegetated areas, the blue crab (*Callinectes sapidus*) may be another agent responsible for the decline of submerged vegetation.

Various species of waterfowl are well known for their food preference for SAV. Annually large flocks feed in Mobile Bay, but there is no indication that waterfowl have been overgrazing in recent years.

Most documented destruction of SAV by fauna is for small areas. It is unlikely that the massive decline in Bay rooted aquatics is attributable to the grazing activities of any animals.

Local Ecological Factors

Several environmental factors have a negative impact upon SAV. Included among these are dredging and boat traffic. Indirect damage can result from changes in depth or increased turbidity. Dredging to deepen channels or to obtain dead-reef oyster shells, as well as any other types of engineering, dislocates considerable quantities of bottom sediments. Filling often accompanies dredging since the spoil must be deposited somewhere. Spoil banks created by dredging in Mobile Bay occur. Ryan (1969) reported that the construction of the Mobile ship channel resulted in modification of the natural circulation within the Bay. This circulation caused above-average rates of sediment accumulation in the southwestern part of the Bay.

A local example of an activity that increases turbidity is the dredging of dead reef shells. This has occurred since 1946. Although the shell dredge does not introduce sediments into the Bay, it does resuspend materials present in the Bay bottom which in most instances have been isolated from the day-to-day ecosystem for a long period of time. The most obvious effect of the discharge from the dredge is a turbid plume of varying length and width . At times in the past when the dredge has operated in close proximity to shore areas, the turbid plume has deposited fine clay and silt particles on beach areas.

The effects of dredging in Mobile Bay have been studied by May (1973). He concluded that the resuspension of sediments by dredging activity does not have serious detrimental effects on the estuarine environment. However, dredging for the purpose of increasing ambient depths completely removes existing vegetation and alters the habitat. Submerged aquatic plants normally colonize the shallower areas along the shoreline and extend into deeper water based on the photic zone. By increasing the depth, SAV would be prohibited from recolonizing due to a decrease in the amount of light reaching the new dredged bottom depth. Dredging results in piece-meal destruction of a localized nature rather than in Bay-wide impacts.

Large construction projects are often responsible for dumping tremendous quantities of sediment into the Bay. An example of such a project in the Bay area is the development in the Spanish Fort area of Baldwin County. Erosion from construction projects in this area has resulted in considerable damage to the biota of D'Olive Creek and D'Olive Bay. The downstream effects of eroded soil from graded areas may prove to be devastating not only to SAV but also to important commercial faunal species.

Dredging operations and construction projects therefore pose a serious threat to the survival of submerged grassbed communities. Those activities alone can destroy or reduce SAV abundance. The abundance of grassbed communities can be decreased either through silting or by a reduction in light intensity below that necessary for photosynthetic maintenance.

It is well known by local fishermen that some of the best fishing in Mobile Bay is located around shallow, submerged grassbeds. Sport fish such as the spotted sea trout (*Cynoscion nebulosus*) red drum (*Sciaenops ocellata*) and sheepshead (*Archosargus probatocephalus*) often feed around submerged vegetation. Shallow, submerged grassbeds provide protection for young brown shrimp (*Penaeus aztecus*) young white shrimp (*P. setiferus*) and young blue crabs (*Callinectes sapidus*). Because of the abundance of marine life, grassbed communities are often visited by man. Protection of SAV therefore makes good economic as well as ecological sense.

In very shallow water, boat propellers uproot and cut up SAV. The extent and permanency of damage depends on the reproductive means of the species involved. Species that normally reproduce only sexually could be virtually wiped out by extensive boat traffic. Species capable of vegetative reproduction have better chances for survival.

Another problem that has resulted in a loss of SAV in certain portions of the Bay is the actual removal by man. Along the eastern shore in certain areas used for swimming, grassbeds have been uprooted and eliminated because certain individuals considered them undesirable. Due to the localized nature this impact could be responsible for SAV losses only in specific areas.

MANAGEMENT RECOMMENDATIONS TO MAINTAIN OR IMPROVE THE CONDITIONS FOR GRASSBED COMMUNITIES IN MOBILE BAY

There is a lack of knowledge of the distribution of this ecologically important floral component in Mobile Bay. Perhaps the first management recommendation should be to construct a vegetation map of Mobile Bay detailing the present (and past) distribution of submerged macrophytes.

Until further research is completed, it is difficult to determine what factor or combination of factors is responsible for the changing patterns of submerged aquatic vegetation in Mobile Bay. The various factors that are known to affect SAV must be analyzed to the extent possible given the availability of published and unpublished literature. Included among these factors are: agrochemicals, turbidity, salinity, temperature, pH, wave action, fauna, epiphytes, bicarbonate ion, chlorine, disease, boat traffic, dredging, nutrient loading, petroleum products, and heavy metals.

Factors which are known to be localized or short term are turbidity, boat traffic, dredging, nutrient loading, and possibly chlorine. Factors that are applicable to the entire Bay or a large portion of the Bay include: agrochemicals, salinity, temperature, turbidity, pH, wave action, fauna, epiphytes, bicarbonate ion, disease, petroleum products, heavy metals, and nutrient loading.

More work should be done to evaluate the effects of agricultural techniques in regard to erosion control. Erosion from runoff and wind erosion can lead to high turbidities and increased sedimentation rates. Another problem which some areas of the Bay are experiencing is shoreline erosion. The costs of arresting this natural process on a large scale may be prohibitive. Also, because Mobile Bay has been experiencing shoreline erosion and subsequent sedimentation since its formation in the Pleistocene, these processes alone cannot account for the dramatic changes that have occurred in the last 30 years.

Construction projects and dredging operations should be carried out in such a manner as to minimize damage to grassbed communities, and in some instances should not be allowed. More caution should be exercised in the issuing of permits by regulatory agencies.

A management option might be to prohibit the operation of motor boats over species of SAV that do not readily regenerate by vegetative propagation. Possible management options might be to prohibit SAV destruction or to educate the public as to the importance of SAV.

If the point source discharges from sewage and water treatment plants are determined to constitute a major problem, tertiary treatment of waste water may help in relieving the high nutrient burden on grassbed communities.

Chlorination alternatives that could be implemented immediately before discharging wastewater into the estuary should be investigated. One possibility is to pass the effluent from existing sewage treatment plants under ultraviolet radiation to kill remaining pathogens before it is discharged. This might reduce the need for chlorination. Another possibility is to use land treatment as a final biological filter to eliminate pathogens from the water before it reaches Mobile Bay. Extensive studies pioneered at Pennsylvania State University have found that forested land can act as an effective buffer in regard to bacteria (Wagner 1974).

Such land disposal methods are limited primarily to low density areas where land is available and not prohibitive in cost. It may be that abundant SAV and low chlorination and nutrient levels around large cities such as Mobile may be incompatible due to the expense of large sewage and water treatment plants.

The possibility exists that significant leakage of agrochemicals into streams and rivers may be the cause of declines in SAV in portions of the Bay. If particular herbicides utilized in the Bay area prove to be a problem, it may be possible to substitute other available chemical compounds which are less harmful to grassbed communities. Careful screening of the existing compounds should be implemented at several levels before any substitutions are made. Submerged aquatic plants should be bioassayed and Bay ecosystem responses need to be determined before specific suggestions can be made.

Another management option might be to encourage farmers in the Bay area to construct ditches that lead to small holding ponds where complete biodegradation of agrochemicals would occur before draining into the estuary. These small ponds would be of additional benefit since they would serve as sediment traps.

If the decline in SAV is related to some intrinsic cyclic population phenomenon of the Bay ecosystem, it should be possible to reestablish them using planting techniques. Planting techniques have been used in Maryland, Florida, and Mississippi with varying degrees of success (Stevenson and Confer 1978). There seems to be considerable difficulty in establishing large beds; however, small beds have been reestablished in other estuaries. Small beds can become large beds given enough time. If the decline in SAV is related to some overall change in water quality of the Bay, it may not pay to attempt large scale replanting. A management option might be to identify those areas in the Bay that are likely to support SAV and attempt to reestablish grassbeds on a small scale.

A reasonable management option might be to incorporate existing productive grassbed communities into an estuarine sanctuary. These could then be protected from dredges and small boat propellers which negatively impact populations of SAV. This would also provide areas where long term experiments could be conducted by researchers to answer management questions.

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THE STATUS OF ZOOPLANKTON SCIENCE IN MOBILE BAY

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ABSTRACT

Physical and biological parameters affecting zooplankton development, distribution, and success are discussed. Data are drawn from studies within Mobile Bay and associated estuaries (Mississippi Sound, Biloxi Bay).

The earliest studies of zooplankton populations within Mobile Bay were those of Herrick in the late 19th century. Recently, a 14-month estuarine inventory by Swingle included information on zooplankton from three passes into Mobile Bay. He indicated *Acartia tonsa* as the numerically dominant copepod, and ctenophores second in abundance. Larval fishes collected by Swingle were predominantly clupeiforms and sciaenids. Post larval shrimp of the genus *Penaeus* were also collected. Jones' study of both planktonic and benthic protozoans in Mobile Bay included organisms from six families of dinoflagellates, and a single species each of a radiolarian and the ciliate family Tintinnidae. Shipp, in her studies of the vertical and horizontal distribution and abundance of larval stages of decapod crustaceans from West Fowl River, a tributary of Mobile Bay/Mississippi Sound, demonstrated numerical abundance of four species with *Uca.* spp. representing 86 percent of the total collection. Only two percent of the total collection of approximately 84,000 individuals were older larval stages which suggests a high mortality rate at the earliest developmental stage.

INTRODUCTION

This is a discussion of general biological and physical parameters affecting the development, success, and survival of zooplankton populations in Mobile Bay. The information is based on zooplankton research from Mobile Bay and its tributaries when available, closely associated estuarine systems (Biloxi Bay, Mississippi Sound), and similar estuarine communities (Apalachicola Bay, Chesapeake Bay, Pamlico Sound).

Estuarine zooplankton are small pelagic animals of limited mobility composed principally of crustacea of the order Copepoda. Members of a wide variety of other animal phyla, e.g. protozoans, chaetognaths, pteropods, tunicates, ctenophores, siphonophores, complete the assemblages. These populations are augmented, sometimes in great numbers, by meroplanktonic forms, larval stages of the benthos, e.g. trochophores, veligers, nauplii of cirripedes, decapod larvae, larvae of echinoderms, medusae of hydromedusan types. Eggs and larval stages of many fish species also are included at times.

PARAMETERS AFFECTING DISTRIBUTION AND ABUNDANCE

Zooplankton species composition and distribution are directly related to general morphometric features of the estuary. Establishment and maintenance of populations within the estuary are dependent in part on flushing rate and patterns of circulation. A combination of reproduction rate and immigration balance the rate of loss by flushing and mortality. The amount of fresh water inflow from associated river systems (e.g. Tombigbee, Tensaw, Alabama, Blakeley) affects flushing rate, regulates salinity, and affects nutrient levels and their cycling rates. Fresh water inflow brings inorganic and organic matter into the estuary and Riley (1967) suggested that such organic matter may have a qualitative influence on zooplankton species composition. River-born silt carried by such inflow may reduce transparency and thus negate some of the effects of nutrient enrichment on the level of primary productivity. Significant environmental gradients are established along the length of the estuary from the fresh water exchange influencing reproduction, growth, distribution, and survival of the species.

Patterns of circulation, especially the presence of a counter-current circulation, may enhance survival of zooplankton populations within the estuary. Many holoplanktonic forms are able to maintain a preferred depth vertically, often seeking bottom waters, regions of least dispersal (Raymont 1963). Sandifer (1975) proposed that the tendency for larvae of estuarine dependent decapod species to retreat to bottom waters where net flow is upstream is a possible mechanism for retention within the estuary, and thus a means of recruitment to adult populations.

Zooplankton abundance as well as changes in species composition are also regulated by such factors as composition and quantity of phytoplankton, abundance of predators, and concentration of pollutants (Gibson and Grice 1977). A relatively shallow topography such as Mobile Bay combined with rapid tidal mixing may result in rapid cycling of nutrients. Such rapid cycling leads to increased primary productivity levels and a smoothing of the seasonal cycle of phytoplankton productivity (Riley 1967), and thus an increased food supply for zooplankters.

Voracious predation by ctenophores on other plankters is well documented (Nelson 1925, Barlow 1955, Grice 1956, and Phillips, Burke, Keener 1969). McIlwain (1968) suggested predation by ctenophores, chaetognaths, and larval fishes was responsible for periodic reductions among copepod populations from the Mississippi Sound. Gibson and Grice (1977) observing controlled laboratory experiments speculated that heavy grazing by carnivorous ctenophores and medusae was the major factor in severe numerical reduction of zooplankton populations. Perry and Christmas (1973) reported low volumes of plankters associated with the presence of the ctenophore, *Mnemiopsis mccradyi*, in Biloxi Bay and Mississippi Sound. The plankton volume for 26 of 95 samples was almost exclusively ctenophores, leading them to speculate that ctenophore predation on seasonally occurring larvae of commercial species, and competition with other plankton feeders (larval, juvenile, and small fishes) might be an important factor in annual fishery production.

Some xenobiotic substances entering estuaries through industrial and urban waste, natural seepages, agricultural runoff, and accidental spills are toxic to zooplankters. Such pollutants are characteristic of waters in proximity to industrial complexes (e.g. Theodore Industrial Complex), agricultural developments (e.g. Baldwin County), and sewage treatment plants.

Reeve et al. (1977a) demonstrated a reduction in fecal pellet and egg production in laboratory populations of copepods from short-term exposure of 5 μg/l copper. Their earlier research (1976) showed that acute toxicity of copper and mercury is a function of size, tolerance of the species, and the population exposed, with differing populations of the same species showing variability. There is, however, inconsistency between reports on the effects of heavy metals in the 1-10 μg/l range on zooplankton. This is associated with the use of different species for study, analysis of metal concentrations, and relating the biological effect to the chemical cause. Reeve et al. (1977b) confirmed that biological effects can be demonstrated within this range, and at least for copper, may be within the same order of magnitude as the environmental background levels in some inshore regions. They suggested the nature of the metal may be less important than the total amounts of metals present over the range, i.e. copepods may possess mechanisms for detoxification of small amounts of mercury even though it is potentially more toxic than copper.

Chlorinated hydrocarbons are highly cumulative and persist in estuarine organisms. Uptake by phytoplankton may concentrate it hundreds of times over ambient levels resulting in suppression of growth (Walsh et al. 1977). Bioconcentration and transfer through estuarine-food chains were demonstrated by Bahner et al. (1977). Bahner reported that initial bioconcentration from water by planktonic food organisms was the dominant source of Kepone[R] to each member of a characteristic food chain tested experimentally (plankton-mysid-fish). However, they speculated that in the field, bioconcentration from water would be the dominant source of the pollutant to all members of the food chain, but with significant quantities (> 85%) transferred from prey to predator.

Epifanio (1971), testing the effects of dieldrin on two species of xanthid crab larvae, found toxicity more dependent on the stage of development than the length of exposure. He reported that 1 ppb significantly affected the survival of larvae in the first zoeal stage. There was no differential mortality as crabs progressed from stage 2 to megalopa. Both dieldrin and the chlorinated hydrocarbon Sevin[R] showed similar effects on crab larvae, affecting the molting process at the first zoeal stage.

The larval stage is the most critical phase in the life history of an organism, with recruitment to adult populations depending on their survival. Shipp (1977), working in West Fowl River, a tributary of the Mobile Bay/Mississippi Sound estuary, demonstrated that natural mortality appears high among decapod larvae and added mortality at the earliest zoeal stage could severely affect population structures and abundance of commercially important invertebrates.

Chlorine concentrations at levels discharged into estuarine waters from sewage treatment plants are toxic to zooplankton populations (Heinle and Beaven 1977). They reported LC_{50} (concentration lethal to 50% of test organisms) of 0.175, 0.062, and 0.028 mg/l of chlorine produced oxidants for adult and immature copepodids (combined) of *Acartia tonsa* at 15° C and salinities 10.4 - 11.8 0/00. Preliminary results with nauplii of *A. tonsa* suggested lower LC_{50} than those for adults at equivalent exposure times. They thus suggested that lethal exposures to chlorine might commonly occur because near-field concentrations of chlorine of .001 to .01 mg/l and up to 2 mg/l have been established adjacent to an estuarine power plant and sewage treatment plants, respectively.

Under favorable conditions, estuarine zooplankton populations exhibit volumetric and numerical abundance but limited diversity. Eurythermy is characteristic of its members, with a number of species able to survive most seasonal temperature ranges. Summer populations are high because of increased primary productivity and the strong seasonal effect of meroplankton.

MOBILE BAY STUDIES

The paucity of data concerning zooplankton populations in Mobile Bay is surprising. The earliest studies were those of Herrick (1884, 1887) listing a number of crustacea collected from the northern Gulf coast including Mobile Bay. Ten species of copepods collected in either Mobile Bay or the Mississippi Sound were identified but because of the date, taxonomic reevaluations are needed. The species listed were: *Temora affinis*, *Temorella affinis*, *Calanus americanus*, *Acartia gracilis*, *Pseudo-Diaptomus pelagicus*, *Amyone intermedia*, *Laophonte mississippiensis*, *Laophonte similis*, *Harpacticus chelifer*, and *Canthocamptus mobilensis*.

Swingle (1971) completed a 14-month estuarine inventory that included 4 plankton stations, 3 at passes into Mobile Bay. The sampling procedure included surface tows only, and most samples were separated to higher taxa. The data are summarized in Tables 1, 2, and 3. The dominant species was the copepod, *Acartia tonsa*, collected in greatest numbers during winter months. Ctenophores were second in abundance. McIlwain (1968) and Perry and Christmas (1973) reported *A. tonsa* as the dominant species from Biloxi Bay and the Mississippi Sound. They listed *Centropages hamatus*, a boreal-temperature calanoid, as a characteristic winter species, and *Temora turbinata*, *Centropages furcatus*, *Labidocera aestiva*, and *Oithona brevicornis* as characteristic populations of warmer months.

Fish larvae were predominantly clupeiforms and sciaenids. Swingle (1971) reported large catches of larval and small juveniles at moderate salinities as indicative of winter spawning for most species. He indicated that the presence of larval silver perch (*Bairdiella chrysura*) substantiated their spawning in the Bay. Larvae of the Bay anchovy (*Anchoa mitchilli*) were rare, as were those of the Atlantic croaker (*Micropogon undulatus*). Perry and Christmas (1973) also indicated this latter species as rare. Other larval species collected in Swingle's study were *Brevoortia patronus*, *Synodus foetens*, *Myrophis punctatus*, *Hippocampus erectus*, *Oilgoplites saurus*, *Larimus fasciatus*, *Leiostomus xanthurus*, and *Lagodon rhomboides*.

Post-larval shrimp of the genus *Penaeus* were collected each month except October through January. Perry and Christmas (1973) also collected post-larvae of this genus, but also the larvae and post-larvae of two other penaeid genera (*Trachypenaeus*, *Sicyonia*) were present.

The data of McIlwain (1968) and Perry and Christmas (1973) from adjacent Mississippi Sound and Biloxi Bay Estuary may be indicative of Mobile Bay populations because of the proximity of the three locations. McIlwain (1968) identified 15 species of free-living copepods (Table 4) indicating greatest abundance from June through August. Perry and Christmas (1973) identified 31 free-living copepod species, 12 of which were listed by McIlwain (1968). They established new Mississippi Sound records for the following 17 species: *Undinula vulgaris*, *Nannocalanus minor*, *Eucalanus attenuatus*, *Rhincalanus cornutus*, *Euchaeta marina*, *Pseudodiaptomus coronatus*, *Eurytemora hirundoides*, *Calanopia americana*, *Pontella meadii*, *Oithona plumifera*, *Oncaea* sp., *Corycaeus (O.) catus*, *Corycaeus subulatus*, *Corycaeus amazonicus*, *Copilia mirabilis*, *Macrosetella gracilis*, *Clytemnestra scutellata*. Also included in their list of species were members of 10 other phyla including the larvae of commercially important shrimp, crabs, and fishes.

Four groups of protozoans are commonly members of the zooplankton: two families of Foraminiferida (Globigerinidae and Globorotaliidae), dinoflagellates, radiolarians, and the ciliate family Tintinnidae. A two-year study of 18 stations in Mobile Bay (Jones 1974) included both planktonic and benthic protozoans. Jones listed 76 families including six families of dinoflagellates, a single species of Tintinnidae, *Tintinnus rectus*, and one species of radiolarian, *Acanthometron pellucidum*. Neither foraminiferan family was present.

Shipp (1977) discussed the horizontal and vertical distribution as well as abundance of larval stages of 13 species of decapod crustaceans. Collections were from West Fowl River, a small coastal river flowing south into Mississippi Sound at Portersville Bay. Surface and bottom plankton samples were taken monthly for an annual cycle at 5 stations that ranged from the more saline conditions

Table 1. Species Composition and Relative Abundance of Major Plankters in Monthly Plankton Sample Aliquots With Settled Volume per 100 m^3, Salinity, and Water Temperature; Mobile Bay, Station 4; April 1968 Through March 1969. Swingle (1971).

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Year
Settled Vol. (ml)	26.6	5.3	0.8	18.7	106.7	1.1	4.0	2.7	6.7	5.3	1.3	7.6	15.6
Salinity (ppt)	9.5	12.1	13.3	26.1	12.0	26.2	25.9	24.5	23.5	9.8	6.7	6.6	16.4
Temperature (°C)	22.1	27.0	29.3	30.1	32.8	26.7	17.7	13.8	10.9	9.0	14.5	14.5	20.7
TAXON													
Ctenophora	A[a]				A		A						
Copepoda	18,000	1,000	100	5,000		70	80	700	800	150	675	11,700	3,190
Amphipoda				1,200					2	1			100
Cladocera									1		576		48
Porcellanidae		15							2				1
Branchyrhyncha						25	.6	12	2	2	1		4
Sagitta spp.		40		60					1				8
Eggs		70	12	40									

[a]A – Abundant

Table 2. Species Composition and Relative Abundance of Major Plankters in Monthly Plankton Sample Aliquots With Settled Volume per 100 m^3, Salinity, and Water Temperature; Mobile Bay, Station 5; April 1968 Through March 1969. Swingle (1971).

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Year
Settled Vol. (ml)	33.3	9.3	1.3	2.7	10.7	6.7	1.3	2.7	2.0	5.0	1.3	2.7	6.6
Salinity (ppt)	23.5	16.2	19.7	26.7	19.5	27.5	26.9	22.2	24.7	22.6	20.5	8.5	21.5
Temperature (°C)	22.8	25.4	28.4	29.2	30.6	27.8	18.0	13.7	14.3	10.8	14.4	15.2	20.9
TAXON													
Ctenophora					A[a]			1,100	500	1,600	900	1,800	1,953
Copepoda	15,000	1,400	100	250	17	720	45		5	5,000	820		485
Cladocera										11			23
Branchyrhyncha			15	1		16	230		7				8
Lucifer faxoni	2	7	17				60				4		17
Sagitta spp.	100	80	20										185
Eggs	2,000	200	14										

[a]A -- Abundant

Table 3. Species Composition and Relative Abundance of Major Plankters in Monthly Plankton Sample Aliquots With Settled Volume per 100 m^3, Salinity, and Water Temperature; Perdido Bay, Station 7; April 1968 Through March 1969. Swingle (1971).

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Year
Settled Vol. (ml)	5.3	1.3	1.3	146.6	53.3	5.3	53.3	30.7	10.7	26.7	21.3	10.7	30.5
Salinity (ppt)	13.0	12.8	13.0	30.3	16.4	20.2	22.3	24.5	22.6	17.6	10.7	9.6	17.8
Temperature (°C)	23.0	26.4	30.8	30.0	31.2	27.8	22.3	15.0	8.9	15.1	10.8	17.5	21.6
TAXON													
Ctenophora	A[a]		80	A	A	A	A		A	A	A	A	
Copepoda	25	12	12			1,500	40	750	7,680	50		1,350	957
Branchyrhyncha	4		7	6	2	150							15
eggs		10											1
detritus							A	A				A	

[a]A – Abundant

Table 4. Monthly Occurrence of Copepods Collected in Mississippi Sound (Jan. 1965-March 1966). McIlwain (1968).

	JAN '65	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN'66	FEB	MAR
Eucalanus pileatus		3				585	815	2,142	6		9				
Paracalanus parvus				1,100	994	189	534		69	174	279				27
Centropages hamatus											327	42		3	
Centropages furcatus						570	315	1,143	30	3	27	9			10
Temora stylifera								57							
Temora longicornis						3	140	2,310	180	15	138				19
Labidocera aestiva				46	30	282	8,856	876	261	24	3				
Labidocera sp.	360	504					15		195	186	3				171
Acartia tonsa	369	329		897	3	165	72	23	258	1,287	3,409	63	4	465	538
Oithona brevicornis				915	895	543	825	198	147	123	324	3			93
Oithona sp.		1					24								
Oncaea venusta						15	270	69							
Corycaeus sp.						321	26	678	3						
Sappharina nigromaculata		3						6							
Euterpina acutifrons		3				1,437	48	48	6		264	6			
No. copepods/m^3	56	20		106	83	178	385	314	53	165	100	2		33	25

of Portersville Bay to near fresh water conditions upstream.

Four species numerically dominated the collections: *Uca* sp. (possibly several species), *Rhithropanopeus harrisii, Sesarma reticulatum,* and *S. cinereum*. *Uca* sp. represented 86% of the total larvae collected (Table 5).

Larvae were present in the plankton from March through November, but abundant only from April through September. Different species showed differing abundance peaks over the 12 months. The data indicated that salinity played a limiting role in the distribution of the larvae. As salinity decreased upstream, fewer species were present. The four numerically dominant species were collected at all 5 stations. Other species were more limited in their distribution. Several species showed a consistent pattern of greater abundance in bottom collections. All zoeal stages of *S. reticulatum* and *R. harrisii* were more frequently collected from bottom samples at all stations. This was true also for older stage palaemonid larvae and all callianassa larvae. These data support Sandifer's (1975) hypothesis that such bottom distributions are potential mechanisms of retention within the estuary as discussed earlier.

Vertical migration in response to changing light conditions was evident for all species collected in significant numbers. The greatest abundance of older stage zoea was collected in late afternoon and throughout the night in surface collections.

Approximately 2% of the total collection of 84,000 individuals were older larval stages. This scarcity was possibly a result of development of older stages downstream in waters of higher salinity or an indication of high mortality at the early zoeal stages. It appeared, however, that hatching and early development occurred within the marsh habitat associated with the adult distribution.

Table 5. Total Abundance of Each Larval Stage of Each Species of Plankter in West Fowl River, Alabama (Dec. 1974-Nov. 1975).

	LARVAL STAGE									
SPECIES	I	II	III	IV	V	VI	VII	VIII	MEG	TOTAL
Palaemonetes spp.	334	18	4	2	0	1	6	X[a]	1	336
Alpheus sp. ("heterochaelis?")	6	11	0	0	0	–	–	–	0	17
Ogyrides limicola	2	2	4	0	0	0	0	0	0	8
Callianassa sp. ("*jamaicense?*")	56	25	X	X	X	X	X	X	0	81
Upogebia affinis	4	0	0	0	X	X	X	X	0	4
Sesarma cinereum	1,262	2	0	0	X	X	X	X	1	1,265
Sesarma reticulatum	3,115	33	1	X	X	X	X	X	0	3,149
Uca spp.	72,067	18	0	0	0	X	X	X	0	72,085
Rhithropanopeus harrisii	4,660	825	247	141	X	X	X	X	0	5,873
Eurypanopeus depressus	483	1	0	1	X	X	X	X	0	485
Panopeus herbstii/ Eurytium limosum	335	0	0	0	X	X	X	X	0	335
Callinectes sapidus	1	0	0	0	0	0	0	0	100	101
										83,770

[a]X Stage does not occur for this species.

ROLE OF ZOOPLANKTON IN THE ESTUARY

The role of zooplankton in the estuary is still unclear. The classical food-chain sequence phytoplankton-zooplankton-carnivores has been questioned, at least for certain shallow estuaries, such as Mobile Bay, where benthic animals are important consumers of phytoplankton. Williams et al., (1968) suggested that the scarcity of zooplankton relative to available plant production may be normal for shallow embayments and that grazing by zooplankton in these areas may have little effect on density of phytoplankton.

Zooplankton is important as a basic food source, with many fishes exhibiting a planktivorous stage in their life history. Fish (1925) indicated food as the most important factor in the distribution of larval fish, scarcity of food resulting in reduced numbers even when other conditions were suitable. He listed crustaceans, especially copepods, as their main diet. King (1954) identified mysids, euphausids, amphipods, larval stomatopods, and larval fishes in stomach contents of commercially important fishes. Sheridan (1978) reported calanoid copepods (*Acartia* spp.) as the major food item for all size classes of the numerically dominant *Anchoa mitchilli* in the Apalachicola estuary. With size increase, *A. mitchilli* predation on copepods decreased in favor of larger zooplankters. Depending on the month, mysids, cladocerans, insect larvae, and crab zoea (*Rhithropanopeus harrisii*) were major food items. Stomach contents of approximately 3,400 *A. mitchilli* were examined; overall 69.2% of their diet was calanoid copepods, 9.1% mysids, with cladocerans and barnacle nauplii next in importance.

Perry and Christmas (1973) suggested the presence of oceanic species as *Euchaeta marina, Eucalanus attenuatus,* and *Rhincalanus cornutus* may act as indicators of current movement within the estuary. Fleminger (1956) noted that such infrequent occurrences of oceanic forms in the regions of the Mississippi Delta and Mobile Bay possibly resulted from an influx of open Gulf water via subsurface currents.

RECOMMENDATIONS

The lack of research on zooplankton in Mobile Bay leaves many questions unanswered. Factors normally controlling zooplankton biomass (i.e., salinity, temperature, food supply, predation) need study. Zooplankton may be turning over rapidly because of heavy predation and abundant food supply but be relatively unimportant as an herbivore link in this estuarine food chain. As indicated by Sheridan (1978) the composition and distribution of zooplankters may be of major importance to the presence of larval and juvenile commercially important fish species. Two ichthyoplankton studies observing egg and population distribution and abundance within Mobile Bay are now in the initial stages (Larry Williams, Don Marley, per comm., Dept. of Biology, University of South Alabama).

Data concerning meroplankton are frequently lumped into higher taxa because of the difficulty of identification. Literature is now available to aid identification of many estuarine larval decapod crustaceans (Kurata 1970; Sandifer 1972). However, because of the number of phyla comprising zooplankton assemblages, research should involve several individuals of varying expertise for a thorough understanding of these populations.

Factors known generally to affect zooplankton populations have been discussed, but until the present conditions of the Mobile Bay populations are explored, little can be said concerning stress levels and their effects. Keeping at a minimum activities that increase water turbidity (e.g., shell dredging, shrimp trawling, increased silt levels through fresh water influx), preventing increased pollutant levels, and maintaining natural estuarine circulation patterns and salinity gradients will maintain these zooplankton populations at their most natural state.

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BENTHOS OF THE MOBILE BAY ESTUARY

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ABSTRACT

Estuarine infaunal benthic communities represent a critical link between coastal wetland ecosystems and higher trophic levels. They also are accepted as good indicators of the fate and effects of chemical pollutants and of impacts of coastal development. Despite their importance in Mobile Bay, the benthos are poorly described. Only three areas have been characterized seasonally: D'Olive Bay; the Theodore Ship Channel project site; and the Mobil Oil test well site. The latter two studies have furnished comprehensive habitat quality data in addition to benthic community structure. Principal recommendations for correcting the existing data gap include defining seasonal benthic community structure throughout the estuary, generating a habitat quality index which will permit comparisons of different benthic habitats, and estimation of monetary values of estuary bottom.

INTRODUCTION

The importance of infaunal benthic organisms in aquatic and marine productivity has been documented by many investigators. Organic detritus/carbon is consumed by detritivores such as deposit-feeding meiofauna, infaunal polychaetes, and fish, and made available to higher trophic levels (Biggs and Flemer 1972; de la Cruz 1973). Coull (1971) reviewed early information on meiofaunal-macrofaunal relationships and concluded that trophic linkage exists between meiofauna and shrimp, polychaetes, and some nektonic animals. This trophic relationship was measured by Diaz et al. (1978), who showed that meiobenthic crustaceans represent a significant prey item for certain fish species in the James River (Virginia) estuary.

The consumption of macroinfauna by predators further documents the value of benthic animals in transfer of energy from coastal wetlands to higher trophic levels. Food sources of hake (Sikora et al. 1972), flounders (Stickney et al. 1974), catfish (Heard 1975), croaker (Overstreet and Heard 1978a), and red drum (Overstreet and Heard 1978b) are dominated by epibenthic crustaceans, but also include infaunal organisms (especially polychaetes). Darnell (1958) and Livingston et al. (1976) showed that polychaetes provide an important link in the detritus-based food chains of estuaries.

Benthic organisms are also good indicators of pollution and construction-related perturbations in the estuary. Because the infauna are generally immotile, their presence/abundance provides presumptive evidence of impacts of habitat change. Reish (1955, 1966) has shown that infaunal polychaetes vary in abundance and diversity with the degree of contamination of sediments in Long Beach Harbor (California). Effects of dredging on the benthos have been studied by Taylor and Saloman (1968), Taylor (1972), Stickney (1973), Lackey et al. (1973), Vittor (1974), Markey (1975), and others. In general, infauna are removed or destroyed by dredging and dredged material disposal. However, unless the nature of the sediment or hydrography is changed, recolonization of disturbed bottoms will be rapid. Polychaetes are the earliest colonizers of dredged material (Rhoads, et al. 1977) largely as a result of year-round reproduction (Dauer 1974).

BENTHIC STUDIES OUTSIDE MOBILE BAY

Several studies have been conducted of the benthic environments in the vicinity of Mobile Bay. The most important of these investigations characterized the oil lease areas in the northeastern Gulf of Mexico, including the area south of Dauphin Island. The Mississippi-Alabama-Florida (MAFLA) program was funded by the U.S. Department of the Interior, Bureau of Land Management from 1974 through 1978, and included intensive seasonal sampling of major benthic habitats on the Mississippi-Alabama Shelf.

Other studies in the area outside Mobile Bay have included several summer class surveys south of Dauphin Island (reviewed in Vittor 1977), and a one-time intensive sampling of the benthos of the Gulf Intracoastal Waterway from St. Marks River, Florida to Lake Borgne, Louisiana (Taylor 1978). Markey (1975) conducted a benthic survey of Gulfport Harbor, Mississippi in relation to dredging of the ship channel. None of these benthic studies examined seasonal variability in community structure, species diversity, and individual abundance.

BENTHIC COMMUNITIES IN MOBILE BAY

There is a general paucity of good data for the benthos of Mobile Bay. A checklist of mollusks in Alabama's coastal waters was compiled by Parker (1960), but did not provide quantitative data for animal-sediment relationships or mollusk communities. His survey identified eight habitats based on the presence of mollusk species:

A. River-influenced, low salinity assemblage;
B. Assemblage in open sound or bay;
C. Assemblage at margins of open sound or bay;
D. Enclosed bay or inter-reef assemblage;
E. Oyster reef assemblage;
F. Inlet and deep channel assemblage;
G. Surf zone, 0-4 meters, assemblage;
H. Inner Continental Shelf, 4-24 meters.

Zoellner and McPhearson (1964) collected trawl samples in several epibenthic habitats in Mobile Bay and Mississippi Sound. They reported large numbers of bottom-dwelling decapods (principally *Callinectes sapidus*, *Penaeus* spp., *Pagurus* spp., *Panopeus herbstii*, and *Libinia emarginata*), and occasional patches of the cnidarian *Renilla reniformis*, the echinoderms *Luidia clathrata* and *Mellita testudinata*, and the polychaete *Chaetopterus variopedatus*. Their data reflect patterns of epibenthic rather than benthic community structure.

Mobile Bay studies which have provided quantitative information on benthic communities are listed in Table 1. Sites where data were collected in these various investigations are depicted in Figure 1. The legend on Figure 1 provides an explanation of sampling intensity. Only 3 of the 10 studies listed can be considered to represent adequately spatial and temporal characteristics of benthic communities. These are the studies of D'Olive Bay (Vittor 1974), the Theodore Ship Channel project site (Vittor 1979a; Hopkins 1979), and the Mobil

Table 1. Sources of Benthic Community Data for Mobile Bay, Alabama.

Study Number	Sample Period	Area Studied	No. Stations/ Frequency	Reference
1	1970	Tidal streams	23/1-3 times	Bault, 1970
2	1972	West shore near Deer R.	9/once	Taylor, 1972
3	1972-73	D'Olive Bay	18/4 seasons	Vittor, 1974
4	1973	Lower Mobile Bay	15/once	Vittor, 1973
5	1973	Intersection of Dog River and Mobile Ship Channels	24/once	Lackey et al., 1973
6[a]	1975	Intertidal, Dauphin I.	6/once	Kennedy, 1975
7[b]	1977-78	Gulf Intracoastal Waterway	56/once	Taylor, 1978
8	1977-78	Theodore Ship Channel project area	3/10 times; 5/5 seasons	Hopkins, 1979; Vittor, 1979a
9	1978	Garrows Bend	12/once	Vittor, 1978
10	1978-79	Lower Mobile Bay, Mobil Oil site	8/2 seasons	Vittor, 1979b

[a] Excluding six stations on the Gulf side of Dauphin Island.
[b] Work performed by B. Vittor and reported by Taylor (1978).

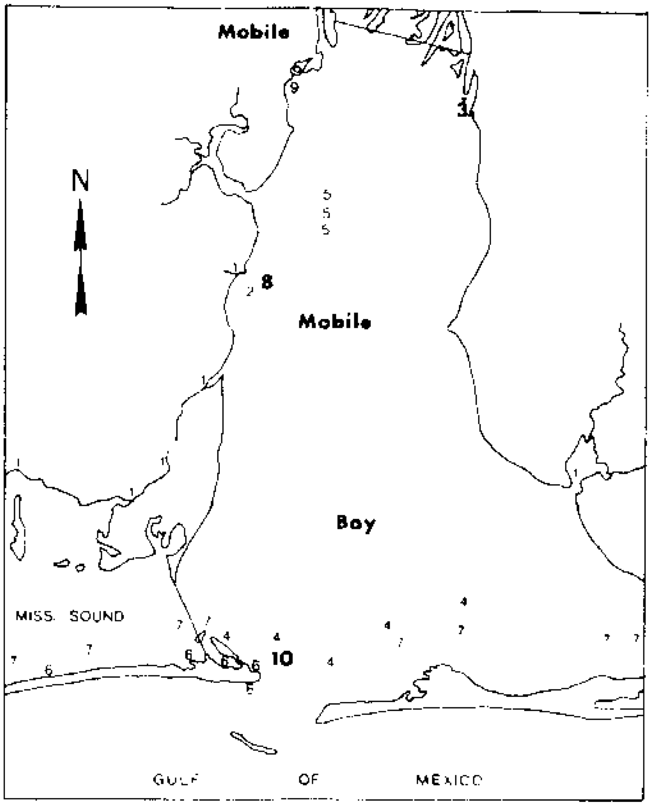

Figure 1. Locations of Historic Benthic Community Investigations in Mobile Bay, Alabama and Mississippi Sound. Refer to Table 1 for explanations of site numbers. Boldface numbers refer to major benthic studies.

Oil test well site (Vittor 1979b). The remainder of the citations represent small-scale or one-time sampling of benthic habitats.

Bault (1970) sampled 23 stations in the coastal streams of Alabama during an 8-month period. He reported approximately 43 species of macroinvertebrates, including 26 species of polychaete worms. Unfortunately, information is not provided regarding sample size or number, or sieve size. Qualitative examination of his results suggests that the benthos of most of the tidal streams sampled were dominated by arthropods, including gammarid amphipods and dipteran larvae.

Vittor (1974) reported a total of only 19 benthic species retained by a 1 mm sieve size in D'Olive Bay. The polychaete *Laeonereis culveri* dominated most benthic habitats although gammarid amphipods and the marsh clam *Rangia cuneata* were abundant at some sites. Species diversity (as H', log base 10) averaged 0.29 for all stations sampled seasonally. D'Olive Bay benthos were shown to be influenced by fluctuations in salinity and dissolved oxygen, as well as by sediment texture. Seasonal changes in species diversity were not statistically significant, although post-dredging infaunal abundance and diversity were considerably lower than prior to dredging.

Several stations near Deer River were sampled once by Taylor (1972) in order to describe the recovery of bottoms affected by oyster shell dredging. Average species richness and individual abundance ranged from 1 to 7 and 0 to 1024 per 1.0 m^2, respectively. Highest macroinvertebrate abundance and diversity occurred in sandy substrates. The data obtained do not appear to represent adequately the benthos in this area, when compared with more recent data described for the Theodore Ship Channel Study.

A preliminary survey of 15 points in lower Mobile Bay by Vittor (1973) suggested that polychaetes dominate infaunal communities in sand and silt bottoms. Of 55 species identified, 36 were polychaetes; 84% of the individuals sampled were polychaetes. The very limited scope of this program precluded adequate characterization of the benthos.

Lackey et al. (1973) reported 18 species in bottom samples collected near the intersection of Dog River Channel with the Mobile Ship Channel. The clam *Tellina texana* dominated most of the 24 sites sampled, while the clam *Mulinia lateralis* was locally abundant. Taxonomic discrepancies between identifications of Lackey et al., and other investigators (e.g., Parker 1960; Hopkins 1979; Vittor 1979a) reflect the difficulty of incorporating varied data bases into an integrated characterization of the benthos. Species diversity values H' log base 10) ranged from 0 to 0.69. Individual abundance ranged from 45 to 1080 per 1.0 m^2, with considerable variability between transects and stations.

Intertidal/subtidal polychaetes at six sites around Dauphin Island were described by Kennedy (1975). Each site was sampled once for sediment texture and polychaete abundance and diversity. Individual abundance ranged from 10 to 56 per 1.0 m^2, while H' (log base 10) ranged from 0.20 to 0.58. Samples were collected during June-July 1975, so these results probably reflect average seasonal environmental stress.

An intensive study of benthic organisms was conducted in the Theodore Ship Channel project area by Vittor (1979a) and Hopkins (1979). This program provided for quarterly sampling of macroinvertebrates at eight stations from November 1977 through October 1978. In addition, monthly samples were obtained at three sites from March through September 1978. Sediment analyses were performed on quarterly samples at each station. A total of 78 macroinvertebrate species was identified, including 38 species of polychaete worms. Dominant infauna included the polychaetes *Mediomastus californiensis, Polydora ligni, Streblospio benedicti, Neanthes succinea,* and *Parandalia (Loandalia) americana.* Other dominant forms were the clams *Rangia cuneata* and *Tellina lineata* and the amphipod *Melita nitida.* Polychaete diversity varied significantly with respect to season: lowest H' diversities (0.18, log base 10) occurred during the summer and fall of 1978. This investigation provided good information on benthic community structure and relationships with environmental conditions.

Benthic communities in and near Garrows Bend were sampled during August 1978 by Vittor (1978). This study defined small-scale variability in Garrows Bend. Average macroinvertebrate abundance ranged from 131 to 590 individuals per 0.07 m^2, while H' (log base 10) ranged from 0.45 to 0.78. Community structure was similar to that observed by Lackey et al. (1973), Vittor (1979a), and Hopkins (1979), although some taxonomic discrepancies existed among the mollusks. Significant differences in mollusk species also occurred between this study and the survey by Parker (1960): neither of the two dominant gastropods (*Probythinella protera* and *Texadina sphinctostoma*) was listed by Parker.

Benthic communities along the Gulf Intracoastal Waterway in Mississippi Sound and Mobile Bay were described by Taylor (1978). Eight transects, each including seven sites, were sampled for macroinfauna and sediment texture during fall-winter 1977. This investigation provided good information on macrobenthos for lower Mobile Bay during the sample period and demonstrated that zoogeographic differences in the lower Bay and Mississippi Sound are largely attributable to substrate characteristics. Dominant taxa in Mobile Bay included the polychaetes *Mediomastus californiensis, Streblospio benedicti,* and *Paramphinome pulchella.* The considerably more diverse and abundant macrobenthos near the Dauphin Island Bridge were dominated by *M. californiensis* and *P. pulchella* in addition to the polychaetes *Scoloplos foliosus, Neanthes succinea, Heteromastus filiformis,* and *Paraprionospio pinnata.* Nemertean worms and the pelecypod *Gemma* were locally abundant.

The most intensive seasonal benthic investigation performed in Mobile Bay is being sponsored by Mobil Oil Corporation in association with their test-well near Dauphin Island (Vittor 1979b). Fourteen stations were sampled before drilling and will be sampled again after completion of operations. Six of these sites have been sampled quarterly. Sediment texture analysis has been obtained in conjunction with collection of macroinvertebrate and meiofaunal samples. The first four sampling seasons (July, August, November, and January) have shown exceptionally high macroinfaunal abundance and diversity. A total of approximately 287 taxa (including 136 species of polychaetes) have been obtained thus far. Individual abundance has ranged from 114 to 3028 per 0.54 m^2, while H' (log base 10) has ranged from 0.77 to 1.56. Highest diversity was observed on sandy silt bottoms during the fall. Heavy recruitment of larval and juvenile polychaetes was observed in the meiofauna during the fall. Dominant macroinfaunal species included the archiannelid *Polygordius*; the polychaetes *Mediomastus californiensis, Owenia fusiformis, Magelona* spp., *Parapionosyllis longicirrata, Malacoceros vanderhorsti,* and *Neanthes* spp.; and the ophiuroid *Micropholis atra.* Seasonal changes in benthic community structure appeared to be related primarily to salinity changes: moderately high salinities sustained through the fall maintained an unusual assemblage of macroinvertebrates including many forms which are only marginally tolerant of low salinities and normally occur in the open Gulf of Mexico.

ASSEMBLAGES OF MACROBENTHOS IN MOBILE BAY

Macroinvertebrate occurrence in major benthic habitats of Mobile Bay and Mississippi Sound is summarized in Table 2. No attempt has been made to interpolate between study sites described above because these sites are very widely spaced, the various investigations differed greatly with respect to sampling intensity and frequency, and the Bay exhibits greater patchiness in sediment types than suggested by the sediment distribution map prepared by Ryan (1969). Oyster reef communities are excluded from Table 2 because they are discussed in a subsequent paper. The distribution of oyster reefs in Mobile Bay was described in May (1971).

Several species are nearly ubiquitous in distribution in the estuary. These include *Mulinia lateralis, Mediomastus californiensis, Neanthes succinea,* and *Streblospio benedicti.* Benthic species which are better indicators of specific habitat types include the following: *Probythinella protera, Texadina sphinctostoma, Gemma* sp., *Rangia cuneata, Polygordius* sp., *Laeonereis culveri, Malacoceros vanderhorsti, Neanthes micromma, Parapionosyllis longicirrata, Corophium lacustre,* and *Micropholis atra.* Implied habitat specificity is doubtless artificial in some cases as a result of inadequate sampling

Table 2. Occurrence of Dominant Macroinvertebrates in Major Benthic Habitats in Mobile Bay and Mississippi Sound, Alabama.

SPECIES	SALINITY CONDITIONS: Fresh Brackish	Brackish	Brackish Marine	SEDIMENT TEXTURE: Clay	Silt	Fine Sand	Sand	GEOGRAPHIC LOCATION: Upper Bay	Middle Bay	Lower Bay	Miss. Sound	Reference Number(s)*
GASTROPODA												
Neritina reclivata		X			X			X	X			5,8
Probythinella protera	X				X			X				9
Texadina sphinctostoma	X				X			X				9
PELECYPODA												
Gemma sp.			X			X					X	7
Macoma mitchelli		X			X	X		X	X		X	7,8
Mulinia lateralis		X			X	X			X	X	X	5,7,8
Rangia cuneata	X	X		X	X			X	X			1,3,8,9
ANNELIDA												
Heteromastus filiformis		X	X		X	X			X	X		6,7
Laeonereis culveri	X	X			X	X		X				1,3
Magelona spp.			X			X	X			X		10
Malacoceros vanderhorsti			X			X				X		10
Mediomastus californiensis	X	X	X	X	X	X		X	X	X	X	7,8,9,10
Neanthes micromma			X		X					X		10
Neanthes succinea		X	X		X	X		X	X	X	X	4,7,8,10
Owenia fusiformis			X									
Paramphinome pulchella		X	X			X	X			X	X	4,7
Parandalia americana	X	X		X	X			X	X		X	1,7,8,9
Parapionosyllis longicirrata			X			X				X		10
Paraprionospio pinnata		X	X	X	X					X	X	4,7
Polydora ligni	X	X		X	X	X			X			7,8,9
Polygordius sp.			X							X		10
Scoloplos foliosus		X	X			X	X			X	X	4,6,7
Streblospio benedicti	X	X		X	X	X		X	X		X	7,8,9
CRUSTACEA												
Corophium lacustre	X					X			X			8
Melita nitida		X			X	X			X		X	5,7,8
ECHINODERMATA												
Micropholis atra			X		X	X				X		10

*Refer to Table 1 for specific reference information.

of most Mobile Bay habitats. For example, upper Mobile Bay and tidal streams are not well described and may be abundantly populated by species not designated in Table 2. Dominance may change seasonally in these habitats as well as near the mouth of Mobile Bay. Data being obtained at the Mobil Oil test well site will give a good indication of such shifts in community structure for the lower Bay. Similar data are needed for the upper Bay.

RECOMMENDATIONS

It is clear that more comprehensive benthic habitat analysis is necessary for most of Mobile Bay and Mississippi Sound. Only two areas - the Theodore Ship Channel Project site and the Mobil Oil test well site - have been studied to the extent that environmental quality can be determined accurately. Studies of D'Olive Bay, Garrows Bend, and the Gulf Intracoastal Waterway have furnished good data, but have omitted either seasonal or chemical aspects of habitat quality.

The principal recommendations of this review are as follows:

1. Define seasonal geographical distributions of benthic organisms, sediments, and chemical contaminants throughout the estuary, with particular emphasis on areas most likely to be effected by development, pollution or both;
2. Define the trophic relationships between benthic organisms and both primary producers and predators;
3. Define pathways of chemical assimilation and bioaccumulation in the estuary;

4. Derive an index of habitat quality based on the benthos throughout the estuary, in order to manage natural habitat resources in terms of relative productivity, ecological sensitivity to change, aesthetic values, and recreation;
5. Obtain estimates of the monetary values of estuarine benthic habitats for use as a management tool in comparing long-range economic impacts of coastal development;
6. Encourage the use of standardized, compatible methodologies for benthic sampling and analysis.

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PANEL DISCUSSION - MODERATOR, DR. JIM JONES, DIRECTOR, MISSISSIPPI-ALABAMA SEA GRANT CONSORTIUM

MEMBERS

Dr. John Borom, Faulkner State College
Ms. Linda Shipp, University of Alabama
Dr. Judy Stout, Marine Environmental Science Consortium
Dr. Barry Vittor, Vittor and Associates

J. JONES: We have been exposed to a great deal of information this afternoon. On this last session we have been very fortunate to have four of the primary experts on Mobile Bay fauna here today. If you have some questions either address them to the panel as a group or to an individual on the panel.

MYRT JONES: Judy, you mentioned that there should be some marsh designated for setting aside. Do you think you might delineate those areas. Barry, you mentioned that you found large communities of benthos in communities around the Mobil Oil rigs. You mentioned because of the high salinity, and then you stated in April they decreased somewhat. I was wondering why.

STOUT: Myrt, I didn't have any particular areas designated for preservation. I could mention a few that I would pick if you would like me to do that. I had in mind that in lieu of the recommendation that we try to prohibit any alteration (recognizing there will be critical needs which will require that there be some alteration), we designate some areas in which even these critical needs do not supersede preservation. The marshlands on Fort Morgan Peninsula and Little Point Clear are among the least disturbed in the state, if not the least disturbed. They are also rather unique both geologically and in terms of the vegetation and fauna that are there. I would look at this area first because of various unique features about it. Portions of the Mobile Delta need consideration, for various reasons, and these may be for educational purposes or research purposes, preservation of endangered species, etc.

MYRT JONES: I was hoping you might mention Little Dauphin Island.

STOUT: I would not put it on the top of my list, primarily because it has already received quite a bit of alteration, and I would hope to preserve first those areas that are in their nearest natural state. I certainly think it is worthy of consideration, though.

BARRY VITTOR: Myrt, one thing that we have attempted to resolve in our Mobil Oil study but don't have all the data yet to do so is why we have observed such high species richness. For example, polychaetes are particularly rich in the vicinity of the well site during the summer and fall and through January. Theoretically, we would expect a very high recruitment of marine forms such as those occurring in the Gulf of Mexico during the summer, late summer especially, and in fall as a result of the sustained high salinity compared to fresh to brackish conditions which probably apply right now. This was the case; we found polychaete species that we have never seen anywhere else but in the open Gulf of Mexico, and yet these forms are not turning up again now apparently because of high rainfall and reduced salinities. It is what we would expect just based on intuition if nothing else.

TATUM: Judy, you said two thousand acres are marsh that have been created. Is this salt marsh, fresh marsh, or brackish marsh or a combination of the three, and is it included in the total number of acres of marshes that we have in Alabama?

STOUT: Yes, to the last one. It is included in the total number of acres. Most of them are fresh to fresh brackish. Things like filling in around Pinto Island, McDuffie Island, the margins of these places, Battleship Parkway, come to mind right away. There will be some brackish marsh creation in the

Theodore Ship Channel. I went ahead and included that because it appears to be imminent. Those are some examples. Most of it is fresh to brackish or fresh brackish.

MARK THOMPSON: But in all cases it's filling of shallow water habitat?

STOUT: All of it that I included was. This was just stuff I was able to document. And that is because most of it is large project resultant. We do have records of this.

VERDA HORNE: The panel has identified some areas that are really critical and they might be attacked by a completely different mechanism than some of the others that I think have a lot going for them. I'm talking about areas which, though they may be fairly small, could be saved because of a variety of reasons in each case. Endangered species, critical habitat, wetlands, spill and the like. There are some of those areas, particularly the Fort Morgan Peninsula, where the historical community, I think, has not been involved and should be because some of those areas could be saved not only for ecological reasons but also for historical reasons. The laws exist but often the people don't know about them. They don't know that they are more than historical and don't know that they are endangered. Do you have an idea about how you go about implementing that kind of coordination? How do you involve numbers of people? Here we are ecologists or biologists. What do you do to get people who are interested in historical areas and don't know that they are important ecologically. How do you get people who are interested in endangered species to begin looking at the other reasons by which they could be saved?

BOROM: Ms. Horne, I think there are probably several ways to do this. I think one primary thing would be to educate the public as to the ecological importance and the significance of various areas along the coast.

VERDA HORNE: How can you do it?

BOROM: I think maybe by a series of seminars, possibly funded by the Coastal Area Board or someone else. We can reach the people through workshops and seminars and let them become aware of what these areas are, where they are and why they are important and why they should be saved. I think primarily it's just a lack of knowledge among the general population, and I think that a weries of workshops would be most helpful in doing something like this.

J. JONES: The meeting here this afternoon is a step in that direction and certainly the variety of response that we have had to this meeting and the variety of individuals that have been attending it, indicate a somewhat more than casual interst in the topic. I was delighted that we have around 100 or more who have signed on the register, and I was hoping in my wildest dreams for about half of this at this meeting. It's very encouraging, and I believe that there are opportunities to acquaint the public on both sides of this issue and that the open forum aspect of this type of thing is one of the most beneficial to air all sides of questions such as this where you have the importance of the preservation, enhancement on the one hand, and the requirement for continued growth and economic well-being on the other. This is one of the types of forums that I think is very good, and the Coastal Area Board certainly is very logical a choice for a continuation of this type of thing.

BARRY VITTOR: Myrt, let me go another step in that direction and use a very messy example—mud on the bottom. That is not a very romantic place to be, and it's also not particularly visible except at low tide. It's hard to encourage people to save mud bottom without having some real attachment to it. You aren't finding a lot of people who are establishing endangered species in benthos, for example. At the same time, more seriously, and more to the point, we have not successfully demonstrated the productivity of the bottom even in Mobile Bay/Mississippi Sound. Therefore, we can't rely on that critical piece of information to justify retaining the bottom that we have. Judy made a good point on this a little earlier concerning the relative value of salt marshes. Is it better to create marginal salt marsh on a good bay bottom or is it better to leave bay bottom the way it is? That is a very important point, but we don't have any information with which to make that decision.

J. JONES: Our developing Sea Grant Program is addressing precisely these aspects of the problem. It will take us about two more years before we start to get definitive answers and those answers will be first to come in from Mississippi Sound, where we initiated that part of the program, and will be moving more directly into Mobile Bay about a year from now. But this is long-term, and while we're finding out the answers the pace continues or increases for disruption and destruction, so we need to move rapidly. Someone this afternoon said he wished that his Indian forefathers would have kept notes, so we could have some idea of what was natural then. I wish we had begun 10 years ago with some of this work in an organized fashion where the methods are compatible, the samples are comparable. We missed a fantastic opportunity in this country with the Bureau of Land Management program. They didn't standardize. We had a tremendous chance at one time of having a standardization of all these various programs in the various parts of the shelf around the country. They didn't do that, so we have these isolated studies that are very difficult to compare one to the other. The situation is more or less similar here in Mississippi Sound/Mobile Bay, where you have a number of investigators and a number of different programs ongoing and a number of agencies doing programs, some of them overlapping, some of them not; some of them almost identical. The coordination for this is something that is very difficult to achieve because there is no obligation to coordinate or to cooperate. So you get a going their own way sort of thing much of the time. We are trying to fill that role to some degree, but it is an impossible role to fill. Since you can't obligate anyone to cooperate, you can only do it with the little bit of money that we have and cajoling threats do not do any good. So we have found ourselves locked into the system and trying to make the best of it.

I want to congratulate the audience on their tenacity, their interest. I am very pleased that I thought that when it got to be 5:20, surely we would be speaking to about four or five of you instead of a room full.

GEORGE ALLEN: I have a question to anybody on the panel, probably Barry Vittor will be the one to answer it. Has there been any type of general research done on Mobile Bay to determine the proper percentage of open water as opposed to marsh and to maintain the highest productivity that we think we can get in the area. This is a very basic question. Are we building too many marshes or are we building enough?

BARRY VITTOR: I can answer that very simply and say no to your immediate question. No, we don't have a master plan for establishing marsh, and we certainly don't have the data, as I indicated to Ms. Horne's question a minute ago. But, George, that is the kind of input that is still required and some ideas of relative value of these to the ecosystems. They certainly interface. This has all been pointed out by Judy and Linda and John. I think that needs to be resolved and at the same time, emotionally, I don't think too many people are going to argue that we have too much salt marsh and brackish marsh, but again, that is a tough one. If you come up with a good program, let's do it.

ANONYMOUS: You said 22% of the marshlands are being destroyed. How long do you think it will take to replant that and get it back up to our standards, or is it even possible in our generation?

STOUT: I recommended that we try to restore some of the area that has been destroyed by spoil disposal. Most of it cannot be restored to the type of marsh it was prior to deposition because of changes in elevation, type of flooding, etc., but it could be restored to a productive marsh situation. Other areas are lost. When you dig a canal through it 8 feet deep, it is going to be awhile before it becomes anywhere near natural. I don't think you'll find anybody to give you the money to fill it back up again, so some of it is totally lost. In terms of revegetating or creating new marsh lands, I think with the spoil disposal needs we have, it's a possibility, but the use of spoil in estuaries is now kind of a "no-no." They are looking more toward open water disposal, and higher elevations, such as the Theodore Island, which won't support much marsh land. It will have marsh along the northwestern fringe of it. So, I don't see much of a way to replace all of what we have lost. Along the lines of George's question, I don't know what 22% of the previously existing marsh lands being lost means. I don't know that that's good or bad, and then there is also the question of which is better, marsh lands or bottomlands or marsh lands or swamps. We don't have the information.

BILL TRIMBLE: Judy said we don't have the information to know. I'm with the Alabama Marine Resource Division; we don't even have the equipment or the money to find out these answers. I wonder if the people from the universities feel that they have the funds to address these problems. We saw some very large ships at sea. Some people here might think that we run around in these big ships, and we have these wonderful budgets. Perhaps, we ought to clear this up.

J. JONES: I might take a stab at some of this, since I have been on both sides of the issue. The opportunities for funding this kind of research through academia are increasing. That is the most hopeful thing I can say. The amounts of dollars that we are getting are severely limited. When I say we, I am talking about programs like NSF and Sea Grant, Bureau of Land Management, whatever. We try to get the maximum amount of information for the dollar, but except for the NSF programs, in general, the programs are very specific to a certain topic, subject or after a particular kind of answer. Application, generally, is highly important for most of the agency studies other than those that would be NSF which are more classically research oriented in general. The kinds of evaluations that we are discussing here this afternoon are expensive, time consuming, both from the standpoint of people time and collecting time. That is, once the samples are in and on a shelf, you usually have some years before these samples are analyzed. This requires teams of experts and you have to do things that are interdisciplinary. We need to break down the classical barriers between the various disciplines. Some places this has been done. Some places they exist very strongly so that a multi-talent approach to these kinds of questions is the only way that the answers will come. You need to bring in sociologists and economists as well as the hard scientists, so it gets to be quite a massive undertaking. That is not to say that we aren't trying or it isn't being undertaken, because it is. If we were to be allowed our wishes, I would guess that if we could increase our funding in these areas by about 10 times, we could probably spend it very wisely and very well. We have the talent pools available and the universities continue to turn out top rate people. There are excellent researchers available in the two-state area, Mississippi and Alabama. The difficulty is in finding the dollars to fund these researchers and to interest them in doing the particular kinds of research that we are talking about here. This is a baseline, benchmark, whatever you wish to call it. It is not very exciting really. You go out and collect, measure, count and then tabulate, and on the basis of these various activities you come up with something that you say, at this moment, is what the norm was and then you try to interpret from that by various kinds of devices, such as the mathematical models you heard talked about earlier this afternoon. You utilize data to prove or disprove certain things and then you wait awhile and do the whole thing all over again and say "Aha!" You have a change. What does the change mean? Usually you can't tell what the change means. The natural variations are there, the perturbations of man. All of these things get tied up into this, and as a result you end up going around in this endless circle. We have four years of data, I believe out of BLM, or four years of effort which will probably be 15 years of data. These are going to provide some answers, and they are not going to happen fast. The difficulty is that once the study is completed, that is, the samples have been collected, and the reports have been made, at that point, there isn't usually additional money to continue the sample analysis or to continue the work, and the investigators are off on another project because they need to put bread on the table and have a roof over their head. So it is a whole variety. I don't want to be flippant about this at all, because it is a major problem, a difficult problem. I wish there were an easy answer. There isn't. It's just keep doing the things that seem right and good and eventually we will have the answers. I firmly believe in that.

MYRT JONES: Judy, we are off again on the reclamation of wetland. From your estimation, is the Fowl River marsh that was dying from the spoil reclaimable?

STOUT: Are you talking about the one at the mouth of the river or west of the bridge?

MYRT JONES: The mouth of the river.

STOUT: Not as marsh land, I don't think. Its elevation is too high.

MYRT JONES: Would you think it would be proper to redike it and respoil it, since it hasn't stayed there before?

STOUT: I wouldn't think so, not because of its location.

MYRT JONES: You do think it would return back to fairly normal, usable marsh area?

STOUT: I think you are using two different things. You say reclaim and return. I think if it were left alone in time it would return, naturally over a lot longer period of time than you are thinking of. I think it would be difficult to reclaim with man's efforts.

MYRT JONES: What about breaching the dikes more?

STOUT: That would probably help it, make it go faster. But look at the area that's west of the bridge, which you may not be familiar with, because you just about have to be in a boat to see it. That's what the closer shot was I showed. The dikes are practically nonexistent around that area now. It was not spoiled to as high elevation, was not spoiled for as long, and the grass and stuff is starting to come back in that area now. So this is probably what would happen there at the mouth, but I think it would be slower because of the greater alterations.

SCHROEDER: Let me say something relative to that whole problem, Myrt. If you break the dikes and you let the material run out and it gains an elevation that the marsh can return on you have now filled Fowl River back in. Now where is the material going to when they dredge it back out so the shrimp boats and the pleasure boats can get in and out of Fowl River? There is a real problem with open water disposal, not just in the temporary depressions or shoaling it may make but the economics of having it go right back in the ditch you just plowed up only to have to use tax money to redo it. So when you get into the problem, it's a dangerous one. Here you want to reclaim some marsh, and I think that's a very valid end point to try to reach, but in the process of doing that you are going to have to lower the elevation which means the material there has got to go somewhere. They are not going to pick it up in dump trucks and take it to Prichard. It's going to go back into Fowl River. I probably shouldn't have said that, how about Idaho? Red River for dikes? You have to understand the problem here you are going to get into when you start talking about what we do with existing spoil areas. It's a toughie.

ANONYMOUS: Dr. Schroeder, what are they doing with the spoil from the Theodore Industrial Channel?

SCHROEDER: The new channel will go upland, everything under the detour bridge and the remainder of it will go into the spoil island. Whereever they start, that will be the diked material and everything will be pumped within the dikes to form the island. There are probably people in the Corps that could answer that a little more exactly than I can.

ANONYMOUS: What is the feasibility of taking some of this spoil and planting it and making it marsh estuaries?

SCHROEDER: That isn't the question for me to answer, except that I have always suggested that we raise kudzu on it and somehow convert that into something to run our cars on. Judy will have to answer the question on the marsh. As she points out, as soon as you gain elevation, you lose the opportunity to do a marsh. A marsh must have a tidal exchange. You get away from the water; you get away from the marsh. If you look at the pictures the Corps drew, we are going to have grass and oak trees out there, and a place to picnic.

STOUT: There are plans along the northeast side to stabilize (I don't recall offhand the number of acres) one side of the triangular-shaped island with marsh grass, *Spartina alterniflora* and *Juncus roemerianus*. It's only a few acres. We have to be careful not to get carried away with rebuilding and reclaiming and all this. I mean, we could fill the bay up and make a marsh out of it, but I'm not sure what we would have then, either.

SCHROEDER: Give nature enough time and it's going to be a big marsh. That's only natural. So, we can't lose track of the fact that some of the processes going on here are Mother Nature and we've got to learn a little about that so we don't get too far afoot. That delta someday is going to be at Main Pass. Giving nature its own way, the estuary is going to fill, so let's not forget that.

WILHELMINA NONKES: Dr. Schroeder, will the Bay eventually itself fill down to the Gulf?

SCHROEDER: People call Mobile estuary a drowned river valley. I call the Mobile estuary a combination of the drowned river valley and a bar build. I believe because of the barrier islands we are never going to see a major delta system built from this particular river system as we see in the Mississippi and elsewhere. There is another example—the Columbia River does not have a major delta system building outward for two reasons; high energy wave action impacting on it and a great big bar that creates some interesting problems. So, I don't mean to get away from what you are implying. Yes, something else is certainly going to happen offshore. But, I don't believe it's going to be another bay. It's going to be something rather unusual. I defer to the geologists to what exactly may happen. The high energy waves and natural island system there are going to prevent some course of events that we might try to predict using other systems as an example.

FRESHWATER FISH AND FISHERIES RESOURCES OF THE MOBILE DELTA

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ABSTRACT

The Mobile Delta includes an area of approximately 12,150 hectares (30,000 acres) of water. At least 115 species of fish have been reported from the Mobile Delta. Five species of fish occurring in the delta have been given a special conservation designation because of modifications to their habitat.

The naturally crowded condition of the largemouth bass population results in a small average size harvested by fishermen. The projected 1980 harvest of fish from the Mobile Delta by sport fishermen is 12.5 kg/ha (11.1 pounds/acre). Of this estimated harvest, 9.2 kg/ha (8.2 pounds/acre) will be game fish, 2.1 kg/ha (1.8 pounds/acre) will be marine fish, and 1.2 kg/ha (1.1 pounds/acre) will be freshwater non-game fish.

There are no indications that the fisheries resources are being overexploited. Data on the present harvest of fish from the Mobile Delta by sport needed to plan long-range management goals.

Pollution, habitat destruction and alteration, and infestations of exotic aquatic plants pose potential threats to the fisheries resource and its utilization.

INTRODUCTION

The Mobile Delta is an extremely valuable resource to the State of Alabama. The area described herein as the Mobile Delta includes the waters from the confluence of the Alabama and Tombigbee Rivers southward to the Interstate 10 and U.S. Highway 90 crossing of upper Mobile Bay. The Mobile Delta contains approximately 12,150 ha (30,000 acres) of water. The watershed of this river basin is 112,820 km^2 (43,560 square miles) and includes portions of Mississippi and Georgia as well as a major portion of Alabama.

The Mobile Delta is subject to tidal influence and salt water intrusion. The waters of the Delta are fertile and support a high standing crop of fish. Fish species from at least 26 families are known to occur in the Mobile Delta. In addition to freshwater fish, some marine species inhabit the lower delta where there is often a measurable degree of salinity. Many species of fish and invertebrates are dependent on the delta at some time during their life history.

The primary use of the fisheries resources of the Mobile Delta is recreational fishing. A good commercial fishery for catfish, buffalo and other commercial species is also supported by delta waters.

There are circumstances which are likely to place increased stress on the aquatic habitat of the Mobile Delta. These are the completion of the Tennessee-Tombigbee Waterway and its stimulus on additional industrialization, the expected oil exploration in the vicinity of the delta, and accelerated urban development resulting from projected population growth. These activities, individually or in combination, have the potential for adversely impacting fisheries resources of the delta by pollution, siltation, and habitat destruction or alteration.

FISH FAUNA OF THE MOBILE DELTA

The species composition of the fish inhabiting the Mobile Delta has been investigated by a number of workers. Smith-Vaniz (1968), Swingle and Bland (1974), and Swingle (1975) have compiled the most current and comprehensive lists of fish species occurring in the Mobile Delta. A listing of species found in the delta is presented in Table 1.

Five species of fish in the delta have been classified as endangered, threatened, or of special concern (Ramsey 1976). These species are the Alabama shovelnose sturgeon *Scaphirhynchus sp.* (endangered), Atlantic sturgeon *Acipenser oxyrhynchus* (threatened), blue sucker *Cycleptus elongatus* (threatened), crystal darter *Ammocrypta asprella* (threatened), and the freckled darter *Percina lenticula* (threatened).

These species have been given their special conservation status because of various modifications

Table 1. Common and scientific names of fishes found in the Mobile Delta.[a]

Family Common name	Scientific name
Petromyzontidae	
Southern brook lamprey	*Ichthyomyzon gagei*
Least brook lamprey	*Lampetra aepyptera*
Acipenseridae	
Atlantic sturgeon	*Acipenser oxyrhynchus*
Shovelnose sturgeon	*Scaphirhynchus platorynchus*
Polyodontidae	
Paddlefish	*Polyodon spathula*
Lepisosteidae	
Spotted gar	*Lepisosteus oculatus*
Longnose gar	*Lepisosteus osseus*
Alligator gar	*Lepisosteus spatula*
Amiidae	
Bowfin	*Amia calva*
Anguillidae	
American eel	*Anguilla rostrata*
Clupeidae	
Alabama shad	*Alosa alabamae*
Skipjack herring	*Alosa chrysochloris*
Gizzard shad	*Dorosoma cepedianum*
Threadfin shad	*Dorosoma petenense*
Gulf menhaden	*Brevoortia patronus*
Engraulidae	
Striped anchovy	*Anchoa hepsetus*
Bay anchovy	*Anchoa mitchilli*
Hiodontidae	
Mooneye	*Hiodon tergisus*
Esocidae	
Redfin pickerel	*Esox americanus*
Chain pickerel	*Esox niger*
Cyprinidae	
Common carp	*Cyprinus carpio*
Cypress minnow	*Hybognathus hayi*
Silvery minnow	*Hybognathus nuchalis*
Silverjaw minnow	*Ericymba buccata*
Speckled chub	*Hybopsis aestivalis*
Silver chub	*Hybopsis storeriana*
Golden shiner	*Notemigonus crysoleucas*
Emerald shiner	*Noptropis atherinoides*

Table 1. Continued

Family Common name	Scientific name
Fluvial shiner	*Noptropis edwardraneyi*
Pugnose minnow	*Noptropis emiliae*
Ironcolor shiner	*Notropis chalybaeus*
Sailfin shiner	*Notropis hypselopterus*
Longnose shiner	*Notropis longirostris*
Taillight shiner	*Notropis maculatus*
Coastal shiner	*Notropis petersoni*
Cherryfin shiner	*Notropis roseipinnis*
Silverband shiner	*Notropis shumardi*
Flagfin shiner	*Notropis signipinnis*
Weed shiner	*Notropis texanus*
Blacktail shiner	*Notropis venustus*
Bullhead minnow	*Pimephales vigilax*
Creek chub	*Semotilus atromaculatus*
Catostomidae	
Quillback	*Carpiodes cyprinus*
Highfin carpsucker	*Carpiodes velifer*
Blue sucker	*Cycleptus elongatus*
Creek chubsucker	*Erimyzon oblongus*
Lake chubsucker	*Erimyzon sucetta*
Sharpfin chubsucker	*Erimyzon tenuis*
Smallmouth buffalo	*Ictiobus bubalus*
Spotted sucker	*Minytrema melanops*
Blacktail redhorse	*Moxostoma poecilurum*
Golden redhorse	*Moxostoma erythrurum*
Ictaluridae	
Blue catfish	*Ictalurus furcatus*
Channel catfish	*Ictalurus punctatus*
Yellow bullhead	*Ictalurus natalis*
Brown bullhead	*Ictalurus nebulosus*
Black madtom	*Noturus funebris*
Tadpole madtom	*Noturus gyrinus*
Speckled madtom	*Noturus leptocanthus*
Freckled madtom	*Noturus nocturnus*
Flathead catfish	*Pylodictis olivaris*
Aphredoderidae	
Pirate perch	*Aphredoderus sayanus*
Belonidae	
Atlantic needlefish	*Strongylura marina*

Table 1. Continued

Family Common name	Scientific name
Cyprinodontidae	
Sheepshead minnow	*Cyprinodon variegatus*
Golden topminnow	*Fundulus chrysotus*
Marsh killifish	*Fundulus confluentus*
Blackstripe topminnow	*Fundulus notatus*
Starhead topminnow	*Fundulus notti*
Blackspotted topminnow	*Fundulus olivaceus*
Rainwater killifish	*Lucania parva*
Poeciliidae	
Mosquitofish	*Gambusia affinis*
Sailfin molly	*Poecilia latipinna*
Atherinidae	
Brook silverside	*Labidesthes sicculus*
Tidewater silverside	*Menidia beryllina*
Syngnathidae	
Gulf pipefish	*Syngnathus scovelli*
Percichthyidae	
White bass	*Morone chrysops*
Yellow bass	*Morone mississippiensis*
Striped bass	*Morone saxatilis*
Centrarchidae	
Rock bass	*Ambloplites rupestris*
Flier	*Centrarchus macropterus*
Bluespotted sunfish	*Enneacanthus gloriosus*
Banded pygmy sunfish	*Elassoma zonatum*
Everglades pygmy sunfish	*Elassoma evergladei*
Warmouth	*Lepomis gulosus*
Longear sunfish	*Lepomis megalotis*
Redear sunfish	*Lepomis microlophus*
Spotted sunfish	*Lepomis punctatus*
Green sunfish	*Lepomis cyanellus*
Orangespotted sunfish	*Lepomis humilis*
Bluegill	*Lepomis macrochirus*
Dollar sunfish	*Lepomis marginatus*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Largemouth bass	*Micropterus salmoides*
Spotted bass	*Micropterus punctulatus*
Percidae	
Crystal darter	*Ammocrypta asprella*

Table 1. Continued

Family Common name	Scientific name
Naked sand darter	*Ammorcrypta beani*
Scaly sand darter	*Ammocrypta vivax*
Logperch	*Percina caprodes*
Freckled darter	*Percina lenticula*
Blackbanded darter	*Percina nigrofasciata*
Johnny darter	*Etheostoma nigrum*
Cypress darter	*Etheostoma proeliare*
Brown darter	*Etheostoma edwini*
Swamp darter	*Etheostoma fusiforme*
Gulf darter	*Etheostoma swaini*
Speckled darter	*Etheostoma stigmaeum*
Banded darter	*Etheostoma zonale*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum*
Sparidae	
Sheepshead	*Archosargus probatocephalus*
Pinfish	*Lagodon rhomboides*
Sciaenidae	
Freshwater drum	*Aplodinotus grunniens*
Mugilidae	
Striped mullet	*Mugil cephalus*
Soleidae	
Hogchocker	*Trinectes maculatus*

[a]From Smith-vaniz (1968), Swingle and Bland (1974), Swingle (1975) and Shipp and Hemphill (1974).

which have occurred in their habitat. These modifications include blocking of spawning migration routes by dams, and alteration of main river channel habitats by impoundments, siltation, eutrophication and navigation.

More collection and study are needed to substantiate the status of these species and to make judgments concerning possible protective measures.

SPORT FISHING

The Mobile Delta is the most frequently visited sport fishing area in Southwest Alabama. The natural fertility of the Mobile Delta has resulted in a productive freshwater sport fishery. State record chain pickerel, bowfin, and alligator gar have been caught from the Mobile Delta. Fish occurring in the delta of interest to sport fishermen include bluegill, redear sunfish, spotted sunfish, warmouth, green sunfish, largemouth bass, spotted bass, black crappie, white crappie, yellow bass, striped bass, chain pickerel, channel catfish, blue catfish, flathead catfish, aligator gar, bowfin and mullet. In addition to these freshwater species, some marine species including spotted seatrout, red drum, and flounder enter the rivers in the fall when salinity is elevated and contribute to the sport fishery of the Mobile Delta.

A creel census conducted in 1964 (Swingle et al. 1966) indicated that 50,950 kg (112,325 pounds) of fish were harvested from the delta by sport fishermen making 3.95 fishermen trips/ha (1.6 trips/a) during the period of July 1, 1963 to June 30, 1964. At the 1980 projected fishing pressure of 12.3 trips/ha (5 trips/acre) (Auburn Univ. 1973), the harvest of fish by sport fishermen is estimated to be 159,218 kg (351,016 pounds) or 12.5 kg/ha (11.1 pounds/acre) assuming that the catch per unit of effort remains the same.

Largemouth Bass

The largemouth bass is one of the most popular sport fish in the Mobile Delta. The 1964 creel census estimated that largemouth bass made up 19% of the fish harvested by sport fishermen. A cove rotenone sample taken 2.4 km (1.5 miles) north of Battleship Parkway in 1969 produced 757 kg/ha (676 pounds/acre) of fish, 118.4 kg (261 pounds) of which were largemouth bass.[1]

Although production is high, the average size of Mobile Delta largemouth bass is smaller than bass from other fresh waters in Alabama. Swingle et al. (1966) reported that the average size of largemouth bass harvested by sport fishermen in the Mobile Delta was 295 g (0.65 pound). Bass of 2.3 kg (5 pounds) and larger are not caught as frequently in the Delta as in non-coastal rivers and impoundments.

Largemouth bass usually spawn heavily in the delta. Suitable areas for spawning are increased because spawning coincides with annual spring flooding which results in lowered salinity in the upper bay. During the month of June, I have collected up to 500 bass fingerlings by seining approximately 30 m (100 feet) of shoreline along Battleship Parkway. Swingle and Bland (1974) found that all age groups of bass were present in the lower coastal waters during winter and spring, but as the salinity increased in summer and fall only age-0 bass were present. In May the one-year-old fish from the lower delta moved into less saline waters which contained an existing population of largemouth bass. According to Swingle and Bland, this annual consolidation of age-1 fish into an established bass population caused natural crowding of age-1 fish.

When population biomass ratios of Swingle (1950) are applied to available fish population data, a crowded predator population is indicated. Based on the seine sampling, the biomass ratios and the small average size of bass harvested from the Mobile Delta, Swingle and Bland (1974) suggested that the largemouth bass population of the Mobile Delta is in a crowded condition. This crowded bass condition results in numerous small bass (Swingle 1956).

A study of largemouth bass in a Louisiana coastal marsh (Manuel and Shireman 1972) indicated that growth of largemouth bass was slower in a coastal freshwater marsh than in other Louisiana waters, especially in the first 2 years of life.

Although the average size of bass in the Mobile Delta is smaller than in other freshwaters of Alabama, the abundant largemouth bass population is attractive to bass fishermen. The current bass fishing popularity has led to the formation of many bass fishing clubs in the Mobile-Baldwin County area. The Mobile Delta has been the site of several national bass fishing tournaments. Sophisticated equipment and techniques and increased numbers of bass fishermen have undoubtedly increased the harvest of largemouth bass from the Mobile Delta.

The increased pressure on the largemouth bass in the Mobile Delta has caused concern among bass fishermen that the fishery is in danger of overharvest. Bass fishing groups frequently call for the imposition of size limits, reduced creel limits, closing of bass fishing during spawning season, stocking of fingerling bass, and other measures to protect bass.

The creel census of 1964 estimated that the harvest of largemouth bass from the Mobile Delta was 0.74 kg/ha (0.66 pound/acre). This harvest was realized at a fishing pressure of 3.95 fishermen trips/ha (1.6 trips/acre). At the 1980 projected fishing pressure, the estimated largemouth bass harvest would be 2.4 kg/ha (2.1 pounds/acre) assuming that the catch per trip of 0.19 kg/trip (0.42 pound/trip) from the 1964 creel census remains the same. Considering the high standing crop of largemouth bass in the Mobile Delta, a harvest rate of 2.4 kg/ha (2.1 pounds/acre) could not be considered overexploration. According to Swingle's (1950) principles of fish population dynamics, an increase in bass harvest would cause an increase in the average size bass in the delta.

Fisheries biologists of the Game and Fish Division conduct annual bass reproduction checks in the Mobile Delta and numerous routine surveys of the largemouth bass population. Based on the available information on the bass production, harvest rate, and field observations, fisheries biologists of the Game and Fish Division do not feel that the bass population of the Mobile Delta is in danger of being overexploited, and do not recommend that new restrictions be placed on bass fishing at this time as a management technique.

At the present time, the only way that the quality of the largemouth bass fishery in the Mobile

[1] Annual Progress Reports on Fishery Research Projects. 1970. Ala. Dept. Conservation, Game and Fish Division. Montgomery, Alabama.

Delta might be enhanced would be to increase the average size of bass or to increase the probability of an angler catching a trophy largemouth bass. With that goal in mind, the Game and Fish Division, through a cooperative program with bass fishing clubs, has provided Florida largemouth bass fingerlings *Micropterus salmoides floridanus* for release in the Mobile Delta. A total of 460 tagged and 519 un-tagged Florida bass advanced fingerlings have been stocked in the delta under this program. Florida bass have also gained access to the Delta via escape over the spillway of Washington County Public Fishing Lake which empties into a tributary of the Tombigbee River. The Florida bass can attain larger sizes than the native northern subspecies *M. s. salmoides* (Bottroff and Lembeck, 1978), and hybrids which will result from the introduction have the potential to grow faster and attain larger sizes than the northern bass (Addison and Spencer 1972, Bottroff and Lembeck 1978).

"Bream" and Crappie

In the 1964 creel census, "bream" made up 45.4% of the harvest by sport fishermen in the delta. These fish consisted primarily of redear sunfish and bluegill but also included rock bass, spotted sunfish, longear sunfish, green sunfish, and warmouth. Swingle et al. (1966) estimated that the "bream" harvest was 1.8 kg/ha (1.6 pounds/acre) in 1964. At the 1980 projected fishing pressure of 12.3 trips/ha (5 trips/acre) the harvest rate will be 5.7 kg/ha (5.0 pounds/acre) assuming that the catch per unit effort remains the same.

Black and white crappie made up 8.7% of the game-fish harvest in 1964. Crappie are more abundant in the deeper lakes of the middle and upper delta while "bream" are abundant in the shallow bays of the lower delta as well. The projected harvest of crappie in 1980 is 1.12 kg/ha (1.0 pound/acre) as compared to 0.35 kg/ha (0.31 pound/acre) in 1964.

Striped Bass

Striped bass once occurred commonly in waters of the Mobile Delta. Only a vestige of the native striped bass population remains, however, because of impoundments which block spawning areas, pollution, and other factors. An anadromous fish, the striped bass spawns in flowing freshwater and spends part of its life in salt or brackish water. The striped bass is a very good sport fish because it attains a large size and can be taken on live bait or artificial lures. The state record for this species is 25 kg (55 pounds).

An intensive stocking program of the Alabama Department of Conservation and Natural Resources and Auburn University has re-established a sport fishery for striped bass. Since 1967 the Marine Resources Division has stocked 2,032,936 striped bass fingerlings into the coastal waters of the delta, Auburn University Department of Fisheries and Allied Aquacultures has stocked 45,557 fingerlings, and the Game and Fish Division has stocked 574,010 fingerlings into fresh waters which drain into the delta. Many of the fish stocked upriver will enter the Mobile Delta. Under current environmental conditions in the Delta, the striped bass is not expected to spawn naturally. Therefore, a continuing stocking program will be required to maintain the now popular sport fishery.

Alligator Gar

The largest fish inhabiting the Mobile Delta is the alligator gar, with the possible exception of the Atlantic sturgeon which has a threatened status. These primitive fish are abundant especially in the mouths of rivers where they serve as both a predator and scavenger. Although the alligator gar is not a traditional favorite among fishermen, it is gaining in popularity because of its fighting ability and large size.

Overview of Sport Fishing

Sport fishermen harvested an estimated 246,202 game fish weighing 37,433 kg (82,526 pounds) from the Mobile Delta in 1964 (Swingle et al. 1966). This game-fish harvest which represents 73.5% of the harvest by sport fishermen, is equivalent to 2.9 kg/ha (2.6 pounds/acre). The 1980 projected harvest of game fish from the delta is 9.2 kg/ha (8.2 pounds/acre).

Marine fish accounted for 16.6% of the 1964 harvest. These fish consisted of spotted seatrout, silver seatrout, mullet, Atlantic croaker, spot, red drum, sheepshead, flounder, sea catfish, and gafftopsail catfish. The catch of marine species occurs only in the lower portions of the delta. The projected 1980 harvest of marine species by sport fishermen in the delta is 2.1 kg/ha (1.8 pounds/ acre).

Ten percent of the 1964 harvest by sport fishermen in the Mobile Delta consisted of non-game on commercial fish. Freshwater catfish (channel, blue flathead, and bullhead) comprised almost 8.2% of the catch. In 1980, the estimated harvest of non-game species by sport fishermen will be 1.2 kg/ha (1.1 pounds/acre). As a general management practice, the utilization of non-traditional species by sport fishermen should be encouraged. This practice reduces pressure on traditional game species and increases the total utilization of the resource.

Commercial Fishing

Current statistics on the freshwater commercial fishery of the Mobile Delta are not available. Commercial fishing is conducted in the Mobile Delta as a part-time and full-time enterprise. The primary species sought by commercial fishermen are catfishes (channel and blue), freshwater drum, and smallmouth buffalo, using trammel nets, gill nets, hoop nets, slat boxes, trot lines and snag lines.

A survey of commercial fishing conducted in 1964 (Spencer et al. 1966) indicated that 205 licensed commercial fishermen fished in the delta and harvested 274,827 kg (605,889 pounds) of fish.

Data collected by Shipp and Hemphill (1974) indicated that commercial species were relatively abundant in the lower Alabama River. Current exploitation rates on the commercial fishery of the Mobile Delta are necessary for making management decisions.

FACTORS AFFECTING FISHERIES RESOURCES OF THE MOBILE DELTA

Pollution and Habitat Alteration

Many activities associated with the growth and development of the Mobile area have had or potentially will have impact on the aquatic resources of the Mobile Delta. Reduction of habitat and alteration of habitat by physical and chemical means are the two basic ways human activities can adversely affect fisheries resources (Swingle 1975). Parts of the Mobile Delta have been affected adversely by both types of activities.

The Chickasaw Creek and Three Mile Creek areas are good examples of aquatic habitat with diminished value in regard to fisheries resources, and many wetland areas have been filled. There have been at least 26 documented fish kills caused by industrial or municipal discharges in this area. Because of tidal influence and poor flushing action, fish kills have extended miles upstream of the discharge points on Chickasaw Creek.

In 1971 the Alabama Water Improvement Commission adopted higher water quality standards for public waters of Alabama. The number of reported fish kills in the Chickasaw Creek - Three Mile Creek area as well as other public waters, has declined. This reduction in fish kills is largely due to stricter permits which limit the amounts of waste products which can be released into public waters.

By-pass Canals

In a study of fish populations and habitat in by-passed loops on the lower Alabama River, Shipp and Hemphill (1974) found that there were sport fishing benefits when meanders of the river were straightened to aid navigation. The reduction in current in the by-passed loop created desirable habitat such as submerged logs and brush tops where fish concentrate, centrarchids were more abundant, and the absence of barge traffic was desirable to fishermen.

However, because of the reduced current, deposition of suspended materials accelerated in the by-passed loop and altered important habitat types such as sand bars and flats. Siltation also can make these areas less accessable to fishermen.

Shipp and Hemphill (1974) concluded that canalization of loops in moderation is not detrimental to fish populations, and recommended that flow be maintained in the loops to reduce siltation and maintain the integrity of productive habitat areas.

Exotic Aquatic Vegetation

Infestations by exotic aquatic plants in the Mobile Delta has not been a problem in recent years. However, there is one plant species in the delta and another which has been found 105 km (65 miles) upriver from the delta that may pose a threat to fisheries resources.

Eurasian watermilfoil, *Myriophyllum spicatum*, is now common in the shallow bays of the lower delta, although Crance (1971) did not list this plant as a major species of aquatic vegetation in the Mobile Delta. In the TVA lakes Eurasian watermilfoil has caused serious problems requiring control. In Lake Seminole (Georgia) Eurasian watermilfoil was not found in 1967, but in 1968 approximately 284 ha (700 acres) were infested, and by 1977, 3,420 ha (8000 acres) of this 14,985-ha (37,000-acres) reservoir were infested with Eurasian watermilfoil (telephone call March 30, 1979 from David R. Bayne, Auburn University, Auburn, Al. 36830).

Eurasian watermilfoil can tolerate 33% sea water strength, can grow in depths up to 5 m (16.4 feet), is tolerant of low temperature (Tarver et al. 1978), and grows in such dense stands that boat traffic and fishing are impeded. Anderson (1972) reported that this plant has been a pest in Chesapeake Bay. Eurasian watermilfoil should thus be considered a potential threat to the resources of the Mobile Delta and Bay.

Hydrilla verticillata, commonly called hydrilla or Florida elodea, is considered to be the most problematic aquatic plant (Tarver et al. 1978). This submerged aquatic which originated in Africa, has caused serious problems in Florida and other southern states. Hydrilla has recently been found in Coffeeville Reservoir on the Tombigbee River, just upriver of the Mobile Delta. Hydrilla can tolerate a variety of water conditions including high turbidity and moderate salinity and can grow from the bottom in water over 15 m (49 ft) deep. Hydrilla is easily spread by fragmentation, tubers, turions (winter buds), and vegetative buds. The U.S. Army Corps of Engineers has begun a control program for hydrilla in Coffeeville Reservoir, but this pest will probably appear soon in the Mobile Delta.

The proper agency should be prepared to deal with nuisance infestations of Eurasian watermilfoil and hydrilla. Exotic aquatic plants will be more manageable if control begins early.

CONCLUSION

The Mobile Delta is a valuable resource to Alabama. Optimum utilization of the fisheries resources of this aquatic system has probably not been realized. Data on the present rate of exploitation of fish in the delta are needed to plan long-range management goals. This ecosystem may be adversely affected by industrial and urban development and infestations of exotic plants. The fisheries resources of the Mobile Delta support an irreplaceable recreational industry which produces thousands of jobs within the region. Adequate consideration of these valuable resources and aquatic habitat must be included in planning the use of the Mobile Delta.

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SUMMARY OF KNOWLEDGE OF FORAGE FISH SPECIES OF MOBILE BAY AND VICINITY

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ABSTRACT

Forage fish species of Mobile Bay are assigned to one of three ecological categories: 1) nearshore/marsh, 2) demersal estuarine, and 3) pelagic estuarine. Dominant species of the nearshore/marsh habitat are livebearers (*Poeciliidae*), killifishes (*Cyprinodontidae*) and silversides (*Atherinidae*). The former two families contain hearty species, resistant to contaminants, while the latter family includes species exhibiting little resistance. The demersal estuarine species are dominated by drums (*Sciaenidae*), and life history data are available, but tolerances to contaminants are not well documented in the literature. The most important forage group is the pelagic estuarine, dominated by anchovies (*Engraulidae*) and herrings (*Clupeidae*). Recent studies citing the place in the food chain and dietary preferences for the bay anchovy *Anchoa mitchilli* demonstrate its dependence on components of zooplankton.

Relative abundance tables indicate that where comparative data are available, most northern Gulf of Mexico estuaries support similar forage fish faunas. Information on early life history is recognized as the most critical need for this group of fishes, while information on species composition, seasonality, and occurrence frequency appears adequate. However, indications of stress on the Bay environment may be recognized by changes in these parameters.

INTRODUCTION AND SCOPE

This paper is intended to provide a summary of the information available regarding the biology of forage fish species of Mobile Bay. Emphasis of the discussion is directed towards those facets of their life history likely to be most affected by modification of the Mobile Bay environment. Thus synopses of works of species abundance, developmental stages, tolerances to environmental parameters, etc., are stressed, and additional references cited. Areas where informational gaps exist are noted, and possible value of forage fish data in the overall assessment of the Bay's well being is indicated.

At some period in its life history, any individual of almost any fish species can be considered a forage fish, that is one that is sought after or utilized as food. However, this report will consider as forage species those forms heavily preyed upon throughout their life cycle, especially by important commercial and sport species. Included are species that may be taken occasionally by sport fishermen, but for which no specific fishing effort is expended. Likewise, although nearly all species taken by animal food and fish meal processors are utilized, and thus can be considered to have commercial importance, most of these species are incidental when compared to more desirable forms, and also are treated herein. Those fish species of lower trophic levels frequently encountered in Mobile Bay, but for which no specific commercial or sportfishing effort exists, are listed in Table 1. A few forms such as Gulf menhaden (*Brevoortia patronus*) and Atlantic croaker (*Micropogonias undulatus*) are included in the table and discussion because, although components of a well-recognized commercial effort, they are also an important element in the forage fish population. Excluded are all predominantly freshwater forms such as species of the genus *Notropis*, which occasionally may venture or be carried into the brackish habitat. Inclusion of species in Table 1 is based on occurrences noted in previous studies of Mobile Bay (e.g., Boschung 1957, Swingle and Bland 1974, Shipp 1979), adjacent Mississippi Sound (e.g., Franks 1970, Franks et al. 1972, and especially Christmas and Waller 1973), and other [illegible]rn Gulf Coast estuaries (e.g., Fore 1975, Ogren and Brusher 1977, Naughton and Soloman 1978).

ECOLOGICAL ROLE OF FORAGE SPECIES

By definition, forage fish species are preyed upon by higher trophic level carnivores. However, different species obviously occupy different trophic levels and perform diverse ecological roles in estuarine systems such as Mobile Bay. To facilitate discussion of these roles, species treated herein are subdivided into three ecological categories based on their primary zones of occurrence. Each of

Table 1. Forage Fish Species Recorded from Mobile Bay.[1]

SCIENTIFIC NAME (COMMON NAME)	OCCURRENCE[a/]	FREQUENCY[b/]
Clupeidae (Herrings)		
Brevoortia patronus (Gulf menhaden)	P	Abundant
Dorosoma cepedianum (Gizzard shad)	P	Occasional
Dorosoma petenense (Threadfin shad)	P	Common
Harengula jaguana (Scaled sardine)	P	Occasional
Engraulidae (Anchovies)		
Anchoa hepsetus (Striped anchovy)	P	Common
Anchoa mitchilli (Bay anchovy)	P	Abundant
Synodontidae (Lizardfishes)		
Synodus foetens (Inshore lizardfish)	D	Common
Ariidae (Sea Catfishes)		
Arius felis (Sea catfish)	D	Abundant
Bagre marinus (Gafftopsail catfish)	D	Common
Batrachoididae (Toadfishes)		
Opsanus beta (Gulf toadfish)	D	Common
Porichthys plectrodon (Midshipman)	D	Common
Gobiesocidae (Clingfishes)		
Gobiesox strumosus (Skilletfish)	D	Common
Polynemidae (Threadfins)		
Polydactylus octonemus (Atlantic Threadfin)	D	Common
Gadidae (Codfishes)		
Urophycis floridanus (Southern hake)	D	Occasional
Sciaenidae (Drums)		
Cynoscion arenarius (Sand seatrout)	D	Abundant
Cynoscion nebulosus (Spotted seatrout)	D	Common
Bairdiella chrysura (Silver perch)	D	Common
Pogonias cromis (Black drum)	D	Occasional
Menticirrhus americanus (Southern kingfish)	D	Occasional
Sparidae (Porgies)		
Archosargus probatocephalus (Sheepshead)	D	Common
Lagodon rhomboides (Pinfish)	N	Common
Ephippidae (Spadefishes)		
Chaetodipterus faber (Atlantic spadefish)	P	Common

[1] Includes indication of ecological occurrence and frequency; a/ D = demersal, N = nearshore/marsh, P = pelagic estuarine; frequency categories are modified from Gilmore et al. (1978), as available from literature reports and collections by Shipp (1979); b/ Occasional = observed or collected at irregular intervals; common = species observed or taken in most to virtually all collections; abundant = common species present in large numbers.

Table 1. Continued

SCIENTIFIC NAME (COMMON NAME)	OCCURRENCE	FREQUENCY
Uranoscopidae (Stargazers)		
Astroscopus y-graecum (Southern stargazer)	D	Occasional
Blenniidae		
Hypsoblennius ionthas (Freckled blenny)	D	Common
Gobiidae (Gobies)		
Gobionellus boleosoma (Darter goby)	N	Common
Gobioides broussonnetti (Violet goby)	D	Occasional
Gobionellus hastatus (Sharptail goby)	N	Common
Gobiosoma bosci (Naked goby)	N	Common
Microgobius gulosus (Clown goby)	N	Occasional
Trichiuridae (Cutlassfishes)		
Trichiurus lepturus (Atlantic cutlassfish)	D	Common
Stromateidae (Butterfishes)		
Peprilus alepidotus (Harvestfish)	P	Common
Peprilus burti (Gulf butterfish)	P	Common
Triglidae (Sea robins)		
Prionotus rubio (Blackfin searobin)	D	Common
Prionotus tribulus (Bighead searobin)	D	Common
Gerriedae (Mojarras)		
Eucinostomus argenteus (Silver jenny)	N	Abundant
Belonidae (Needlefishes)		
Strongylura marina (Atlantic needlefish)	P	Common
Cyprinodontidae (Killifishes)		
Adinia xenica (Diamond killifish)	N	Common
Cyprinodon variegatus (Sheepshead minnow)	N	Abundant
Fundulus confluentus (Marsh killifish)	N	Common
Fundulus grandis (Gulf killifish)	N	Common
Fundulus jenkinsi (Saltwater topminnow)	N	Common
Fundulus similis (Longnose killifish)	N	Abundant
Lucania parva (Rainwater killifish)	N	Common
Poeciliidae (Livebearers)		
Gambusia affinis (Mosquitofish)	N	Abundant
Poecilia latipinna (Sailfin molly)	N	Abundant
Atherinidae (Silversides)		
Membras martinica (Rough silversides)	N	Occasional
Menidia beryllina (Tidewater silverside)	N	Abundant

Table 1. Continued

SCIENTIFIC NAME (COMMON NAME)	OCCURRENCE	FREQUENCY
Mugilidae (Mullets)		
Mugil cephalus (Striped mullet)	N	Abundant
Mugil curema (White mullet)	N	Occasional
Syngnathidae (Pipefishes)		
Syngnathus louisianae (Chain pipefish)	N	Occasional
Syngnathus scovelli (Gulf pipefish)	N	Common
Carangidae (Jacks)		
Chloroscombrus chrysurus (Atlantic bumper)	P	Common
Oligoplites saurus (Leatherjacket)	P	Common
Vomer setapinnis (Atlantic moonfish)	P	Occasional
Selene vomer (Lookdown)	P	Occasional
Sciaenidae (Drums)		
Micropogonias undulatus (Atlantic croaker)	D	Abundant
Leiostomus xanthurus (Spot)	D	Abundant
Bothidae (Left-eyed flounders)		
Citharichthys spilopterus (Bay whiff)	D	Common
Etropus crossotus (Fringed flounder)	D	Occasional
Soleidae (Soles)		
Achirus lineatus (Lined sole)	D	Occasional
Trinectes maculatus (Hogchocker)	D	Abundant
Cynoglossidae (Tongurfishes)		
Symphurus plagiusa (Black cheek tonguefish)	D	Common
Tetraodontidae (Puffers)		
Sphoeroides parvus (Least puffer)	D	Common
Diodontidae (Porcupine fishes)		
Chilomycterus schoepfi (Striped burrfish)	D	Occasional

these categories is treated in terms of its physical and chemical parameters as it may influence the included species. These are not mutually exclusive categories, and some overlap may exist.

The three ecological categories are:

1) Nearshore/Marsh habitat (N)
2) Demersal estuarine habitat (D)
3) Pelagic estuarine habitat (P)

All species listed in Table 1 are assigned to the category judged to be their primary area of activity during the late juvenile to adult phase of their life history. These assignments were made based on extensive personal observations as well as literature data (e.g., Swingle and Bland 1974, Ogren and Brusher 1977, Naughton and Soloman 1978).

Nearshore/Marsh Zone

Physical properties of the nearshore area, including salt marsh, beach, mud bottom, and intermediate habitats are described elsewhere in this volume. Recent reports dealing with environmental modification and degradation as they influence nearshore biota, especially fishes, in the north central Gulf of Mexico include Bechtel and Copeland (1970) for Galveston Bay, Fore (1975) for Escambia Bay, and Livingston (1975) for Apalachicola Bay. May (1973) reported on effects of dredging in Mobile Bay, but accorded only tangential attention to fishes.

Livebearers (*Poeciliidae*), killifishes (*Cyprinodontidae*), and silversides (*Atherinidae*) dominate the nearshore populations of forage fishes in Mobile Bay. In addition, numerous species of other families such as the mullets (*Mugilidae*), ladyfishes (*Elopidae*), and mojarras (*Gerreidae*), use the nearshore areas as refuge during juvenile stages of their life history. Life history studies for nearshore species of the northern Gulf region include Simpson and Gunter (1956) for cyprinodontids, Hastings and Yerger (1971) for the diamond killifish (*Adinia xenica*) and Relyea (1975) for killifish distributions. In addition the contribution of Franks (1970) on the fish populations of the inland freshwaters of Horn Island, Mississippi are directly applicable to many similar habitats in the vicinity of lower Mobile Bay. His data indicate overwhelming dominance of livebearers, killifishes and silversides in his study area. Franks (1970) and Christmas and Waller (1973) list these species, including abundance data, for the Mississippi Sound area. These and other studies previously cited give indication of general abundance, from which data in Table 1 were derived. In addition, Naughton and Soloman (1978) provided detailed data on abundance, seasonality, and species composition of the St. Andrew Bay, Florida estuary, also located along the Northern Gulf. No table of comparative abundance is provided for nearshore/marsh zone fishes because studies of Mobile Bay were trawl oriented and biased against collections of these forms.

Of special interest is the response of nearshore/marsh resident fish species to pesticide contamination. This area frequently is subjected to direct application of insecticides and larvicides for mosquito control. The majority of permanently resident forage fish species in this region, the killifishes and livebearers, contains species, such as the mosquito fish (*Gambusia affinis*), which are voracious predators on mosquito larvae. Fortunately, species of both these families are frequently tolerant of chemical introductions. For example, Cherry et al. (1975) demonstrated that *Gambusia affinis* survived numerous elemental concentrations and high temperature stress conditions which were lethal to other fish species. In addition, Jolly et al. (1978) showed this same species to be more tolerant than other unrelated fish species when tested with concentrations of permethrin, a pesticide widely used for insect control in the Southeast. Species in these families are noted for their tolerances to wide fluctuations in physical parameters (Simpson and Gunter, 1956; Hastings and Yerger, 1971) and there may be a physiological relationship between this and their tolerance to some pesticides.

Numerous families (e.g., drums (*Sciaenidae*), porgies (*Sparidae*), ladyfishes (*Elopidae*), and silversides represented in the Mobile Bay nearshore areas (Table 1), contain forms less able to tolerate pollution or other stressful environmental deterioration. For example, Morgan and Prince (1977) worked with chlorine toxicity to eggs and larvae of several estuarine forms, including the tidewater silverside (*Menidia beryllina*), an abundant Mobile Bay nearshore species. Although comparative data were few, indications were of a highly sensitive very early developmental period of the eggs, with 95% mortalities resulting from about 0.5 mg/l residual chlorine levels. His results indicated that eggs several days old had sharply increased resistance.

Another aspect of pollution in nearshore areas is interference of trophic relationships due to behavioral modification of affected species. Mirex significantly impeded escape capabilities of grass shrimp (*Palaeomonetes vulgaris*), a widespread species in nearshore areas of Mobile Bay, in the presence of the predatory pinfish (*Lagodon rhomboides*) (Tagatz 1976), while gulf killifish (*Fundulus grandis*) preyed more successfully on crustaceans when the pesticide methyl parathion was present (Farr 1978). Farr suggested such effects in estuaries could alter species composition and species diversity. Of special interest in these studies is the increased vulnerability of the crustacean species to predation by fish species. Such effects on a broad scale might drastically alter the present relationship between forage fish species and their prey in Mobile Bay, especially as it concerns juvenile commercial shrimp.

Most predatory species entering the nearshore area are opportunistic carnivores, and large enough to capture the forage species found there. Those commercially important predatory species most likely to be found in this zone of Mobile Bay are southern flounder (*Paralichthys lethostigma*), spotted sea trout (*Cynoscion nebulosus*), sand seatrout (*Cynoscion arenarius*), and red drum (*Sciaenops ocellatus*).

Demersal Estuarine Zone

Mobile Bay is characterized by a mud bottom, rich in nutrients and fine sediment, with few sand or grassy areas. The fish populations of the demersal estuarine zone are dominated therefore by forms preferring such habitat. The bottom is subjected also to wide daily and seasonal fluctuations of salinity, temperature, and oxygen, primarily due to tidal intrusion of the salt wedge, and sporadic high levels of runoff from regional precipitation. These parameters are discussed in detail in other sections of this volume.

The forage fish species inhabiting the demersal estuarine region are primarily detritus feeders and carnivorous scavengers. Their distribution throughout the Bay system probably is based on the bottom characteristics associated with food availability, and fluctuations of the physical parameters mentioned above. However, many of the species included in Table 1 as demersal species spawn offshore during well-defined spawning seasons (e.g., the porgies) while others display well-defined seasonal movements through the estuary (e.g., soles). Therefore, seasonal distribution in the Bay is a function of a certain growth stanza.

Pelagic forms were not distinguished from demersal forms in surveys of Mississippi Sound (Christmas and Waller 1973), Mobile Bay (Swingle and Bland 1974), Apalachicola Bay (Livingston 1976) or St. Andrew Bay (Ogren and Brusher 1977). However, based on the categories assigned in Table 1, those species considered demersal are listed in Table 2 by order of abundance for the various northern Gulf estuaries for which appropriate data were available. These data indicate a high degree of similarity, with drums numerically dominant in all estuaries. Similarity between estuaries would be even greater except for the sporadic occurrence of the Atlantic threadfin (*Polydactylus octonemus*) in tremendous numbers throughout the northern Gulf during 1972 and 1973 (Ogren and Brusher 1977), and reflected in the St. Andrew Bay data in Table 2.

Recently Ogren and Brusher (1977) provided detailed data on seasonal abundance for 50 species occurring in the St. Andrew Bay, Florida estuary. These were mostly demersal forms and their data strongly indicate a marked increase in abundance for most species and in species diversity in spring and summer. Comparable data in even greater detail were provided earlier by Christmas and Waller (1973), and both reports were in basic agreement. Due to their lesser numbers, and time spent away from the estuary, the demersal estuarine forage-fish fauna is probably less important, as a forage resource, than the midwater fauna discussed below.

Life history studies of individual species are scattered. The most comprehensive source for these data in the northern Gulf is the excellent study of Christmas and Waller (1973) in Mississippi Sound. More detailed studies of individual species include the study of food habits of *Symphurus plagiusa* in Georgia (Stickney 1976), the study of resource partitioning in several sciaenid species in the Apalachicola estuary of Florida (Sheridan 1979), and studies on feeding preference by larval forms of demersal

Table 2. Demersal estuarine forage fish species listed in descending order of abundance for several northern Gulf of Mexico estuaries.

MISSISSIPPI SOUND	MOBILE BAY		ESCAMBIA BAY	ST. ANDREW BAY	APALACHICOLA BAY
	Mid Bay	Watercourses			
Micropogonias undulatus	*Micropogonias undulatus*	*Micropogonias undulatus*	*Leiostomus xanthurus*	*Polydactylus octonemus*	*Micropogonias undulatus*
Leiostomus xanthurus	*Leiostomus xanthurus*	*Leiostomus xanthurus*	*Micropogonias undulatus*	*Micropogonias undulatus*	*Cynoscion arenarius*
Cynoscion arenarius	*Cynoscion arenarius*	*Cynoscion arenarius*	*Cynoscion arenarius*	*Leiostomus xanthurus*	*Leiostomus xanthurus*
Anopsis felis	*Sphoeroides parvus*	*Gobiosoma boleosoma*	*Polydactylus octonemus*	*Symphurus plagiusa*	*Baridiella chrysura*
Trinectes maculatus	*Arius felis*	*Lagodon rhomboides*	*Ariopsis felis*	*Lagodon rhomboides*	*Polydactylus octonemus*
Bairdiella chrysura	*Trichiurus lepturus*	*Bairdiella chrysura*	*Lagodon rhomboides*	*Orthopristis chrysoptera*	*Ariopsis felis*

[1] Mississippi Sound, Mississippi data from Christmas and Waller (1973); Mobile Bay, Alabama, from Shipp (1979) for mid-Bay and Swingle and Bland (1974) for watercourses; Escambia Bay, Florida, data from Fore (1975); St. Andrew Bay, Florida, data from Naughton and Soloman (1978); Apalachicola Bay, Florida from Livingston (1976).

species (Kjelson et al. 1975) for the Newport river estuary in North Carolina. Complete life history studies for those forms of little or no direct commercial value are few; however, Caldwell (1957) provides a complete life history treatment of the pinfish, *Lagodon rhomboides*, and the study by Springer and Woodburn (1960) remains the classic general ecological treatment of Gulf of Mexico estuarine forms.

Pelagic Estuarine Zone

The pelagic estuarine zone, as defined by Rounsefell (1975), is the water column above the estuary bottom. Swingle and Bland (1974) have indicated that those species, considered herein (Table 1) as pelagic estuarine forms, are numerically the most important forage fish species in Mobile Bay. In addition, there are strong similarities in species composition among northern Gulf estuaries where appropriate data are available based on the same reports used in comparison of demersal forms (Table 3).

The predominance of *Anchoa mitchilli* in all these studies underscores the importance of this species as a forage organism. This species, the more halophilic *A. hepsetus*, and possibly other engraulid species, are well known to sports fishermen and commercial fishermen as "anchovies." Schools are in evidence throughout the lower Bay by their "roughening" of the surface, by appearance in large numbers of individuals from regurgitation by Spanish mackerel (*Scomberomorus maculatus*) when boated, and by flocks of terns seeking them out for food.

One of the most important studies on life history aspects of the bay anchovy has been published recently by Sheridan (1978) for Apalachicola Bay populations. His data stress ontogenetic, spatial and temporal aspects of the food habits of *A. mitchilli*, and indicate calanoid copepods are a major dietary component; however, their importance declines with anchovy growth, and importance of mysids increases. Insect larvae and cladocerans were also major food items for populations near the mouth of the Apalachicola River.

Such studies are extremely important in understanding the intricate relationships of trophic levels in estuarine systems, and emphasize the potential hazards of pesticides and habitat modifications. These factors may have severe effects on commercial and sport fisheries by adversely affecting organisms not readily recognized as critical. Sheridan's tables of *A. mitchilli* food organisms are detailed by length grouping, site, and season, and probably could be applied to the Mobile Bay system. Darnell (1958) also provided comparable food preference data for Lake Pontchartrain, Louisiana, and the species he discussed are generally the same as those of the Mobile Bay system.

Of the pelagic estuarine species listed in the

Table 3. Pelagic estuarine forage fish species listed in descending order of abundance for several northern Gulf of Mexico estuaries. Sources as in Table 2.

MISSISSIPPI SOUND	MOBILE BAY		ESCAMBIA BAY	ST. ANDREW BAY	APALACHICOLA BAY, FLORIDA
	Mid Bay	Watercourses			
Anchoa mitchilli	*Anchoa mitchilli*	*Anchoa mitchilli*	*Anchoa mitchilli*	*Anchoa mitchilli*	*Anchoa mitchilli*
Brevoortia patronus	*Anchoa hepsetus*	*Brevoortia patronus*	*Brevoortia patronus*	*Harengula juguana*	*Harengula juguana*
Peprilus burti	*Brevoortia patronus*	*Dorosoma petenense*	*Anchoa hepsetus*	*Anchoa hepsetus*	*Chloroscombrus chrysurus*
Anchoa hepsetus	*Dorosoma petenense*	*Anchoa hepsetus*	*Chloroscombrus chrysurus*	*Brevoortia patronus*	Not Available
Harengula jaguana	*Peprilus alepidotus*	*Oligoplites saurus*	*Harengula jaguana*	*Peprilus burti*	Not Available
Chloroscombrus chrysurus	*Vomer setapinnis*	*Chloroscombrus chrysurus*	*Peprilus alepidotus*	*Chloroscombrus chrysurus*	Not Available

Table 1, all but *A. mitchilli* are more or less transients. Species of the shad genus *Dorosoma* are anadromous, and while adults may spend extended periods in upper estuaries, the juveniles are inhabitants of coastal streams and rivers (Smith-Vaniz 1968, Shipp and Hemphill 1973). Therefore their value as forage in the Mobile Bay estuary is lessened. Likewise, the Gulf menhaden *Brevoortia patronus* is a quasicatadromous form; however, the larger juveniles and adults frequent the lower Bay system.

The scaled sardine, *Harengula jaguana*, was noted in abundance from the more easterly northern Gulf estuaries but its ranking is much less in the Mobile Bay system. However, this form is more halophilic than other species listed and though not abundant in the upper and mid Bay regions, it becomes extremely abundant in the lower Bay and around barrier islands. It is thus an integral component of the forage populations, especially for the Gulf predators such as larger jacks (Carangidae) and mackerels (Scombridae). Life history data on this species are summarized by Houde et al. (1974) and indicate that spawning in the lower peninsular Florida area is close to shore. This implies potential susceptibility to runoff pollutants of the Bay during critical early life history stages.

All the pelagic estuarine species discussed above are members of the order Clupeiformes (clupeids), which includes shad, herring, and anchovies. Clupeids, especially *Brevoortia*, comprise the majority of victims of summer "fish kills" (Christmas and Waller, 1973). These are caused by lowered dissolved oxygen levels, frequently a result of poor circulation during summer, and possibly industrial or municipal discharge. Fore (1975) discussed numerous fish kills in Escambia Bay, Florida, and suggested industrial pollution operating with the synergistic effect of warm summer water was a major cause.

Several small species of jacks such as the Atlantic bumper (*Chloroscombrus chrysurus*), the leatherjacket (*Oligoplites saurus*) and the Atlantic moonfish (*Vomer setipinnis*) occupy intermediate trophic levels between smaller forage fish species and top carnivores in Mobile Bay. These forms rarely exceed 20 to 30 cm in total length, and occur in large schools near the mouth of Mobile Bay and around barrier islands. They are thought to be quasicatadromous, and young juveniles apparently migrate well up into the Bay where they frequently are trawled in significant numbers. Comments on ecology and life history of lesser known species such as these are best sought in the synoptic treatments, such as Christmas and Waller (1973) and Springer and Woodburn (1960).

Discussion

Compared to some other groups of organisms (e.g., plankton, infauna) knowledge of forage fish species frequenting Mobile Bay is plentiful. Information on species composition, abundance, and distribution appears well documented for most regions of the Bay, and comparisons to adjacent estuaries are readily available. However, information on early life history of many forms is widely scattered, sparse, or lacking entirely. Recently, this condition has been partially remedied by the appearance of the "Fishes of the Mid Atlantic Bight" (U.S. Department of Interior 1978), which provides an extensive compilation of data on early life history phases for many forms. However, little of this report is directly applicable to the north central Gulf. In Mobile Bay, a study is presently underway by students of University of South Alabama, Dauphin Island Sea Lab, assessing distribution of eggs and larvae in the lower Bay.

Information on early stages of life history is fundamental in evaluating the status of any species or group of species. During these stages natural fluctuations of physical parameters can eliminate massive numbers of individuals. When combined with synergistic effects of introduced products, effects may be drastic. Therefore, intensified early life history studies, designed to determine seasonality and distribution of spawning stocks appears as a high priority goal.

One of the most important contributions regarding pollutants in estuaries is that of Sindermann's review (1979) of pollution associated diseases and abnormalities of fin fish and shellfish. Included in his conclusions is the following:

> "The presence of marginal or degraded estuarine/coastal environments may be signaled by the appearance of, or the increase in prevalence of a number of diseases, including fin erosion, red sores, ulcers, and possibly lymphocystis in fish. . ."

It is in this respect that forage fishes are functional indicators. The high numbers of specimens available (e.g., 611,972 in the Mississippi Sound study of Christmas and Waller, 79,372 in the Escambia Bay study of Fore and 99,579 in the St. Andrew Bay study of Naughton and Soloman) make possible statistical comparisons of the health and species composition of the populations. In addition, the appearances of such abnormalities need to be monitored closely, as should significant changes in species composition, as possible indicators of undesirable influences on the Bay.

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A SUMMARY OF INFORMATION PERTINENT TO THE MOBILE BAY RECREATIONAL FINFISHERY AND A REVIEW OF THE SPOTTED SEATROUT'S LIFE HISTORY

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ABSTRACT

Specific data on Mobile Bay as a sportfishing area are not available. However, data including the Mobile Bay sportfishery were collected during 1975. The Mobile Bay recreational fishery is largely a shoreline fishery.

In 1975, marine recreational anglers harvested 3,641 metric tons (8,027,779 pounds) of fishes' and devoted more than 3.7 million man-hours to sportfishing.

Primary factors that may affect the marine sportfishery of Mobile Bay are physical and chemical habitat alteration and fishing pressure. The degree to which the availability of fishes is affected by these factors is not known.

Physical alteration has been due largely to dredge and spoil operations conducted in Mobile Bay since 1827. Spoil banks along the eastern edge of the Mobile Bay Ship Channel have compounded the water circulation problems in the eastern bay and have contributed to salinity stratification and oxygen depletion.

Typical water-borne pollutants flowing into Mobile Bay include: oxygen demanding organic materials, pesticides, petroleum products, silt, sewage and various substances found in upland runoff.

A review of the life history of the most important recreational species found in Mobile Bay, the spotted seatrout (*Cynoscion nebulosus*) is included.

INTRODUCTION

This is a summary of the available information that is pertinent to the marine recreational fishery of Mobile Bay. Research data relative to the sportfishery in Mobile Bay are extremely limited. The single most important recreational species found in the Bay is the spotted seatrout (*Cynoscion nebulosus*) known locally as the speckled trout. A review of its life history is included.

DESCRIPTION OF FISHERY

Statistics

Specific data on Mobile Bay as a sportfishing area are not available. The only data including the Mobile Bay sportfishery were collected during 1975 (Wade 1977). With the exception of the northern and southern most extremities, the Bay's sportfishery is comprised primarily of shoreline anglers (small private and commercial piers included). Wade estimated that 43,560 "fisherman occasions" occurred along the shorelines of Mobile and Baldwin counties. The term fisherman occasion is defined as any one-time fishing activity conducted by one individual. Wade estimated 308,045 boat and shoreline trips representing 765,117 fisherman occasions were made by anglers fishing the marine waters of Alabama during 1975. It is possible that a decline in sportfishing along the Gulf coastal waters has occurred between 1976 and 1978 due to the lack of an adequate supply of king mackerel (*Scomberomorus cavalla*).

In 1975 the Alabama marine recreational fishery represented expenses of more than $4.9 million on expendable items directly related to one-time fishing events (Wade 1977). More than 3.7 man-hours were devoted to that pastime (Table 1). Wade estimated that 3,641 metric tons (8,027,779 pounds) of fishes were harvested by recreational anglers (Table 2). Swingle (unpublished 1964, Completion Report, Alabama Department of Conservation and Natural Resources) estimated that 8.4 metric tons (18,600 pounds) of marine fishes were harvested by recreational fishermen in the delta area at the north end of Mobile Bay during July 1, 1963 to June 30, 1964. However, no estimate was made for the balance of the marine sportfishery that year.

Table 1. Estimated Catch (pounds) of Marine Sportfish in Alabama During 1975.

	Private Boat	Pier	Shoreline	Charter Boat	Total
Amberjack	10,306	–	–	133,144	143,450
Black drum	–	5,285	5,147	–	10,432
Bluefish	885,182	17,155	5,923	–	908,260
Blue runner	63,560	1,503	–	–	65,063
Catfish	80,699	51,360	8,909	–	140,968
Cobia	100,565	32,673	–	5,544	138,782
Croaker	441,477	40,715	43,957	–	526,149
Dolphin	51,689	–	–	6,028	57,717
Flounder	76,884	44,869	4,476	–	126,229
Grouper		–		3,850	3,850
Jack crevalle	156,051	39,283	15,989	4,969	216,292
Kingfish	70,092	53,029	17,641	–	140,762
King mackerel	939,054	38,438	–	76,494	1,053,986
Ladyfish	163,972	5,652	–	–	169,624
Little tunny	333,506	7,396	–	47,542	388,444
Mullet	42,583	2,855	35,062	–	80,500
Pompano		1,267	64	–	1,331
Red drum	306,719	35,723	44,690		387,132
Sand seatrout	483,822	17,586	18,893	–	520,301
Shark	563,028	33,662	–	–	596,690
Sheepshead	145,030	49,208	10,698		204,936
Snapper	79,410	1,750	–	57,882	139,042
Spanish mackerel	920,622	26,589		14,498	961,709
Spotted seatrout	774,740	14,679	9,218	–	798,627
Miscellaneous	195,568	34,413	17,512	–	247,493
GRAND TOTALS	6,884,559	555,090	238,179	349,951	8,027,779

Fishes

Important marine fishes caught by recreational anglers in Mobile Bay are included in Table 3. Large schools of tarpon observed in lower Mobile Bay during July and August of 1978 (Wade, personal observation) increase the possibility of the return of this fishery that flourished as recently as the late 1950's.

FACTORS AFFECTING THE SPORTFISHERY

Habitat Alteration

Physical

Physical alteration of habitat for marine fin-

Table 2. Summary of Information Pertinent to the Alabama Marine Recreational Fishery During 1975.

	Private Boat	Pier	Shoreline	Charter Boat	Total
No. trips	247,858	32,219	23,942	4,026	308,045
No. fisherman occasions	621,680	79,774	43,560	20,130	765,117
Expenses	$3,365,301	$763,623	$230,668	$593,835	$4,953,427
Hours fished	1,141,444	197,195	129,283	32,208	1,500,130
Man-hours fished	2,884,722	499,712	231,452	161,040	3,776,926
Pounds caught	6,884,559	555,090	238,179	349,951	8,027,779
Pounds per man-hour	2.39	1.11	1.03	2.17	

Table 3. Important Marine Fishes in Mobile Bay Utilized by the Recreational Fishery.

Atlantic croaker	*Micropogonias undulatus*
Black drum	*Pogonias cromis*
Bluefish	*Pomatomus saltatrix*
Crevalle jack	*Caranx hippos*
Gulf flounder	*Paralichtys albigutta*
Kingfishes	*Menticirrhus* spp.
Red drum	*Sciaenops ocellata*
Sheepshead	*Archosargus probatocephalus*
Sand seatrout	*Cynoscion arenarius*
Spotted seatrout	*Cynoscion nebulosus*
Striped mullet	*Mugil cephalus*
Tarpon	*Megalops atlantica*
Tripletail	*Lobotes surinamensis*

fishes has occurred in Mobile Bay primarily from dredging of channels and placement of spoil in adjacent waters. Dredging of Mobile Bay was first done in 1827 (May 1973a), although only the outer bar was affected. Between 1870 and 1957 the Mobile Ship Channel was dredged to its present length, width, and depth. Between 1871 and 1971 approximately 331,000,000 m^3 (253,215,000 cubic yards) of spoil were placed in Mobile Bay adjacent to the ship channel. The relief of these spoil banks has created large basins in which the bottom waters have become isolated from the surrounding estuary. This situation is particularly prevalent in the area east of the ship channel between Daphne and Mullet Point. Water circulation has been altered to the point that salinity stratification occurs and oxygen depletion has become a frequent problem. This problem is compounded by the influx of organic matter from rivers entering the Bay east of the ship channel. When slugs of this oxygen deficient water escape into the adjacent estuary to the east, "jubilees" occur along the eastern shore of Mobile Bay. Generally, the more pelagic fishes are not directly affected by this phenomenon; however, sessile benthic organisms and plantonic organisms are often suffociated. Probably the greatest effect of this phenomenon on the sportfishery is the loss of aquatic organisms in the food chain. The effect on larval and juvenile sportfishes is not known. This is an area that needs investigation. This phenomenon is particularly stressful on demersal fishes such as flounders.

Physical alteration by filling of coastal wetlands not only deprives marine organisms of habitat, but also decreases the amount of detrital-based nutrients available to organisms on the lower end of the food chain. The value of the marshlands as a source of filtration for water-borne pollutants is well documented. Wetlands of Mobile Bay have been filled during construction of causeways, the dredging of various channels and in the process of industrial, military, and residential expansion. The loss of marshlands on a cumulative basis can ultimately have a detrimental effect on the marine sportfishery. The degree to which the sportfishery in the Bay has been affected by such activities cannot be determined because of the lack of historical recreational catch statistics.

Chemical

Pollution is a major threat to estuaries. Typical pollutants found in estuaries include oxygen-demanding organic materials, pesticides, petroleum products, silt, radioactive substances, heavy metals, heat, sewage and various substances found in upland runoff. With the possible exception of radioactive substances, Mobile Bay receives all of the above. Few, if any, estuarine areas in Alabama are in pristine condition.

The Mobile Bay-Mobile Delta-Mississippi Sound complex comprises 95% of the total open water area of the Alabama estuaries (Crance 1971). Currently there are at least 56 known point sources of industrial and municipal effluent flowing into the Mobile Bay area (unpublished, 1979, Draft Environmental Impact Statement - Theodore Industrial Pipeline, U.S. Army Corps of Engineers, Mobile, Alabama). The most obvious result of this pollution is the adverse effect on the oyster fishery. The extent to which the sportfishery is affected by these water-borne pollutants is now known. Undoubtedly the degradation of water quality by various pollutants has had at the very least an effect on the availability of marine sportfish in the Bay. Many anglers feel that the decline in the tarpon fishery in Mobile Bay is a direct result of the presence of water-borne pollutants.

The Mobile River system carries an estimated annual average of 4.3 million metric tons (4.7 million tons) of suspended solids into Mobile Bay (Ryan 1969). Alteration in circulation patterns due to construction of the ship channel has caused the sedimentation rate in the southwest portion of the Bay to increase. The effect of this sedimentation on the sportfishery is unknown.

The effects of dredging operations in Mobile Bay were studied by May (1973b). He reported that effluents from maintenance dredging generally have no widespread or long term deleterious effects on estuaries and indicated that gross physical modifications as a result of spoil deposits and channel dredging were far more likely to affect water quality on a long term basis.

Fishing Pressure

The degree to which the availability of fishes is affected by fishing pressure is not known. However, it seems reasonable to assume that the number of fishes available to each angler has decreased as the number of anglers has increased.

Most, if not all, of the species utilized by the recreational community are also harvested by commercial interests. The degree to which important species are affected is not known.

There is a 4.9-m (16 foot) sport trawl fishery that utilizes many of the same species that are taken by hook-and-line anglers. The degree to which the hook-and-line fishery is affected by this trawl fishery is not known.

RESEARCH NEEDS

Important research needs include the following:

1. The life histories of all important finfishes in Alabama estuaries should be determined.
2. Statistical data that will delineate the recreational catch by water body in all Alabama estuaries are needed. Catch-effort data should be included.
3. The precise degree to which the recreational harvest is affected by the commercial harvest should be clearly understood.
4. A determination of the effects on the finfishery caused by dredging of channels and creation of spoil banks should be made.
5. The degree to which the food chain and larval and juvenile forms of important species have been and are being affected by the filling of wetlands surrounding the estuary should be investigated.
6. The degree to which oxygen depletion affects larval and juvenile forms of important finfish species should be studied.
7. The degree to which the fishery is affected by water-borne industrial and municipal pollutants should be determined.
8. The degree to which water-borne substances alter water quality and habitat should be determined.
9. The degree to which sedimentation from upland sources affects benthic biota and habitat should be studied.
10. Age and growth data and population dynamics data need to be collected for key marine species.

MANAGEMENT

Formulation of effective management programs is impossible without a sufficient data base. Specific recommendations cannot be made before specific problems are studied. Management regimes should be geared to biological principals where possible. Social and political problems affecting the fishery should be understood and dealt with on a case-by-case basis with underlying biological principals playing a major role in decision making. Through knowledge of the life history and population dynamics of each species is essential to formulation of management recommendations. Many management plans incorporate restrictions on gear type and size, catch quotas, restricted fishing areas (sanctuaries), restrictions on minimum and/or maximum size, and restrictions by season. Whether any of the above restrictions are necessary in the Mobile estuary is not known.

The Alabama Marine Resources Division drafted legislation to obtain a saltwater sportfishing license in 1971 and has pursued a license during every subsequent legislative session. Initially there was very little understanding on the part of legislators and the general public for the need. However, in recent years wide spread support for the license has begun to develop. The license is needed to finance the development of the sportfishery and to obtain accurate statistics on the user group.

LIFE HISTORY OF SPOTTED SEATROUT (*CYNOSCION NEBULOSUS*)

Distribution

The spotted seatrout occurs from Cape Cod to the Gulf of Campeche. It is found in coastal areas and is primarily a warm water fish that is abundant throughout the Gulf States (Guest and Gunter 1958).

Reproduction

Spotted seatrout reach sexual maturity between the ages of one and four years with males maturing earlier (Guest and Gunter 1958). Most females do not spawn until their second or third summer while some males spawn at age one. Sexual maturity occurs between 210 mm (8.27 inches) and 270 mm (10.63 inches) in females and 180 mm (7.09 inches) and 250 mm (9.84 inches) in males.[1/] However, some data indicate that sexual maturity occurs at different ages and at different sizes in various estuaries.

Fecundity estimates range from around 15,000 eggs to over 1,100,000 eggs. The greatest fecundity occurs in age IV fish (average size 504 mm or 19.84 inches) while age-class III has the greatest spawning power (average size 450 mm or 17.72 inches).[1/]

The spawning season ranges from March to October in south Florida and from May through September along the northern Gulf Coast. In south Florida ripe females were found year round and peak spawning may be bi-modal with peak periods varying among estuaries. Spawning areas are believed to be in deeper channels and holes adjacent to shallow flats, bays and bayous. Spawning occurs at night. Optimal spawning temperature appears to range between 20° C (68° F) and 30° C (98° F) with optimal salinity occurring between 20 and 35 parts per thousand (ppt).[1/]

Age and Growth

Characteristics of age and growth vary among populations from different estuaries. It appears that several factors influence age and growth: food supply, predators, temperature, salinity, optimum habitat.[1/] Temperature is probably the single most important factor. Growth does not appear to be continuous throughout the year and obtaining accurate age and growth data is hampered by the prolonged spawning period characteristic of spotted seatrout and by overlapping of year classes.

Tatum (1978) examined catch records from annual fishing tournaments (1964-1977) in Baldwin County and concluded that age-class III+ represented the first age group that is fully vulnerable to the sportfishery. He stated that the degree to which this year-class contributes to the fishery determines to a large extent the availability of seatrout to the angler. He estimated the mortality rate to range between 36.2% and 58.1% with an average of 49.8%. He concluded that the two most exploited age-classes were II+ and III+. Tatum compared growth data from Texas fish and found them to be similar. He concluded that Alabama's size limit of 305 mm (12.0 inches) total length, is adequate based on a 50% sexual maturity rate for trout 250 mm (9.8 inches).

Kline and Tabb[1/] found while working in Florida that male fish outnumber female fish in the one- to three-year olds and may be three to four times as numerous. Males apparently do not live beyond age eight and do not comprise more than 18% of the population beyond age five. The significance of these sex ratios is not understood. Kline and Tabb's data suggest that a significant portion of the trout fishery, which is represented by males one- to three-years old, is lost to natural mortality before they reach age five. Stewart[1/] found roughly equal sex ratios in his study of Florida Bay fish through age three, but females predominated ages 4 through 7. This sex-related differential mortality is an important area that needs further investigation before we can understand problems associated with seatrout abundance.

Food Habits

Stomach content analysis has revealed that shrimp and small finfish constitute the bulk of the diet for seatrout (Guest and Gunter 1958). Postlarval seatrout feed on larval and postlarval shrimp, copepods, small fish and crabs.[1/] Apparently their diet changes with size. Fingerling seatrout (132-225 mm or 5.2-8.9 inches) prefer invertebrates. As young adults (226-350 mm or 9.8-13.8 inches) they prefer a mixture of vertebrates and invertebrates and as large and old fish (351 mm+ or 13.8 inches+) they prefer primarily vertebrates. Seatrout prefer to feed in the morning hours.[1/]

Temperature and Salinity Tolerance

Tabb[1/] reported in 1958 that the optimum temperature range for seatrout was from 15° C (59° F) to 27° C (81° F). Seatrout have been found in temperatures as low as 4° C (39° F) and as high as 33° C (91° F). Fish kills have been observed when strong cold fronts suddenly move through the south Alabama area. This undoubtedly happens when the fish are too far from the deeper and warmer water to escape the sudden temperature change.

Temperature influences abundance in seatrout populations. Increases in seatrout abundance have been noted in areas of thermal effluent.[1/] Decreases in abundance have been noted after unusually cold winters which may result from fish kills, a decrease in spawning success, or both. A survey of the literature indicated that temperature may be the single most influential environmental factor in seatrout abundance.

Guest and Gunter (1958) reported the optimum salinity range to be from 5 to 20 ppt. Seatrout have been found in salinities ranging from 0.2 ppt to 75 ppt.[1/] Spawning has not been reported in salinities above 45 ppt (Guest and Gunter 1958).

Movement

Tagging investigations along the Gulf Coast have confirmed that the seatrout is primarily a resident fish that normally does not move more than an average of 48 km (30 miles). The maximum movement recorded is 563 km (315 miles).[1/] Seatrout tend to school throughout most of their life but may lose this tendency with old age.

Temperature, salinity and availability of food are important factors governing the movement of seatrout. Tag returns from seatrout tagged in Alabama have been too limited in number to delineate any pattern.

Habitat

Large shallow grassy flats of brackish water areas are believed to offer optimum support for young seatrout populations. These areas should be located close to channels or other deep water areas to offer refuge from winter cold fronts. Grass flats such as these are quite limited in Mobile Bay and their importance to Alabama populations is not known. Mobile Bay may not be optimum habitat for seatrout because large expanses of grass flats are not present, and the Bay waters are subject to rapid temperature fluctuation after sudden cold fronts. Further, salinity of the Bay can drop to 0 ppt after heavy rainfall in upper portions of the State.

Parasitism and Disease

Spotted seatrout are subject to protozoan infestation in gill tissue during cold water stress.[1/] During prolonged cold periods seatrout may become inactive as the protozoan infestation proliferates. Under these circumstances they are subject to fungal and bacterial infections which may eventually cause death.

The pleuroceroid stage of the tape worm *Poecilancistrium robustum* is often seen in the flesh of spotted seatrout, but the parasite is not harmful to man. Other parasites such as blood flukes have been identified in seatrout, but none has been found that is transmitted to man.

Fishing Pressure

The literature indicates that environmental factors have considerable effect on the availability of seatrout, but the effects of fishing pressure are not known. The only landings available for the sportfishery in Alabama are from Wade (1977) for the year 1975. He estimated that 362.2 metric tons (798,637 lbs.) (Table 1) of spotted seatrout were harvested by recreational fishermen that year. During the same year it was estimated that 27.9 mt (61,600 pounds) of trout were harvested by commercial interests. What portion of this total estimated 390.1 mt (860,237 pounds) came from Mobile Bay is not known. There is a commercial fishery for seatrout in Mobile Bay that operates largely during the winter months when seatrout are concentrated in deep holes and channels in the upper Bay. The author's opinion is that a considerable portion of the Alabama commercial harvest of seatrout comes from Mobile Bay. The sportfishery of Mobile Bay proper is confined primarily to the causeway and delta areas and to the Cedar Point Reef area at the confluence of Mobile Bay and Mississippi Sound. Considerably more seatrout are harvested by recreational anglers utilizing the tributaries surrounding the Bay. Fowl River, Fish River and Bon Secour River are important areas in the spotted seatrout recreational fishery. The commercial harvest of seatrout from Mobile Bay proper probably exceeds the recreational harvest from the Bay; however, the total recreational harvest from all Alabama waters far exceeds the commercial harvest.

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COMMERCIAL FISHERIES AND THE MOBILE ESTUARY

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ABSTRACT

Harvest of fish and shellfish from the Mobile Estuary has played an important role in the development of the Alabama coastal area for more than 3000 years. There is ample evidence demonstrating the importance of seafoods in the diet of coastal inhabitants since the movement of the first Indians into the area and throughout the history of the area until the present. Alabama's commercial fishing industry developed from a small locally important trade in the late 1800's into the multimillion dollar industry of today.

INTRODUCTION

Brackish water clams and oysters have been abundantly available to the coastal inhabitants along the coastal area of Alabama since before recorded history. Radiocarbon dates of middens composed largely of oyster shell along the coastal area indicate that Indians utilized oysters extensively in their diet more than 2500 years ago (Wimberly 1960) and the presence of oyster and whelk shells in the middens some 40 or more miles inland demonstrates that there was at least limited bartering of these shellfish during that time.

Fish and shellfish were primarily of local importance until development of methods for preserving and transporting these highly perishable foods to inland areas. Drying, smoking, and salting were the main methods of preserving seafoods for inland Alabama inhabitants until the first cannery was built in Bayou La Batre in 1897 (Swingle and Hughes 1976). During the early 1900's there were several canneries operating in Bayou La Batre and Coden processing oysters, shrimp, crab and some vegetables. Certain canneries would process oysters from January until May, vegetables or crab meat during the late spring and summer and shrimp from August through late fall or early winter. In 1926, there were five canneries operating in the Bayou La Batre-Coden area (Swingle and Hughes 1976). The decline of the canneries from the peak years of the 1920's until the closure of the last operating cannery in the mid-1960's resulted largely from the loss of producing oyster bottoms in the Portersville Bay area, periodic closure of oyster reefs by the Alabama Department of Public Health, restrictions on harvest of oysters from private beds and out-of-state competition.

Development of better methods of refrigeration, freezing, and transportation methods changed the distribution of Alabama seafood products from a local commodity to the present distribution system throughout the United States. Changes in fishing methods also changed the nature of the fishery. Motorized vessels, the introduction of the shrimp trawl ca. 1918 and crab trap ca. 1950, synthetic netting, more reliable engines and other innovations gradually replaced less efficient means and methods of harvesting seafoods. The most significant change in Alabama's commercial fishery began in the 1950's as the smaller inshore or "bay boats" were gradually replaced by larger vessels capable of extended offshore fishing trips. During the period from 1964-1973, the number of bay boats decreased from 231 to 156 while the number of large offshore vessels increased from 230 to 550 (U.S. Department of Commerce, various years) reflecting the offshore expansion of the fishing fleet. Consequently, the catch of seafoods from internal waters (bays and sounds) declined in percentage of the total catch as the offshore catch of seafoods increased (Table 1). The catch of finfish and shellfish from internal waters varies annually but no significant trend is apparent from available data on total catch from state waters.

The total number of commercial fishermen and persons employed in both wholesale and processing plants has not increased proportionately to the dockside value or the processed value of seafoods landed in Alabama (Table 2). The total value of seafoods landed in Alabama cannot be determined from existing data because the percentage of seafoods landed that is later processed within the state is unknown. Also, an unknown amount of seafood landed in other states is trucked into Alabama for processing.

Landing statistics from specific water areas around Mobile Bay are maintained by the National Marine Fisheries Service but are not published. Swingle (1976) presented these catch statistics in

Table 1. Finfish and Shellfish Caught from Internal Waters (Bays and Sounds) of Alabama and Offshore Waters Landed at Alabama Ports During Various Years.[a] All values expressed in thousands of pounds.[b]

	1965	1970	1971	1972	1973	1975
Total finfish[b]	5,855	12,895	15,137	15,796	22,025	15,211
Inside Catch	1,860	3,466	2,705	1,689	2,804	1,796
Percent of total	32	27	18	11	13	12
Total shellfish	11,930	16,726	19,101	20,273	14,719	16,336
Inside catch	4,363	3,382	3,469	3,881	3,579	4,050
Percent of total	37	20	18	19	24	25
Total finfish and shellfish	17,785	29,621	34,238	36,043	36,744	31,547
Inside catch	6,223	6,848	6,174	5,570	6,383	5,846
Percent of total	35	23	18	16	17	19

a/ Data modified from Swingle (1977)
b/ 1 pound 0.454 kg

Table 2. Number of Fishermen, Wholesale and Processing Plants and Employees and Values of Seafoods Landed and Processed in Alabama for the Period of 1964-1974.[a] Values in $1,000.

	Fishermen	Plants	Seasonal Employees	Dockside Value	Processed Value
1964	1,733	57	1,135	$3,975	$7,434
1965	1,854	58	1,070	4,986	6,838
1966	2,084	66	1,343	6,807	9,613
1967	2,130	68	1,643	8,300	13,390
1968	2,195	71	1,726	9,617	15,373
1969	2,290	67	1,673	10,557	17,616
1970	2,042	56	1,806	9,925	10,575
1971	1,958	62	2,182	13,810	20,908
1972	1,967	63	2,082	17,728	30,888
1973	2,146	62	1,925	17,667	43,188
1974	1,766	60	1,641	16,579	31,176

a/ From U.S. Dept. Commerce, various years.

detail for the period 1964-1972. A summary of these data is presented in Table 3.

Landings from Mobile Bay make up approximately 52% of the landings from the internal waters of the state and 10% or less of the total from both internal and offshore waters that is landed at Alabama ports. Considerable fluctuations have occurred in the quantity of seafoods taken from Mobile Bay during this period (Table 3) of data analysis. Oyster landings from Mobile Bay have varied from a low of 9.5 mt (21,000 lbs.) during 1965 to a high of 301 mt (663,000 lbs.) during the 1967 steam oyster season.

During the special oyster seasons in 1967 and 1968 the minimum size of oysters that could be harvested legally was lowered during the oyster canning season in Mississippi.

Overharvest of small oysters during 1967 and 1968 caused a very much reduced catch during 1969, 1970, and 1971. Great floods, low dissolved oxygen over the oyster reefs and other disasters which cause significant mortality upon oysters or affect their spawning will cause a reduced harvest for the following 3-year period.

Fishing effort also affects the amount of seafoods landed. During the winter flood period, Alabama oyster reefs are closed by the Alabama Department of Public Health for periods varying from 2 weeks to 4 months duration for health reasons causing fluctuations in annual landings.

Table 3. Seafood Landed from Mobile Bay by Alabama Commercial Fishermen for the Period 1964-1972.[a/] Data in thousands of pounds.[b/]

	Shrimp	Oysters	Crabs	Finfish	Total
1964	1,223	349	614	1,072	3,257
1965	1,086	21	675	1,437	3,219
1966	1,028	237	728	1,410	3,403
1967	1,726	663	962	2,965	6,316
1968	1,394	275	991	2,838	5,498
1969	954	72	680	2,984	4,690
1970	696	42	535	2,930	4,203
1971	543	53	643	2,173	3,412
1972	722	239	596	1,328	2,885

a/ Data from Swingle (1976)

b/ Weights expressed as whole weight for shrimp, crabs and finfish and as meats only for oysters.

1 pound = 0.454 kg.

The decrease in the catch of shrimp from Mobile Bay (Table 3) appears to be related to effort rather than a decrease in productivity. The number of smaller inshore shrimp boats registered in Alabama decreased from 231 in 1964 to 179 in 1972. Correspondingly, the number of shrimping trips made in Mobile Bay declined from 2,144 in 1964 to 1,159 in 1972. However, with decreased effort, the catch per trip increased from 259 kg (570 lbs.) heads-on weight in 1964 to 283 kg (623 lbs.) in 1972 (Swingle 1976).

While the reported commercial landings of seafoods from Mobile Bay show no significant trend (Table 3) for the period 1964-1972, an unknown but significant quantity of seafoods is taken by the recreational fishing sector. Based upon the known increase in the number of recreational boats registered in the coastal area, the recreational catch has likely increased substantially during the past decade. Without data on the recreational sector, few if any conclusions can be reached concerning the status of the fishery of Mobile Bay. Without historical catch-effort data from both the commercial and recreational user groups, no meaningful interpretation of existing landings data is possible because commercial landings statistics are influenced not only by population abundance but by consumer demand, seasonal and area closures, the number of days and units of gear fished and numerous other factors.

LIFE CYCLE

The Atlantic croaker *(Micropogonias undulatus)* typifies the estuarine-dependent life cycle of most fishes common to Mobile Bay. It is the second most abundant species in both Mobile Bay (Swingle 1971) and the tidal rivers along the Bay (Swingle and Bland 1974). Croaker is commonly found throughout a range from fresh to over 35 ppt salinity and is present in our estuarine waters throughout the year. Peak spawning occurs during the fall and winter months, probably in October (White and Chittenden 1976), or January and February (Warren et al. 1978). Juveniles enter Mobile Bay and tidal rivers from October through April at a size of 15 mm or less (Swingle 1977, Swingle and Bland 1974). Spawning peaks are variable and are likely associated with climatological variation.

Spawning occurs offshore and generally takes place at depths of 20 m or less in the proximity of tidal passes. Developing eggs are pelagic and range in diameter from 0.6 to 0.7 mm. Hatching normally occurs 30 to 40 hours after fertilization, with the newly hatched larvae measuring approximately 1.2 mm. Croaker larvae are first encountered in the bays and sounds at a length of 5 mm. Growth is rapid in the estuarine area with immigration back into the Gulf usually occurring in the fall at a size of 120 mm.

Feeding habits vary with croaker size as well as with food availability. Smaller fish feed on zooplankton and bottom invertebrates with the diet changing to predominantly large bottom dwelling organisms as the croaker grows. The change in food preference is associated with the movement of the mouth from a terminal position in the smaller fish to an inferior position in adults. Feeding observations reveal a "plunge and sort" feeding behavior with fish diving to the bottom, obtaining a mouthful of material, and sifting the material through the gills. Adult fish prefer polychaetes, crabs, mysid shrimp, copepods, and mollusks in that order. Fish become a more important food item as the croaker grows, with anchovies and small croaker constituting principal species consumed. Penaeid shrimp are infrequently seen in croaker stomachs and do not appear to represent a major food item.

Croaker movement on the Gulf fishing grounds appears to be related to bottom temperature, with general offshore movement in the fall and shoreward movement in the spring. Croaker school throughout their lives, but the schools are less defined during winter and spring than during summer and fall. Catch per unit effort (CPUE) is much greater during the defined schooling period with industrial trawling vessels taking 10-20 mt of fish in 10-20 minutes of trawling.

Estimated annual croaker mortality rates are difficult to obtain since there is disagreement on annual growth rate of the species (Roithmayr 1965, Chittenden 1976, Herke 1971). The total annual mortality rate for Gulf of Mexico groundfish was estimated by Klima (1976) to be 57% and by Chittenden to be 95%. Since 83% of the estimated groundfish catch is taken and discarded by the shrimp fishery, Chittenden's estimate appears realistic and likely an appropriate total annual mortality estimate for croaker.

Wade (1977) estimated a total recreational croaker catch of 239,159 kg (526,149 lbs.) in Alabama coastal waters during 1975 and ranked the species as the sixth most abundant species in recreational landings. The directed commercial and recreational catch coupled with the non-directed by-catch from commercial and recreational shrimpers place the croaker in a highly exploited position.

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THE OYSTER FISHERY IN MOBILE BAY, ALABAMA

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ABSTRACT

Alabama oyster landings have averaged 463,395 kg (1,019,469 lbs) from 1880 through 1977. Heavy fishing pressure and the lack of shell planting in recent years have reduced the oyster population on the major reefs and the landing for 1978 and 1979 will be below average. The total area of productive reefs has remained relatively constant while the centers of productivity have shifted in a southwesterly direction.

Bon Secour Bay oyster reefs were depleted by over harvesting. The present spat set is extremely low and insufficient for the reefs to recover. Bon Secour Bay may be rehabilitated for private oyster leasing if ample seed oysters can be obtained.

The future of the Alabama oyster fishery is dependent on the amount of freshwater entering Mobile Bay, the frequency and extent of oxygen depletions, and the extent of domestic wastes discharged near shellfish areas.

Shell planting, relaying oysters from polluted waters, and selective closures to control fishing pressures are needed to manage the oyster fishery. The lease program in Alabama depends on the development of a seed oyster program and overcoming the prevailing attitude of the local oystermen.

INTRODUCTION

The oyster landing for Alabama in 1977 were 702,730 kg (1,549,230 lb); of this only 10% of 69,854 kg (154,000 lb) were taken from Mobile Bay with the remainder coming from Mississippi Sound. Because the landing statistics do not separate the catches from Mobile Bay and Mississippi Sound, the major producing reef, Cedar Point (Fig. 1), will be included in the discussion of the oyster fishery of Mobile Bay.

The average annual landing from 1880 through 1977 was 463,395 kg (1,021,594 lb). The landing for 1976 and 1977 averaged 631,638 kg (1,392,500 lb) with the 1978 landing expected to be less than the average from previous years. The outlook for 1979 is not encouraging because of the lack of shell planting and extensive oyster mortalities due to predation by the southern oyster drill, *Thais haemostoma*.

Extensive harvests from 1976 through 1978 have removed most of the cultch, the substrate upon which oysters set, from Cedar Point Reef. This will result in a decrease in the abundance of oysters available for harvest from Cedar Point Reef. Other reefs in western Mobile Bay are supporting large populations of harvestable oysters. The abundance of oysters fluctuates with periods of high landings often followed by poor harvests. The oyster population in western Mobile Bay is in excellent condition but may decrease and then be followed by a resurgence due to the cyclic nature of oyster populations.

The greatest threat to a successful 1979 season is the oyster drill, the abundance of which is controlled by nature. The winter and spring flood waters from the Tombigbee and Alabama rivers reduce the salinity of Mobile Bay. If these floods, called freshets, reduce the salinity to zero for approximately six weeks, the drill population will decrease to a level of minor importance.

CHANGES IN THE OYSTER POPULATION

Observing changes in the oyster populations can be accomplished only by examining the reefs, which in Mobile Bay (Fig. 1) can be divided into two sections. The small section, Bon Secour Bay, is bounded on the west by a line from Great Point Clear to Little Point Clear. The area west of that line and extending one mile west of Dauphin Island Bridge will be called Mobile Bay in this discussion.

Mobile Bay

Oysters are not harvested north of a line from the mouth of East Fowl River to Great Point Clear. A few small reefs occur north of this line but they are not harvestable because the area is permanently closed by the Alabama Department of Public Health for public health reasons.

Cedar Point Reef

Cedar Point Reef (Fig. 1) occupied 18.2 ha (45 a) in 1894 (Ritter 1896) and was depleted as a result of overfishing. Cedar Point Reef recovered and expanded to 81.3 ha (201 a). Eight more reefs covered the area between Dauphin Island and Cedar Point. The complex of nine reefs had a combined area of 489.7 ha (1,210 a) (Moore 1913), an increase of 172% in 16 yr. The flood of 1929 completely destroyed Cedar Point Reef with 132.7 ha (328 a) lost from the 489.7 ha (1,210 a) of productive bottom in 1910 (Galtsoff 1930). Cedar Point Reef decreased to 70.4 ha (174 a) in 1943 and began to merge with adjacent reefs. That consolidation resulted from shell deposition, from culling and dredging operations. The eastern side of the Reef received a higher spat set than the other sections, and at the same time oyster drills were a serious problem, destroying 24% of the spat (Engle 1945). When Bell (1952) examined Cedar Point Reef in 1951 the Reef had grown to 588.8 ha (1,455 a) and accounted for 75% of the Alabama oyster catch. Cedar Point Reef in 1968 (May 1971) ran from Cedar Point to the Intracoastal Waterway, extending 1.6 km (1 mile) into Mississippi Sound and covered 562.3 ha (1,389.5 a). Cedar Point Reef increased 212% in 74 yr. It was planted with 22,562 m^3 (29,509 yd^3) of clam shell in 1975. That planting increased spat density and by 1977 the resulting oysters entered the fishery. Spat fall in 1978 was less than that found in 1969 but the oyster density was higher (William Eckmayer, unpublished, Alabama Marine Resources Laboratory). The Reef was overharvested because more oysters were being taken than could be replaced by spat. Overfishing precipitated the closure of Cedar Point Reef during the summer of 1978. Oystermen are now harvesting other reefs, weather permitting, thus offering some relief to Cedar Point Reef.

Sand Reef

Sand Reef (Fig. 1) was the largest, 329.0 ha

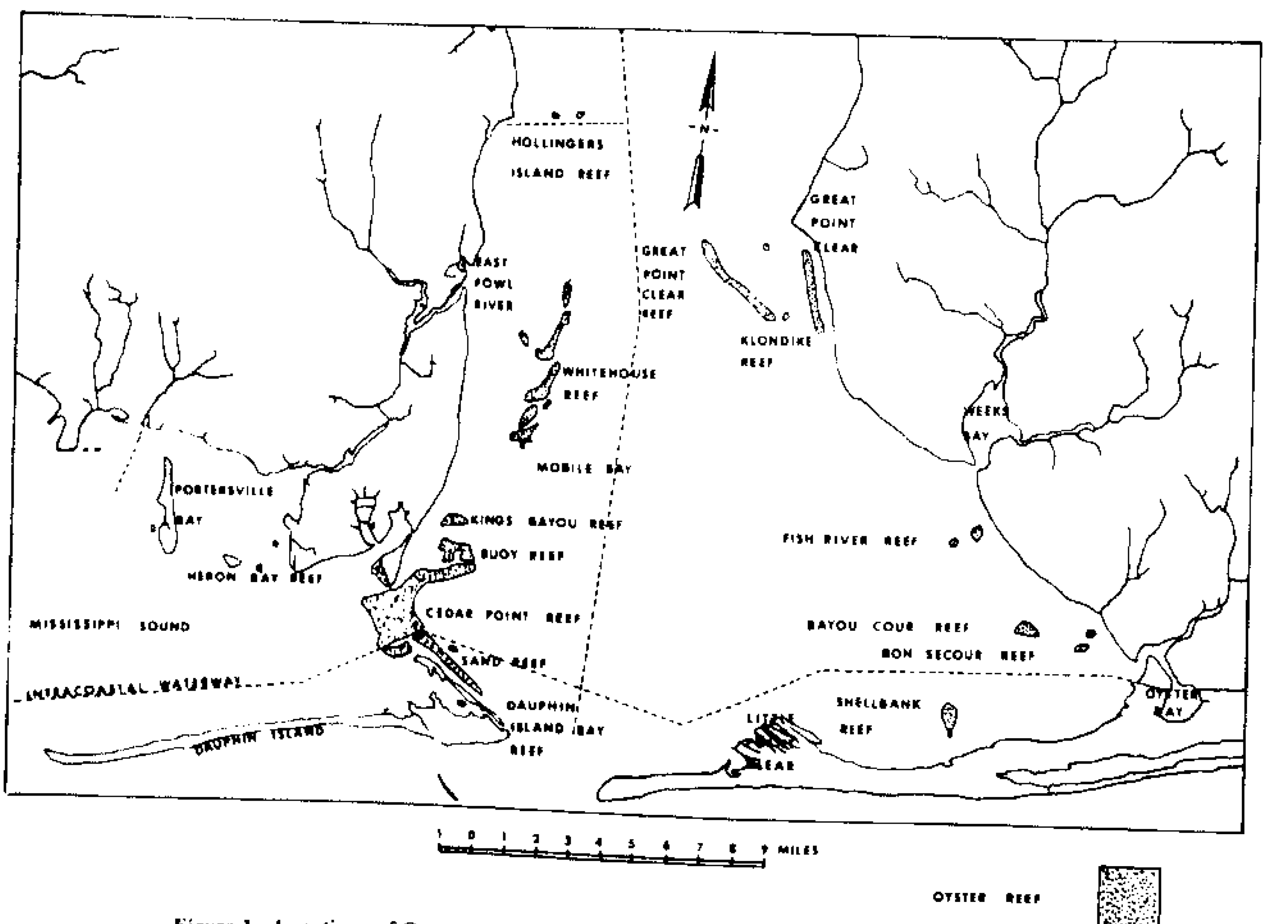

Figure 1. Locations of Oyster Reefs in Bon Secour Bay, Mississippi Sound, and Mobile Bay.

(813 a), and most productive reef in 1894 (Ritter 1896). The Reef was partially depleted by overharvesting and many oysters died in the freshet of 1893. Moore (1913) found Sand Reef covering 265.1 ha (655 a) in 1910. Oysters from Sand Reef were considered inferior because of poor keeping quality (Engle 1945). Few single valves were found on the Reef yet it produced an abundant spat set. Oysters on Sand Reef in 1943 were effected extensively by *Polydora websteri*, *Diplothyra smithii* and oyster drills. Nine years later Sand Reef decreased to 202.8 ha (501 a) (Bell 1952). When it was remeasured in 1968 it covered 15.5 ha (38.2 a) and consisted of two reefs. The 92% decrease in 17 yr probably was related to the closure of Pass Drury in the early 1960's. An attempt was made in 1974 to enlarge the main portion of Sand Reef from 11.7 ha (28.9 a) to 65.5 ha (162 a) by planting 11,265 m^3 (14,734 yd^3) of clam shell. The planting failed to enlarge the reef, because most of the shell sank into the mud. From 1977 to 1978 the number of spat decreased while the number of oysters increased during the same period (William Eckmayer, unpublished, Alabama Marine Resources Laboratory). In 1979, the densest oyster population in all of Mobile Bay was on Sand Reef.

Bon Secour Bay

Bon Secour Bay was depleted of harvestable oysters by overfishing in 1894 (Ritter 1896). There are presently less than 202.4 ha (500 a) of natural oyster reef in the Bay but in 1914 there were 1,618 ha (4,000 a) in private, riparian leases. The private, riparian beds decreased to 283.3 ha (700 a) in 1943 (Engle 1945), and now there are none.

Loss of Oyster Bottoms

The overall trend for oyster reefs in Mobile Bay is a shift of the centers of production to the south and west. The total area of natural oyster reefs remained relatively constant with 1,256 ha (3,105 a) reported in 1894 (Ritter 1896) and 1,240 ha (3,064 a) in 1968 (May 1971). That relative stability was maintained by the growth of Cedar Point Reef which compensated for the loss of Whitehouse, Great Point Clear and Klondike reefs and the reduction of Sand Reef (Table 1).

Mackin (1951) noted a reduction of oyster bottoms in western Mobile Bay. He suggested three possible explanations for that reduction: the subsidence of the Gulf coast tidal region, rising water level of the Gulf of Mexico, and deforestation of the Mobile Bay drainage basin which resulted in the erosion of lands converted to agriculture. The deforestation of the drainage basin had two effects on the periodic floods. First, the intensity of the floods increased with the rivers carrying more water over a given period of time, thus producing high flood crests which penetrated farther down Mobile Bay. The other effect was the loss of ground cover which increased the amount of silt entering the river and settling out in the southern areas of Mobile Bay.

Cedar Point Reef and various reefs around it consolidated into one large reef by 1951 as a result of the filling of gaps between them. Following this union and because of the protected nature of the reef, it assumed a dominant role in oyster production.

FACTORS AFFECTING OYSTER PRODUCTION

Pesticides

The oysters in Alabama in 1965 and 1966 exhibited organochloride pesticide residue levels below those considered harmful (Casper et al. 1969). The effect of pesticides on oyster populations is not fully understood. Butler (1969) concluded that environmental pesticide levels as low as 10 parts per billion (ppb) may decrease growth rates in oysters. Oysters exposed to DDT concentrations as low as 0.1 ppb in the surrounding water may concentrate up to 7 parts per million (ppm) in their tissue in about one month (Butler 1966). That ability to concentrate pesticides points out the need for a more thorough understanding of the chronic effects of sublethal concentrations on the health, reproduction and growth of oysters.

Sedimentation

Some areas are seasonly covered with a layer of fine silt and later are hard and clean. An undetermined number of oysters on several reefs in Mobile Bay were smothered by silt following the summer floods of 1970 (May 1971).

Ryan (1969) estimated about 4.3 x 10^6 metric tons (mmt) (4.7 x 10^6 tons) of suspended sediment enters Mobile Bay every year. In addition, the U.S. Army Corps of Engineers (file report, U.S. Army Corps of Engineers, Mobile District) reported channel dredging between 1871 and 1971 resulted in the redeposition of 331 x 10^6 m^3 (432.9 x 10^6 yd^3) of sediment. Shell dredging operations in the Bay redeposit approximately

Table 1. The area in hectares of the oyster reefs in Mobile Bay and Bon Secour Bay, Alabama, reported from various surveys. The net changes in area from the earliest to the most recent are listed.

	1894[a]	1910[b]	1943[c]	1951[d]	1968[e]	Net Change
Mobile Bay Reefs						
Hollingers					3.2	0
Fowl River	40.5		0			-40.5
Whitehouse	356.5			282.9	183.2	-173.3
Kings Bayou		33.2		81.3	27.8	-5.4
Buoy	164.3	164.3		84.6	84.1	-80.2
Cedar Point	180.1	489.7	70.4	588.8	562.3	+382.2
Sand	329.0	265.1		202.8	15.5	-313.5
Dauphin Island Bay	12.1	306		69.2	3.5	-8.6
Heron Bay		85.8			44.1	-41.7
Great Point Clear	21.5			48.6	83.2	+61.7
Little Point Clear			16.2		0	-16.2
Bon Secour Bay Reefs						
Klondike				78.9	65.0	-13.9
Fish River	33.6			56.7	42.7	+9.1
Bayou Cour	27.5			39.7	27.1	-0.4
Bon Secour			15.4	11.3	12.0	-3.4
Shellbank	76.1			26.3	60.3	-15.8
Total	1,241.2	1,344.1	102.0	1,571.1	1,210.8	

a/ Ritter 1896.
b/ Moore 1913.
c/ Engle 1945.
d/ Bell 1952.
e/ May 1971.

3.8×10^6 m^3 (5×10^6 yd^3) of bottom material each year (May 1971). The bottom of Mobile Bay is mostly fine silt and current and wave action easily resuspended that silt during storm activity. One km^2 of water 3.05 m deep can hold over 86.9 mmt of suspended silt under normal conditions. Storm winds can increase that amount of suspended silt to over 434.5 mmt per km^2 (Macklin 1953). Minor damage from silt to oysters has been reported by Ritter (1896), Galtsoff (1930), and Engle (1948).

Current long-term sediment accumulation in Mobile Bay has been estimated at 52 cm (1.7 ft) per century (Ryan 1969). May (1976) reported the sedimentation rate for the last 5 to 6×10^3 yr to be about 12 cm (0.4 ft) per century. The higher sedimentation rate for the last 150 yr probably indicates the effects of lumbering and agriculture on the amount of sediment in the water. I could not detect any reduction in total area of oyster reefs that resulted from siltation from the data for the last 75 yr (May 1971).

Channel Dredging

Dredging in Alabama began in 1827 with the construction of the Mobile Ship Channel. The earliest record of dredging that affected oyster bottoms was in 1838 when Grants Pass was dredged. Ritter (1896) attributed the loss of Fowl River Reef to the deposition of spoil from Mobile Ship Channel. He also reported that 178.1 ha (440 a) of Whitehouse Reef were covered with channel spoil. An undetermined amount of oyster bottoms were destroyed or altered by dredging Pass aux Huitres and Pass aux Herons channels and by dredging during the construction of the Dauphin Island Causeway Bridge. Sedimentation and channel dredging caused changes in salinity and current patterns that probably had a more pronounced effect on oyster bottoms than the immediate effects of silt and spoil. The construction of Mobile Ship Channel permitted a deeper penetration of the salt wedge into Mobile Bay. The salinity regime was also altered by the dredging of the Gulf Intracoastal Waterway in 1942. Dredging and filling projects should not be considered without carefully evaluating their effect on sedimentation, current and salinity in the vicinity of oyster reefs. Minor changes in any one of those environmental factors could be disastrous to oyster populations.

Salinity

Oysters are found in waters with a wide range of salinity but are more abundant in waters ranging from 10 to 20 ppt. Seasonal variation in salinity is a characteristic of waters inhabited by oysters and is an important environmental factor for oysters. Prolonged periods of low salinity seriously affect oysters in Mobile Bay. The Alabama-Tombigbee river system, which drains into Mobile Bay, flooded 27 times from 1893 to 1929 with the floods lasting from 4 to 31 days. Galtsoff (1930) reported that mortalities in 1929 ranged from 100% in the upper bay to 54 to 85% in the lower bay and 1929 and 1930 landings were the lowest recorded since 1888. Oystermen reported that the 1912 spring floods killed a majority of the oysters in Mobile Bay, Portersville Bay, and near Cedar Point (Nelson 1914). Many oysters were killed in 1913 by freshwater on the reefs around Cedar Point (Alabama Department of Conservation, Annual Report, 1952-1953). The extent of the damage caused by the 1961 flood was not well documented, but there were mortalities (Alabama Department of Conservation, Annual Report, 1960-1961). The 1962 harvest was the lowest since 1934. The effects of 1970 and 1971 floods were studied by May (1972). He reported that the 1970 mortalities ranged from 26 to 76% and were followed by a spat failure. The floods between December 1972 and June 1973 resulted in heavy oyster mortalities in Mobile Bay; those mortalities ranged from 29 to 85% on individual reefs and averaged 42% for all reefs. Heavy siltation from those floods destroyed 101.2 ha (250 a) of oyster reef. Data on the duration and frequency of floods in Mobile Bay are given by Gamble (1965) and U.S. Army Corps of Engineers (1963).

Although floods occasionally have resulted in mass mortalities, they have caused relatively little long-term damage to oysters in Mobile Bay. The benefits of the fresh water, such as control of diseases and predators and input of nutrients may alleviate these losses.

Natural, long-term shifts in salinity have drastically affected the distribution of oyster reefs in Mobile Bay during the past 5,000 yr (May 1972). Many extinct reefs are buried in upper Mobile Bay. Reefs that exist in areas of marginal salinity (Whitehouse, Hollingers Island, Great Point Clear and Klondike reefs) may be the next casualties of the encroaching fresh water resulting from the southward advance of the Mobile Delta.

Any substantial increase in the amount of fresh water could result in the destruction of marginal reefs and the addition of new reefs to that marginal category. Any project which could increase the amount of fresh water entering the Bay should be examined for the potential damage it may inflict upon the Mobile Bay oyster population.

Dissolved Oxygen

Dissolved oxygen (DO) is a vital component of all aquatic systems, but is possibly unique in its role in Mobile Bay. Periodic oxygen depletions, "jubilees," occur in Mobile Bay and were recorded as early as 1867.

Oysters are resistant to complete oxygen depletion for up to a week (Von Brand 1946); however, oxygen depletion over the reefs for a considerable period of time will kill them. At DO concentrations less than 1.0 ppm, and at a temperature of 17C (63F) and a salinity of 25 ppt oysters can survive for up to five days (Sparks et al. 1957). Low DO killed oysters on Point Clear Reef from July 27 to August 6, 1971. Seventy-nine ha (195.2 a) of reef were affected and an estimated 2,653,000 oysters died (May 1971). Oyster deaths from unknown causes have been reported in the past summers (Alabama Department of Conservation, Annual Reports, various years; May 1968). The puzzling circumstances of some of these die-offs suggested a cause other than disease or an associated cause (May 1971; Beckert et al. 1972). The mortalities that occurred in August 1967 on the reefs of upper Mobile Bay and on planted beds in Bon Secour Bay were probably due to oxygen depletion rather than disease. Low oxygen levels may be responsible for the lack of consistent production of the reefs of Bon Secour Bay. Extensive oxygen depletion occurred in July and August 1971 with values of 1.0 ppm or below for 75% of that period. During that depletion 22,654.7 ha (155,980.4 a) had DO concentrations of 1.0 to 0.0 ppm (May 1973). Two jubilees occurred in Billy Goat Hole off Dauphin Island on July 8, 1977 and August 2, 1977. An extensive oxygen depletion was checked in western

Mobile Bay on August 19, 1977. The area involved included Whitehouse Reef which has been in poor shape since 1970. A large portion of eastern Mobile Bay and western Bon Secour Bay experienced oxygen depletion during July 1978.

Stagnation of water has been shown to depress oxygen in other shallow bays (U.S. Department of the Interior 1969, 1970). Except when the water is moved by wind or current waters with low DO are restricted to depressions along the bottom. Depressions in Mobile Bay were created as a result of natural scouring and dredging of the ship channel (May 1973). Dredging of the channel and deposition of the spoil along both sides of the channel formed baffles which alter the circulation and water exchange in the Bay thereby increasing the possibility of water stagnation in certain areas. Until the circulation of Mobile Bay and its relationship to the bottom topography are fully understood, the cause of the depressed oxygen level will not be positively identified.

Predators

The southern oyster drill, *Thais haemostoma*, is the most important predator in Mobile Bay, but that has not always been the case. The black drum, *Pogonias cromis*, was the most destructive predator in the late 1800's. A school of drum could move onto a reef and eat many oysters regardless of size, which prompted some lease holders to place brush or fences around their beds to keep the drum out. Some unknown factor, possibly the widening of Petit Bois Pass in Mississippi Sound resulted in a salinity change that permitted the drill to become the most serious threat to the oyster population.

The oyster drill population, which has been known to have numerical supremacy over oysters on some reefs (May 1971), can be controlled by two methods of which only one is used. The method utilized by oystermen is hand separation of drills from their catch followed by the deposition of the drills on dry ground. The other method, placing stakes in the water, attracts the negatively-geotactic, spawning drills and tending the stakes from May through June permits the removal of eggs thus reducing the number of future drills. This is the only method available for reducing the distribution of the drill over wide areas and it is ineffective at best. The drill larva is unique among boring gastropods in that they are planktonic and thus dispersed by water currents. Once the larvae leave the egg cases the hand-picking method must be employed.

Drill populations are naturally controlled via floods. Drills cannot survive long periods in water less than 15 ppt salinity. When freshets occur, the drills burrow into the mud and await the return of more saline waters. If the freshet is of sufficient duration, the drills will die. This is the most effective method of control at this time.

Three other predators take their toll but are not as noticeable. They are mud crabs (family Xanthidae), blue crabs (*Callinectes sapidus*) and oyster leeches (*Stylochus ellipticus*).

Three species of mud crabs occur in Mobile Bay (*Eurypanopeus depressus*, *Panopeus herbstii*, and *Menippe mercenaria*). The last species, *M. mercenaria* or stone crab, is the most destructive to oysters, but fortunately the least abundant in Mobile Bay. An adult stone crab can eat 15 times as many oysters as a drill. The most abundant mud crab is *E. depressus* (May 1974). McDermott (1960) studied the role of mud crabs as predators and Hoese (1964) examined the crab's relationship to the transmission of protozoan disease, "Dermo" or *Perkinsus marinus* (syn. *Dermocystidium marinum*). Hoese concluded from his studies that mud crabs prey on spat and may be vectors in the transmission of certain oyster diseases by eating weak or dying adults infected with the disease.

Blue crabs prey mostly on oysters less than 25 mm in size, posing a serious problem to leases if hatchery-reared seed oysters are planted. Blue crab predation on cultchless oyster spat, those set on plastic sheets as opposed to on shell materials, resulted in mortalities of 79 to 99% within one month of planting (Krantz and Chamberlain 1978). The Alabama Marine Resources Laboratory is currently conducting a study on planting hatchery-reared spat on reefs in Bon Secour Bay. The spat were planted in mid-December 1978 with the idea that lower water temperatures will reduce the rate of blue crab predation.

The oyster leech, *Stylochus ellipticus*, a polyclad flatworm, is easily overlooked but presents a problem since the oyster is unable to eject the worm by rapid closure of its valves. Overstreet (1978) reported that adult oysters attacked by oyster leeches also harbor an infection of "dermo."

Diseases

The most destructive disease to an Alabama oyster population is "dermo" caused by the protozoan, *Perkinsus marinus* (formerly referred to as a fungus, *Dermocystidium marinum*). That disease is usually present throughout the year and may be transmitted by crabs, leeches, or by planktonic reproductive units. Oysters are most susceptable to "dermo" during the summer when the waters are warm and salty. Mortalities by unknown causes occurred in 1942 (Alabama Department of Conservation, Annual Report, 1943-1944). "Dermo" was listed as the cause of mortalities in the summer of 1955 (Alabama Department of Conservation, Annual Report, 1954-1955). A die-off encompassing Whitehouse Reef and the eastern shore from Point Clear to Bon Secour River occurred in August 1967. Mortality was 73 to 98% on 1,214.1 ha (3,000 a) of natural and private bottoms (May 1968). Buoy Reef oysters sustained 99% mortality over 40.5 ha (100 a) within a few weeks in September 1968. Ten to 20% of the oysters on Cedar Point Reef died during August and September 1968. The oysters tested during that period had a high incidence of "dermo" (Beckert et al. 1972). "Dermo" poses an ever present threat since there is no warning when it will strike and the resulting die-off is swift. Nothing can be done when it occurs.

A digenetic trematode (*Bucephalus* sp.) also infects oysters although it does not cause mortality. It has a more subtle effect upon the oyster population. Heavily infected oysters are castrated and thus removed from the spawning population. Hopkins (1957) stated that this parasite can benefit the fishery because the oysters remain fat during the summer. *Bucephalus* occurs in low salinity waters so the major reefs in Mobile Bay should not be affected.

Symbionts

The symbiotic "pests" of oysters are mostly confined to the shell and if their numbers are great enough the shell becomes brittle and weakened. The symbionts include mud worms (*Polydora websteri*), burrowing sponges (*Cliona celata* and *C. truitti*), and burrowing clams (*Diplothyra smithii*).

The burrowing clam (*D. smithii*) is the most interesting historically. Early literature referred to the burrowing clam *Martesia* sp. Since *Martesia* is a wood borer, the authors no doubt referred to *D. smithii*. The burrowing clam also weakens single valves rendering them useless as cultch. Engle (1945) reported many reefs sustained destruction from burrowing clams. I found no evidence of this clam on any of the reefs in Mobile Bay in 1978. The disappearance of this high salinity clam is indicative of a mean salinity decrease since 1943.

Mud worms (*P. websteri*, a polydorid polychaete) and burrowing sponges (*Cliona* spp.) both weaken oyster shells by burrowing tunnels. When their incidence is high they will destroy the shell making it unsuitable for cultch. While living the oyster will continue to secrete new shell material which keep the borers from breaking through. Mud worms were more common on oyster shell in 1943 than now. The sponge is still prevalent and is most common in Bon Secour Bay.

Overfishing

Overfishing has been the rule in the Mobile Bay oyster fishery. Ritter (1896) reported that excessive fishing pressure caused the depleted conditions in Bon Secour Bay, eastern Mobile Bay and in the Cedar Point vicinity. Galtsoff (1930) determined that continuous fishing on the more accessible reefs and the failure to replant shells resulted in the depletion of some of the reefs. Nelson (1914) and Engle (1936) stated that oyster dredges were responsible for the depletion of some reefs. Many factors influence the production of a reef, so that exact cause of a depleted reef cannot be determined. Ritter (1896) and Moore (1913) noted that in contrast to the depleted reefs some reefs were overcrowded with oysters, indicating underutilization of the resources; however, May (1971) found no such crowding.

Cedar Point Reef, responsible for about 90% of the State's oyster landings, is being overfished, certain areas are depleted of all commercial stocks, and little cultch remains for future spat fall. Neighboring reefs, Sand and Buoy, support dense populations of oysters that, if not harvested will result in crowded conditions. Those reefs are not as easy to harvest as Cedar Point Reef because they are not always accessible and the water is deeper.

Industrial and Domestic Pollution

Sixteen municipalities and 27 industries, excluding farming and fishing industries, empty their effluents into Alabama's coastal waters (Alabama Water Improvement Commission 1967). Gallagher et al. (1969) reviewed the effects of pollution on shellfish harvesting in Mobile Bay and found no oyster mortalities that were attributed to pollution by organic or inorganic wastes. Although the effects of specific pollutants on oysters are reasonably well-documented, little is known of their dispersion, concentrations and effects on oyster populations in Mobile Bay. The anticipated increase in industrialization of the Mobile and Theodore areas will likely create problems for the oyster fishery in the future.

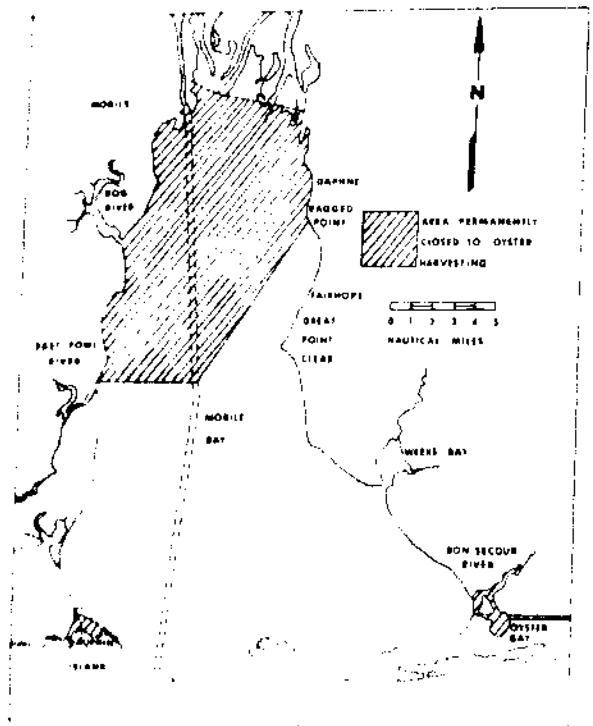

Figure 2. Areas Permanently Closed to Oyster Harvesting by the Alabama Department of Public Health in Participation with the National Shellfish Sanitation Program Administered by the U.S. Department of Health, Education and Welfare, Food and Drug Administration.

The most obvious effect of pollution is closure of areas to oyster harvesting. The permanently closed area (Fig. 2) in Alabama covers approximately 29,947 ha (74,000 a); included in this are approximately 80.9 ha (200 a) of oyster reef. The closed area includes Dauphin Island Bay, Oyster Bay, and Hollingers Island Reef. Any southward extension of the closure line would seriously affect harvesting on the public reefs.

The Alabama Department of Public Health periodically closes the oyster reefs in Mobile Bay. Those temporary closures are necessitated by increased bacterial counts that result from increased land run off into the Bay. Prior to 1978, the coliform bacteria count could not exceed 70 most probable number (MPN) per 100 ml and not more than 10% exceeding a MPN of 230 per 100 ml for a five tube decimal dilution. A more selective standard, median fecal coliform value, was implemented in 1978. That method determines the water quality based strictly on fecal coliforms and samples must not exceed a MPN of 14 per 100 ml with no more than 10% of the sample exceeding 43 for a 5-tube three dilution test. Although a lower MPN is used, the fecal coliform standard allows the reefs to remain open longer without endangering the public health.

Reef closures are always associated with low salinity periods which result from flooding of the Alabama-Tombigbee river system. If the Tennessee-Tombigbee Waterway increases freshwater influx, that increase may lengthen the duration of closures.

FUTURE RESEARCH

Mobile Bay Circulation

The planktonic nature of the oyster larvae necessitates understanding the circulation patterns of the water in Mobile Bay. Knowing the possible transportation routes of the larvae would enable the biologist to predict those areas likely to receive spat sets.

Knowledge of circulation patterns also would aid in understanding the most limiting environmental factor for all life in Mobile Bay, the pockets of low dissolved oxygen. The potential sites of trouble could be located by correlating the circulation pattern with bottom topography.

Spat Setting Study

A study of the seasonal distribution of oyster spat and larvae is currently in progress by the Alabama Marine Resources Laboratory. We should know where the highest concentrations of setting larvae are in order to determine new potential oyster bottoms for development as reefs or leases. The data should also enable us to predict the ideal time to plant shells.

A similar study was conducted in 1967 which analyzed the spat set for a 7-month period (Hoese et al. 1972). The current spat study will cover three years and help us understand the spat distribution in Mobile Bay and the eastern Mississippi Sound.

Population Monitoring

A continuous assessment of the oyster population supplies the needed background data for evaluating the management of the reefs. Without understanding the conditions of each reef's population, sound management practices cannot be formulated. The appropriate management practices include shell planting, closures to maintain the population size, and size reductions. This research is necessary for sound management of the fishery.

Oyster Farming/Reef Rehabilitation

Oyster farming and reef rehabilitation are similar in that both establish a population when there was none previously. Whether an absence of oysters is the result of no cultch or a disaster, both oyster farming and reef rehabilitation practices are designed to establish a harvestable population on unproductive bottoms. That may involve shell planting, or seeding bottoms with young oysters. The method of seeding the bottom with young, hatchery-reared oysters is being attempted by the Alabama Marine Resources Laboratory to reestablish a spawning population in Bon Secour Bay.

MANAGEMENT PROPOSALS

Management of the oyster fishery is oriented primarily towards public reefs. The main thrust, shell planting, depends on the state legislature for funding. Management of the oyster fishery depends upon a self-sustaining system which allows routine expenditures that are necessary for maintaining the fishery.

Public Reefs

Shell Planting

Shell planting is the backbone of the oyster fishery. The addition of shells to the reef supplies the clean substrate necessary for spat setting. The continued harvest of oysters results in a gradual removal of shells available for the spat to set on, thus the oyster population declines. Shell plantings have not been regularly funded, and the 1979 planting will be the first since 1975 when funds were provided by a grant from the National Marine Fisheries Service following a natural resources disaster (P.L. 88-309, 4b). Shell plantings, from 1976-1978 were cut from the Marine Resources Division's budget. In 1978 the legislature approved the funding for a 1979 shell planting program.

Since shells should be planted on an annual basis, an alternate source of funding should be secured. One possible method is to levy a severence tax on oysters landed in Alabama, similar to the tax now used in Mississippi, Virginia and Maryland. That would necessitate specified ports of entry where the oysters would be sacked and tagged and the tax collected.

The estimated cost of a cubic yard of shell is $9.00 or $1.64 per barrel. Since a barrel of oysters would yield less than a barrel of shell, a small tax could be levied to raise the money for replacing the shell. A tax of $0.50 per barrel of oysters would add $0.25 to the cost of a gallon of oysters. An average landing of 453,600 kg (1.0×10^6 lb) of oysters would generate $28,500, which would help sustain a shell planting program.

Relaying

Relaying is the transfer of oysters from closed areas to open, approved areas for natural cleansing. Relaying would be utilized for transferring the oysters from permanently closed areas (Dauphin Island Bay) to an area which is opened for oyster harvesting. The ideal time for relaying would be when the oyster reefs are closed because of bacterial pollution. When the reefs are reopened the relayed oysters should be cleansed and available for harvest.

The financing of a relaying program would be expensive. It would depend on the availability of money and the abundance of oysters in the closed areas. A possible relaying program could be scheduled once every two years thus allowing the reef to return to a dense population before a new relaying program is undertaken.

The priority of relaying, as a management technique, should not supercede shell planting because relaying only boosts the landing temporarily. Long-term benefits come from healthy populations in closed areas since their spawn is distributed to the other reefs in the vicinity where they attach to available cultch.

Closures for Stock Management

The history of overfishing some reefs and underutilizing other reefs indicates the need for shifting the fishing pressure from certain areas to others. That could be accomplished by seasonal closures. A small number of oystermen fish year-round so a few reefs must be open all year. Reefs should be closed when the spat are setting but this is not practical. Closing the most heavily fished reefs from June through September would provide a period of rest for those reefs while transferring the pressure to the other less heavily fished reefs. Periodic closures should increase the yield by distributing the fishing pressure and protecting the spat on the most productive reefs.

Private Leases

Historic Background

Leases were prevalent in 1914 covering 1,618 ha (4,000 a) of state bottoms. Private leases decreased to 26.2 ha (64.8 a) by 1942. The reason for the decrease in leased acreage was stated by Engle (1945:7):

> *"There are many thousand acres of this bottom that have been used in the past but, due to difficulties in settling estates, restrictions on the procurement of seed, ...and discouragement brought about by prevailing lack of respect for the property of others, especially when that property consists of planted oysters, most of it has now been abandoned."*

The last productive leases were in Bon Secour Bay in 1967 and their contribution to the oyster landing was 18% by weight. Those leases were cancelled because of the lack of seed oysters and closure of Bon Secour Bay by the Alabama Department of Public Health.

One lease proposal was submitted for state bottoms west of Little Dauphin Island. The lease was rejected by the Governor's office because of local opposition which appears to be the major stumbling block for future leases. The attitude of the local oystermen is that the state should plant every acre capable of producing oysters rather than leasing the bottoms to individuals.

That philosophy of the state planting all productive bottoms sounds good until the economics of it are examined. There are 19,627.5 ha (48,500 a) of bottom firm enough to support oysters in Mobile Bay (May 1971). Planting clam shells at the rate of 255.6 m^3/ha (118 yd^3/a) would cost \$2,624/ha (\$1,062/a). The cost to the state for planting those bottoms would be \$51,507,000. The state could not support a planting program of that magnitude. The only alternative for putting these bottoms into production is through leases. The most promising areas would be those in western Mobile Bay. The key to creating productive bottoms in eastern Mobile Bay and Bon Secour Bay is in locating ample seed oysters.

Public Seed Beds

The source of seed for leases could come from historically productive reefs that currently catch spat but fail to produce harvestable oysters. Whitehouse Reef would be suitable for seed oysters. That reef receives a spat set but produces few oysters because of mortalities resulting from spring floods. If shells were planted in June, the seed could be relayed to private reefs during November. The cost of such a program should be the responsibility of the lease holders who obtain their seed from the public beds. A severence tax could be levied on the volume of seed removed from the bed. McHugh and Andrews (1955) reported that one bushel holds approximately 3,000 seed oysters of various sizes. They also reported that only 1,000 to 1,200 seed oysters per bushel would survive the planting. A bushel contains approximately 300 marketable oysters. By assuming an annual mortality rate of 52.2% (William Eckmayer, unpublished, Alabama Marine Resources Laboratory) and one to two years to obtain a marketable oyster, 90,488 seed oysters per hectare (36,653 per acre) would be needed to yield a harvest of 9,884 oysters/ha (4,000/a), which is the density of oysters on most harvestable reefs in Alabama. If Whitehouse Reef was used as a source of seed oysters, there would be enough seed oysters for only 47.7 ha (118 a). Securing a sufficient quantity of seed oysters will be the major obstacle to establishing a successful, private oyster lease program.

All seed oysters should come from Alabama or adjacent states because imported seed oysters could introduce parasites, predators, commensals and diseases which are not present in Mobile Bay. The use of public seed beds for supplying private leases would benefit the entire fishery by producing more oyster larvae when the oysters on the lease spawn. The increase in larvae could result in heavier sets which could produce more oysters on the public reefs in the Bay.

SUMMARY

1. There has been a southwesterly shift in the location of the productive oyster reefs in Mobile Bay accompanied by a consolidation of the southern reefs thereby maintaining a constant acreage.
2. Bon Secour Bay oyster reefs were depleted through overfishing. The spat set in that bay is extremely low and insufficient for the reefs to recover. As an area for private leases the Bay may be useful if an ample supply of seed oysters can be obtained.
3. The future of the oyster fishery will depend on the amount of freshwater entering the Bay, the frequency and extent of oxygen depletions and the extent of domestic wastes discharged near shellfish areas.

4. Shell planting, relaying oysters from polluted waters and selective closures to control fishing pressure are needed to manage the oyster fishery.
5. The future of a lease program depends on the development of a seed oyster program and overcoming the prevailing attitude of the local oystermen.

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SHRIMP ASSESSMENT AND MANAGEMENT IN THE MOBILE ESTUARY

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ABSTRACT

The shrimp fishery is economically the most important commercial fishery in Alabama. The Mobile Bay estuarine system comprises 72% of the estuarine area of Alabama and is extremely important, because 99% of the shrimp caught in and adjacent to Alabama are dependent upon estuaries for a part of their life. Fifteen species of shrimp are found in the Mobile Bay estuarine system, but only brown shrimp, *Penaeus aztecus*, white shrimp, *P. setiferus*, and pink shrimp, *P. duorarum* are of commercial value. Pink shrimp occurs only sporadically and amounts to less than 1% of the total landings. The white shrimp was the major species caught in Mobile Bay until 1945 but by 1959 the brown shrimp had eclipsed the white shrimp as the major species. In 1976 an estimated 15% to 25% of the total shrimp catch from the inside waters of Alabama was taken by 16-foot trawls. Peak immigration of brown and white shrimp postlarvae is in March to April and June to September, respectively. Emigration is greatest in June and September for juvenile brown and white shrimp, respectively. The primary limitation on the size of shrimp stocks appears to be environmental. Alabama has regulated its seafood resources since 1911 and the present shrimp license schedule was set in 1921. Alabama's shrimp assessment and monitoring program was begun in 1967 and was greatly expanded in 1977.

INTRODUCTION

The shrimp fishery is economically the most important commercial fishery in Alabama. In 1977 it comprised 72% of the weight and 91% of the value of the total Alabama seafood landings. Although the percentage of Alabama's shrimp landings from Mobile Bay declined from 18% in 1964 to 5% in 1976, catch per trip has remained almost constant. Mobile Bay and the Mobile Delta encompass 113,917.2 ha (284,793 a) of estuarine area; 72% of the total estuarine area of Alabama (Crance 1971). This area is extremely important because 99% of the shrimp caught both inshore and in the Gulf of Mexico adjacent to Alabama are dependent upon the estuarine environment for part of their life cycle.

Although 15 species of shrimp are found in Mobile Bay and the Mobile Delta (Table 1), only white shrimp, *Penaeus setiferus*; brown shrimp, *P. aztecus*; and pink shrimp, *P. duorarum* are of commercial value. Pink shrimp are found only sporadically in Mobile Bay and make up about 1% of the landings (Gulf Coast Shrimp Data, various years).

Table 1. Shrimp Species Occurring in the Mobile Estuarine System (Swingle 1971).

Common Name	Scientific Name
Brown shrimp	*Penaeus aztecus* Ives
White shrimp	*Penaeus setiferus* Linnaeus
Pink shrimp	*Penaeus duorarum* Burkenroad
Sea bob	*Xiphopeneus kroyeri* Heller
Sergistid shrimp	*Acetes americanus* Ortmann
River shrimp	*Macrobrachium ohione* Smith
River shrimp	*Macrobrachium acanthurus* Wiegmann
Hardback shrimp	*Trachypenaeus similis* Smith
Hardback shrimp	*Trachypenaeus constrictus* Stimpson
Rock shrimp	*Sicyonia brevirostris* Stimpson
Rock shrimp	*Sicyonia dorsalis* Kingsley
Grass shrimp	*Palaemonetes pugio* Holthuis
Grass shrimp	*Palaemonetes vulgaris* Say
Grass shrimp	*Palaemonetes paludosus* Gibbes
Snapping shrimp	*Alpheus heterochaelis* Say

This paper will deal primarily with brown and white shrimp, which are heavily fished by the inshore fishing fleet during April and June to October. In 1974, 127 boats weighing less than 4.5 mt (10,000 lb) and 437 vessels over 4.5 mt were registered in Alabama. Almost none of the large vessels fish in the inside waters.

Periodic surveys of the shrimp in the Mobile estuarine system have been conducted from 1953 to 1977. A regular program of assessment and monitoring was established for this area in 1977. Landings for Mobile Bay have been reported separately since 1963 (Table 2).

HISTORY OF THE FISHERY

Commercial Fishery

Shrimp fishermen were active in Mobile Bay before 1880. Shrimp were harvested by haul seines until the otter trawl was introduced along the Gulf Coast in 1915. Haul seines were still common in Alabama until 1948 (Swingle 1971). White shrimp was the major species caught in Mobile Bay until about 1945. Brown shrimp landings increased after white shrimp declined during 1945-1959 (Loesch 1965). In 1976 brown shrimp comprised 70% of the landings from Mobile Bay. Although the shrimp landings for Mobile Bay declined from 1963 to 1976, the catch per trip remained relatively constant. The decline in total landings is attributed to a shift in the fishery from small inshore boats to large offshore vessels (Table 2). The commercial shrimp harvest in 1973 was one of the lowest in several years because of severe flooding.

Table 2. Shrimp Fishery Statistics for Mobile Bay, Alabama, 1963-1976. (Modified from Swingle 1976, 1977 and From Gulf Coast Shrimp Data and Fisheries Statistics of the United States - U.S. Department of Commerce.)

Year	No. Boats	No. Vessels	Landings (heads-off lb)[a/]	No. Trips	Catch/trip (heads-off lb)
1963	247	247	1,486,638	2,819.0	527.3
1964	231	230	775,246	2,144.0	361.6
1965	206	295	683,713	1,158.8	590.0
1966	203	366	640,310	1,742.0	367.6
1967	174	397	1,080,067	2,247.0	480.7
1968	139	467	873,436	2,077.5	420.4
1969	129	506	632,929	2,112.0	299.7
1970	149	448	459,637	1,565.0	293.7
1971	169	456	353,970	975.0	363.0
1972	179	451	462,127	1,159.0	398.7
1973	156	550	221,626	965.0	229.7
1974	127	439	329,733	997.0	330.7
1975	NA[b/]	NA	498,196	923.0	539.8
1976	NA	NA	580,259	1,517.3	382.4

[a/] 2.2 lb = 1 kg

[b/] not available

Bait Fishery

Data are not available on the present number of live-bait-shrimp fishermen working in Mobile Bay. Loesch (1957) reported that 7.92 mt (17,415 lb) of bait shrimp were caught from the Mobile Delta during an experimental open season in the fall of 1956. Twenty-nine bona fide live-bait dealers were operating in Alabama in 1968. These fishermen sold approximately 22.73 mt (50,000 lb) of live and dead shrimp as bait (Swingle 1972). Of 40 live-bait dealers, who bought licenses in Alabama during 1977-1978, 10 operated in Mobile Bay. The rest of the dealers probably fished in Mobile Bay part of the time. Bait shrimp landings since 1968 are not available.

Recreational Fishery

Anyone can shrimp for bait in the waters of Mobile Bay at any time except in those areas permanently closed to shrimping (Fig. 1). People shrimping for bait are limited to 2.3 kg (5 lb) of shrimp (no size limit) per person or a maximum of 6.8 kg (15 lb) per boat containing three or more persons per day in areas closed to commercial shrimping. In areas open to commercial shrimping,

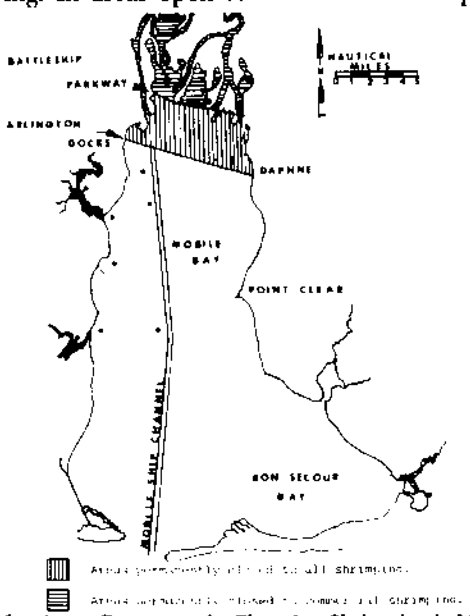

Figure 1. Areas Permanently Closed to Shrimping in Mobile Bay, Alabama and (*) Sampling Stations for Current Shrimp Assessment and Monitoring Program.

people are allowed 11.3 kg (25 lb) per person per day of shrimp larger than 68 shrimp to the pound heads-on. No license is required for a trawl measuring 4.9 m (16 feet) or less along the cork line, provided no shrimp are sold. The actual number of recreational trawls now in use in Mobile Bay is not known. Because no license is required, it would be difficult to obtain estimates of the number. However, a survey conducted from 1972-1974 by Swingle et al. (1976) estimated that 4,961 recreational trawls were used to catch 125.93 t (277,051 lb), 92.99 t (204,577 lb), and 132.06 t (290,541 lb) of shrimp in 1972, 1973, and 1974, respectively. The survey indicated that 35.5% of the respondents launched boats most often in the Mobile Bay area. In Mobile County, 50.3% of the respondents used their shrimp for bait and 49.7% for food. In Baldwin County these values were 11.3% and 88.7%, respectively. Swingle et al. (1976) also estimated that 15% to 25% of the total shrimp catch for the inside waters of Alabama was taken by 16-foot trawls. Although no statistics are available on recreational landings in the Mobile Bay area since 1974, it is suspected that the number of fishermen, landings and effort have risen substantially since that time.

LIFE HISTORY

Brown and white shrimps have similar life cycles (Christmas and Etzold 1977) . Both species spawn offshore. Larvae undergo several molts as planktonic larvae, metamorphose into postlarvae (shrimp less than 25 mm (0.98 in) , total length) and appear in inside waters at about 9 mm (0.35 in) total length (Fig. 2). Loesch (1965) indicated that postlarvae are less than a month old when they appear in Mobile Bay. Christmas and Etzold (1977) indicate that shrimp spawned in late summer and fall may overwinter in the Gulf of Mexico. The growth rate of these shrimp during the early life stages is very slow and they enter the bay as postlarvae the following spring. Postlarvae shrimp immigrate to the bayous and marshes along Mobile Bay where they find protection and grow rapidly on the abundant detrital food supply. Juvenile shrimp (more than 25 mm (0.98 in) total length) move into the open bay prior to their emigration to the Gulf of Mexico. Emigration lasts several months, and during this period shrimp are fished heavily by inshore fishermen. Shrimp become sexually mature during emigration and those that escape capture return to the Gulf of Mexico to spawn.

Figure 2. General Life History of a Shrimp: (a) Shrimp eggs, (b) Nauplius Larva, (c) Protozoea, (d) Mysis, (e) Postlarva, (f) Juvenile Shrimp, (g) Adolescent Shrimp, (h) Mature Adult Shrimp.

Brown and white shrimps differ in seasonal migration patterns. The peak spawning period for brown shrimp is in December and January. Brown postlarvae appear in inside water from February through May and sometimes as late as August. The peak month of white shrimp postlarvae immigration is July and immigration usually continues through August. Emigration of white shrimp usually begins in August and continues through October with the peak in September.

DISTRIBUTION OF SHRIMP IN MOBILE BAY

Loesch (1965) found more shrimp in the western half of Mobile Bay than in the eastern half. He found small brown shrimp less than 20 mm (0.79 in) total length in greatest abundance in water less than 1.22 m (4 ft) deep. Abundance decreased with depth. Small white shrimp were in greatest abundance in water less than 0.61 m (2 ft) deep. A similar distribution of brown and white shrimp occurred also in samples taken in Mobile Bay in 1977 to 1978 (Stevens R. Heath, unpublished, Alabama Marine Resources Division, Dauphin Island, Alabama). Juvenile brown shrimp appear later in Mobile Bay than in other inside waters of Alabama. Juvenile white shrimp appear generally north of the Intracoastal Waterway in July and August but in far greater numbers in upper Mobile Bay (Stevens R. Heath, unpublished, Alabama Marine Resources Division, Dauphin Island, Alabama). This general distribution probably is determined by the salinity regime of the bay.

FACTORS INFLUENCING SHRIMP PRODUCTION

Shrimp are considered to be a yearly crop. There is no apparent relationship between the spawning stock and the subsequent population available for harvest at the present rate of exploitation. Overfishing shrimp stocks to the extent that spawning stock is reduced to a level below that necessary to maintain the population does not appear economically feasible. The population size from year to year seems to be controlled more by environmental factors than exploitation. As previously mentioned the catch per trip has remained relatively constant over the past 14 years. Several environmental factors can affect the available population of shrimp in a given year.

Pollution

Pollution from either domestic, industrial, or agricultural wastes, if present in high enough concentrations, could decrease shrimp stocks or render them unfit for human consumption (Butler 1966; Kutkuhn 1966; Nimmo and Bahner 1974). There is no record of contamination of the shrimp stocks in Mobile Bay, although the delta was closed to commercial fishing north of Battleship Parkway from 1970 until 1971 because of mercury contamination of fish. However, shrimping is not allowed in this area because of the large percentage of small shrimp in the area throughout the year.

Hydrology

More research is needed concerning relationship of shrimp to their environment. Based on data collected to date, the shrimp population from year to year is greatly affected by the hydrologic conditions in the system (Kutkuhn 1966). Several investigators have presented information on the effects of salinity and water temperature on the behavior and survival of brown shrimp (Barrett and Gillespie 1973; Gunter et al. 1964; Venkataramiah et al. 1974). Although the results of these studies cannot be directly applied to white shrimp, the effects are probably similar. The optimum salinity and temperature ranges differ between the two species.

Barrett and Gillespie (1973) found that water temperature after April 8 can be the dominant factor in shrimp survival in inshore waters of Louisiana. They found that if the water temperature is below 20°C (68°F) for more than 33 hours after April 8, then temperature becomes the deciding factor in survival of young shrimp. However, if the duration is less than 33 hours then other factors such as salinity and food availability become dominant. Venkataramiah et al. (1974) found in laboratory situations that survival and behavior of brown shrimp were affected greatly by water temperature and salinity in combination. The salinity and temperature to which the shrimp were initially acclimated had a definite effect on the range of salinity tolerance. Postlarvae survived higher salinities and juveniles survived lower salinities but the optimum salinity range for growth and survival appeared to be 8.5 to 17 ppt. Gunter et al. (1964) suggested an optimum salinity range of 0.5 to 10.0 ppt for white shrimp during periods of rapid growth. The rate of change of salinity and temperature is also an important factor in the range of salinity tolerance (Venkataramiah et al. 1977). Situations such as flooding in Mobile Bay can have an extremely detrimental effect on the shrimp population of that season. The effect of hydrologic conditions is reflected both in number and distribution of shrimp in Mobile Bay.

Although Swingle (1971) found shrimp in water with an average monthly temperature range of 10.9 to 30.5°C (51.6 to 86.9°F) and salinities from 0.2 to over 30.0 ppt, the greatest catch per unit effort (CPUE) for juvenile brown shrimp from January 1968 through March 1969 was at a combination of 30.0 to 34.9°C (86.0 to 94.8°F) and 2.0 to 4.9 ppt salinity. The greatest CPUE for juvenile white shrimp over the same period was at 15.0 to 19.9°C (59.0 to 67.8°F), and 25.0 to 29.9 ppt. Heath (unpublished, Alabama Marine Resources Division, Dauphin Island, Alabama) collected shrimp in salinities from 1.0 to 30.0+ ppt and temperatures of 15 to 30+°C (59.0 to 86+°F). However, the greatest CPUE for juvenile brown shrimp from April 1977 to September 1978 was at a combination of 0 to 4 ppt and 30+°C (86+°F). The greatest CPUE for juvenile white shrimp was at 0 to 4 ppt and 25.0 to 29.9° C (77.0 to 84.2°F). The difference in the optimum salinity for white shrimp reported by Swingle and Heath was probably attributable to the location of the sampling stations in the respective surveys. Using Swingle's (1972) length-weight conversion for white shrimp, the mean count for white shrimp in Swingle's (1971) greatest CPUE was 33. The mean count for white shrimp in Heath's (unpublished, Alabama Marine Resources Division, Dauphin Island, Alabama) greatest CPUE was 171. Shrimp move into deeper water as they grow and the majority of Swingle's (1971) samples was taken in deeper water.

Data collected by Loesch (1976) in 1953 to 1955 in Mobile Bay showed that in general larger shrimp were found in the lower, more saline portion of Mobile Bay while shrimp became smaller toward the upper end of the bay, less saline areas. He also found that the preferred salinity range of brown shrimp depended on the water temperature. From April to October when water temperatures were lower, brown shrimp were common in salinities from 5 to 30 ppt, but from November to March with warmer water temperatures, the range was reduced to 10 to 15 ppt. During warmer months white shrimp were most plentiful in water below 15 ppt salinity. During cooler months white shrimp were not plentiful at any stations, and no recognizable relationship with salinity was found.

The effect of dissolved oxygen (DO) content seems to depend on the extent and duration of the values. Brown shrimp held in ponds with DO concentration of 2 ppm showed definite signs of stress while those held at 4 ppm did not (Broom 1971). Juvenile shrimp 55 mm (2.17 in) total length died at a lower mean lethal dissolved oxygen (LDO) level than subadults 91 mm (3.58 in) total length in 10 ppt salinity (Kramer 1975). Sudden salinity changes caused variation in the LDO levels for juvenile shrimp but not for subadults. Kramer concluded that LDO levels for brown shrimp are size dependent and affected by temperature and salinity. Heath (unpublished, Alabama Marine Resources Division, Dauphin Island, Alabama) found shrimp in water with DO content varying from 1.0 to 14.9 ppm. Shrimp obtained in samples with DO values below 4 ppm probably were in transit through or out of the area. Shrimp probably are able to avoid extremely low DO concentrations by moving through or out of the areas of extreme oxygen depletion unless these areas are extensive. A lower shrimp production may result from the loss of these areas to shrimp utilization. The ability of shrimp to withstand a particular DO level would be influenced by the temperature and salinity of the water involved. Research is badly needed to determine the frequency of occurrence, extent and duration of these areas of low DO in Mobile Bay.

While certain environmental conditions are beyond human control, other activities under human control can alter the environment significantly. Salinities within Mobile Bay are influenced greatly by the amount of river discharge, therefore, potential impact of projects altering the normal river discharge, upon salinity should be considered. Channelization can produce changes in the circulation regime of Mobile Bay and thus modify the salinity due to a change in the mixing of the Gulf and riverine waters. Temperature could be influenced by thermal effluents from industrial development along the bay. Because of the number of variables involved and the complexity of their interactions, a much broader data base is needed to determine the amount of change than can be imposed upon the system without deleterious effects upon the shrimp populations.

Habitat Destruction

Habitat destruction is one of the most adverse influences man can have on the shrimp populations in Mobile Bay. Some of the most important habitat is the marsh area fringing the Mobile Bay system. Shrimp are extremely dependent upon the marshes for sustenance and protection during the early portion of their lives. Barrett and Gillespie (1975) showed a correlation of the amount of nursery ground (salinities 10 ppt and above) available in April and May with subsequent brown shrimp catches. Commercial penaeids become less dependent upon the marshes for habitat as they mature but continue to depend directly and indirectly upon marshes for sustenance. Many species of shrimp which are not harvested commercially spend their entire life within the marsh habitat, and are important to the food web of the estuarine system. Projects that eliminate marsh areas or adversely alter salinity, temperatures or currents within these areas must be avoided if the integrity of the estuarine ecology is to be protected and/or enhanced.

MANAGEMENT AND RESEARCH

History of Management and Research

Commercial landings for Alabama were first recorded in 1880 by the United States Department of the Interior but were taken only periodically until 1948. Landings were not reported separately for Mobile Bay until 1963 (United States Department of the Interior 1963).

The State of Alabama has regulated the shrimp fishery since 1911 (Table 3) when the Alabama Oyster Commission was formed and given authority to control the state's seafoods. The authority to regulate seafood resources was passed to the Alabama Department of Conservation in 1919 and has remained with that agency. The Alabama Seafoods Division was established in 1951. In 1921 the first licensing schedule was set for shrimp boats and trawls. That schedule is the same set of fees used day although the costs of managing the resource and the value of the product have increased many fold. The legal size for commercial shrimp was set at 40 per .45 kg (1 pound) (heads-on) in 1931 and changed to 50 per pound in 1963. The present legal size or "count" was set at 68 per pound (heads-on) in 1967 to conform with the count law in Mississippi thus improving coordinated management between the two states. In 1940 a law was passed prohibiting shrimping north of a line from Arlington Docks in Mobile, Alabama to the community of Daphne, Alabama in Baldwin County. The measure was imposed to protect small shrimp in that area. In 1947 the area north of the line to Battleship Parkway (Fig. 1) was opened to bait shrimping and a bait-shrimp dealers license was established. In 1962 a regulation was promulgated which limited the length of net towed by a shrimp boat in Mobile Bay to 15.2 m (50 feet) measured along the cork line. This regulation provides an equitable allocation of shrimp stocks.

Table 3. A Partial History of Shrimp Management in Alabama.

1880	First statistics reported on Alabama Landings.
1911	First Alabama Oyster Commission given jurisdiction over all seafoods.
1919	Department of Conservation given authority to regulate seafoods.
1921	First licensing schedule for shrimp boats and trawls established.
1931	Legal size of shrimp set at 40 per pound with heads on.
1940	Shrimping prohibited north of a line from the Arlington Docks in Mobile to the community of Daphne in Baldwin County.
1947	The area north of the Arlington Docks to the causeway was opened to bait shrimping.
1948	Regular annual reporting of landing statistics for Alabama.
1951	Alabama Seafoods Division established.
1962	Regulation promulgated limiting the amount of net that could be pulled by a shrimp boat in the inside waters of Alabama to 50 feet measured along the cork line.
1963	Statistics reported for Mobile Bay landings separately.
1966	The first biologist was hired by the state to organize a staff of biologists to study the seafood of Alabama.
1967	The legal size of shrimp for commercial purposes set at 68 per pound with heads on. A shrimp assessment and monitoring program was begun.
1977	The present expanded shrimp assessment and monitoring program was begun.

In 1966 the first biologist was hired by the Alabama Department of Conservation and Natural Resources, Marine Resources Division, to organize a staff of biologists to study fish, shrimp and oysters. Although some studies were conducted through contracts with university personnel prior to 1966, little was known about the commercially important seafood resources in Alabama. Alabama did not have a complete monitoring and assessment program aimed specifically at shrimp until 1977. Except for surveys of the bait and 16-foot trawl shrimp fisheries, the only shrimp data collected from 1966 to 1977 was incidental to surveys for marine organisms in general or was performed to aid in setting shrimp seasons in Alabama. Since 1977 an expanded shrimp monitoring and assessment program for Mobile Bay has been in effect. The expanded program provides twice-monthly sampling from March to October each year and once per month during November to February. The stations sampled are indicated in Figure 1. Other supplemental stations are sampled irregularly to provide knowledge of specific problem areas. Bottom temperatures, salinity, and dissolved oxygen data are recorded with each sample. Data generated from this program have enhanced the management and regulation of shrimp stocks.

A shrimp tagging program was concluded in the fall of 1977 (Heath, unpublished Alabama Marine Resources Division, Dauphin Island, Alabama).Two thousand white shrimp raised in ponds at the Claude Peteet Mariculture Center in Gulf Shores, Alabama were tagged and released in Mobile Bay. To date 12 tags have been returned, and although this percent return may appear small, the information gained was useful. The pond-raised shrimp mixed with the wild stocks of white shrimp, and a general movement into the Gulf of Mexico, with some westward movement, was indicated. One tagged shrimp was captured near Deer Island, Mississippi in August 1978, 283 days after its release. It had grown 69 mm (2.7 in). The greatest growth of a tagged shrimp was 79 mm (3.1 in) after 232 days.

Recommendations for Research and Management

A number of measures are needed to improve the general knowledge and management of shrimp in Mobile Bay. The work will require a great deal of support from the State of Alabama. Needed research has been delayed by a lack of legislative action, money, manpower, and public support.

The license schedule for all fisheries resources in coastal Alabama should be increased to bring the fees into the realm of reality based on today's economy. Fee increases require legislative action and public support. A license should be established for recreational shrimp trawls to provide an estimate of recreational fishing pressure exerted on shrimp stocks. The increased revenue that could be derived from increased license fees would provide the necessary funds for sound management and research. Presently the Marine Resources Division of the Alabama Department of Conservation and Natural Resources receives no money from the state's general fund. The total operating budget for the Marine Resources Division is provided from the following sources:

Severance tax on buried shell deposits	31%
Marine gas tax	22%
Federal aid to research	17%
Non-resident sportfishing license	15%
Commercial fishing licenses	9%
Other (salvage, grants, fines, etc.)	6%

Seventy-five percent of the funds allocated for shrimp research and management in Alabama is federal funds for research provided by the Commercial Fisheries Research and Development Act (P.L. 88-309). This does not speak highly of a state whose shrimp industry is valued at $33.4 million in 1977, dockside. That value does not include the economy of the supportive industries (i.e., boat building, equipment manufacture and sale, and general commerce) or the resale value of the shrimp. The Marine Resources Division has drafted legislation which if enacted would provide revenue increases sufficient for the needed increase in research and management efforts. However, the recommended legislation was not enacted. Obviously no increase in the license fees will occur without adequate public support and concern of the legislators.

Much public controversy arises each year concerning shrimping regulations in Mobile Bay. Paramount are the concerns over closing most of the waters of the bay to commercial shrimping while allowing the continuance of bait and recreational shrimping. Although precise data are not available, it appears probable that considerable pressure is put on small shrimp by the recreational fishermen using 16-foot trawls. Closing the waters of Mobile Bay to all shrimping during periods when they are closed to commercial shrimping would eliminate this pressure.

More information is needed concerning movement and mortality of shrimp in Alabama waters. To obtain this information, a large tagging project similar to those being conducted by the U.S. Department of Commerce, National Marine Fisheries Service in Louisiana and Texas must be done in Alabama. The deterrent to this project at the present time is a limitation of equipment and manpower within the Marine Resources Division.

More research is needed concerning the relationship of shrimp to their environment. At present, personnel at the Alabama Marine Resources Division are analyzing catch and hydrographic data from samples collected since 1977 to determine correlations which may exist. A larger data base will probably be needed before definitive conclusions can be drawn from this subject.

Evaluating present management procedures is a major problem because of a lack of current landing statistics. It would be extremely helpful if shrimp fishermen were required to report monthly statistics concerning their shrimping effort (i.e., landings, location, days fished, vessel size, gear type, etc.). There is considerable resistance to this concept among commercial fishermen who have no desire to inform others of their degree of success.

Hopefully in the future some or all of the measures mentioned above will be accomplished.

SUMMARY

The shrimp fishery is economically the most important commercial fishery in Alabama. Although the percentage of Alabama shrimp landings harvested from Mobile Bay declined from 18% in 1964 to 5% in 1976, the catch per trip has changed little and the decrease in landings was probably due to a shift in the fishery from inshore to offshore. The Mobile Bay estuarine system makes up 72% of the estuarine area of Alabama and is extremely important because 99% of the shrimp caught in and adjacent to Alabama are dependent upon estuaries for a part of their life. The white shrimp was the major species caught in Mobile Bay until 1945 but by 1959 the brown shrimp had eclipsed the white as the major species. The primary limitation on the size of shrimp stocks at the present time appears to be environmental. Projects which might alter the habitat or hydrography of the estuarine system of Mobile Bay must be examined with their direct and indirect impacts in mind. Several measures could be undertaken to improve Alabama's shrimp management and research program. These include revision of the license structure, altering the law to allow regulation of all shrimp fishing in Alabama waters, more research on shrimp movement and mortality and the relationship between shrimp and their environment, and more current statistical reporting. The amount of change that can be imposed on the environment without deleterious effects on shrimp populations cannot be accurately determined without further research in those areas.

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THE BLUE CRAB FISHERY OF ALABAMA

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ABSTRACT

The earliest available record of blue crab (*Callinectes sapidus*) landings in Alabama was 1888 when 43.6 metric tons were harvested. Many problems which faced early crab fishermen have been solved but many remain.

Blue crabs mate and ovulate in Mobile Bay but egg hatching normally occurs when ovigerous females migrate offshore. Larval development, metamorphosis to first crab and growth to harvestable size generally are accomplished in a 12-month period. Fish is a major food item for all crab sizes, but is more important for crabs over 40 mm (1.6 inches) in carapace width. Oyster spat, although present in the stomach of crabs over 50 mm (2.0 inches), does not constitute a major food item for blue crabs.

Blue crabs are infected by numerous parasites and diseases, including viruses, bacteria, protozoans and metazoans. Many of these infections are temporarily eliminated in the molting process.

Mean annual blue crab commercial catch in Alabama for the periods 1950-1959, 1960-1969, and 1970-1977 was 470.3, 692.1, and 796.0 metric tons, respectively. Since 1950, approximately 95% of the commercial crab landings was harvested by crab pots with the remaining 5% taken by shrimp trawl.

Associated problems with the crab fishery in Alabama include fluctuating landings, unknown user density, low dissolved oxygen, lack of recreational catch statistics, by-catch from non-directed fisheries, lack of information on developing soft-shell industry and labor problems in the commercial fishery.

INTRODUCTION

The earliest reported commercial landings of blue crab (*Callinectes sapidus*) from Mobile Bay was in 1888 during which 43.6 t[1/] (96,000 lbs) were harvested. During the early years of the Alabama crab industry, trot lines baited principally with beef tripe, were set from wooden row boats and the daily catch cooked in barrels on the shore near the landing areas. The cooked crab was then transported to the fisherman's home where the meat was picked by hand and stored for marketing or barter. [2/] The industry has revolutionized in the past 90 years with traps replacing trot lines; fiberglass boats equipped with fast outboard and inboard engines replacing wooden row boats; sterile, stainless steel cooking pots replacing the old cooking barrels; and sanitary processing rooms replacing the fisherman's kitchen or backyard "crab picking" area.

Many of the problems that plagued early crab fishermen have been systematically solved as technology evolved but other problems continue to plague contemporary crab fishermen. Mechanical meat separators have not developed adequately to replace expensive and uncertain hand labor. During the peak harvest months of July, August, and September there are days and often weeks in which unpredictable masses of oxygen deficient water completely engulf trap lines, killing and rendering useless the trapped crabs. Peak crab harvest months occur simultaneously with peak shrimping months; therefore, diverting fishermen and crab pickers to the more lucrative shrimp fishery and associated processing plants. Crab harvest in Mobile Bay is extremely seasonal with virtually no fall and winter fishery. Annual crab harvests are variable with no particular trends to adequately forecast available stocks.

This paper presents limited data on the biology and life history of the blue crab in Mobile Bay and a general profile of the commercial crab fishery with historical landings. Biological, ecological, and sociological data gaps which should be bridged in order to properly manage the fishery are identified with suggestions for filling these needs.

[1/] t = metric ton (2,204.6 lbs).

[2/] Personal communication, Buddy Zirlott, Zirlott Seafood, Fowl River.

BIOLOGY

Life History

For most marine species, mating and spawning is synonymous; however, in the case of the blue crab the two events occur at different times. Mating occurs after the juvenile female has had her terminal molt (ecdysis). The male assumes a protective position over the juvenile female immediately prior to the terminal molt. After molting, the male implants the female's seminal receptacles with sperm-bearing semen and retains his protective position until the new chitinous shell hardens (Leary 1964; Oesterling 1976; Tagatz 1968). Spawning may occur until the female dies but mating occurs only once. Ovulation (spawning) usually occurs within two months after mating, but may be delayed for as long as five months depending upon the temperature. During ovulation, eggs are forced from the ovaries through the seminal receptacles containing spermatozoa where they are fertilized and then are exuded onto fine hairs located on the abdominal swimmerettes. The eggs form a mass which occupies a space approximately 33% of the size of the crab and forces the abdomen, normally folded under the cephalothorax (carapace), away from the carapace area (Figure 1).

Figure 1. Female ovigerous blue crab with eggs attached to fine hairs on cephalothorax.

Spawning normally takes place in the lower estuary where the salinity is over 20 ppt and in the Gulf of Mexico. Extreme drought conditions with subsequent high salinities may expand the estuarine area where successful hatching can take place (personal communication, Harriet Perry). The eggs when first deposited are light, yellow-orange in color, turning darker to a gray color, as the yolk is absorbed by the developing unhatched larvae.

The first larval stages of the blue crab, usually found offshore, are called zoeae (Figure 2). There are seven molts in the zoeal stage and each molt results in a slight morphological change. Blue crab zoeae are approximately 1 mm (0.4 inches) in length and in no way resemble the adult crab. Blue crabs remain in this planktonic stage for 31 to 49 days (dependent upon temperature and salinity) and their principal movement during this period is related to tidal action, oceanic currents, and wind currents (Tagatz 1968). Zoeal stages of blue crab rarely complete the first molt in salinities lower than 20 ppt (Costlow and Bookhout 1959), and consequently are rarely found in the inside waters of Mobile Bay.

The second larval blue crab stage is called the megalopa (Figure 3) and it is this stage which first enters the estuarine area. Blue crab megalops are 2-4 mm (.08-.2 inches) total length and approximately 1 mm (.04 inches) wide. They remain in this stage for 6 to 20 days (Costlow and Bookhout 1959) again dependent upon temperature and salinity, after which they metamorphose to the first crab stage.

Growth

Growth is quite rapid after metamorphosis. The legal harvest size in Alabama of 10.2 cm (4 inches), measured from the widest point on the carapace, is attainable within one year.

More (1969) estimating blue crab growth from Galveston Bay, Texas reported monthly size increases of 15.3 – 18.5 mm (0.6 – 0.7 inches). He indicated similar growth of juveniles recruited during the months of February, March, and July. Based on data collected in 1968 and 1969 (Swingle 1971), there appear to be three major juvenile crab recruitment peaks in Alabama (April, August, and December) with crab growth among periods differing greatly. Juvenile crabs recruited in April, August, and December grew at monthly rates of 19, 10, and 5 mm (.75, 0.4, and 0.2 inches), respectively (Figure 4). Juvenile crabs recruited in April are likely the progeny of late fall spawns; those in August from late spring spawns; and those in December from early fall spawns. One would expect the growth from both the latter two spawns to pick up considerably and equal the former as spring approaches and the water begins to warm.

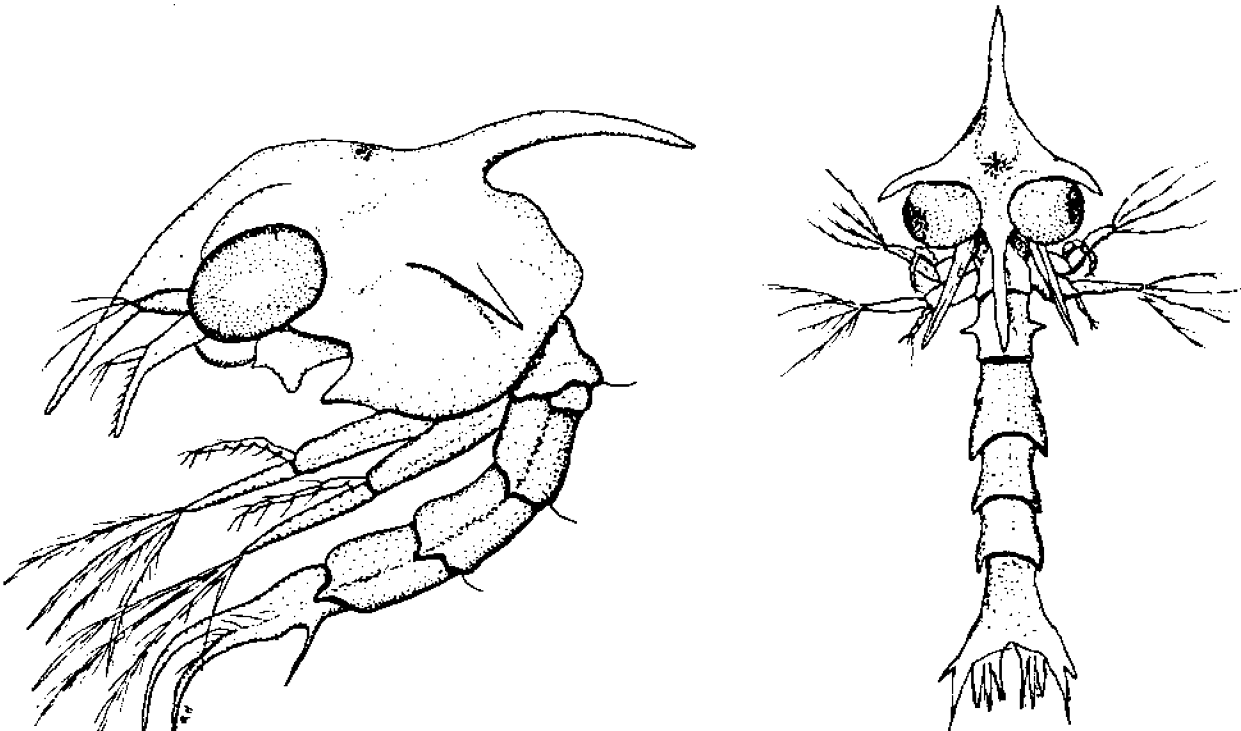

Figure 2. Blue crab (*Callinectes sapidus*, Rathbun) zoea. (Drawing by Ralph Havard, Marine Resources Division.)

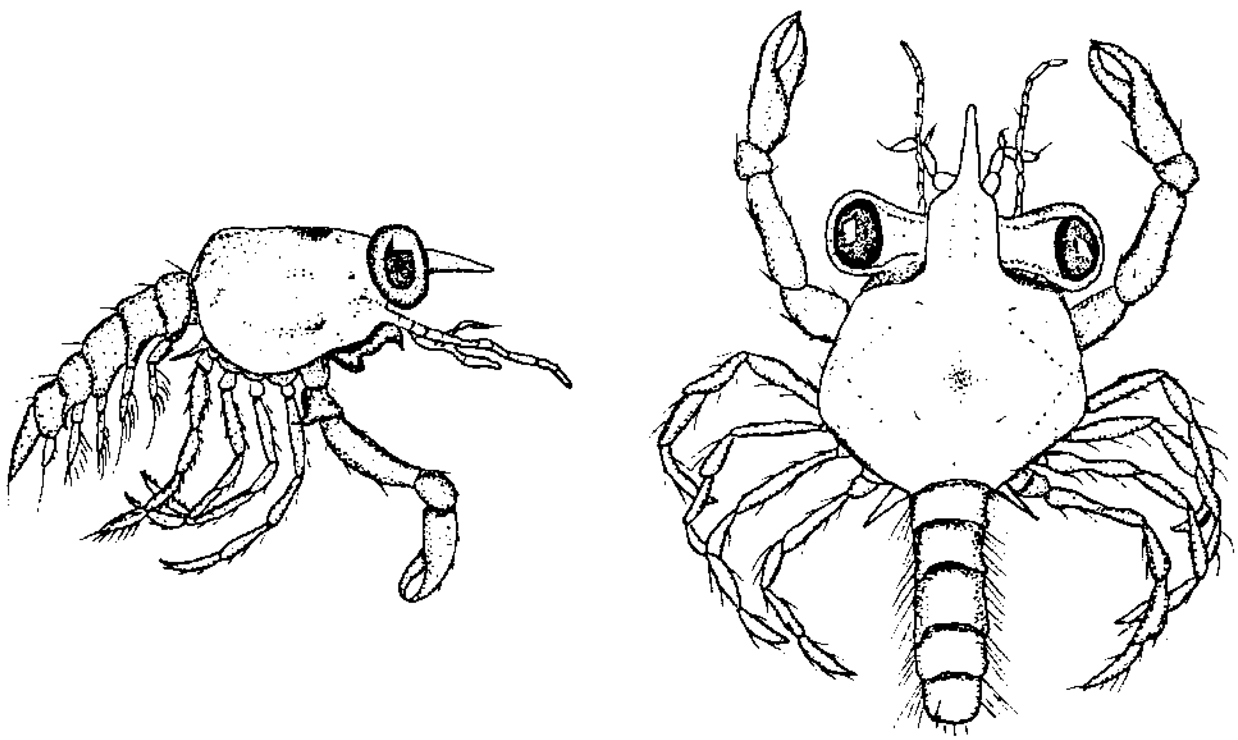

Figure 3. Blue crab (*Callinectes sapidus*, Rathbun) megalopae. (Drawing by Ralph Havard, Marine Resources Division.)

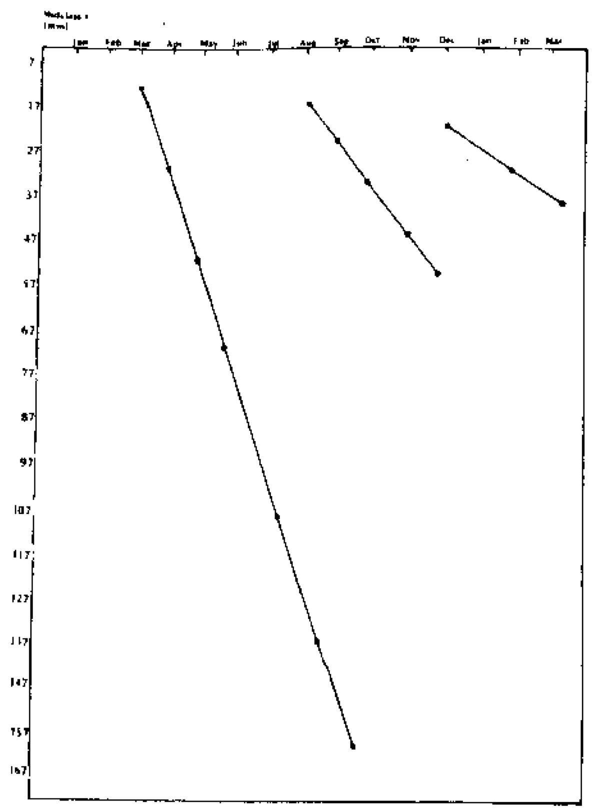

Figure 4. Size distribution of *Callinectes sapidus* taken in Alabama in 1968 and 1969 (adapted from Swingle, H.A. 1971).

Food Habits

Tagatz (1968) conducted extensive food habit studies of the blue crab from St. John's River, Florida and summarized previous studies by other workers. Principal factors that influenced blue crab food intake included crab size, food abundance, and size of food particles. Tagatz's work is summarized in Table 1. The principal food items for all crabs sampled were mollusks, organic debris, fish, and crustacea, respectively. Fish was a major food item for all crab sizes examined but appeared more important for crabs over 40 mm (1.6 inches) wide. Organic debris was found in all sizes examined but was more abundant in crabs less than 40 mm (1.6 inches).

Table 1. Class of Food Found in Blue Crab Stomachs in St. John's River, Florida (Tagatz 1968).

Food Item	Percent
Mollusks	39.0
Organic Debris	19.8
Fish	19.4
Crustaceans	15.0
Plants	3.9
Annelids	1.8
Insects	0.9
Bryozoan	0.1
TOTAL	99.9

Mollusks were found in all crabs examined and included mussels, clams, oysters, and snails. Clams, principally *Rangia cuneata* and *Mulinia lateralis*, were found in the stomachs of all sizes examined. Mussels and snails were not found in crabs under 21 mm (0.8 inches) wide but were major items for larger crabs. Oyster spat, although present in the stomachs of crabs over 50 mm (2.0 inches) wide, did not constitute a major food item of those examined. Amphipods and crabs were the dominant crustaceans eaten with amphipods being found in all sizes examined and crabs being found in all sizes larger than 10 mm (0.4 inches).

Parasites and Diseases

Overstreet (1978) listed a wide variety of parasite and disease organisms which infect the blue crab including viruses, bacteria, protozoans, and metazoans. Overstreet points out that while the blue crab is host to many parasite and disease organisms, many of the infections are temporarily eliminated in the molting process. Examples of some of the more important and more evident parasite and disease organisms include:

Ameson michaelis, a microsporidan protozoan, produces symptoms in blue crabs referred to by fishermen as "sick crabs." According to Overstreet, infestation of this organism produces a chalky appearance in the appendage joints and the abdominal area usually turns grayish. The muscle tissue of the blue crab is invaded by this host-specific microsporidian and in some infestations a large portion of the host's musculature is replaced by the parasite.

Virbrio parahaemolyticus, a bacterial infection, that produces large jelly-like blood clots or white nodules on the gills of infected crabs. It readily causes mortality among its hosts and can bring about a form of food poisoning in man. Overstreet points out that food poisoning in man by this organism can be prevented with minimal heating of the crab meat.

Urosporidium cresens, a hyperparasitic, haplosporidan protozoan, infects encysted worms in the blue crab musculature. The protozoan undergoes extensive multiplication, produces spores, and a condition referred to as "pepper crabs." According to Overstreet, the spores harm neither man nor the infected crab.

Chelonibia patula, an external barnacle symbiont, demonstrates host-specificity for a small group of crabs, including the blue crab. Mature female crabs are particularly affected by this organism since they cannot shed the infestation. The weight of large barnacle sets produces severe strain on the crab host.

Octolasmis muelleri, a pedunculate (gooseneck) barnacle infects the gill region of the blue crab. Infections from this organism have been observed on emigrating female blue crabs, producing lethargic effects on its host. Overstreet has observed over 1,000 gooseneck barnacles in a single gill chamber. Although the barnacle is not reported to receive nourishment from the crab, its presence undoubtedly affects the crab's respiratory capacity.

Overstreet mentioned other parasites and diseases that although present on the Eastern Coast of the United States have not been implicated in Gulf Coast crab mortalities. Among those included were *Paramoeba pernicosa* commonly called "gray crab disease," a "herpes-like" virus and one of four viruses isolated recently from blue crab; *Epistylis* sp. a stalked ciliate, that attaches to the gill lamellae; and *Lagenophrys callinectes*, a ciliate that also attaches to the gill lamellae.

COMMERCIAL FISHERY

Commercial landings of blue crab in Alabama for the past 90 years have shown growth similar to that of other commercial species. During the developing years of the blue crab fishery (1897-1937), annual catches range from 10.9 to 343.3 t. Commercial catches were similar during the 1940's except during the years of 1945, 1948, and 1949 when catches rose to 1001.1, 1076.4, and 965.3 t, respectively (Table 2).

Table 2. Historical Commercial Landings of Blue Crab in Alabama (from Alabama Landings and Fishery Statistics of the United States).

Year	Weight		Year	Weight	
	Pounds	Metric Tons		Pounds	Metric Tons
1888	96,000	43.6	1954	972,000	440.9
1897	24,000	10.9	1955	1,612,000	731.2
1902	75,000	34.0	1956	725,000	328.9
1908	246,000	111.6	1957	1,462,000	663.2
1918	96,000	43.6	1958	1,182,000	536.2
1923	84,000	38.1	1959	1,093,000	495.8
1927	32,000	14.5	1960	499,000	226.3
1928	105,000	47.6	1961	838,000	380.1
1929	107,000	48.5	1962	634,000	287.6
1930	81,000	36.7	1963	1,297,000	588.3
1931	80,000	36.3	1964	1,762,000	799.2
1932	71,000	32.2	1965	1,812,000	821.9
1934	259,000	117.5	1966	2,183,000	990.2
1936	998,000	452.7	1967	2,353,000	1067.3
1937	757,000	343.4	1968	1,980,000	898.1
1938	511,000	231.8	1969	1,072,000	486.3
1939	558,000	253.1	1970	1,407,000	638.3
1940	1,381,000	626.4	1971	1,997,290	906.0
1945	2,207,000	1001.1	1972	1,612,406	731.4
1948	2,373,000	1076.4	1973	2,098,471	951.9
1949	2,128,000	965.3	1974	1,825,678	828.1
1950	598,700	271.6	1975	1,639,484	743.7
1951	1,109,400	503.2	1976	1,298,653	589.1
1952	655,300	297.2	1977	2,174,142	986.2
1953	1,087,000	493.1			

Monthly blue crab landings for the period 1970-1977 are shown in Table 3 and the 8-year monthly mean catch and monthly catch for 1976 (low catch for period) and 1977 (high catch for period) are presented in Figure 5. During the past 8 years, 78.7% of the blue crab catch occurred from April through October. July produced greatest monthly catches of blue crab during the years 1970, 1973, and 1975, while June was most productive during 1974 and 1976. The months of April, August, and October were most productive in 1971, 1972, and 1977, respectively. December, January, February, and March contributed 5.4, 2.7, 2.5, and 3.7%, respectively of the mean monthly catch.

Prior to 1950, virtually all of the commercial catch of blue crab was by trot line. During the 1950's, the influence of East Coast crab fishermen began to shift harvest methods to the more efficient crab pot or trap and in 1966 (the last year in which crabs were taken by trot line in Alabama) only 0.4% of Alabama crab landings were by trot line (Swingle, W.E. 1976). The trap catch drops off criticially as the water temperature drops in November and most fishermen use this period to mend traps, replace floats, etc., with processors depending principally on trawl caught crabs. Approximately 5% of the total blue crabs landed annually in Alabama are harvested by shrimp trawl, while 95% are harvested by crab traps (Fisheries Statistics of United States).

Crab fishermen usually set their trap lines, consisting of 200-1000 traps, during the spring and rarely move them until November. There are exceptions to this procedure during the early spring when some upper Bay crabbers make initial sets in the lower Bay to harvest mating crabs, then move fishing activities back to the upper Bay with major male crab concentrations.

Most crabbers and crab processors prefer to handle male crabs. Conservation of the species is incidental in this preference and economics and sociology are paramount. Crab fishermen prefer male crabs because they are larger and bring more money per individual. Processors prefer male crabs because shop employees, who are usually paid by picked weight of crab meat, spend equal time cleaning small, low-yield females as they do large, high-yield males.

To a large extent crab catch sex ratio is influenced by fishing area. Crab fishermen who have

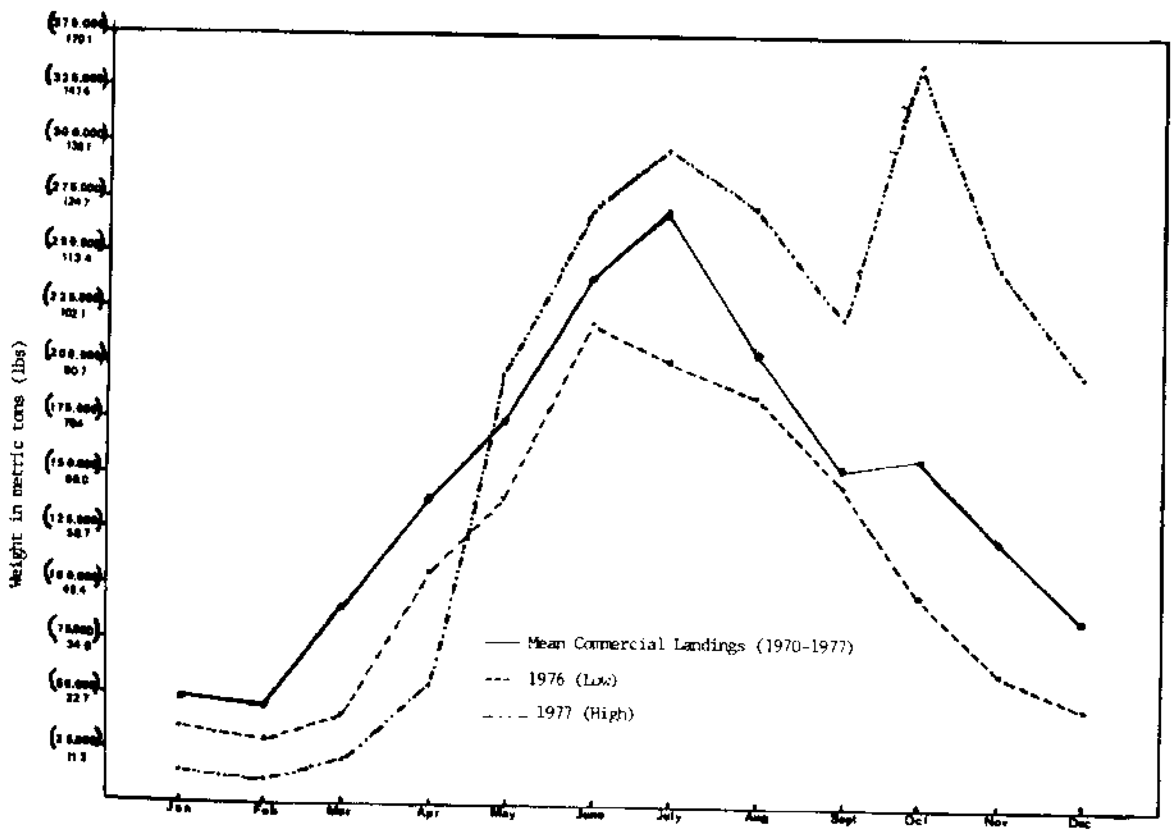

Figure 5. Monthly Mean Commercial Blue Crab Landings from Alabama for the Period 1970-1977, as well as High and Low Extremes for the Period.

Table 3. Alabama Blue Crab Monthly Landing in Metric Tons (lbs) for Years 1970-1977.

Year	January	February	March	April	May	June	July
1970	18.21 (40,150)	15.02 (33,120)	20.46 (45,100)	28.79 (63,468)	29.32 (64,632)	86.73 (191,196)	120.29 (265,190)
1971	21.82 (48,102)	16.32 (35,970)	24.58 (54,185)	195.68 (431,411)	122.92 (270,987)	136.78 (301,553)	109.07 (240,450)
1972	18.61 (41,020)	22.57 (49,757)	28.95 (63,813)	32.29 (71,185)	33.82 (74,563)	95.44 (210,416)	127.17 (280,351)
1973	24.62 (54,276)	29.05 (64,052)	41.26 (90,959)	76.42 (168,471)	119.10 (262,559)	147.44 (325,049)	197.63 (435,705)
1974	27.38 (60,358)	28.52 (62,880)	57.79 (127,397)	62.39 (137,552)	139.50 (307,527)	143.10 (315,488)	110.26 (243,087)
1975	36.26 (79,943)	31.75 (69,997)	37.83 (83,390)	27.20 (59,962)	63.74 (140,515)	73.75 (162,579)	101.67 (224,153)
1976	19.50 (42,958)	11.78 (25,980)	16.28 (35,901)	45.48 (100,255)	59.66 (131,533)	94.84 (209,085)	93.27 (205,625)
1977	6.75 (14,881)	5.44 (11,999)	10.29 (22,684)	26.18 (57,720)	88.30 (194,672)	121.91 (268,768)	135.76 (299,309)
Mean	21.64 (47,711)	20.06 (44,219)	29.68 (65,429)	61.80 (136,253)	82.04 (180,872)	112.50 (248,017)	124.39 (274,234)

Year	August	September	October	November	December	Total
1970	67.34 (148,447)	64.79 (142,842)	68.77 (151,621)	77.92 (171,791)	40.68 (89,691)	638.32 (1,407,248)
1971	77.30 (170,422)	52.97 (116,785)	60.84 (134,129)	43.45 (95,788)	44.23 (97,508)	905.96 (1,997,290)
1972	131.61 (290,141)	92.04 (202,916)	75.13 (165,642)	42.58 (93,877)	31.18 (68,735)	731.38 (1,612,406)
1973	197.09 (236,083)	71.17 (156,905)	63.54 (140,078)	41.72 (91,967)	32.83 (72,367)	951.85 (2,098,471)
1974	78.96 (174,085)	64.98 (143,260)	46.71 (102,969)	35.52 (78,315)	33.02 (72,790)	828.13 (1,825,708)
1975	97.14 (214,160)	80.92 (178,399)	84.85 (187,067)	57.68 (127,169)	50.87 (112,150)	743.66 (1,639,484)
1976	84.75 (186,845)	70.24 (154,851)	49.80 (109,801)	27.72 (61,104)	15.75 (34,715)	589.06 (1,298,653)
1977	124.70 (274,910)	104.84 (231,125)	152.55 (336,323)	112.94 (248,980)	96.51 (212,771)	986.17 (2,174,142)
Mean	96.11 (211,887)	75.24 (165,885)	75.28 (165,954)	54.94 (121,124)	43.13 (95,091)	796.81 (1,756,672)

been engaged in this fishery know the right area for catching the proper product for their clients. There appears to be a general understanding among crab fishermen regarding historical fishing areas and seldom are there any fishing ground disputes among these fishermen. One fisherman/processor fishes an area in Heron Bay and Cedar Point which yields around 90% female crabs. He has historically fished this area, has geared his operation to a predominantly female catch, and enjoys working an area that interests no other crab fishermen. Other fishermen who must keep shop employees happy by catching large male crabs fish principally in the upper Bay on trap lines running north and south from Deer River (Hollinger Island Channel).

One of the larger crab processors in Alabama purchases virtually all of his products from Mississippi and Louisiana because of the undependable harvest in Alabama (Personal communication, George and Anita Bryant, Bryant Seafood, Bayou La Batre).

PROBLEMS RELATED TO BLUE CRAB FISHERY AND POSSIBLE SOLUTIONS

Fluctuating Landings

Although the general catch trend for blue crab since 1963 is considered stable, there are year to year landing fluctuations. The crab catch in 1977 was 60% greater than the 1976 catch; however, it was approximately the same as the catch in 1945, 1966, and 1967. One must therefore question whether annual commercial blue crab landings reflect the general condition of the crab population or the economics of the crab fishery in Mobile Bay.

If processors are unable to quickly handle crab catch during peak production months, crab fishermen simply slow down their harvest. This decrease in effort is reflected in the monthly catch statistics as a production drop and is easily misrepresented as a biological problem. If catch statistics are to be used effectively, they must demonstrate catch per unit effort (CPUE) which is not misleading. If a crab fisherman catches a consistent or increasing weight of crabs per pot then the fishery is stable or expanding, respectively. If the CPUE is dropping over a period of time, biological instability or increased user density is implicated.

Unknown User Density

There is no license requirement for commercial or recreational crab fishermen in Alabama and the number of fishermen (full-time, part-time, or recreational) participating in the fishery, as well as the number of fishing units used, is unknown. Knowledge of user and gear density is fundament in fishery management and licensing is the most effective means of gaining this knowledge. Commercial crab fishermen support such a license and also regulations on trap markers to enable enforcement officers to quickly match fishermen and traps.

Lack of Blue Crab Monitoring and Assessment Program

A sound blue crab assessment and monitoring program is extremely important to all users of this resource. Although the blue crab life history and biological requirements for growth and reproduction are similar throughout its range, there exists some degree of uniqueness within each estuarine system. This unique estuarine character must be identified in order to regulate and manage the resources effectively.

A monitoring and assessment program is quite expensive requiring obligated personnel and equipment. The Alabama crab fishery, although important to those who depend on the resource for livelihood, represented only 4.5% of total weight of seafood landed, and 1.1% of the total seafood value in 1972 (Alabama/Mississippi Sea Grant Advisory Service). The most equitable means of initiating an ongoing blue crab monitoring and assessment program in Alabama is to incorporate it into a total resource monitoring and assessment program.

Low Dissolved Oxygen

Extensive areas of bottom water in Mobile Bay suffer oxygen depletion during the summer months, particularly during August. Extensive oxygen depletion in the bottom waters occurred in July and August 1971 when values of 1.0 ppm or below were found somewhere in the Bay on 75% of the days sampled (May 1973). At this time, low oxygen (3.0 ppm or less) waters covered an area of 44,541 ha (111,353 acres) or 44% of Mobile Bay including Bon Secour Bay. Included in this area were 22,655 ha (56,288 acres) containing dissolved oxygen of 1.0 ppm or less. This phenomenon, although not unique in Mobile Bay, has been implicated by May (op. cit) and Loesch (1960) as a precursor for mass shoreward migrations of demersal fishes in Mobile Bay, known locally as "jubilees."

Free swimming crabs are usually able to avoid oxygen deficient bottom waters by either swimming shoreward or moving to the surface. Trapped crabs; however, are killed and rendered useless when they are engulfed by waters of low dissolved oxygen. Some area crab fishermen indicate that 75% of their mid-summer catch dies and some fishermen cease their crabbing altogether during July and August because of heavy die-offs or reduced catch. On a positive note, Melvin Plash (Plash Seafood, personal communication) has indicated a trapped crab mortality decline in recent years. Oxygen deficient waters still occur in Mobile Bay presenting a constant threat to the crab fishery. A study to identify the cause of this phenomenon and seek a resolution to the problem is badly needed.

Lack of Recreational Catch Statistics

In order to completely evaluate exploitation rate of blue crab, some estimate of the number of users and catch per annum is essential. Tatum (unpublished) estimated that approximately 20% of the annual commercial crab catch is harvested by recreational crabbers and therefore unrecorded. This estimate was very conservative and based on the number of estuarine waterfront parcels in Mobile and Baldwin counties and on blue crab by-catch estimates from recreational shrimping intensity (Swingle, et al. 1976).

Recreational catch of blue crab could easily be higher than estimated and therefore play a significant role in the total harvest. Resource managers must be aware of user intensity if they are to equitably manage crab stocks. Recreational licensing of these users and periodic user surveys would be helpful in identifying the intensity of these user groups.

Blue Crab Shrimp Trawl By-Catch and Destruction

As previously mentioned, trawl caught crabs represent approximately 5% of the total commercial crab landings in Alabama. This area of the fishery is very important since it sustains the crab processing plants during the period when trap catches are low. Trawl caught crabs are seldom used during peak trapping months and are usually returned to the Bay. Damage imposed on these unused and frequently undersized crabs likely plays an important role in the overall crab fishery. Although the areas are presently undocumented, there are juvenile blue crab staging grounds in Mobile Bay which should be protected during periods of high utilization by undersized crabs. An assessment program can identify these areas and document high use periods by juvenile crabs.

Soft-Shell Crab Industry

One of the more lucrative sidelines of the blue crab fishery is in the landing of soft-shell crabs. To a large extent commercial and recreational crabbers consider this valuable product incidental to the hard crab and there is presently no directed fishery towards the soft-shell crabs. One processor in Baldwin County has constructed holding facilities for crabs exhibiting premolting signs, but his use of this system is infrequent and his supply undependable.

A technique for economically operating a crab shedding house should be developed. Some work along this line has been done by the Gulf Coast Research Laboratory (Perry, personal communication).

Labor Problems in Commercial Fishery

Although mechanical crab meat separators are available that reduce labor in crab processing plants, the quality of meat produced by mechanical means is not equal to that produced by hand labor. One mechanical separator in use in Alabama requires initial blanching prior to introduction to the automatic separator; afterwhich, the separated meat must be completely cooked. The industry is in need of a separator which will produce quality meat at a rapid rate.

During good shrimping years, there is considerable pressure to divert the crab processing labor force, both to the shrimp fishery and associated processing plants. If the shop happens to be multi-fishery oriented, there is no problem since the shop owner places processing emphasis on the most important immediate product. If; however, the processing plant handles only crab products, the effects of the diverted labor force from his plant can be catastrophic. This re-emphasizes the immediate need for advanced technology in crab processing.

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PANEL DISCUSSION - MODERATOR, DR. HAROLD LOYACANO, FISH AND WILDLIFE BIOLOGIST, U.S. FISH AND WILDLIFE SERVICE

MEMBERS

Mr. William Eckmayer, Alabama Department of Conservation and Natural Resources
Mr. Stevens Heath, Alabama Department of Conservation and Natural Resources
Dr. Robert Shipp, University of South Alabama
Mr. Hugh Swingle, Alabama Department of Conservation and Natural Resources
Mr. Walter Tatum, Alabama Department of Conservation and Natural Resources
Mr. William Tucker, Alabama Department of Conservation and Natural Resources
Mr. C. William Wade, Alabama Department of Conservation and Natural Resources.

LOYACANO: All these gentlemen presented very fine papers. They were all very interesting and timely, and they pointed out a number of existing data gaps that, hopefully, we will be able to address in the near future.

M. JONES: One of the gentlemen was talking about oysters, and he mentioned the word "relaying" the oysters. Not knowing too much about that, depuration came to mind. I know Mississippi is building some kind of a facility to depurate the oysters. Can you explain that a little bit. Is Alabama planning on working within the system or are we going to develop something like this in our area?

ECKMAYER: I was involved with that project when they first started the feasibility study checking out local regulations, zoning programs in the local communities for determining the feasibility whether Alabama would be a logical location to put the plant, and I have not heard the completion of that first stage of the program. All they are doing with that depuration plant is determining the economic feasibility of a plant of that form. There is actually no set location for the plant. The process involves placing oysters in bins and, through either closed or open systems, running water through the bins. As the water passes out, if it's on closed system, it is recycled through a purifier which uses either ozone or ultraviolet light. They will monitor the effluent from the bins and when the water leaves the safe standard for the bacteria count they will say the oyster is safe. But they have had certain problems with depuration of oysters, and the FDA is not certain about the health problems involved with okaying a program in this form.

ANONYMOUS: One of the gentlemen who dealt with the oysters said 10% of the oysters were caught in Mobile Bay. I was wondering about the percentage of the shrimp catch.

HEATH: Walter mentioned that 52% of the inshore catch from the Alabama waters comes from Mobile Bay. Inshore waters include Mississippi Sound and Wolf Bay, Perdido Bay and the areas of Baldwin County.

NONKES: Is it known how many metals, coliforms, and pesticides shrimp and crabs take up out of the water and put into their systems? How often is it monitored?

TATUM: Yes, they do. They can. How often is it monitored?

HEATH: We don't do this sort of monitoring. I did check with the personnel of the Food and Drug Administration lab on Dauphin Island. They do monitor seafood samples; crabs, shrimp, oysters, from around the gulf region which includes the Mobile Bay area. I don't know what the frequency of analysis is, but up to this time they have found well below minimum requirements of these substances in the shrimp, crab and oysters, as a matter of fact. This is, of course, excluding coliform in the oyster which occurs somewhat regularly. I was told they had to modify some of their analytical equipment to get down to the range where they could detect some of the heavy metals in these animals, shrimp and crabs, so that was encouraging.

SAVAGE: What area of socioeconomic research do you feel is most important at this present time? What particular topics, if any, come to mind?

HEATH: In the shrimping industry, we just went around and around with this on some of the council in shrimp management task force meetings. We have a very complicated situation in Alabama, and most of the other states in the gulf have the same problem. We have, in essence, three groups of people using a single resource. We have a large offshore fleet. We have an inshore fleet of smaller boats in the commercial sector depending on it for their livelihood. And then we have another whole sector of small boats, small net owners who use shrimp as bait and to put into their freezer. We might well do some sort of socioeconomic research on the size of these groups, the dependence of these groups on this resource, and the interrelationship between the groups. There is certainly enough controversy among members of the groups, as I am sure Dr. Rawson is aware of, since he interfaces with these people considerably. As far as shrimp goes, I think that would be a good idea just to find out the social impact the changes will have in management on this species.

LOYACANO: Would anyone else like to address the socioeconomic aspects of our research?

TATUM: I think that each one of the panelists has spoken with perhaps the exception of Dr. Shipp and Bill. I think Bill may have eluded to it, too. The one thing that we don't know is the number of users that we have. Another thing we don't know is the amount of fishery resources that we have. One day, and it's probably coming around a lot sooner than any of us would like to realize, we're going to be charged with allocating that resource to the various users. Without a handle on the number of users that we have and without a handle on the amount of resource we have, it's not going to be a very equitable distribution of it. So, this is paramount in our opinion.

GARDNER: What effect do oil spills have on our oysters, and shrimp, and the fish that live in the Bay?

ECKMAYER: There have been a few studies done at Woodshole in Massachusetts concerning what effects an oil spill would have on oysters. These were all precipitated from the Argo-Merchant problems. The work they have been doing hasn't been working with straight crude oil. They have been concentrating on various grades and extracts from the refined process. It varies and depends on the type of oil that is spilled. The lighter grades of oil that would be suspended in the water flowing above the bottom would have no effect on the oysters. The heavier grades, which almost flow like tar, could possibly sink to the bottom and suffocate the oysters.

HEATH: I haven't read any particular studies on the effect of the different oils on shrimp. I know that the work has been done. The shrimp would probably avoid the oil initially. It would depend on the extent of the spill. I know that there has been some basic laboratory work done on this. I'm just not familiar with it.

LOYACANO: Dr. Shipp, can a variegated cyprinodon live in oil?

SHIPP: If anybody can, he can. Actually, most fishes would be able to avoid it, too. They leave. Oil spills over extensive areas usually do not influence too greatly the amount of dissolved oxygen. It is surprising to a lot of people how much oxygen is maintained in the water and the image of a massive kill due to low DO's is not a subsequent event always of an oil spill. I think fishes in general can escape. The exception comes during the early life history stages when they are not very mobile. If the oil should get up into shallow estuarine areas, then I think it could be a problem.

THOMPSON: What about open water disposal of dredged material? How does that not affect fish, their larvae and eggs?

SHIPP: If it became unpleasant, undesirable for them, they would simple leave. That is the advantage they have. The larval fishes offshore wouldn't be too much affected, but the larval ones that are trapped in limited areas nearshore would encounter severe problems.

LOYACANO: Would anyone else care to comment on dredge spoil or the oil spill problem?

GARDNER: In 1977 there was an international symposium on oil spills in New Orleans, and some papers were presented that oil would be harmful to larvae of fish and also of lobsters and shrimp. So, I would like to put that in the record.

M. JONES: I would like to add that also regarding Argo-Merchant, Woodshole has shown that zooplankton was picking up some of that oil, and they did not know what this might be doing to fishes. I was told that one of the reasons there are not so many people fishing in the Bay is because of the lack of recreational species, a decline of speckled trout, etc. One person told me that he was very concerned because up in the northern part of the Bay some of the big commercial trawlers up there at certain periods of the year were capturing small fishes that maybe should not be touched at that time. Maybe that area should be closed at that time in order to allow these species to become larger and know where they are supposed to go.

WADE: Myrt, I think I alluded to that in my paper this morning. We don't know the effect of the commercial fishery on the sport fishery at this point. One of the things in the 10 key points that I made about the research needs was that this relationship between the sport and commercial fishery needs to be understood, but at this point nobody really knows what the effect is. We don't know if there is a real problem (we are talking about speckled trout fisheries at this point) or not. If the problem exists, we don't know if it's due to environmental changes or changes in the environment induced by man or if it's fishing pressure or just what. This is one of the basic needs we need to address in our research program. The Marine Resources Division has recently undertaken a study of the speckled trout fishery, and the first thing we are doing is collecting basic data on age and growth in these fishes in our estuary. As a matter of fact, this Friday I am going up to Auburn to get the computer printout on the speckled trout fishery in Alabama. This will be the first piece of data we have collected, and hopefully in a period of maybe four to five years we will have some answers to these important questions. It is not only possibly a biological problem, but it is very definitely a social problem, if nothing else. This is something that we need to address.

SHIPP: Regarding the specific comments about the trawling in the upper areas of the bay, I don't know whether that has taken place or not, but most of our commercially valuable species spawn in the lower part of the Bay or offshore, and rarely do the juveniles get too far up in the Bay. So, that particular problem would not be a valid concern. It may be for other reasons, but most of the drums and other commercial species spawn in the higher saline waters and the larvae and juveniles stay there, too. They rarely get high up in the Bay.

TABBERER: In several talks, I heard circulation alluded to as a major problem in the Bay. Disregarding harvest regulations and socioeconomics and so on, from a habitat management standpoint from all the resources you've addressed, what do you see as the major management needs or data needs in the Bay to optimize management for the resources.

WADE: This morning most of the speakers did, in fact, mention problems that they thought needed to be looked into and studied. In my paper I listed 10 important areas that we need to investigate before we could establish a management program. When I mentioned management, I said one of the main things I felt we needed was the data before we started a mangement program, but so many of the programs in the past have been based purely on guess work and social problems and so forth that the biological aspects have never entered into it. My thrust would be to get some biological data and try to match it up with the social problems, and so forth, that exist in the different fisheries. Certainly these other basic questions that are outside of my expertise such as the hydrographic work and all this has to be worked out because it ties in directly with the resource we are trying to manage.

SHIPP: I totally agree, and I would like to reiterate. I think that the major purpose of this symposium is to gather together the data that are available and put them in one place and go from there.

LOYACANO: I think we may be a little premature in attempting to identify just what management steps could be taken, but hopefully we will have that information available after this symposium, or some of it.

HORNE: It is my impression this year that crabbing has been unusually good in the Bay. I may be mistaken about that, but I'm sure there have been a lot of crabs caught and a lot of crabs thrown back that couldn't be used. If that is true, does that have an impact on the commercial production of crabs? Can we sell crabs when so many are caught by anyone who wants to put a trap in the water in front of his house? Or is there just enough crab appetite for everybody?

TATUM: It is going to be a good crabbing year, and what is beneficial to the recreational crabber is also beneficial to the commercial crabber because they are bringing in extremely large catches right now. Can the private sector sell their crabs? Yes they can, since there is no license requirement for either recreational crabbers or commercial crabbers. Can you find somebody to buy them? Perhaps, I don't know; but it looks like it is going to be a good year, and one of the other things that makes a good crabbing year is when you have a poor shrimping year. If you have a poor shrimping year, then you have crabbers working extremely hard and shrimpers crabbing. So it is going to show up as a super good crabbing year, but there are a lot of crabs out there, too.

TABBERER: Mr. Eckmayer, you alluded to the fact that anything fresher than 15 ppt would harm the oyster drill and you also talked about dissolved oxygen. If you were to prescribe an oxygen and a salinity regime for the estuary, what would it be for optimum oyster production. Then you could implement it out there on the ground.

ECKMAYER: As far as our technology, we will probably never be able to actually manipulate the environment to that degree for controlling a water mass the size of Mobile Bay, but the ideal, if you wanted to draw the ideal picture for the environment for oyster production, I'd say the water should be somewhere around 13 ppt. That way the drills would be held in check because they could not control their body fluid levels to survive. Most of the diseases would be eliminated. The oysters would be able to reproduce because it falls within their optimum range, and it is still salty enough for survival of the oyster larvae and spat, which go into stress below 10 ppt. That's the most vulnerable year of mortalities; the first year of life on the bottom. Any dissolved oxygen regime over 2 ppm is more than adequate because they have been shown to be able to do rather well down to 2 ppm, while the level most finfish draw is about 3 ppm.

ALLEN: Did Bob Shipp or anybody ever mention the mullet? I mean whatever happened to the mullet? That used to be a pretty good fish.

LOYACANO: Does that come under sport fishery or commercial or both?

WADE: The mullet comes under both. I mentioned it in my recreational paper about the Bay. In the Dog River up to around the Causeway area, it happens to be one of the key species in the recreational shoreline fishery. The last survey we did was in 1975, and it's surprising the number of pounds of striped mullet that were harvested by the recreational fishermen. Of course, there is a commercial fishery for it, presently.

SHIPP: I really thought George would know better; mullet are going to be considered this afternoon—they are not fish, they are birds. They've got a gizzard.

LOYACANO: I want to sincerely thank these panelists, these authors for the fine papers they have presented, and the manuscripts that these and all of the other symposium participants have submitted. Since Dr. Rawson will moderate this afternoon, I want to take this opportunity to thank him for the tremendous amount of work that he and his co-workers have done in preparing for the symposium. I would also like to thank Dr. Bruce Trickey and his co-workers, who have also done a tremendous amount of work. I would like to thank Dr. Jimmy Jones from the Sea Grant Program. He and his co-workers also contributed greatly. I would especially thank my predecessor, Dieter Busch, who, with the encouragement from Paul Smith, initiated this symposium. And I would like to thank Paul for all the assistance and encouragement that he has given us in bringing this off finally. And, once again, I would like to thank the speakers, especially, and thank all of you for coming, and I thank you for your attention.

WADING BIRDS OF COASTAL ALABAMA

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ABSTRACT

Twenty-four colonial wading bird nesting sites have been identified for the coastal counties surrounding Mobile Bay, Alabama. Information concerning location, species composition, relative abundance, historical occurrence, and present status of each colony have been gathered from a variety of sources.

Of the 24 nesting sites identified 15 occur in the lower estuary (Mississippi Sound, Fort Morgan Peninsula, and lower Perdido Bay), six occur inland, above the legal coastal zone boundary both within Mobile and Baldwin counties, and three colonies have been reported in the river delta above Mobile Bay. Seven of the colonies are presently considered active (as of the 1978 nesting season). Six colonies are considered inactive, while the nesting status at 11 sites is considered questionable.

Thirteen species of wading birds including herons, egrets, and ibis are reported to nest in the 24 colonies identified for coastal Alabama. Their seasonal occurrence, migratory habits, natural history, and preferred nesting and feeding habitats in this area are discussed. Seven species were found to nest exclusively in the lower reaches of the estuary, while only one species was found to nest exclusively in the delta. The remaining five species were found to nest in more than one habitat area of coastal Alabama.

A case study of the wading bird colony on Cat Island, Alabama illustrates problems that are encountered in obtaining the type of information needed to assess environmental impacts of construction and contamination on wading bird populations in the coastal zone. A management plan based on monitoring of colonial wading bird nesting populations in the Alabama coastal zone is recommended.

INTRODUCTION

The wading birds (Order Ciconiiformes: herons, egrets, and ibises) are a conspicuous component of the coastal, estuarine, and wetland habitats of Alabama. Readily recognized by their long bill and neck, and stilt-like legs (Fig. 1 A-C), wading birds are most often seen feeding in marshes and other wetlands in and around Mobile Bay. Their presence, in terms of both abundance and diversity, lends an added dimension to the scenery of the coastal zone and provides a terminal link in the aquatic based food chains of many ecosystems that they inhabit. Their diet of aquatic animals makes these species particularly vulnerable to environmental contamination through the biological concentration of chemical pollutants (i.e., pesticides and heavy metals). The tendency of herons, egrets and ibises to assimilate and accumulate pesticides and other environmental contaminants is well-documented (Faber et al., 1972, Heath et al., 1972, Faber and Hickey 1973, Ohlendorf et al., 1974, and others). This sensitivity is currently viewed as a highly suitable measure of overall environmental quality, a measure becoming increasingly important as industry expands into coastal areas.

Migratory wading birds nest on isolated coastal islands (see Fig. 1 D-E), in secluded marshes and in insular pockets of hardwood wetlands. Suitable breeding habitats are becoming increasingly scarce because of encroachment of industrial and urban development. Although known to be resilient in re-establishing their populations after direct eradication (Bent 1926, Robertson and Kushlan 1974), wading birds may not be able to overcome the combined effects of reduced environmental quality and the reduction or alteration of their required nesting and feeding habitats. For example, South Florida populations of wading birds continue to decline despite preservation and protection of their traditional nesting sites (Kushland and White 1977). This population decline (89% since the 1930's) has been attributed to altered feeding habitats in this area. Local declines of waders in other areas also reflect these assumptions (Owen 1960, Imhof 1976). However, Ogden (1978) has recently reported a 2% reoccupation of nesting habitat by wading birds on the Atlantic coast.

Over the past 10 years colonial wading birds have attracted much attention. Recent colonial bird nesting surveys conducted by U.S. Fish and Wildlife Service along the Atlantic coast (Custer and Osborn 1977), and the northern Gulf of

Figure 1-A. Louisiana Heron.

Figure 1-B. Snowy Egret.

Figure 1-C. Cattle Egrets Nesting.

Figure 1-D. Cat Island, Alabama.

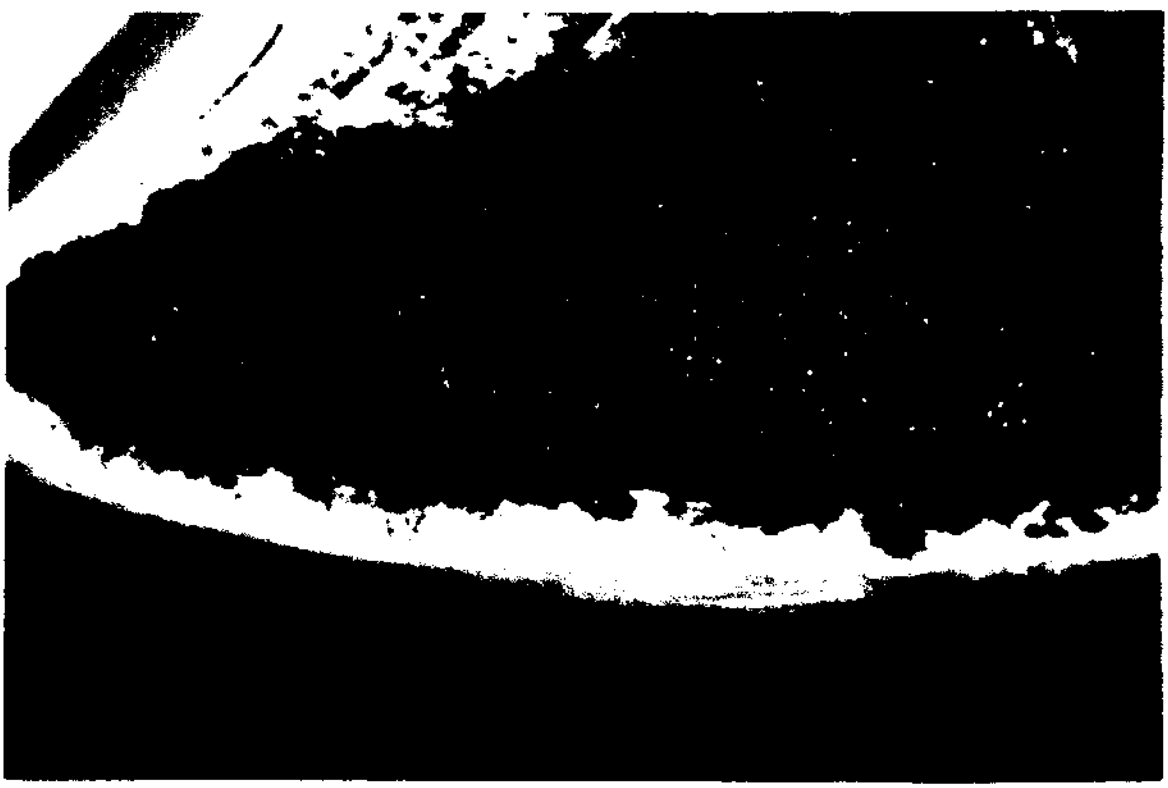

Figure 1-E. Cat Island, Alabama.

Mexico (Portnoy 1977) have been attempts to establish a nationwide data base for all coastal colonial nesters in these areas. Although Portnoy's report on colonial wading birds included coastal Alabama, the eastern limit of his survey was the western shore of Mobile Bay and did not include major wading bird concentrations along the eastern shore of the Bay, the Fort Morgan Peninsula or the extensive freshwater areas of the Mobile Delta.

Portnoy (1977) stated that "changes over time in nesting populations of colonial seabirds and waders may be used as biotic indicators of the stability of coastal ecosystems." This obviously requires the collection of reliable, synoptic data over the entire area in question. It is for this reason that the following background information on the colonial nesting wading birds of coastal Alabama has been assembled. For without accurate and current data on local wading bird colony locations and species abundance, resource managers and decision makers cannot effectively assess environmental quality of coastal habitats or allocate and protect habitats critical to wading bird populations.

INFORMATION SURVEY

Wading Bird Nesting Colonies:

Information on colonial wading-bird nesting sites for coastal Alabama provided in this report was gathered from a variety of sources. These included: 1) published accounts in the literatue; 2) local ornithological journals and newsletters; 3) personal communications with local ornithologists and bird enthusiasts; and 4) personal observations and unpublished data. Because of the subjective nature of some of these data, the following criteria were established for their inclusion in this report: 1) substantial documentation of the colony in the literature; 2) the colony under consideration was discussed in personal interviews by more than one person; 3) the nesting colony was observed by an individual over a period of years; or 4) the nesting colony was observed by the author.

The results of this wading-bird nesting information survey are provided in Appendix A of this report. All references included fit one or more of the criteria listed above. In cases where two observers provided essentially the same information, only the first interviewee is referenced. An asterisk is indicated in the appendix for those colonies in which an exact date of nesting activity could not be established. In most cases, these were observations that were made 20 to 30 years ago, therefore, their present status as nesting sites was considered "UNKNOWN."

Results

The sites of 24 wading-bird nesting colonies have been identified for the coastal counties surrounding Mobile Bay, Alabama (Fig. 2, Table 1).

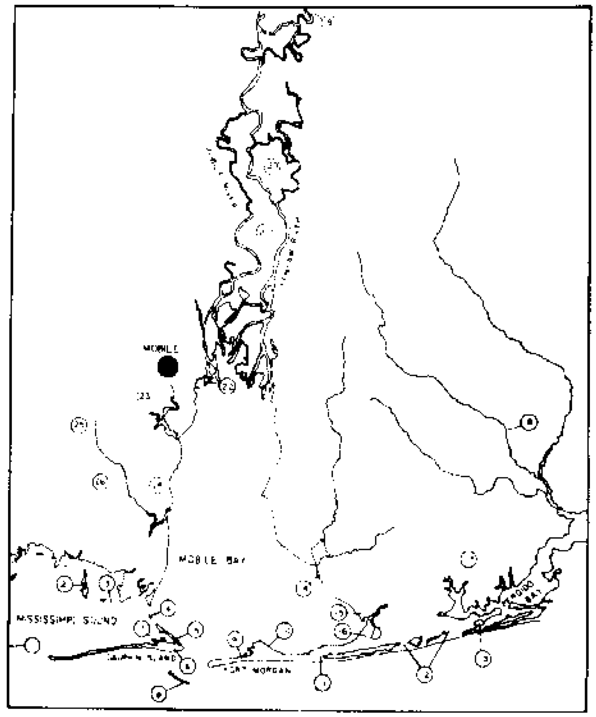

Figure 2. Distribution of Wading Bird Nesting Colonies Identified for Coastal Alabama During the Present Survey.

Available information on their location, historical record, species composition and relative abundance, and present status may be found in Appendix A. Their distribution and present status in coastal Alabama as related to habitat type is summarized in Table 2.

Fifteen (62%) of the wading-bird colonies identified are reported in the coastal (lower estuary) habitats of Mobile Bay and are equally distributed between Mobile and Baldwin counties. Six colonies (25%) occur at more inland sites usually associated with freshwater tributaries leading into both Mobile and Perdido Bays, while only three colonies (13%) have been identified for the river-delta region.

Only seven of the 24 colonies described supported nesting populations during 1978 breeding season and are still considered active. Six have become inactive and are no longer used as nesting

Table 1. Wading Bird Nesting Colonies Identified for Coastal Alabama, Species Present, and Their Present Status.

Colony[a] No.	Colony Location	Species Present[b]	Present[c] Status
1	Petit Bois Island	CE, GE, LH	NA
2	Isle Aux Herbes	LH	NA
3	Cat Island	CE, GE, SE, RE, GH, LH, LB, WG, GI, WI	A
4	Grant's Isle	LH, SE	A
5	Pass Drury	LB, GH	NA
6	Dauphin Isl. Audubon Santuary	GB, LB, GH	A
7	Salt Creek	GH, BC	A
8	Sand Island	Colonial Seabird (see text)	-
9	Navy Cove	GB	NA
10	Little Point Clear	GB	UK
11	Little Alligator Lake	GB	NA
12	Gulf Shores - Orange Bch.	GB	UK
13	Walker Island	GB	A
14	Weeks Bay	SE, LH, LB	UK
15	Bon Secour River	CE	UK
16	Oyster Bay	LH, LB	UK
17	Miflin Creek	LB, CE	NA
18	Gatewood Colony	CE, LB, WI	A
19	Southfield and Mims Lake	WI, GE, LB, YC	UK
20	Miflin Lake	GH, LB	UK
21	Negro Lake	GH, LB, WI, CE, YC	UK
22	Blakeley Island	Colonial Shore-bird	–
23	Dog River	GH, LB, CE	UK
24	East Fowl River	GH, LB	UK
25	Theodore-Dawes Rd.	LB	A
26	Deakle's Farm	CE	UK

a) Colony numbers used in Figure 1.

b) Species abbreviations: GB (Great Blue Heron), LB (Little Blue Heron), LH (Louisiana Heron), GH (Green Heron), SE (Snowy Egret), CE (Cattle Egret), GE (Great Egret), RE (Reddish Egret), GI (Glossy Ibis), WFI (White-faced Ibis), WI (White Ibis), YC (Yellow-crowned Night Heron), BC (Black-crowned Night Heron).

c) Colony status abbreviations: A (Active), NA (Not Active), and UK (Unknown).

Table 2. Summary of the Distribution of Wading-Bird Nesting Colonies for r Coastal Alabama, With Respect to Habitat Type and Present Status.

			Number of Colonies		
Habitat Type	Total	%	Active	Inactive	Status Unknown
Coastal (lower estuary)	15	62	5	5	5
Inland (upper estuary)	6	25	2	1	3
River-Delta	3	13	–	–	3

sites by colonial waders, while the status of 11 sites is questionable.

Of the seven nesting colonies still considered active in the Mobile Bay study area, five are coastal, located in the lower portion of the Mobile Bay-Mississippi Sound estuarine system. Two of the active colonies are located in more inland areas. No active wading-bird nesting colonies have been confirmed in the delta region since the 1960's.

Thirteen species of wading-birds have been reported in the present survey as nesting in and around coastal Alabama. A list of these species, with information on the number of colonies in which they occurred, their distribution with respect to habitat type, and their present status is provided in Table 3.

Of the thirteen species nesting in coastal Alabama, seven (54%) were found to nest exclusively in the lower reaches of the estuary. The only species found to nest exclusively in the delta was the Yellow-crowned Night Heron. The Great Egret is reported to nest in both coastal colonies as well as at specific sites in the delta. The remaining four species nested in all three habitat areas of coastal Alabama.

Other Colonial Bird Nesting Sites:

In addition to the colonial wading birds discussed above, two colonial shore and sea bird nesting sites are included in the present survey. The two areas support populations of birds unique to our coastal zone of Alabama.

Colony No. 8 located on Sand Island, just south of Dauphin Island, and just west of the entrance to Mobile Bay, represents one of the largest colonial Sea Bird nesting sites for the state. Species known to nest on Sand Island include: Black Skimmer (*Rynchops nigra*), Common Tern (*Sterna hirundo*), Gull-Billed Tern (*Gelochelidon nilotica*), Least Tern (*Sterna albifrons*), and Snowy Plover (*Charadrius alexandrinus*). The latter of these species is presently listed as threatened on Alabama's endangered and threatened species list (Boschung 1976). Another threatened species that frequents Sand Island, but does not nest there, is the Reddish Egret (*Dichromanassa refescens*). Increased use of this once isolated island by boating picknikers and beachcombers, especially during the summer nesting season, undoubtedly will have a pronounced impact on present populations of species known to nest there.

Table 3. Wading Birds Nesting in Coastal Alabama; the Number of Colonies in Which They Occur and Their Present Status in the Three Habitat Types.

Species	COASTAL				INLAND				RIVER – DELTA			
	Active	Inactive	Unkn	Total	Active	Inactive	Unkn	Total	Active	Inactive	Unkn	Total
Great blue heron	2	2	2	6								
Little blue heron	2	1	3	6	2	1	3	6	–	–	3	3
Louisiana heron	2	2	2	6								
Green heron	3	1		4	–	1	2	3	–	–	2	2
Snowy egret	2	–	1	3								
Cattle egret	1	1	1	3	2	1	2	5	–	–	1	1
Great egret	1	1	–	2					–	–	1	1
Reddish egret		–	1	1								
Glossy ibis	1	–	–	1								
White-faced ibis	1	–	–	1								
White ibis	–	–	1	1	1	–		1	–	–	2	2
Yellow-crowned night heron									–	–	2	2
Black-crowned night-heron	1	–	–	1								

The other nesting site of particular concern includes the dredge spoil areas of Blakeley, Pinto, and McDuffie Islands. These areas represent the only known nesting site of the Black-necked Stilt (*Himantopus mexicanus*) in Alabama. First reported nesting on Blakeley Island in 1976 by John Winn (Imhof 1976), the species has increased its nesting area to include both Pinto and McDuffie Islands and presently sustains a nesting population of 58-60 breeding pairs (Personal conversation March 27-28, 1979 with John T. Winn, Mobile, Alabama 36609). The consequences of increased, unmanaged, use of these already industrialized areas to the nesting of this species is uncertain at this time. A thorough study of the species nesting requirements, nesting success, and response to impacts in other areas is essential to answer questions regarding their future in Alabama.

NATURAL HISTORY

Great Blue Heron (*Ardea herodias*)

Largest of the herons, the Great Blue Heron is a locally common, permanent resident of the coastal zone. Although often encountered in the upper estuary and river delta, this bird is frequently seen along the barrier islands during winter and during the breeding season. The Great Blue Heron inhabits fresh to salt water habitats and feeds on a variety of aquatic animals.

The species breeds locally in solitary to mixed colonies on Dauphin Island, Walker Island (at the mouth of Perdido Pass), and along Fort Morgan Peninsula. The Great Blue Heron prefers insular stands of tall trees (Pine or Tupelo Gum) near or over water as nesting sites. The nest consists of a platform of sticks placed in the upper most branches of the tree. Nesting sites for this species in other areas are quite variable (Cameron 1906, Finley 1906, Giles and Marshall 1954, Pratt 1970, 1972a, 1972b, Georing and Cherry 1971, Simersky 1971, McAloney 1973, Werschkul et al. 1977). Banding data (Henny 1972) indicates that young birds produced in this area do not migrate seasonally. The largest nesting colony of Great Blue Herons for Alabama was reported by M. W. Gaillard in May, 1943 when 100 breeding pairs were observed nesting near Navy Cove on the Fort Morgan Peninsula. Since that time this colony of birds apparently has moved up and down the coast in search of new nesting habitats. The reason for these relocations is not fully known. However, increased residential and recreational activity along the coast surely has had some effect.

A slightly larger, all-white subspecies, the Great White Heron, *Ardea herodias occidentalis* has been sighted about every other summer since 1963 (Imhof 1976). Occurring in a variety of locations throughout the coastal zone, especially on the barrier islands, this bird's status as a threatened or endangered species remains undetermined at this time (Boschung 1976).

Little Blue Heron (*Florida caerulea*)

A medium-size wader, the Little Blue Heron is more common in the upper coastal plain and Tennessee Valley regions of Alabama than along the Gulf Coast (Imhof 1976). However, the species is considered a common breeding summer resident of the coastal area (Keller et al. 1975) and frequently winters in the upper estuary and river delta. Records for Little Blue Herons banded in Alabama indicate a southerly migration extending through Florida, the Bahamas, and to Central and South America (Dusi 1967). At present, the Little Blue Heron is included on the State's rare and endangered species list as a species of special concern (Boschung 1976).

The Little Blue Heron, the most frequently encountered wader in the present survey, occurred in 15 of the 24 colonial nesting sites identified. Of these, six were located in the lower estuary along Mississippi Sound, Dauphin Island, and Perdido Bay; six were located inland from the upper estuary; and three were located in the delta region. The relatively low number of Little Blue colonies reported from the delta region is questionable because this represents the preferred nesting habitat for these birds. This more likely represents a lack of information from this area rather than a true reflection of nesting distribution. The vast area, sparse resident population and inaccessibility of nesting areas by road or boat make reports of nesting waders scarce. In addition, delta colonies appear to be ephemeral and move seasonally from one location to another, because of changing conditions in, or adjacent to, the nesting site. Four possible explanations are: 1) changes in the condition of the nesting vegetation, 2) changes in the location and abundance of available food supplies, 3) changes in the accessibility of nesting sites to predators and disturbance by man, and 4) fluctuating water levels in the delta. The last of these conditions may have a pronounced effect on all three of the previously mentioned explanations. A more thorough survey of this region is needed to document present locations and populations of nesting waders in order to assess changes as they occur. In Louisiana, expansion of field surveys to include the Atchafalaya River basin, have added well over

4,000 nesting Little Blue Herons to existing figures (Kennedy 1974, Ogden 1978).

Louisiana Heron (*Hydranassa tricolor*)

The Louisiana Heron (Fig. 1A) is one of the most abundant estuarine waders nesting along the Gulf coast (Portnoy 1977). About the same size and somewhat similar in appearance to the Little Blue Heron, the Louisiana Heron is reported as a common, breeding summer resident to coastal Alabama (Keller et al. 1975, Imhof 1976). Adult birds usually migrate south of the U.S. in late fall (Imhof 1976), however, small numbers of these birds are known to remain near their breeding colonies during winter (Paul G. Johnson personal observation).

This species prefers estuarine marshes, shallow bays, and coastal barrier islands as feeding sites. Its diet, mainly marine and brackish-water fish and invertebrates, makes it an ideal candidate for bioaccumulation studies of pesticides and other chemical contaminants in the estuary.

Although Louisiana Heron nesting has been reported in the delta region (Keller et al. 1975), no specific nesting sites for this area were reported in the present survey. This species was found to nest exclusively in the lower estuary of Mobile Bay. These findings agree with those reported from other areas of the Gulf (Portnoy 1977).

Of the six nesting sites identified for this species, two are considered active, two are no longer active, and the status of two located off the eastern shore of Bon Secour Bay is questionable. The major active nesting site for Louisiana Herons in coastal Alabama is Cat Island.

This colony supports a relatively stable population of 600-800 breeding birds (Johnson Unpubl. Data 1976-1978), during the nesting season which lasts from April to July. Nesting success at this colony is variable and dependent on a variety of environmental factors. Gaston and Johnson (1977) reported severe weather conditions responsible for massive nesting failure of Louisiana Herons during the 1976 nesting season.

A smaller nesting colony on Grant's Island supports a breeding population of 10 to 20 pair of Louisiana Herons. The Island's potential as a major nesting site is limited because of its size and paucity of nesting vegetation. The large number of adult birds within this colony reported by Portnoy (1977) was undoubtedly an overestimation of its present breeding potential.

Nesting colonies of Louisiana Herons from other areas have been described by Bent (1904), Erichsen (1921), Christy (1928), Teal (1965), and Jenni (1961). Breeding behavior and nesting display of this species has been studied recently by Rodgers (1977, 1978).

Green Heron (*Butorides striatus*)

The Little Green Heron, as it is often called, is the smallest of the North American herons. It is commonly seen from spring to fall in all wetland habitats throughout the State. This species is mainly a summer breeding migrant which winters locally in swampy areas, along Dog and Fowl Rivers but usually travels as far as Cuba, Puerto Rico, Trinidad, Venezuala, and Guyana (Dusi, J. L., bird banding data in Imhof 1976). This bird feeds mainly in fresh to brackish water habitats, but may be found on occasion feeding along the coast on rock jetties and beaches.

The Green Heron is secretive and solitary by nature and usually nests alone, but may nest occasionally in small single-species groups, or among other colonial waders. The breeding season for Alabama lasts from March to July (Imhof 1976). Nests discovered on Cat Island, Alabama, during the 1976, 1977, and 1978 breeding seasons were composed of twigs lined with grasses and concealed in isolated stands of marsh elder (*Iva frutescens*), approximately 0.75 m (2.5 feet) above the ground (Paul G. Johnson Unpublished Data). One nesting site was used for two seasons in a row. Nesting sites for other locales have been described by Chase (1906) and Wheelock (1906).

Cattle Egret (*Bubulcus ibis*)

This all-white, stocky egret (Fig. 1C) first appeared in the Western Hemisphere in Surinam, South America between 1877 and 1882, and moved northward into North America via Florida in about 1950. Since then the Cattle Egret has rapidly expanded its range across North America. This apparently unaided trans-Atlantic immigration and subsequent colonization of the Americas is well-documented in the literature (Sprunt 1955, Rice 1956, Davis 1960, Crosby 1972, Shanholtzer 1972, and others).

First discovered in Alabama in November 1957 (Keller 1957) the first positive nesting record for the state was reported by C. E. Summerour in June 1963, (Dusi and Dusi 1963, Summerour 1964). Since that time the Cattle Egret has become the dominant nester in mixed-species heron colonies throughout the state (Imhof 1976), and at present is considered a common summer resident throughout the coastal counties, wintering only rearly in swamp habitats of the river delta (Keller, et al. 1975). The population increase of the Cattle Egret for Alabama apparently is not responsible for the relatively small losses of native North American herons since its introduction.

Primarily a terestrial feeder, the Cattle Egret is encountered most often in grassy areas bordering marshes, along roadsides, lawns and in pastures among cattle, where it feeds mainly on a diet of insects and amphibians. The movements and distribution of Cattle Egrets in Alabama are thought to depend on the presence or absence of lush pastures and abundant insects (Dusi and Dusi 1967). Unlike other herons this species is not dependent on aquatic habitats for feeding or nesting. Their distribution, abundance, and levels of chemical contamination in the area are primarily a reflection of the terrestrial situation.

Breeding populations occur throughout coastal Alabama in a variety of habitats from marsh islands in upper Mississippi Sound to upland hardwood swamps located in the delta. Major nesting colonies identified in the present survey include the Cat Island Colony, Theodore-Dawes Colony, and Gatewood Colony. The Gatewood Colony, relatively new to this area presumably was established by breeding birds from the currently inactive Miflin Creek Colony located approximately 32 km (20 miles) away. This latter colony was abandoned in 1974-75 because of increased human distrubance and malicious harassment from local residents (telephone conversation March 26 and 28th with P. (Fairly) Chandler, Magnolia Springs, Alabama 36555).

Although the Cattle Egret arrives along the Alabama Gulf Coast in early February (Imhof 1976) it is usually the last of the wading birds to begin nesting. Records for the Cat Island colony over the past three nesting seasons (Gaston and Johnson 1977, Johnson, P. G. Unpublished Data) show that they arrive at the colony site from early May to June, and establish nesting sites adjacent to already existing nests of Louisiana Heron, Little Blue Heron and Snowy Egrets (some of which already contain eggs and young birds). This delayed nesting is well-documented in the literature (Dusi 1968, Dusi and Dusi 1968, Jenni 1961, Dusi et al. 1971, Weber 1972).

Data on Cattle Egret banding recoveries, observations of population movements, and densities of the species for the more northern counties of Alabama, from 1963 to 1967, are provided by Dusi and Dusi (1967). In summary, Cattle Egrets from colonies in Alabama migrate westward through Texas, Mexico, and into Central America. This differs from the pattern of migration previously mentioned for the Little Blue Heron. This westerly migrational trend appears to coincide with the direction of range expansion experienced along the Gulf coast. Byrd (1978), however, suggests that as a relatively recent invader, Cattle Egrets may not have established permanent migratory routes.

Snowy Egret (*Egretta thula*)

This all-white heron (Fig. 1B) is similar in size and appearance to the Cattle Egret and is a common permanent resident of coastal Alabama (Keller et al. 1975). The Snowy Egret inhabits a variety of habitats frequented by other herons and feeds on small fish and aquatic animals, as well as on insects in pastures.

Data on the winter migratory habits for this species in Alabama are sketchy at this time (Ryder 1978). However, according to Imhof (1976), large numbers of these birds are known to congregate in winter at the head of Mobile Bay.

In the present survey Snowy Egrets were found to nest exclusively along the coast, within the same colonies as those previously mentioned for Louisiana Herons. These results, however, do not entirely agree with those of Portnoy (1977) who found Snowy Egrets nesting heavily in fresh water habitats, including cypress swamps. This large number of Snowy Egrets nesting in freshwater habitats may be a reflection of the major area considered in his survey (coastal Louisiana), but more likely reflects the absence of recent nesting information available for the delta region of Alabama.

Seasonal distribution and time of nesting for Snowy Egrets in coastal Alabama are essentially the same as that for the Louisiana Heron.

Great Egret (*Casmerodius albus*)

This large, all-white Egret is a locally-common, breeding, summer resident in our area (Keller et al. 1975); wintering regularly on the Gulf Coast and inland near its breeding places (Imhof 1976). Commonly encountered in the coastal area, the Great Egret feeds in and frequents the same marshes and swamps as the Great Blue Heron. Hundreds of these birds may be seen feeding in winter, especially along the Mobile Causeway.

This species has made a remarkable recovery since its near-eradication in the early 1900's, when birds were indiscriminately exterminated by the thousands to provide plume feathers for women's hats. In 1924, no species of Egret was known to nest in the State (Howell 1928). About 1913, legislation was passed that saved this beautiful bird from almost sure extinction, and the species has since continued to re-establish its range northward.

Of the three colony sites identified for the Great Egret in coastal Alabama, only one has been confirmed as an active nesting site. Presumably, the same breeding pair of birds has been observed nesting on Cat Island successfully for the past three years (Johnson Unpublished Data). Arriving at the colony in early April, the birds remain on the island until their young have fledged, usually in early July.

The largest reported nesting colony of Great Egrets for the area was reported in the delta (Lake Southfield, Colony No. 19) in 1956-1957 when 100-200 breeding pairs were observed nesting with Little Blue Herons and White Ibis. The status of this colony is presently not known. However, as described for the Great and Little Blue Herons, this colony may have moved to a more remote section of the river delta. This is likely the case, for many adult birds presumably nesting in the area, are seen every summer feeding in the food enriched marshes along the Mobile Causeway and Mobile and Tensaw Rivers.

Reddish Egret (*Dichromanassa rufescens*)

The Reddish Egret is a medium-sized wader fairly common during migration in the coastal area and occasionally summers or winters on sand beach habitats which it prefers (Imhof 1976). It is most commonly seen on the bay side of Dauphin Island, Sand Island, and the Fort Morgan Peninsula where it actively feeds on marine fish and crustaceans in shallow bays and mud flats.

Nesting almost exclusively in coastal areas in Texas (Palmer 1962), the Reddish Egret has been reported as nesting in Alabama only once. This nesting record was reported by W. M. Gaillard in 1965 for Cat Island (Imhof 1976). McMurray (1971) described typical nest sites and composition along the lower Texas coast.

The present nesting status for this species in coastal Alabama is doubtful. However, numbers of adult birds observed in the area during the summer breeding season are on the increase (Mobile Bay Bird Club Records for Dauphin Island). If this trend continues nesting may occur in the future.

Black-Crowned Night Heron (*Nycticorax nycticorax*)

The Black-crowned Night Heron is a locally common, permanent resident of the Gulf Coast, presently breeding in small numbers on Dauphin Island. It formerly bred and may still breed at the head of Mobile Bay and near Mississippi Sound (Imhof 1976). However, exact locations of these nesting sites were not available for the present nesting survey.

The Black-crowned Night Heron actively feeds at night in salt marshes and on the edge of open bays. The main food of this heron is fish and other small marine and freshwater animals.

The species status is presently listed as, of special concern, on the State's rare and endangered species list (Boschung 1976).

Yellow-Crowned Night Heron (*Nyctanassa violacea*)

The Yellow-crowned Night Heron is also a common, permanent resident of coastal Alabama, breeding locally in mixed or single species assemblages in the delta. Although a few, single nest sites have been identified within 30 miles of the coast (Imhof 1976) no colonial nesting site has been verified as active in the present survey. The species is most common along the coast in late summer and fall, when many of the young birds raised in the delta start moving south into the lower estuary to feed. Feeding habits for this species are essentially the same as discussed previously for the Black-crowned Night Heron.

Glossy Ibis (*Plegadis facinellus*)

This dark ibis species is an uncommon, breeding, summer resident of the coastal area that frequents salt and brackish marshes, mud flats, and small bays that border Mobile Bay and Mississippi Sound (Imhoff 1976). This species has successfully nested on Cat Island in small numbers for the past five years (Paul G. Johnson Unpublished Data). Arriving at the colony site in early April, the birds nest among other waders in marsh elder and leave the island after the young have fledged in July.

White-Faced Ibis (*Plegadis chihi*)

This more westerly distributed dark ibis is rare to the Gulf coast of Alabama and occurs in the same habitats as the Glossy Ibis. The reported nesting of these two species on Cat Island for the past three years is most significant in that it represents one of three areas in the world where dark ibis sympatry occurs (Duncan and Johnson 1977). The other two areas listed by Pratt (1976) are Cameron Parish, Louisiana, and the Mississippi Delta.

White Ibis (*Eudocimus albus*)

This, almost all-white bird is common along the barrier islands, upper Mobile Bay, and delta region in late summer and fall (Keller et al. 1975). Once an abundant breeder at upland and river delta nesting sites, the present nesting status of this species in these areas is questionable.

CAT ISLAND COLONY DESCRIPTIONS

Cat Island, Alabama (Fig. E-F) is a 5.2 ha (13-acre) island, located 11 km (6.8 miles) north of Dauphin Island and 1 km (0.62 miles) south of the Alabama mainland. Fifty percent of the island is covered by tidally inundated salt marsh providing an ideal feeding habitat for most wading birds that nest there. Twenty percent or approximately 0.9 ha (2.25 acres) of the island is densely populated with marsh elder and groundsel tree (*Baccharis halimifolia*), which grows to a maximum height of 2 cm (6.4-10 feet) (Gaston and Johnson 1977). This vegetated portion of the island provides nesting habitat for the eight species of wading birds known to nest there (Table 1). Approximately 2500 nests of these species were found in this area during the breeding season, making Cat Island the largest coastal heron-egret colony in Alabama.

In addition to the availability of nesting sites and food sources, several other features of Cat Island make it an ideal location for a wading-bird nesting colony. Because it is surrounded by shallow water and oyster shoals, it is isolated from most human intrusion and protected from most mainland predators (i.e., racoons and opossums) not indigenous to the island. Moreover, while the vegetation of the island is optimal for wading birds, it lacks pine trees and is thus quite unsuitable for nesting by predaceous fish crows (*Corvus ossifragus*) which often pillage heron and egret colonies near their nests. However, some crow predation has been observed on Cat Island (Gaston and Johnson 1977).

Data on colony structure and nesting success for Cat Island have been obtained for the past three nesting seasons. However, problems in methodology of data collection resulted in only a preliminary baseline for the above parameters. A review of these problems hopefully will elucidate the difficulties involved in obtaining and interpreting information on heron-egret colonies. For example, past survey methods for estimating nesting populations of wading birds on Cat Island were variable with respect to the time, place, and number of times they were taken each year. This is quite important for certain species of wading birds prefer to nest in specific areas of the island and initiate and cease nesting at different times during the nesting season. This nest site selection and nesting chronology can have a profound effect on population estimates if an investigator is not familiar with their occurrences. A combination of belt transect samples of active nests and visual ground and/or aerial estimates of adults present at specific times during the nesting season is the best method of censusing nesting populations of colonial waders on Cat Island, Alabama (Portnoy 1977, Johnson personal observation).

In addition, early identifications of nests used in determining nesting success for certain species of waders were not always accurate. This was attributed to uncertainty in distinguishing between the young of certain species of wading birds (especially the Little Blue Heron and Snowy Egret) and the inability of the investigator to assign a species name to nests that were abandoned prior to egg hatching. Both these problems have, however, been corrected through reference to material on field identification of nestling herons and egrets (Dusi 1966, McVaugh 1972) and experience developed by the researchers over the years.

In light of these problems and solutions, certain conclusions can be drawn from the information collected on Cat Island. In general, colony structure (i.e., species present and their relative abundance) does not appear to have changed over the last three years; however, nesting success for selected species has fluctuated drastically. For example, nesting success (number of birds fledged/number of eggs produced x 100) determined for 90 Louisiana heron nests surveyed by Gaston and Johnson (1977) during the 1976 nesting season was only 18.1% as compared to 71.7% (46 nests) reported for the following year (Johnson Unpublished Data). The low nesting success reported for 1976 was attributed to adverse weather conditions during the early part of the nesting season when the survey was made, resulting in high mortality of hatchlings for this species (Gaston and Johnson 1977).

Fluctuations in nesting success for Cattle Egrets have also been noted on Cat Island. In 1976, 78% nesting success was reported for this species for the 47 nests surveyed (Gaston and Johnson 1977). In 1977, only 58.4% of the eggs laid in the 81 nests surveyed produced fledglings, and in 1978 a complete nesting failure was observed for Cattle Egrets attempting to nest on Cat Island (Johnson Unpublished Data). Explanations for these changes in nesting success exhibited by Cattle Egrets are not apparent at this time. However, they do tend to show the variability that can be encountered in monitoring nests in heron and egret colonies.

MANAGEMENT PLAN

Preliminary baseline data are available for selected nesting populations of colonial wading birds in coastal Alabama. However, a more refined and comprehensive survey program is needed to assess environmental impacts of habitat alteration and contamination on wading-bird populations in the coastal zone. In order to accomplish this task, a program for monitoring wading-bird colonies in coastal Alabama is proposed.

This monitoring program may be divided into two phases. The first phase would entail an up-to-date field survey of coastal Alabama to document the present location of wading-bird colonies and standardized estimates of abundance of each species nesting at each colony site. This field survey should be repeated at least every five years to correlate population trends of colonial waders with development trends in particular areas of the Alabama coastal zone, as well as trends established for the Atlantic coast and adjacent Gulf states.

The second phase of the survey program would be the selection of specific colony sites representative of the three habitat types delineated in this review (lower estuary, inland, and river-delta) for a continuing, yearly monitoring program. The selection of the three colonies for yearly monitoring would be based on data provided in phase one of the management program. For selection colonies should:

1. Be representative of most wading bird colonies found in this particular habitat type with respect to species composition and nest site composition;
2. Support a significant nesting population of birds inhabiting this particular habitat type;
3. Be relatively well-established and accessible for study.

The data to be collected for each colony are:

1. Colony structure: species composition, relative abundance and succession of nesting species;
2. Nesting success: clutch size and survival rate of eggs and nestlings of selected species;
3. Density dependent population pressures: predation, interspecies competition, and food and habitat resource utilization;
4. Density independent pressures: rainfall, temperature, storms, nest site changes, water levels, etc.
5. Possible contaminants: pesticide and related compound residue levels in eggs and young of selected species, and egg shell thickness.

The methodology for collecting these data, along with a more detailed rationale for its interpretation has been previously outlined for the Cat Island colony (Duncan and Johnson 1978). This program format can be readily applied to other colony sites in the coastal zone.

This monitoring program will provide an objective and ongoing indication of both natural and environmental factors effecting changes in the coastal zone. The type of information provided in the two phases of this monitoring program is needed to differentiate between the variability of colony structure and nesting success caused by natural fluctuations in environmental conditions and those attributed to non-cyclic influences of encroaching coastal development.

Further management potential, especially attractive in light of current dredge material disposal practices in Mobile Bay, is the use of dredge islands as nesting sites by wading birds. Parnell and Soots (1978) have suggested that declines in natural nesting habitat have been more than offset by the availability of spoil islands, resulting in an overall increase in wader populations on the east coast. They estimate that herons and egrets will begin nesting as early as ten years after deposition and will continue to utilize a given site for thirty plus years (Soots and Parnell, 1975). Many other species of colonial nesting seabirds, however, including American Oystercatchers (*Haematopus palliatus*), Gull-billed Terns, Black Skimmers and Common Terns will nest on spoil islands during the first or second year. Factors which are significant in the selection of spoil islands for estuarine heronries include: (1) availability, (2) stability, elevation above mean high water and appropriate vegetation, (3) location near inlets with high prey density and (4) location in open water which maintains an absence of mammalian predators. Legal, financial, engineering and management consideration for development of dredge islands are reviewed in Parnell and Soots (1975).

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Appendix A. Location and Historical Information on Wading Bird Nesting Colonies Identified for Coastal Alabama.

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
1	East end of Petit Bois Island	CATTLE EGRET	3 NP	1966	Delta-Breton Nat. Wldf. Refuge Rpt. 1949-1974	NOT ACTIVE since 1960's
		GREAT EGRET	1 NP	1966	Delta-Breton Nat. Wldf. Refuge Rpt. 1949-74	
		LOUISIANA HERON	100 BP	1913	Burleigh, 1944	
			50 BP	1928	Howell, 1928	
			NP	1962	Gandy and Turcotte, 1970	
2	Isle Aux Herbes (Coffee Island) Mississippi Sound, Mobile Co.	LOUISIANA HERON	NP		Howell, A. H., 1928	NOT ACTIVE -loss of nesting habitat
3	Cat Island; small Marsh Isl. located in North Mississippi Sound bordering Portersville Bay to the South, Mobile Co.	GREAT EGRET	1 NP	1976	Gaston & Johnson, 1977	ACTIVE -largest coastal Heron-Egret colony in Alabama (see text)
			1 NP	1977	Johnson, P. G., (Unpubl. Obs.)	
			1 NP	1978	Johnson, P. G., (Unpubl. Obs.)	
		SNOWY EGRET	NP	1964	Dusi, J. L., 1967	
			160 BP	1971	Imhof, T. A., 1976	
			100 BP	1974	Hayward, R. E., Jr., (Pers. Comm.)	
			600 AB	1976	Portnoy, J. W., 1977	
			200-300 BP	1977	Johnson, P. G. (Unpubl. Obs.)	
			200-300 BP	1978	Johnson, P. G., (Unpubl. Obs.)	

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative [a] Abundance	Date Observed	Reference[b]	Present Status
3 (cont'd)	Cat Island; small marsh Isl. located in North Mississippi Sound bordering Portersville Bay to the South.	CATTLE EGRET	75 N P	1965	Dusi & Dusi, 1967	ACTIVE
			75 N P	1966	Dusi & Dusi, 1967	
			400 BP	1974	Hayward, R. E., Jr. (Pers. Comm.)	
			2000 AB	1976	Portnoy, J. W., 1977	
			800-1000 N P	1976	Gaston & Johnson, 1977	
			600-800 BP	1977	Johnson, P. G. (Unpubl. Obs.)	
			100-300 BP	1978	Johnson, P. G. (Unpubl. Obs.)	
		LOUISIANA HERON	80 BP	1958	Imhof, T. A., 1976	
			NP	1965	Dusi, J. L., 1967	
			285 BP	1971	Imhof, T. A., 1976	
			100 BP	1974	Hayward, R. E., Jr. (Pers. Comm.)	
			800 AB	1976	Portnoy, J. W., 1977	
			200-400 N P	1976	Gaston & Johnson (Unpubl. Obs.)	
			300-400 BP	1977	Johnson, P. G. (Unpubl. Obs.)	
			300-400 BP	1978	Johnson, P. G. (Unpubl. Obs.)	
		LITTLE BLUE HERON	400 AB	1976	Portnoy, J. W., 1977	
			20-30 BP	1976	Gaston & Johnson (Unpubl. Obs.)	
			20-30 BP	1977	Johnson, P. G. (Unpubl. Obs.)	
			20-30 BP	1978	Johnson, P. G. (Unpubl. Obs.)	

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
3 (cont'd)	Cat Island; small marsh Isl. located in North Mississippi Sound bordering Portersville Bay to the South, Mobile Co.	REDDISH EGRET	BP (?)	1965	Gaillard, Wm., (Pers. Comm.)	ACTIVE
			5 AB	1965	Imhof, T. A., 1976	
			AB	1977	Johnson, P. G. (Unpubl. Obs.)	
		GREEN HERON	2 NP	1976	Gaston & Johnson (Unpubl. Obs.)	
			2 NP	1977	Johnson, P. G. (Unpubl. Obs.)	
			3 NP	1978	Johnson, P. G. (Unpubl. Obs.)	
		GLOSSY IBIS	2 BP	1974	Hayward, R. E., Jr.	
			100 AB	1976	Portnoy, J. W., 1977	
			2 BP	1976	Gaston, G. R., 1977	
			2 BP	1977	Johnson, P. G. (Unpubl. Obs.)	
		WHITE-FACED IBIS	1 BP	1976	Duncan & Johnson 1977	
			1 BP	1977	Duncan & Johnson 1977	
			1 BP	1978	Johnson, P. G. (Unpubl. Obs.)	
		WHITE IBIS	1 AB	1976	Portnoy, J. W., 1977	

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
4	Grant's Isle, small sand spit Island located near Grant's Pass, west side of Dauphin Island Bridge, Mississippi Sound, Mobile Co.	LOUISIANA HERON	40 AB	1976	Portnoy, J. W., 1977	ACTIVE
			15 BP	1976	Gaston & Johnson, (Unpubl. Obs.)	
			NP	1977	Johnson, P. G. (Unpubl. Obs.)	
			AB	1978	Johnson, P. G. (Unpubl. Obs.)	
		SNOWY EGRET	140 AB	1976	Portnoy, J. W., 1977	
			NP	1976	Gaston & Johnson (Unpubl. Obs.)	
			NP	1977	Johnson, P. G. (Unpubl. Obs.)	
			AB	1978	Johnson, P. G. (Unpubl. Obs.)	
5	Pass Drury, Dauphin Island, Mobile Co.	LITTLE BLUE HERON	100-200 BP	1950's	Imhof, T. A. (Pers. Comm.)	NOT ACTIVE Dredged and filled for transportation and residential use.
		GREEN HERON	NP	1950's	Imhoff, T. A. (Pers. Comm.)	
6	Audubon Sanctuary, Dauphin Island, Mobile Co.	GREAT BLUE HERON	3-4 NP	1960's	Gaillard, M. W. (Pers. Comm.)	ACTIVE
			1 NP	1976	Johnson, P. G. (Unpubl. Obs.)	
			4 AB	1978	Johnson, P. G. (Unpubl. Obs.)	
			AB	1979	Havard, R.A. (Pers. Comm.)	

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
6 (cont'd)	Audubon Sanctuary, Dauphin Island, Mobile Co.	LITTLE BLUE HERON	NP	1960's	Gaillard, M. W. (Pers. Comm.)	ACTIVE
			NP	1978	Gaillard, M. W. (Pers. Comm.)	
		GREEN HERON	NP	1976	Gaston, G. R. (Pers. Comm.)	
			4 AB	1978	Johnson, P. G. (Unpubl. Obs.)	
7	Salt Creek, Dauphin Island, Mobile, Co.	GREEN HERON	NP	1976	Gaillard, M. W. (Pers. Comm.)	ACTIVE
		BLACK-CROWN NIGHT HERON	NP	1978	Gaillard, M. W. (Pers. Comm.)	
8	Sand Island, small barrier Island just South of Dauphin Island, Mobile Co.	REDDISH EGRET	2-3 AB	1976	Johnson, P. G. (Unpubl. Obs.)	NEVER AN ACTIVE SITE - for wading bird nesting (see text)
			2-3 AB	1977	Johnson, P. G. (Pers. Obs.)	
			2-3 AB	1978	Havard, R.A. (Pers. Comm.)	
9	Navy Cove, Fort Morgan Peninsula, Baldwin Co.	GREAT BLUE HERON	100 BP	May, 1943	Gaillard, M. W. (Pers. Comm.) Imhof, T. A., 1976	NOT ACTIVE
10	Little Point Clear, Fort Morgan Peninsula, Baldwin Co.	GREAT BLUE HERON	3-4 NP	1950's	Gaillard, M. W. (Pers. Comm.)	UNKNOWN
			AB	1978	Gaillard, M. W. (Pers. Comm.)	
11	Little Alligator Lake, Fort Morgan Peninsula	GREAT BLUE HERON	4-5 BP	1950's	Gaillard, M. W. (Pers. Comm.)	NOT ACTIVE

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
12	Gulf Shores, Orange Bch. Fort Morgan Peninsula, Baldwin Co.	GREAT BLUE HERON	BP	1960's	Chandler, P. F. (Pers. Comm.)	UNKNOWN
			BP	1960's	Imhof, T. A., 1976	
13	Walker Island, Mouth of Perdido Pass, Baldwin Co.	GREAT BLUE HERON	50-100 BP	1946	Imhof, T. A. (Pers. Comm.)	ACTIVE
			60 NP	1972	Dusi, J. L. (Pers. Comm.)	
			100 BP	1975	Chandler, P. F. (Pers. Comm.)	
			79 NP	1978	Chandler, P. F. (Pers. Comm.)	
			70-80 NP	1979	Chandler, P. F. (Pers. Comm.)	
14	Weeks Bay, off Bon Secour Bay, Baldwin Co.	SNOWY EGRET	NP	*	Gaillard, M. W. (Pers. Comm.)	UNKNOWN
		LOUISIANA HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	
		LITTLE BLUE HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	
15	Bon Secour River, Bon Secour Bay, Baldwin Co.	CATTLE EGRET	NP	*	Gaillard, M. W. (Pers. Comm.)	UNKNOWN
		LITTLE BLUE HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	
16	Oyster Bay, Bon Secour Bay, Baldwin Co.	LOUISIANA HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	UNKNOWN
		LITTLE BLUE HERON	NP	*	Gaillard, M.W. (Pers. Comm.)	

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
17	Miflin Creek, Head of Wolf Bay, Baldwin Co.	LITTLE BLUE HERON	100-200 BP	1970	Chandler, P. F. (Pers. Comm.)	NOT ACTIVE - Abandoned
		CATTLE EGRET	500-1000 BP	1970	Chandler, P. F. (Pers. Comm.)	about 1974-75 due to human disturbance
		GREEN HERON	NP	1970	Chandler, P. F. (Pers. Comm.)	
			NP	1973	Chandler, P. F. (Pers. Comm.)	
18	Gatewood, North of Styx River, Baldwin Co.	CATTLE EGRET	1000 BP	1978	Chandler, P. F. (Pers. Comm.)	ACTIVE - relatively new
		LITTLE BLUE HERON	40-50 BP	1978	Chandler, P. F. (Pers. Comm.)	colony, 5-10 years, may be
		WHITE IBIS	15-20 AB	1978	Chandler, P. F. (Pers. Comm.)	relocation of old Miflin Creek colony
19	Lake Southfield and Lake Mims, upper delta, Baldwin Co.	WHITE IBIS	5-10,000 BP	1956-7	Beshears, W. W. (Pers. Comm.)	UNKNOWN
		GREAT EGRET	100-200 BP	1956-7	Imhoff, T. A. (Pers. Comm.)	- The most recent survey
		LITTLE BLUE HERON	500 + BP	1956-7	Imhoff, T. A. (Pers. Comm.)	of this area reported no nesting
			15-20 AB	1974	Chandler, P. F. (Pers. Comm.)	activity of wading birds
		YELLOW-CROWNED NIGHT HERON	50-100 BP	1930's	Gaillard, M. W. (Pers. Comm.)	
			5-6 AB	1974	Chandler, P. F. (Pers. Comm.)	UNKNOWN

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
20	Mifflin Lake, upper delta, Baldwin Co.	GREEN HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	UNKNOWN
		LITTLE BLUE HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	
21	Negro Lake, upper delta, Baldwin Co.	GREEN HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	UNKNOWN
		YELLOW-CROWNED NIGHT HERON	NP	*	Gaillard, M. W. (Pers. Comm.)	
		LITTLE BLUE HERON	AB	*	Gaillard, M. W. (Pers. Comm.)	
		WHITE IBIS	NP	*	Gaillard, M. W. (Pers. Comm.)	
		CATTLE EGRET	NP	*	Gaillard, M. W. (Pers. Comm.)	
22	Blakeley Island, McDuffie Island, Pinto Island, Mobile Co.	BLACK-NECKED STILT	12 BP	1976	Winn, J. T. (Pers. Comm.)	ACTIVE - not a wading bird nesting site (see text)
			28 BP	1977	Winn, J. T. (Pers. Comm.)	
			58 BP	1978	Winn, J. T. (Pers. Comm.)	
23	Dog River tributary, Mobile Co.	GREEN HERON	AB, NP	*	Gaillard, W. M. (Pers. Comm.)	UNKNOWN
		LITTLE BLUE HERON	AB, NP	*	Gaillard, W. M. (Pers. Comm.)	
		CATTLE EGRET	AB	*	Gaillard, W. M. (Pers. Comm.)	

Appendix A. (Continued).

Colony No.	Location of Colony	Species Present	Relative[a] Abundance	Date Observed	Reference[b]	Present Status
24	East Fowl River, Mobile Co.	GREEN HERON	AB, NP	*	Gaillard, W. M. (Pers. Comm.)	UNKNOWN
		LITTLE BLUE HERON	AB	*	Gaillard, M. W. (Pers. Comm.)	
25	Theodore-Dawes Rd., Mobile Co.	CATTLE EGRET	100-500 BP	1976	Hayward, R. E. (Pers. Comm.)	ACTIVE
			NP	1978	Johnson, P. G. (Unpubl. Obs.)	
		LITTLE BLUE HERON	AB	1977	Hayward, R. E. (Pers. Comm.)	
26	Deakle's Farm off Bellingrath Rd., Mobile Co.	CATTLE EGRET	BP	*	Gaillard, W. M. (Pers. Comm.)	UNKNOWN

*Exact date of observation unknown.

(a) Observation abbreviations: NP (Nests Present), BP (Breeding Pair), AB (Adult Birds).

(b) Personal Communications

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WATERFOWL IN THE MOBILE ESTUARY

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ABSTRACT

The Lower Mobile Delta is the most important waterfowl habitat in the Mobile Estuary, Alabama, with 95% of the total wintering populations and 95% of the total harvest. Within a 37-year period between 1939 and 1978, the highest number of ducks recorded was 104,000 in 1941, while the highest number of coots seen was 44,000 in 1943. There are no wintering geese in the Mobile Delta. Relatively few ducks are found in Mobile Bay from a point three miles south of Battleship Parkway to the Gulf Coast. Twenty species of ducks have been recorded in the Delta. Lesser scaup, gadwall, green-winged teal, mallard, wigeon, ringneck, and pintail, in that order, are the most important species. Few mergansers winter on the Delta. Coots are important game birds in the Delta and are harvested in greater numbers than any other bird. The average daily bag of ducks is 1.64 while the average for coots is 2.30 per hunter per day. Harvest figures in the Delta compare favorably with those from public shooting areas in other sections of the United States. Crippling losses are 15% to 20%. Between 75 and 100 arrests are made annually for violations of waterfowl hunting regulations. Mobilians make up 90% of the hunters on Mobile Delta, while 5% are from Baldwin County, and 5% are from other counties or out of state. Less than 5% of Delta hunters are black. About 5% are over 65, while 3% are under 16 years of age.

Possible management measures recommended in previous studies include diking and plantings of both wild and domestic plant species; however, these are not recommended at present due to prohibitive costs. Local regulations and restrictions on hunting are not recommended. Spot control of water hyacinth is recommended. Other recommendations include the purchase of marshland in fee title, close monitoring of Eurasian milfoil, and the elimination or reduction of pollution to a level compatible with basic biological needs of plant and animal life of the Estuary.

INTRODUCTION

Nearly all available information on waterfowl in the Mobile Estuary is from the Lower Mobile Delta, or treeless portion, from Chuckfey Bay southward to a line 3.2 to 4.8 km (2 to 3 miles) below Battleship Parkway (previously the Bay Bridge, or Cochrane Bridge, Causeway)(Fig. 1). The southern boundary corresponds with the outer limits of submerged aquatic plant life. This Lower Delta is about 20,235 hectares (50,000 acres) of which one-half is open water. It is approximately 25% of the entire area in southwest Alabama commonly known as the Mobile Delta, which extends from the open Mobile Bay to the confluence of the Alabama and Tombigbee Rivers—a distance of about 64 km (40 miles) in a straight line. It is about 16 km (10 miles) wide and, unlike a typical delta, is bound on both sides by high land. An estimated 95% of waterfowl populations in the Mobile Estuary winters in the Lower Delta, and 95% of the hunting occurs here.

The Lower Mobile Delta, with its shallow bays and grass-covered marshes, has been the subject of a number of studies dealing with waterfowl and waterfowl food sources. Two of the first recorded investigations were by Neil Hotchkiss, U.S. Biological Survey (now U.S. Fish and Wildlife Service), who examined the feasibility of establishing a migratory waterfowl refuge in 1930 and 1935. John J. Lynch reported on the waterfowl food resources of Mobile Bay in 1940. George C. Moore listed the waterfowl foods from a study in 1941. Francis X. Lueth was the project leader for the Mobile Bay Waterfowl and Muskrat Research from 1946 to 1950. A final report was distributed on this study in 1963. William P. Baldwin, Wildlife Management Consultant, Summerville, South Carolina, in 1956 published a report entitled "An Inspection of Waterfowl Habitats in the Mobile Bay Area," which also included coastal areas of Mobile and Baldwin Counties. Herbert L. Dozier (1942) and Francis M. Uhler (1956, unpublished, U.S. Fish

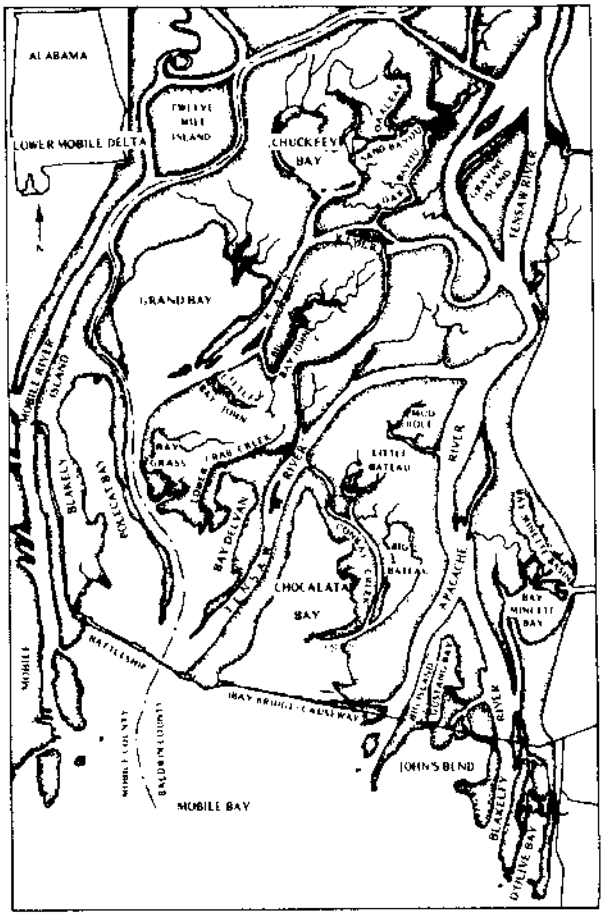

Figure 1. Lower Mobile Delta.

and Wildlife Service) are other wildlife authorities who have studied and reported on the fauna and flora of the Delta.

The author first studied the Mobile Delta in 1952, and results are included in the report "Alabama Waterfowl Habitat Investigation" published in March 1955. The habitat study was expanded in late 1952 to include aerial inventories and hunter bag checks. Populations and hunter kill data have been collected each winter season since that time (no kill data were collected in 1960). Job progress reports on winter inventory and waterfowl harvest and hunting pressure were published in 1969. These reports included 17 years of data from the Lower Delta. Annual job progress reports of the Wildlife Section, Alabama Department of Conservation and Natural Resources, Division of Game and Fish, have included these data since that time.

After the Baldwin study, a new job was added to the Wildlife Section's waterfowl studies in 1957. The Mobile Delta Vegetative Study has been made each late summer or early fall since that time to determine gross ecological changes in plant species composition, and association, with particular emphasis on those submerged aquatics that furnish the bulk of the food for waterfowl. Bottom samples of submerged plants are taken from the same areas each year. The amounts and kinds of emergent plants also are recorded at the same locations. Fifty fixed camera points with numbered marker signs show changes that occur from year to year.

WATERFOWL POPULATIONS

Waterfowl inventory figures are available for the Lower Mobile Delta from 1939 through 1949 (Fig. 2), and from 1952 through January 1979 (Table 1). They show considerable differences in numbers of both ducks and coots observed during these periods. The greatest number of ducks was 104,000 recorded in January 1941. The highest figure for coots was 44,000 observed in January 1943. The lowest count of ducks was 4,918 in January 1975, while the lowest number of coots was 6,000 in January 1941.

Few geese have been observed by Delta census takers. Lueth stated that "The geese are usually transients, and in many years may fly over, but rarely stop on the Delta. In 1947, flocks of geese could be heard at night during late October and throughout November. In 1948, a flock was heard over Blakeley Island on October 20. Six (presumably Canada geese, *Branta canadensis*) were seen resting in some water-filled sand pits on that island on October 22. The same number of birds in the same ponds were observed on October 28. Sometime during the week of November 15, a flock of

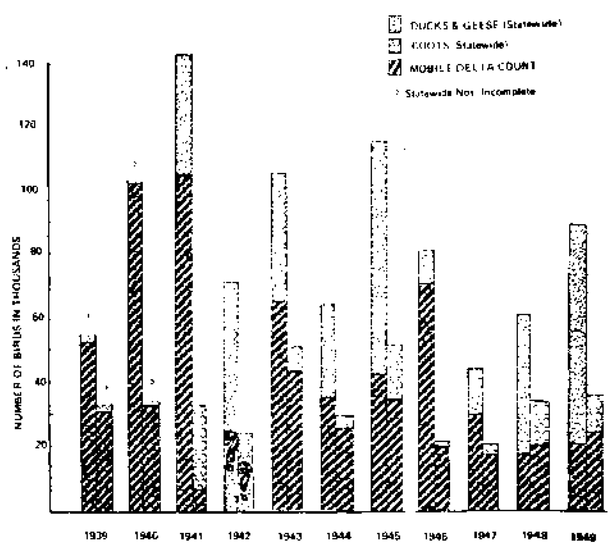

Figure 2. Mobile Delta Waterfowl Inventories, 1939-1949 (Lueth).

Table 1. Wintering Populations of Ducks and Coots in the Lower Mobile Delta.

Year	November Ducks	November Coots	December Ducks	December Coots	January Ducks	January Coots
1952	39,925	26,065	36,065	20,280	37,222	18,600
1953	20,810	25,000	32,342	12,000	18,488	15,000
1954	23,268	15,150	29,420	15,800	21,545	19,000
1955	12,750	10,000	17,045	11,800	14,930	8,600
1956	19,200	15,000	27,150	18,000	21,310	17,005
1957	11,870	6,300	9,715	11,800	12,627	12,000
1958	25,000	25,000	18,800	16,000	18,625	16,275
1959	14,060	13,050	16,000	15,000	13,165	19,450
1960	23,146	21,440	18,250	25,000	19,759	29,500
1961	11,770	13,925	17,151	18,760	18,800	18,300
1962	22,000	17,975	29,935	36,265	28,599	28,825
1963	28,050	27,175	24,170	23,225	17,850	19,950
1964	17,842	24,700	17,200	15,000	18,922	17,600
1965	36,805	35,550	20,000	12,000	22,500	16,225
1966	25,000	25,000	18,450	27,200	18,475	20,600
1967	5,560	8,200	11,743	14,644	10,000	10,000
1968	17,500	7,250	19,175	22,580	7,575	7,625
1969	12,303	20,825	14,778	12,115	10,600	10,000
1970	15,126	31,240	7,116	20,095	6,765	14,035
1971	13,387	35,225	8,365	17,760	7,198	12,725
1972	8,559	16,745	5,160	11,550	5,043	11,595
1973 a/			12,108	35,100	6,300	21,800
1974			22,948	28,150	4,918	15,595
1975			13,476	36,360	5,610	27,570
1976			13,931	37,942	10,895	28,722
1977			11,990	19,050	10,680	22,900
1978 b/	12,300	16,600			12,000	14,000

a/ Only two counts per year have been made since 1973.

b/ The 1978 census was on 11/13/78 because of the zoning of Mobile and Baldwin Counties and early opening of the duck season on 11/16/78. From 1973 through 1977, the first inventory was about December 1, or just prior to opening of the hunting season.

from 40 to 100 blue geese (Lesser snow geese, *Anser caerulescens caerulescens*) began to feed on a spoil pile formed by dredging the Mobile River, where they remained until November 29. Singles, pairs, and trios of geese were seen after this, and an occasional one was taken by hunters."

A total of 50 Canada geese and 50 lesser snow geese was seen in November 1958, and 100 Canadas were recorded in November 1961. Hunter bag checks since 1952 also have shown that few geese are killed on the Delta. One or two lesser snow geese were checked the first of the hunting seasons in 1952, 1953, 1955, and 1957. Eight lesser snows were checked in 1958. One Canada goose was checked in 1962.

Only a few aerial inventories have been made of Mobile Bay and the coastal areas of Mobile and Baldwin Counties. Lueth reported 8,500 ducks seen in lower Mobile Bay from the southern end of the study area to the coast—Mississippi to Florida lines—in 1947. He saw 7,000 ducks in this area in 1948. Some flights were made in the 1950's, usually in conjunction with the January mid-winter inventory, down the western side of the Bay, in Heron Bay, Portersfield Bay, and Grand Bay along the Mobile Coast, in the Navy Cove-Three Rivers area of the Fort Morgan Peninsula of Baldwin County, and back up the eastern side of Mobile Bay to the Causeway. About 4,500 birds were observed on one flight; however, most counts totalled only about 300 to 500 ducks, and for this large acreage did not justify the effort and expense.

Most species of ducks are either migrants or winter residents in the Lower Mobile Delta. Only small numbers of the wood duck (*Aix sponsa*) and mottled duck (*Anas fulvigula maculosa*) are breeders and summer residents.

Alabama is one of 14 states in the Mississippi Flyway. It is at the southeastern edge of the flyway, and therefore, does not receive large wintering duck concentrations. The bulk of the flyway population, of course, migrates down the Mississippi River and winters in the vast expanse of marshland in Louisiana.

Three factors influence variations in numbers of waterfowl in the Mobile Delta. Weather is a very important factor affecting numbers of wintering birds. The area is at the southern end of the flyway, and more ducks and coots will stay in more northern climates when the winters are warm. The heaviest concentrations in the Delta were in 1940 and 1941, years of cold winter temperatures. These were also years of high continental populations, which is the second influencing factor. The third factor is commonly known as "short-stopping" of birds on areas to the north. In recent years, states to the north have developed attractive feeding areas which now hold and winter ducks even in extreme cold weather that would normally move them farther south. With limited continental populations, the Delta will never again experience the high populations of the early 1940's. A fourth factor, which is just beginning to influence numbers of waterfowl in the Delta, is the decrease in desirable submerged aquatic duck foods.

Migration and Wintering

Dabbling Ducks

The blue-winged teal (*Anas discors*) is the earliest fall migrant to appear on the Lower Mobile Delta, with the first flights observed about mid-

August in most years. Peak populations of bluewings occur about the first of October. Teal inventories made during the first years of the special 9-day September teal season showed 5,000 to 10,000 birds. Green-winged teal (*Anas crecca carolinensis*) and a few pintails (*Anas acuta acuta*) arrive in late September. Greenwings account for 5% to 10% of the total bag of teal in the September season.

Most of the bluewings have moved on to Central America and points farther south by mid-November, with only a few remaining after the first of December. They appear again in large numbers about mid-February to mid-March during the northward spring migration to the breeding grounds. Some linger as late as mid-May.

Green-winged teal and pintail arrive in large numbers the latter part of October, with peak populations present about mid-November. Both species are winter residents on the Delta, with greenwings nearly always more numerous than pintails.

Most other species of dabbling ducks that winter on the Delta begin to arrive about mid-October. These include mallards (*Anas platyrhynchos platyrhynchos*), black ducks (*Anas rubripes*), shoveler (*Anas clypeata*), gadwall (*Anas strepera*), and American wigeon (*Anas americana*). Peak populations of the first four occur about mid-December, while the highest numbers of wigeon are present the latter part of December.

Diving Ducks

The diving ducks, except redheads (*Aythya americana*) and canvasbacks (*Aythya valisineria*), arrive in significant numbers in late October, and reach peak numbers in late November. These include lesser scaup (*Aythya affinis*), ring-necked ducks (*Aythya collaris*), ruddy ducks (*Oxyura jamaicensis rubida*), buffleheads (*Bucephala albeola*), goldeneyes (*Bucephala clangula americana*), oldsquaws (*Clangula hyemalis*), and greater scaup (*Aythya marila mariloides*). Redheads and canvasbacks first appear in the Delta in significant numbers in late November, with peak numbers in late December. Lesser scaup and ringnecks usually make up the bulk of the diver populations that winter in the Delta. Ruddy ducks and buffleheads are fairly common in most years, while goldeneyes, oldsquaws, and greater scaup are rare in most years.

All of the above named species of ducks have been observed and recorded in the aerial inventories and hunter bag checks of the Lower Mobile Delta. There is one record of another duck, the fulvous tree duck, or whistling duck (*Dendrocygna bicolor helva*), checked in a hunter's bag in 1956.

Mergansers

Mergansers have never been recorded in substantial numbers on inventories of the Mobile Delta, and figures for this group of birds are not given in this report. Hooded mergansers (*Mergus cucullatus*) are even more rare in the Lower Delta than wood ducks, although both of these cavity nesters are common in the Upper Delta from Chuckfey Bay northward. The common merganser (*Mergus merganser americanus*) also is few in number in the Lower Delta. The red-breasted merganser (*Mergus serrator*) is the most common winter resident of the Delta, with 1,000, or more, recorded on some inventories. Large numbers of common and red-breasted mergansers have been observed at times in coastal areas.

Coots

The American coot (*Fulica americana*), a member of the family Rallidae, is an important game bird in the Lower Mobile Delta, and for this reason it is discussed in this paper. Coots are taken in greater numbers than any other species in this area. There are a few records of coots breeding in the Delta. Although no actual nests have been found, the young have been seen and recorded on a number of occasions in late summer (Imhof 1976).

The first flights of coots arrive around the first of October, and peak populations occur about mid-November. In some years, populations have decreased somewhat about December 1, with a second peak noted about mid-December or the latter part of December.

A great many hunters at Mobile consider coots to be a delicacy. Each year on opening day of the duck hunting season, some coot hunters are checked coming out of the marsh after an hour or less of hunting, with their limit of 15 coots. They have not attempted to shoot a duck. They have only the ingredients for their favorite dish—"Poule d'eau stew."

Movements Within the Area

Lueth discussed movements of waterfowl in the Lower Delta. He stated that although movements are affected by hunting pressure, they can best be correlated with the availability of food. In all three years of his study, the first arrivals of ducks and coots visited areas where foods were not only abundant but where they were readily available with a minimum of dabbling. Vegetation in deep water, or aquatic vegetation exposed or nearly exposed on "mud flats" was seldom used by any waterfowl prior to the shooting season.

In most years prior to the hunting season, gadwall, wigeon, and coots concentrate in Chocalata Bay. A great deal of the hunting pressure is exerted in this bay the first few days of the season each year, and this causes the birds to leave in the morning and return after shooting hours. Pre-hunting season concentrations in Grand Bay usually are relatively small. After the start of the season, however, large concentrations building up in the center of this large bay, where there is little food. Pre-hunting season populations usually are high in the area immediately south of Battleship Parkway where submerged aquatics grow. When the shooting begins, the birds often raft by the thousands in the open waters far below the Parkway where the hunters cannot get to them.

Tidal Fluctuations

Tide fluctuation in the Delta affects the availability of waterfowl foods, and this in turn affects movements of waterfowl within the area. Mobile Bay is on that portion of the Gulf Coast where there is only one tide daily. From September 15 through March 15, the majority of the high tides occur at night, while the rest of the year they occur during the day. During spring tides, which occur on the new and full moon, fluctuation is from .675 m (2.25 feet) to .75 m (2.5 feet) between high and low tides. Neap tides occur during the first and third quarters of the moon, and fluctuation is often less than .30 m (one foot). From the lowest to the highest tide each month, there is a difference of about 1.2 m (four feet). The average daily fluctuation, however, is about .465 m (1.55 feet). The tide cycle takes about 25 hours, and when a neap tide occurs, there is a rearranging of time and a new cycle begins. Wind velocity and direction greatly influence tidal fluctuations and food availability. Strong north winds cause low tides, and strong south winds cause high tides.

River floods also have an effect on water levels. It is not great along Battleship Parkway, but does influence the vegetation and waterfowl populations in Chuckfey Bay. Such floods usually are in February or March.

HARVEST AND HUNTING PRESSURE

Daily Bags

Waterfowl harvest and hunting pressure figures for the Lower Mobile Delta have been compiled for the years 1952-78, with the exception of 1960 when no bag checks were made, and are listed in Table 2. Lueth obtained figures during his 3-year study in 1946-49, and these are given in Table 3. In spite of considerable fluctuations in populations, the daily bag of ducks for the average hunter has been fairly consistent through the years. The lowest daily bag was .58 ducks per hunter per day reported by Lueth in 1946, while the highest daily bag was 2.59 ducks per hunter per day in the hunting season of 1978. Lueth reported daily bags of 1.17 in 1947 and 1.42 in 1948. The daily bag averaged 1.0 ducks or more per hunter per day in all but five of the 26 years of bag checks from 1952-78.

Lueth reported that Mobile Delta hunters averaged 5.63 coots per hunter per day in 1946, 3.07 in 1947, and 3.01 in 1948. The average daily bag of coots, as shown in Table 2, has fluctuated a great deal in the years 1952-78. The highest daily bag of coots during this period was 5.08 in 1975, while the lowest daily bag was 0.8 in 1965.

Comparison with Other Areas

The average daily bag of 1.64 ducks and 2.30 coots for the Delta can be considered as good for a public shooting area. The figures compare favorably with those from other section of the country. Lueth reported 1.31 ducks and .78 coots per hunter in 1944 and 1.02 ducks and .48 coots per hunter in 1945 from figures he obtained at Rice Lake Wildlife Area, a controlled public shooting area in Illinois. The daily bag has averaged about 0.5 ducks per hunter on the Tennessee River public shooting areas in north Alabama throughout the years since 1953. According to administrative reports from the Fish and Wildlife Service, the average daily bag for the entire Mississippi Flyway each year is less than 1.0 duck per hunter.

Species Composition

Lueth reported that gadwalls were by far the most important species harvested by hunters in all three years of his study in 1946-49. Lesser scaup ranked second for two years, while ringnecks were second the third year. The canvasback was third, fourth, and fifth in each of the three years. Lueth further reported that although pintails made up

Table 2. Waterfowl Harvest and Hunting Pressure
in the Lower Mobile Delta.

Year	Hunters Checked	Hours Hunted	Hours/ Hunter	Ducks Checked	Ducks/ Hunter	Coots Checked	Coots/ Hunter
1952	750	2,278	3.0	1,643	2.19	1,643	2.19
1953	426	1,522	3.57	633	1.48	1,834	4.3
1954	751	2,959	3.94	1,136	1.51	3,009	4.0
1955	577	2,715	4.7	986	1.71	1,278	2.21
1956	497	2,050	4.1	654	1.32	1,201	2.42
1957	323	1,365	4.2	297	.92	943	2.92
1958	387	1,477	3.8	530	1.37	1,137	2.94
1959	111	329	2.96	204	1.84	112	1.0
1960	0						
1961	153	490	3.2	274	1.78	158	1.03
1962	79	225	2.8	63	.8	143	1.8
1963	116	364	3.1	203	1.75	186	1.6
1964	57	228	4.0	121	2.12	220	3.86
1965	106	415	3.9	204	1.9	85	.8
1966	87	284	3.26	68	.78	169	1.94
1967	97	392	4.0	199	2.05	130	1.34
1968	163	570	3.49	221	1.36	147	.90
1969	84	410	4.88	214	2.5	77	.92
1970	147	523	3.56	246	1.67	306	2.08
1971	50	124	2.48	48	.96	73	1.46
1972	220	592	2.69	186	.85	674	3.06
1973	270	720	3.34	665	2.46	865	3.2
1974	85	280	3.3	126	1.5	101	1.2
1975	279	1,001	3.58	492	1.76	1,419	5.08
1976	217	732	3.37	354	1.6	644	2.9
1977	281	664	2.36	568	2.0	593	2.1
1978	336	1,361	4.05	872	2.59	899	2.64

Table 3. Waterfowl Hunters and Kill

Mobile Bay Delta
(Lueth 1950)

Season Dates	1946-1947 Nov. 23- Jan. 6	1947-1948 Dec. 8- Jan. 6	1948-1949 Nov. 26- Dec. 25
Number of Days	45	29½	29½
Number of Hunting Trips	6,250	7,000	7,700
Number of Ducks Killed	3,625	8,200	10,900
Number of Coots Killed	35,200	21,500	23,200
Ducks per Hunter-Day	.58	1.17	1.42
Coots per Hunter-Day	5.63	3.07	3.01

6.6% of the kill in 1947 and mallards 6.0% in 1946, they were relatively unimportant during his study.

Species composition of the eight major species for the years 1952-78 is shown in Table 4. Mallards were number one the first year in 1952, when they accounted for 27.0% of the total bag. They ranked second to the gadwall for the next three years, 1953-55, at which time Noxubee National Wildlife Refuge was started with a large acreage of "greentree" reservoirs. This refuge proved to be on the "flight lane" of mallards to Mobile, since their numbers were reduced immediately in the Delta. They have remained relatively unimportant and have been fourth or fifth in the bag in most of the hunting seasons since that time.

Lesser scaup have been the number one duck in hunter's bags in nine of the 26 years in which kill data have been obtained, while gadwalls have been number one eight years, green-winged teal seven years, mallards one year, and ringnecks one year.

Crippling Losses

Hunters interviewed throughout the studies at Mobile Delta have been asked the number of ducks downed but not retrieved to determine crippling loss. They usually report 15% to 20% crippled.

Hunting Pressure Fluctuations

The number of hunters has always been greatest on the starting day of the season each year. Numbers decrease about 50% on the second day, and another 25% the third day. There is nearly always

Table 4. Species Composition of Ducks Killed in the Lower Mobile Delta (Percent)

1971	Mallard	Gadwall	Wigeon	G.W. Teal	Pintail	Scaup	Ringneck	Can'back
1952	27.0	22.3	10.2	9.0	7.0	13.2	4.8	4.2
1953	17.4	20.1	14.2	3.3	5.3	16.1	11.5	3.1
1954	20.4	30.4	9.5	4.4	4.0	9.5	6.0	4.4
1955	16.8	31.0	13.3	2.0	3.2	9.0	11.5	7.3
1956	7.5	39.7	18.2	4.4	8.8	6.6	4.6	3.8
1957	8.0	32.0	15.5	5.7	2.7	19.2	2.3	1.7
1958	13.4	12.6	12.8	5.1	3.7	18.7	13.6	4.0
1959	9.8	13.2	1.0	12.2	1.0	53.4	1.0	2.4
1960								
1961	7.6	9.4	6.2	16.4	6.2	37.2	3.2	2.5
1962	15.8	19.0	7.9	3.1	4.7	3.1	25.3	3.1
1963	9.3	6.8	7.8	15.7	9.3	30.0	8.8	2.8
1964	4.1	16.5	10.7	6.6	2.4	38.0	2.4	7.4
1965	4.9	32.8	22.1	5.9	8.3	10.8	2.4	5.4
1966	11.7	19.1	8.8	11.8	7.4	13.2	5.9	2.9
1967	7.0	17.0	12.5	21.1	16.0	4.0	.5	4.5
1968	6.9	4.0	8.7	48.5	7.2	4.1	1.8	4.0
1969	7.0	15.4	10.2	20.0	17.2	10.2	1.4	5.1
1970	11.4	18.7	15.0	26.0	4.4	11.4	2.8	2.8
1971	6.2	37.5	12.5	14.5	4.2	14.5	4.2	2.1
1972	1.6	2.2	2.2	39.2	1.1	25.8	.6	---
1973	.5	1.2	.3	5.0	1.4	84.6	3.2	---
1974	---	8.7	4.7	20.6	6.3	40.5	1.6	---
1975	6.9	7.1	4.1	31.1	6.7	5.9	5.3	---
1976	10.4	6.2	7.3	13.5	6.7	30.5	5.1	---
1977	2.3	4.7	3.9	17.9	5.3	51.4	1.4	---
1978	10.3	6.8	7.1	29.3	12.6	12.9	4.0	---

an increase in hunters on weekends and holidays, except Christmas day. The smallest numbers of hunters usually is on Mondays.

Violations

State Conservation Officers and Federal Game Agents do not encounter an excessive amount of violations in the Delta. The area is readily accessible to both the hunter and the officer. Local officers and agents are assisted by those from other localities at the beginning of the hunting season, when all of the bays are patrolled and checked for violations. Additional officers also assist on some weekends and holidays. Routine patrols by local officers are made at other times.

In the September teal season, there are always a number of arrests made for shooting before the legal starting time. This is mainly due to confusion among the hunters, since the time to start is sunrise each day during the teal season and one-half hour before sunrise each day during the regular duck season. Some arrests are made for harrassment of waterfowl, and for shooting from motor-propelled boats. There are few arrests for hunting without a license or duck stamp, or for over-the-limit kills. From 75 to 100 arrests for all types of violations during the season have been made in recent years.

Customs

About 90% of the hunters in the Lower Mobile Delta are from the city of Mobile, or Mobile County, 5% are from Baldwin County, and the remaining 5% from other counties or out of state. Most of the duck hunters are members of the Mobile County Conservation Club, which is the largest and most active of its kind in the state. Members love the Delta, and fully appreciate the richness of its flora and fauna. They have witnessed the gradual deterioration of the area, especially in the western bays, in recent years, and are constantly seeking ways to improve it. They have placed a number of local restrictions on themselves in regard to waterfowling, such as one-half day shooting in certain areas. Few have yielded the desired result of better hunting.

Although the great majority of the hunters are Mobilians, they do not try to monopolize the area, or close it to anyone. Most of the hunting is from blinds constructed of common cane (*Phragmites communis*) which is abundant in the area. A custom of the area permits the hunter to use the blind he built, prior to the season, on the first day of the season only. From then on it is first come, first served, in the use of that particular blind.

Less than 5% of the Delta hunters are black, while about 3% are under 16 years of age. Only a small percentage of the hunters are over 65, since a great deal of stamina is required to hunt the shallow, soft mud-bottomed bays of the Delta.

A relatively large number of decoys are a necessity for successful hunting, and at least 90% of the hunters use them. Although retrieving dogs are a great advantage in the recovery of downed birds, only about 5% of the hunters use them.

MANAGEMENT RECOMMENDATIONS FOR WATERFOWL IN THE LOWER MOBILE DELTA

Habitat Management Recommended by Lueth

Management of Water Areas

Lueth reported an extremely high percentage of the water areas covered with aquatic plants attractive to waterfowl during his study in 1946-49. He found the more important factors limiting these desirable plants were water levels, wave action, and "weed" plants. He further stated that in some years, particularly those of low rainfall, salinity may also limit the range or abundance of desirable plants.

Lueth also reported that control of water levels might be desirable if it were not for a few other factors. The cost of control structures would be prohibitive, and the presence of such structures would cut off tidal action that now acts as a "flushing agent" for the silt in most of the bays. Additional silting of the bays with soils now swept out to the bottom end of the Delta would be more destructive than the control would be advantageous.

Winds from the north or from the south are the most destructive to aquatic plants. If islands or breakwaters were placed in Polecat Bay or Grand bay, the wave action would be somewhat reduced, and additional aquatics would grow. This might also apply to some places below the Bay Bridge Causeway. Lueth concluded, however, that the abundance of food throughout the Delta did not justify the very high cost of such projects.

Lueth reported a pondweed (*Potamogeton epihydrus*), fanwort (*Cabomba caroliniana*), marestail (*Myriophyllum* spp.), water-stargrass (*Heteranthera dubia*), and water hyacinth (*Eichornia crassipes*) as the more abundant weed plants that compete with more valuable food plants. Although locally abundant, the weed plants extend over a relatively small portion of the Delta. No control was recommended by Lueth because of the possible detriment to fish or fishing. He further stated, however, that if at some future date a chemical method of controlling these plants can be found that is not harmful to fish life, then it should be used initially in Bay Minette Basin on an experimental basis.

Lueth was of the opinion that control of water hyacinth in the lower bays could hardly be justified as a waterfowl habitat improvement measure. It might be of some value to wildlife, however, in the upper bays and swamp bayous. The direct value to the sportsman, whose navigation was previously hindered by the plant, certainly would justify expenditures for continued control.

Lueth reported the planting of aquatic species, to supplement those of the Delta, had been tried in previous years. In 1926-27 and again in 1941-42, extensive planting programs were conducted. Some of the plants grew, but most of them resulted in failures. Those plants that did grow were the species already found in the Delta. Lueth cited as an example the recent spread of wild rice (*Zizania aquatica*) as proof that when conditions are right for the aquatic plant to grow, it will spread by natural means. A reduction of waterfowl food plants brought about by low tides rather than a depletion by wintering waterfowl, should not be used as a reason to plant more aquatics.

Lueth concluded that management of the open water areas of the Delta, at least in years of high water, was not needed or recommended. On the other hand, changes that would adversely affect the bays should be opposed. Projects that would pollute the waters, bring additional silt into the bays, or change the salinity of the water, should be watched. Ditches from the active rivers to the relatively stable bays should not be permitted.

Management of the Tidal Marsh

During his study in 1946-49, Lueth found waterfowl food plants throughout the tidal marsh, but for the most part they were not used by waterfowl because the birds could not get to them. Dense stands of alligator grass (*Alternanthera philoxeroides*) cover most of the seeds and even surround the roots of the desirable plants during that period when the ducks were present. Along with cutgrass (*Zizaniopsis miliacea*), it chokes out the more desirable plants. Methods of controlling these plants, if not actually needed, would be highly desirable. However, Lueth found that both alligator grass and cutgrass were used by muskrats. By increasing waterfowl feeding areas it is possible that muskrat areas might be reduced. Until some method is found to get heavy spray equipment into or across the soft-bottomed marsh, such control is impractical on a wide scale.

Plantings of emergent aquatics in the tidal marsh were not recommended by Lueth. Such plantings would not make more foods available. If planted species did grow, they would not be used any more than native plants, for the same reason that the native plants are not used. That is, they would not be readily available to the ducks.

Dynamiting ditches through this type of marsh was attempted in 1941. These ditches, which did not connect with any bay or creek, were used by waterfowl and some furbearers; marsh annuals grew on the banks, but the ditches filled in rapidly and were of value for only a few years.

Management of the High Marsh

Lueth reported that on the high marsh there is the same problem as on the tidal marsh. Some food plants grow there each year, but are seldom used by waterfowl because they are not accessible. Dense grasses prevent ducks from using the higher marsh. Additional feeding areas are not actually needed for the low numbers of ducks present. However, when a series of natural conditions such as low water, high salinity, and extreme low temperatures occur in any year or in successive years and reduce amounts of submerged foods, many of the birds move to other areas. Supplemental foods might prevent such movements. The best place to grow these supplemental foods is on the higher grounds, where they would be utilized by mallards, pintails, and some other species. Geese might also be attracted to winter in the area by such feeding grounds.

In the *Panicum-Spartina-Scirpus* zone, fires in September and October burn off the undervegetation, but leave many of the taller grasses. In that zone covered by cowpeas (*Vigna* sp.), fires will usually not burn until mid-November. To clear any extensive area of mixed vegetation in the early fall, it has been found necessary to both mow and then burn it. The area can then be planted to a mixture of fescue and Ladino clover. Italian ryegrass may also be used. Any great deviation from normal in water levels or rainfall will cause failures in any plan for management of the Delta marshes.

Other Management for Waterfowl

Lueth made a number of recommendations in his report in regard to management of the hunting in the Delta. He suggested dates for hunting of varying lengths. He stated that in most years, 35% to 40% of the hunting occurs in the first week of the season, and that the number of birds present is more of a factor in creating shooting pressure than the number of days in the season. Lueth also discussed bag limits, shooting hours, and local regulations. It was his opinion that closing certain days during the season, regulating the numbers of hunters, prohibiting shooting except from blinds, prohibiting blinds from being built within a given distance of an occupied blind, and prohibiting outboard motors and air boats would have little effect in reducing the total hunting pressure in a season, but would increase the hunting pressure on those days that shooting was permitted. He stated there is no evidence that any of these would increase the waterfowl population in the Delta.

Habitat Management Recommended by Baldwin

In his report in 1956 on the Lower Mobile Delta, Baldwin estimated that there were 5,060 ha (12,500 acres) of submerged aquatics dispersed through an enormous marsh and bay area. He stated that "...the bulk of this flora is of great value as waterfowl food...No aquatic stand compares with it on the Atlantic Coast south of Currituck and Back Bays, in North Carolina-Virginia...It is to be regretted that winter tides do not flood the area to improve winter duck use and hunter success...The greatest problem facing the hunter is that waterfowl can retreat to the sanctuary of open water in Mobile Bay. If there are any outstanding complaints from hunters that the populations and daily bags are declining the blame must be placed on the following conditions: (1) On a continental basis waterfowl hunting is taking all of the annual population that can be spared from breeding stock; (2) The northern breeding grounds are far from being in excellent condition, and (3) At Mobile Bay, waterfowl behavior in relation to water level cycles and the large acreage guarantees a low daily bag."

Baldwin discussed two management measures that might be tried experimentally in the Delta: (1) The high marsh could be improved through diking, soil discing, and annual cultivation of crops. Winter flooding would have to be by pumping. Seedings should be browntop millet and Japanese millet in July-August, and (2) Wild plant introductions offer modest possibilities of improvement. Species recommended are Asiatic dayflower (*Analeima keisak*), delta duck potato (*Sagittaria platyphylla*), and banana waterlily (*Nymphaea mexicana*).

Baldwin also recommended that chemical spraying of water hyacinth should be continued, with a coordinated effort made to eliminate it from the entire drainage basin. He suggested that the Department of Conservation make every effort to halt the dumping of spoil into Polecat Bay. Instead, the spoil should be deposited inside low dikes constructed by dragline. He also suggested construction of a high levee across the mouth of Grand Bay to stop wave action which contributes to the absence of plants in this 810-ha (2,000-acre) basin.

In his concluding discussion, Baldwin stated "...The Mobile Delta and Bay is a large area rich in a flora valuable to waterfowl...We cannot avoid the fact that there are over 4,856 ha (12,000 acres) of submerged aquatics...In the light of this great resource most biologists and administrators would question the feasibility of expending funds and effort to attempt improvement, such as through diking and crop production. Rather, the money might better be used elsewhere in Baldwin and Mobile Counties, or at other locations in Alabama."

DISCUSSION AND CONCLUSIONS

The Alabama Department of Conservation and Natural Resources is charged with certain management responsibilities, and state officials have made periodic investigations of the Mobile Delta to keep the public advised of conditions and trends. Figs. 3 and 4, which show areas of submerged and emergent vegetation, respectively, and Table 5 which gives ownership acreages for a majority of the Delta, are included in this paper as points of information.

The vegetative surveys have revealed certain conditions in recent years which are cause for alarm. The effects of pollution which began to show up in the 1960's, in combination with certain adverse natural factors, have greatly decreased the amounts and kinds of desirable duck foods in the Lower Delta. Perhaps the most dramatic evidence of adverse effects was in 1972 (and to a lesser extent in subsequent years), at which time the combination of factors caused a high percentage of the vegetation to die out in mid-summer.

Table 5. Ownership of the Lower Mobile Delta.

Owner	Marshland (Acres)	Water a/ (Acres)
State of Alabama	5,613	27,917
Adams Lumber Co.	10,956	
Michael Baer	2,794	
Alcoa	1,500 b/	
Individuals (20)	2,000	
Totals	22,863	27,917

a/ Ownership of the bay waters to Mean Low Tide level is vested in the State of Alabama, and management is a function of the Department of Conservation and Natural Resources.

b/ About one-half of this acreage is mud lakes.

It was evident that conditions were favorable in the early spring for germination and growth, but then something happened about midsummer which caused the vegetation to die. There was a complete kill in some of the western bays and in areas along Tensaw Bar south of the Parkway. The typical condition of a bay was completely dead vegetation in the lower end, covered with a thick film of brownish, mucky sediment. When the vegetation was scooped up and squeezed out for examination, the leaves and stems would crumble and appear black in color. In the middle and upper portions of these bays, when the sediment was squeezed off, small amounts of green color could be seen at the nodes and joints of the stems and branches. The waters were considerably more turbid throughout the western bays than in most previous years. Thick mats of filamentous algae were often present in the upper portions.

This condition was evident even in Chuckfey Bay, the northern-most bay examined. There were abundant beds up to 0.6 m (2 feet) thick of bushy pondweed (*Najas guadalupensis*) with some wild celery (*Vallisneria spiralis*), coontail (*Ceratophyllum demersum*), muskgrass (*Nitella* sp.), etc., mixed in. This vegetation was all dead or dying, however, by September 10.

Even the eastern bays of Gustang, Bay Minette, etc., which nearly always exhibit a healthy condition, showed some dead or dying vegetation in 1972. The typical condition of a bay on the east side during this inspection was dead or dying

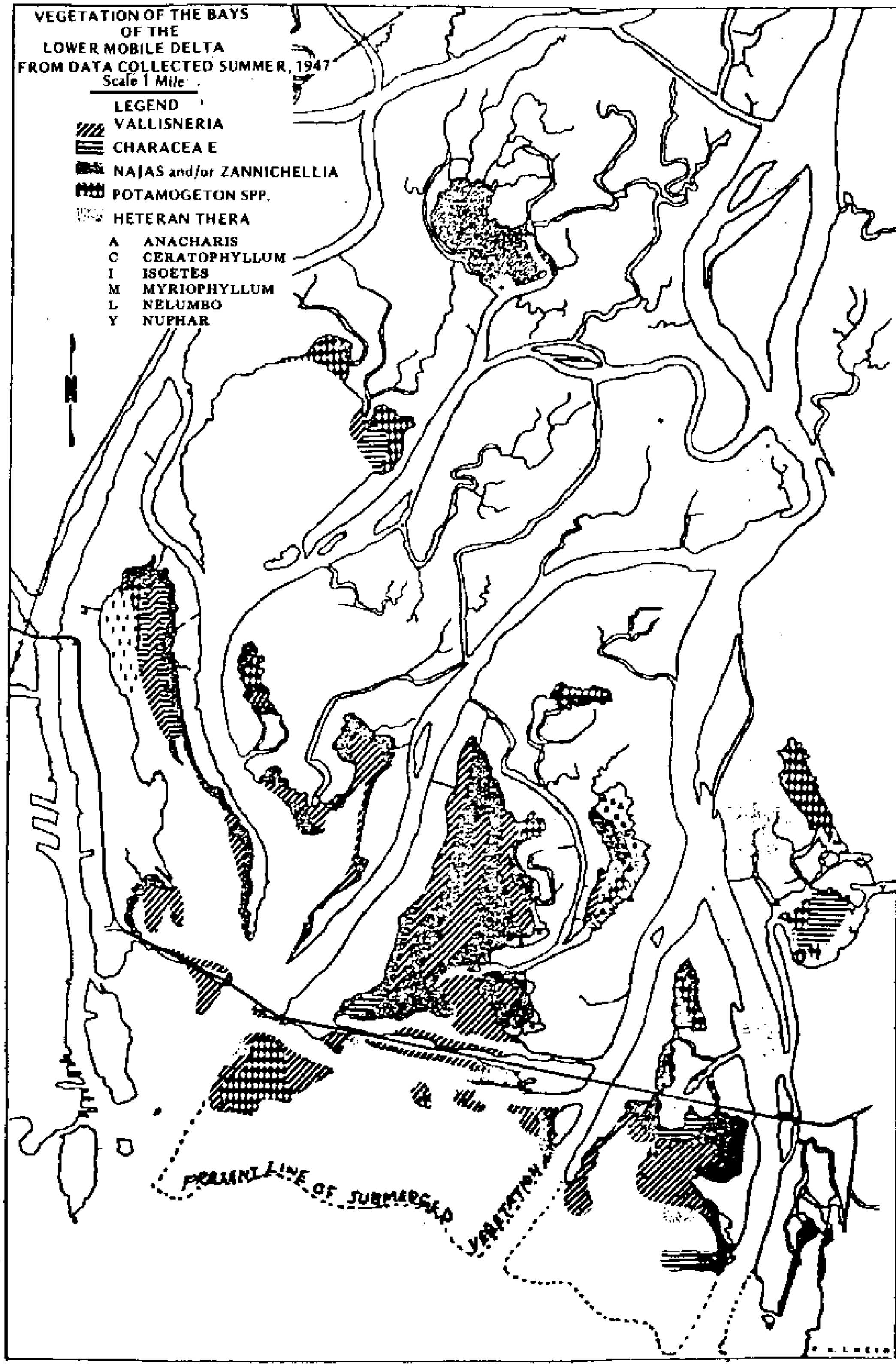

Figure 3. Vegetation of the Bays of the Lower Mobile Delta, Summer

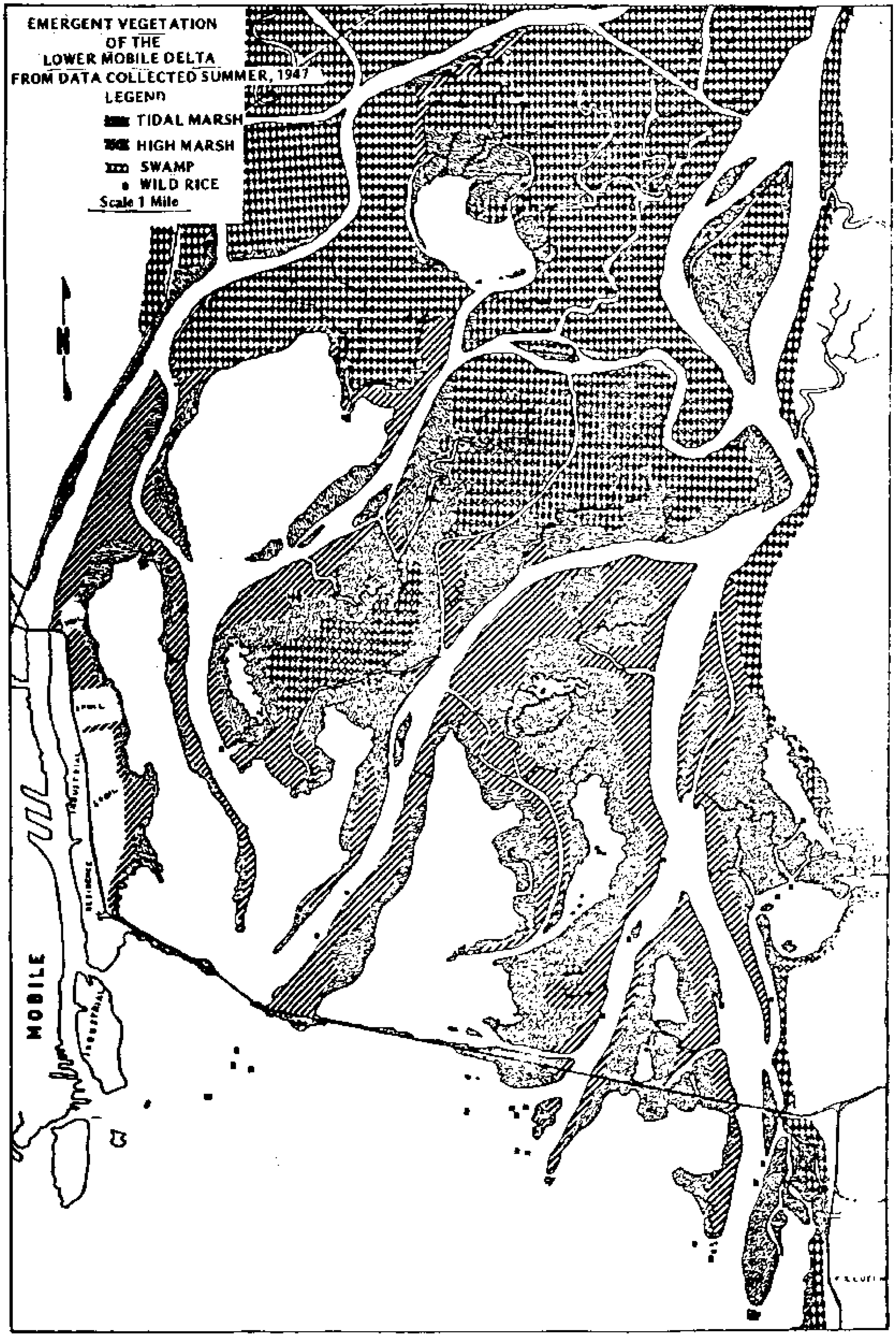

Figure 4. Emergent Vegetation of the Lower Mobile Delta, Summer 1947.

vegetation covered with sediment in the lower end in fairly turbid water, greenish-brown vegetation covered with thick mats of filamentous algae in slightly turbid water in the middle portion, and healthy, green vegetation in clear water in the upper portion.

Visiting biologists from Florida, Georgia, and Mississippi assisted in the vegetative survey in 1972. The question as to what caused the vegetation to die was discussed at length during the survey. First, it was evident that an unusual amount of salt water was present north of the Parkway. Several specimens of wigeon grass (*Ruppia maritima*) were scooped up. Never in the history of the surveys had this salt-tolerant species been found north of the Parkway. The water also was salty to the taste. Some salt could be tasted in the water as far north as Chuckfey, and this had never been noted in previous surveys. Secondly, despite a period of drought and low water flow, the majority of the Delta waters were considerably more silt-laden and turbid than normal. Thirdly, the waters were very warm to the touch, and temperatures apparently were higher than normal. Fourthly, it appeared that a great deal more industrial and domestic pollution was present than ever before. A trip was made from McDuffie Island up Mobile River past the drydocks, shipyards, state docks, the aluminum plant, and the paper mills. The air and water conditions, the floating mess and the foul odor, were terrible. The visiting biologists were amazed. They all emphatically stated that they had never witnessed such a polluted condition.

It was the opinion of participants in the 1972 survey that several factors including low rainfall, low water flow, high turbidity, high salinity, and excessive pollution, combined to cause the vegetation to die out. All but the last of these are natural limiting factors, and they undoubtedly have occurred in the Delta from time to time for hundreds of years without lasting detrimental effects.

The pollution is the greatest limiting factor, and could totally destroy the area, even in the not too distant future. It could be the "coup-de-grace", or the "straw that broke the camel's back," in combination with natural causes. The various chemical, industrial, and domestic wastes, all of which probably are very acid, are combining with the salt water to "burn out" the vegetation. If this condition worsens in succeeding years, it will be just a matter of time until <u>all</u> the submerged vegetation is adversely affected, and seed production limited to such an extent that germination will cease.

The second cause for alarm in regard to the vegetation of the Delta is the phenomenal increase in Eurasian watermilfoil (*Myriophyllum spicatum*). This plant first appeared in the southeastern corner of Chocalata Bay in the early 1970's. By 1975, it was noted in Delvan Bay and Bay Grass. In September 1978, this pest plant had continued its rapid spread into all the Delta bays and a large portion of the area immediately below the Parkway, and occupied at least 75% of the shallow portions where desirable submerged duck foods normally grow.

None of the "Big Five" duck foods (*Najas, Vallisneria, Potamogeton, Nitella,* and *Zannichellia*), nearly all of which were plentiful in the early years of these surveys, could be classed as abundant in 1978. Of the five, bushy pondweed continued to be number one, although it was scarce in all bays except Chuckfey. Wild celery was neither abundant nor common in any area. It was classified as fair on four of the bars and in Chuckfey Bay, and scarce elsewhere. Gray duck moss (*Potamogeton pusillus*) was found in only scarce amounts in three areas. Only a single plant of horned pondweed (*Zannichellia palustris*) was found, in Big Bay John. The muskgrasses were scarce, and found in only six areas. Claspingleaf pondweed (*Potamogeton perfoliatus*) was the number one plant south of the Parkway, although not abundant (as in previous years) in any area.

The ducks undoubtedly are beginning to utilize the milfoil on the Delta, as they do on some of the TVA impoundments such as Guntersville. It remains to be seen just how much it will affect waterfowl populations in the Lower Mobile Delta.

RECOMMENDATIONS

1. None of the habitat management measures suggested by Lueth and Baldwin such as diking and planting, is recommended at this time. Of course, they are all good suggestions which would be of benefit to waterfowl and waterfowl hunting. Costs of such measures to the Department of Conservation and Natural Resources at this time are prohibitive. Instead, the limited funds available should continue to be used to purchase marshland in fee title whenever possible to insure that it remains in its natural state.

2. Eurasian watermilfoil should be monitored closely over the next few years to determine if a control program is feasible and, if so, when it should be initiated.

3. If the Lower Mobile Delta is to continue to be important as a commercial and sport fishery, as a seafoods spawning ground, and as habitat for waterfowl and other wildlife, pollution from all sources must be stopped or at least reduced to a level compatible with the basic biological needs of the primary plant, fish, and wildlife species of importance.

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THE STATUS OF MAMMALS IN THE ALABAMA COASTAL ZONE AND A PROPOSED RESOURCE PLAN FOR THEIR MANAGEMENT

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ABSTRACT

Fifty-four forms of mammals are documented from the coastal zone of Alabama. Ten different coastal habitats are described on the basis of plant species. An estimate of abundance and distrbution data is given for each mammal. Stress sources for coastal habitats are described and discussed. Quantitative estimates for vegetative communities are summarized. Endangered and rare mammals are listed along with an indication of specific data gaps. The status of marine mammals in Alabama waters is reviewed. Recommendations for a resource plan are outlined.

INTRODUCTION

Only a few early naturalists left brief recorded accounts of mammals from the Mobile delta region. An examination of their journals reveals they traversed the Alabama coastal zone during their travels up and down the Alabama, Tensaw and Mobile rivers. Usually their destinations were Mobile, Montgomery and other towns located in northwestern Alabama. Their references to mammals are brief and for the most part incidental to their travels. Howell in A Biological Survey of Alabama, pp. 1-88 (1921), summarized an early history of Alabama mammalogy as follows:

> Apparently, the first naturalist to visit the state was William Bartram, who, in the summer and fall of 1776 (or possibly 1777, the date not being clear from his narrative), in the course of extended travels in southern states, passed through Alabama from the old Muscogee town of Uche on the "Chata Uche" River to Tallahassee on the Tallapossa River, thence southward along the general course of the Alabama River to "Taensa" and Mobile. His narrative, although replete with interesting descriptions of the flora, contains only a few brief references to the larger mammals such as wolves, bears, "tygers" (cougars), and deer. In 1820, Adam Hodgson made an extended journey through the southern states, cross-Alabama twice—first from Ouchee bridge in Russel County to Blakely and Mobile, and later from Franklin County eastward to Madison County via Tuscumbia, Muscle Shoals, Athens and Huntsville. In his narrative he refers casually to "panthers" cougars), gray foxes and bears. In 1830, James Stuart journeyed across Alabama from Fort Mitchell to Montgomery thence to Mobile. Apparently the only mammals which attracted his attention were deer, which he mentions incidentally. Two years later, in 1832, C.D. Arfwedson covered practically the same route and likewise in his narrative mentions only deer. In 1856, Charles Lanmon published an account of his "Adventures", in which are included four chapters on Alabama with few casual references to mammals.

Audubon and Bachman (1846-1854) in their monumental work on The Viviparous Quadrupeds of North America made reference to a few Alabama mammals that occurred in the coastal zone. Howell (1909) published a paper containing brief notes on the distribution of southern mammals based on a field trip made during the summer and fall of 1908. John H. Wallace, Jr. (1916) published a list of the mammals of Alabama comprising some 20 species. His paper was brief and contained no information as to the exact distribution of coastal zone mammals in Alabama. Howell (1921) summarized field investigations carried on by the Biological Survey from 1908 to 1916. His annotated list of 65 forms contained numerous records of Alabama mammals in the coastal zone. Zambernardi (1956) collected *Neotoma floridana* from Mobile and Baldwin counties and referred his specimens to the subspecies *floridana*. Holliman (1959) collected *Sylvilagus floridanus mallurus* from Dauphin Island and Bayou La Batre and suggested that there were also present intermediates between *alacer* and *mallurus*. White (1959), although primarily gathering life cycle data on bat parasites, collected bat specimens from the coastal regions of Mobile and Baldwin counties.

Lueth (1963) described the ecology of both the muskrat and nutria. Holliman (1963) listed numerous records and life history notes concerning mammals in the coastal zone. Sanford (1963) concluded that all gray squirrels in Alabama belonged to the same subspecies (*carolinensis*) except those in the coastal regions along the delta and possibly on Dauphin Island. He designated these as intergrades between *carolinensis* and *fuliginosus*. Bowen (1968) reworked the *Peromyscus polionotus* complex and determined there to be two geographic races along the Gulf Coast. In a paper on the mammals of Mobile and Baldwin counties Linzey (1970) made numerous distributional references to mammals occurring in the coastal zones. Symposia concerning rare and endangered organisms (Keeler 1972 and Boschung 1976) documented mammals imminently threatened with extinction along the Gulf Coast. Chermock (1974) and Boschung (1976) briefly described habitat preferences for certain mammals in the environment of offshore and estuarine Alabama.

The purpose of this paper is to describe the current status of mammals in the Alabama coastal zone. Emphasis will be placed upon their distribution and present condition. Attempts will be made to identify stress sources and possible consequences of long term environmental changes. Specific data gaps will be identified and listed in priority as management and research recommendations.

COASTAL MAMMALS

Fifty-four forms of mammals are found in 10 different vegetative habitats (Table 1). The coastal area is defined as that portion of the state southward from the 10 foot contour line to the outer limit of the territorial sea (Act. No. 534, S. 501,

Table 1. Usual Habitat Preference of Mammals Associated with the Coastal Zone.

Order Marsupialia	
Opossum	C,D,E,F,G,H,I,J,K
Order Insectivora	
Short-tailed Shrew	H
Least Shrew	F
Eastern Mole	G,H,I
Order Chiroptera	
Southeastern Myotis	M
Red Bat	M
Seminole Bat	M
Yellow Bat	M
Hoary Bat	M
Evening Bat	M
Brazilian Free-tailed Bat	M
Order Edentata	
Nine-banded Armadillo	A,E,J,K
Order Lagomorpha	
Marsh Rabbit	C,D,G
Eastern Cottontail	A,E,F,I,J,K
Swamp Rabbit	G,H
Order Rodentia	
Gray Squirrel	G,H,I,K
Bayou Gray Squirrel	H, I
Bachman Fox Squirrel	I
Southern Flying Squirrel	H,I
Southeastern Pocket Gopher	J ?
Beaver	G
Marsh Rice Rat	B,C,D,G
Oldfield Mouse	I ?
White-fronted Beach Mouse	A
Florala Beach Mouse	A
Cotton Mouse	H,I
Golden Mouse	H
Hispid Cotton Rat	F
Eastern Wood Rat	H
Louisiana Muskrat	B,C,D,G
Black Rat	K (3 subspecies)
Norway Rat	K
House Mouse	K
Nutria	B,C,D,G
Order Cetacea	
Atlantic Bottle-nosed Dolphin	L
Short-finned Pilot Whale	L
Order Carnivora	
Coyote	G
Red Fox	E,F,I,J
Gray Fox	C,D,E,F,G,I,J
Florida Black Bear	G
Raccoon	A,B,C,D,E,F,G,H,I,J,K
Long-tailed Weasel	I
Mink	C,D,G
Spotted Skunk	E,F,G,H,I,J
Striped Skunk	E,F,G,H,I,J
River Otter	B,C,D,G
Mountain Lion	G,H
Bobcat	A,B,C,D,E,F,G,H,I,J
Order Pinnipedia	
California Sea Lion	L
Order Sirenia	
Manatee	L
Order Artiodactyla	
White-tailed Deer	F,G,H,I,J (2 subspecies)

LEGEND FOR TABLE 1.

A. BEACH - SAND DUNE *Uniola paniculata* (sea oats), Spartina patens (saltmeadow cordgrass), some *Distichlis spicata* (seashore saltgrass), *Hydrocotyl bonariensis* (pennywort), *Quercus virginica* var. *maritima* (live oak), *Pinus elliottii* (slash pine), *Pinus clausa* (sand pine) in Baldwin County only, *Seronoa repens* (saw palmetto), *Ilex vomitoria* (yaupon), *Ceratiola ericoides* (seaside rosemary), *Solidago pauciflosculosa* (seaside goldenrod).

B. SALTMARSH Predominantly *Spartina alterniflora* (smooth cordgrass) with limited amounts of *Juncus roemerianus* (black needlerush).

C. BRACKISH-MIXED MARSH *Juncus roemerianus, Spartina cynosuroides* (giant cordgrass), *Distichlis spicata, Borrichia frutescens* (sea ox-eye), *Scirpus* spp. (three-squares), *Spartina alterniflora* and *S. patens.*

D. FRESH-MIXED MARSH *Typha angustifolia* (narrowleaf cattail), *Typha latifolia* (cattail), *Sagittaria falcata* (duck potato), *Zizania aquatica* (wild rice), *Zizaniopis miliacea* (cutgrass), *Alternanthera piloxeroides* (alligator grass), *Scirpus validus* (giant bullrush), *Scirpus americanus* (three-square), *Orontium aquaticum* (never wet), *Phragmites communis* (common cane), *Cladium jamaicense* (saw grass), *Panicum virgatum* (feather grass), *Vigna repens* (cow pea).

E. SALTBUSH - SALTFLAT *Baccharis halimifolia* (saltbush), *Iva frutescens* (marsh elder), *Salicornia* sp. (glasswort), *Batis maritima* (saltwort), *Distichlis spicata,* bluegreen algae.

F. SAVANNAH *Spartina patens, Pinus elliottii, Pinus palustris* (long-leaf pine), *Taxodium distichum* (cypress), *Rhynchospora* spp. (sedges), *Juncus* spp. (rushes), and *Andropogon* spp. (broom sedges, *Sphagnum* spp. (mosses), *Sarracenia* spp. (pitcher plants), *Cyrilla racemiflora* (leather-wood), *Ilex glabra* (ink berry), *Drosera* spp. (sundews), *Dichromena colorata* (narrow-leaf dichromena).

G. SWAMP *Taxodium distichum* and *T. ascendens* (cypress), *Salix nigra* (willow), *Magnolia virginiana* (white bay), *Nyssa biflora* (black gum), *Acer rubrum* (red maple), *Cliftonia monophylla* (titi), *Pinus serotina* (pond pine).

H. MIXED BOTTOMLAND FOREST *Magnolia grandiflora* (southern magnolia), *Acer rubrum, Taxodium* spp., *Salix* spp., *Carya aquatica* (water hickory), *Rubus* spp. (blackberry), and *Vitis aestivalis* (wild grape).

I. MIXED UPLAND FOREST *Magnolia grandiflora, Myrica cerifera* (wax myrtle), *Liquidambar styraciflua* (sweet gum), *Cornus florida* (dogwood), *Quercus marilandica* (blackjack oak), *Quercus nigra* (water oak), *Ilex opaca* (American holly), *Carya glabra* (pignut hickory), *Vitis aestivalis, Rubus* spp. *Pinus palustris* (long-leaf pine), *Pinus echinata* (short-leaf pine).

J. PINE *Pinus palustris, P. echinata, P. taeda* (loblolly pine).

K. URBAN AND SUBURBAN AREAS Areas characterized by industrial, commercial, municipal and/or residential development.

L. MARINE Coastal waters.

M. TRANSITIONAL Bat species may be found associated with all habitat types.

1976 Regular Session, Alabama Law). Marginal records are listed for a few mammals whose range normally occurs above the 10 foot contour line. These are included because of their possible migrational or territorial movements into the immediate coastal area.

ANNOTATED SPECIES LIST

Relative abundance and comments concerning specific data gaps are given for each mammal. Stress sources are identified and discussed where pertinent. Documented location records are listed in parentheses.

Order Marsupialia
Didelphis marsupialis pigra (Bangs)
Opossum

This mammal is abundant throughout most of the coastal zone with exception of the Beach-Sand Dune and Saltmarsh habitats. Here it may occur incidentally. It has been observed frequently in the Saltbush-Saltflat communities at the Point aux Pins Field Station at night. This mammal was abundant on Dauphin Island before the completion of the bridge (Holliman, personal observation). Since this time there has been a reduction in number on the island. There are no data relative to hunter harvest in this area. However, a few may be taken by local hunters and trappers. Location record - (Howell 1921).

Order Insectivora
Blarina brevicauda carolinensis (Bachman)
Short-tailed Shrew

This shrew has been reported by Linzey (1970) from Alabama Port as occurring in moist woodland bordering swamps or streams. The species is probably more abundant than is suspected in the northern limits of the coastal zone in the mixed bottomland and upland forest habitats. Destruction of habitat is probably the greatest single cause of limitation of its range. More distributional data are needed for this mammal. Location record – (Linzey 1970).

Cryptotis parva parva (Say)
Least Shrew

This small mammal has been recorded from Alabama Port, Grand Bay, Bon Secour and Lillian. It occurs in drier habitats than does the short-tailed shrew. Little is known about the relative abundance of the least shrew. Preservation of habitat is essential for survival of the species. Location record – (Linzey 1970).

Scalopus aquaticus howelli (Jackson)
Eastern Mole

This mole is common in the coastal region wherever there is sandy loam soil. Its burrow systems can be seen in several habitat types in and around Dauphin Island, Gulf Shores and Magnolia Springs. As with other fossorial mammals, habitat preservation is necessary for its survival. Location record – (Howell 1921).

Order Chiroptera
Myotis a. austroriparius (Rhoads)
Southeastern Myotis

This bat has been collected at Fairhope, but it and other bat species probably range throughout the coastal region. The species has been observed roosting in boat houses and beneath docks extending out into Mobile Bay. Location records – (White 1959; Linzey 1970).

Lasiurus b. borealis (Muller)
Red Bat

The Red Bat has been recorded from both Fairhope and Point Clear. Like the other bats it probably occurs through the coastal region, and roosts in man-made structures as well as in vegetation. Location record–(Howell 1921).

Lasiurus seminolus (Rhoades)
Seminole Bat

This bat has been recorded from Dauphin Island, Orange Beach and Point Clear. It is more common than realized. Location record–(Howell 1921).

Lasiurus c. cinerus (Palisot de Beauvois)
Hoary Bat

This far ranging bat has been recorded from Dauphin Island and Point Clear. Specimens have been observed throughout the coastal regions (Holliman, personal observation). Location record–(Howell, 1921).

Lasiurus intermedius floridanus (H. Allen)
Yellow Bat

The first state record for this bat is from Chickasaw which is outside of the coastal zone. It probably ranges throughout the coastal area. More data are needed to determine its distribution and abundance. Location record–(Linzey 1970).

Nycticeius h. humeralis (Rafinesque)
Evening Bat

The Evening Bat was first recorded from Bon Secour and Fairhope. It is particularly attracted to old homes along the Coden Road and on the east end of Dauphin Island. This bat has been collected also from a bridge over West Fowl River. It is probably one of the most common bats in the area. Location record–(Howell 1921).

Tadarida brasiliensis cynocephala (Le Conte)
Brazilian Free-tailed Bat

Observations of this bat have not been recorded since 1953 when four individuals were collected from the rafters of a fishing pier at Fairhope. Little distributional data are available for this mammal. Location records–(Howell 1921 White 1957).

Order Edentata
Dasypus novemcinctus mexicanus (Peters)
Nine-banded Armadillo

Since 1950 the armadillo has expanded its range from Mobile and Baldwin counties northward. It was first recorded in the state from Foley. It is generally common throughout the area where it burrows in sandy soil. It is considered to be a pest because its burrow systems are often constructed in road rights-of-way and beneath foundations of houses. The species feeds on an assortment of invertebrates that live in its burrows. Location record–(Fitch et al. 1952).

Order Lagomorpha
Sylvilagus p. palustris (Bachman)
Marsh Rabbit

The marsh rabbit probably is found in limited numbers east of Mobile Bay in brackish-mixed marshes and swampland. Specimens have been collected from Bon Secour, Magnolia Springs, Orange Beach and Perdido Bay. There are no published records since those of Howell in 1921. There are also no hunter harvest data for this or any other rabbit species in the coastal area. This rabbit is easily confused with *S. aquaticus*. This similarity between the marsh rabbit and the swamp rabbit probably accounts for the lack of distributional data that could be gathered from local residents. Location record–(Howell 1921).

Sylvilagus floridanus mallurus (Thomas)
Eastern Cottontail

The Eastern Cottontail is commonly found in pine and mixed upland forest habitats and in savannah and saltbush-saltflat habitats. Before construction of the bridge in 1950 it was abundant on Dauphin Island. Feral house cats probably contributed to a reduction of cottontails in this area. At one time this rabbit was common in the Beach-Sand Dune habitat. This species occurs at Alabama Port, Bayou la Batre, Grand Bay, Point Clear, Bon Secour, Orange Beach and Perdido Bay. There are no hunter harvest data for this mammal in the coastal area. Location record–(Holliman 1959).

Sylvilagus aquaticus littoralis (Nelson)
Swamp Rabbit

The coastal race of *Sylvilagus aquaticus* is found west of Mobile Bay at Cedar Point (Holliman, personal observation), Bayou la Batre and in the Blakely Island area. Like the marsh rabbit it occupies areas with a dense growth of marsh grasses which probably accounts for lack of hunter interest. There are no data available relative to hunter harvest in the coastal area. Location record–(Howell 1921).

Order Rodentia
Sciurus carolinensis carolinensis (Gmelin)
Gray Squirrel

This squirrel is common in the coastal zone in swampland, mixed bottomland and mixed upland forest. Sanford (1963) referred all gray squirrels in Alabama to the subspecies *carolinensis* except those in the southwestern part of the state. He suggested that those gray squirrels occurring north of Mobile in the timbered river swamps and westward along the coast were intermediates between *fuliginosus* and *carolinensis*. The gray squirrel is probably the most sought after small game mammal in the coastal region. There are no hunter harvest data available. The species occurs in Bayou la Batre, Coden, Grand Bay, Little Bayou Canot, Bon Secour, Daphne, Fairhope, Gulf Shores, Orange Beach, Perdido Bay, Point Clear and Fort Morgan. Location records–(Howell 1921).

Sciurus carolinensis fuliginosus (Bachman)
Bayou Gray Squirrel

The Bayou Gray Squirrel may still be found in the creek bottoms along certain bayous and in swamps north of Mobile. Individuals on Dauphin Island are more referable to *carolinensis*. This may be due to the introduction of *S.c. carolinensis*. Areas around Bayou la Batre, and upper Mobile delta would be considered likely locations for the Bayou Gray Squirrel. Location record–(Howell 1921).

Sciurus niger bachmani (Lowery and Davis)
Backman Fox Squirrel

The Fox Squirrel is found in isolated, scattered locations at higher elevations in mixed upland forests. Individuals have been observed at Bayou la Batre, Grand Bay, Magnolia Springs, Orange Beach, Weeks Bay, Fairhope, Lillian and Perdido Bay. Location record–(Howell 1921).

Glaucomys volans saturatus (A.H. Howell)
Southern Flying Squirrel

The Flying Squirrel is commonly found in mixed bottom land and in mixed upland forest. It prefers hardwood trees for den sites and will live in the attics of houses and other buildings. However, distributional data for this species are lacking in the coastal region. Removal of mature hardwood trees represent a threat to this mammal. It has been found at Grand Bay, Perdido River, Gulf Shores, Perdido and Point Clear. Location record–(Howell, 1921).

Geomys pinetis mobilensis (Merriam)
Southeastern Pocket Gopher

The occurrence of this mammal south of the 10-foot contour line is doubtful. However, specimens have been recorded from Daphne, Fairhope, Orange Beach and Point Clear. Pocket gophers prefer sandy soils usually associated with pine woodlands. More data are needed before the status of this species can be determined. Location record—(Linzey 1970).

Castor canadensis carolinensis (Rhoads)
Beaver

Beavers are considered common in the northern portion of the delta. Specimens have been taken from Satsuma, Bayou la Batre and Mt. Vernon. There are no harvest data for this important fur bearer in the coastal region of the state. Location record—(Howell 1921).

Oryzomys p. palustris (Harlan)
Marsh Rice Rat

The rice rat is common in saltmarshes, brackish-mixed and fresh-mixed marshes. Specimens have been collected from Bayou la Batre, Dauphin Island, Bon Secour, and Gulf Shores. Location record (Howell 1921).

Peromyscus polionatus polionotus (Wagner)
Oldfield Mouse

The occurrence of the Oldfield Mouse in the coastal zone is unlikely. However, four specimens have been collected from 5 miles north of Gulf Shores.

P.p. ammobates (Bowen)
White-fronted Beach Mouse

The White-fronted Beach Mouse has been recorded from the coastal sand dunes between Mobile Bay and Perdido Bay. It has been collected also on Ono Island at the mouth of Perdido Bay. This mouse prefers sand dunes nearest the surf. Location record—(Bowen 1968).

P.p. trissyllepsis (Bowen)
Florala Beach Mouse

The Florala Beach Mouse is found between Perdido Bay and Pensacola, Florida. It has been collected from Florida Point, east of Perdido Inlet in Baldwin County along the primary sand dune system. Location record—(Bowen 1968).

Peromyscus g. gossypinus (Le Conte)
Cotton Mouse

The cotton mouse is commonly found in timbered swampland and mixed forests near water ways. It has been recorded from Grand Bay, Daphne, Gulf Shores, Lillian, Magnolia Springs, Orange Beach and Point Clear. Location record—(Linzey 1970).

Ochrotomys nuttalli aucrolus (Audubon and Bachman)
Golden Mouse

Scattered populations of the golden mouse occur in wet mixed forests. It has been collected at Point Clear. Location record—(Linzey 1970).

Sigmodon h. hispidus (Say and Ord)
Hispid Cotton Rat

The cotton rat is perhaps the most abundant rodent in the coastal zone. It is found in *Spartina patens* meadows, particularly at the Point aux Pins Field Station. Other localities include Coden, Grand Bay, Bon Secour, Fairhope, Gulf Shores, Lillian and Magnolia Springs. Location record—(Howell 1921).

Neotoma floridana rubida (Bangs)
Eastern Wood Rat

More field work is needed before the exact distribution pattern of the wood rat in coastal Alabama can be determined. It has been recorded thus far from isolated colonies at Orange Beach and Point Clear. Location record—(Schwartz and Odum 1957).

Ondatra zibethicus rivalicius (Bangs)
Louisiana Muskrat

This mammal is common in the Mobile delta. It has been recorded from Alabama Port, Bayou la Batre, Little Bateau Bayou and in Lower Crab Creek. Location record—(Howell 1921).

Rattus r. rattus (Linnaeus)
Rattus r. alexandrinus (E. Geoffry Saint-Hilaire)
Rattus r. frugivorus (Rafinesque)
Black Rat

The black rat is abundant in urban and suburban areas. It has been collected in garbage dumps from the west end of Dauphin Island, Alabama Port, Bayou la Batre and Mobile Causeway. Location record–(Holliman 1963).

Rattus n. norvegicus (Berkenhout)
Norway Rat

This rodent is not as common as *R. rattus.* It has been collected from Alabama Port and Bayou la Batre. Location record–(Holliman 1963).

Mus musculus brevirostris (Waterhouse)
House Mouse

The House Mouse occurs as a commensal of man and has been reported from Dauphin Island, Point aux Pins, Bayou la Batre, Grand Bay, Fairhope, Gulf Shores, Lillian, Magnolia Springs and Point Clear. Location record–(Holliman 1963).

Mayocastor coypus bonariensis (E. Geoffrey St.-Hilaire)
Nutria

The nutria was introduced to the Mobile Delta in 1948 and again in 1949 and 1950. It has caused extensive damage to shore-line vegetation. The nutria has been recorded from Alabama Port, throughout the Mobile Delta, Lower Crab Creek, Raft River Peninsula, Slater Island, Tensaw River, Daphne and Gulf Shores. Location record–(Lueth 1949).

Order Cetacea
Tursiops truncatus (Montagu)
Atlantic Bottle-nosed Dolphin

This is the most common species of marine mammal in the Alabama coastal waters. It usually can be seen throughout the year and occasionally will be found in mouths of coastal rivers that empty into Mobile Bay. Location record–(Caldwell and Caldwell 1973).

Globicephala sp. (probably *macrorhyncha* Gray)
Short-finned Pilot Whale or Blackfish

In September of 1962 a single specimen of this whale was documented from Alabama waters. This record was established on the basis of a photograph published in the October issue of the South Alabama Sportsman. Location record–(Linzey 1970).

Order Sirenia
Trichechus manatus latirostris (Harlan)
Manatee or Sea Cow

Little is known about the occurrence of this mammal in Alabama waters. It has been reported off the Baldwin County coast by Caldwell and Caldwell 1973).

Order Pinnipedia
Zalophus californianus (Lesson)
California Sea Lion

Caldwell and Caldwell (1973) show one distributional record for this mammal in Alabama waters. Location record–(Gunter 1968).

Order Carnivora
Canis latrans
Coyote

The occurrence of this canid is based upon the collection of a single specimen on February 23, 1970. It was taken at the junction of Middle and Tensaw Rivers. Location record–(Linzey 1970).

Vulpes fulva fulva (Desmarest)
Red Fox

This Red Fox is considered to be common in the Alabama coastal zone. It has been observed along the saltbush-saltflat and savannah habitats at the Point aux Pins Field Station as well as in timbered woodland. It has also been reported from Grand Bay, Bayou la Batre, Magnolia Springs, Bon Secour, Fort Morgan, Gulf Shores and Perdido. Location record–(Linzey 1970).

Urocyon cinereoargenteus floridanus (Rhoads)
Gray Fox

This fox is more common than the Red Fox. It is particularly abundant north of the Mobile delta. The Gray Fox has been reported from Bayou la Batre, Grand Bay, Bon Secour, Orange Beach, Fort

Morgan and Gulf Shores. Location record—(Linzey 1970).

Ursus americanus floridanus (Merriam)
Florida Black Bear

Black bears were more common in the early 1900's than now around the Mobile area. Howell (1921) reported them to be abundant in the swamps of the delta, and along the Tensaw and Mobile rivers. There is still some confusion as to the taxonomic status of this subspecies. Miller and Kellogg (1955) and Hall and Kelson (1959) suggested that the coastal population was more referable to *floridanus* than to *luteolus*. The records are from Bayou la Batre, Bon Secour, Lillian and along the Tensaw River. Location record—(Howell 1921).

Procyon lotor varius (Nelson and Goldman)
Raccoon

The raccoon is the most abundant predator in the coastal marshes where it also feeds along exposed mud flats during periods of low tide. It is the principle predator of clapper rails in Alabama marshes (Holliman, 1978). The species has been reported from Alabama Port, Cedar Point, Dauphin Island, Grand Bay, Little Bayou Canot, Bon Secour, Gulf Shores, Magnolia Springs, Orange Beach, Perdido Bay, Fort Morgan, Little Bateau Bayou, Little River and along the Tensaw and Middle rivers. Location record—(Linzey 1970).

Mustella frenata olivacea (Howell)
Long-tailed Weasel

The only record for this mammal is an unpublished one (Holliman, personal observation 1974) from a single specimen picked up as a road kill west of Alabama Point on Alabama Road 188. The identification was confirmed as *olivacea*. No other specimens have been recorded from the coastal region.

Mustella vison mink (Peale and Palisot de Beauvois)
Mink

There are no data relative to trapper harvest for this mammal. It is found in the northern delta region more often than along the coast. Records are from Bayou la Batre and Orange Beach. Location record—(Linzey 1970).

Spilogale p. putorius (Linnaeus)
Spotted Skunk

This species has been sporadically observed mainly in the saltbush-saltflat and savannah habitats. Records are from Grand Bay, Bon Secour and at Orange Beach. Location record—(Howell 1921).

Mephitis mephitis elongata (Bangs)
Striped Skunk

Like the spotted skunk this species is not common along the coastal region. Occasionally at night it can be observed in the saltbush-saltflat and savannah habitats. Records are from Grand Bay, Bon Secour and at Orange Beach. Location record—(Howell 1921).

Lutra c. canadensis (Schreber)
River Otter

This mammal is not commonly observed. The author has seen it in tidal pools on the western end of Dauphin Island in 1949 and at Cedar Point in 1975. Other records include those from Bayou la Batre, Grand Bay, Mobile Delta region, Little Bateau Bayou, Magnolia Springs, Bon Secour, Fish River, Gulf Shores, Magnolia River, Orange Beach, Perdido River, Point Clear and along the Tensaw River. Location record—(Howell 1921).

Felis concolor coryi (Bangs)
Mountain Lion

This cat was more common in earlier times than in recent years. Howell (1921) reported a specimen from near the Blakeley area. The most recent positive record was from Ralph Allen (per comm., State of Alabama Department of Conservation and Natural Resources, Montgomery, AL) who observed a pair of cougars with cubs in Baldwin County in 1974 and again in 1975. Location record—(Howell 1921).

Lynx rufus floridanus (Rafinesque)
Bobcat

The bobcat is common throughout the coastal region especially along the edges of swamps and bottomland forests. It has been frequently seen at the Point aux Pins Field Station along the open saltbush-sandflat habitat. It has been reported also from Fairhope, Fort Morgan, Gulf Shores, Lillian, Orange Beach and Perdido Bay. Location record – (Howell 1921).

Odocoileus v. virginianus (Zimmerman)
Odocoileus v. osceola (Bangs)
White-tailed Deer

The taxonomic status of this species is confused due to the introduction of stock from other areas. Deer are particularly abundant in the northern reaches of the coastal zone along the Mobile and Tensaw rivers. They are less common immediately along the coast. However they have been observed frequently at the Point aux Pins Field Station by the author. There are no hunter harvest data available for this area. Other records come from Grand Bay, Orange Beach, Perdido Bay and Lillian. Location record – (*D.v. virginiana* Howell 1921) (*D.v. osceola* Miller and Kellogg 1955).

DISCUSSION

Habitat

Preservation of habitat is paramount for the survival of coastal mammals. Development and other human pressures resulting in loss or alteration of the environment have greatly decreased both quality and quantity of the available habitat. The first comprehensive survey of coastal habitat was accomplished by Vittor and Stout (1975). Their work involved measurements of vegetative communities inland to the 50-foot contour line (Table 2). A summary of their data follows, along with an indication of the number of mammals associated with each habitat.

A current survey of the coastal area below the 10 foot contour undoubtedly would reflect a reduction in the total area, and particularly the acreage of fresh-mixed marsh, swamp, mixed bottomland

Table 2. Acreage Values for Coastal Alabama Habitats, Extending Inland to the 50-foot Contour Line. The Number of Mammalian Species Present, and the Sensitivity of Each Habitat Type to Human Perturbations are Indicated.

Habitat Type	Area Hectares	Acres	Number of Mammalian Species[a]	Sensitivity[b]	Adverse Activities
Beach Sand Dune	3,801	9,388	6	A	Vegetation removal
Saltmarsh	943	2,330	6	A	Sedimentation; dredge/fill
Brackish-mixed Marsh	5,470	13,512	10	A	Sedimentation; dredge/fill
Fresh-mixed Marsh	4,547	11,231	10	A	Sedimentation; dredge/fill
Saltbush-Saltflat	111	273	9	B	Diking; Ditching; Pollution, dredge/fill
Savannah	7,284	17,992	11	A	Ditching; dredge/fill
Swamp	31,171	76,992	20	A	Ditching; dredge/fill
Mixed Bottomland Forest	77,130	190,512	16	B	Vegetation removal/fill
Mixed Upland Forest	20,516	50,674	17	B	Vegetation removal
Pine	6,636	16,391	11	B	Vegetation removal
Urban-suburban areas	4,087+	10,095+	8	B	Dredge, disposal pollution
Marine	c		5	B	Near shore, off-shore development, pollution

[a]exclusive of bat species.

[b]Class A sensitivity – indicates habitats intolerant of alteration
Class B sensitivity – indicates habitats that are tolerant of some modification

[c]an estimate of the area of the marine environment is not given because of the difficulty in determining the boundary of the tide lands

and upland forest and pine forests. The effect of adverse activities should be reassessed on an annual basis.

Endangered Mammals

Presently there are four mammals that are endangered and four that are listed in the special concern status in the Alabama coastal region. During the second symposium for Endangered and Threatened Plants and Animals of Alabama (Boschung 1976) that was held on March 6-7, 1975, the following categories were established: Endangered species are those organisms in danger of extinction throughout all or a significant portion of their range in Alabama. Endangered species are those whose prospects for survival are in immediate jeopardy. An endangered species must have help, or extinction and/or extirpation from Alabama will probably follow. Threatened species are those species which are likely to become endangered within the foreseeable future throughout all or a significant portion of their range in Alabama. Special concern species are those organisms which must be continually monitored because imminent degrading factors, their limited distribution in Alabama or other physical or biological characteristics may cause them to become threatened or endangered in the foreseeable future.

Endangered Species
Peromyscus polionotus ammobates (Bowen)
White-fronted Beach Mouse

Residential development and increased recreational activities between Mobile Bay and Perdido Bay are destroying the primary sand dune areas that provide a habitat for this endemic rodent. Vehicles such as dune buggies contribute to the alteration of sand dune structure and hence the survival of sea oats which is the principle food of the white-fronted beach mouse. The Wild Sea Oats Act, Acts of Alabama, 1973, provides protection for this valuable plant, but under this act the term "beaches" is poorly defined and therefore the extent of the prohibition is unclear. In 1973, the legislature enacted a measure designed to preserve coastal sand within Baldwin County, Acts of Alabama, 1973, Act. No. 775. This statute prohibits the operation of any motor vehicle upon coastal sand dunes located 50 feet or further from the waterline without the express written permission of the landowner. The enforcement of both of these acts is encumbent upon the Department of Conservation and Natural Resources. The establishment of beach dune refuges, which would exclude man from the habitat, appears to be the only possible solution to saving the white-fronted beach mouse from certain extinction.

Peromyscus polionotus trissyllepsis (Bowen)
Florala Beach Mouse

The Florala Beach Mouse is restricted to the primary beach dunes between Perdido Bay, Alabama and Pensacola Bay, Florida. It is subject to the same ecological restrictions as those experienced by the White-fronted Beach Moiuse. The rigid enforcement of legislation relative to sand dune protection and the establishment of beach dune refuges would enhance its survival.

Ursus americanus floridanus (Merriam)
Florida Black Bear

At the symposium in 1975 Lueth (per comm., Department of Conservation and Natural Resources, Montgomery, Ala.) estimated that there were probably 150 black bears in Alabama. The species was once distributed over all of Florida, and the southern counties of Georgia, Alabama and into Mississippi. In the Alabama coastal zone this mammal resides in the Mobile Delta swamp and in the Lillian area. On July 2, 1975 a single specimen was observed by the author in the Lillian swamp. Human disturbance and degradation of bottomland and swamp habitat are prime factors affecting the survival of this mammal.

Felis concolor coryi (Bangs)
Mountain Lion

The Mammal Committee of the Symposium estimated the entire Alabama population of mountain lions to be less than 12 individuals. This mammal probably occurs in the Mobile Delta region and upper swamp land and heavily timbered river bottoms. Disturbance by humans and alteration of habitat has contributed to its decrease.

Special Concern
Myotis austroriparius austroriparius (Rhoads)
Southeastern Myotis

Although this bat has been collected from only a few localities in the coastal region, it is found throughout the state. Because this bat is disturbed and persecuted by man in his activities in caves and because more distributional data are needed this mammal has been placed in the special concern category.

Lasiurus floridanus (Miller)
Yellow Bat

A single specimen of this bat has been collected from the coastal zone. This is the first state record, although it is commonly found in Florida. Because Alabama is on the periphery of its range and because so little is known about this bat, it is placed in the special concern category.

Sylvilagus p. palustris (Bachman)
Marsh Rabbit

The reduction of habitat and lack of knowledge concerning this rabbit have raised some serious questions about its survival in Alabama. Except for three specimens collected in 1921 (Howell), no other studies have revealed specimens from Alabama. More field studies are needed to verify the existence of this rabbit in coastal Alabama.

Sciurus carolinensis fuliginosus (Bachman)
Bayou Gray Squirrel

This subspecies of the gray squirrel is peripherally distributed in Alabama and prefers swamp habitat in the delta region. Because little is known about this squirrel it is placed in the special concern category.

The distribution of these mammals should be monitored on a regular basis in order to ensure their survival.

MARINE MAMMALS

Little is known about the marine mammals that frequent Alabama waters. Southward, beyond the three mile limit and within the territorial waters, there are scattered records of both whales and dolphins (Table 3).

Inside the three mile limit the bottle-nosed dolphin is clearly the most common species. It is encountered in about equal numbers throughout the year. Occasional individuals move well into the mouth of Weeks Bay and even into Fish, Magnolia and Bon Secour rivers. Little is known about their seasonal movements, and the location of their calving and feeding grounds. The possible effects of poaching, malicious killing and harassment is not known.

It is highly probable that the manatee is a frequent visitor to Alabama waters. Various unconfirmed reports of this mammal have come from several boat captains operating out of Bayou la Batre in recent times. In Mississippi a single manatee was sighted in Wolf River on January 1, 1979 (telephone call March 20, 1979 to J. Corcoran, Gulf Coast Research Laboratory, Ocean Springs, MS 39564). A second sighting of this same individual was made on January 3, 1979 in a small craft harbor at Gulfport. Finally on January 6, 1979, the manatee was captured and transported to Sea World in Florida where it was treated for pneumonia. There is no information available to the author as to whether subspecific identification was determined for this specimen. It appears that the manatees from the eastern Gulf of Mexico represent the subspecies *Trichechus manatus latirostris*, while those from Louisiana, Texas and Mexico represent the subspecies *Trichechus manatus manatus* (Morre 1951).

There is no state law pertaining to marine mammals. Presently the stringent Marine Mammal Protection Act of 1972 is utilized by the state for protection of all marine mammals in Alabama waters. This law regulates the importation of marine mammal products into the U.S. as well as protecting all marine mammals in the territorial waters of the

Table 3. Marine Mammals Observed in Territorial Waters Off Alabama Coastal Zone.

Caldwell and Caldwell (1973).

Marine Mammals	Number of Records
Fin Whale *Balaenoptera physalus*	2
Rough-tooth Dolphin *Steno bredanensis*	1
Common or Saddleback Dolphin *Delphinus delphis*	3
Bottlenosed Dolphin *Tursiops truncatus*	11
Spotted Dolphin *Stenella plagiodon*	22
False Killer Whale *Pseudorca crassidens*	1 a.
Sperm Whale *Physeter catodon*	3
Manatee or Sea Cow *Trichechus manatus latirostris*	1
California Sea Lion *Zalophus californianus*	1

a. a sighting along eastern boundary of territorial sea.

United States. The Fishery Conservation and Management Act of 1976 does not provide specifically for mammals. However in Title IV, Sec. 404 of this act, reference is made to the prevailing authority of the Marine Mammal Protection Act of 1972.

RECOMMENDATIONS

A sound resource plan will become increasingly important in view of projected potential dangers to the coastal zone. This area will become more sensitive to land development occurring near shore, and resource development that is yet to come in offshore waters. Habitat alterations and loss will adversely affect the distribution and abundance of mammals. This plan should be a long range effort involving civic, state and federal agencies. The public should be encouraged to participate in any decisions involving coastal zone management. Priorities should be set for specific jobs within each program. Hard decisions will have to be made in spite of inflationary costs. The basic philosophy relative to the implementation of the resource plan (Table 4) should contain three elements. These elements are:

Table 4. Recommendations for a Resource Plan for Coastal Mammals.

Major Program or Area for Funding	Specific Jobs Within Each Program	Research or Management (R or M)	Job Priority	Continuing Job
Habitat Acquisition		M	1	Yes
Habitat Studies	Evaluate and inventory habitat (by remote sensing and ground truth studies)	M	1	Yes
	Improve habitat (landowner subsidy)	M	2	Yes
	Identify habitat preferences for each species	R	3	No
Public Education	Expand educational efforts related to habitat protection and endangered species	M	1	Yes
Harvest	Conduct harvest survey of game mammals and fur bearers	M	1	Yes
	Study effects of hunting and trapping on population dynamics	M	2	Yes
Population Dynamics	Conduct distribution studies	R	1	Yes
	Identify limiting factors	R	2	
	Study life histories	R	3	No
	Conduct density studies	R	4	No
	Conduct pesticide studies	R	5	No
	Conduct disease studies	R	6	No

1. Research and management programs should be rangewide rather than confined by state boundaries.
2. Cooperation with educational institutions should be encouraged, particularly in those institutions that are related to the Sea Grant Program. Specific jobs could be accomplished on a cost sharing basis and at the same time offer training for potential field biologists in the coastal zone environment.
3. Ongoing state and federal land use programs should be utilized where possible.

Habitat

The acquisition and maintenance of coastal habitat are paramount for the survival of mammals. Constant monitoring of habitat parameters is necessary for the welfare of species at all trophic levels. Habitat acquisition should be given first priority. An attempt should be made to correlate other federal land-use and coastal zone programs so that efforts will not be duplicated. Sanderson (1977) documented an organization plan for the management of migratory shore and upland game birds in North America. Habitat acquisition and management were placed as the first priority by the nine species chairmen responsible for designing comprehensive plans for these resources. It would seem reasonable to dovetail ongoing programs, particularly where mammals and birds are sympatric and have relatively the same basic habitat requirements. Sources for landowner subsidies should be identified with priorities given to those habitat types that are critical. This is especially true for those habitats that support endangered species. Habitat preferences for certain mammals should be evaluated. In this regard little is known concerning the bottle-nosed dolphin in the Mobile Bay Estuary.

Public Education

The successful conservation of our natural resources depends upon an educated public. It is exceedingly important to formulate a sound conservation ethic that will give the public the wisdom it needs to recognize the ecological value of living resources. Symposia on resources should be an annual occurrence along the Gulf coast. Graded school curricula concerning wetland ecology should be a part of a basic education. Coastal landowners should be informed of the significance of their possessions. Clear explanations of public laws should be made available to the general population.

Harvest

Limited management data are available concerning game and fur mammals in the coastal zone. Most of the research and management efforts directed to coastal mammals have been supported by the hunter's dollar and have involved game and furbearing species. Management and research efforts for non game mammals are not directly supported by state and federal programs. Priorities should be set by both state and federal agencies to provide the data that are needed for a sensible, balanced management program for all mammals. The assignment of additional state and federal district biologists and law enforcement officials should be considered.

Population Dynamics

It will become exceedingly more important for us to gain additional population data as human pressures increase in the Alabama coastal zone. In all probability some mammalian species will be extripated from the coastal zone. Again, the conspicuous absence of biological data for cetaceans cannot be ignored. Rabies vectors should be monitored. In 1978 a single bat specimen was tested positive for this disease (personal communication, March 12, 1979, Center of Communicable Diseases, Atlanta, Georgia). Telemetry studies and the analysis of heavy metal and pesticide residues require teams of scientists. Equipment for such studies is expensive. Here cooperative efforts could mitigate rising costs.

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PANEL DISCUSSION - MODERATOR, DR. MAC RAWSON, SEA GRANT ADVISORY SERVICE, MISSISSIPPI-ALABAMA SEA GRANT CONSORTIUM

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Mr. Paul Johnson, Vittor and Associates

SHIPP: Dr. Holliman, did Caldwell and Caldwell speculate whether or not the California sea lion that you mentioned was an escape?

HOLLIMAN: Yes, they did, Bob. They said it was, in all likelihood, an escape and it had a wound on one side, which indicated that someone had tried to recapture it. There is, incidentally, a recent manatee record out of Mississippi. It was collected in Wolf River and subsequently returned to Florida. We probably have more manatees in the state than we think we have.

M. JONES: All three of the gentlemen brought up some good management needs and some future needs that will be heeded. I enjoyed Paul's slide presentation on the possible use of herons as pollution indicators. I have seen other research on that, and it's something that we could really use in this area. Paul, what should we do to increase the population of these birds, not only the herons, but some of the other wading birds, and give them proper protection?

JOHNSON: I think the answer to that was brought out in all three of our presentations; that is, the setting aside of critical habitat for these animals. For example, Cat Island is a very productive area for mammals, and not only wading birds, but shorebirds and a vast variety of wildlife. Areas such as Cat Island, which is an isolated area insular group that it is its own continuing ecosystem, could be set aside. And, I think that is one of the major programs. As far as increasing wading bird populations, as Dr. Holliman pointed out, a public education program would be warranted because many people look at wading birds as target practice, specifically on Cat Island. Until recently it was a common practice to go to this nesting colony and collect eggs during the early spring. I think that has been pretty much phased out with the recent environmental interests, but an educational program would be in order. Also, there was talk in yesterday's meetings about what to do with these dredge spoil islands that are going to be formed, such as the Theodore Industrial Park, and ones that will be brought up in the future. Judy Stout mentioned that due to the elevation on the islands they are not suitable for planting and establishing salt marshes, but the higher elevation would be perfect for development in the succession of spoil islands for heron and egret colonies. The nesting vegetation they use is in secondary stages established after about three or four years, and there have been some excellent papers on this brought out in the gulf coast in Texas, and some studies done in New Jersey on development of spoil islands into breeding bird sites.

TABBERER: What are the socioeconomics of waterfowl hunting on the delta? Is the land leased for waterfowl hunting? If so, what is the going price?

BESHEARS: It is a public hunting area. Most of the emergent marsh is privately owned. The state-owned marsh is open to public hunting, and all of the bays are open to public hunting. The bay bottoms are under state control by the Conservation Department.

HORNE: I am worried about how you foresee any possibility of protecting some of these animals, I am thinking of the reptiles that make nests on dunes and the dune buggies that eradicate or break the nests and break the shells and break the as fast as they find them. What kind of protection are we going to have to have from such intrusions? In Baldwin County, we have a law, but the law doesn't prohibit a dune buggy from moving unless there is some officer there to do it and there aren't officers. The nesting turtles that come on the dunes and lay eggs are not being protected on the dunes.

RAWSON: Maybe the answer to your question is that if the laws already exist, enforcement is needed. That, sometimes, is more easily said than done.

M. JONES: Mr. Beshears, there is a concern of mine about industrialization in the delta area. One point in fact is that pesticide plant that gave us so much trouble on the Tensaw. Has any attempt been made to make this company pay for some of the damages that they have caused to the many acres of swampland that they killed? Also, I noticed that Amoco is asking for another permit to dredge an area. I do not know if this is marsh or not, but every time we allow an oil company to get up into this delicate area and dredge a canal they not only kill the marsh by dredging it, but they pile the spoil on top of other areas that can be very sensitive. The state should not encourage drilling in this area, especially with the dredging of canals. We should encourage oil companies to try upland areas out of the marshy areas. I would like for the state to consider if the company is going to drill have them fly in the rig, have them go to more expense to keep from dredging out these areas.

BESHEARS: Yes, I agree with you. I know of no attempts that we have made to get any money from those who have destroyed any of the marsh areas.

TATUM: I have a question for Walter. I noticed the count that you stated on your waterfowl count in the delta ranging from several thousand on up to 10,000. That doesn't sound like many birds to me, and I'm wondering how the kill could be so high with just that few birds, or is that a lot of birds?

BESHEARS: No, it isn't Walter. Usually at the beginning of the season, for the past few years, we've had about 14,000 to 18,000 ducks present. After the first two or three days of the hunting season, the kill drops down, and, of course, the population drops down. Usually in midwinter inventory, we will see 6,000 to 10,000 birds. There are some fluctuations in populations during that time. More birds may have moved into that area, but it is a heavily hunted area, and it receives considerable pressure.

TATUM: How many birds do you estimate are killed? How many ducks are killed each year in the delta?

BESHEARS: We made some estimates back in earlier years. We haven't done that from year to year to try to arrive at a total figure. I could go back to old Fish and Wildlife Service reports and pull that out county by county, but it wouldn't apply to the delta itself. It would be a wild estimate, for me to give you any figure. May 10,000 or 15,000 ducks, and, of course, at least that many coots are killed.

TABBERER: Do you have any problem with lead poisoning in the delta?

BESHEARS: No.

ANONYMOUS: Mr. Beshears, apparently historically there were large numbers of canvasback in Mobile Bay and apparently what attracted them was all of the desirable aquatic plants they fed on. Almost everyone who has talked about aquatic plants in papers here has expressed the fact that the plants seem to be being replaced by other less desirable food species. Do you attribute the lack of canvasbacks in this area to the diminishing food source or to the more common state population problems like the short-stopping or lower continental flight?

BESHEARS: It is attributed mainly to the low continental population of canvasback. They are in a low population level, and we have tried several different management procedures to try to bring them back, but they are not responding too well. We've had to close canvasback and red head seasons the past several years, and they haven't responded. Back in the early 1950's, we had 8,000 to 10,000 canvasbacks present on the delta. Of course, red heads fit right along in there with canvasback.

ALLEN: Are you in a position right now to give any predictions about the state's attitude toward the Eurasian water milfoil. It's going to cost an awful lot of money.

BESHEARS: I don't know what we could do, how we could do it, how we could finance it or anything. We made a survey with some of the fellows from the Mobile District Corps of Engineers in 1975. We started seeing a good bit of milfoil. At that time, of course, we were concerned; but we recommended to monitor it closely because we felt that any type of control program might destroy the good duck foods adjacent to it. Last year I estimated at least 75% of the shallow bottoms are covered with Eurasian milfoil, so it is an increasing problem.

RAWSON: Harold thanked quite a number of people, and we appreciate that. A lot of people put a lot of time and effort, and the young ladies that have been here during the meeting; Ann Clark, my secretary, Helen Farmer; and Darlene Marsh from the Fish and Wildlife Service; my partners in crime, Bill Hosking and Gale Trussell; and Barry McIlwain have worked during the period. I do very much thank them. They have been great to us, and we thank you, too. I don't think I've heard anyone thank the audience. Without the audience, there wouldn't be any point in the other. We do appreciate the opportunity. I think we all feel it's been a success; it has worked out extremely well, and maybe in a few more years we can have another update session to see where we have gone from this point.

MANAGEMENT RECOMMENDATIONS

Hugh A. Swingle
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Many recommendations were made in the papers presented at this important Symposium on the Natural Resources of the Mobile Estuary. Recommendations for needed research are closely interwoven with those recommendations for better management of the renewable natural resources of this important estuary. This should be so, as many years of research are required before a sound management plan can be implemented.

Management recommendations are grouped under the categories listed below. After each recommendation, reference is made to symposium papers from which the recommendation was derived.

I. FISH AND SHELLFISH

A. Improve collection of statistics on recreational and commercial fisheries catch from fresh and salt waters of Alabama to provide better data on catch per unit of effort, landings by species, area of capture, catch by gear type, and other information required to determine the status of the various species (see Heath, Swingle, Tatum, Tucker, and Wade).

B. Monitor and assess fisheries stocks including species composition and biomass, migratory patterns, life histories, and population dynamics (see Heath, Shipp, Tatum, Tucker, and Wade).

C. Evaluate present management restrictions and licensing requirements (see Heath, Tatum, and Wade).

D. Evaluate present oyster management program to determine ways to provide annual shell planting, relaying, leases of state waterbottoms, seed beds, and rotation of harvest areas (see Eckmayer).

II. BIRDS AND MAMMALS

A. Acquire and manage (State or U.S.) coastal habitats especially important to mammals and resident and migratory birds (see Beshears, Holliman, and Johnson, also III-D).

B. Evaluate the feasibility of control of Eurasian watermilfoil and continued control of water hyacinth (see Beshears).

C. Monitor and assess wading bird and mammal population dynamics (see Holliman and Johnson).

D. Educate public on the values of coastal habitats (see Holliman).

E. Conduct surveys on harvest of game mammals and fur bearers as a basis for preparing a management program for all coastal mammals (see Holliman).

III. HABITAT

A. Develop a benthic habitat quality index based on benthic organisms (see Vittor).

B. Assess submersed grassbeds, with emphasis on factors affecting distribution and productivity, in order to identify areas where grassbeds could be reestablished (See Borom).

C. Establish monetary value of estuarine habitats for comparison of long-range economic impacts of coastal developments (see Vittor).

D. Assess marshland resources, including means of protecting, reestablishing, and determining health indices (see Heath, Stout; also II-A).

E. Reduce point source and nonpoint source discharges that degrade water quality and upgrade existing treatment plants to meet best available technology levels by 1983 (see Beshears, Brady, Eckmayer, and Wade).

F. Determine current patterns and hydrological conditions of Mobile Bay from ground truth data and mathematical modeling (see April, Eckmayer, Heath, Lamb, and Schroeder and Lysinger).

G. Assess the effects of spoil banks from navigational channels upon circulation patterns and the "jubilee" phenomenon (see Eckmayer, Heath, Schroeder, Lysinger, Tatum, and Wade).

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