

BASELINE DATA COLLECTION EXPERIMENTAL MONITORING PROGRAM,
THEODORE SHIP CHANNEL AND BARGE CHANNEL EXTENSION, MOBILE
BAY, ALABAMA.

VOLUME I

TEXT

Prepared for

Mobile District Corps of Engineers
Contract No. DACW01-78-C-0010

Prepared by

Marine Environmental Sciences Consortium
Dauphin Island, Alabama

ERRATA

VOLUME I

Page 22, last line: ...precautions the samples still showed
clear evidence of oxidation...

Page 39, last line: ...October benthic sampling periods.

VOLUME II APPENDIX A

Page A-1, bottom margin:

YEAR

1977

1978

- 1 Includes...
- 2 "Turbidity"...
- 3 "Turbidity"...
- 4 "Turbidity"...
- 5 Aerial...

Title: Baseline Data Collection Experimental Monitoring Program,
Theodore Ship Channel and Barge Channel Extension, Mobile
Bay, Alabama.

Contract Number: DACW01-78-C-0010

Period: October, 1977 - October 1978

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I. Introduction

Mobile Bay is one of the major estuarine systems of the Gulf of Mexico. It is characterized as a shallow semi-enclosed basin which receives large volumes of river water, high levels of suspended solids, has a temperature range of $\sim 25^{\circ}\text{C}$, and undergoes periods of severe dissolved oxygen depletion. Major port and industrial development is taking place along the western shore. To provide access to the new Theodore Industrial Park, the federal government has authorized the construction of a 12 m ship channel and an enlargement of the existing barge canal into the park itself (Fig. 1) under Section 201 of Public Law 89-298.

The dredged material disposal plan calls for the creation of a large island ($\sim 5.2\text{ km}^2$) in the triangle created by the existing and new ship channels. The island will accommodate $\sim 2.4 \times 10^7\text{ m}^3$ of construction material and $\sim 1.5 \times 10^6\text{ m}^3$ of maintenance material is anticipated annually.

There is a paucity of coherent field data for the wetlands and Bay area involved with the new ship channels and disposal island. This created the need for a baseline characterization which may be used in conjunction with a monitoring program to ascertain the actual environmental impact of the proposed construction.

The locations of the various sampling stations are given in Table 2 and depicted in Figure 1. The frequency and dates for each sample type are given in Table 1. The majority of samples were taken on a quarterly/seasonal basis with the intention of describing the area's sedimentology, benthic biology and hydrography including estimates of "turbidity." The adjacent marshes and submersed flora were monitored on the same basis.

Hydrographic data (temperature and salinity) were also taken on a continuous basis with recording units while monthly benthic/hydrography sampling was initiated in the spring of 1978. An intensive investigation of dissolved oxygen levels in Deer River was also pursued.

The sampling details and methodology are described within each appropriate section but the general categories are described as follows: (Table 3)

1. Hydrography - The hydrographic regime (temperature & salinity) was pursued in two ways. Recording instrumentation

was installed near the surface and bottom of stations (M) that were originally used by the Corps' Waterways Experiment Station in developing the hydraulic model at Vicksburg (MS) and near the bottom of stations (X). Data collected from these continuous recording stations will be used for the monitoring effort and model verification studies.

Additional hydrographic data were taken on the regular quarterly basis and in conjunction with all of the other field exercises that were either planned initially or added later.

2. "Turbidity"/suspended solids - Vertical stations (T) were profiled bimonthly with a submarine transmissometer and surface/bottom data were developed using gravimetric and optical methods.

3. Bay Bottom - These stations (B) were sampled quarterly. The biological sampling was essentially divided into two techniques. Grab samples are taken to determine the community structure of the infauna, principally polychaete worms, but the category includes all the macro-invertebrates living in the bottom sediment. Trawl tows effectively sampled the demersal fauna, which are the fish and invertebrates living on or near the bay bottom.

In addition the sediment from each of the (B) stations was characterized in the standard sedimentological format and selected stations were analyzed for biochemical "quality." The various specific parameters of this category have been interpreted as having significance in the functional activity of the microbial benthos and materially impacting the dissolved oxygen values in and near the uppermost sediment layer.

Separate surface sediment transects were run away from the proposed island in an effort to define the areas where mud flow was anticipated.

4. Monthly Samples - Stations B-1, B-5, and B-7 were selected after the first seasonal survey for more intensive work and samples were taken on a monthly basis. These were limited to infaunal and hydrographic data recovery.

5. Grass Beds - The importance of shoreline submersed grasses was recognized and addressed by special surveys in the spring and routine surveillance of the seasonal demersal samples. One aerial survey was flown (Table 1).

6. Deer River Dissolved Oxygen - The historical studies of dissolved oxygen in the barge canal have suggested that the river cannot tolerate any additional oxygen demand. A study of the area was added to the baseline collection in an effort to clarify this situation.

Most of these various elements were developed by separate investigators representing five institutions in the state. It is understood that the environment of Mobile Bay is largely influenced by the river discharge of fresh water (Table 4 Fig. 2) and the wind regime. The tidal flux is influential primarily near the passes and in the ship channel. The hydraulic performance of the Bay is the net balance of these three factors and the benthos, including the sediment, responds to the seasonal averages. In view of the dredging nature of the project, it was also deemed advisable to ascertain the extremes of suspended solid response to the various driving forces. Consequently, specific efforts were made on an opportunistic basis to determine the ranges. These efforts can also be identified on Table 1. The monthly weather summaries are found in Table 5, but must be used in conjunction with Table 4 to develop any approximation of the actual driving forces.

The data base has effectively been developed for the five quarter period involved. In order to provide some degree of efficiency the tabulated data have been included as Appendix A. Some attempt at analysis and correlation have been attempted, but most results must be considered descriptive and the ultimate values will be derived from comparisons with the data acquired during construction. This effort is oriented only toward the short-term effects of construction itself. Figures have been placed in Appendix B while the raw data have been accumulated in Appendix C, available in one copy only.

II. Hydrography - (P.I. Dr. W. W. Schroeder)

1. Continuous Recording instruments (salinity and temperature)

Reporting period: October, 1977 to October, 1978.

The instrumentation utilized for this element of the project were ENDECO 101 Recording Refractometer/Thermograph units. During the first and second quarters three units owned or under the control of the University of Alabama - Marine Science Program were used. In earlier 1978, eight units purchased by the USACOE (Mobile) were added to the instrumentation pool and the number of units deployed increased to eight in the third quarter, nine in the fourth quarter and eight in the fifth quarter. The location and performance records of this instrumentation is presented in Table 7.

The salinity and temperature data from each location monitored is grouped into julian weeks (Table 8) and averaged (Table 9.). Figures 3, 4, 5, 6 and 7 respectively depict the average weekly salinity and temperature values for: (1) East Fowl River /X-1 (bottom); (2) Great Point Clear /X-2 (bottom); (3) Dog River /M2 (surface and Bottom); (4) Fairhope /M3 (surface and bottom) and (5) Whitehouse Reef /M-4 (surface and bottom).

All of the salinity data indicate that the salinity regimes at each of the stations are highly variable. The average weekly salinities in the bottom waters at East Fowl River, Great Point Clear, Fairhope and Whitehouse Reef range from river waters (< 1 ppt) to upper moderate salinities or higher (> 21 ppt). The surface waters at Fairhope and Whitehouse Reef have averaged weekly salinities in the range of > 1 to 19 ppt and > 1 to 11 ppt respectively. The salinity pattern observed at any of the stations is principally a function of the behavior of the Mobile River System. When any of Figures 3a to 7a are compared with the daily average river discharge (Fig. 2) it becomes obvious that during the highest river discharge periods, January-February 1978 (julian weeks 4 to 6), March 1978 (julian weeks 10 to 12) and May 1978 (julian weeks 19 to 22), the surface and bottom salinity regimes in the study area have the lowest salinity values observed. On the whole, surface waters are impacted by river waters over longer time scales and to a greater degree than bottom waters.

On the other hand, during the lowest river discharge period, August-October 1978 (julian weeks 31 to 43) the surface and bottom salinity regimes have the highest values observed. During moderate river discharge the surface and bottom salinity regimes undergo a wide range of fluctuations between the two extremes. Since the river system on a day-to-day, week-to-week, month-to-month and year-to-year basis varies greatly, no specific conclusions should be drawn from these data but rather they should be used to simply characterize the study area over the period they were collected.

The temperature data from all five stations indicates a remarkably uniform thermal regime. Seasonally, the central and upper bay follows a temperature ($\pm 2^\circ \text{C}$) pattern of: (1) Winter (December-January-February) the cold season, $< 12^\circ \text{C}$; (2) Spring (March-April-May) the cold to hot transition season, 12 to 26°C ; (3) Summer (June-July-August) the hot season, $> 26^\circ \text{C}$; and (4) Fall (September-October-November) the hot to cold transition season, 26 to 12°C .

2. Bay Bottom Stations

Salinity, temperature and dissolved oxygen data taken in conjunction with the quarterly and monthly grab sampling elements are presented in Table 10 and 11 respectively. These data are not collected in a manner that allows them to be treated quasi-synoptically and therefore graphics have not been produced. The monthly grab sample element consists of data from just three stations (B-1, B-5 and B-7) and is of minimal value in characterizing the study area. However, a review of the tabulated quarterly data, consisting of eight stations (B-1 through B-8), can produce important insights into the study area.

The salinity data for all five quarterly surveys (Table 10) correlates well with river discharge data (Figure 2 and Table 4). The low (1 to 7 ppt) and moderately low (8 to 14 ppt) salinities of November occurred during moderate to high ($1,500$ to $3,500 \text{ m}^3 \text{ sec}^{-1}$) river discharges. Water column structure varied from well mixed (i.e. Sta. B-1) to stratified (i.e. Sta. B-6 and Sta. B-7). The low salinities (1 to 7 ppt) of January and April occurred during or just following high ($> 4,000 \text{ m}^3 \text{ sec}^{-1}$) river discharge. Water column structure was mostly mixed with some stratification (i.e. Jan. Sta. B-5 and Sta. B-6). The July and October surveys were taken during moderate to low ($< 1,000 \text{ m}^3 \text{ sec}^{-1}$) river discharges. The salinity values during both surveys ranged from moderately low (8 to 14 ppt) to moderate (15 to 21 ppt) and the water column structure was almost entirely stratified. All of the bay bottom salinity data cross checks nearly perfectly with the continuous recording instrument data in Section II. 1.

All of the quarterly temperature data (Table 10) conforms to the same seasonal thermal ranges presented at the end of section II. 1. The dissolved oxygen data (Table 10) are reported both in units of ppm and % saturation. Because the solubility of oxygen in water is a function of temperature, salinity and pressure it is useful to utilize both the measured ppm value and the calculated % saturation value. Measured values of < 2.0 ppm are considered to be at or below the lower limit of dissolved oxygen adequate for normal respiration of many estuarine animals (Emery and Stevenson, 1957) and calculated values of $< 50\%$ saturation are considered, by this P.I., to be a sign of potential stress on the oxygen budget

of Mobile Bay. If the data in Table 10 are reviewed following these two criteria only the July survey indicates any dissolved oxygen problems. The bottom waters throughout the entire survey area had oxygen concentrations of < 2.0 ppm.

3. "Turbidity" and Suspended Solids Stations

Table 12 and Figures 8 through 14 present hydrographic data taken in conjunction with the "turbidity" and suspended solids element. All of the salinity and temperature data cross checks nearly perfectly with the continuous recording instrument data in Section II. 1. Only salinity data are illustrated in the figures because temperature data in general does not serve well as a signature for bay processes. The figures demonstrate the degree of variability in both the quantity and distribution patterns of marine (salt) waters in Mobile Bay.

The salinity fields of central Mobile Bay range from nearly nonexistent (almost total dominance by river water < 1.0 ppt) as during May, 1978 (not illustrated) to low (2 to 7 ppt), moderately low (8 to 14 ppt) and moderate (15 to 21 ppt) salinities with significant longitudinal, lateral and vertical gradients, as during Oct. - Nov., 1977 (Figure 8), Aug. 1978 (Figure 13) and Oct. 1978 (Figure 14).

Consistent with northern hemisphere conditions, river waters in the study area, favor the western shore (right-hand side) as they move to the south. Marine (salt) waters tend to move into the study area in the mid to eastern bay region. The source of these marine (salt) waters can either be from a broad bottom intrusion originating in the lower bay or as overflow waters from the 12 m deep main shipping channel.

4. "Turbidity" and Suspended Solids Event Monitoring

On May 22 and 23, three "turbidity" and suspended solids surveys were carried out during a low wind - high ($> 6,000 \text{ m}^3 \text{ sec}^{-1}$) river discharge period. The surveys covered tidal states of low water, rising water and high water. Salinity values ranged from < 1.0 to 4.4 ppt with the majority of the observations falling below 2.0 ppt.

On July 10 and 11, during a low wind - low river discharge ($< 1,000 \text{ m}^3 \text{ sec}^{-1}$) period, three more "turbidity" and suspended solids surveys were carried out. These surveys covered tidal states of high water, falling water and low water. The surface and bottom salinity fields observed during these three surveys are depicted in Figures 12, 15 and 16 respectively. For the high wind - low river discharge case the "turbidity" and suspended solids data taken on January 28, 1978 (Table 12) during the 2nd quarterly (Winter, 1978)

sampling period are utilized. The surface and bottom salinity fields observed during this survey are presented in Figure 9. Severe weather conditions prevented obtaining data for the high wind - high river discharge case.

5. Theodore Barge Canal Dissolved Oxygen Study

The Theodore barge canal dissolved oxygen study sites are depicted in Figure 17. Table 13, 14, 15 and 16 present the five day twice daily observations taken at Station 2 (Fig. 17) during the winter, spring, summer and fall quarters respectively. A summary of the quarterly five day sampling is presented in Table 17. The 26 hour hourly observations made at Stations 1 and 2 (Fig. 17) during each of the same quarterly sampling periods are tabulated in Tables 18, 19, 20 and 21 and summarized in Table 22.

The variability the absolute values exhibit on an hour-to-hour, am-to-pm, day-to-day or surface-to-bottom basis during any of the quarters precludes a simple straight forward analysis of the data. The summary of the quarterly five day data (Table 17) shows that during all four quarters the absolute dissolved oxygen values were moderate to high, with the absolute minimum value being only 5.5 ppm and the lowest percent saturation being 69%. The summarized quarterly 26 hour data (Table 22) for both Stations 1 and 2 during the winter, spring and summer and Station 2 during the fall agrees reasonably well with the summarized quarterly five day data for Station 2 (Table 17). On the other hand the fall quarter 26 hour data for Station 1 (Table 21) indicates that a severely depressed dissolved oxygen condition existed in the bottom waters of the central portion of the barge canal. Absolute values of < 1.0 ppm were encountered early in the sampling on October 9 at 3.6 meters (Table 21). Observations made at 2.0 and 0.5 meters suggest that the maximum dissolved oxygen depression was confined to the lower half of the water column. In fact the 0.5 m measurements taken simultaneously were almost all above the 100% saturation level indicating a surplus of dissolved oxygen in the surface waters.

III. "Turbidity" and suspended solids - (P.I., G. F. Crozier)

1. Optical measurements - The field stations (T, Fig. 1) were established to provide areal coverage of optical properties that are usually associated with the subjective concept of "turbidity." The method of choice for speed and ease of data acquisition was a submarine transmissometer. A Hydro-Products 612 S system utilizing a 0.1 m path length was employed and data recorded as a percentage of light transmitted (% T). This instrument is easily handled and can be towed for continuous recording. Its drawbacks are tedious calibration procedures and a poor field performance record. In addition universal correlations with gravimetric results cannot be readily developed. Routine calibration by gravimetric analysis can yield acceptable results (Fig. 18).

The transmissometer essentially measures white light transmitted (and scattered) at 180° from the source. If the light scattered at 90° is measured (90° scatterance) there is a broader response band and a better theoretical relationship to particle load. A 90° scatterance meter is technically referred to as a nephelometer. During the summer a Hach 2100 laboratory turbidimeter was employed utilizing formazin standards and reporting the data from water samples in nephelometric turbidity units (NTU).

2. Gravimetric measurements. The requirement for calibration of the transmissometer and universal acceptance of gravimetric determination for suspended particulate material (SPM) led to the use of "grab" water samples and the station approach rather than the surface tows originally proposed.

Water samples were taken by Niskin water bottles at the surface and "near" the bottom. The difficulty of sampling a shallow water column over an unconsolidated bottom was reflected on a number of occasions by unacceptably high values almost certainly resulting from artificial perturbation of the bottom. Every attempt was made to minimize the effect and the vast majority of bottom samples seemed within acceptable limits.

The samples were returned to the Dauphin Island Sea Lab and processed as quickly as possible. The samples were filtered through pre-weighed glass fiber filters. These were washed to remove the salts and weighed to the nearest 0.1 mg/l. It is still apparent that the gravimetric procedure, although time consuming and therefore expensive, still provides the more sensitive and reliable approach to the problem of suspended particulate material. Consequently, statistical comparisons were made using the surface mg/l values unless otherwise noted.

3. Results - The data are presented in Table 23. F-test comparisons of the surface and bottom samples by (1) station or (2) sampling exercise failed to show significance at even the $p = 0.10$ level ($F = 2.01/3.4$ and $1.78/2.7$) in terms of mg/l but the optical values do indicate the logical trend of reduced % T nearer the bottom. The relatively large data base did allow for the calculation of the correlation coefficient between % T and mg/l at -0.7 ($p > 0.02$).

Annual averages for the individual stations were computed (Table 24) because the F-test indicated critical values of less than 25% in seasonal comparisons (by % T). The similarities of the stations within a given sampling exercise also allows the establishment of an areal average (Table 25) utilizing the stations as essentially random points in a dynamic water column.

Seasonal, as defined by the calendar, comparisons were made for those periods of essentially moderate river discharge (Fig. 2). All were found to be insignificantly different at the $p = 0.05$ level. The Fall, 1977 mg/l values were higher than Fall, 1978 and did reach statistical significance ($p > .05$).

The input of river-borne SPM and river discharge energy resuspending bottom sediments associated with river discharge are assumed to be responsible for large increases in the bay "turbidity." Fig. 18 reflects this trend but the comparison of the May, 1978 (high river discharges) to the April results (low river discharges) yielded an F value of only 1.235 and was hence insignificant ($p < 0.05$) for both surface and bottom waters. The correlation coefficient with river discharge for the surface mg/l ($r = 0.887$) was slightly higher than bottom values ($r = 0.833$) as might be expected during river discharge (Table 4). This positive correlation of discharge to areal SPM was better than anticipated.

The wind-contributed kinetic energy has a more pronounced effect. The areal SPM mean for the "high wind" sample is significantly higher ($p > 0.02$) than the high river discharge values and obviously the "moderate" conditions as well.

4. Discussion - It would appear that an adequate baseline has been established for "turbidity" and/or suspended particulates in the area of the planned project. Obviously this statement is restricted to the climatic conditions surrounding the five calendar quarters sampled. Within that context however, the extremes have been documented and quantified. Areal and "seasonal" means have been developed and compared, as have the factors known to be effective in raising the "turbidity" or SPM levels.

The optical data (Table 23) indicate that surface waters in the area of the proposed project range from high % T values of 80 during periods of low wind and low river discharge (summer samples) to extreme lows of 25 % T following periods of high wind. High river discharge ($6,000 \text{ m}^3 \text{ sec}^{-1}$) induced surface values ranging from 29 % T to 53 % T averaging 39 % T while bottom values were similar in range (27-45 % T) but averaging somewhat less (35 % T). It is obvious (Fig. 18) that the area, under low energy conditions, has an SPM load ranging from 3 mg/l - 18 mg/l with most averages, (surface and bottom) lying between 5-10 mg/l. However, with significant energy contributions from the river hydraulics and/or the wind, the values can reach levels near 80 mg/l with averages between 35-50 mg/l. It is most interesting to note that the averages of the two "high energy" situations are similar ($\sim 33 \text{ mg/l}$) but again the greater extreme is wind-induced. The persistently higher values of the surface samples presumably reflect the less effective entrainment of the heavier particles near the bottom and the influence of less dense. SPM - bearing river water on the surface.

If the optical and SPM characteristics of each station are compared for the entire year (Table 24) it is obvious that on the average, the stations are essentially similar. The relatively uniform bottom type (see Hooks below) supports this observation. With this generality in mind, the values for the entire area have been calculated (Table 25) for each sampling period and presented in Figure 18.

From the figure it is obvious that there is no "seasonal" influence if the term is viewed as a temperature/calendar function. It is principally kinetic energy rather than thermal, which has an impact on the SPM load. Any chronological period which is characterized by high wind and/or river discharge will have typically high "turbidity" levels, but these periods are variable and their occurrence is not well correlated with the traditional seasons. The one exception is the summer which is relatively dry and calm.

There is an obvious relationship between the SPM load and those energy sources, or driving forces, which effectively induce resuspension and/or introduction of new material from the riverine system. Additional monitoring and expansion of the data base will effectively improve our understanding of these interactions and allow a more accurate assessment of developmental impacts.

IV. Sedimentology - (P.I. W. Gary Hooks)

Introduction

1. Purpose and Scope - The purpose of this project was to determine the pre-construction distribution of sediments in the Theodore Ship Canal area, Mobile Bay, Alabama. This base-line phase of the program covered a time interval from January, 1978, to December, 1978, and included sample collection intervals of January, April, July, and October, 1978.

2. Sample Locations - Sample locations were chosen to: 1) correlate sediment distribution with benthic biotic data, and 2) determine present sediment distribution in and adjacent to the proposed construction area in order to monitor mud flow away from the proposed island site.

Benthic samples are illustrated in Figure 1 and are designated by stations B-1 through B-8. Mud flow stations were located along four transects away from the proposed dispersal island. These stations, located with Loran "C", are designated as transects I-N (north), I-W (west), II-S (south), and II-W (west). The location of these transects is shown in Figure 1.

Samples were not taken at the corners of the proposed island since the exact location of the island was not known, and since subsequent activity on the island and in the adjoining channels would limit the reproducibility of the sample sites.

Procedures

1. Laboratory Methods - Four grab samples were taken at each benthic sample location. From two of these grab samples, sub-samples were taken and placed in plastic vials that were capped to preserve the moisture content.

Samples, when received in the laboratory, were split into two fractions. One fraction was oven dried in order to determine the moisture content, and the other sample was used for particle size analyses. These samples were dispersed overnight in a calgon-deionized water mixture, stirred 15 minutes in an electric milkshake mixer, then were washed on a 230 mesh screen (62 microns). The material that remained on the screen was oven dried and weighed. The material that passed through the screen was collected in a 1000 ml graduated cylinder and was analyzed using pipette and Coulter Counter methods. In some cases analyses were checked with the hydrometer.

No attempt was made to remove the carbonate fraction since, in most samples, the carbonate fraction was minor. In several samples, however, the carbonate fraction was large and consisted of large, broken shell matter. This hash material was assumed to represent recent dredging activities in the sample area, therefore the samples were not used for size analyses.

Organic matter was noted in all samples, however no attempt was made to remove the matter since removal techniques frequently are detrimental to sediment analyses in the very fine sizes.

2. Size Analysis - The cumulative percent for each sample, as determined by combined sieve, pipette, and Coulter analysis, was plotted against phi size for that fraction on arithmetic probability graph paper. Points were connected by straight line segments and individual statistical parameters were read directly from these graphs. Parameters determined included: frequency distribution, phi mean diameter, phi median diameter, phi quartiles, sorting (standard deviation), skewness, percent sand, percent silt, and percent clay. Phi mean, sorting, and skewness were determined using formulae suggested by Folk and Ward (1957). These are:

$$\text{Phi Mean} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

$$\text{Sorting} = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

$$\text{Skewness} = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$$

The sediment type was determined according to the ternary classification of Folk (1954).

Sediment Distribution

The distribution of sediments as determined through analyses of the January, April, July, and October samples are included in Table 26. This table contains the percentage determinations for moisture, sand, silt, and clay, and also includes the statistical parameters. Table 27 contains the sediment size distribution, adjusted to whole phi classes, for each sample. Those samples that are missing represent sample locations that were possibly disturbed by dredging activities.

Cumulative curves for each sample are included in the appendix (C-10). Those figures with two curves represent two gram samples taken at the same location during the same sampling interval.

The general sediment distribution pattern for the study area is shown in Figures D-2 through D-17 (Appendix C-10). These illustrations indicate that the sand, silt, and clay deposits occur in broad bands that approximately parallel the shoreline of the Bay. Although the distribution, with sand closest to the shore and clay the greatest distance offshore, is as would be expected, there is considerable overlap of the sediment types and there is considerable variation between the quarterly samples.

Sands, typically very fine grained, (Fig. 1) include 6 percent or less of the average sample. Station B-8 for the October sampling interval contained 50 to 65 percent of coarser grained, micaceous sand. This sand was considered to be anomalous and probably related to dredging or dumping activities in the area.

The predominant or average sediment in the study area is silt. This material, with an average mean diameter of 6.67 ϕ (standard deviation 1.12), would be included in the fine silt range. The January, April, and July samples indicate that the major silt distribution pattern roughly parallels the sand distribution. The October distribution pattern is distorted, particularly in the area of the proposed island.

The distribution of clay sediments is highly variable and distinct trends are not apparent. The clay sized particles are extremely susceptible to movement by natural and artificial disturbances.

Conclusions

Sedimentation data reflects a wide range of variability between samples collected during the four quarterly intervals. Variations were also noted between samples collected at the same location at the same time. The reasons for these variations are uncertain; however some possible causes might include:

1. Sampling Errors - The basic assumption must be made that each individual station could be re-occupied with reasonable accuracy. Since samples can vary significantly within a few meters, precise location is critical.
2. Laboratory Analysis - The size analysis of fine grained sediments is extremely sensitive to pre-treatment, incomplete

dispersion, flocculation, and instrumental fluctuation. Variation in any one or combination of factors can significantly reduce the reproducibility of results.

3. Dynamics of the Bay Environment - The results of the present sediment distribution analyses seem to indicate that the Bay environment is a complex system of constantly fluctuating sedimentation conditions. These conditions, both natural and artificial, have produced a distribution of sediments that is constantly in the process of change. Natural forces, such as flooding, normal bay currents, and wind waves combined with shell and channel dredging and waves generated from ships have contributed to the complexity and variability of sediment distribution.

Because of the apparent interplay of these various factors it appears that a precise or "baseline" determination of sediment distribution would be difficult using a quarterly sampling interval. Refinement in the determination of sample location and collection of samples on a much shorter time interval might significantly improve results. Core sampling conducted on a shorter time interval during the actual dredging of the channel and construction of the disposal island should provide a much more effective means of monitoring mud flow patterns and sediment distribution patterns.

V. Sediment Quality - (P.I. Mario Pamatmat)

1. Introduction

We are trying to learn Mobile Bay's characteristics and properties, hydrographic, meteorological, physical oceanographic, biological, chemical, sedimentological and their interactions in order to assess the impact of industrial, shipping, engineering, etc. activities on these properties and say with scientific accuracy what changes might occur and in what way.

It should be understood by everyone concerned that Mobile Bay has been, throughout its recent history, affected by human activities to some unknown degree. During this study, in the Theodore area itself, fairly intensive dredging for buried oyster shells was in progress. Thus any "baseline" information about Mobile Bay must be regarded as that collection of data under present conditions and levels of environmental perturbations, including channel dredging, shell dredging, shipping, pollution, bottom trawling, etc. The level of these activities, unfortunately, is difficult to quantify and the extent of their effects is at least equally difficult if not impossible to determine.

In comparison with 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. Mobile Bay is a very shallow estuary (average depth = 3.2 m) and here we see striking, sometimes catastrophic, evidence of the role played by the bottom in the oxygen budget and distribution in the bay. The bottom waters of Mobile Bay, especially in the hollows during spring and summer, are characteristically low in oxygen. May (1973) described the probable sequence of events that lead to the movement of these low-to-zero oxygen waters towards the eastern shores, culminating in the well-known "jubilee" phenomenon. It appears that the "jubilees" are occurring with increasing frequency.

The chronic, and at times acute, low oxygen conditions in the bottom waters of Mobile Bay can be described and documented by intensive and extensive determinations of dissolved oxygen. This approach alone, however, will never lead to a satisfactory understanding of oxygen distribution in the bay because this distribution is continuously changing as the result of the interplay between many processes, e.g. circulation, vertical mixing, photosynthesis, respiration, all of which in turn are driven by other processes and factors. Oxygen-consuming processes

in the bottom play a very significant, and at times dominant, role in Mobile Bay because of the shallowness of the bay.

This part of the baseline study is an effort to determine the rates of oxygen-consuming processes in the bottom, how they vary with time and place, and why they vary. We measured the concentration of reduced substances in the sediment because this is related to the uptake of oxygen by inorganic chemical oxidation (Pamatmat, 1971). We measured ATP concentrations because this is the best available measure of living biomass in sediments, which in turn should be related to total metabolic activity, both aerobic and anaerobic. Since anaerobic bacteria are important in organically rich sediments, and since oxygen uptake measurements do not accurately measure the metabolic activity of such anaerobic communities (Pamatmat, 1975), we tried to measure their metabolism in terms of their heat flux.

The baseline data sought are indispensable for the formulation of an accurate, predictive model of oxygen distribution in Mobile Bay. The model in turn is needed as a basis for management decisions on matters pertaining to the effect of industry on the oxygen budget of the bay.

OBJECTIVES

- 1) To measure total oxygen uptake of sediment cores from four stations during each quarter
- 2) To measure residual oxygen uptake (= inorganic chemical oxidation) of some cores after poisoning with formaldehyde
- 3) To measure anaerobic metabolism of subsurface sediment in terms of heat production
- 4) To extract ATP from sediments and measure it by means of the luciferin - luciferase assay technique
- 5) To measure the concentration of total reduced substances (= immediate chemical oxygen demand) by oxidizing with dilute, standard acid dichromate solution

2. Methods

Total Oxygen Consumption and Chemical Oxygen Uptake

Four sediment cores (25.3 cm² surface area) were taken with a hand corer from each station and taken back to the

laboratory. The cores were immediately placed on a 20° water bath. Prior to sealing each core tube with an oxygen electrode and stirrer, the water was aerated by gently bubbling air through a gas dispersion tube. After several hours of monitoring the decline in dissolved oxygen at 20° C some of the cores were poisoned with enough buffered formaldehyde to make a 2% formalin solution, then re-aerated, resealed with the oxygen electrode, and the measurement of dissolved oxygen with time continued for several more hours. Glutaraldehyde was tested and found as effective as formaldehyde at half the concentration (1%) and since it is less obnoxious to handle than formaldehyde it was preferred and used later on.

The rate of total uptake is the sum of respiratory and chemical oxygen uptake. The residual rate after poisoning represents chemical uptake only. The difference between total and residual rates is respiratory uptake by all the aerobic organisms in the sediment.

Total Reduced Substances (= Immediate Chemical Oxygen Demand)

A sediment core was sectioned and the desired sediment layers (0-1 cm, 1-2, etc.) transferred into separate wide-mouthed bottles which were immediately flushed with N₂ gas and capped. All samples, vials, reagents, and equipment were placed inside a N₂ glove bag. Approximately 1 ml of sediment, in triplicates, was placed in 10.0 ml of acidified (10 N H₂SO₄) standard dichromate solution (0.05N) previously deoxygenated by N₂ bubbling inside the glove bag. The mixture was shaken periodically for 5 min. Micro-organisms were killed by the acid, thereby eliminating biological oxygen demand. The mixture was then centrifuged, the supernatant subsampled (2.0 ml), treated with KI, and the liberated iodine titrated with standard sodium thiosulfate using a platinum redox electrode to detect the endpoint.

The amount of reduced substances was computed from the difference between initial and residual amount of dichromate. The remaining sediment was dried at 95°C and the concentration of reduced substances expressed per unit weight of dry sediment.

"COD" and "BOD" are both standard measures which may be useful in comparing characteristics of sediments from various sources, but they do not directly relate to actual rates of chemical and biological oxidative processes in the sediments. On the other hand, the measured concentration of reduced substances should be most closely related to the rate of chemical oxidation after poisoning the water in the cores. This relationship has so far only been shown as a statistically significant

correlation between the two measurements (Pamatmat, 1971). More studies are required in this area.

The concentration of reduced substances as determined is proportional to the actual chemical oxygen demand (Pamatmat, 1973) as determined by adding the sediment to formalin-poisoned water of known oxygen content. It takes 36 hr to fully oxidize the sediment with dissolved oxygen in comparison with 5 min using standard dichromate. It should also be noted that the amount of reduced substances measured does not include large organic molecules like cellulose, fatty acids, proteins, but dichromate may react with aldehydes and reducing sugars. The result is different from "COD" which is measured by refluxing with concentrated H_2SO_4 and 0.25N $K_2Cr_2O_7$ (APHA, 1965) and measures total organic matter. It is also entirely different from "BOD" which is essentially a measure of how much organic matter can be oxidized by bacteria under standard conditions, e.g. at 20° C for five days.

Adenosine Triphosphate (ATP)

Upon termination of total oxygen uptake measurement for one core per station, surface sediment and, later, several subsurface layers as well, was dropped in boiling 0.1M $NaHCO_3$ to extract ATP (Bancroft et al., 1976). The boiled mixture was centrifuged and the supernatant sub-sampled while the sediment was dried to constant weight at 95° C. The subsample was kept frozen for analysis later. On the day of analysis, the samples were thawed at room temperature, buffered with TRIS, measured into a cuvette, and treated with luciferin-luciferase enzyme preparation in a Chem-Glow Photometer.

Rate of Heat Production

The heat flux from sediment samples was determined with a double-twin heat-flow calorimeter which is an improved version of the instrument described by Pamatmat (1978). The instrument's calibration constant is 2.16×10^{-5} wat uv^{-1} .

Subsamples from various layers were transferred into polyethylene bags and heat-sealed. All transfers and handling were done inside a N_2 glove bag. The bagged samples were kept inside a N_2 -flushed bottle, later also submerged in mineral oil.

During measurement each sample was placed inside an aluminum pillbox-type can which was flushed with N_2 gas and filled with mineral oil. The oil facilitated heat transfer as well as minimized any oxygen diffusion.

To distinguish metabolic heat production from possible heat effects of purely chemical reactions simultaneously taking place in the sediments, some sediment samples were treated with formaldehyde, glutaraldehyde, and mercuric chloride. The residual heat flux after poisoning was expected to be the heat effect of chemical reactions only and the difference between total and residual heat flux would represent anaerobic heat production.

Stations Sampled

On the first sampling in October 1977, five stations, B1, B2, B3, B5, and B7 (Fig. 1) were sampled. Afterwards B1 was dropped and B8 was substituted for B7.

3. Results

Total Oxygen Uptake

Rates of total oxygen uptake were measured in October, January, and April (Tables 28, 29, and 30) at the same temperature of 20° C. The variability of results is evident when oxygen concentration varies greatly from core to core, indicating the positive effect of dissolved oxygen concentration on rates of oxygen consumption (Table 28 vs. 29 and 30). To eliminate this variability, oxygen uptake in January and April was measured after oxygenating the overlying water of all cores to practically the same concentration.

Within a relatively narrow range of oxygen concentrations, and at the same temperature of 20° C, in January and April, the measured rates of oxygen uptake ranged from a minimum of 16.5 at B5 in April to 41.7 ml/m² per hr at B3 in April. The average rates ranged from 17.8 at B5 in April to 32.5 at B3 in April. The measured and average rates for B2, B3, B5 and B8 in January lie between the extreme values for April.

Effect of core size

One experiment was conducted in October 1977 to determine the effect of core size on rate of oxygen uptake (station B7, Table 31). The limited amount of data so far indicate that there is no significant difference between the rates of uptake of large and small cores. As might be expected, the variability with small cores tends to be greater (coefficient of variation = 17%) than with larger cores (c.v. = 2%). The large cores were with the sampling platform and equipment available. After October, all sampling was done with small coring tubes only.

Seasonal change

B3 showed a significant increase from an average of 25.5 in January to 32.5 ml/m² per hr in April ($t = 1.96$ with 7 d.f.). B5, on the other hand, showed a significant decrease from 27.1 in January to 17.8 ml/m² per hr in April ($t = 5.21$ with 6 d.f.). The other two stations, B2 and B8 showed no significant change from January to April.

Differences between stations

In January all four stations were statistically similar in rates of total uptake ($t \leq 1.77$ with 6 d.f. vs. $t_{.05} = 1.94$). In April only B2 and B8 were similar to each other; there were statistically significant differences between any other two pairs of stations ($t \geq 2.89$).

Relationship between total uptake and oxygen concentration

The oxygen uptake of several cores from B1 and B2 was monitored continuously until dissolved oxygen concentrations of their overlying water dropped to less than 0.1 ml/liter. The estimated rates of oxygen uptake at decreasing oxygen concentration were fitted by least squares regression to the average oxygen concentration during the various time intervals. The relationship is best described by the equation

$$Y = 13.54 + 5.38 \log_e X$$

where X is average oxygen concentration and Y is rate of total oxygen uptake. The coefficient of determination is 0.69 and the standard error of estimate of Y is 3.6 ml O₂/m² per hr.

Effect of vigorous stirring and sediment resuspension

One large core from B2 was fitted with an oxygen electrode and a large stirrer which circulated the water vigorously and carried more and more sediment into suspension with time. This core showed a rate of oxygen uptake which was nearly double that of small cores whose overlying water remained clear during measurement (Table 31). The difference is significant ($t = 4.72$ with 2 d.f.).

Effect of prolonged oxygen depletion

When live cores were depleted of oxygen on long standing and, subsequently, the overlying water was oxygenated, the rates of oxygen consumption were much higher than before (Table 4). Poisoned cores did not exhibit this increase under similar conditions (see later under Chemical Oxidation). The increased

uptake rate of the live cores appears not to be the result of aerobic microbial growth but the result of accumulated oxygen debt during the period of low oxygen and anoxia, because cores that were stored for equivalent periods without undergoing oxygen depletion and anoxia did not exhibit increased rates of uptake. In other words, the increase appears to have been due to increased chemical oxidation and not to increased aerobic respiration.

Effect of salinity changes

Three sediment cores from each of B3 and B8 were subjected to salinity increases, and one core from B8 to subsequent salinity decreases (Table 32). This experiment shows that salinity increases of 8 to 13 parts per thousand have little or no significant effect on rates of total oxygen uptake. A 24 part per thousand increase in salinity, however, caused a 20 to 25% decrease in rates of total uptake. When the salinity of core 3 from B8 was subsequently lowered the rate of uptake increased to a slightly higher level than the initial rate. This particular run had lasted nearly 36 hr and it is possible that by the time salinity had been lowered to the last level of 9.8 parts per thousand bacteria were already growing on the walls of the core tubing, raising its oxygen uptake.

Inorganic Chemical Oxidation

Like the rate of total oxygen uptake, the rate of inorganic chemical oxidation is greatly dependent on dissolved oxygen concentration and when the latter varies greatly there will be a large variability in rates of chemical oxidation (Table 28).

Within a more restricted range of oxygen concentration and at the same temperature of 20° C in January and April, the measured rates of chemical oxidation ranged from 6.5 at B5 in April to 18.1 ml/m² per hr at B3 in January. The average rates ranged from 8.6 at B5 in April to 15.5 at B3 in January.

Seasonal change

B5 showed a significant decrease from an average rate of 13.9 in January to 8.6 ml/m² per hr in April ($t = 4.06$ with 4 d.f.). B8 on the other hand, increased significantly from 9.2 in January to 14.4 ml/m² per hr in April ($t = 3.82$ with 4 d.f.). The other two stations, B2 and B3, and B8 had significantly higher rates of uptake than B5 ($t \geq 2.4$) while not differing from each other.

Differences between stations

In January, B2, B3, and B5 had statistically higher rates of

chemical oxidation than B8 ($t \geq 3.08$ vs. $t_{0.05} = 2.13$ with 4 d.f.) but there were no differences among the three stations. In April B2, B3, and B8 had significantly higher rates of uptake than B5 ($t \geq 2.42$) while not differing from each other.

Effect of prolonged oxygen depletion

Unlike live cores, when the overlying water of poisoned cores were depleted of oxygen and subsequently reoxygenated, there was no apparent increase in the rate of chemical oxidation (Table 4). Poisoning evidently killed not only aerobic but also anaerobic organisms that produce reduced substances. This result supports the notion that the rate of chemical oxidation is dynamically related to anaerobic processes in near-surface sediment.

Quantitative relationship between rates of chemical oxidation and respiration

The measured rates of chemical oxidation, on the average, amounted to 46% of total uptake. The other 54% represents oxygen uptake by aerobic organisms. From station to station, however, the ratio of respiration to chemical oxidation varied from 0.64 to 1.94 with a mean of 1.2. This mean ratio is significantly greater than 1.0 ($t = 1.96$ with 12 d.f.), indicating that the aerobes exert significantly more influence than the anaerobes on the oxygen budget of the bottom waters of Mobile Bay when the sediment is not disturbed.

Anaerobic Heat Production

A main difficulty in measuring anaerobic sediment metabolism was found to be the problem of distinguishing metabolic heat production from heat effects of other chemical processes going on simultaneously. The addition of various poisons to reduced sediment generated heat for surprisingly long times, presumably from the oxidation of sulfides and other reduced substances. After many days the rate of heat production eventually dropped below the original rate before poisoning. There is a great likelihood, however, that heat-producing or heat-absorbing processes were permanently altered by poisoning; therefore, the final difference would not represent metabolic heat production.

Recognizing the need to exclude oxygen, precautions in handling and storage were undertaken. Sometimes subsurface sediment samples were momentarily exposed to the atmosphere but these were immediately flushed with nitrogen gas. Sediment layers were transferred from the cores into polyethylene bags (which were then heat-sealed) while inside a nitrogen glove bag. The bagged samples were then dropped in a jar of mineral oil. The oil served not only to minimize oxygen diffusion but also as a medium for heat transfer during calorimetry. Even with all these precautions, the samples still showed clear evidence of oxidation

and change in external appearance, indicating growth of aerobic microorganisms such as iron bacteria on the sediment in contact with the walls of the polyethylene bags. The measurements, therefore, are strongly suspected to be anything but representative of naturally occurring rates of anaerobic metabolism.

These measurements were discontinued.

Reduced Substances

Average values and their standard deviations from all stations sampled from October to June are presented in Tables 33 and 34. The concentration of reduced substances over the year ranged from 0.02 to 0.68 milli-equivalents per g of dry sediment. These values are equivalent to 0.09 to 3.0 ml oxygen per g dry sediment. The overall average value for all determinations of samples from all stations throughout the year is 0.35 meq per g, or 1.5 ml O_2 /g dry sediment.

Vertical profile

Commonly, but not invariably, the topmost 1 - cm layer contained the lowest concentration of reduced substances. Some sediment cores showed a significant trend of increasing concentration with layer depth, e.g. B3 and B5 in October 1977, others showed a fairly uniform vertical distribution, e.g. B2 and B3 in April, while others showed a bit more variability from layer to layer without any significant trend with depth. At least part of this variability is reflected by the appearance and composition of some layers. It was not unusual to find layers of sand, gravel, and bivalve shells in a core that was otherwise of soft mud.

Horizontal distribution

There are significant differences in average concentrations of reduced substances between cores from various stations, e.g. between B1 and B3, B1 and B5, B1 and B7 in October. Likewise, B8 differed significantly from B2, B3 and B5 in January. On the other hand, all four stations had about the same average concentrations in April. The following June, B2 and B5 turned out to have significantly different average concentrations.

In general, the differences between stations are not consistent. It appears that the concentration of reduced substances in Mobile Bay sediments is highly dynamic. An

alternative explanation is that the distribution is patchy even within the sampling area of each station. This sampling area for each station is estimated to be a radius of about 100 m.

Seasonal changes

There was no significant change in concentration of reduced substances from October to January in any of the stations. All four stations showed a significant increase in concentrations from January to April, followed by significant decreases in June at B2 and B5, the only two stations samples in June.

In view of what was stated in the previous section, it is possible that the apparent significant seasonal changes are the result of horizontal patchiness. However, the increase in concentration in April could have really been due to increased metabolic activity of anaerobes in spring, while the decrease in June could have been the result of sediment resuspension during a previous week of bad weather and consequent oxidation of reduced substances. This would also explain why the concentrations in June at B2 and B5 were significantly lower than the previous January or October.

Adenosine Triphosphate

Known amounts of ATP mixed with sediment extracts gave values, on the average, that were only 37% (95% confidence limits of 36.5 to 38.6%) of their values in standardization curves prepared with ATP in distilled water. In other words, interfering compounds in sediment extracts decreased light scintillation levels by 63% on the average. It may be reasonably assumed that extracted natural ATP from the sediment was also determined by the assay with the same degree of efficiency. Hence, all measured amounts were multiplied by a factor of 2.7 to correct for the average 63% loss. This correction does not include other possible losses due to absorption of ATP to clay mineral and other unknown causes during extraction.

Horizontal distribution

The surface 1 -cm layer of two cores from station B2 in October had average ATP values of 0.52 and 0.27 ug/g dry sediment (Table 35). There is a highly significant difference between these two mean values ($t = 19.5$ with 4 d.f.). Furthermore, this difference between two cores from the same station is about the same magnitude as the differences between stations

in October and January was 0.37 ug/g dry sediment.

There are significant differences between cores from the four stations in April and between the two stations in June; B2 and B3 had about 10 times the concentration of B5 and B8 in the surface layers; there are only small if any differences between the deeper layers than 4 cm below the surface.

Vertical profile

This was done only beginning April and the results clearly show decreasing concentrations of ATP from the near-surface layers becoming undetectable with depth. Keeping the problem of sediment mixing in June in mind, those cores still showed an indication of decreasing ATP concentrations with depth.

Seasonal changes

There are significant differences between months, e.g. for B5 between October and January, between January and April, and between April and June. The mean concentrations decreased from October to January, increased from January to April, then decreased in June to even lower levels than in the previous January. The difference between October and January for B5 is the same magnitude as the difference between B1 and B5 in October, i.e. the apparent seasonal changes are of the same order as horizontal differences. These apparent seasonal changes could have merely been the result of spatial heterogeneity or the response of microbial populations to short-term disturbances.

The most striking change with time is the order of magnitude increase in the top layers of B2 and B3 in April while the deeper layers below 4 cm remained the same.

Discussion

The rates of total oxygen uptake, averaging for all stations during the three seasons, at 20° C, 23.9 ml O₂ m⁻² h⁻¹ (n = 54, s.d. = 5.8) are surprisingly low for such shallow-water organically rich bottom. This average rate is not significantly higher than a year-round average rate of 21.1 ml m⁻² h⁻¹ at a 7-11 m depth station in Puget Sound, Washington (year-round temperature range of 7.7 to 15.6° C, sediment 90% mud, 10% sand, 2.6% organic matter) reported by Pamatmat (1971). It is definitely lower than a 7 m deep station off Sapelo Island, Georgia on the SE continental shelf studied by Smith (1971) who measured

values ranging from $56.7 \text{ ml O}_2 \text{ m}^{-2} \text{ h}^{-1}$ in January at 6° C to $101 \text{ ml O}_2 \text{ m}^{-2} \text{ h}^{-1}$ at 28° C in July. The rates in Mobile Bay tend to be lower than much deeper stations up to 100 km offshore on the continental shelf off Georgia and Florida where the average rate in June 1977 is $26 \text{ ml O}_2 \text{ m}^{-2} \text{ h}^{-1}$ (Pamatmat, unpublished).

The average rate of $10.9 \text{ ml O}_2 \text{ m}^{-2} \text{ h}^{-1}$ for chemical oxygen uptake is about the same as the Puget Sound shallow station (Pamatmat, 1971) but definitely higher than measurements on the continental shelf off Georgia and Florida. Smith (1971) reported values of 2.8 to $8.5 \text{ ml m}^{-2} \text{ h}^{-1}$ while the average value for 12 stations farther offshore was $6.0 \text{ ml m}^{-2} \text{ h}^{-1}$ (unpublished).

The low rates of oxygen uptake agrees with the low abundance of polychaetes reported by Vittor and the low catch per unit effort of the bottom trawl reported by Hopkins. The concentration at ATP tends to be lower than values reported by Bancroft et al. (1976) for the Gulf of Mexico and the Georgia estuary, although in one instance the values found for station B2 in April were very high. If measurements of oxygen uptake in summer had been made, they would have been found to be even lower at the prevailing levels of oxygen tension in bottom waters than the rates in other seasons at higher oxygen tensions, in spite of the higher water temperatures in summer.

Since benthic oxygen uptake is greatly affected by the sedimentation of fresh organic matter to the bottom (Pamatmat, 1971, 1973; Hargrave, 1973), it is probable that the low level of benthic community metabolism in Mobile Bay is due to low primary productivity of phytoplankton. High turbidity of the water column may be effectively depressing annual primary production and thus limiting the supply of readily oxidizable organic matter to the bottom.

The low benthic community metabolism also indicates that the store of organic matter in the sediments, though surprisingly large, is of relatively little use to the benthos. It is also possible that there are toxic substances in the sediment that inhibit the full development of the benthic community.

Implications Regarding Further Studies in Mobile Bay

The results on oxygen uptake, reduced substances, and ATP all indicate that the bottom of Mobile Bay is highly dynamic, probably because of its shallow depth, making the sediment

very easily scoured and resuspended and subject to short-term changes. As a result of short-term disturbances, infrequent sampling and widely spaced samples show significant differences which are not convincingly real seasonal changes. There is a real problem of patchiness, to be sure, with coarse sediment here and there buried or even exposed in soft mud.

The results on hand suggest that Mobile Bay should not be studied or samples on regular intervals only, but that sampling should be decided on the basis of observed events. For example, it would be interesting to sample one station every day for one week when the weather is uniformly good, then once a week for 1 month, or less frequently if the weather remains the same. However, if the weather becomes stormy it would be desirable to immediately take samples again as soon as it is feasible after the storm has abated. Then the once-a-day sampling for another week should be resumed to see how the measured rates and sediment properties return to original levels with time. Until this study has been done, it seems that samples should be taken after at least a week of stable weather conditions every season in order to avoid complications by transient events.

The rates of oxygen uptake were measured only at 20° C although the bottom water of Mobile Bay ranges in actual temperature from 6.0° C in winter to 30.5° C in summer (Table B-9). Furthermore, in January and April, oxygen uptake rates were measured only at near oxygen saturation although the bottom water ranges in dissolved oxygen concentration from 13.2 ppm in winter to 1.1 ppm in summer ($= 9.2 \text{ ml liter}^{-1}$ to $0.8 \text{ ml liter}^{-1}$).

At 20° C and near oxygen saturation the rates of oxygen uptake may be conservatively stated to remain about the same throughout the year. With our general knowledge of a positive temperature effect on sediment oxygen uptake, it is fair to expect that the rates will be lower in winter and correspondingly higher in summer, i.e. that there will tend to be a seasonal cycle coincident with the temperature cycle. However, there will be a simultaneous effect of dissolved oxygen concentration which will tend to counteract the seasonal effect of temperature. The net combined effect of temperature and dissolved oxygen cycle remains to be seen.

The results also suggest that the planned dredging and deposition will undoubtedly cause drastic changes in benthic microbial and metabolic distribution. However, the return to

initial conditions would appear to be quite rapid and certain. Even if the planned island shoal deposit should alter circulation patterns and, thereby, change salinity distribution the degree of changes that could take place will probably have no material effect on benthic oxygen uptake as the sediment community appears to be adapted to rapid and fairly large salinity changes.

The ratio of respiration to chemical oxidation, averaging about 1.2, indicates that aerobes are slightly more influential on the oxygen budget of Mobile Bay's bottom water than the anaerobes, which exert their influence indirectly through subsequent chemical oxidation of their reduced end-products. It should be noted, however, that this ratio applies only to undisturbed sediment surface. In fact, Mobile Bay's sediment appears to be easily scoured and resuspended. During storm events, oxygen uptake by chemical oxidation will surely far exceed oxygen uptake by aerobic respiration. The estimation of the natural relative importance of respiration and chemical oxidation in Mobile Bay, taking all physical disturbances into consideration, will require many more measurements and a different approach than was called for by the Corps of Engineers.

Problems Encountered

Measurement of Anaerobic Heat Production

The measurements obtained evidently represented heat production under the conditions in which the sediment samples were handled and contained inside the calorimeter. They would be difficult to correct in order to derive in situ rates of anaerobic heat production. There was evidence of oxygen diffusion, chemical oxidation, and, therefore, heat production from unknown oxidation reactions. Suitable containers that are both impermeable to oxygen and with satisfactory coefficient of thermal conductivity have to be specially fabricated for calorimetric work.

A common method for differentiating live metabolic activity from non-metabolic reactions is to stop the former with a suitable poison and determine the difference (e.g. in rates of oxygen uptake) before and after poisoning. This approach turns out to be impossible when measuring sediment heat production because any reactive poisonous substance will cause significant side reactions of long duration so that heat production after becomes higher than before the addition of poison. There is as present no known proven technique for killing all sediment organisms without affecting all other on-going chemical reactions that are not mediated by respiratory enzymes.

ATP Determination

As more work is done on the determination of ATP in sediments, it has become clear that the techniques that have been developed for plankton and isolated organisms are not satisfactory for use in sediments. The problem is two-fold: 1) uncertainty of variously determined extraction efficiency, and 2) interference in the luciferin-luciferase reaction by extracted colored compounds from sediments such as humic and fulvic acids. The effect of interference is easily determined by adding known amounts of ATP to a known volume of sediment extract and comparing luminescence in this with that produced by the same amount of ATP in distilled water. The determination of extraction efficiency is considerably more uncertain. Until this question is settled, it appears that values reported here and in the literature are all of doubtful accuracy.

Oxygen Uptake

The only feasible sampling procedure was to take sediment cores from a small boat at the time when other samples were being collected. This meant holding the samples for as long as 6 to 8 hr before their oxygen uptake could be measured. Once the samples were back in the laboratory, they were held in a water bath at 20° C. During the long standing without stirring the dissolved oxygen content of the overlying water decreased. The resulting oxygen concentration differed among the cores and this constituted another variable. Consequently, after the October sampling, all cores were carefully oxygenated with air through a gas dispersion tube prior to sealing with an oxygen electrode.

The last time when field samples could be taken was during a weekend in June. A squall hit the small boat and made it impossible to obtain undisturbed cores. Cores were taken from B2 and B5 nevertheless, but the water overlying the sediment was so well mixed that it looked like mud slurry. We went ahead and analyzed some cores for ATP and reduced substances and these values reflect the effect of mixing. We decided that it was pointless to measure oxygen uptake of these cores.

Determination of Reduced Substances

If residual or excess dichromate is not determined right away, on letting the centrifuged sediment with the overlying dichromate solution stand for more than 1 hr a greenish layer

begins to develop at the sediment-solution interface and gradually thickens with time. When this solution is later titrated with thiosulfate there is some variability in the amperometric determination of the endpoint. It is possible that the green solution consists of chromous ions which, being stronger reducing agent than hydrogen and platinum, causes instability in the platinum redox electrode (Orion Research Incorporated, personal communication). If titration is carried out immediately after centrifugation and any green colored layer that might have formed is avoided, no problems are encountered with the described technique.

V-B. Sediment Quality, Summer, 1978 - (P.I. Dr. Joe Murphy)

Methods

ATP analyses were performed by (a) suitable extraction of core sub-samples, and (b) assay of light emission using the luciferin-ATP luciferase catalyzed reaction. For the core extraction, we prefer refluxing core samples with boiling Tris buffer (0.05M Tris, pH 7.74) rather than Pamatmat's method of sodium carbonate extraction. The latter method yields much darker extracts which (a) must be neutralized before assay since luciferase is inactive at alkaline pH and (b) after neutralization contain substantial levels of inorganic salts which strongly inhibit the catalytic activity of luciferase. The refluxing Tris buffer method circumvents these problems and is, in fact, the standard method for extracting ATP from microorganism cells.

Our original method for measuring the light emission from the luciferin-luciferase-ATP reaction by fluorescence was frustrated by the low sensitivity of the photomultiplier of our instrument, leading to a minimum detection limit of 0.1 microgram ATP. Subsequently, we have used a scintillation counter and an ATP photometer, which with the enzyme preparation we have been using (Sigma dried lantern extract) allows us to determine down to 0.01 nanogram ATP, measured using standard solutions.

For determination of total reduced substances, Pamatmat's method calls for treatment of the sediment sample with 0.01N potassium dichromate | 10N H_2SO_4 for several minutes, centrifuging, and titrating the residual dichromate with standard thiosulfate solution, using sodium diphenylaminesulfonate indicators. We obtained irreproducible end points when different aliquots of the same centrifuged solution are titrated, mainly due to irreversible oxidation of the indicator in the strong acid solution, and to the difficulty in visually observing the last trace of a purple coloration in a deep green solution. To obtain reproducible end points, we have adopted the following method. After suspending approximately 1 ml of sediment in 10 ml of 0.03N potassium dichromate | 10N H_2SO_4 for 30 minutes, aliquots of the centrifuged solution are diluted 10-fold with water, and the residual dichromate stoichiometrically reduced with excess potassium iodide. The iodine released in this reaction is then titrated with standard sodium thiosulfate (0.10N) to a starch end point. The sediment pellet obtained by the centrifugation is washed several times with water, dried at 95° C, and weighed.

The ATP and total reduced substances analyses were performed

at 0-1 cm and 9-10 cm depth on each core, except where some cores were expended entirely in determination of ATP. After removal of the 0-1 cm and 9-10 cm slices, the core residues were subjected to total organic carbon analyses (performed by Geological Survey, using combustion infrared methods and sucrose standards).

Results

Visual inspection of each frozen core revealed no obvious black zone at the surface. The surface was also slanted and had ice channels running most of the depth of the core, suggesting that the cores had spent considerable time in a thawed and non-vertical state prior to receipt in our laboratories.

None of the 16 core samples analyzed contained ATP, either at the surface or at 10 cm, irrespective of the method of extraction. When each core sample was spiked with a known quantity (0.1-1000 ng) of authentic ATP, however, this level of ATP was readily and quantitatively detected by the liquid scintillation counter or the ATP photometer. Thus, there are no apparent problems with our methods and our observation of no ATP (< 0.1 ng/g, our detection limit) in these cores seems to be valid.

The results of our total reduced substances analyses are presented in Table 36. Each number is the average (\pm standard deviation) of three titrations of aliquots of the centrifuged dichromate solutions (see Methods). These results are discussed further below.

The total organic carbon analyses are listed in Table 37. There is no obvious correlation of TOC with total reduced substances.

Discussion

The most surprising result we have noted is the low level of ATP in our core samples (< 0.1 ng/g). Our ATP levels are at least 10,000-fold lower than those noted by Pamatmat in earlier months. Since it seems unlikely that the sediment at all four stations should be devoid of microorganisms, we suspect that ATP originally present was destroyed by spontaneous hydrolysis before the cores were thoroughly frozen (see comments on visual inspection of the frozen cores).

Our total reduced substances results indicate considerable variation between different cores taken from the same station.

Even more striking variations can be seen in the numbers for different sub-samples of the same core. This marked variance generates the large standard deviations in the average values for each station. These average values are the same order of magnitude as those previously reported by Pamatmat, who found for April that the surface reduced substances level is higher than that at 10 cm depth. Although our average values seem to corroborate this conclusion, our large standard errors prevent us from making any definitive statements. A comparison of Pamatmat's April results with ours does indicate, however, that the reduced substances concentration at station B-8 has decreased 4-6 fold between April and August, although the concentration at other stations has not appreciably changed.

The total organic carbon analyses also show large variations between cores taken from the same stations. The southernmost stations, B-2 and B-8, yielded results (Table 37) significantly higher ($F(3,3) = 12.84$ and 18.98 respectively) than stations B-3 and B-5 which are in the immediate vicinity of the proposed island. B-5 is also the station consistently less silty than the others (sections IV and VIII, this report).

VI. Submerged Grasses - (P.I. Dr. J. P. Stout)

1. Methods

Several techniques were employed to determine the location, coverage and species composition of any submersed grass beds in the project study area.

a. Aerial Reconnaissance - Low altitude reconnaissance of the nearshore area was accomplished in June, 1978 by flying overlapping flight lines parallel to the shore in a two-engine airplane. Observers on each side of the plane were given an opportunity to survey the same track on alternating passes. Altitude was maintained at approximately 1,000 feet.

b. Trawl Stations - During the quarterly trawl sampling, all macrophytes were separated from trawl contents, preserved and identified in order to verify the existence of any grasses at the deeper stations.

c. Nearshore Survey - Nearshore and shallower areas north and south of the proposed canal location were surveyed on two occasions. 1) In October, 1977 these areas were covered by wading the entire shore area and subsequently searching the shallow areas (0.5 m) in a skiff. 2) Nearshore areas from the current barge canal north to the navigation light and south to a dredged residential canal at South Deer River (see map) were surveyed in late May by snorkling. Transects perpendicular to the shore and out to approximately 1.5 meters deep were surveyed at 30 meter intervals.

2. Results

Trawl samples yielded fragments and partially decayed mats of two freshwater species Elodea sp. and Ceratophyllum demersum. These were especially obvious in October and April. Both species are abundant in the Mobile Bay Delta system and adjacent to the Mobile Bay Causeway, but do not survive in areas in which salinities greater than zero occur. (Haller et al. 1974). Fragments recovered in the study area do not represent existing grassbeds at the trawl stations, but rather are detritus washed down from beds in the northern arch of the Bay and the Delta.

No living submersed grassbeds were located by the trawling exercise. Poor water clarity prohibited observers from surveying portions of the study area deeper than 2 meters from the air. Nearshore areas, shallower than 2 meters, were lacking in grassbeds large enough to be observed (2-3 meters on a side) except for a single small bed observed just south of the existing canal.

The survey of the nearshore area by foot and skiff revealed no existing beds in October, 1977. It was felt that this may be in part due to seasonality of the species occurring in Mobile Bay, but later surveys after spring regrowth confirmed the near absence of grassbeds. A single bed (as observed from the air) approximately 2 meters in diameter was located by snorkling in 0.5 m of water just south of the existing canal. The bed consisted of a monospecific stand of Wild Celery (Valisneria americana) with leaves averaging 6 cm in height and a density of approximately 80 plants per one-tenth of a square meter. Due to the small size of the bed no destructive sampling was performed for productivity measurement or faunal associates. Numerous individuals of Rangia cuneata, approximately 8 cm were found amongst the grass stems, but were also abundant in non-vegetated adjacent bottoms.

3. Discussion

Results indicated that there is no significant occurrence of submersed grasses in the project area. Trawling transects may have failed to detect beds in the waters deeper than 2 meters which could not be detected by aerial observation. This is doubtful, due to the apparent reduced light penetration.

Though snorkling transects may have missed smaller beds in the shallower waters, no additional beds were identified from the fly-over.

Discussions with local residents and area fisherman yielded many comments about "extensive" nearshore grassbeds in the past, and marked reduction and disappearance over the last ten years. Severe erosion of the shoreline and gradual eroding away of a spoil island located south of the canal mouth may have contributed significantly to the loss of grassbeds by burial and increased turbidity.

The single small bed of Wild Celery located during the study will not survive project activities because of its location.

VII. Marshland - (P.I. Dr. J. P. Stout)

The Deer River Complex (North, South and Middle Forks) encompass approximately 87 hectares (215 acres) of low salinity brackish marshes. The most extensive marsh development is along the bayshore from the Hollinger's Island Channel south to the South Fork of Deer River. Small packets and fringes of marsh border the existing barge canal.

Juncus roemerianus (Black Needlerush) is the dominant plant over all of the marsh. Distichlis spicata (Saltgrass) and Spartina cynosuroides (Rough Cordgrass) are also abundant in the area, but little S. alterniflora (Smooth Cordgrass) is found (see Figure 1). A number of freshwater marsh species have limited distribution within the marshes, primarily in the inland sections of the river. The most common of these species are Sagittaria falcata (Duck Potato) and Cladium jamaicense (Sawgrass).

The river/marsh system has been altered by repeated channeling, dredging and spoil deposition. Spoil ridges along channel and river banks support stands of Phragmites communis (Roseau Cane). The impact of these perturbations cannot be determined because no information is available on prior conditions.

The planned construction route and right-of-way of the Inland Barge Canal involves approximately 20 hectares (50 acres) of marshland, most of it located along the existing canal and already in a stressed, altered condition (Figure 1). Sagittaria falcata and Cladium jamaicense dominate these areas, though Juncus roemerianus dominates the marshes at the mouth of the canal. Construction activities will not involve the majority of the marsh system. The effect of possible changes in flow through the marsh from the barge canal is not known.

VIII. Benthic Polychaetes - (P.I. Barry A. Vittor)

INTRODUCTION

Impacts of dredging on estuarine ecosystems have been defined by changes in benthic macro-infaunal communities (Lackey, et al., 1973; Markey, 1975; Taylor and Saloman, 1968; Vittor, 1974a; and others). Some studies have been directed at such problems encountered in Mobile Bay, Alabama and Mississippi Sound (Mississippi-Alabama), notably Lackey, et al., (1973); Markey, (1975); Taylor (1972), and Vittor (1974a).

The program described hereunder was initiated to correct the continuing deficiency of background data. The magnitude of the Theodore Ship Channel project (over 2,000 acres of Mobile Bay bottom is to be covered by one disposal island) precludes superficial treatment of its environmental impacts on the estuary.

Barry A. Vittor & Associates, Inc.'s involvement in this study has been the measurement of the abundance and diversity of the benthic Polychaeta. This report describes the results of sampling and analysis of several sites in the project area during the period November, 1977 through October, 1978. Sampling was scheduled to accomplish two primary tasks: (1) to characterize seasonal patterns of polychaete abundance and diversity; and (2) to determine short-term (monthly) variability in polychaete abundance and diversity. A third task involved correlation of polychaete data with sediment chemical/physical parameters.

MATERIALS AND METHODS

STATIONS SAMPLED

Eight stations were designated for benthic sampling. (See figure 1). Except for the Fall, 1977 sample period, all eight stations were sampled quarterly. (Seven stations were sampled in November, 1977). Three of the eight stations were designated for monthly sampling after the first survey was completed. These sites (B-1, B-5, and B-7) were chosen on the basis of (a) high abundance/diversity and (b) location.

SAMPLING AND SORTING PROCEDURES

Four replicate samples were taken with a 0.1 m² Petersen grab sampler, each time a station was sampled. All sample material (generally, fine sand and silt and macro-infauna) was placed in labelled cotton bags and transferred to the laboratory of Barry A. Vittor & Associates, Inc. In the laboratory, each sample bag was immediately immersed in buffered 10% formalin solution.

Sample bags were removed and their contents rinsed in fresh water, stained with 1% Rose bengal solution for 15 minutes, and then sieved through a 0.5 mm mesh brass screen. All debris, sediment,

and organisms remaining on the screen were placed in white enamel trays for examination under magnifying illuminators.

All macro-infauna (i.e., organisms which are retained by a 0.5 mm mesh sieve) were picked from the sample material and placed in 70% ethanol solution. These animals were then viewed under a dissecting microscope (less than 75X magnification) and identified to Phylum level. Non-polychaetes from each replicate were placed in a separate vial and transferred to Dr. T. S. Hopkins at the Dauphin Island Sea Lab.

IDENTIFICATION

Polychaetes were identified to the species level in most cases; exceptions included fragments, damaged specimens, and those forms which appeared to be distinctly different from known species. The number of each species was recorded for each benthic sample taken. A voucher collection of specimens was developed for future reference, and has been maintained at Barry A. Vittor & Associates, Inc. All other polychaete material has also been archived, but only in whole-sample screw-cap vials in 70% ethanol.

RESULTS

Polychaetes comprised the majority (11,348 of 14,292 excluding station B-8, or 79%) of macro-infauna for all samples processed. A total of 38 species were identified among approximately 11,840 individuals. Identification was accomplished using a great variety of taxonomic literature, little of which pertained specifically to northern Gulf estuarine fauna. Most identifications have been verified through comparison with specimens at the U.S. National Museum (Smithsonian Institution). Appendix C-11 presents a listing of species found. Tables 39 to 46 contains summarized data for all sample periods.

Species richness is defined as the total number of species per station during each sample period. Species diversity is estimated as the Shannon-Wiener index H' , after Pielou (1969):

$$H' = \sum P_i (\log P_i),$$

where P_i is the proportion of individuals in the sample represented by species i . Log base 10 was used in order to facilitate comparisons with other Mobile Bay benthic macro-infauna data. Species evenness was estimated as J' (Pielou, 1969), according to the following formula:

$$J' = \frac{H'}{H'_{\max}}$$

where H'_{\max} is defined as the log of the number of species in the sample.

GENERAL ABUNDANCE AND DIVERSITY PATTERNS

Table 39 summarizes polychaete abundance, species number, average species diversity, and average species evenness for each of the eight stations surveyed during the baseline program. The most striking patterns among these data are low average Shannon-Wiener species diversity (H'), the generally small number of species, and population densities which varied greatly from site to site and between sample periods. Table 40 summarizes statistical treatment of these data, and shows that average polychaete abundance differed significantly ($p < 0.05$) between locations and seasonal sampling periods. Average species diversity did not differ significantly ($p > 0.10$) between stations, but did differ ($p < 0.01$) with respect to season.

The greatest abundance observed (469 worms per 0.1 m^2) occurred at station B-7 during March, 1978. Species diversity remained high, however, because the number of species (13) was also high. Most of the polychaetes enumerated were among the following species: Mediomastus californiensis, Steblospio benedicti, Neanthes succinea, Parandalia (Loandalia) americana, Polydora spp., and Paraprionospio pinnata. Unusually high abundances of the first two species accounted for most of the densities in excess of 100 polychaetes per 0.1 m^2 . Both are very small (less than 10 mm in average length) and typically opportunistic. Except for N. succinea, all the dominant species reported are indicative of brackish water systems rich in organic matter and marked by periodic oxygen depletion.

Summer high temperatures, reduced river discharge, and probable low dissolved oxygen appeared to have a severe impact on the benthos throughout the study area. Except for occasional high values observed at station B-5 (July and September), polychaete abundance and diversity were extremely low for June through September. Station B-1 contained virtually no polychaetes in August, September, and October.

SEASONAL PATTERNS

Seasonal variation in polychaete populations is also illustrated in Table 41. However, the issue is clouded by what appears to be highest abundance during Summer, 1978. This figure (66 per 0.1 m^2) includes one excessively high value of 336 per 0.1 m^2 . When this number is excluded from our calculation an average of only 27/ 0.1 m^2 is obtained. Since all other parameters (species number, species diversity, and species evenness) were lowest during Summer, 1978, this figure is probably a better estimate of population densities in general. Fall, 1978 polychaete community measures were also very low. The community was dominated especially by Mediomastus californiensis, an opportunistic capitellid which appears to be tolerant of oxygen-poor conditions (Table 43). This relationship is not supported by dissolved oxygen data reported by Schroeder (this report), since bottom depths were more than 50% saturated during the September and

MONTHLY VARIATION

A similar seasonal change is reflected by Table 42, which summarizes monthly averages for polychaete population analysis. However, this table is particularly illustrative of the large variation in these statistics from one month to the next. Stations B-1, B-5, and B-7 were selected after the November, 1977 samples were processed because each site appeared to support an abundant and varied polychaete community. Subsequent sampling did not provide similar results. Rather, there were large changes in abundance at each site from month to month. This was especially evident during March, when an average abundance of 227 worms per 0.1 m² was estimated. Station B-7 had an average of 469 per 0.1 m² and accounted for most of the month's increase. A similar effect was noted during July and September as a result of high polychaete abundance at station B-5.

Figure 2 depicts the monthly changes in abundance and species diversity at the three monthly monitoring sites (B-1, B-5, B-7). In general, there appears to be no correlation between abundance and H'. The three stations did differ with respect to both parameters; however, station B-1 exhibited generally low abundance and H'. Station B-5 displayed somewhat higher and great variability in average abundance and diversity. Station B-7 supported a more diverse but less abundant polychaete fauna.

Table 43 summarizes the relative abundance of the capitellid Mediomastus californiensis. This species, like most other capitellids, appears to have an affinity for fine silt-clay bottoms. It is also abundant year-round, and does not exhibit major fluctuations in density due to periodic spawning/recruitment. M. californiensis comprised over 75% of all polychaetes present in 22 of 54 sample sets, and over 50% in 41 of 54 sample sets. It was most prevalent at station B-1, B-2, B-3, B-4, B-6, and B-8. Station B-5 exhibited great variability in the percent abundance of M. californiensis (2 to 88%). This station was characterized by shell hash during several sample periods and by fine silt during others (see Hooks, Table 26). Station B-7 represented an intermediate degree of dominance by this species. These data are surprising because Hooks reported that mean particle size decreased significantly during the seasonal sampling program. Spearman rank correlation analysis of the percent abundance of M. californiensis versus mean particle size showed no significant relationship ($p > 0.10$), and consequently the influence of shell hash is apparently not seen.

POLYCHAETE-SEDIMENT RELATIONSHIPS

Sediment texture (mean particle size and sorting) varied seasonally, but did not differ with respect to location (Table 44). This analysis does not compare station B-5 with other sites because shell hash was present in April and July, 1978 (see Hooks, Table 26).

Station B-5 generally supported a richer infauna than any other site (see section IX in this report).

Exclusion of sediment texture data for station B-5 also affects the interpretation of this analysis of the regression of abundance and diversity on sediment mean particle size and sorting coefficient. There was a significant correlation only between species diversity for the January, April, and July seasons combined and mean particle size ($b = 0.14; p > 0.05$). Figures 3 and 4 illustrate regressions of abundance and diversity on mean particle size. (It should be noted that in order to facilitate diagrammatic representation of the regressions, parametric regression analysis was used even though the data were enumerative.)

SHELL DREDGE EFFECTS

Shell dredging in the Theodore Ship Channel study area was examined as a possible factor in the variability of polychaete community data. Table 45 summarizes sediment composition before and after shell dredging (June 16-25, 1978) occurred near station B-1. Station B-7 lies east of the Mobile Ship Channel and was assumed to have been unaffected by shell dredging. It is apparent that the proportions of sand, silt, and clay varied seasonally at both sites while mean particle size increased from January to July. Temporal variations also occurred in polychaete abundance and species richness at these stations (Figure 5). There was no relationship between these parameters and sediment texture, although abundance increased at B-7 during Fall, 1978 but remained low at B-1. The only other station likely to have been affected by shell-dredging (B-8) was not sampled after the dredge operated in the area (January 3-18, 1979).

HYDROGRAPHIC EFFECTS

Bottom water characteristics averaged for all stations during benthic sampling are given in Table 46. Although these data do not describe short-term variation in hydrography of the area, they do give a gross illustration of seasonal trends. As shown in Figure 5 for stations B-1 and B-7, seasonal trends also occurred in polychaete abundance and species richness. There appears to be a decrease in species richness with higher salinity and temperatures and low dissolved oxygen. This was especially pronounced in July and August sample periods. Continued high salinity and temperature in October, 1978 appears to maintain a community which is very depauperate in comparison with that present during November, 1977 (refer to Tables 40 and 41 for data summaries). Periodic heavy recruitment of species such as Mediomastus californiensis, Streblospio benedicti, and Polydora ligni cannot be correlated with available hydrographic data nearest to the study area (see Schroeder, Figures B-3a and B-3b for Dog River).

SAMPLING ADEQUACY

The representativeness of the benthic sampling effort was not tested rigorously prior to beginning the study program. Earlier studies by Dr. Vittor have indicated that from three to five replicate grab samples are adequate to characterize the infauna in Mobile Bay and Mississippi Sound. As shown in Figure 23, at least 80% of the total number of polychaete species present was obtained with just two 0.1 m² samples at station B-1 and with three samples at B-2 and B-7. From these results, it was concluded that the benthic program would provide representative data regarding composition and abundance of the macro-infaunal community.

DISCUSSION

Although polychaete community structure varied greatly from month to month during the baseline study, some inferences can be made regarding polychaetes and habitat characteristics. Other records of benthic macro-infaunal analysis for Mobile Bay and vicinity occur in Vittor (1974a); D'Olive Bay, Vittor (1974b; lower Mobile Bay), and Vittor (1977; review of data near the mouth of Mobile Bay). Vittor (1974a) reported a total of 19 benthic species including non-polychaetes in D'Olive Bay, a shallow ecosystem subject to extreme fluctuations in temperature, dissolved oxygen, and salinity. Species diversity (H') averaged 0.29 in D'Olive Bay, while an average H' of 0.38 was estimated for polychaetes alone in the present study. Considerably higher abundance and diversity values characterize benthic habitats nearer the mouth of Mobile Bay; however, the total number of polychaete species is not much greater than that encountered during this study (Vittor, 1977).

Benthic habitats south of Dauphin Island support a still richer benthic infauna. Near the Wallace artificial fishing reef, for example, over 1100 animals per 0.56 m² were found during sampling in 1976; 64% of which were polychaetes (Vittor, 1977). Of 124 species identified, 79% (98) were polychaetes. H' was estimated at 1.57 at that site. Similar high abundance and diversity of polychaetes was reported by Vittor (1977) for the MAFLA area south of Dauphin Island. Over 70 species were found at some stations, while H' values ranged from 1.02 to 1.57. Evenness (J') in those communities was very high, indicating that the communities were not dominated by a few species, as is the case near the proposed Theodore Ship Channel (average J' values ranged from 0.41 to 0.81). Vittor (1974b) reported H' values ranging from 0.28 to 1.08 during a one-time survey of several points in lower Mobile Bay. Lowest diversities occurred in Dauphin Island Bay (average $H' = 0.34$), while highest abundance and diversities were observed east of the Mobile Ship Channel. Species diversity values for the present study were not similar to those reported for protected areas of the Mobile Bay estuary. Polychaete abundance and species richness, on the other hand, were generally higher during this study than reported for D'Olive Bay and Dauphin Island Bay (Vittor, 1974a; 1974b). The Theodore Ship Channel study area supports a depauperate polychaete fauna in comparison with lower Mobile Bay and northern Gulf of Mexico habitats.

This study suggests that the polychaete infauna which occur near the Theodore Ship Channel site are subject to extreme fluctuations in sediment texture, salinity, temperature, and dissolved oxygen. The physically-accommodated community that inhabits the fine sediments in the Theodore study area exhibits dramatic variations in both abundance and diversity; this is largely as a result of periodic recruitment/die-off of opportunistic species such as Polydora ligni and Streblospio benedicti.

This low-diversity community is probably tolerant of perturbations such as would occur from channel dredging and island construction. Copland (1970) showed that a high diversity marine ecosystem was disrupted much more by oil pollution than was a temperate estuary subjected to pollution of a similar magnitude. Boesch (1972) reached similar conclusions in an investigation of a Virginia estuary. He stated that in perturbed areas " 'typical' benthic species were replaced by more eurytolerant species characteristic of lower salinity and lower diversity habitats." Reish (1955) cited use of certain polychaetes as indicators of benthic pollution. The capitellid Capitella capitata dominated bottoms which were characterized as highly polluted by organic waste. In this study, the capitellid Mediomastus californiensis dominated five silt-clay habitats, while the nereid Neanthes succinea was most abundant in silt-shell hash habitats.

The ability of infauna to recolonize disturbed bottoms has been described by Taylor (1972) and Dauer (1974). In both cases polychaetes were the initial colonizers, apparently, as a result of the influx of a large planktonic larval assemblage and the extensive motility (invasion) of adult polychaetes. This fact may be of particular importance in the Theodore Channel study since a considerable acreage of bay bottom will be affected by construction. It is interesting to note (Figures 3 and 4) that polychaete abundance and diversity are less limited by sediment texture (over the range measured during this study) than by periodic recruitment and die-off of opportunistic species. Monitoring of the construction site will provide additional information in regard to re-establishment of benthic organisms.

CONCLUSIONS

The Theodore Ship Channel project area exhibits considerable variability in habitat characteristics and polychaete infauna. The data available do not provide consistent correlations between environmental and polychaete parameters; however, extremes in abundance, species diversity, and richness were often related to extremes of sediment texture and hydrographic conditions. The following comments reflect these relationships:

1. Species number, diversity, and individual abundance decreased during the summer-fall months (June-October, 1978). This trend was related to high temperature and salinity and low dissolved oxygen.
2. Coarse shell hash sediments at station B-5 supported the richest polychaete infauna; this despite the influence of the Mobile Ship Channel on ambient salinities.
3. Major short-term (monthly) fluctuations in community structure appeared to be related to periodic recruitment of opportunistic species; however, some variation may have been introduced by (a) number of replicates, and (b) methodology in navigation. This program has provided good baseline data for the geographical area, and suggests that temporal variability is more significant than spatial variability in the benthos.

4. Shell dredging did not appear to have an impact on the polychaete community.

5. The project area is a high-stress benthic environment resulting in low polychaete diversity. This community is expected to suffer less ecological damage due to channel construction than habitats populated by less eurytolerant species.

IX. Macroinfauna Exclusive of Polychaetes - (P.I. T. S. Hopkins)

1. Results and Discussion

A review of summarized station data reveal that of the seven stations sampled, Station B-5 consistently shows the highest degree of biological activity in terms of (a) diversity by season and (b) diversity overall. This seasonal and annual diversity is correspondingly present in the polychaete analyses. Stations B-3 and B-4 are noteworthy because of their large seasonal populations of Tellina lineata and Rangia cuneata which are bivalve mollusks and usually regarded as important bio-indicators of community structure (Table 47, Appendix A).

Further addressing these two bivalves, we see some apparent seasonal trends. Tellina apparently reached its peak density in April - May and was then virtually replaced by Rangia in July. Both species were insignificantly present or unaccounted for during August - September and their resurgence will be interesting and worthy of close scrutiny. A similar seasonal replacement phenomena at Station B-5 only is seen with the amphipods, Corophium lacustre and Melita nitida which peak in July and September respectively (Appendix C-12).

In an esoteric vein, the specific occurrence of Pinnixa sp. in August is scientifically noteworthy in that pinnotherid crabs are usually obligated commensals of polychaetes (as inhabitants of tubes) or molluscs (as inhabitants of siphons and mantle cavities). I think we can assure they were collected along with some particular tube dwelling polychaete in August.

X. Demersal Invertebrates - (P.I. T. S. Hopkins)

1. Results and Discussion of Trawl Samples

There is no clear pattern for the invertebrates collected by trawling. Neither density, diversity, or seasonal trends are clearly in evidence. Commercial species were encountered in small numbers at all stations throughout the period. Catch per unit effort is certainly not impressive. (Table 48, Appendix A).

2. Whitehouse Oyster Reef (P.I. William Eckmayer)

Whitehouse Reef, 272.8 acres, was planted with 111,271 barrels (20,195 cubic yards) of clam shell during 1972. The mean density of clam shell on Whitehouse Reef was 213.8 per square yard. The estimated density of spat on clam shell, 123,158 per acre, was greater than that of the unplanted area, 39,112 per acre. The density of oysters on the reef was 6% of the 1969 density (May, 1971). The half-shell density was 91% of the 1969 density (Table 49). Spat set data is available from a recent independent study in the Whitehouse reef area and other sites near the proposed project (Lee, 1979).

XI. Demersal Fishes - (P.I. Dr. R. L. Shipp)

Collections from five sampling periods at the designated stations B-1 through B-7 have provided significant data on demersal fish populations. Of especial interest are year to year comparisons of the fall data. All data on demersal fishes are summarized in tabular form in Tables 50 to 57 (Appendix A). The following discussion can only be evaluated by reference to those tables.

Seasonality was the strongest single factor influencing composition of demersal fish samples. This is true in terms of abundance, age composition, and diversity of samples. Conversely, station location is of secondary importance.

Examples which illustrate are consistently low catches during cold winter sampling, when most forms have retreated from the Bay to higher salinity, warmer coastal areas. Similarly, summer collections, occurring during a period of extreme depression of dissolved oxygen levels, were also characterized by low numbers of all but the hardiest forms.

Spring collections revealed high numbers of those forms returning to the estuaries from offshore. These collections were marked by numerous yearlings. Fall collections were somewhat reduced from spring abundances, but were characterized by larger individuals.

Comparison of fall, 1977, with fall, 1978 collections was expectedly similar, and thus indicates low level of sampling and habitat variance.

Nearly all of the demersal fishes collected are typical estuarine associated, euryhaline species. However, as is well known for these forms, the juveniles are found in lower salinity areas, whereas adults are frequently associated with higher salinity zones of estuaries or may even be fully marine. Our data are not in conflict. While the biology of the collected forms is, for many species, adequately understood, occurrence, abundance, and their implications for purposes of the report for several species is discussed below.

The anchovies (Engraulidae), are of importance in the northern Gulf, primarily as forage species. Anchoa mitchilli, the most abundant and most frequently encountered species in the study, is one of the very few forms which can and typically does spend its entire life in moderate salinity estuaries. The other anchovy taken, A. hepsetus, is a form usually encountered offshore.

The herrings, Clupeidae, are represented by three forms in collections. These are forage species, and the menhaden, Brevoortia patronus, represents the staple for the animal food or "pogy" operations along the north central Gulf. Clupeids are anadromous or semi-anadromous, intolerant of low O₂ levels, and the first victims of hot summertime, low O₂ levels. Their survival under such conditions is limited.

Catfishes are represented in collections by two forms, the ubiquitous sea catfish Arius felis, which is tolerant of relatively wide physical changes, and the blue catfish, Ictalurus furcatus, a freshwater form, whose sporadic appearance is indicative of flood conditions.

The croaker family, Sciaenidae, contains numerous forms of commercial importance to both the sportfishing and commercial fishing interests (see Table 1). Their presence in significant numbers during most seasons at most stations indicated the vicinity of the sampling is important in the life history of these forms. Almost all collections were of young of the year or yearling juveniles. Adults are typically characteristic of higher salinities.

The other species collected represent a diverse assemblage of forms whose importance is primarily forage. Notable exceptions include some jacks (Curangidae) and left-eyed flounders (Bothidae).

A sampling regime of increased field collections is needed to better understand true cyclic changes, removed from temporary overriding physical perturbations such as flooding and sporadic wide fluctuations in various chemical and physical parameters.

Discussion and Conclusion

An environmental baseline study does not propose to test a hypothesis, nor does it attempt to elucidate the cause-effect relationships which are, in fact, described. It is designed to characterize a designated area in terms of specific parameters chosen by a technically proficient group of individuals. The approach utilized in this study established definite stations with a view toward a monitoring effort. A thorough sampling of the benthic community and associated sedimentary characteristics has been accomplished for the 15 month period. Periodic water column sampling provided surprisingly good descriptive data and an areal characterization related to river discharge appears to be well established.

1. Water Column

a. Hydrography - The Bay salinity regime is controlled by the balance of influences from the Gulf of Mexico and the Mobile River system. While the Gulf is relatively consistent, the variability of river discharge characteristics is high and thus the conditions existing in the Theodore area reflect the riverine influence. The temperature generally follows the seasonal trends.

b. "Turbidity"/suspended particulate - The Theodore area water clarity is clearly influenced by the major driving forces of wind and hydraulic flow characteristics. The fine nature of the bottom sediments also contributes significantly to the particulate load being rather easily resuspended.

Those occasions where surface layers were more "turbid" than bottom water may indicate river-borne contributions but density-gradient separations of bottom resuspensions is also possible.

2. Sediment Studies

a. Sedimentology - The gross characterization of the entire area is mud. Using the phi scale there were no samples reaching even the coarse silt range. Most stations are relatively unconsolidated and sampling the surface half-meter will invariably give you a physically confused sample unless cryocoring techniques are used.

b. Sediment quality - The mud type indicated by the sedimen-

tological work does not adequately describe the Bay bottom in the Theodore area, for even the casual observer. The organic load is visible and sensible in both tactile and olfactory modes. This is reflected quantitatively in the Total Organic Carbon loads and the reducing substance levels throughout the area. Station differences seem to be minimal.

3. Biota

a. Submerged grasses - The Theodore area has no grassbeds of any significance whatsoever.

b. Infauna - Most of the information is deduced from the polychaete communities, which constitute the dominant organisms of the area. The vast majority of species, including the molluscs, are opportunistic and tolerant of the physical conditions described above. They are generally considered indicative of a stressed and variable environment.

c. Epifauna - The demersal animals of the area reflect a typical estuarine community. The details are found in the appendices. This group did respond to the seasonal low temperatures by leaving the area and low catches were also associated with the low dissolved oxygen period usually encountered during the summer.

4. General Summary

As a baseline, the major characteristics usually mentioned for Mobile Bay have been quantitatively captured and described. The extreme static variability and/or dynamic nature of the bay bottom is difficult to assess and deal with. It has been suggested that the accuracy of sampling site location contributed to the high variance between stations but while this may be true, it is more likely an exception rather than the rule.

If valid, this observation would dictate that the sampling grid or design must be tighter, both in time and space, to produce a data base that would describe the area to a high degree of satisfaction. On the other hand, since there were few consistent differences between the stations for any of the parameters, it may be possible to deal with areal averages as presented in the water column sections and, for management levels decisions, ignore the "fine-tuning" of the baseline description.

A further complication is the recurring suspicion that man's ongoing activities in the area are already significantly disrupting the parameters at the level under scrutiny. These activities range from boat traffic through the area to trawling

and the shell dredge. The dredge was active throughout the area during the study period and field observations indicated a direct impact on the sedimentation and "turbidity" parameters. There is also direct and indirect impact on the biota, all of which confuse a "baseline" effort. It is felt that the alteration of bottom type by shell and channel dredging activity near station B-5 probably explains the unique nature of that one site.

However, this baseline was designed to establish the area's environmental conditions prior to initiation of the Theodore Ship Channel and we can only speculate on the historical, "true" baseline of the area. It is a well established fact that the specific area under question has been severely impacted by man for over three decades and the year's data presented above accurately and effectively reflect that situation. Whether the pending project can measurably impact the current conditions remains to be seen.

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