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ENVIRONMENTAL STUDIES,

## SOUTH TEXAS OUTER CONTINENTAL SHE F <br> BIOLOGY AND CHEMISTRY



ENVIRONMENTAL STUDIES, SOUTH TEXAS OUTER CONTINENTAL SHELF, BIOLOGY AND CHEMISTRY

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## by

The University of Texas Marine Science Institute Port Aransas Marine Laboratory

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Acting for and on behalf of a consortium program conducted by:

Rice University
Texas A\&M University
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Supplemental Reports to
Contract AA550-CT6-17
I

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## FOREWORD


#### Abstract

The reports contained herein are the result of supplemental studies to the 1976 STOCS biology and chemistry program that were authorized by Contract Modification No. 5 to Contract AA550-CT6-17 and were funded with surplus shiptime and navigational funds from that contract.

The report has been reviewed by the Bureau of Land Management and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Bureau, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.


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## CHAPTER ONE

# COMPLETION OF SHELLED MICROZOOBENTHON SAMPLES 

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#### Abstract

The South Texas Outer Continental Shelf was sampled for living benthonic foraminiferans at 12 stations during three seasons in 1975. During 1976, 29 stations were sampled during three seasons and 10 of these stations were sampled during six monthly cruises. These samples were processed and the living benthonic foraminiferans were picked, counted, identified and the data evaluated via cluster analysis and maps of density, diversity and richness.

The significant findings include: the division of benthonic foraminiferans into groups or individuals characteristic of such features as near-shore-offshore, seasonality, regions of the shelf such as the modern mud blanket, etc. Findings that may prove useful for site evaluation or monitoring include: the use of Bolivina Zowmani as an indicator of silting and bottom current movement, the use of Anmonia beccarii and other species to indicate perturbations in the water column and sediments, and the suggestion that the bank stations may represent a region very susceptible to man's activities.


## INTRODUCTION

## Purpose

The purpose of this study was to supplement taxonomic identification of shelled microzoobenthic organisms (benthonic foraminiferans) taken from primary stations (Stations 1-3, Transects I-IV) during the 1976 sampling year. The data were combined with those from the 12 primary stations and analyzed via cluster analysis. Dendrograms were prepared and evaluated. Maps of dominance, diversities and richness were plotted for the seasonal and monthly Transect II samples.

## Literature Survey and Previous Work

Most of the many studies made on the foraminifera of the Gulf of Mexico and its continental shelf have been concerned with the distribution of dead and total assemblages. There have been relatively few studies of living populations of the Northwest Gulf of Mexico. Of these the most useful are the studies of Phleger (1951, 1956). There have been no other comprehensive seasonal studies on living benthonic foraminiferans except for our current studies on the South Texas Outer Continental Shelf (STOCS). A thesis by Anepohl (1976) concerns itself mainly with the taxonomy of living benthonic foraminifera collected for the Bureau of Land Management (BLM) in the STOCS area during 1975. A thesis in progress by Camille Hueni of Rice University concerns itself with the distribution of living benthonic foraminifera on the STOCS, 1975 and 1976 and down core fossil studies.

## MATERIALS AND METHODS

## Collecting Procedures

For 1975 , bottom samples were obtained by subsampling the SmithMcIntyze grabs at Stations 1,2 and 3, all transects, during the winter, spring and summer ( 36 stations). There were 24 samples studied for the 1975 Final Report. The subsampling was accomplished by inserting a 6.5 cm diameter coring tube at least 5 cm into the sediment from the sediment surface. The sample was then preserved in 25 ml of buffered formalin solution with rose Bengal stain added.

For 1976, bottom samples were obtained by subsampling Smith-McIntyre grabs at Stations 1-6, Transects I-III and Stations 1-7, Transect IV, and two stations on Southern Bank (SB) and Hospital Rock (HR) (29 stations) during seasonal samplings and at Stations 1-6, Transect II, and two stations on SB and $H R$ ( 10 stations) during monthly samplings ( 147 total samples). Subsampling was accomplished by inserting a 3.5 cm diameter coring tube at least 5 cm into the sediment from the sediment surface. On-board processing of samples was identical to that described for the 1975 samples.

As different size cores were used for the 1975 and 1976 sampling, a comparison was made by collecting samples with both cores during the 1976 spring sampling period. Comparing the two samplers, the dominant species appear to be the same for both size subsamplers. Densities also appear to be within $10 \%$ which is comparable to the regular patchiness of these organisms.

## Post-Collecting Procedures

The samples were mixed and split with a large, modified plankton
splitter. One-half of the sample was archived and the other half washed through a $63 \mu \mathrm{~m}$ screen. The sands on the screen were dried in an oven at $70^{\circ} \mathrm{C}$. If only a small amount of material remained on the screen, the sample was ready for picking or identifying. If considerable non-organic material remained, the sample was floated as described below. A 400-ml beaker was filled with 200 ml of carbon tetrachloride, a $500 \mu \mathrm{~m}$ screen was placed over the beaker, and the dried sands were sprinkled through the screen. The floating fraction was then decanted onto a paper towel folded as a filter and supported by a glass funnel. The residue was swirled to suspend lighter material, allowed to stand for two seconds and decanted. (This process was repeated several times to process a large sample by aliquots.) The paper towel plus filtrate was oven-dried at $70^{\circ} \mathrm{C}$ as was the residue. Both portions were placed in labeled bottles.

The seasonal samples from the 12 primary stations were hand-picked under a dissecting microscope for live foraminiferans and other live, shelled microzoobenthon and placed on cardboard foraminiferan slides. The picked organisms were then identified to the lowest possible taxon and counted.

Samples from the remaining bottom stations (other than the 12 primary stations) were processed as above, except not all were hand picked. Those processed samples not hand-picked were identified and counted for dominant foraminiferans only. The data were placed on computer cards and cluster analyses performed and dendrograms prepared. The dendrograms, density plots, and other faunal maps were compared to each other and to data of other oceanographic parameters.

Eight of the processed samples from the 1976 stations proved to be suspiciously barren. In these suspicious cases the residue was investigated and any data recovered from the residue (positive or negative) was parenthetically inserted on the maps. These data were not used in the calculations of densities, diversities, richness, etc. nor were they used in the cluster analysis.

## RESULTS AND DISCUSSION

A discussion of the physical and chemical oceanography setting, seasonal circulation patterns, and results of the work-up of the 1975 and 1976 shelled microzoobenthon samples is contained in the 1975 and 1976 BLMSTOCS Final Reports [see Casey, In Parker (ed.) 1976 and In Groover (ed.) 1977].

Living Benthonic Foraminiferans 1976 and 1975 (new data)
Specifically for this report, we have produced four cluster dendrograms and map-figures. Three dendrograms have been produced by using all 29 stations for each 1976 season (Figure 1 for winter 1976, Figure 2 for spring 1976 and Figure 3 for summer-fall 1976), and one dendrogram for the six monthly sampling periods along Transect II (Figure 4). Our cluster program does not have the capacity to process a combination of all 1976 seasonal or all 1976 Transect II monthly data into dendrograms. Appendix A contains a complete printout of the 1976 benthonic foraminiferan data.

The winter 1976 seasonal dendrogram (Figure 1) can be divided into the following cluster groups: a weak inner-mid shelf southern transect group (IMSSo); an outer shelf northern transect group (OSNo); a mid-shelf


Figure 1. Benthonic Foraminiferan Collected During the Winter, 1976.

Figure 1. Key to Benthonic foraminifera winter, 1976 dendrogram.



OS $1=$ outer shelf group
INS $=$ inner and mid shelf group
OS $2=$ outer shelf group 2
IS = inner shelf group
OS $3=$ outer shelf group 3

Figure 2. Benthonic Foraminifera Collected During Spring, 1976.

Figure 2. Key to Benthonic foraminifera spring, 1976 dendrogram


FIGURE 2 CONT.'D



Figure 3. Benthonic Foraminiferan Collected During Summer-Fall, 1976.

Figure 3. Key to Benthonic foraminifera summer-fall, 1976 dendrogram




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|  | 11 | 12 |
| Figure 4. Dominant species in adjacent ( 4,5 and 6): total | ies (maps 1,2 and 3 <br> les); Density of <br> ity (7,8 and 9): Ri | ntour of dominant na lowmani $\# / 10 \mathrm{~cm}^{2}$ s $(10,11,12)$ |

(MS) strong group including arenaceous foraminifera; an outer shelf mid transect (OSMid) association; and, a loose inner and mid shelf group (IMS). The absence of a tight inner and mid shelf or distinct inner shelf (Stations 1 and 4) cluster found in the other seasons may be due to the mixing of assemblages as a result of "isothermal conditions" of the winter season. Figure 4 shows Bolivina Zowmani (a component of these tight inner and mid shelf clusters of the other seasons) as a dominant in outer shelf stations during the winter season. We interpret this to indicate that this meroplanktonic species can reach the bottom, during these winter isothermal periods, in a reasonable time, so it is still very viable.

The spring 1976 seasonal dendrogram (Figure 2) can be divided into the following cluster groups: three strong outer shelf groups (OS1, OS2, and OS3); a strong inner and mid-shelf group (IMS); and a strong inner shelf group (IS). The presence of strong well developed outer shelf clusters probably represents the incursion of offshore waters. These shared-dominance, deep-water faunas are well established at the shelf edge and move into the mid-section (Transects II and III) modern mud blanket and occasionally into the inner shelf region (Stations 1 and 4) during the spring [Casey In Parker (ed.) 1976 and Groover (ed.) 1977), The spring also exhibits the greatest number of living benthonic species. This is probably due to the addition of species from the upper slope environment as a result of the incursion of deep offshore waters. We believe this incursion is caused by the open ocean estuarine type upwelling bringing these deeper faunal components in with the "salt water wedge" bottom intrusion.

The summer-fall 1976 dendrogram (Figure 3) can be divided into: outer-mid'shelf (OMS) with northern offshore (OSNo), southern offshore
(OSSo), and mid-shelf (MS) subgroups; and, an inner shelf cluster (IS) with northern (ISNo), and mid and southern (ISMiSo) subgroups. Here the inner (essentially Stations 1 and 4), mid (essentially stations 2 and 5) and outer (essentially 3, 6 and 7) shelf regions appear to show their greatest "individuality". We believe this to be due to the relatively calm bottom conditions of the summer-fall. These calm bottom conditions are a result of the "grounding of a detached loop ring pushing into the mid-shelf stations", little runoff, a relatively weak southerly wind system, and a strong thermocline over the area.

These general groups shown in the dendrograms complement the interpretations of the seasonal data presented on Figure 4. Figure 4 illustrates the dominant benthonic foraminiferan species (maps 1,2 and 3 ), the density of BoZivina Zowmani (maps 4,5 and 6), the total density of benthonic foraminiferans (maps 7, 8 and 9), and the richness of benthonic foraminiferans (maps 10, 11 and 12).

The dominance maps were constructed by contouring the species dominant in more than one adjoining station. This method allows the visual presentation of the main seasonal dominance in the area. From these dominance maps it can be seen that $B$. Zowmani, the most abundant benthonic foraminiferan on the STOCS, exhibits a very interesting pattern showing dominance over most of the shelf in winter including the outer shelf stations, and showing greatest dominance in the area of the northern stations. In the spring (Figure 4, map 2) the dominance of B. Zowmani switches to the south, and in the sumer-fall it appears to "invade" the north via a mid-shelf route from the south. This same sequence can be seen in the 1975 sampling period (Figure 5 , maps 1,2 and 3).


Figure 5. Dominant species (maps 1,2 and 3-contour of dominant species in adjacent samples); Density of Bolivina lowmani $\# / 10 \mathrm{~cm}^{2}$ (4,5 and 6); Total density (7,8 and 9); Richness (10,11 and 12)

The density of $B$. Zowmani show somewhat the same pattern with a high density in the northern transects during winter (Figure 4, map 4), an increase in the south in spring (Figure 4, map 5) and an indication of the northern "invasion" in the summer-fall (Figure 4, map 6, the 5 contour). We believe this is due to $B$. Zowmani being meroplanktonic and moving to the outer shelf during the winter water column mixing; somewhat eutrophic or mesotrophic and establishing itself in the south during opportune times in the spring; and, being an indicator of general bottom circulation and reflecting the bottom water movement to the north along mid-shelf with the northerly directed arm of the spital of the anticyclonic gyre that grounded on the shelf in the summer-fall. Figure 6 shows this movement of water from the south to the north inferred from the microplanktonic and physical and oceanographic data.

The maps of total benthonic foraminiferan density (Figure 4, maps 7, 8 and 9) are useful in delineating the modern mid-shelf mud blanket which is roughly outlined by the 20 individuals $/ 10 \mathrm{~cm}^{2}$ contour for 1976 . When comparing the total densities for 1976 (Figure 4) with 1975 (Figure 5, maps 7, 8 and 9), it appears that the 1975 densities are generalify higher than 1976, and that the low density mud blanket fauna of 1976 cannot be defined by the same contour. In 1975, there were greater densities in this mud area and the richness of the modern mud blanket in 1976 (Figure 4, maps 10, 11 and 12) can be defined by the five species contour but in 1975 (Figure 5, maps 10, 11 and 12) the richness appears to be greater in the mud blanket. The richness in other areas appears to be similar in 1975 and 1976.

The same parameters of dominance, density of B. Zowmani, total benthonic foraminiferan density, and richness compiled for the seasonal data


4-WINTER 1976 BIRPSEYE

$\angle=$ WIND DIRECTIO
$z=$ SURFACE FLOW
$t-=$ INTO AND OUT OF
$\zeta=$ UPWELLING OR UPBOWING
$\circlearrowright=\begin{aligned} & \text { WINTER PONDS PEALING } \\ & \text { OFF OFFSHORE CURRENT }\end{aligned}$


Figure 6. Generalized Picture of the Seasonal Circulation Patterns of the STOCS During 1976.
for 1976 and 1975 were compiled for the nine monthly samplings of Transect II in 1976. A dendrogram was also produced of the Transect II monthly samples exclusive of the seasonal samples.

This dendrogram (Figure 7) can be divided into the following groups: a mid-shelf spring and summer fauna ( MSSpSu ); an inner shelf spring fauna (ISSp); an inner and mid-shelf fauna (IMS) that is subdivided into a possible epibenthic (IMSepi) and inbenthic (IMSin) groups; and two outer shelf groups (OS1 and OS2). These groups agree with the dominance groups for each of the nine percent dominance maps (Figure 8). A. beccarii (the IMS individual on Figure 7) is the only benthonic foraminiferan from the study area to be known as an infaunal member from the literature (Brooks, 1967). Species were considered epifaunal (IMSepi on Figure 7) if they commonly appeared in plankton samples in the BLM-STOCS area (Casey, 1975). This difference between infaunal and epifaunal species is suggested from separation on the dendrogram (Figure 7).

Figure 8 illustrates the percentages of the various benthonic foraminiferans at each of the nine monthly stations on Transect II, and Figure 9 illustrates the density of $B$. Zowmani at each of these stations. These data agree well with the seasonal maps on Figure 4. During winter there is a dominance of and a higher density of $B$. Zowmani in the inner and mid shelf and a high percentage on the outer shelf (Figures 8 and 9, February maps), a low point in $B$. Zowmani dominance and density in late spring (Figure 4, map 2; and Figures 8 and 9, June and July maps), a slight increase in $B$. Zowmani dominance and density in late summer and fall (Figure 4, map 5; and Figures 8 and 9, August map), and the beginning of a re-establishment of $B$. Zowmani in winter (Figure 4, maps 2 and

## -mmmBENTHONIC FORAMINIFERA SERSONAL SAMPLES 1976mmmme



MSSpSum $=$ mid shelf spring and summer group INSin $=$ inner mid shelf inbenthic ISSp = inner shelf spring group IMSepi $=$ inner mid shelf epibenthic OS $1=$ outer shelf group $1^{\prime}$ OS 2 = outer shelf group 2

Figure 7. Benthonic Foraminifera Collected Seasonally, 1976.

FIGURE 7. Key to Benthonic foraminifera Seasonal (monthly) samples dendrogram



Figure 8．Relative Abundance（\％of Total of Those Greater than 10\％）（Capital Letters Refer to Genus，Lower Case Refer to Species；see Appendix A for Complete Names）（Squared Area Equals Other Species of Less than 10\％）．（）Equals Questionable Data；see Text．


6; and, Figures 8 and 9, November and December maps).
Figures 10 and 11 illustrate the total density of benthonic foraminiferans and the richness for these nine samplings on Transect II. There appears to be a positive correlation between total density and richness on both a monthly Transect II (Figures 10 and 11) and STOCS seasonal (Figure 4) level. In general, both rich (many species) and high density collections are from the sand as opposed to the modern mud blanket areas (Figure 4, maps 7 through 12). This generality holds for Transect II (Figures 10 and 1I) except during April (when there was an increase in richness and total density) at Station 2, followed by a drastic decline in density but not richness in May. This trend appears again, but not as dramatically at Station 2 from July to August. These trends may represent a succession on a sub-seasonal leve1 that may be linked to different times of reproduction for different benthonic foraminiferan species.

## Bank Stations

Figures 12, 13 and 14 illustrate the dominant species, richness and total densities of benthonic foraminiferans on the bank stations (Hospital Rock and Southern Bank) in relation to the surrounding stations of Transect $I$ and II. The bank stations exhibit extreme variability in all these characteristics. In general, the bank stations exhibit a more diverse fauna with a greater amount of shared dominance than the transect stations. Also, the densities are generally higher than the surrounding stations. There appears to be a greater number of Ammonia beccarii and arenaceous species on the banks than the surrounding stations.

Hospital Rock averages a greater density throughout the year than Southern Bank does ( $41.04 / 10 \mathrm{~cm}^{2}$ compared to $32.28 / 10 \mathrm{~cm}^{2}$ ), and Southern


Figure 10. Total Benthonic Foraminiferan Density in Number/ 10 cm for Transect II Monthly Stations. () Equals Questionable Data; see Text.


Figure 11. Richness (Number of Species per Sample) of Benthonic Foraminiferans for Transect II Monthly Stations. () Equals Questionable Data, See Text.




Figure 14. Percent Abundance of Benthonic Foraminiferans Greater than $10 \%$, and Densities at the Monthly Sampling of the Bank Stations (H=Hospital, $S=$ Southern) and Stations 5 and 6 of Transect $I$, and Stations 2 and 6 of Transect II. The Lines Joining the Bank Stations and the Percent and Density Plots show the Approximate Station Location in Relation to The Bank. () Equals Questionable Data. See Text.

Bank a slightly greater richness ( 6.59 to 6.17 species/sample).
The bank stations do not appear to conform to the patterns of $B$. Zowmani dominance and migration that were mentioned earlier. In fact, as can be seen on Figure 4 , the banks appear to be the greatest anomaly in the general patterns that have been developed in this report for the benthonic foraminiferans.

Perhaps the simplest reasons for these anomalies are that the hank regions are regions of relatively great relief and considerable variability in sediment texture. The variability in sediment texture may account for the presence of $A$. beccarii which is usually a nearshore infaunal component existing in the coarse sediment regions of the banks. The great local relief plus the sediment variability may account for the common occurrences of deep and shallow forms; and, mud and sand facies members.

The peaks in density appear to occur mainly in February and July at both banks except for the greatest density recorded from the banks at Station HR 1 in November of 1976. Although up-current and down-current trends were looked for, none have been found in the benthonic foraminiferans to date.

CONCLUSIONS
The general distribution in time and space has already been addressed in previous BLM-STOCS reports and will not be repeated here. We will mention only new conclusions, and add some comments that might be useful for site evaluation and future monitoring. The modern mud blanket fauna can usually be characterized by low density and richness values of benthic foraminiferans. These trends change on at least a seasonal basis and may perhaps be used as an indicator of silting.

Perhaps one of the best indicator species of the benthonic foraminiferans is the most abundant species $B$. Zowmani. This species appears to be meroplanktonic and present in the water column throughout the year, but it only appears to settle out in shallow waters, or in deep waters when the waters become isothermal such as in winter. Therefore, the presence of this species in deeper waters may indicate a water column mixing. B. Zowmani densities and dominance in benthon samples appear to be useful as a tracer for bottom currents on a robust scale (months). This is good since the microplankton in contrast appear to be indicators for immediate circulation patterns. The migration of B. Zowmani to the north in late summer of both years of this study seems to be a true and good trend.

Another possible good indicator is Ammonia beccarii a species that is common in the lagoons and estuaries and may illustrate outflow periods. A. beccarii appears to be an infaunal component and most of the other species appear to be epifaunal (such as B. Zowmani). This difference shows up on the dendrograms and may be useful in determining the amount of perturbations (in the water column and sediment) of ofl spills, etc.

Lastly, the bank stations appear to be unique and perhaps very susceptible to perturbations due to their complex and diverse fauna in an obvious area for oil drilling.

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APPENDIX A

COMPLETE PRINTOUTS FOR 1976 BLM-STOCS BENTHONIC FORAMINIFERAN DATA. NUMBERS ON LEFT-HAND COLUMN ARE THE NUMBERS ASSIGNED EACH SPECIES, NUMBERS ACROSS TOP REFER TO THE STATIONS AS LISTED AT THE FIRST OF EACH DATA SECTION;
THE REMAINING NUMBERS AND FRACTIONS CORRESPOND TO DENSITIES OF SPECIES (INDIVIDUALS/5 $\mathrm{cm}^{2}$ )

Explanation of Tables:
$\mathrm{W}=$ Winter sampling period
$\mathrm{S}=$ Spring sampling period
$\mathrm{F}=$ Summer-Fall sampling period
$\mathrm{M}=$ March sampling period
$\mathrm{A}=$ April sampling period
$\mathrm{J}=\mathrm{July}$ sampling period
$\mathrm{U}=$ August sampling period
$\mathrm{N}=$ November sampling period
$\mathrm{D}=$ December sampling period

TABLE 1

## WINTER SAMPLING PERIOD DATA PRINTOUTS

Explanation of Table:

Species Names: The left-hand column gives the names of the benthonic foraminiferans as they appear on the data printouts. The right-hand colum gives the complete scientific name.

| Alveoloph. sp. | Alveolphra gmium sp. |
| :---: | :---: |
| A. wiesneri | Alveolophragmium wiesneri |
| A. beccarit | Ammonia beccarii |
| A. paucilocul. | Ammonia pauciloculata |
| A.ilessoni | Amphistegina ? lessoni |
| A. carinata | Astigerina carinata |
| B. irregularis | Eigunerina irregularis |
| B. subspinesc. | Bolivina subspinescens |
| Brizalina sp. | Erizalina sp. |
| B. lowmani | Eolivina lowmani |
| B. spinata | Brizalina spinata |
| B. hannai | Buccella hannai |
| B. marginata | Eulimina marginata |
| B. cf. bassend. | Euliminella cf. bassendorfensis |
| B. elegantiss. | Buliminella elegantissime |
| C. sagra | Cancris sagra |
| C. subglobosa | Cassidulina subglobosa |
| C. cf. subglob. | Cassidulina cf. subglobosa |
| C. mollis | Cibicides mollis |
| C. umbonatus | Cibicides umbonatus |
| C. orbicularis | Cassidulina orbicularis |
| D. candeiana | Discorbis candeiana |
| D. Floridensis | Discorbis floridensis |
| E. poeyanum | Elphidium poeyanum |
| E. vitrea | Epistominella vitrea |
| Florilus sp. | Florilus sp. |
| F. atlantica | Florilus atlantica |
| F. grateloupi | Florilus grateloupi |
| F. pontoni | Fursenkoina pontoni |
| E. strattoni | Hanzawaia strettoni |

TABLE 1 CONT.'D

La. atlantica
L. gelbi
M. planata
N. terquemi
N. antillarum

Nonion sp.
N. basiloba
N. ef. basiloba
P. corrugeta
P. diffugifor.

Quinquelocul.
Q. aff. compta
R. advena

Reo. atlantic.
R. comprima
R. atlantica
R. sp. "A"
S. bradyane
S. affinis
T. advena

Uvigerina sp.
U. bellula
U. peregrina

Virgulinella
T. earlandi
C. oblonga
B. hasta
H. concentrica

Eponides sp.
A. bella
C. laev. carin.
R. floridana
B. fragilis
B. albatrossi
P. mexdcana
T. bella
T. trigonula
R. comatula

Lamarckina atlantica
Loxostoum gelbi
Marginulina planata
Neoconorbina terquemi

- Neoeponides antillarum

Nonion sp.
Nonionella basiloba
Nonionella of. besilobe
Patellina corrugata
Proteonina diffugiformis
Quinqueloculina sp.
Quinqueloculina aff. compta
Rectobolivina advena
Reophax atlantica
Reophax comprima
Reussella atlantica
Robulus sp. "A"
Siphonina bradyana
Siphotextularia affinis
Trochaminina adrena
Uvigerina sp.
Uvigerina bellula
Uvigerina peregrina
Virgulinella sp.
Textularia earlandi
Cancris oblonga
Erizalina hastata
Hanzawaia concentrica
Epondies sp.
Angulogerina bella

Cassidulina laevigata var. carinata
Rosalina of. floridana
Brizalina fragilis
Bolivina albatrossi
Pseudoclavulina mexicana
Trifarina bella
Triloculina trigonula
Pseudonodosaria comatula

TABLE 1 CONT. 'D

WINTER


TABLE 1 CONT. ${ }^{\text {D }}$
WINTER


TABLE 1 CONT. ${ }^{\prime} D$

## WINTER



TABLE 1 CONT. 'D
WINTER


TABLE 1 CONT. ${ }^{\text {D }}$

## WINTER



TABLE 1 CONT. ${ }^{\text {D }}$
WINTER


TABLE 1 CONT.'D
WINTER


TABLE 1 CONT. ${ }^{\text {D }}$

## WINTER



TABLE 1 CONT.'D

## WINTER


table 1 CONT.'D

## WINTER



TABLE 2

SPRING SAMPLING PERIOD DATA PRINTOUTS

Explanation of Table:
Species Names: The left-hand column gives the names of the benthonic foraminiferans as they appear on the data printouts. The right-hand column gives the complete scientific name.

Alveolph. sp.
A. wiesneri
A. beccarii
A. paucilocul.

Ammosclaria
Arenaceous sp.
B. irregularis
B. sub. mexicana
B. lowmani
B. spinata
B. hannai
B. marginata
B. cf. basiloba
B. cf. bassend.
B. bassend.
B. elegantiss.
B. curta
C. sagra
C. sagra juv.
C. subglobosa
C. aff. florid.
C. umbonatus
C. orbicularis
D. floridensis
D. cf. nitida
E. poeyanum

Epistominella
E. vitrea
E. repandus
F. atlantica
F. gratelopius
F. pontonius
G. australisus
H. strattoni
L. nebulosa
L. spirata

Alveolphragmium sp.
Alveolphragmium wiesneri
Ammonia beccarii
Ammonia pauciloculata
Ammosclaria sp.
Arenaceous sp.
Bigenerian irregularis
Bolivina subaenariensis var. mexicana
Bolivina lowmani
Brizalina spinata
Buccella hannai
Bulimina marginata
Buliminella cf. basiloba
Buliminella cf. bassendorfensis
Buliminella bassendorfensis
Buliminela elegantissima
Buliminella curta
Cancris sagra
Cancris sagra juvenile
Cassidulina subglobosa
Cibicides aff. floridanus
Cibicides umbonatus
Cassidulina orbicularis
Discorbis floridensis
Discorbis cf. nitida
Elphidium poeyanum
Epistominella sp.
Epistominella vitrea
Eponides repandus
Florilus atlantica
Florilus grateloupi
Fursenkoina pontoni
Guttulina australis
Hanzawaia strattoni
Lagena nebulosa
Lagena spirata

TABLE 2 CONT. ${ }^{\circ} D$
L. atlantica

La. atlantica
L. peregrina
M. villa

Neoconorbina
N. terquemi
N. ? terquemi
N. antillarum

Nonion sp.
N. basiloba
N. cf. basiloba
P. diffugifor.
P. ? decorata

Pseudoparrela
P. quinqueloba

Quinquelocul.
Q. compta

Reo, atlantic.
R. bilocularis
R. ? bilocularis
R. comprima
R. atlantica
R. deffugifor.
R. sp. A
S. distorta
S. bradyana
S. pulchra
S. affinis
T. cf. candeina

Uvigerina sp.
U. bellula
U. parvula
U. peregrina
U. per. per.
U. per. parv.

Virgulinella
A. psoudospir.
T. errlandi
C. oblonga
B. hasta
H. concentrica
S. minuta
B. fragilis
T. bella
T. trigonula
T. mayori

TABLE 2 CONT. ${ }^{\text {D }}$
SPRING

UUEER Of GKOÚS
NUMELR HF GHARACTLRS
NLMEER UF SAMPLES BI



## VARIABLES in ǵtouf

 12.442TABLE 2 CONT. D
SPRING


TABLE 2 CONT．${ }^{1} \mathrm{D}$

## SPRING



TABLE 2 CONT. ${ }^{\prime} D$

## SPRING



TABLE 2 CONT. ${ }^{\prime} D$
SPRING


TABLE 2 CONT. ${ }^{\prime} \mathrm{D}$
SPRING


TABLE 2 CONT. 'D

## SPRING



TABLE 2 CONT. ${ }^{1}$ D
SPRING


TABLE 2 CONT. 'D

## SPRING



TABLE 2 CONT. ${ }^{\text {D }}$ SPRING


TABLE 3
SUMMER-FALL SAMPLING PERIOD DATA PRINTOUTS

Explanation of Table:
Species Names: The left-hand column gives the names of the benthonic foraminiferans as they appear on the data printouts. The right-hand column givés the complete scientific name.
A. wiesneri
A. beccarii
B. irregularis
B. subspinesc.
B. sub. mexicana
B. lowmani
B. spinata
B. marginata
B. cf. bassend.
B. bassend.
B. elegantiss.
C. sagra
C. subglobosa

Cibicides sp.
C. mollis
D. candeiana
D. floridensis
E. poeyanum

Epistominella
F. atlantica
F. grateloupi
F. pontoni
H. strattoni
L. spirata
L. atlantica
L. gelbi
N. terquemi
? N. terquemi
N. antillarum
N. basiloba
N. ef. basiloba
P. diffugifor.
P. ? decorata
P. quinqueloba

Quinquelocul.
Q. compta
R. comprima
R. atlantica
R. diffugifor.

Alveophragmium . wiesneri
Ammonia beccarii
Bigenerina irregularis
Bolivina subspinescens
Bolivina subaenariensis var. mexicana
Bolivina lowmani
Brizalina spinata
Bulimina marginata
Buliminella cf. bassendorfensis
Buliminella bassendorfensis
Buliminella elegantissima
Cancris sagra
Cassidulina subglobosa
Cibicides sp.
Cibicides mollis
Discorbis candeiana
Discorbis floridensis
Elphidium poeyanum
Epistominella sp.
Florilus atlantica
Florilus grateloupi
Fursenkoina pontoni
Hanzawaia strattoni
Lagena spirata
Lagenammina atlantica
Loxostoum gelbi
Neoconorbina terquemi
? Neoconorbina terquemi
Neoeponides antillarum
Nonionella basiloba
Nonionella cf. basiloba
Proteonina diffugiformis
Pseudoparrella ? decorata
Pullenia quinqueloba
Quinqueloculina sp.
Quinqueloculina compta
Reophax comprima
Reussella atlantica
Proteonina diffugiformis

TABLE 3 CONT. ${ }^{\text {D }}$
S. pul. var. prim
S. bradyana
S. affinis
T. cf. candeina
U. bellula
U. flintii
U. parvula
U. peregrina
U. per. per.
U. per. parv.

Virgulinella
T. earlandi
H. concentrica

Lagena sp.
B. barbata
B. translucens
E. communis
B. fragilis
T. bella
E. vitrea

Sagrina pulchella var. primitiva
Siphonina bradyana
Siphotextularia affinis
Textularia cf. candeina
Uvigerina bellula
Uvigerina flintii Uvigerina parvala Uvigerina peregrina
Ưvigerina peregrina peregrina
Uvigerina peregrina var. parvula Virgulinella sp.
Textularia earlandi
Hanzawaia concentrica
Lagena sp.
Brizalina barbata
Bolivina translucens
Enantiodentalina communis
Bolivina fragilis
Trifarina bella
Epistominella vitrea

TABLE 3 CONT. 'D
SUMMER-FALL


TABLE 3 CONT. 'D
SUMMER-FALL


TABLE 3 CONT. 'D
SUMMER-FALL


TABLE 3 CONT.!D
SUMMER-FALL


TABLE 3 CONT. ${ }^{\text {D } D ~}$
SUMMER-FALL


TABLE 3 CONT. ${ }^{\prime} D$
SUMMER-FALL


TABLE 4

MONTHLY SAMPLING PERIOD DATA PRINTOUTS

Explanation of Table:
Species Names: The left-hand column gives the names. of the benthonic. foraminiferans as they appear on the data printouts. The right-hand column gives the complete scientific names.
A. beccarii
A. tenquimargo
A. bella
B. irregularis
B. lowmani
B. marginata
B. cf. bassend.
B. fragilis
B. elegantiss.
B. spinata
B. sub. mexicana
C. sagra
C. aff. florid.
C. umbonatus
C. subglobosa

Cibicides sp.
Cibicides juv.
C. mollis
E. poeyanum
E. vitrea
F. grateloupi
F. atlantica
F. pontoni

Hanzawai juv.
H. concentrica
H. strattoni Juv. benthonic
Lenticulina sp.
Lagena sp.
N. ef. basiloba

Ammonia beccarii
Ammosclaria tenquimargo
Angulogerina bella
Bigenerina irregularis
Bolivina lowmani
Bulimina marginata
Buliminella cf. bassend.
Brizalina fragilis
Buliminella elegantissima
Brizalina spinata
Bolivina subaenariensis var. mexicana
Cancris sagra
Cibicides aff. floridensis
Cibicides umbonatus
Cassidulina subglobosa
Cibicides sp.
Cibicides juvenile
Cibicides mollis
Elphidium poeyamum
Epistominella vitrea
Florilus grateloupi
Florilus atlantica
Fursenkoina pontoni
Hanzawaia juvenile
Hanzawaia concentrica
Hanzawaia strattoni
Juvenile benthonics
Lenticulina sp.
Lagena sp.
Nonionella cf. basiloba

TABLE 4 CONT．＇D

N．basiloba
N．antillarum
P．mexicana
P．diffugifor．
P．？decorata
Quinquelocul．
R．iotus
R．advena
R．atlantica
R．comprima
Reo．atlantic．
S．affinis
S．pulchra
S．bradyana
T．earlandi
T．jamaicensis
T．parvula
T．bella
U．bellula
U．peregrina
U．parvala
U．var．parv．
V．pertusa
S．pul．var．prim
Virgulinella
L．peregrina

```
Nonionella basiloba
Neoeponides antillarum
Pseudoclavulina mexicana
Proteonina diffugiformis
Pseudoparrella ? decorata
Quinqueloculina sp.
Robulus iotus
Rectobolivina advena
Reusella atlantica
Reophax comprima
Reophax atlantica
Siphotextularia affinis
Siphonina pulchra
Siphonina bradyana
Textularia earlandi .
Trifarina jamaicensis
Textularia parnula
Trifarina bella
Uvigerina bellula
Uvigerina peregrina
Uvigerina parvula
Uvigerina peregrina var. parvula
Virgulinella pertusa
Sagrina pulchella var. primitiva
Virgulinella sp.
Lenticulina peregrina
```


## TABLE 4 CONT.'D



TABLE 4 CONT.'D

## MARCH



TABLE 4 CONT.'D
MARCH


TABLE 4 CONT.'D
APRIL


TABLE 4 CONT.'D
APRIL


TABLE 4 CONT. ${ }^{1} \mathrm{D}$
JULY


## JULY



TABLE 4 CONT. ${ }^{\text {D }}$
AUGUST


TABLE 4 CONT. ${ }^{\prime}$ D
AUGUST


TABLE 4 CONT. ${ }^{\prime} \mathrm{D}$
NOVEMBER

| r | numbeit | sample namc | 1 |
| :---: | :---: | :---: | :---: |
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|  | a | A. iencuimarguipid | .0 |
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|  | 12 | c.sagra | 0 |
|  |  | C.ate oflumid.men | 0.0 |
| - | 14 | c.umbuna tusan | 0.0 |
|  | 15 | c.subululusama | 0.0 |
| , |  | giticides sp.m | 0.0 |
|  | 17 | caatcines juv...N | 0 |
|  | 18 | camullism | 0.0 |
|  | 19. | E.ple ranumma. | 0.0 |
| $\ldots$ | 20 | E.vithearen | 0.0 |
|  | 21 | F.ghatel duproma | 0.0 |
|  | 22 | f.athanticame: | U,4 |
|  | 23 | f.flurionion | 0.0 |
| - | 44 | hanzamal juvom | 0.0 |
|  | 25 | h.clnclntricama | 4.0 |
|  | 20. | h. Stitatiluim | 0.0 |
|  | 27. | Jug.deind humicoun | 0.0 |
|  | 28 | Lenticulina smon | 0.0 |
|  | 29 | Laglna sa | 4.0 |
|  | 30 | n.cituasilubaira | 4.0 |



TABLE 4 CONT.'D

## NOVEMBER



TABLE 4 CONT. 'D
DECEMBER


TABIE 4 CONT. ${ }^{\text {D }}$
DECEMBER


Principal Investigator
Patricia L. Johansen


#### Abstract

\section*{ABSTRACT}

Seventy-two (72) one liter samples were collected from the BLM-STOCS Transect II during 1975 and 1976. These samples, which were preserved with $5 \%$ buffered formalin, were analyzed for ciliated protozoa using the Utermohl method.

Extremely poor and inconsistent preservation of the ciliated protozoa by buffered formalin makes interpretation of the data difficult. Interpretation problems were further complicated by infrequent sampling during the 1975 effort.

Some quantitative information was obtained from samples collected in November and December 1976, and preserved with basic Lugol's fixative. During November and December 1976, the protozoan biomass ranged from three to seventeen percent of the macrozooplankton biomass.

Some qualitative information was obtained from the remaining data. Oligotrichs as a group were widespread in both time and space, while tintinnids, foraminifera, radiolaria/acantharia and other protozoa tended to be more restricted in both temporal and spatial distribution.

It is possible that marine protozoa may serve as both short and long term indicators of water quality and should therefore be monitored at regular intervals.


## INTRODUCTION

During 1975 and 1976 the microzooplankton effort of the BLM STOCS program was directed toward the sarcodine protozoa, i.e., foraminifera, radiolaria and acantharia. The ciliated protozoa were largely ignored, primarily because most of them either passed through the $76 \mu \mathrm{~m}$ mesh of the net or were destroyed by filtration through the net. However, the ciliated forms (mostly tintinnids and oligotrichs) commonly comprise > $90 \%$ numerically of the marine protozoan community (Beers and Stewart, 1967, 1969, 1970, 1971; Johansen, 1976) and, on the Scotian Shelf in summer, at least, the protozoan biomass exceeds the macrozooplankton biomass. Hence, the ciliated protozoan component of the zooplankton is rather significant. This problem was partially corrected in 1977 with the inclusion of a ciliate sampling program into the BLM project.

During 1975 and 1976, 1-l unconcentrated seawater samples were collected along Transect II, preserved and stored by Dr. R. E. Casey for future reference. These samples were kindly made available to Dr. P. L. Johansen for analysis of the ciliate fraction of the protozoa. It was hoped that the 1975-76 samples would provide back-up and comparative data for the 1977 microzooplankton study. This report is the result of the analyses of those 1975-76 samples.

METHODS

## Sampling

During three seasonal cruises in 1975 and during three seasonal and six monthly cruises in 1976 , $1-\ell$ water samples were collected with a $50-\ell$ Niskin bottle from 10 m and from $1 / 2$ the depth of the photic zone at Stations 1, 2 and 3 along Transect II on the South Texas Outer

Continental Shelf. These samples were preserved with $5 \%$ buffered formalin. In addition, during November and December 1976, additional $1-\ell$ samples were taken from the surface and $1 / 2$ the depth of the photic zone at Stations 1,2 and 3 along Transect II. These samples were preserved with $1 \%$ basic Lugol's fixative.

## Sample Analysis

A 500-ml aliquot of each $1-\ell$ sample was placed in a graduated cylinder and allowed to settle for 24 hours. At this time, 400 ml were drawn off and the remaining 100 ml transferred to an Utermohl settling chamber. The ciliates were identified to species and enumerated. The foraminifera, radiolaria and acantharia were enumerated. Following counting, the aliquot was combined with the original sample, resettled, drawn down to 10 ml and archived.

Biomass estimates were calculated by estimating the volume of the ciliates (not including the lorica). Assuming a cell density of one, then one $\mu^{3}$ approximately equals $10^{-6} \mu g$; dry weight was assumed to be $13 \%$ of the wet weight (Beers and Stewart, 1970). Total dry weights (mg/m ${ }^{3}$ ) were calculated by multiplying the abundance of each species in the sample by its respective volume, converting to dry weight and summing the individual estimates.

The Shannon-Wiener Index (Pielou, 1974) was used to calculate species diversity of each sample. The Shannon-Wiener Index was calculated as follows:

$$
H_{s}=\sum_{i=1}^{S} \text { pi In pi; where: }
$$

```
H = the diversity index of the sample;
S = the number of species in the sample;
pi=the relative abundance of the ith species measured;
In pi = the natural log of pi.
```


## RESULTS

Seventy－two（72）protozoan species were observed in the 84 samples analyzed．Of these， 39 were tintinnids， 9 were oligotrichs， 5 were foraminifera， 10 were radiolaria／acantharia and 9 were other protozoan species．Forty（40）species（56\％）were found in 1975 while 61 （ $85 \%$ ） were found in 1976．Eleven（11）species（15\％）were found only in 1975 while 32 （44\％）were found in 1976．Twenty－nine（29）species（40\％）were found in both years．Table 1 lists the occurrence of each species in 1975 and 1976.

Species lists and abundances for each sample are presented in Appendix A．The number of individuals of the various groups per liter， the percentage of the total protozoa of each group represented，number of species per sample，species diversity indices，and total dry weight of the protozoan are presented in Appendix B．

Table 2 indicates the distribution of the various species at the three stations．Values were obtained by averaging all data from each station regardless of month or depth．Table 3 indicates the occurrence of the various species during the course of the sampling period each year． These values were obtained by averaging all data from each month regard－ less of station or depth．Figure 1 shows the abundance of total protozoa for each station，depth and month during 1975 and 1976.

TABLE 1
OCCURRENCE OF PROTOZOAN SPECIES ALONG TRANSECT II BY YEAR

| Species | 75 | 76 | Species | 75 | 76 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| TINTINNIDS |  |  |  |  |  |
| 1 Amphorides quadrilineata | X | X | 45 Strombidium ovale | X | X |
| 2 Climacocylis scalaroides | X | X | 46 Strombidium strobilus | X | X |
| 3 Cadonellopsis americana | X | X | 47 Strombidium sulcatum | X | X |
| 4 Dadayiella ganymedes | X | X | 48 Strombidium typioum | X | X |
| 5 Dictyocysta Lata |  | X | FORAMINIFERA |  |  |
| 6 Dictyocysta reticulata |  | X |  |  |  |
| 7 Epiplocycloides acuta | X | X | 49 Bolivina striatula |  | X |
| 8 Eutintinnus apertus | X |  | 50 Bucella frigida |  | X |
| 9 Eutintinnus Zasus-undae | X | X | 51 Globigerina pachyderma | X | X |
| 10 Eutintinnus tenue |  | X | 52 Hastigerina pelagica |  | X |
| 11 Ormosella bresslaui |  | X | 53 Robulus reniformis | X |  |
| 12 Parundella dificilis |  | X | RADIOLARIA/ACANTHARIA |  |  |
| 13 Parundella subcaudata | X |  |  |  |  |
| 14 Proplectella claparedei |  | X | 54 Acanthostarus pallidus |  | X |
| 15 Proplectella subcaudata |  | X | 55 Acanthostarus purpurascens |  | X |
| 16 Protorhabdonella curta | X | X | 56 Acrobotrys sp. |  | X |
| 17 Pseudometacylis ornata | X |  | 57 Anthocyrtidium ophirense |  | X |
| 18 Rhabdonella brandti | X |  | 58 Conchidizon argiope |  | X |
| 19 Rhabdonellopsis triton | X |  | 59 Hexaloncha philisophica |  | X |
| 20 Salpingacantha undata | X | X | 60 Lithomellisa setosa | X | X |
| 21 Salpingelてa acuminata | X | X | 61 Neprospyris docris | X | X |
| 22 Salpingella minutissima | x |  | 62 Sticholonche zanclea |  | X |
| 23 Steenstrupiella gracilis | X | X | 63 Triplaciacantha abietiha |  | X |
| 24 Stenosemella ventricosa | X | X |  |  |  |
| 25 Tintinnidium incertum | X | X | OTHER PROTOZOA |  |  |
| 26 Tintinnopsis acuminata | X | X |  |  | X |
| 27 Tintinnopsis compressa |  | X | 65 Ephelota geminaria |  | X |
| 28 Tintinnopsis dadayi | X | X X X | 66 Euglypha Zoevis |  | X |
| 29 Tintinnopsis directa |  | X X | 67 Euplotes minuta |  | X |
| 31 Tintinnopsis levigata |  | X | 68 Euplotes sexcostatus |  | X X - |
| 32 Tintinnopsis Zobiancoi | X | X | 69 Mesodinium rubrum |  | X |
| 33 Tintinnopsis minuta | X |  | 71 Tiarina fusus |  | X |
| 34 Tintinnopsis sacculus | X |  | 72 Tontonia gracillima |  | X |
| 35 Tintinnopsis tocantinensis | X |  | 72 Iontonia gracillima |  |  |
| 36 Tintinnopsis tubulosa | X | X |  |  |  |
| 37 Tintinnus tubulosus | X | X |  |  |  |
| 38 Undella hyalina |  | X |  |  |  |
| 39 Xystonella treforti | X | X |  |  |  |
| OLIGOTRICHS |  |  |  |  |  |
| 40 Lohmaniella oviformis | X | X |  |  |  |
| 41 Strombidium acuminatum | X | X |  |  |  |
| 42 Strombidium calkinsi | X | X |  |  |  |
| 43 Strombidium conicum | X | X |  |  |  |
| 44 Strombidium cornucopiae | X |  |  |  |  |

TABLE 2
AVERAGE ABUNDANCE (INDIVIDUALS/\&) OF PROTOZOA BY SPECIES AT EACH OF THE SAMPLING STATIONS ON TRANSECT II DURING 1975 AND 1976

| Species | St 75 | ก $\begin{array}{r}1 \\ 76\end{array}$ |  | on 2 |  | on 3 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| TINTINNIDS |  |  |  |  |  |  |
| Amphorides quadrilineata | 2 | . 7 | . 7 |  | 7.3 | 1.1 |
| Climacocylis scalaroides | . 7 | . 2 |  | . 2 | 10 | . 2 |
| Codonellopsis americana | 21.3 | . 7 |  | . 2 |  |  |
| Dadayiella ganymedes | 2.7 |  |  | . 2 | 24.7 | . 2 |
| Dictyocysta lata |  |  |  |  |  | . 2 |
| Dictyocysta reticulata |  |  |  |  |  | . 2 |
| Epiplocycloides acuta | 6.7 | . 2 | 1.3 | . 6 | 3.3 |  |
| Eutintinnus apertus |  |  |  |  | . 7 |  |
| Eutintinnus Zasus-undae | . 7 | 2.2 | 2 | 2.6 | 7.3 | 2.8 |
| Eutintinnus tenue |  |  |  |  |  | . 2 |
| Ormosella bresslaui |  |  |  |  |  | . 2 |
| Pamundella dificilis |  |  |  |  |  | . 2 |
| Pamundella subcaudata |  |  |  |  | . 7 |  |
| Proplectella claparedei |  | . 6 |  |  |  |  |
| Proplectella subcaudata |  | . 2 |  | . 2 |  | . 2 |
| Protorhabdonella curta |  |  |  | . 7 | 2.7 | . 8 |
| Pseudometacylis ornata | . 7 |  |  |  |  |  |
| Rhabdonella brandti | . 7 |  | 1.3 |  | 2.7 |  |
| Rhabdonellopsis triton |  |  |  |  | . 7 |  |
| Salpingacantha undata |  | . 2 |  | . 2 | 2.7 | 1.1 |
| Salpingella acuminata |  |  | . 7 |  | . 7 | . 2 |
| Salpingella minutissima | 1.3 |  |  |  |  |  |
| Steenstmupiella gracilis |  |  |  |  | 3.3 | . 6 |
| Stenosemella ventricosa | 4 | 16.7 | 1.3 | . 9 |  | . 4 |
| Tintinnidium incertum | 43.3 | 20.7 | 8 |  | 2 |  |
| Tintinnopsis acuminata | 4 | 2.7 |  |  |  |  |
| Tintinnopsis compressa |  | 1.9 |  |  |  |  |
| Tintinnopsis dadayi | 4.7 | . 2 |  |  |  |  |
| Tintinnopsis directa |  |  |  |  |  | . 2 |
| Tintinnopsis fennica |  | . 6 |  |  |  |  |
| Tintinnopsis levigata |  | . 2 |  |  |  |  |
| Tintinnopsis lobiancoi |  |  |  |  | 2 | . 4 |
| Tintinnopsis minuta | 29.3 |  |  |  | . 2 |  |
| Tintinnopsis sacculus |  |  |  |  | 11.3 |  |
| Tintinnopsis tocantinensis | 11.3 |  |  |  |  |  |
| Tintinnopsis tubulosa | 3.3 | . 2 |  | . 2 |  |  |
| Tintinnus tubulosus | 4 | 5.6 | 2.7 | . 4 | . 7 | 1 |
| Undella hyalina |  |  |  | . 9 |  | . 4 |
| Xystonella treforti |  |  |  | . 4 | 2 | . 2 |
| OLIGOTRICHS |  |  |  |  |  |  |
| Lohmaniella oviformis | 5.3 | 22.7 | 11.3 | 36.1 | 12 | 9.7 |
| Strombidium acuminatum | 1.3 | . 9 | 2.7 | . 7 |  |  |
| Strombidium calkinsi | 6.7 | 22.7 | 15.3 | 13.4 | 3.3 | 3.3 |

TABLE 2 CONT.'D


TABLE 3
AVERAGE PROTOZOAN ABUNDANCE (INDIVIDUALS/ $\ell$ ) BY SPECIES FOR EACH SAMPLING MONTH IN 1975 AND 1976

| SPECIES | $\begin{gathered} \text { Jan } \\ 75 \end{gathered}$ | $\begin{gathered} \text { Feb } \\ 76 \end{gathered}$ | $\begin{gathered} \mathrm{Mar} \\ 76 \end{gathered}$ |  | $\begin{aligned} & \mathrm{pr} \\ & -76 \end{aligned}$ | $\begin{aligned} & \text { May } \\ & 75 \end{aligned}$ | June 76 | $\begin{gathered} \text { July } \\ 76 \end{gathered}$ | $\begin{gathered} \text { Aug } \\ 76 \end{gathered}$ | $\begin{gathered} \text { Sept } \\ 75-76 \end{gathered}$ | $\begin{gathered} \text { Nov } \\ 76 \end{gathered}$ | $\begin{gathered} \text { Dec } \\ 75-76 \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| TINTINNIDS |  |  |  |  |  |  |  |  |  |  |  |  |
| Amphorides quadrilineata |  | . 7 | . 7 | 2 |  | 22 |  | 2.7 | . 7 | . 7 | . 7 | 2 |
| Climacocylis scalaroides |  |  |  |  |  | 14 |  |  | . 7 | 21.3 |  | 8 |
| Cadonellopsis americana |  |  |  |  |  |  | 2 |  | . 7 | 2.7 |  |  |
| Dadayiella ganymedes |  |  |  |  | . 7 | 72 | . 7 |  |  |  |  | 1 |
| Dictyocysta lata |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| Dictyocysta reticulata |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| Epiplocycloides acuta |  |  |  |  |  | 2 |  |  | . 7 | 81.7 |  | 4 |
| Eutintinnus apertus |  |  |  |  |  |  |  |  |  | . 7 |  |  |
| Eutintinnus lasus-undae |  | 2.7 | 2 | 2 | 2 | 14 | 7 | . 7 |  | 1.3 |  | 4.7 |
| Eutintinnus tenue |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| Ormosella bresslaui |  | . 7 |  |  |  |  |  |  |  |  |  |  |
| Pamundella dificilis |  |  |  |  |  |  |  |  |  |  | . 7 |  |
| Parundella subcaudata |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| Proplectella claparedei |  |  |  | 1 |  |  |  |  |  | 1.7 |  |  |
| Proplectella subcaudata |  |  | 1.3 |  |  |  |  |  |  | - |  |  |
| Protorhabdonella curta |  |  |  |  |  | 4 | 1.7 |  |  |  |  |  |
| Pseudometacylis ornata |  |  |  |  |  |  |  |  |  | . 7 |  |  |
| Rhabdonella brandti |  |  |  |  |  | 8 |  |  |  | 2 |  |  |
| Rhabdonellopsis triton |  |  |  |  |  | 2 |  |  |  |  |  |  |
| Salpingacantha undata |  | . 7 | . 7 |  | . 7 |  | . 7 |  | . 7 |  | . 7 | $4 \quad .7$ |
| Salpingella acuminata | 2 |  |  |  |  |  |  |  |  | 1.3 | . 7 | 1 |
| Salpingella minutissima |  |  |  |  |  |  | $1.7{ }^{\text { }}$ |  |  |  |  | 5 |
| Steenstrupiella gracilis |  |  |  |  |  |  |  |  |  |  |  |  |
| Stenosemella ventricosa | 2 |  | . 7 | 4 | 3.3 |  | 8.7 | . 7 | . 7 |  | 2.7 | 137.3 |
| Tintinnidium incertum |  |  | 3.3 | 68 | 11.3 |  |  |  |  | 5.3 |  | 448.7 |
| Tintinnopsis acuminata |  |  |  |  |  |  |  |  |  | 3.3 | . 7 | 17.3 |
| Tintinnopsis compressa |  |  |  |  |  |  |  |  |  | 1.7 | . 7 | 4 |
| Tintinnopsis dadayi |  |  |  | 7 |  |  | . 7 |  |  |  |  |  |
| Tintinnopsis directa |  |  |  |  |  |  |  |  |  |  | . 7 |  |

TABLE 3 CONT.'D

| SPECIES | $\begin{gathered} \hline \text { Jan } \\ 75 \\ \hline \end{gathered}$ | $\begin{gathered} \text { Feb } \\ 76 \end{gathered}$ | $\begin{gathered} \text { Mar } \\ 76 \\ \hline \end{gathered}$ |  | $\begin{aligned} & \mathrm{pr} \\ & -76 \\ & \hline \end{aligned}$ | $\begin{gathered} \hline \text { May } \\ 75 \\ \hline \end{gathered}$ | $\begin{gathered} \text { June } \\ 76 \\ \hline \end{gathered}$ | $\begin{gathered} \text { July } \\ 76 \end{gathered}$ | $\begin{gathered} \text { Aug } \\ 76 \\ \hline \end{gathered}$ |  | $76$ | $\begin{gathered} \hline \text { Nov } \\ 76 \\ \hline \end{gathered}$ |  | $\begin{aligned} & \text { Dec } \\ & -76 \\ & \hline \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Tintinnopsis fennica |  |  |  |  |  |  |  |  |  |  | 1.7 |  |  |  |
| Tintinnopsis levigata |  |  |  |  | . 7 |  |  |  |  |  |  |  |  |  |
| Tintinnopsis lobiancoi |  |  |  |  |  |  |  | 1.3 |  |  |  |  | 4 |  |
| Tintinnopsis minuta |  |  |  |  |  |  |  |  |  | 29.3 |  |  |  |  |
| Tintinnopsis sacculus |  |  |  |  |  |  |  |  |  |  |  |  | 17 |  |
| Tintinnopsis tocantinensis |  |  |  |  |  |  |  |  |  | 11.3 |  |  |  |  |
| Tintinnopsis tubulosa |  |  | . 7 |  |  |  |  |  |  |  | 3.3 |  |  | . 7 |
| Tintinnus tubulosus |  | 2 | 3.3 |  |  |  | 1.7 | 4 | 1.3 |  |  |  |  | 7.3 |
| Undella hyalina |  |  |  |  |  |  | 2.7 |  |  |  |  |  |  |  |
| Xystonella treforti |  | . 7 | 1.3 |  |  |  |  |  |  |  |  |  | 3 |  |
| OLIGOTRICHS |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Lohmaniella oviformis | 28 | 22 | 2.7 | 5 | 12 | 8 | 3 | 2 | 2 | 5 | 4.7 | 66 | 13 | 90.7 |
| Strombidium acuminatum |  |  | 2 | 6 |  |  |  |  |  |  |  | 1.3 |  | 1.3 |
| Strombidium calkinsi | 28 | 1.3 | 5.3 | 9 | 4 | 2 | 1.3 |  |  | 6 | 1.7 | 29.3 | 5 | 73.3 |
| Strombidium conicum | 42 | 18.7 | 12 | 19 | 19.3 | 34 | 25.3 | 6.7 | 2 | 10.7 | 9.7 | 134.7 | 28 | 115.3 |
| Strombidium cornucopiae |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |
| Strombidium ovale | 8 | 10 | 11.3 | 3 | 7.3 | 4 | 10.7 | 3.3 | 2 | 8.7 |  | 1.3 | 29 | 30.7 |
| Strombidium strobilus | 32 | 5.3 | 12 | 6 | 20.7 | 12 | 15.3 | 6.7 | 5.3 | 12,7 | 6.3 | 53.3 | 4 | 18.7 |
| Strombidium sulcatum | 56 | 32.7 | 22.7 | 43 | 31.3 | 14 | 26.7 | 10 | 16.7 | 36 | 9 | 188.3 |  | 184 |
| Strombidium typicum | 6 | . 7 | 1.3 | 2 | 4 | 4 | 3 | . 7 | . 7 | 2 |  | 34 | 3 |  |
| FORAMINIFERA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Bolivina striatula |  |  | . 7 |  |  |  |  |  |  |  |  | 2 |  |  |
| Bucella frigida |  |  |  |  |  |  |  |  |  |  |  | . 7 |  |  |
| Globigerina pachyderma | 2 | . 7 | . 7 |  |  |  |  |  |  |  |  |  |  |  |
| Hastigerina pelagica |  |  |  |  |  |  | 1.7 |  |  |  |  | 1.3 |  |  |
| Robulus reniformis |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |
| RADIOLARIA/ACANTHARIA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Acanthostams pallidus |  |  |  |  |  |  |  |  |  |  |  | . 7 |  |  |
| Acanthostarus purpurascens |  |  | . 7 |  |  |  |  |  |  |  |  |  |  |  |

TABLE 3 CONT. 'D

| SPECIES | $\begin{gathered} \hline \mathrm{Jan} \\ 75 \\ \hline \end{gathered}$ | $\begin{gathered} \hline \mathrm{Feb} \\ 76 \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{Mar} \\ 76 \end{gathered}$ | $\begin{gathered} \mathrm{Apr} \\ 75-76 \end{gathered}$ | $\begin{gathered} \text { May } \\ 75 \end{gathered}$ | $\begin{gathered} \text { June } \\ 76 \\ \hline \end{gathered}$ | $\begin{gathered} \text { July } \\ 76 \end{gathered}$ | $\begin{gathered} \text { Aug } \\ 76 \end{gathered}$ | $\begin{gathered} \text { Sept } \\ 75-76 \end{gathered}$ | $\begin{gathered} \hline \text { Nov } \\ 76 \end{gathered}$ |  | $\begin{aligned} & \text { ec } \\ & -76 \\ & \hline \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acrobotrys sp. |  |  |  | . 7 |  |  |  |  |  |  |  |  |
| Anthocyrtidium ophirense |  |  |  |  |  |  |  | . 7 |  |  |  |  |
| Conchidium argiope |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| Hexaloncha philisophica |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| Lithomellisa setosa |  |  |  |  |  |  |  |  |  | 2 | 4 | 2 |
| Neprospyris docris |  |  |  |  |  |  |  | . 7 | . 7 |  |  |  |
| Sticholonche zanclea |  |  |  | . 7 |  |  |  |  |  |  |  |  |
| Triplaciacantha abietiha |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| OTHER PROTOZOA |  |  |  |  |  |  |  |  |  |  |  |  |
| Amphisia pernix |  |  |  |  |  |  |  |  |  |  |  | . 7 |
| Ephelota geminaria |  |  |  |  |  |  |  |  |  | 6 |  | 19.3 |
| Euglypha loevis |  |  |  |  |  |  |  |  |  |  |  | 2 |
| Euplotes minuta |  |  |  | 4 |  |  |  |  |  |  |  |  |
| Euplotes sexcostatus |  | 1.3 |  |  |  |  |  |  |  |  |  |  |
| Mesodinium rubrum |  |  |  |  |  |  |  |  |  | 3.3 |  | 28 |
| Tiarina fucus |  |  |  |  |  |  | . 7 | . 7 |  | . 7 |  |  |
| Tiamina fusus |  |  |  |  |  |  |  |  | - | 1.3 |  | 9.3 |
| Tontonia gracillima |  |  |  | . 7 |  |  |  | . 7 |  | 1.3 |  | 1.3 |



Figure 1. Abundance of Protozoa on STOCS Transect II, 1975-76.

## DISCUSSION

The extremely low numbers of protozoa observed in these samples (Figure 1) is due to the inadequacy of the buffered formalin fixative. The extent of this problem is revealed clearly in Table 2, Appendix A which lists the total of protozoans found during November and December 1976 in samples preserved with basic Lugol's as opposed to samples preserved with formalin. None of the soft-bodied" ("other") protozoa (Tables 1 and 3) survived formalin fixation. Occasionally, some oligotrichs were preserved. Tintinnids with arenaceous loricae, as well as those with hyaline or sculptured loricae, were preserved. Tintinnids with agglomerated (biogenic) loricae occasionally survived but were usually destroyed. The foraminifera, radiolaria and acantharia were all preserved with the buffered formalin. Due to the inconsistent preservation abilities of formalin, it is impossible to extrapolate these data to more realistic estimates of abundance for the various groups of protozoa. These data, then, should not be used for the interpretation of the role of protozoa in marine food web. Likewise, correlations with physical or other biological data would be meaningless.

Also, because of very low abundances, no trends are evident in the abundance data (Figure 1). However, in more recent data (1977), there are indications of a winter and early spring maximum in protozoa abundance. The apparently greater protozoan abundance in 1975 may be spurious. The 1975 samples merely seemed to be in a better state of preservation than the 1976 samples. The reason for the different preservation is unknown. Perhaps the formalin used in 1976 was not buffered properly.

Besides the preservation difficulty, the 1975 data also suffers from extreme infrequency of sampling. The greater number of species observed
in 1976, especially among the radiolaria, (Tables 1 and 3 ) merely reflects the greater number of samples collected in 1976. Many protozoa species are somewhat restricted in their periods of maximum occurrence (Johansen, 1976; Hedin, 1974) and can easily be missed when sampling is infrequent.

Despite the lack of quantitative information contained in the data, there is much valuable qualitative information. For example, the data reveal that the oligotrichs, as a group, are widely distributed in time (Table 3) and space (Table 4). This quality may permit the Oligotrichs to be useful indicators of water quality. On the other hand, the tintinnids as a group are more restricted in temporal and spatial distribution. For example, the hyaline and sculptured-loricate forms (e.g. Anphorides, ClimacocyZis, DadayielZa, Eutintinnus, OrmoseZZa and RhabdonelZa) tend to inhabit more offshore regions while the arenaceousloricate forms (e.g. Cadonellopsis, Tintinnidium, Tintinnopsis) tend to inhabit inshore areas. Population alterations in individual species of tintinnids, therefore, may serve as very sensitive and immediate (shortterm) indicators of water quality at specific times or specific areas in the Gulf. The pelagic foraminiferans encountered and the radiolaria/ acantharia tend to occupy offshore areas while the "other" protozoa are more common at Station 1 .

A small piece of quantitative data can be obtained from the NovemberDecember 1976 samples which were preserved with basic Lugol's (Table 2, Appendix A). Table 4 shows the biomass data from the two depths at each station compared with the average macrozooplankton biomass data for each station reported by Park (1976).

Protozoan biomass averaged $8 \%$ of the macrozooplankton biomass. More recent data (Johansen, unpublished data) reveal that the protozoan biomass

## TABLE 4

AVERAGE PROTOZOAN BIOMASS DATA EXPRESSED AS PERCENTAGE OF MACROZOOPLANKTON BIOMASS，NOVEMBER AND DECEMBER 1976

| MONTH | STATION |  |  |
| :--- | :---: | :---: | :---: |
|  | 1 | 2 | 3 |
| November | $5 \%$ | $4 \%$ | $17 \%$ |
| December | $12 \%$ | $6 \%$ | $3 \%$ |

may be as high as $59 \%$ of the macrozooplankton biomass, indicating that the protozoa are a significant fraction of the zooplankton community.

There is increasing evidence (Hirota and Szyper, 1976; Beers et al., 1977) that stressed ecosystems tend to go from a macrozooplankton-net phytoplankton community to a microzooplankton-nanoflagellate community. If this is the case, a frequent monitoring of the changes in abundance and composition of the microzooplankton community may reveal short-term as well as long-term changes in the health of the marine community of the STOCS as a whole.

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## APPENDIX A

## TABLE 1

LIST OF SPECIES AND THEIR ABUNDANCE IN NUMBERS/l FOR EACH SAMPLE COLLECTED IN 1975 FROM STATIONS 1, 2 AND 3 ALONG TRANSECT II

Explanation of Table:
SACD $=$ Sample Code
S = Station
T = Transect
Date = Date
Time $=$ Time of Sampling
Z = Depth of Sample
SPCD $=$ Species Code
NOPL $=$ Number of Organisms/ $\ell$




| SACU | S 1 | UAIE | IIME 2 | SPCD | SPECIES NAME | NOPL |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ALPF | 22 | 041875 | 151015 | 2405 | SIROMBIDIUM CONICUM | 36 |
| ACPF | 22 | 041875 | 151015 | 2415 | Strumbidium ovale | 8 |
| ACPF | 22 | 641875 | 151015 | 2420 | Strombidium sirubilus | 12 |
| ALPF | 22 | 441875 | 151015 | 2425 | STRUMBIDIUM SULCAIUM | 88 |
| ACHF | 2.2 | 041875 | 151615 | 1456 | IINTINNIDIUM INCERTUM | 24 |
| ACSC | 32 | $\Delta 51075$ | 161510 | 1045 | AMPHUKIDES GUADRILINEATA | 32 |
| ACSC | 32 | 051675 | 101510 | 1085 | CLIMACOCYLIS SCALAROIDES | 4 |
| ACSC | 32 | 151075 | 161510 | 1115 | DADAYIELLA GANYMEDES | 68 |
| ACSC | 32 | 051675 | 1615 10 | 1160 | EPIPLOCYCLOIDES ACUIA | 4 |
| ACSC | 32 | 051675 | 161510 | 1185 | EUIINIINNUS LASUS-UNDAE | 20 |
| ALSC | 32 | H51675 | 161510 | 2235 | LUHMANIELLA OVIFORMIS | 4 |
| ALSC | 32 | 451675 | 1615 16 | 1305 | Prutorhabuonella curia | 8 |
| ACSC | 32 | 451675 | 161516 | 1336 | RHABUONELLA GRANUTI | 16 |
| ACSC | 32 | 051675 | 161514 | 1345 | hHa甘UUNELLUPSIS TRIION | 4 |
| ACSC | 32 | 051675 | 161516 | 2445 | Strombidium cunicum | 4 |
| ACSC | 32 | 151675 | 161510 | 2415 | SIKUMBIDIUM OVALE | 8 |
| ACSC | 32 | 051675 | 161510 | 2424 | SIROMBIDIUM STRUBILUS | 12 |
| ACSC | 32 | 051675 | 161510 | 2425 | SIROMUIDIUM SULCAIUM | 20 |
| ACSC | 32 | \$51075 | 161516 | 2430 | STKOMEIDIUM IYPICUM | 4 |
| ACSE | 32 | 851675 | 161523 | 1015 | ACANTHOSTOMELLA NORVEGICA | 4 |
| ACSE | 32 | 451675 | 101523 | 1045 | AMPHORIDES GUADRILINEATA | 12 |
| ACSE | 32 | 451675 | 161523 | 1685 | CLIMACOCYLIS SCALAROIDES | 24 |
| ACSE | 32 | 451075 | 161523 | 1115 | dadarlella ganymedes | 76 |
| ACSE | 32 | 351615 | 161523 | 1185 | EUIINIINNUS LASUS-UNUAE | 8 |
| ACSE | 32 | d51675 | 161523 | 2235 | LUHMANIELLA OVIFUHMIS | 12 |
| ACPS | 32 | 451675 | 161523 | 1285 | parundella subcaudatá | 4 |
| ACSE | 32 | 051075 | 161523 | 2466 | SIRUMBIDIUM CALKINSI | 4 |
| ACSE | 32 | 051015 | 161523 | 24105 | SIKUMBIDIUM CONICUM | 64 |
| ACSE | 32 | 451675 | 161523 | 2428 | STKOMBIDIUM SIROEILUS | 12 |
| ACSE | 32 | 051675 | 161523 | 2425 | Sthumbidium sulcatum | 8 |
| ACSE | 32 | 451615 | 161523 | 2430 | SIKOMEIDIUM IYPICUM | 4 |
| AlSt | 32 | 051675 | 161523 | 1568 | IINTINNUS IUBULOSUS | 4 |


| SACD | \$ 1 | UAIt | time | $L$ | Srco | SPECIES NAME | NOPL |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| nelz | 12 | 090475 | 1345 | 10 | 1490 | CUDUNELLOPSIS AMERICANA | 76 |
| AELL | 12 | 196475 | 1345 | iv | 1115 | dadaylella ganymedes | 12 |
| AEL 2 | 12 | 096415 | 1345 | 10 | 1125 | dadayiella pachridecus | 4 |
| AEL2 | 12 | d96475 | 1345 | 10 | 1160 | EPIPLuCYCloides acuia | 16 |
| AELC | 1 2 | 196475 | 1345 | is | 1185 | EutiniInivus lasus-undae | 4 |
| AELZ | 12 | d46475 | 1345 | 10 | 2235 | LOHMANIELLA OVIFURMIS | 12 |
| AELZ | 12 | 1096475 | 1345 | 10 | 1365 | SALPINGELLA MINUIISSIMA | 4 |
| AELL | 12 | 09.4415 | 1345 | 14 | 1385 | Stenusemella venikicosa | 8 |
| AELL | 12 | 109445 | 1345 | 1H | 2406 | SIRUMBIUIUM CALKINSI | 8 |
| AELZ | 12 | 096475 | 1345 | is | 2405 | STROMBIDIUM CONICUM | 24 |
| AELZ | 12 | 190475 | 1345 | 10 | 2415 | StRUMBIdidum ovale | 32 |
| AELZ | 12 | 0964775 | 1345 | is | 2426 | SIKUMBIDIUM Sthubilus | 20 |
| AELL | 12 | 1994475 | 1345 | in | 2425 | SIKOMEIDIUM SULCAIUM | 88 |
| AEL2 | 12 | 096475 | 1345 | 10 | 2436 | SIROMEIDIUM TYPICUM | 8 |
| AtLZ | 12 | d9n475 | 1345 | 10 | 1456 | TINIINNIDIUM INCERTUM | 4 |
| AELZ | 12 | 096475 | 1345 | 14 | 1455 | TINIINNOPSIS ACUMINAIA | 16 |
| AELL | 12 | 490475 | 1345 | 10 | 1524 | TINTINNOPSIS MINUTA | 132 |
| AEL2 | 12 | 646,475 | 1345 | 14 | 1550 | TINTINNOPSIS TOCANTINENSIS | 40 |
| AELL | 12 | 440475 | 1345 | 16 | 1555 | TINTINNUPSIS TUBULOSA | 8 |
| AEMB | 12 | 090475 | 1345 | 11 | 1085 | Climacucrlis scalaroides | 4 |
| AEMB | 12 | 090475 | 1345 | 11 | 1898 | CODUNELLOPSIS AmERICANA | 52 |
| AtMB | 12 | 1494475 | 1345 | 11 | 1115 | dadayiella ganymedes | 4 |
| ALME | 12 | 096475 | 1345 | 11 | 1125 | dadariella pachrioecus | 4 |
| AEMS | 12 | 19.6475 | 1345 | 11 | 1160 | EPIPLOCYCLOIUES ACUTA | 24 |
| AEMB | 12 | 194415 | 1345 | 11 | 2235 | LOHMANIELLA UVItORMIS | 12 |
| Atrib | 12 | 140475 | 1345 | 11 | 1310 | PSEUDOMETACYLIS URNATA | 4 |
| AEmb | 12 | 49.4475 | 1345 | 11 | 1330 | RHABDONELLA HRANDII | 4 |
| AEMH | 12 | 090415 | 1345 | 11 | 1365 | SALPINGELLA MINUIISSIMA | 4 |
| AEMS | 12 | 090475 | 1345 | 11 | 24bn | SIMOMGIDIUM CALKINSI | 28 |
| AEME | 12 | 496475 | 1345 | 11 | 2445 | Strombidium cunicum | 20 |
| AtMB | $1<$ | 496475 | 1345 | 11 | 2415 | SIRUMBIDIUM OVALE | 16 |
| AEMB | 12 | 1098475 | 1345 | 11 | 2420 | SIKOMGIOIUM STKOBILUS | 46 |



## APPENDIX A

## TABLE 2

LIST OF SPECIES AND THEIR ABUNDANCE IN NUMBERS/ $\ell$ FOR EACH SAMPLE COLLECTED IN 1976 FROM STATIONS 1,2 AND 3 ALONG TRANSECT II

## Explanation of Table:

```
SACD = Sample Code
    S = Station
    \(\mathrm{T}=\) Transect
Date = Date
Time \(=\) Time of Sampling
    Z = Depth of Sample
SPCD = Species Code
NOPL \(=\) Number of Organisms/ \(\ell\)
```

| SACU | 5 | DAJE | IIME | 2 | SPCU |  | SPECIES NA |  | NOPL |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| AGSP | 2 | 426c 76 | 1736 | d | 24ns | SIRUMbIUIUM | CINICUM |  | 24 |
| AGSP | 2 | －20276 | 1738 | $\Delta 5$ | 2426 | Strumbidilum | Sthueilus |  | 4 |
| AGSP | 2 | 420276 | 1134 | 45 | 1560 | IINIINNUS IU | ubulusus |  | 12 |
| AGSN | 12 | 026216 | 1730 | 10 | 5175 | EUPLUTES SEX | xCOSIATUS |  | 8 |
| AGSN | 12 | －2й16 | 1730 | 14 | 2408 | STRUMHIDIUM | CALKINSI |  | ， |
| AGSN | 12 | v20276 | 1730 | $1 \Delta$ | 2405 | Strumbidium | CONICUM |  | 8 |
| AGSN | c | －25216 | 1730 | 1. | 2420 | STHOMBIUIUM | Sirusilus |  | 8 |
| AGSN | 12 | －26276 | 1736 | If | 2425 | SIROMBIUIUM | SULCAIUM |  | 4 |
| Alsug | 22 | $\triangle 20276$ | 1210 | 16 | 2235 | LUHMANIELLA | uVIf URMIS |  | 36 |
| AGUG | 22 | ज2u2l6 | 1214 | 10 | 2465 | Strumbioivia | CONICUM |  | 52 |
| agug | 22 | 426276 | 1210 | 10 | 2415 | Strumbidium | OVALE |  | 32 |
| AliUG | 22 | 026276 | 1218 | 16 | 2426 | Strunilidium | Strubilus |  | 8 |
| AGUG | 22 | v26276 | 1210 | 10 | 2425 | Strombioium | SULCATUM |  | 76 |
| AGUJ | 22 | 42v216 | 1210 | 14 | 3210 | globigerina | Pachrotikma |  | 4 |
| abuJ | 22 | 020216 | 1210 | 14 | 2235 | Luhialiviella | OVIFURMIS |  | 96 |
| aguj | 22 | － 20216 | 1210 | 14 | 2460 | Sthumbiolum | CALKINSI |  | 4 |
| AGUJ | 22 | 028く76 | 1210 | 14 | 2405 | Sirumbioium | CONICUM |  | 116 |
| AGUJ | 22 | 020276 | 1210 | 14 | 2415 | Strumbidium | UVALE |  | 16 |
| AGUJ | 22 | 020276 | 1210 | 14 | 2425 | STROMBIDIUM | sulcatum |  | 88 |
| aguj | 22 | 420276 | 1210 | 14 | 2430 | STROMEIDIUM | IYPICum |  | 4 |
| AGwK | 32 | 020170 | 1755 | 16 | 1185 | EUIINIINNUS | lasus－undae |  | 8 |
| AGwk | 32 | ט20176 | 1755 | 10 | 1265 | ORMOSELLA BR | RESSLAUI |  | 4 |
| AGWK | 32 | טご1／6 | 175s | 10 | 1355 | SALPINGACANI | iha undata |  | 4 |
| AGwk | 32 | 026176 | 1755 | 1 is | 2465 | Strombiolum | CONICUM |  | 4 |
| Atink | 32 | a20176 | 1755 | 1s | 2415 | STRUMEIUIUM | OVALE |  | 4 |
| AGwk | 32 | n20176 | 1755 | 10 | 2420 | SIROMBIDIUM | Strobilus |  | 4 |
| AGwk | 32 | actil6 | 1755 | 10 | 2425 | Strumbidium | sulcatum |  | 8 |
| AGiwk | 32 | 020176 | 1755 | 16 | 1590 | XYSTUNELLA 1 | TREFORII |  | 4 |
| AGWM | 32 | 626176 | 1808 | 27 | 1145 | AMPHUKIDES G | huadrilineata |  | 4 |



```
SALD S I DAIE TIME L SPCD SPECIES NAME NUPL
AJN1 2 < B31476 0B2W 14 4WHS ACANTHOSTARUS PURPURASCENS 4
AJIVI 2 2 $31976 UU20 14 l#85 CLIMACUCYLIS SCALARUIUES 4
AJNI 2 2 HS1976 D&2V 14 118S EUTINIININUS LASUS-UIVIAE 4
AJINI 2 2 O31476 UB20 14 2235 LOHMANIELLA UVIFURMIS 4
AJN1 2 2 631476 UO2U 14 1306 PROPLECTELLA SUBCAUDATA 4
AJNL 2 2 131976 d824 14 1305 PROTOKHABDONELLA CUHTA 4
AJNI 2 < U314/6 UB20 14 240U STHUNIBIOIUM CALKINSI 8
AJNI 2 < U31470 DE2U 14 2405 STKUMHIDIUM CUNICUM 32
AJN! 2 2 bS1470 UB2W 14 2415 STRUMBIOIUM UVALE 16
AJNI 2 2 OS1970 SB20 14 2420 SIRUMBIDIUM STKUBILUSS 28
AJNI < 2 031976 UB2N 14 2425 STROHHIOIUM SULCAJUM 36
AJNI 2 2 131916 OH2G 14 2430 STROMUIDIUM TYPICUM 4
AJNI 2 2 N31476 DA2U 14 155S TINIINNUPSIS TUBULUSA 4
AJNI 2 2 U31916 UB2W 14 1590 XYSIONELLA TREFORTI 4
AJPK 3 2 J31476 153N 1G 1045 AMPHOKIDES OUADRILINEATA 4
AJPK S 2 1031976 153U 10 1185 EUTINTINNUS LASUS-UNDAE 8
AJPK 3 2 S31476 153| 1N 321ט GLOBIGERINA PACHYOERMA 4
AJPK 3 2 031476 1530 16 2235 LOHMANIELLA UVIFORMIS 4
AJPK 3 2 631476 153U 10 24U5 STRUMBIDIUM CONICUH 16
AJHK 3 2 U31476 153U 10 2415 STRUMBIDIUM UVALE 20
AJPK 3 2 U31Y76 153G 1U 2420 STKUMBIUIUM STROUILUS &
AJPK 3 2 U31476 153U 16 2425 SIRUMUIDIUM SULCATUM 48
AJHM 3 2 031Y/6 15SU 15 1085 CLIMACOCYLIS SCALAROIDES 4
AJPM S 2 D31976 153J 15 1355 SALPINGACANTHA UNDATA 4
AJPM S 2 $31476 1530 15 240U SIRUMBIDIUM CALKINSI 4
AJHM 3 2 U319/6 153U 15 24U5 STRUMBIUIUM CONILUM 8
AJFM 3 2 U31476 153| 15 2415 STROMBIDIUM OVALE B
AJPM 3 2 0319/6 1530 15 2420 STKUMBIOIUM SIKOBILUS 4
AJPM S 2 U31476 1530 1S 2425 STHOMBIDIUM SULCATUM 36
AKEK 1 2 B4VL7% 1210 U6 517U EUPLOTES MINUTA 16
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SACU S I UAIE IIME L SPCU SPECIES NAME NOPL
AKEN 1 2 04WC16 1210 00 2235 LOHMANIELLA OVIFURMIS 16
AKEK 1 2 |4ロL76 12IN HO 1385 STENUSEMELLA VENTRICUSA B
AKEK 1 2 \triangle4\Delta2/6 1210 U6 240U STKONHIUIUM CALKINSI *
AKEK 1 2 U4U270 121U U6 24U5 SIKUMBIOIUM CONICUM 4
AKEK 1 2 S4w276 121n Db 2420 STHOMBIOIUM STROBILUS 20
AKEK I ? S4णC/O 12I0 06 2425 SIHUMBIUIUM SULCAIUM 36
AKEK 1 2 D4w2/6 121U D6 243U STRUMBIUIUM TYPICUM 4
AKEK 1 2 04U270 12IU U6 145U TINTINNIUIUM INCERTUM 4V
AKEI 1 2 ज4JC70 121U 10 S170 EUPLUTES MINUTA 4
AKt1 1 2 w40C76 1210 10 223S LOHMANIELLA OVIFUHMIS 16
AKEI 1 2 G4d276 1210 10 1385 S1ENUSEMELLA VENTKICOSA 4
AKEI 1 2 U4U276 121v IV 24bU SIRUMBIOIUM CALKINSI 0
AKE1 1 2 リ4U2/6 1210 1U 2405 SIRUMB10IUM CONICUM 12
AKEI 1 2 b4WC76 1210 10 2420 SIKUMBIDIUM SIRUBILUS 76
AKEI 1 2 U4凶&76 12IU 10 2425 STKOMBIOIUM SULCATUM 28
AKE1 1 2 U4NC10 1210 1n 2430 SIRUMBIOIUM TYPICUM 4
AKEI I 2 S46276 1210 10 1450 IINTINNIOIUM INCENTUM 20
AKEI 1 2 U4W276 121U10 156ט IINIINNUS TUBULUSUS 8
AKGN 2 U. U4S76 UH25 U8 2235 LOHMANIELLA UVIFOHMIS . 4
AKGN 2 2 U46376 טU25 W8 240日 SIROMBIUIUM CALKINSI 4
AKGN 2 2 040376 UB25 O& 24US STKOMBIOIUM CONICUM 28
AKGN 2 2 U4WS76 U825 AB 242G SIKUMBIOIUM STRUBILUS 40
AKGN 2 2 ט4ロS70 U825 D8 2425 STRUMBIUIUM SULCATUM 36
AKGN C 2 S40376 U825 U8 2430 SIKOMBIOIUM IYPICUM 4
AKGN < 2 H4US76 U825 UB 14SO IINTINNIDIUM INCERTUM 8
AKGL 2 2 U4U376 d825 10 2235 LOHMANIELLA OVIFURMIS 24
AKGL C2 U4VS76 DB2S 1v 1385 STENOSEMELLA VENIRICUSA &
AKGL 2 2 U4W376 UB25 10 24UU STKOMBIOIUM CALKINSI 4
AKGL 2 2 ص4H376 UB25 10 2405 SIRUMBIUIUM CONICUM SN
AKGL C C U4U376 UB2S 10 2415 STHUMBIUIUM OVALE 28
AKGL 2 2 S40376 1825 10 242U SIROMBIUIUM STRUBILUS 16
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SACD S I UAIE IIME Z SPCD SPECIES NAME NOPL
ALFE 3 2 W6067t 692b 21 2405 STRUMBIDIUM CONICUM 3U
ALFE 3 2 06U676 U925 21 2415 STROMBIDIUM OVALE IO
ALFE 3 2 U6W6/6 U925 21 2420 SIRUMBIUIUM STROBILUS 20
ALFE 3 2 U6W676 0925 21 2425 STROMBIDIUM SULCATUM 30
AUHE I 2 671N76 12NU U9 1645 AMPHURIDES QUADHILINEAIA 4
AUNE & 2 U71676 12HU U9 2465 STROMBIDIUM CUNICUM 4
AUUE 1 2 S71\Delta70 12UU U9 2415 SIRUMBIUIUM OVALE 6
AUBE 1 ? G71W76 120ה \DeltaY 242U STRUMBIUIUM STRUBILUS &
AUBE 1 2 U11n76 12U\Delta UY 242S SIRUMBIOIUM SULCATUM 12
AUHE I 2 UTIUTG I2UU UY 1S6U IINIINNUS TUBULUSUS 4
AUHC 1 2 U71076 12UU 1U 118S EUTINTINNUS LASUS-UNOAE 4
AUBC 1 2 U71076 12BH 1U 2235 LUHMANIELLA OVIFORMIS 4
AUBC 1 2 S71076 120U 10 2405 STRUMBIDIUM CONICUM 28
AUBC 1 2 U71076 12UU 1S 2415 STKUMBIDIUM OVALE 4
AUBC 1 2 U7IUIO 120U 10 2420 SIRUMBIUIUM STRUBILUS 16
AUBC 1 2 071676 120日 In 2425 STROMBIDIUM SULCATUM 28
AUBC 1 2 U/IU16 1200 IU 2430 STRUMBIDIUM TYPICUM 4
AUBC 1 2 U71N76 12US 1\Delta 5435 TIARINA FUCUS 4
AUBC 1 2 071076 12UB 10 1560 TINIINNUS TUBULOSUS 16
AUUA 2 2 W71016 1855 15 NO PHUTOZUA OBSERVED D
AUCY 2 2 U71076 18S5 10 2235 LOHMANIELLA OVIFURMIS 4
AUCY 2 2 U71476 185S 10 2405 STRUMBIOIUM CONICUM B
AUCY 2 2 U71U76 1855 10 2415 STRUMBIDIUM UVALE 4
AUCY 2 2 ט/1076 1855 10 2420 STROMBIDIUM STROGILUS I2
AUCY 2 2 071076 1855 10 2425 STRUMBIUIUM SULCATUM, 16
AUCY & 2 U71076 18S5 10 1560 TINIINNUS TUBULUSUS , 4
AUEU 320/1176 153U 10 1515 TINIINNOPSIS LOBIANCOI 8
AUES 3 2 U71176 153U 20 1045 AMPHUKIDES OUAURILINEATA I2
AOES 3 2 671176 1530 2d 2235 LOHMANIELLA OVIFOKMIS 4
AUES 32,071176 153@ 201385 STENOSEMELLA VENIRICOSA &
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SACD S I UAIE TIME Z SPCU SPECIES NAME NOPL
AUES 3 < U71176 1530 2U 2415 STKOMBIOIUM OVALE 4
AOES 3 2 H71176 1530 20 2420 STROMBIOIUM STHOBILUS 4
AUES 3 2 U71170 1530 2U 2425 SIRUMBIDIUM SULCATUM 4
APUHI L 2 UBUY76 152Q 16 305S BOLIVINA STKIATULA &
APUH 1 C UBUY76 152U 1U 13S5 SALPINGACANTHA UNUAIA &
APUH 1 2 UBE476 1520 10 138S STENUSEMELLA VENIRICOSA 4
APUH 1 2 UBE976 1520 10 2415 STROMBIDIUM OVALE A
APUH 1 2 &BロY76 152甘 1H 2420 STRUMBIDIUM STRUBILUS 8
AFUH I 2 UQUY76 152U 10 242S STKOMBIDIUM SULCATUM 24
AHUH 1 2 JBW976 1S2U 10 2430 STROMBIUIUM TYPICUM 4
APUH 1 2 ABU976 1520 10 2565 TONTONIA GRACILLIMA 4
APUJ 1 2. UBVY76 1520 18 1045 AMPHOKIDES GUADRILINEATA 4
ARUJ I ¿ NBUY76 152U 18 3USS BULIVINA STRIAIULA 4
APOJ 1 2 טBUY76 152U 18 1085 CLIMACUCYLIS SCALAROIDES 4
APUJ 1 2 DBUY76 152U 18 1160 EPIPLOCYCLOIUES ACUTA 4
APUJ 1 2 U8#Y16 152U 18 1185 EUTINIINNUS LASUS-UNDAE 4
AHUJ L & UBGY70 1520 18 2235 LUHMANIELLA OVIFURMIS 8
APUJ 1 2 UBUY76 1520 18 2405 STRUMBIDIUM CONICUM 8
APOJ 1 2 UBUY76 152U 18 2415 STRUMBIOIUM UVALE &
APOJ 1 2 086976 152v 10 2420 STRUMBIOIUM STROBILUS 12
AHOJ 1 2 UBUY76 152Q 18 242S SIROMUIDIUM SULCATUM 40
APUJ 1 2 UBGY16 1520 18 5435 TIAKINA FUCUS 4
APUJ 1 2 UBUY76 152| 18 1560 TINIINNUS TUBULOSUS 4
AHEN 2 己 UBIU76 UB35 16 1305 PRUIURHABUONELLA CURTA 4
APEW 2 2 DBIU76 0835 10 24UU SIRUMBIDIUM CALKINSI` 4
APEN 2 C DUIV76 0B35 1U 242U SIKUMBIDIUM STKOBILUS 4
APEW 2 2 U81U76 4835 1U 242S STRUMBIDIUM SULCAIUM %
APEY 2 2 S $076 U835 41 118S EUTINTINNUS LASUSOUNDAE 8
APEY 2.2 UB1U16 UB55 41 4255 NEPHKUSPYRIS DOCRIS 4
APEY 2 2 H&IGI6 \B35 4I 242# STROMBIDIUM STRUBILUS 4
```

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SACU S I DAIE IIME L SPCU SPECIES NAME NOPL
APEY 2 C B81076 D835 41 2425 SIROMBIDIUM SULCATUM
APEY 2 2 BB1076 D835 41 1560 TINIINNUS TUBULOSUS 4
APGI 3 2 b81070 18US in 24\DeltaU STRUMBIDIUM CALKINSI B
APGI 3 < DOIUT6 18US ib 24BS SIROMBIDIUM CUNICUM 4
APGI 3 2 U&IOIO 1甘AS 10 2426 SIROMBIUIUM SIRUBILUS 4
APGI 3 2 ABID76 18US 10 242S SIROMBIDIUM SULCAIUIG 16
APGK 3 2 UBID76 18GS 26 404B ANTHUCYRTIOIUM OPHIRENSE 4
APGK 3 2 DU1\Delta76 18U5 20 1185 EUIINIINNUS LASUS-UNDAE 4
AfGK 3 2 HBIU76 18GS 2b c235 LUHMANIELLA OVIFORMIS 4
AUGA 1 2 \triangleY1b70 1610 \triangleB 1470 IINTINNUPSIS COMPRESSA 10
AWGA 1 2 U91616 1610 U8 1490 IINTINNUPSIS FENNICA 10
AUFY 1 2 b91076 1610 10 1290 PROPLECTELLA CLAPAREOEI 10
AUHK 2 2 $91470 15S5 10 1185 EUTINTINNUS LASUS-UNDAE 10
AUHK 2 2 UY1476 1555 1U 2405 SIRUMBIDIUM CONICUM 20
AGHK 2 2 GY1476 1555 1% 2426 STRUMGIDIUM SIRUBILUSS 10
AUHK 2 2 d91476 1555 10 242b SIKOMBIOIUM SULCAIUM 20
AGHM 2 < DY14/6 1555 31 116| EPIPLUCYCLOIDES ACUTA 10
AGHM 2 2 S41476. 1555 S1 118S EUTINIINNUS LASUS-UNDAE 20
AUHM 2 2 U91476 1555 31 2235 LOHMANIELLA OVIFURMIS 30
AGHM 2 2 041470 1555 31 24&U SIRUMBIDIUM CALKINSI I0
AWHM 2 2 $91476 1555 31 2485 SIRUMBIUIUM CONICUM 30
AGHM 2 2 091476 15S5 31 242U STROMBIDIUM STRUBILUS 20
AUHM 2 2 041476 1555 31 2425 SIRUMBIDIUM SULCAIUM 30
ANIY S 2 041476 6925 35 NO PRUTUZOA OBSERVED ©
AGIW 3 2 b41476 by25 in 24Gb SIROMBIUIUM CONICUM 8
```



```
AGIW 3 2 641476 6925 10 2425 SIRUMBIDIUM SULCAIUM 4
```




| SACU | s | 1 | UAIE | IIME | 2 | SPCD |  | SPECIES N |  | NOPL |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| A $2 \times 1$ | 3 | 2 | 116976 | 1335 | 01 | 2430 | STRUMBIOIUM | TYPICUM |  | 12 |
| A $2 \times 1$ | 3 | 2 | 116976 | 1335 | $0_{1}$ | 1478 | TINTINNOPSIS | C COMPRESSA |  | 4 |
| A $2 \times 1$ | 3 | 2 | 110976 | 1335 | $\Delta 1$ | 1485 | IINIINNOPSIS | 5 direcia |  | 4 |
| A $2 \times J$ | 3 | 2 | 110976 | 1335 | 17 | 4230 | lithumellisa | a SETOSA |  | 4 |
| A $2 \times \mathrm{XJ}$ | 3 | 2 | 114976 | 1335 | 17 | 2235 | LOHMANIELLA | OVIFORMIS |  | 36 |
| $A<x J$ | 3 | 2 | 110976 | 1335 | 17 | 1355 | SALPINGACANT | antha undata |  | 4 |
| $A<x J$ | 3 | 2 | 116476 | 1335 | 17 | 1368 | SALPINGELLA | acuminata |  | 4 |
| A $\langle x J$ | 3 | 2 | 110476 | 1335 | 17 | 24＊6 | Strumbidilum | CALKINSI |  | $\theta$ |
| $A \geq X J$ | 3 | $\ldots$ | 110976 | 1335 | 17 | 24145 | SIROMBIDIUM | CONICUM |  | 16 |
| A $2 \times X J$ | 3 | 2 | 116476 | 1335 | 11 | 2420 | SIRUMBIDIUM | StROBILUS |  | 12 |
| $A<x J$ | 3 | 2 | 114976 | 1335 | 17 | 2425 | STRUMBIDIUM | SULCATUM |  | 132 |
| $A<x J$ | 3 | 2 | 116976 | 1335 | 17 | 2434 | Strumbiuium | TYPICUM |  | 8 |
| $A<x J$ | 3 | C | 116976 | 1335 | 17 | 5435 | IIARINA FUCU |  |  | 4 |
| A $<x K$ | 1 | 2 | 120176 | 12 bu | 1 | 5155 | EPHELOTA GEM | MINARIA |  | 20 |
| A $2 \times K$ | 1 | 2 | 126176 | 12ヵu | $\Delta_{1}$ | 2235 | LOHMANIELLA | OVIF URMIS |  | 68 |
| A $2 \times K$ | 1 | 2 | 120176 | 1200 | $\Delta 1$ | 5245 | MESODINIUM R | RUBRUM |  | 12 |
| ALXK | ， | 2 | 124176 | 1280 | $\Delta 1$ | 1385 | SIENUSEMELLA | a venthicosa |  | 104 |
| ALXK |  | 2 | 120176 | 1208 | $\Delta 1$ | 2395 | STRUMBIDIUM | ACUMINATUM |  | 8 |
| A LXK | 1 | 2 | 120176 | 1206 | 41 | 2406 | STHOMBIDIUM | CALKINSI |  | 88 |
| ALXK | 1 | 2 | 120176 | 1200 | d 1 | 2465 | Strumbidium | CONICUM |  | 112 |
| ALXK | ， | 2 | 126176 | 1280 | 01 | 2420 | STROMBIVIUM | Strubilus |  | 48 |
| AZXK | 1 | 2 | 128176 | 1204 | $d$ | 2425 | SIROMBIDIUM | sulcatum |  | 260 |
| A $2 \times K$ | 1 | 2 | 124176 | 1208 | 11 | 2436 | SIHOMBIDIUM | TYPICUM |  | 132 |
| ALXK | 1 | 2 | 126176 | $12 ⿰ 口 口$ | 01 | 5440 | IIARINA FUSU |  |  | 20 |
| ALXK | 1 | 2 | 126176 | 1208 | 01 | 1450 | IINIINNIDIUM | InCERTUM |  | 116 |
| A $2 \times \times$ | 1 | 2 | 126176 | 1206 | 1 | 1455 | IINIINNOPSIS | acuminata |  | 32 |
| ALXK | 1 | 2 | 126176 | 1200 | bl | 1478 | IINIINNOPSIS | compressa |  | 24 |
| AZXK | 1 | 2 | 120176 | 1208 | $\Delta 1$ | 1555 | IINIINNOPSIS | tubulusa |  | ， |
| A $2 \times K$ | 1 | 2 | 120176 | 1200 | 01 | 1560 | IINIINNUS TU | ubulusus |  | 36 |
| AZXK | 1 | 2 | 128176 | 12ns | $\Delta$ | 2565 | IUNTUNIA GRA | ACILlima |  | 8 |
| ALXK | 1 | 2 | 120176 | 1200 | 1 | 5165 | EUGLYPHA LUE | VIS |  | 12 |



| SALO | S | 1 | DAIE | IIME | 2 | SPCD |  | SPECIES NA |  | NOPL |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $A<X N$ | 2 | 2 | 120276 | 1700 | 18 | 2415 | SIRUMEIDIUM | OVALE |  | 64 |
| A $2 \times N$ | 2 | 2 | $12 ⿰ 276$ | 1700 | 18 | 2420 | SIROMBIUIUM | STROBILUS |  | 16 |
| $A L X N$ | 2 | 2 | 120276 | 1700 | 18 | 2425 | STKOMBIDIUM | SULCATUM |  | 164 |
| ALXN | 2 | 2 | 128216 | 1706 | 18 | 2430 | SIROMEIDIUM | TYPICUM |  | 4 |
| $A L \times 0$ | 3 | 2 | 124276 | 1030 | 01 | 3095 | CONCHIDINIUM | A ARGIUPE |  | 4 |
| A $2 \times 0$ | 3 | 2 | 120276 | 1436 | 01 | 1135 | DICTYUCYSTA | LATA |  | 4 |
| $A \angle X O$ | 3 | 2 | 120276 | 1030 | 01 | 1190 | EUTINIINNUS | TENUE |  | 4 |
| A $2 \times 0$ | 3 | 2 | 120276 | 163b | 01 | 2235 | LOHMANIELLA | OVIFURMIS |  | 32 |
| $A 2 \times 0$ | 3 | 2 | 120276 | 1036 | H1 | 1300 | PROPLECTELLA | SUBCAUOATA | * | 4 |
| A $2 \times 0$ | 3 | 2 | 120216 | 1030 | 01 | 24nv | STRUMEIDIUM | CALKINSI |  | 12 |
| $A 2 \times 0$ | 3 | 2 | 120276 | 103n | W1 | 246b | STKOMEIUIUM | CONICUM |  | 20 |
| A $2 \times 0$ | 3 | 2 | 120216 | 1030 | 01 | 2415 | SIROMBIOIUM | OVALE |  | 4 |
| A $2 \times 0$ | 3 | 2 | 120276 | 1030 | 01 | 2420 | STHOMUIDIUM | STRUBILUS |  | 4 |
| $A 2 \times 0$ | 3 | 2 | $12 n 276$ | 103n | 01 | 2425 | STROMBIDIUM | SULCAIUM |  | 28 |
| $A<X O$ | 3 | 2 | 120276 | 1030 | 01 | 4580 | JRIPLACIACAN | NTHA ABIEIIHA |  | 4 |
| $A \angle X P$ | 3 | 2 | 126276 | 1030 | 21 | 1140 | DICTYUCYSTA | RETICULATA |  | 4 |
| $A \angle X P$ | 3 | 2 | 120276 | 1030 | 21 | 4220 | HEXALUNCHA P | PHILISUPHICA |  | 4 |
| ALXP | 3 | 2 | 120276 | 1436 | 21 | 2235 | LUHMANIELLA | OVIFORMIS |  | 40 |
| $A<X P$ | 3 | 2 | 120276 | 1630 | 21 | 1355 | SALPINGACANT | THA UNDATA |  | 4 |
| A $2 \times P$ | 3 | 2 | 120276 | 1030 | 21 | 1385 | SIENUSEMELLA | VENTRICOSA |  | 4 |
| A $2 \times P$ | 3 | 2 | 12 1276 | 1030 | 21 | 2406 | SIRUMBIUIUM | CALKINSI |  | 28 |
| $A 2 \times P$ | 3 | 2 | 120276 | 1030 | 21 | 2405 | SIRUMBIDIUM | CONICUM |  | 12 |
| A $2 \times P$ | 3 | 2 | 120276 | 1030 | 21 | 2415 | STROMBIOIUM | UVALE |  | 4 |
| A $2 \times P$ | 3 | 2 | 12 ¢ 76 | 1030 | 21 | 2420 | STROMBIUIUM | SIROBILUS |  | 8 |
| A $2 \times P$ | 3 | 2 | 120276 | 1030 | 21 | 2425 | STRUMBIDIUM | SULCATUM |  | 36 |
| $A \angle X P$ | 3 | 2 | 120276 | 1630 | 21 | 1560 | IINIINNUS TU | UBULOSUS |  | 8 |

APPENDIX B

TABLE 1

## STATISTICAL DATA FOR THE 1975 SAMPLES

Explanation of Table:

```
SACD = Sample Code
    S = Station
    T = Transect
Date = Date
Time = Time of Sampling
    Z = Depth of Sample
TPPL = Total Number of Protozoa/\ell
TTPL = Total Number of Tintinnids/\ell
TOPL = Total Number of Oligotrichs/\ell
TFPL = Total Number of Foraminifera/\ell
TRPF = Total Number of Radiolaria+Acantharia/\ell
TMPL = Total Number of Miscellaneous Protozoa/\ell
TPCT = Tintinnids as % of Total Protozoa
OPCT = Oligotrichs as % of Total Protozoa
MPCT = Miscellaneous Protozoa (including foraminifera, radiolaria,
    and acantharia) as % of Total Protozoa
NSPS = Number of Species/Sample
    SDI = Shannon-Weiner Species Diversity Index
TDWT = Total Dry Weight in mg/m
```

| SALU | S | 1 | UAIE | I MME | $L$ | IPPL | I IPL | TUPL | TFHL | IKPL | 1 MPL | TPLT | UPCI | MPCI | NSPS | SU1 | 1UN1 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| AAKN | 1 | 2 | 121714 | 1510 | 05 | 48 | 8 | $4 n$ | $\Delta$ | n | 0 | 17 | 83 | v | 0 | 1.540 | ． 06 |
| AAKL | 1 | 2 | 121174 | 1310 | 10 | 28 | 16 | 12 | 0 | $b$ | 0 | 57 | 43 | 0 | 4 | 1.217 | .105 |
| AAINM | $\checkmark$ | 2 | k104／5 | 1／54 | 18 | 116 | 4 | 112 | 6 | 0 | $v$ | 3 | 97 | $b$ | 1 | 1.792 | .14 |
| AAINK | 2 | $\llcorner$ | 016473 | $1 / 45$ | 10 | 240 | 4 | 288 | 4 | 0 | ， | 1 | 97 | 1 | 4 | 1.881 | .11 |
| AANM | 3 | 2 | 1212／4 | 1200 | 10 | 35 | 116 | 232 | $b$ | 4 | 10 | 33 | 66 | 1 | 16 | 2．321 | ． 63 |
| AAGS | 3 | 2 | 121274 | 1205 | 2b | 344 | 96 | 236 | 0 | 12 | $v$ | 28 | 64 | 3 | 10 | 2.344 | ． 51 |
| ACivis | 1 | 2 | －41／1 | 1525 | $b$ | 144 | 124 | 2n | $\Delta$ | $\square$ | $b$ | 86 | 14 | 0 | 7 | 1.272 | ． 23 |
| ACLL | 1 | 2 | 041／1 | 15 co | 10 | 20n | 100 | 30 | 4 | 0 | 0 | 86 | 18 | 2 | 10 | 1.322 | 46． 87 |
| ACOU | $\leqslant$ | 2 | 1041875 | 1510 | 10 | 260 | 44 | 152 | 4 | 0 | $b$ | 20 | 16 | 2 | 11 | 2．04b | ． 52 |
| ALHE | c | 2 | 1041875 | 1510 | 13 | C04 | 56 | 164 | 4 | $n$ | 10 | 18 | 46 | 2 | 110 | 1.184 | .34 |
| ALSL | 3 | 2 | 051615 | 1015 | 10 | 208 | 150 | 52 | $b$ | 0 | $\Delta$ | 15 | 2 | 0 | 14 | 2.172 | －6 |
| ACJt | 3 | 2 | 051075 | 1015 | 23 | 236 | 132 | 144 | 0 | 0 | $b$ | 50 | 44. | 0 | 13 | 1.981 | ． 52 |
| AtLC | 1 | 2 | 146475 | 1345 | 10 | 510 | $3 C 4$ | 192 | 0 | 0 | 0 | 63 | 31 | 0 | 19 | 2.371 | 1.24 |
| Ativis | 1 | $c$ | 109n475 | 1345 | 11 | 452 | 2こn | 212 | $b$ | $\Delta$ | 0 | 51 | 49 | d | 21 | 2.583 | 1.22 |
| AErt | 2 | $\stackrel{1}{2}$ | A90 ל－b | 1430 | 10 | bo | 8 | 40 | k | 8 | 0 | 14 | 71 | 14 | 8 | 1.847 | 4.47 |
| AEHG | 2 | 2 | a90ちls | 1430 | 2 | c 4 | 12 | 10 | $b$ | 0 | $\checkmark$ | 43 | 57 | 0 | 4 | 1.277 | .15 |
| AtSC | 3 | 2 | 09w0／b | $16>2$ | 10 | 26 | 4 | 8 | 0 | $n$ | $v$ | 20 | 46 | 40 | 4 | 1.332 | .14 |
| AtSt | 3 | $c$ | 岛0075 | 1652 | 24 | 24 | $b$ | 16 | 0 | $\Delta$ | 0 | 33 | 67 | 0 | 4 | 1.242 | .103 |

## APPENDIX B

## TABLE 2

STATISTICAL DATA FOR THE 1976 SAMPLES

Explanation of Table：

```
SACD = Sample Code
    S = Station
    T = Transect
Date = Date
Time = Time of Sampling
    Z = Depth of Sample
TPPL = Total Number of Protozoa/\ell
TTPL = Total Number of Tintinnids/\ell
TOPL = Total Number of Oligotrichs/\ell
TFPL = Total Number of Foraminifera/\ell
TRPF = Total Number of Radiolaria+Acantharia/l
TMPL = Total Number of Miscellaneous Protozoa/\ell
TPCT = Tintinnids as % of Total Protozoa
OPCT = Oligotrichs as % of Total Protozoa
MPCT = Miscellaneous Protozoa (including foraminifera, radiolaria,
and acantharia) as % of Total Protozoa
NSPS = Number of Species/Sample
    SDI = Shannon-Weiner Species Diversity Index
TDWT = Total Dry Weight in mg/m
```

| SACD | $s$ | DATE | IIME | 2 | PPL | IIPL | TOPL | JFPL | TRPL | IMPL | TPCT | OPCT | MPCT | NSP3 | SDI | WT |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| AGSP | 12 | 020276 | 173 18 | 45 | 40 | 12 | 28 | $\Delta$ | $\Delta$ | 0 | 30 | 76 | 0 | 3 | . 898 | .87 |
| AGSN | 12 | 020276 | 1730 | 10 | 32 | 0 | 24 | $\Delta$ | 0 | 8 | 0 | 75 | 25 | 5 | 1.560 | .16 |
| AGUG | 22 | 426276 | 1210 | 10 | 204 | $\theta$ | 204 | 0 | 0 | 0 | 0 | 100 | 0 | 5 | 1.440 | .23 |
| agus | 22 | 820276 | 1210 | 14 | 328 | 1 | 324 | 4 | 0 | 0 | 0 | 99 |  | 7 | 1.389 | .51 |
| AGwK | 32 | -20176 | 1755 | 10 | 45 | 20 | 20 | $b$ | $\Delta$ | $\Delta$ | 50 | 50 | 0 | 8 | 2.025 | .12 |
| AGWM | 32 | 020176 | 1800 | 27 | 56 | 12 | 44 | $\theta$ | 0 | 0 | 21 | 79 | 0 | 6 | 1.668 | . 12 |
| AJLL | 12 | 031876 | 1140 | 05 | 60 | 24 | 36 | 0 | 1 | $\Delta$ | 40 | 60 | 0 | 7 | 1.767 | .21 |
| AJLJ | 12 | 031876 | 1140 | 10 | 68 | 28 | 36 | 4 | 0 | $\Delta$ | 41 | 53 | 6 | 10 | 2.084 | .25 |
| AJNG | 22 | 031976 | 0820 | 10 | 104 | 8 | 96 | $\Delta$ | 0 | $\Delta$ | 8 | 92 | 0 | 9 | 1.984 | .21 |
| AJNI | 22 | 831976 | 482』 | 14 | 156 | 24 | 128 | $\theta$ | 4 | 0 | 15 | 82 | 3 | 14 | 2.203 | . 42 |
| AJPK | 32 | 631976 | 153日 | is | 112 | 12 | 96 | 4 | 0 | 0 | 11 | 86 | 4 | 8 | 1.683 | .21 |
| AJPM | 32 | 031976 | 1530 | 15 | 68 | 8 | 68 | 0 | 0 | 0 | 12 | 88 | 0 | 7 | 1.507 | .07 |
| AKEK | 12 | 040276 | 1210 | 06 | 152 | 48 | 88 | 0 | 0 | 16 | 32 | 58 | 11 | 9 | 1.935 | . 29 |
| AKEI | 12 | 448276 | 1210 | 16 | 180 | 32 | 144 | $\theta$ | 0 | 4 | 18 | 88 | 2 | 10 | 1.824 | . 59 |
| AKGN | 22 | 040376 | 0825 | 48 | 124 | 8 | 116 | 0 | $\Delta$ | $\Delta$ | 6 | 94 | $\Delta$ | 7 | 1.569 | . 30 |
| AKGL | 22 | 140376 | 0825 | 10 | 184 | 8 | 176 | $\Delta$ | 0 | 0 | 4 | 96 | 0 | 8 | 1.814 | . 29 |
| AKIT | 32 | 140376 | 1620 | 10 | 72 | 4 | 68 | $\Delta$ | 4 | 4 | 6 | 83 | 11 | 8 | 1.908 | . 12 |
| AKIV | 32 | 040376 | 1635 | 16 | 84 | 20 | 610 | b | 4 | $\square$ | 24 | 71 | 5 | 10 | 2.137 | .23 |
| ALBW | 12 | 060376 | 1120 | 67 | 76 | 32 | 44 | 0 | 0 | 0 | 42 | 58 | 0 | 7 | 1.764 | . 24 |
| ALBu | 12 | 066376 | 1120 | 10 | 128 | 68 | 60 | $b$ | $\Delta$ | 1 | 53 | 47 | 0 | 8 | 1.895 | . 57 |
| ALOL | 22 | 460576 | 0925 | 10 | 68 | 12 | 56 | 0 | 0 | $\Delta$ | 18 | 82 | 0 | 6 | 1.395 | . 39 |
| ALON | 22 | 460576 | 4925 | 20 | 104 | 12 | 92 | 0 | 0 | $\checkmark$ | 12 | 88 | 0 | 8 | 1.721 | . 55 |
| ALFC | 32 | 060676 | 0925 | 10 | 198 | 10 | 170 | 10 | $\Delta$ | 0 | 5 | 89 | 5 | 8 | 1.851 | . 26 |
| ALFE | 32 | 060676 | 0925 | 21 | 120 | 36 | 90 | $\checkmark$ | 0 | $\Delta$ | 25 | 75 | 0 | 7 | 1.824 | . 24 |
| AUEE | 12 | 471076 | 1206 | 49 | 40 | 8 | 32 | 0 | $n$ | 0 | 2 H | 80 | 0 | 6 | 1.696 | .147 |
| AUBC | 12 | 171076 | 1246 | 10 | 108 | 26 | 84 | 0 | 0 | 4 | 19 | 78 | 4 | 9 | 1.876 | . 23 |
| AUDA | 22 | 171076 | 1855 | 15 | $\Delta$ | $\Delta$ | 0 | 0 | 4 | $\Delta$ | 0 | 0 | 0 | 0 | 0.000 | 0.00 |
| AUCY | 22 | 4711476 | 1855 | 10 | 48 | 4 | 44 | 0 | 0 | $\Delta$ | 8 | 92 | 0 | 6 | 1.633 | .10 |
| AUEG | 32 | 171176 | 15310 | 10 | 8 | 8 | 0 | 0 | 0 | $\checkmark$ | 100 | 0 | 0 | 1 | 0.000 | .02 |
| AOES | 32 | 071176 | 1530 | 20 | 32 | 16 | 16 | 0 | 6 | $\Delta$ | 50 | 50 | 0 | 6 | 1.667 | . 09 |
| APUH | 12 | 480976 | 1528 | 10 | 56 | 8 | 44 | 4 | 0 | 0 | 14 | 79 | 7 | 8 | 1.772 | . 23 |
| APDJ | 12 | 080976 | 152b | 18 | 104 | 210 | 76 | 4 | $\square$ | 4 | 19 | 73 | 8 | 12 | 2.086 | . 37 |
| APEW | 22 | 081076 | 14835 | 10 | 20 | 4 | 16 | 0 | 0 | 4 | 20 | 80 | 0 | 4 | 1.332 | . 15 |
| APEY | 22 | 081076 | 0835 | 41 | 32 | 12 | 16 | 0 | 4 | 0 | 38 | 50 | 13 | 5 | 1.494 | . 13 |


|  | SACD | 3 | DAIE | IIME | 2 | TPPL | TIPL | TOPL | IFPL | TRPL | IMPL | TPCT | OPCT | MPCT | N3PS | SOI | TOWT |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | APGI | 32 | 481076 | 1805 | 16 | 32 | 0 | 32 | 0 | $\Delta$ | $\Delta$ | 0 | 100 | 0 | 4 | 1.213 | . 05 |
|  | APGK | 32 | 081476 | 1805 | 26 | 12 | 4 | 4 | 0 | 4 | 0 | 33 | 33 | 33 | 3 | 1.099 | . 21 |
|  | AUGA | 12 | 491076 | 1614 | 18 | 20 | 20 | 0 | 0 | 0 | $\Delta$ | 140 | 0 | 0 | 2 | . .693 | 0.14 |
|  | AgFy | 12 | 091676 | 1610 | 14 | 10 | 16 | 0 | $\Delta$ | 0 | 4 | 100 | 0 | 0 | 2 | 0.000 | .04 |
|  | A GHK | 22 | 091476 | 1555 | is | 60 | 10 | 50 | 0 | 0 | 0 | 17 | 83 | 0 | 4 | 1.330 | 14 |
|  | AGHM | 22 | 091476 | 1555 | 31 | 150 | 30 | 120 | 0 | 0 | 0 | 20 | 88 | 0 | 4 | 1.864 | 45 |
|  | AWIY | 32 | 091476 | 0925 | 35 | $\Delta$ | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | .00 |
|  | Aalw | 32 | 191476 | 0925 | 10 | 20 | 0 | 20 | 0 | 0 | 0 | 0 | 100 | 0 |  | 1.055 | . 85 |
|  | AUIN | 12 | 111476 | 1214 | 14 | 12 | 0 | 12 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 1.050 0.009 | 08 |
|  | AUTP | 12 | 111016 | 1210 | 14 | 20 | 0 | 20 | 0 | 0 | 0 | 0 | 100 | 0 | 3 | . 6.950 | . 62 |
|  | Auvf | 2 | 116976 | 6740 | 17 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.040 | 0.00 |
|  | AUVD | 22 | 1110976 | 0740 | 10 | 16 | 0 | 16 | 0 | - | 0 | 0 | 100 | 0 | 2 | . 562 | . 67 |
|  | AUWR | 32 | 116976 | 1530 | 10 | 4 | 0 | 4 | $\Delta$ | 0 | 0 | 0 | 100 | 0 | 1 | 0.000 | .00 |
|  | AUWT | 32 | 118976 | 1530 | 24 | 8 | 0 | 8 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 0.000 | .00 |
|  | avor | 12 | 120176 | 1220 | 44 | $\downarrow$ | 0 | 0 | $\Delta$ | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 | 0.00 |
|  | Avaw | 12 | 120176 | 1220 | 10 | 0 | 0 | 0 | $\Delta$ | 0 | $\Delta$ | 0 | 0 | 0 | 0 | B.bes | 0.00 |
|  | AVSS | 22 | 120276 | 1720 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.060 | ט.00 |
|  | AVSO | 22 | 124276 | 1720 | 10 | 8 | 0 | 8 | 0 | 0 | 0 | 0 | 100 | 0 | 2 | . 693 | .03 |
|  | avuk | 32 | 124276 | 1145 | 20 | 0 | 0 | 0 | 0 | d | $\Delta$ | 0 | 0 | 0 | 0 | y.bus | 0.00 |
|  | Avul | 32 | 124276 | 1145 | 16 | 4 | 0 | 4 | 0 | 0 | 0 | 0 | 100 | 0 |  | 0.000 | .01 |
|  | A $2 \times 1$ | 12 | 111676 | 1100 | 11 | 996 | 16 | 960 | 0 | 0 | 20 | 2 | 96 |  | 10 | 1.661 | 1.97 |
|  | A $2 \times 5$ | 12 | 111076 | 1100 | 11 | 888 | 0 | 836 | 8 | 0 | 44 | 0 | 94 | 6 | 10 | 1.575 | 1.47 |
|  | A $2 \times \mathrm{XG}$ | 22 | 111076 | yobs | 17 | 664 | 12 | 542 | 0 | 0 | 0 | 2 | 98 | 0 | 18 | 1.640 | . 94 |
|  | A $2 \times \mathrm{H}$ | 22 | 111076 | 0600 | 17 | 264 | 0 | 244 | 12 | 8 | $\Delta$ | 0 | 92 | 8 | 9 | 1.705 | . 55 |
|  | A $2 \times 1$ | 32 | 110976 | 1335 | 01 | 176 | 12 | 156 | 4 | 4 | 0 | 7 | 89 | 5 | 10 | 1.736 | 3.61 |
|  | A $2 \times 3$ | 32 | 1118976 | 1335 | 17 | 228 | 8 | 212 | ${ }_{0}$ | 4 | 4 , | 4 | 93 | 4 | 10 | 1.468 | . 32 |
|  | ALXK | 12 | 124176 | 1200 | 01 | 1104 | 316 | 724 | $\Delta$ | 0 | 64 | 29 | 66 | 6 | 18 | 2.428 | 1.97 |
|  | A ZXL | 12 | 121176 | 1200 | 44 | 1524 | 304 | 1088 | 0 | 0 | 132 | 20 | 71 | 9 | 12 | 2.135 | 2.34 |
|  | ALXM | 22 | 124276 | 1700 | 01 | 932 | 4 | - 820 | 0 | 8 | 100 |  | 88 | 12 | 13 | 2.135 1.910 | 2.34 |
|  | ALXN | 22 | 128276 | 1700 | 18 | 556 | 0 | 484 | 0 | 4 | 68 | 0 | 87 | 13 | 11 | 1.924 | . 67 |
|  | A $2 \times 0$ | 32 | 120276 | 1030 | 81 | 120 | 12 | 100 | 4 | 4 | $\Delta$ | 14 | 83 | 7 | 11 | 2.015 | .35 |
|  | AZXP | 32 | 120216 | 1030 | 21 | 152 | 20 | 128 | 0 | 4 | $\checkmark$ | 13 | 84 | 3 | 11 | 1.993 | .37 |

*Preserved with 1\% basic Lugol's

CHAPTER THREE

DETERMINATION OF AVERAGE DRY WEIGHTS OF IMPORTANT NEUSTON SPECIES COLLECTED IN 1976

Principal Investigator:
John H. Wormuth


#### Abstract

Dry weights per individual of a number of neuston taxa，considered to be ecologically important，were determined and then used in conjunc－ tion with the actual concentrations to give estimates of dry weights of the 1976 winter through April samples．In addition，analyses of variance were run to look at diel，seasonal and spatial variability；factor analysis was used to look at species groupings；comparisons of neuston and zooplankton data were made；and plots of seasonal variation of selected species means along Transect II were made．

Groups of species which respond to the environment in similar ways are defined，The relationships of these groups to other parameters are not apparent in the 1976 data，but most of the other parameters were measured on different cruises than those on which the neuston samples were collected．


The objectives of this project involved some laboratory work, but was mainly concentrated on analysis of the existing data using several statistical computer programs. The results were most interesting to us and will be most helpful in making comparisons to the 1977 data and compilation of a comprehensive overview of all the neuston data.

METHODS
Initially we wanted to determine dry weights per individual for a number of taxa which we considered to be ecologically important. After separation of 200 to 300 (or more, if necessary) individuals, of each taxa, they were rinsed in distilled water and treated in a similar manner to the usual aliquots (Groover, 1977). This gave us dry weight and ash-free dry weights per individual. These values were then used in conjunction with the actual concentrations to give estimated dry weights for the 1976 winter through April samples. During this time, dry weights were not a part of the program.

Secondly, we have run analyses of variance on Transect II only and on the three seasonal cruises, all transects, to look at diel, seasonal and spatial variability. We have also used all the samples to look at species groupings using a procedure known as factor analysis (Harman, 1967). These analyses were performed on the Amdah1 $470 \mathrm{v} / 6$ computer at Texas A\&M. Comparisons of neuston and zooplankton data were also made on this computer.

Finally, plots of seasonal variation of selected species means (day and night separately) along Transect II were made. This procedure ignores onshore-offshore variation, but shows diel and seasonal variation.

## RESULTS

Table 1 lists the individual dry weights and ash-free dry weights. In some cases samples from different seasons were compared. We are somewhat suspicious of the Temora turbinata values due to the low percentage of ash-free dry weight of the total dry weight, but we have not rerun this species yet. The estimations of dry weight for the Winter through April samples are given in Table 2.

For the analysis of variance tests the data were first log transformed to normalize the values. The results are summarized for 33 taxa in Tables 3 and 4. Time of collection was only divided into day or night. This is shown to be an important source of variation for many of the taxa, suggesting diel migrations. Month of collection is also an important source of variation for many taxa. Sampling station (onshore-offshore) variation is somewhat less important. Significant interaction terms occur less frequently. When males, females, and immatures of a single species were treated separately, there was an agreement as ta which sources of variation are significant.

The data for all 108 samples were again log transformed and subjected to factor analysis. This gave us taxa groupings as determined by underlying sources of variation. These results are presented in Table 5. Taxa groups indicated by the analysis are delineated.

Figures $1-15$ show the seasonal variation of average values along Transect II. Day and night samples are averaged and plotted separately. These plots are in addition to the five taxa already plotted in our final report for 1976.

Finally, correlation coefficients were calculated for neuston, phytoplankton, zooplankton and hydrographic parameters. These results are

TABLE 1

INDIVIDUAL DRY WEIGHTS AND ASH-FREE DRY WEIGHTS


Table 1 (cont.)


TABLE 2
ESTIMATED DRY WEIGHTS FOR WINTER - APRIL 1976 BASED ON SPECIES COMPOSITION AND TABLE 1 VALUES


## KEY TO TABLES 3 AND 4

$$
\begin{aligned}
& { }^{*} \mathrm{p}<.05 \\
& \text { ** } \mathrm{p}<.01 \\
& \text { *** } \quad \mathrm{p}<.001 \\
& \text { **** } \mathrm{p}<.0001 \\
& \text { gms/1000 } \mathrm{m}^{3} \\
& 2 \\
& \mathrm{mg} / \mathrm{m}^{3} \\
& { }^{3}{ }^{\circ} \mathrm{C}
\end{aligned}
$$

TABLE 3
analysis of variance for all transect il samples (1976) for selected taxa

| Source of variation | Degrees of freedom |  |  | $\left.\begin{array}{ll} 1 & \frac{0}{1} \\ \frac{4}{3} \\ 0 & 0 \\ 0 \\ 0 \\ 0 \\ 0 & > \\ 0 \end{array} \right\rvert\,$ |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Month | $(8,16)$ | 1.03 | 5.51 **. | $7.84{ }^{* * *}$ | 2.48 | $3.44{ }^{*}$ | . 83 | $2.83 *$ | $1.18$ | 2.36 |
| Station | $(2,16)$ | 2.33 | . 15 | 1.88 | $6.88{ }^{* *}$ | 1.30 | . 07 | 2.64 | . 47 | 10.20 ** |
| Time | $(1,16)$ | $4.88{ }^{*}$ | $6.41{ }^{*}$ | 1.09 | $22.24 * * *$ | 63.73*** | 6.53* | 5.37* | 20.92 *** | 53.29 *** |
| Month x Station | $(16,16)$ | 2.15 | 2.23 | 2.00 | 1.71 | 1.31 | . 92 | 2.19 | 1.03 | 1.25 |
| Month x Time | $(8,16)$ | . 64 | 1.67 | . 36 | 2.32 | 2.89 * | 1.14 | $2.94 *$ | . 49 | $2.92 *$ |
| Station $x$ Time | $(2,16)$ | 1.82 | . 95 | . 20 | 2.05 | . 62 | . 23 | . 54 | 1.20 | 2.14 |


|  |  |  |  | Table | 3 (Cont.) |  |  |  |  | - |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Source of variation | Degrees of freedom |  | $\begin{aligned} & n \\ & 0 \\ & 0 \\ & 0 \\ & 4 \\ & i \\ & 0 \end{aligned}$ |  |  |  |  |  |  | 荡 |  |
| Month | $(8,16)$ | . 88 | 3.88* | 7.51 *** | 4.09** | 6.60*** | 7.22 *** | 3.81* | $7.53{ }^{* * *}$ | 14.29*** | $\stackrel{\sim}{1}$ |
| Station | $(2,16)$ | . 51 | 7.13 ** | 7.12 ** | $4.15{ }^{*}$ | $11.73 * * *$ | 12.46 *** | $23.92 * * *$ | 2.22 | 2.00 |  |
| Time | $(1,16)$ | 16.29 *** | 31.73 *** | 23.39 *** | 26.09 *** | 15.87** | 17.64 *** | $52.94 * * *$ | 4.13 | 11.44** |  |
| Month x Station | $(16,16)$ | . 77 | . 79 | 1.28 | . 75 | $3.58{ }^{* *}$ | 2.46 * | 3.39 ** | 1.62 | 1.15 |  |
| Month x Time | $(8,16)$ | 1.43 | . 34 | 1.54 | . 66 | 1.27 | 3.43 * | 2.23 | 1.48 | 1.66 |  |
| $\begin{aligned} & \text { Station } x \\ & \text { Time } \end{aligned}$ | $(2,16)$ | 2.55 | . 59 | 2.69 | . 59 | . 84 | 2.05 | $7.35{ }^{\text {** }}$ | 2.30 | . 55 |  |

Table 3 (cont.)

| Source of variation | Degrees of freedom |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Month | $(8,16)$ | 27.10 *** | $36.89 * * *$ | 64.83 *** | 12.92 *** | $6.15{ }^{* * *}$ | $2.81{ }^{*}$ | 4.51** | - 4.62 ** |
| Station | $(2,16)$ | 24.67 *** | $29.82{ }^{\text {*** }}$ | 36.38*** | 48.38*** | 24.77*** | $6.94 * *$ | $5.12{ }^{*}$ | 9.63 ** |
| Time | $(1,16)$ | 2.25 | 1.60 | 2.73 | 9.06** | . 02 | . 01 | 3.38 | . 51 |
| Month x Station | $(16,16)$ | $6.82{ }^{* * *}$ | 11.02*** | 11.90*** | 4.41** | 1.85 | $2.84 *$ | 1.59 | 1.78 |
| Month $x$ Time | $(8,16)$ | . 88 | 1.28 | 2.35 | 1.78 | . 98 | . 68 | 1.37 | . 85 |
| Station $x$ Time | $(2,16)$ | 2.38 | 1.26 | . 35 | . 39 | . 78 | . 12 | 1.17 | 1.39 |

Table 3 (cont.)

| Source of variation | Degrees of freedom |  |  |  |  |  | $\begin{aligned} & \text { ת } \\ & \text { © } \\ & \frac{\pi}{i n} \end{aligned}$ | $\stackrel{\square}{1}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Month | $(8,16)$ | 15.22 *** | $12.25{ }^{\text {*** }}$ | $10.48{ }^{* * *}$ |  | 2.18 | $2.78{ }^{*}$ | $5.07 * *$ | $4.42 * *$ |
| Station | $(2,16)$ | $19.97{ }^{* * *}$ | 2.64 | . 51 |  | 1.40 | $5.54{ }^{*}$ | 2.23 | 1.51 |
| Time | $(1,16)$ | 26.79 *** | . 05 | . 09 |  | 19.52*** | 1.65 | . 02 | . 22 |
| Month x Station | $(16,16)$ | 2.80 * | 2.09 | 1.64 | ; | 1.22 | 1.71 | $3.75{ }^{* *}$ | 1.87 |
| Month x Time | $(8,16)$ | 4.67** | 1.39 | 2.36 |  | 1.02 | . 54 | 1.17 | . 69 |
| Station x Time | $(2,16)$ | 2.27 | . 66 | . 93 |  | . 49 | 5.87* | 1.08 | 3.63 |

TABLE 4
ANALYSIS OF VARIANCE FOR ALL SEASONAL SAMPLES (1976) FOR SELECTED TAXA


Table 4 (cont.)

| Source of variation | Degrees of freedom |  | $\begin{aligned} & \text { 乫 } \\ & 0 \\ & 0 \\ & H \\ & H \\ & 0 \end{aligned}$ |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Month | $(2,40)$ | 16.51 *** | 1.44 | $11.67 * *$ | 5.60 ** | 20.98*** | 16.80*** | 8.14** | 45.85*** | 11.30*** |
| Transect | $(3,40)$ | 2.02 | 1.55 | 2.25 | . 55 | 2.11 | 3.26 * | 1.66 | 1.12 | $5.79 * *$ |
| Station | $(2,40)$ | 2.07 | 3. 32 * | 2.39 | . 89 | 3.38* | 2.80 | 15.89*** | 5.21** | 6.90 ** |
| Time | $(1,40)$ | 17.73 *** | 73.56 *** | 57.01 *** | 42.33*** | 18.37*** | 17.91 *** | 40.41*** | 9.45** | 12.62*** |
| Month x Transect | $(6,40)$ | 1.25 | 1.67 | 2.83* | 1.87 | . 33 | . 40 | 1.58 | 2.44* | 3.10 * |
| Month x Station | $(4,40)$ | . 28 | 1.11 | 1.11 | 1.79 | $5.17{ }^{* *}$ | 2.75 * | 3.06* | 4.24** | 5.65** |
| Month x Time | $(2,40)$ | 1.82 | . 39 | 5.45** | 2.13 | . 50 | . 11 | . 84 | 2.34 | 1.09 |
| Transect x Station | $(6,40)$ | 1.52 | 1.06 | $3.39 * *$ | . 61 | . 63 | 1.16 | . 80 | 1.05 | . 38 |
| $\begin{aligned} & \text { Transect } \mathrm{x} \\ & \text { Time } \end{aligned}$ | $(3,40)$ | 3.47 * | . 73 | 3.08 * | . 46 | . 91 | 2.07 | . 91 | $6.27 * *$ | . 95 |
| $\begin{gathered} \text { Station } x \\ \text { Time } \end{gathered}$ | $(2,40)$ | . 29 | . 61 | $6.14{ }^{* *}$ | 1.84 | 2.28 | 2.33 | 7.85** | . 42 | 1.82 |

Table 4 (cont.)

| Source of variation | Degrees of freedom |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Month | $(2,40)$ | 404.98*** | $160.27^{* * *}$ | 281.01 *** | 15.02 *** | 6.57 ** | 13.90*** | 11.73*** | 4.73* |
| Transect | $(3,40)$ | . 50 | . 31 | 1.09 | 8.74*** | 5.93** | 1.39 | 1.00 | 1.20 |
| Station | $(2,40)$ | $15.85{ }^{* * *}$ | 11.76 *** | 8.24*** | 39.83*** | 11.44*** | . 80 | 5.38 ** | $-7.22^{* *}$ |
| Time | $(1,40)$ | . 54 | . 15 | . 28 | 6. 25 * | . 23 | . 09 | 2.38 | . 47 |
| Month x Transect | $(6,40)$ | . 50 | . 31 | 1.09 | 1.03 | . 49 | 1.07 | 1.89 | $2.34 *$ |
| $\begin{aligned} & \text { Month } x \\ & \text { Station } \end{aligned}$ | $(4,40)$ | $15.85 * * *$ | 11.76** | $8.24 * * *$ | 11.13 *** | $7.07{ }^{\text {*** }}$ | 1.83 | 2.28 | 1.25 |
| Month x Time | $(2,40)$ | . 54 | . 15 | . 28 | 5.25 ** | 3.33 * | 2.86 | 1.57 | 1.93 |
| Transect x Station | $(6,40)$ | 2.27 | 1.62 | 1.37 | 2.11 | . 72 | . 90 | . 51 | . 54 |
| $\underset{\text { Tfme }}{\text { Transect } x}$ | $(3,40)$ | . 94 | . 43 | 1.21 | 2.46 | . 57 | . 21 | . 78 | . 53 |
| $\text { Station } \mathrm{x}$ Time | $(2,40)$ | . 65 | . 03 | . 91 | 2.32 | . 81 | . 93 | 1.03 | . 81 |

Table 4 (cont.)

| Source of variation | Degrees of freedom |  |  |  |  |  | H |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Month | $(2,40)$ | 6.46** | 21.70*** | 17.68*** | 3.15 | 5.36 ** | 3.39* | $8.58{ }^{* * *}$ |
| Transect | $(3,40)$ | 1.61 | 1.33 | 2.48 | 1.08 | . 76 | 5.46** | . 11 |
| Station | $(2,40)$ | . 65 | 4.55* | 2.74 | 1.79 | $5.64 * *$ | 2.41 | 13.46*** |
| Time | $(1,40)$ | 6.19* | . 86 | . 17 | 16.10*** | 3.78 | . 58 | . 29 |
| Month $x$ Transect | $(6,40)$ | 2.25 | $6.29 * *$ | $4.85{ }^{* * *}$ | . 63 | . 42 | 1.83 | $5.63^{* * *}$ |
| Month $x$ Station | $(4,40)$ | 1.75 | . 61 | . 91 | 1.48 | 5.05** | 1.13 | $7.21 * * *$ |
| Month x Time | $(2,40)$ | . 94 | 1.54 | 2.44 | 1.14 | . 50 | . 23 | . 60 |
| Transect $x$ Station | $(6,40)$ | . 42 | 1.89 | . 75 | . 39 | 2.12 | . 64 | 1.79 |
| $\begin{gathered} \text { Transect } \mathrm{x} \\ \text { Time } \end{gathered}$ | $(3,40)$ | . 94 | 1.34 | . 06 | 2.64 | . 63 | 3.70 * | . 66 |
| $\underset{\text { Station } x}{\text { Time }}$ | $(2,40)$ | 1. 35 | . 35 | . 11 | . 05 | 2.68 | 2.56 | . 86 |

TABLE 5
FACTORS ONE-THREE FOR THE THIRTY-THREE TAXA USED.
groups indicated are based on nearness in three dimensional space

| Taxa | Factor 1 | Factor 2 | Factor 3 |
| :---: | :---: | :---: | :---: |
| Gastropod meroplankter | . 43 | . 09 | -. 24 |
| Caridean shrimp | . 45 | . 01 | -. 17 |
| Nannocalanus minor | . 45 | . 20 | -. 18 |
| Creseis acifula | . 37 | -. 31 | . 16 |
| $\frac{\text { Pontel lops is }}{\text { males }} \frac{\text { villosa }}{:}$ | . 22 | -. 41 | -. 01 |
| $\frac{\text { Pontel lops is villosa }}{\text { females }}$ | . 29 | -. 48 | . 03 |
| Creseis virgula | . 28 | . 17 | . 37 |
| Labidocera immature | . 17 | . 07 | . 38 |
| $\frac{\text { Labidocera scotti }}{\text { males }}$ | . 32 | -. 03 | . 41 |
| Limacina trochiformis | . 65 | -. 10 | -. 05 |
| Hyperiids | . 80 | . 06 | -. 07 |
| Brachyuran zoeas | . 74 | . 10 | -. 06 |
| Lucifer faxoni | . 72 | . 05 | . 21 |
| $\frac{\text { Centropages }}{\text { males catus }}$ | . 65 | . 10 | . 29 |
| $\frac{\text { Centropages }}{\text { females }}$ | . 71 | . 15 | . 26 |
| Brachyur an megalops | . 58 | -. 20 | -. 33 |
| Ostracods | . 70 | -. 06 | -. 32 |
| $\frac{\text { Calanopia americana }}{\text { males }}$ | . 49 | . 06 | -. 51 |
| $\frac{\text { Calanopia }}{\text { females }}$ | . 62 | . 01 | -. 49 |
| Temora turbinata | . 30 | . 29 | -. 45 |
| Sapparhina stel lata | . 11 | . 24 | -. 22 |

Table 5.

| Taxa | Factor 1 | Factor 2 | Factor 3 |
| :---: | :---: | :---: | :---: |
| $\frac{\text { Anomolocera }}{\text { males }}$ | -. 23 | . 76 | -. 47 |
| $\frac{\text { Anomolocera ornata }}{\text { females }}$ | -. 25 | . 74 | -. 46 |
| $\frac{\text { Anomolocera ornata }}{\text { immatures }}$ | -. 29 | . 72 | -. 47 |
| $\frac{\text { Labidocera aestiva }}{\text { males }}$ | . 31 | . 70 | . 19 |
| $\frac{\text { Labidocera aestiva }}{\text { females }}$ | . 25 | . 67 | . 28 |
| $\frac{\text { Pontelita meadif }}{\text { Males }}$ | -. 10 | . 41 | . 59 |
| $\frac{\text { Pontella meadif }}{\text { females }}$ | -. 02 | . 49 | . 59 |
| Pontella immature | -. 20 | . 26 | . 57 |
| Fisheggs | -. 07 | . 51 | . 41 |
| Tar | -. 11 | . 42 | -. 05 |
| Stomat op od | . 46 | . 03 | . 09 |
| Temora stylifera | . 65 | . 14 | . 39 |
| Chaetognaths | . 66 | . 28 | . 05 |
| Portion of total variance | . 21 | . 13 | . 11 |
| Cumulative variance | . 21 | . 34 | . 45 |




Figure 2. Annual Variation of Mean Day and Night Abundances (Individuals/ $1000 \mathrm{~m}^{3}$ ) Along Transect II for Hyperiidae.


Figure 3. Annual Variation of Mean Day and Night Abundances (Individuals $/ 1000 \mathrm{~m}^{3}$ ) Along Transect II for Lucifer faxoni.






Figure 8. Annual Variation of Mean Day and Night Abundances (Individu-i als $/ 1000 \mathrm{~m}^{3}$ ) Along Transect II for Temora stylifera.




Figure 11. Annual Variation of Mean Day and Night Abundances (Individuals/ $1000 \mathrm{~m}^{3}$ ) Along Transect II for Labidocera aestiva males.


Figure 12. Annual Variation of Mean Day and Night Abundances (Individuals $/ 1000 \mathrm{~m}^{3}$ ) Along Transect II for Pontella meadii males.


Figure 13. Annual Variation of Mean Day and Night Abundances (Individuals $/ 1000 \mathrm{~m}^{3}$ ) Along Transect II for Pontella meadii females.


Figure 14. Annual Variation of Mean Day and Night Abundances (Individuals $/ 1000 \mathrm{~m}^{3}$ ) Along Transect II for Pontellopsis villosa males.

presented in Table 6.

## DISCUSSION

Several things are obvious from these results while other things are suggested，but should await comparison with 1977 data．

1．There is considerable variation in neuston catches．Different sources of variation are responsible in different taxa．
a．A group of taxa with significant diel variation is apparent． With few exceptions night catches exceed day catches．Graphic examples are shown in Figures 1，2，4，5，6， 7 and 15 ．
b．A different group of taxa shows significant temporal variation． However，few patterns are even broadly similar，nor are they easily explained． Examples are Figures 6，8，9，10，11，12， 13 and 14.
c．With the exception of Figure 6，these are non－overlapping taxa．
d．Few taxa show significant transect variability．Graphs are not available to illustrate these patterns（for the six out of 33 taxa）．
e．The patterns of significant variation for month，station and time along Transect II（Table 3）are shown to be typical of all transects （Table 4）with very few exceptions．
f．There are too many groups in Table 5 to warrant discussion at this time．They need to be clustered in some manner．They broadly agree with the groupings from recurrent group analysis presented in our final report．

Table 6 shows the results of linear correlations．This is not the best way to compare many of these parameters．Scatter plots are presently being examined and should lead to curve fitting．

In summary，there are obviously groups of species which respond to the environment in similar ways．We have defined these groups．Their

TABLE 6

SPEARMAN'S RANK CORRELATION COEFFICIENT
FOR SELECTED BIOLOGICAL AND PHYSICAL PARAMETERS


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relationships to other parameters are not apparent in the 1976 data, but most of the other parameters were measured on the water column cruise while neuston samples were collected on the benthic cruises. Separation in time was several days at best and several weeks at worst.

Groover, R. D. (Editor) 1977. Environmental Studies, South Texas Outer Continental Shelf, Biology and Chemistry. Final Report for 1976 submitted to the Bureau of Land Management, Washington, D.C., Contract AA550-CT6-17.

Harman, H. H. 1967. Modern factor analysis. Chicago. Univ. Chicago Press. 474 pp.

## CHAPTER FOUR

TRAVEL OF BENTHIC TAXONOMISTS
TO SMITHSONIAN INSTITUTE

Principal Investigator:
J. S. Holland

Associate Investigators:
Allen Dixon
Rick Kalke
Nancy Rabalais
Steve Rabalais
Granvil Treece

## INTRODUCTION

Five taxonomists from the UTMSI/PAMI benthic ecology group spent five to seven days each at the Smithsonian Institute, National Museum of Natural History in Washington, D.C. during the fall of 1977 , in order to better understand the taxonomy of samples collected during the 1976 STOCS study and to establish relations with professionals in the field. We feel that the trips were entirely successful in that our taxonomic knowledge was increased and contacts were made so that further enhancement is made easier.

RESULTS

Steve and Nancy Rabalais spent October 12-14 and 17-21, 1977 in the National Museum. Their time was spent with specimens from a large number of polychaete families, decapod crustaceans and nemerteans. They reported valuable additions to our basic literature and met with the following scientists:

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Dr. Thomas Bowman
Dr. Isabel Perez Farfante Canet
Dr. Fenner Chace Jr.
Dr. Anne Cohen
Dr. Maureen Downee
Dr. Dwayne Hope
Dr. Meredith L. Jones
Dr. Louis Kornicker
Dr. Marion Pettibone
Dr. Mary Rice
Dr. Austin B. Williams.
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Rick Kalke, Granvil Treece and Allen Dixon spent November 6-11, 1977 at the National Museum. They each worked in areas of their special taxonomic interest, e.g. crustaceans, molluscs and polychaetes. In addition to the above taxonomists, the following group of scientists were consulted on this second trip:

Dr. J. L. Barnard
Dr. Allan Child
Dr. Arthur Clark
Dr. Richard Houbrick
Dr. Kensly
Dr. Harold Rebder
Dr. Clyde Roper
Dr. Joseph Rosewater
Dr. Thomas Waller
Dr. Anders Warén.

Upon returning from their trips we have exchanged specimens and information with many of the Smithsonian taxonomists. Also, contacts have been made with taxonomists that the museum personnel had suggested as sources of additional information.

Many changes in the taxonomy of our benthic invertebrates and a broadening of our avenues of approach to other taxonomic groups resulted from the trips. The 1976 data base has been improved in that its accuracy has been enhanced but certain problems have also arisen.

In cases in which a single species was mistakenly identified as another single species, a simple name change in the computerized data base was sufficient to correct the error. In many instances, however, we found that several species have been lumped together or one species has been split into several. These instances will require returning to the original specfmens to check identifications. This has not been possible with our need to meet 1977 sample analysis deadlines. Further work will be necessary to check the identification of these organisms.

## CHAPTER FIVE

SUMMER POSITION FOR BENTHIC ECOLOGISTS AT UTMSI/PAML

Principal Investigator:
J. S. Holland

Visiting Scientists:
H. W. Harry, TAMU
A. D. McIntyre, Marine Laboratory, Aberdeen, Scotland

## INTRODUCTION

Two internationally known scientists were invited to participate in a review and enhancement of 1976 benthic data from the STOCS study. Drs. Harold Harry of Texas A\&M University and Alasdair D. McIntyre of the Department of Agriculture and Fisheries for Scotland, Marine Laboratory at Aberdeen, Scotland, visited the UTMSI/PAML during the late summer and fall of 1977.

RESULTS

Dr. Harry spent ten days consulting at the UTMSI/PAML and an additional ten days at home reviewing the 1976 Draft Final Report and preparing his report. His time spent at the UTMSI/PAMI was very instructive as he spent a great deal of his time interacting with persons actively engaged in the taxonomic aspects of our work. His knowledge of the molluscs, echinoderms and other more obscure groups as well as his tremendous knowledge of pertinent literature made his stay extremely beneficial to our group and to the enhancement of 1976 data. Dr. Harry made a very detailed study of the 1976 draft final report, analyzing not only the benthic ecology aspects but many others as well. His comments were well received and a copy of his. report is appended.

Dr. McIntyre visited the UTMSI/PAML for two periods (August 22-September 11 and October 24 -November 5, 1977). During his stay, he did an indepth analysis of the overall BLM-STOCS project, an evaluation of the benthic facet, interacted with data-analysis personnel on the benthic ecology staff and became particularly interested in the Rig Monitoring aspect of the 1976 study program. Dr, McIntyre's extensive knowledge of benthic ecology, collecting techniques and data analysis were liberally
shared with all of us to the benefit of our efforts for the BLM-STOCS program. Drs. McIntyre and Holland are to co-author a paper on the benthic data from the Rig Monitoring study. This paper is in preparation. Dr. McIntyre prepared a report which is appended.

Report on Consultation of August-September 1977 with the Team Studying Benthic Invertebrates of the South Texas Outer Continental Shelf Survey (BLM-STOCS)
by
Harold W. Harry
Associate Professor Biology Department
Texas A\&M University College Station, Texas 77843

It was only possible to spend a week and a half at Port Aransas (August 15 to 24); an appraisal of the 1976 report occupied about the same amount of time at College Station.

My work with the professional personnel of this project consisted mostly in conferring about identifications of specimens, chiefly molluscs and echinoderms. It was possible to furnish literature references and in a few cases to provide copies of important articles relevant to their work. Drawings and descriptions were made of a few species of molluscs, mostly nudibranchs and bivalves, which could not be immediately identified. At least one large nudibranch is probably new to science, and one minute bivalve ( 0.8 mm maximum dimension), which is very frequent in the samples, is probably new. It may represent the smallest sexually mature mollusc in the world.

Some echinoderms were drawn, specifically several heart urchins, holothurians and ophiurians, toward the preparation of an illustrated key to the echinoderms of the northwestern Gulf of Mexico. Preliminary
copies of the keys（Asteroidea，Ophiuroidea，Echinoidea）and drawings were left with the team personnel．

I participated in a discussion on determining the biomass of the benthic macro－invertebrates，and led a discussion on taxonomic principles．

Suggestions on sampling and preservation of macro－invertebrates．
Separating the animals from the substrate of those samples taken by grab－sampler，isolating each species in its individual container， and preserving them for further study are problems which may be simpli－ fied．In the past，the samples have been sieved at sea，the animals anesthetized with magnesium sulphate then preserved in $10 \%$ formalin in sea water，with rose bengal added．In the laboratory the samples were again washed in a series of sieves，to separate the specimens in－ to groups according to size，and placed in $50 \%$ isopropyl alcohol （Chapter 9，page 7，8）．Mention is made of debris from which the organisms were separated by picking out the individuals under a micro－ scope；but what this debris was is nowhere stated．Moreover，since the samples were initially washed through a mesh of 0.5 mm opening，and this was large enough to allow passage of the largest grain sizes re－ ported as present in the area（Chapter 14），one wonders what this debris was，and how much of it was present．

Fragmentation of specimens，particularly worms，results in part from washing the sample free of sediments．If the saran bag of 0.5 mm mesh used to wash the sample on ship board is kept under water（gently agitated in a pail full of water，for example）while the sample is being
sieved, fragmentation might be reduced. Also, the samples are later passed through three sieves; perhaps the three sieves could be used on ship, thus further reducing fragmentation; or dispense with the second sieving altogether.

If alcohol preservation is used, it should be $70 \%$ rather than a lower concentration, because the alcohol evaporates more rapidly than the water, and the lower percentages tend to allow bacterial action, producing acid conditions, and dissolving delicate calcareous parts.

Evaluation of alternate methods of preservation of specimens would be useful, particularly for more precise biomass studies in which specimens are weighed, or linear measurements taken. The conventional methods of preservation, using formalin or alcohol, are essentially designed to stop autolysis and bacterial action by denaturing protein. One possible alternative would be to freeze the freshly sieved material in a small amount of sea water, but this would tend to soften the tissue, so that the specimens would be difficult to weigh, or examine for identification in some instances; perhaps damaging the specimens too much for the purposes intended.

Another method, which theoretically is more promising, would be to pasteurize the freshly sieved material (possibly after narcotization) in a small amount of sea water, by placing the specimens in sea water heated to 145 degrees $F(63$ degrees $C$ ) for 30 minutes or less (determined by trial). They might then be preserved in water, to which a small amount of bacteriocidal agent has been added. A few ml of concentrated solutions of salts of heavy metals $(\mathrm{Cu}, \mathrm{Zn}, \mathrm{Cd}$, but not Ag , if sea water is used) might suffice, and other agents (thymol, sodium azide) should
be tested.
The terms "epifauna" and "macro-infauna" as used in the 1976 report are somewhat misleading, even though their usage is explained (Chapter 9, page 6). Some of the "epifaunal" organisms are undoubtedly infaunal. It would be less confusing to list the organisms by method of capture, notably, by trawl or by grab-sampler.

The larger samples obtained by the trawl at night than during the day might be explained by avoidance of the net by the more motile nektonic species, when there is light enough for them to see it. But larger catches of neuston, which could presumably not escape the net, seem to occur during the night also (Chapter 7, page 3). The neuston reported is chiefly planktonic, unable to avoid the net by swiming away. Neuston is perhaps being too narrowly defined, on the basis of how it is being sampled. The apparatus used, although skimming a surface area 2 m wide, extended only 15 cm deep. This may not allow adequate sampling of Sargassum, Physalia, Scyphozoa, and other mega-planktonic forms. Very likely there are nektonic forms hovering just below the surface (one would expect fish, squid, decapod crustacea) which are being overlooked in this study.

A subsurface trawl would be a useful adjunct for sampling that zone; such a trawl might be made of fine nylon thread, somewhat larger than that used for the "mist nets" used to catch flying birds. A mesh opening of about 2 to 5 cm should suffice. Instead of weighted doors, floating pontoons could be used to keep it near the surface, so that it would sample the upper 2 meters of water. Lifting a full trawl on board might be a problem, but using a canvas sling to do so would
perhaps suffice.
Similarly, the nekton in the water column should be sampled, between the top and the bottom. I am informed by people who have used them at greater depths that mid-water trawls could be used in the depths of the area of study. Nekton sampled at the middle of the water column at each station, at night, during the day, and seasonally, might add much useful data to explain the total ecology.

Coments on the 1977 report.

1. The benthic macro-invertebrates.

The systematic list of benthic invertebrates (Appendix G, Table I) is essentially a "biotic index" of much interest to anyone familiar with systematic biology and the marine benthos of eastern North America.

Several items are worthy of comment.
Sponges: Were no boring sponges (Cliona sp.) found? These mostly live
in dead shells, and such material seems not to have been examined (although hermit crabs are reported).

Coelenterates: The encrusting coral, Astrangia sp. is not reported, and it is often present on shells of hermit crabs from off shore along the upper Texas coast. Was none present?

Mollusca: The discovery of Aplacophora, represented by 3 species in as many genera, is most praiseworthy. The class had previously been known from the Gulf of Mexico by only a single specimen, from great depth. But the absence of any squid, of which 2 genera and
perhaps 3 species occur, is perplexing. Squid are reported in Chapter 11.

The boring bivalve, Gastrochaena, could be expected in dead shells, such as those inhabited by hermit crabs.

Several families of the molluscs reported are known to be commensals with other benthic organisms, but we do not know the specific host for the species of this area. Analysis of the data to see what other organisms most frequently occur with these semiparasites would provide clues to these relationships. The molluscs include Pyramidellidae, Melanellidae, Erycinidae, Leptonidae and Sportellidae.

Crustacea: Ten species of Callianassa are reported; near shore, these burrowing shrimp dig very deep holes. Are those of the present stations at the top of deep burrows when captured, or do they have different habits than the species living in the intertidal zone? Observations on living specimens, brought into the laboratory, would provide useful data on this point.

Twelve species, in two families, of hermit crabs are reported. It would be useful to know what species of mollusc shells they were inhabiting, and what organisms were attached to, or penetrating, these shells.

Annelida: Several species of tubicolous worms which are essentially epifaunal are reported. It would be interesting to know to what objects these were attached (e.g., Serpulidae).

Some groups could easily be identified more specifically than has
been done in Table I, notably the Ostracods (none identified to genus or species); this is doubtlessly a function of the time available to the systematists on the team, and the available literature. The lack of adequate reference collections no doubt also plays a part.

The approach used by those teams dealing with systematic or environmental groups (demersal fish, plankton, neustop, melofauna and benthic macro-invertebrates) is essentially a synecological one; that is, the organisms of a given habitat are studied collectively. The alternative is an autecological approach, which concentrates on the environment, habits, and life history of a species.

An autecological approach would be a useful adjunct to the present program. Much data is already at hand, but has not been correlated with individual species. Thus, Table I, Appendix G could be much more useful if it contained, opposite each species, such data as the following (in columns):

1. Depth range
2. Depth of maximum density (frequency of occurrence)
3. Sediment range by percent sand
4. Sediment range by phi system of size measurement
5. Salinity range
6. Temperature range
7. Stations and seasons of occurrence

The list could be considerably extended, to include size array correlated with season; the organisms which are most frequently present with each species, the frequency of encounter, etc. But those, more
complex data, and others which would occur as the study progressed, would perhaps be best preserved in a file to be kept on each species. Of course, it may be in a computer bank, but access to it there is very limited.

In a master file of species, other data could be added from time to time, which would not easily be entered in a computer bank: notes on behavior, drawings and descriptions of anatomy, important literature references, etc.

This approach might provide a more satisfying determination of assemblages, or communities, than merely counting individuals at a station, and then processing the numbers by idealized formulas. The formulas of population dynamics and numerical taxonomy treat all species of equal value (each is a unit), which is certainly not biologically valid. Some larger predators may establish territory, from which other predators are excluded. A large specimen of the giant snail, Pleuroploca, may occur in a single trawl sample or replicate grab sample at a station, and it would not be logical either to ignore its occurrence, or to count it as equivalent to some small, abundant arthropod or annelid. And how are colonial forms to be processed mathematically (e.g., bryozoa, hydrozoa)? .

The esoteric mathematical indices may have their legitimate function, yet they should not preempt time and effort spent seeking generalizations expressed in words. Man thinks in words, not in numbers.

## 2. General comments on the report.

The report should be more carefully edited. A few of the errors and deficiencies are noted here.

## Technical errors:

Appendix G: pages 173 through 185 are repeated as pages 186 through 198.

Appendix J: page 119, bottom row, third column: 2 should be 3 (station number).

Appendix J: page 127 , sixth row from top, third column, 4 should be 5 (station number).

Appendix J: All five tables have four adjacent column labeled as expressed in percent. But only the three columns on the left add up to $100 \%$. The percent of the column on the right is enigmatic; of what whole is it a percent?

## Deficiencies of style:

Authors should be urged to select words with care, and to express themselves as simply and lucidly as possible. Although fashionable in technical writing today, the tendency to use multiple nouns in apposition (sometimes as many as five) is an obfuscation to be eschewed. Some random examples:

Page 15-35: "The near-bottom samples were almost always lower than the surface samples ..."

Page 1-35: "sediment grain size distribution (texture) data"
Page 14-5: "grain size distribution parameters"

Page 9-43 (Table heading) "Species typical of seasonal infaunal cluster analysis station-group"

Page 1-34: "The bulk of this work was accomplished by typewriter terminals while waiting for the delivery of the remote job entry terminal."

Page 9-68: "By accumulating these percentages and plotting against replicate number, a curve representing sampling efficiency at each replication number was constructed."

Page 3-6: "The great temporal variability of the surface mixed layer, coupled with the spacial variability and the mobility of the water column, make it inadvisable to attempt to sub-classify surface mixed layer water with adjectives relating to season, longshore or cross-shelf location and/or vertical position."

## Deficiencies of organization:

Appendix J: Tables 1 and 2 are extensive, each occupying many pages, yet they differ from each other in only four of the 15 columns of figures which they contain (Mean, s.d., Skew and Kurt). The same comment applies, but to different columns, in the case of Tables 3 and 4.

Hydrographic data: Salinity and temperature data are presented in Chapter 5, p. 5-11 to 5-33, and an additional, extensive analysis occupies the whole of Chapter 3. Could the hydrographic data be all in one chapter, and so sumarized that it would be useful to biologists? The data of Chapter 5 is somewhat more easily adapted to biological correlations than are those of Chapter 3.

Sediment data: The data of the sediment program (Chapter 14) will be useful in interpreting the distribution of benthic invertebrates, but there is little attempt to make such correlation in the 1976 report. The sediment analyses were limited to quantitative analyses of particle size at each station.

Qualitative analyses might also be useful. What minerals besides quartz are present? Is there any glauconite? Is any appreciable amount of calcium carbonate present? Some might be expected, particularly where sand predominates, and at the stations near the edge of the continental shelf, where pelagic foraminifera and pteropods may form calcareous "sand". What was the "detritus" remaining in the samples screened through a mesh of 0.5 mm , from which the benthic invertebrates had to be sorted under a microscope (Chapter 9, methods); was it not molluscan shells, which should appear as "gravel" in the quantitative analysis of sediments on the basis of texture?

Many questions will occur to the thoughtful reader, which are not answered in the 1976 report. Perhaps the study as originally designed was not intended to include such information, yet it would seem essential if a complete account of the ecology of the area is intended. Some examples follow.

What were weather conditions during the sampling? Were rough seas encountered? How often? Did it interfere with the sampling? Were there sightings of neuston, such as Sargassum, Physalia, Velella, and associated organisms? Were any marine mammals or sea turtles seen? What birds were seen, how often, in what abundance? Were flying fish seen? Was
there evidence of trash, or flotsam and jetsam? Often such objects are inhabited by shipworms (at least, the. wooden ones), or have attached to them abundant colonies of hydroids and goose-neck barnacles. 0 bservations on trawl and bottom samples made immediately after the samples are brought on deck would no doubt provide much information which is not in the report.

Suggestions for the future.
Chapter 1 (p. 1-2) of the 1976 report notes that a monitoring program will be continued for a number of years after the initial baseline study. Specialists on invertebrates, authoritative in their knowledge of their groups, should be needed for such a program. The team on hand now would be the most useful one, for such an extended program. At present the program is limited to "what is where", but in the future this knowledge could be extended to determine dynamic interrelationships among the species of the various communities. This should not be limited to studies of mathematical ecology or mere biomass, however useful the concepts of those subjects may be.

Many people, and particularly the team-workers themselves, have commented on the dearth of literature useful for identifying the organisms of this region. Such a literature could be developed during the extended monitoring period. The systematists could make studies on anatomy (essential for proper identifications), life histories, behavior, etc., generally thought of as "pure" knowledge, as contrasted to "useful" or "applied" knowledge. Such "pure" knowledge is ultimately essential for a broad understanding of the environment, and how man is
to deal with it so that it is of maximum use to human economy, yet not damaged excessively.

Some specific suggestions for such an extended program follow:

1. The professional systematists should be relieved of such work as counting, measuring specimens, etc., which can as well be done by non-biologists.
2. The professional systematists should spend more time studying living organisms, brought into the laboratory, from off-shore.
3. The research collection should be given continued support, through funds for materials and for curatorial assistance.
4. The library should be extended to include more material on systematics and ecology. Much of that literature is out of print, but occasionally available from second-hand book dealers in this country and abroad, if it is ordered immediately after it is advertised (the demand for it is very great). Perhaps funds could be sought from alumni or other sponsors, so that the library would have a direct source, to buy such literature without the complicated purchasing routine now required.

The 1976 report contains a wealth of useful information; the constructive criticism offered above should not detract from that fact.

# BUREAU OF LAND MANAGEMENT SOUTH TEXAS OUTER CONTINENTAL SHELF REPORT OF CONSULTANCY ON BENTHIC ECOLOGY PROGRAMME - 

22 August - 11 September and
24 October - 5 November, 1977
by
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## 1. INTRODUCTION

1.1 This report reviews work done to date in the benthos ecology programme, giving particular attention to an evaluation of data collected during the first three years, and examining possible future developments. Consideration of other elements in the total STOCS programme was not within my terms of reference, but since that programme represents a single coherent attack on a specific well-defined objective, some account must be taken of related aspects, and I therefore comment more generally where this seems appropriate.
1.2 In evaluating the work, it is necessary to bear in mind the aims of the BLM programme. These are clearly stated. They are to achieve an understanding of how to assess and control the impact of petroleum exploitation and development in the STOCS area, and in particular to protect the living marine resources from deleterious effects, the overall aim being the general management of the OCS leasing programme.
1.3 A prerequisite for using benthos as a major part of such a programme is a sound knowledge of the identity, distribution and density of the fauna of the area. In the work so far, which is not yet complete, this is being achieved in a highly competent manner. The macrobenthic group is impressively well organized and managed. Its members show considerable dedication to their tasks, and there is within the group an esprit de corps which is by no means common. The latter is a valuable asset which cannot be bought on a contract basis, and is due in no small measure to the quality of the leadership. The research considered in this report falls mainly into two parts - in general surveys of first the macrobenthic infauna and second the epifauna, but two related programmes, on regions of topographic highs, and on the monitoring of drilling rig effects, are also included.
1.4 It is a pleasure to acknowledge the courtesy with which $I$ was received
by the Director and staff at Port Aransas．The consideration I was shown by everyone I met，and in particular the ready co－operation of the macro－ benthic group，greatly facilitated the preparation of this report．

## 2．MACROBENTHIC INFAUNA

### 2.1 Existing Procedures and Samples

2．1．1 The macrobenthic infauna is collected in a series of grab hauls cover－． ing a surface area of $1 / 10 \mathrm{~m}^{2}$ ，and no haul is accepted unless an adequate volume of sediment is taken．The sampling is sound and can be regarded as quantitatively valid，although it is RECOMMENDED that to achieve some improvement in the collection of small surface－living arganisms，the solid top flaps of the grab be replaced by hinged mesh－screens，free to open during descent．It is further RECOMMENDED that the volume of sediment in each grab haul be measured and recorded，and that when sediment cores are extracted from grab hauls，macrofauna should be retrieved from the cores and returned to the grab collections．The possible advantages of turning to another type of sampling gear were discussed．The box corer was iden－ tified as the most attractive alternative，but such an instrument designed to cover $1 / 10 \mathrm{~m}^{2}$ is extremely large and heavy，so the operational diffi－ culties would probably not justify the change for work on the shelf．

2．1．2 In the trawl samples，some organisms such as the echinoderm Bryssopsis are recorded．It is well known that such infauna species，which are large， or sparse，or deep－burrowing，are not amenable to sampling by grab or corer It is RECOMMENDED that the use of some other instrument，such as the Foster anchor dredge，be considered for the sampling of these species．

2．1．3 The most labour－intensive and time consuming aspect of the benthic programme，the sorting or＂picking＂of animals from the sediment residue on the 0.5 mm screens，is very well organized and most efficiently done．

Picking is a repetitive task but it is vital in that it provides all the basic data, so it is important to stimulate and maintain the picker's interest. When I first visited the pickers they were isolated in a single room, separated from the staff who later classified and evaluated the collections. It is RECOMMENDED that a closer link, if only in terms of space, be developed between those picking, classifying and tabulating. At present, picking is done from sediment residues preserved in alcohol. This involves discomfort and even a possible health risk to the pickers which is not necessary. A sample which has been adequately fixed and stored in formalin can be returned to water for picking, and specimens should remain in good condition in water for several days. It is RECOMMENDED that this procedure be adopted. The most difficult samples to pick are those containing large quantitites of shell gravel. The possibility of using some other technique, such as the fluidising sand bath, should be considered for these samples, and I have arranged to provide details of this technique.
2.1.4 The considerable fragmentation of specimens in the samples was noted. It is RECOMMENDED that the sieving procedures both at sea and ashore be reviewed to determine when the fragmentation occurs. Attempts should then be made to reduce it by the use of larger surfaced screens, revised washing techniques, or other appropriate measures.
2.1.5 The small group concerned with the classification and further evaluation of the specimens may be congratulated on its performance. It started with a largely unknown fauna, and has already substantially advanced our knowledge of the benthos of the area. It is RECOMMENDED that this information should be made available to the scientific community as soon as possible by a paper or series of papers on new records and distributions,
and descriptions of new species. On the taxonomic side, it is important that the few remaining problems among the dominant species be quickly resolved. In particular, this refers to the identifying of specimens in certain "difficult" groups, especially Nemertinea and Sipuncula, and to the specific recognition of some important juveniles among the molluscs, mainly "Tellina sp.". The examination of living material is often useful in this context, and the culturing of juveniles until their adult characteristics appear can be helpful. It is RECOMMENDED that a considerable effort should be made, and every facility provided, to tie up these loose ends.
2.1.6 The single significant gap in sample processing is the pmission of biomass data. The original decision not to include this can be defended on the grounds that when dealing with a relatively unknown fauna, the major effort should be directed to identifying the communities and establishing the species structure. The inclusion of the best type of biomass data, ash-free dry weights, is not entirely consistent with such a programme, since ashing would not only have destroyed specimens which initially might have been only provisionally identified, but would also have substantially extended the work in terms of time and/or staff, or reduced the sample coverage. However, now that most of the taxonomic problems are under control, it is essential that biomass data be obtained to complete the picture of the communities, and to allow comparisons with other communities elsewhere, and the calculation of energy flow. Proposals are made later in the report to include this in the design of future programmes (see paragraph.2.3.7) but for the 1977 surveys, a useful index of biomass in terms of rough wet weight of major taxa and of individual large organisms could be obtained for fall 1977 by relatively minor additional procedures inserted between the final picking of the samples and the initial identification of
the specimens. This was discussed in detail during my first visit before the fall survey and is RECOMMENDED. The fact that existing collections are preserved in alcohol complicates any attempt to back-date the exercise, at least for the infauna, and such an attempt is not considered justified.

### 2.2 Data Processing

2.2.1 As indicated above, the initial effort of the benthos group was, reasonably, directed to achieving a good description of the species structure of the populations. This has been well accomplished, using a range of data-reducing techniques. While this approach does, to a large extent, produce an objective result, there is a certain subjective element in deciding which technique to adopt, and, in some cases, selecting between several possible versions of the technique. In general, because the thrust of the work so far has been with numbers of species, there may have been a tendency to opt for procedures which stress "presence or absence" of species, rather than dominance or abundance of individuals. However, because of the large number of species produced by the extensive sampling, and the sparse occurrence of many taxa, only $40 \%$ of the possible taxa have been used in the cluster analysis. This may slightly weaken the argument for the "pres-ence-absence" option. Therefore, while not suggesting there may be any serious shortcomings in the existing cluster analysis, it is RECOMMENDED that a selection of the possible variations be used on the data for comparison. With the large volume of data available, this would be a valuable exercise in its own right, and might be of sufficient interest to other ecologists to justify publication.
2.2.2 While a definition of species structure and a recognition of animal associations is of major importance as an initial descriptive step, information on the structure of the populations, in particular for those which
are dominant by numbers of individuals or biomass, is necessary for analyzing change and understanding the flux of energy through the system. This requires adequate statistical data on the confidence limits of the mean numbers in individual species populations, expressed on a unit area or sample basis, so that significant differences between age-groups, stations, surveys, seasons and years can be detected. Although computations have not yet been done with this in mind, it is fortunate that the past surveys have been sufficiently well designed to provide this information. It is RECOMMENDED that a rigorous statistical analysis be made of the 1975-77 surveys to determine site, seasonal and annual trends in population numbers. This could focus in particular on the monthly Transect II data. Correlations should be sought between population numbers and edaphic factors, and the whole should be viewed in the context of the hydrographic regime. The addition of these types of information to the data already in the 1976 report, together with some knowledge of biomass from the 1977 fall survey, will provide a useful picture of the macrobenthic infauna during the period 1975-77, and this should be presented in a scientific paper.

### 2.3 Future Programme

2.3.1 The information collected during 1975-77 constitutes an extensive data base which is open to several kinds of further detailed study, but its development relative to BLM interests can perhaps best be defined in the light of decisions about the immediate extension of the programme. A consideration of this extension therefore forms the framework of the following discussion, and proposals for further development of the 1975-77 data will emerge appropriately.
2.3.2 It is apparent from the statement of BLM aims that the studies should ultimately provide a capacity to detect environmental change, to assess its
significance, and to relate the change to its cause. Numerous investigators confirm that because of the normal variability of natural populations and the difficulty of measuring it with statistical precision, there are substantial problems in detecting variability which can be attributed to specific sources. To be able to make this attribution, no single approach is adequate, and the mosti effective procedure is probably a combination of several techniques - general field surveys and detailed examination of impact sites, coupled with a range of experimental studies both in the laboratory and in the field. The 1975-77 benthos exercise has provided much of the necessary framework of field data within which such a programme could be operated. The future package should thus be designed to elucidate the fluctuations in the benthos, providing an understanding of community dynamics which will allow changes in polluted or threatened areas to be clearly assessed in relation to the threat, and at the same time to provide a suite of experimental techniques which will reinforce the assessment. The data collected in the past three years should be further developed only in so far as it supports this aim.
2.3.3 As already indicated, the approach so far has been towards recognizing animal associations and defining species structure but as proposed in paragraph 2.2.2, a useful picture of the variability of the population may also be derived from the existing data by appropriate statistical analysis. Having completed this necessary step, the next move must be to focus on those few species which are dominant by number or weight of individuals, and which are therefore of major importance in the flux of energy through the system. By measuring the fluctuations of these species and determining the factors (e.g. predation, competition, physical factors) which control this under normal circumstances, it should be possible to recognize and evaluate the impact of adverse factors due to man. Sample processing so
far，however，has correctly been kept to the minimum necessary to produce data on the identity，numbers and distribution of species．Much informa－ tion remains as yet unexposed in the samples，and some of this，in parti－ cular the sizes of individuals，sex ratios and state of maturity will be useful in planning and amplifying later work．However，for economy of effort，such examination should be confined to those samples from which information is strictly relevant to future needs．

2．3．4 These needs，in pursuit of the aims already stated，will involve continued monitoring on a long term basis to establish the range of natural variability expected within the area．However，given the extensive back－ ground information already available on the animal communities，it should be possible to focus on a restricted range of sites，and to concentrate on a single season of the year．The region of Transect II is attractive because of the high frequency of sampling there in 1976 ，but against this must be set the consideration that it appears to carry lower populations than the other transects，and that it may be affected by the proximity of the shipping channel．It is therefore RECOMMENDED，subject to review when all the 1977 collections are tabulated，that such monitoring should be done in spring in the region of Transect $I$ ．It is further RECOMMENDED that con－ sideration should also be given to an exploratory extension of the sampling into water shallower than 10 m ．It is appreciated that this will extend the work slightly beyond the zone of defined BLM interest，but if the 10 m line is near the outer edge of the rich bivalve community，some knowledge of that community may be required to explain the dynamics of the shallowest BLM zones．

2．3．5 In designing a monitoring study of this type，it should be recognized that the optimum number of samples and the most effective pattern may not be the same as was satisfactory for the earlier work when the main object
was to define species numbers and distribution. An important aspect of the monitoring will be to detect changes in the populations of the dominant species and to plan this adequately, a statistical analysis should be done of the precision of the means of relevant existing data to determine the optimum number of samples required. The sampling pattern should be reviewed, since the concept of a transect is not necessarily the best one for this new direction of the work. It might for example be useful to think of a station more as a habitat, encompassing a wider area than in the earlier surveys, so that a more extensive section of the substratum could be covered by groups of 2-3 samples. A suitable statistical design could be employed to give the best estimate of within-station variance. Investigation of these suggestions is RECOMMENDED.
2.3.6 Processing the monitoring programme samples would, for the most part, follow the procedures already in use. One major exception is that ash-free dry weights would be required. Standard techniques are available for this, and have been discussed with the group.
2.3.7 A long term monitoring programme of this type, done against the background of the earlier studies, will permit the detection and quantification of changes in the benthic communities. However, because of the variable turn-over rate of different species, and of the same species in different years, knowledge of the productivity as well as of the standing stock is required if the changes are to be interpreted. Production data will confirm the predictions, made initially from standing stock values, of what species are important in terms of energy transfer, and will allow evaluation of how changes in the main species populations will affect the ecosystem as a whole.
2.3.8 Secondary production may be studied by concentrating on representative
sections of selected communities and sampling at sufficiently short inter－ vals（ $6-8$ weeks）over a 12 －month period，to give estimates of recruitment， growth and mortality．Productivity estimates of this kind may be confined to selected species which earlier observations have highlighted as likely to play an important part in the community by reason of number or biomass， but the work must be done in a rigorously quantitative manner，and collec－ tion and processing of samples must be designed to secure adequate estimates of the smallest benthic stages，which constitute the recruit class．This could entail using a very fine sieve，perhaps of the order of 0.25 mm for at least a proportion of the samples．From the data at present available it would seem that $20-30$ samples would be required for each survey，but the economic approach would be to collect the estimated maximum，and pro－ cess only those needed to provide enough specimens for study．

2．3．9 It is RECOMMENDED that a start should be made，if possible during 1978，on a study of secondary production as described above，in one of the STOCS areas where the benthic infauna is clearly dominated by a manageable group of animals－for example the bivalve，polychaete or amphipod facies of the shallow muddy sand community．When the results from the first productivity study are available，the value of continuing this type of work in other areas should be reassessed，particularly since the role of benthos is ambiguous in the deep water community，where the density of individuals is low but the species diversity high．

2．3．10 The proposals above are concerned with evaluating changes within benthic communities，and because of the relatively static life－style of the infauna it may be felt that such an exercise would be sufficient in itself for pollution studies．But this point of view is short－sighted， since the benthic changes cannot normally be understood with reference to the rest of the ecosystem．In the case of point－source pollution（e．g．
from an effluent pipe or a drilling rig), or for utilizing the integrating capabilities of the benthos (as is the basis for the "mussel watch" programme), exclusive focus on benthic organisms may be acceptable, but in general, before benthic changes can be unequivocally attributed to pollution and their significance determined, a good understanding of the relation of benthos to the rest of the ecosystem is required - its dependence on water movements to distribute larvae and bring food, and its role in passing on material from one trophic level to another. An important aspect of this is prey-predator relationships - involving studies not only of how the benthos feed, but also of how they are preyed upon by other infauna species and by epifauna and fish. The existing trawling procedure for epibenthos and fish could be employed to obtain stomachs for analysis of food preferences, and data on the nature and intensity of predation. Ideally, smaller animals should also be brought in, and the influence of meiofauna on the food web considered. It is thus RECOMMENDED that a quantified food web be constructed in conjunction with the work on secondary production.
2.3.11 The work proposed so far is concerned with establishing a capacity to detect significant change in the benthos, and particularly to explain that part of the change which can be attributed to natural factors. Since comparable changes may be caused by pollutants, the ability to distinguish between natural and pollution-induced changes is essential in an effective impact study. Surveys in a region which is subject to impact may detect obvious changes and produce circumstantial evidence of a gross effect, but if chronic sublethal effects are to be unequivocally related to a source, then some experimental demonstration must be added to the field observations. One aim of the experiments would be to show that the levels of pollution actually measured in the field could in fact be expected to produce the effect observed.
2.3.12 In this context, small-scale laboratory studies of the $L_{50}$ type are a necessary preliminary. Such studies have been done on a wide range of species, and this type of work need be repeated here only when required information is not available from published sources. However, even in areas of acute impact, it may be difficult to extrapolate data from small scale $\mathrm{LC}_{5} 0$ experiments to the field in a realistic manner, and in those more extensive areas where it is the low level sublethal impact which is at issue, the results of $\mathrm{LC}_{50}$ tests must be regarded as only an initial step.
2.3.13 Additional experiments are required, using low levels of pollutants comparable to those found extensively in the sea, and applying this on a long term basis not to single species but to a significant portion of the food chain. These experiments should be on as large a scale as possible in an attempt to simulate open sea conditions and to represent a link between the lab and the field. Such an approach involves, in a sense, taking either the field to the lab, or the lab to the field.
2.3.14 The former approach can be accomplished using large containers set up in a lab, pier or shore, preferably with access to a continuous supply of natural sea water which will provide suitable physical and biological medium for the experimental community. The tanks should be large enough to permit the survival of more than one trophic level of the food chain, and to allow pre-predator interaction to take place. The experiments should continue long enough for detectable sublethal changes to be manifest. An adequate system of control tanks is essential. A number of possible facilities exist for such work at Port Aransas. Tanks could be sited on the jetty, on the land outside the lab, or inside the laboratory itself. It would be possible to collect sediment from the shallow muddy sand zone and stock it with a selection of the dominant species, such as Ampelisca agassiz, Abra equalis or Tellina versicolor which occur in numbers of 500-1000 indi-
viduals per $\mathrm{m}^{2}$ in some areas, and which might be amenable to experimental work. The project would consist first of establishing the set-up in a viable condition, then of using it as a tool to examine the effects of selected pollutants or other perturbations - drilling muds, sedimented oil residues, soluble oil, etc.
2.3.15 The lab-to-field approach involves such techniques as isolating an area of seabed with at least the lower segment.of the water column, by, for example, inserting large cylinders (up to several feet in diamter) into the sediment, and examining the effects of a variety of experimental treatments compared with both control enclosures and natural sediments. The strong team of divers gives considerable scope for this type of work, and the large number of species present even in the inshore communities in the Gulf offers the possibility of detecting change not only by variations in the numbers of individuals, but also by alteration in species structure.
2.3.16 Each of these two types of large-scale experiment has both advantages and disadvantages. The shore-based tanks are more easily controlled in the experimental sense and supervised in the physical sense, but they are isolated from the real environment. Underwater chambers are much closer to nature, but may be more difficult to manage and to protect from damage. It is RECOMMENDED that consideration be directed to building appropriate experimental work into the programe.
2.3.17 Given such a package of field observations and experimental work it should be possible to produce information relevant to the two types of situations which require reaction. First that in which a low level increase in hydrocarbons on other pollutants might raise the question of a long-term adverse effect. Second, that in which a point source of pollution might pose a threat to a more limited area.

## 3．TOPOGRAPHIC HIGH STATIONS

3．1 The substantial effort devoted to the two bank areas－Hospital Rock and Southern Bank，has produced a well－documented description of the macrobenthic infauna there throughout the year．The comments made earlier in this report on grab sampling generally，apply also to this aspect of the programme，and will not be repeated here，except to empha－ size the difficulties of processing samples containing large quantities of shell gravel，and the value of an automatic picking technique（see paragraph 2．1．3）．

3．2 The data collected so far will serve as valuable background if these sites require evaluation at a later date because of direct pollution impact，but they make up only a small proportion of the study area，and are neither convenient to sample nor attractive for experimental work． Thus，unless they can be shown to deserve special attention because of commercial fisheries or intrinsic ecological interest，it is RECOMMENDED that no further effort be devoted to them at present．

## 4．MACROBENTHIC EPIFAUNA STUDIES

4．1 Many epifauna species are mobile and migratory and may be relatively sparsely distributed．They must，therefore，be collected by towed gear， which does not have the same efficiency or precision as the grab．Sam－ pling must thus be regarded as，at best，semi－quantitative，requiring a major effort to achieve a good account of population fluctuations．In view of this，the decision to base the epifauna programme on specimens taken from the trawl used in fish sampling was probably a wise compromise． The admittedly sparse data have been fully exploited to provide a useful account of the epifauna populations but in view of the paucity of the material，it is doubtful if further processing of these samples would be
justified.
4.2 If however, the extension of the benthos programme outlined in paragraph 2:3.10, does take place, a relevant epifauna study is RECOMMENDED to complement it. For such work, a suitably modified dredge or a 3 m Agassiz traw1, with mesh small enough to collect juveniles might be more appropriate than the otter trawl at present employed. A number of techniques - the use of a pedometer, careful timing of hauls, operating from a marker buoy in set directions in relation to the tide, etc., might be used to reduce variability.
4.3 Such a programme would be related to the detailed infauna studies, being concerned with the role of epifauna in the overall community and its relationship with other ecosystem components. It would not deal with epifauna as part of a commercial fishery. This is an aspect to which BLM may wish to give additional attention. It is therefore RECOMMENDED that further consideration be given to potential threats to the epifauna as a resource. Experimental studies of the type referred to in paragraph 2.3.16, would be relevant here, but in addition, further examination of comercial statistics and much more extensive sampling at commercial intensity would be required.

## 5. RIG MONITORING PROGRAMME

5.1 This small study of an area immediately before and after occupation by a drilling rig is of special interest. Problems of sampling and variability make interpretation of the epifauna and fish data difficult, but the benthic infauna collections are more than adequate and should provide a picture which will be not only relevant to the site in question but also of general interest in much wider context.
5.2 Having analyzed the first five infauna stations ( 30 samples) and
demonstrated great similarity between them, the investigators were permitted in the interests of economy of effort to defer analysis of further pre-drill samples. A full analysis of all the post-drill samples was done, however, and some comparison can be made of the pre- and postdrill situation. This suggests that it would be useful to analyze at least another seven of the pre-drill stations to make the comparison more effective, and that a limited number of additional hauls might be of interest at the site about 12 months after the original collection to establish the current state of the area. It is RECOMMENDED that this additional analysis and sampling be put in hand, and that the study be written up as soon as possible for publication in the scientific literature.

## 6. OTHER SECTIONS OF THE STOCS STUDY

6.1 Although my terms of reference include only the macrobenthic work, it has been necessary to read and discuss, among other things, the entire Draft Final Report for 1976 to obtain a grasp of the overall approach. Since benthos cannot be separated from the other ecosystem components if a full understanding is to be achieved, some comments on other aspects of the programme may be appropriate.
6.2 Although primary production studies are referred to in the 1976 report, no estimates seem to have been provided in terms of carbon production on a unit time and area basis. This is a standard method of expressing production and is essential information if a food web is to be constructed and the flow of energy through the system is to be examined. It is also of value in comparing one area with another, and might therefore be required by BLM in relation to other OCS projects.
6.3 The smaller elements of the metazoan populations are dealt with, but it is unfortunate that the samples are processed and evaluated at a lab
widely separated from the one in Port Aransas where the main part of the benthic community is studied. The division between meiofauna is an artificial, operational one, between sections of a continuous spectrum, and it is important that regular and frequent contact be maintained between scientists working on these two components. Similar comments apply to sediment analysis. The sediment is clearly of fundamental importance to benthic organisms, and edaphic factors are of major relevance in determining their distribution. For this reason the collection, processing and evaluation of at least the basic sediment data should be done in close conjunction with the benthic studies. An important characteristic of the sediments which deserves further attention is their organic carbon content. Total organic carbon may be the most easily measured value, but some indication of available carbon, perhaps by enzyme digestion, would be more relevant.
6.4 The histopathology studies are of great interest, but will need to be followed up by relating the observed phenomena to effects. It is perhaps surprising that such detailed lab histopathology is covered but no effort seems to have been devoted to more direct field observations on superficial defects - lesions, fin rot, shell disease, skeletal deformities, etc., which might act as immediate signals of environmental stress.
6.5 Finally, in any broad consideration of the effects of Continental Shelf exploitation, a major source of concern must be possible threats to biological resources, in this case shellfish (particularly crustaceans) and finfish. A general reading of the 1976 report suggests that more weight might be placed on this area.

## 7. SUMMARY

7.1 This report is based on two periods totalling five weeks (22 August-

11 September and 24 October-5 November, 1977) spent with the benthos group at Port Aransas. It provides an evaluation of the macrobenthos component of the current BLM:programme on the STOCS, makes proposals for developing the existing data, and sets out suggestions for extensions of the work to meet BLM aims. Other aspects of the total programme are referred to where appropriate.
7.2 The major effort of the benthic programme is directed towards the macro infauna. The collection and processing of samples are carried out with a high degree of technical skill and efficiency and the staff are organized in such a way that their energies and abilities are utilized to full advantage. It has been possible to make only a few minor suggestions for modification to the existing procedures, with the single major exception that data on biomass are lacking, and proposals to rectify this are made.
7.3 Data processing has been approached in a highly professional manner and a sophisticated framework erected. The distribution of species and an exhaustive account of the animal associations of the area have been produced. The potential of the data base has not yet been fully exploited however, and it is suggested that a rigorous statistical analysis of the populations of the main species be undertaken to assess the significance of station, seasonal and annual differences.
7.4 Progress so far would seem to provide an excellent basis for the furtherance of BLM aims as stated in the introduction to the programme. It is suggested that advancement of these aims can now be best achieved by concentrating future versions of the benthos programme on studies designed to detect and explain changes, to assess their significance and to identify their cause. It is proposed that they can best be detected and assessed by a longer monitoring programme combined with a study of
secondary production on the bottom and a quantification of the benthic food web. Identification of their cause, if this is tied up with low levels of pollution, can be achieved by building on to this programe a suite of experimental techniques designed to demonstrate any relationship between the organisms and the pollutant. A package containing these programme proposals is outlined.
7.5 The sampling of the two topographic heights has been successfully completed and a useful picture of the benthos there has been produced. It is suggested that this aspect of the programme be now terminated.
7.6 The epifauna collections have produced a large volume of data on the specific taxa included in this study. These data have been well exploited to give a general picture of the distribution and associations of the animals and it is not considered, since trawl data are at best semi-quantitative, that continuation of this work is justified. However, the necessity of epifauna studies in relation to any food web programe is emphasized, and the possibility of looking further at the commercial aspects raised.
7.7 The Rig Monitoring Study, at least in its benthic aspects, is an excellent example of a well designed project which sets out to answer a specific question and does so in a strikingly successful manner. The data would be greatly enhanced by a small amount of additional analysis, and it is proposed that this should be done and that the results of this study be written up for publication.
7.8 Some comments are made on the overall STOCS programme. While it gives exceptionally comprehensive coverage to the environmental components of the area, the absence of data on primary production (as distinct from biomass) and available organic carbon in the sediment is noted. The histopathology component makes a useful and often neglected contribution to the
problem, and deals with the most technically demanding aspect, yet no provision seems to be made for relevant and much more straightforward observations to be made in the field. The disadvantage of macro meiofauna and sediment studies all being conducted in separate establishments is stressed and the resulting necessity for regular and frequent consultations is stressed. Finally, the possibility of directing more effort to commercial fisheries is raised.

## 8. RECOMMENDATIONS

8.1 Throughout the report a number of recommendations are made. This section brings these together and provides references to the appropriate paragraphs. All the recommendations were discussed as they arose with the benthos group and some of them may have been accepted and already put into effect or may be in the process of implementation, but for the sake of completeness, they are all included here under suitable headings.

### 8.2 Macrobenthic Infauna <br> Sample Collection <br> 8.2.1 Make structural alterations to top surface of the grab (2.1.1) <br> 8.2.2 Measure and record sediment volumes in grab hauls (2.1.1) <br> 8.2.3 Extract fauna from sediment cores and replace in main sample (2.1.1) <br> 8.2.4 Consider alternative sampling gear for larger infauna (2.1.2) <br> Sample Treatment

8.2.5 Arrange closer link between sample "pickers" and related members of the staff (2.1.3)
8.2.6 Pick the samples from water, not alcohol (2.1.3)
8.2.7 Investigate cause of specimen fragmentation and alter procedures as necessary (2.1.4)
8.2.8 Tie up loose ends of taxonomy (2.1.5)
8.2.9 Publish new reocrds of fauna and descriptions of new species (2.1.5)
8.2.10 Derive an index of biomass from the fall 1977 survey (2.1.6) Data Treatment
8.2.11 Examine alternative approaches to cluster analysis (2.2.1)
8.2.12 Analyze data statistically to detect differences in the populations of individuals between stations, seasons and years (2.2.2) Future Programme .
8.2.13 Consider a long-term monitoring programme, restricted to a selected area and season, using an appropriately modified sampling approach and possible including shallower water areas (2.3.4 and 2.3.5)
8.2.14 Initiate a study of secondary production of the infauna (2.3.9) including with this an attempt to construct and quantify the food web (2.3.10 and 4.2)
8.2.15 Introduce relevant experimental studies to supplement the field work, as an aid to identifying pollution effects (2.3.16)

## Topographic High Studies

8.2.16 No further benthic effort is recommended on this programme at present (3.2)

## Macrobenthic Epifauna Studies

8.2.17 Some epifauna sampling may be required to back up future infauna work (4.2)
8.2.18 Further work on the epifauna as a resource should be considered (4.3)

## Rig Monitoring Programme

8.2.19 Limited additional sampling and analysis are proposed, after which an account of this work should be published (5.2)

MACROINVERTEBRATE STUDY

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#### Abstract

Benthic invertebrate data from the STOCS were examined for spatial and temporal variation in abundance. Species which were characteristic of station groups and which showed strong variation in population density were studied. Samples collected in 1976 were retrieved and individuals sexed and measured.

Length-frequency histograms of all species measured are presented. Variations in epifaunal abundance due to recruitment of young size classes into the study area were verified. Infaunal data analysis did not show seasonal peaks of reproduction possibly because generation time of infaunal organisms is short. Simple linear regressions of mean length of an epifaunal species against physical variables revealed significant correlations with depth, salinity and grain size parameters. Preliminary examination of non-linear, multi-variate analysis shows it to be a useful tool for explaining the distribution of a species.


Populations of organisms in an ecosystem are responding and adapting to the conditions found there. The complexity of the physical, biological and chemical system makes it difficult to define the needs of a species without a thorough investigation of all factors that impinge on the individuals. The benthic invertebrates of the STOCS area have never been sampled as extensively as in the present study nor has so much supportive biotic and abiotic data been available. With the broad data base from the BLM-STOCS studies coupled with data on reproduction, growth and abundances, it is possible to delineate optimal ranges of environmental factors for a particular species.

Analysis of the 1976 benthic data revealed spatial and temporal fluctuations in population densities particularly in areas of 10 to 50 m depth. The causes of these variations in abundance were assumed to be related to reproduction and recruitment of young into the populations. This study was undertaken to investigate the time of occurrence of reproduction to test the hypothesis that size is related to abundance, and to increase our understanding of factors affecting the distribution of a few of the benthic invertebrates.

## METHODS

Benthic invertebrates which were characteristic of station groups in 1976 and which exhibited strong spatial and temporal variation in abundance were retrieved from the collections and individuals were measured and sexed. In the epifauna, total length of shrimp was: measured from the tip of the rostrum to the tip of the telson, crab width was measured across the widest part of the carapace and mollusc height was measured from the umbo to the
ventral margin; all to the nearest 0.5 cm . Small infauna were measured under the microscope with an ocular micrometer. Mollusc height was measured from the umbo to the ventral margin and amphipod length was total length of the dorsal surface of the..head segment. Polychaetes were generally fragmented so the width of the parapodia between the 7 th and 8 th segment was used as a measure of size. Total length was possible with only one species, Armandia maculata.

Measurements for each of the species were recorded and entered into the computerized data base. Simple linear correlations were used to test the hypothesis of reproductive recruitment and to define significant relationships of size to benthic physical variables. Generalized multivariate analysis was used to identify important factors affecting the distribution of a few species. All work was performed on 1976 BLM-STOCS benthic collections.

## RESULTS AND DISCUSSION

No significant linear correlations of species length with abundance were found in the epifauna data investigated. The smallest (which should have been most abundant) were not collected in large numbers either because they were too small to be taken consistently with the trawl or because they were not in the study area (i.e., Penaeus spp.). Many of the species exhibited a normal distribution of lengths, slightly skewed toward the smaller sizes. The first year class was definitely correlated with high abundance in certain seasons. Temporal variations in abundance at the shallow to intermediate depth stations were due to recruitment of large numbers of young. Winter and spring were periods of peak recruitment for many of the species.

A length-frequency histogram of 1976 SquilZa empusa data (Figure 1) indicate that the smallest class enters the study area in winter and spring.
כ-0


Growth of the most abundant size class can be followed through the year.
Penaeus aztecus males and females grew at different rates so they were separated in this analysis (Figures 2 and 3). Young P. aztecus entered the STOCS study area in spring and their growth can be traced through the year. Second and third year classes (in female data) are apparent.

The pink shrimp Penaeus duorarum, and two srabs Callinectes similis and Portunus gibbesii, also had the largest recruitment of young in spring although some young were also seen in the winter collections (Figures 4, 5 and 6). In most of the above species the lowest abundance occurred in the fall season when only large adults were collected.

Large abundances in winter epifaunal collections were associated with the influx of young Trachypenaeus similis (Figure 7) into the shallow stations. Penaeus setiferus, while not as numerous, also contributed to the abundance in the winter collections (Figure 8). The abundances of these species were very low in fall due to loss of numbers with age.

Intermediate to deep stations in the 1976 STOCS did not have such extreme temporal variations. Length-frequency histograms of Squilla chydaea (Figure 9) and Portunus spinicarpus (Figure 10), species collected most frequently in deeper water, show little difference in size throughout the year. These two species appear to be reproductive year round. A third species collected from deeper water, Amusium papyraceus, showed an increase in abundance in fall (Figure 11). This increase was probably related to reproduction but the picture of growth is not clear. Analysis of another year of data is needed to trace size changes.

Penaeus aztecus (female)


Figure 2. Length-Frequency Histogram of Penaeus aztecus Data, 1976.


Figure 3. Length-Frequency Histograms of Penaeus aztecus Data, 1976.


Figure 4. Length-Frequency Histogram of Penaeus duoramm Data, 1976.


Figure 5. Length-Frequency Histogram of Callinectes similis Data, 1976.


Figure 6. Length-Frequency Histogram of Portunus gibbesii Data, 1976.

Trachypenaeus similis
FALL


Figure 7. Length-Frequency Histogram of Trachypenaeus similis Data, 1976.


Figure 8. Length-Frequency Histogram of Penaeus setiferus Data, 1976.


Figure 9. Length-Frequency Histogram of Squilla chydaea Data, 1976.


Figure 10. Length-Frequency Histogram of Portunus spinicarpus Data, 1976.

Amusium papyraceus


Figure 11. Length-Frequency Histogram of Amusium papyraceus Data, 1976.

Definite reproductive cycles are evident for species collected at shallow to intermediate depth stations. The resultant increases in population abundance in winter and spring but not in fall caused the patterns reported for the 1976 epifauna data. To determine the causes of spatial variation the locations of young and adult size classes were investigated. Correlations of mean length of a species were run against the benthic physical variables (Table 1). In most cases mean length was significantly correlated with depth, salinity and the sediment parameters. The smaller size classes were in shallow, sandy, low salinity habitats while the adults generally moved offshore to deeper water. This was also true of the species found in deeper water; the young were in the shallowest regions of the species range and the largest adults were at the deepest stations. The three exceptions to this trend Portunus gibbesii, Penaeus duoramm and Penaeus setiferus are limited to the shallower parts of the STOCS ( 40 m or less) and the majority of the population, at least of the two Penaeus spp. is located outside our study area in depths less than 10 m . In general, the variations in spatial and temporal abundance in 1976 at the shallow to intermediate depth stations were caused by the large number of young at the shallowest stations and the migration of the adult population (accompanied by reduction in abundance of the larger sizes) to the deeper stations.

Attempts to find reproductive cycles in infauna data were not very successful. In most cases (Figures 12 through 15) the same size classes were present each season. This could be a result of year round reproduction. One polychaete Armandia maculata and the amphipod Ampelisca agassizi showed recruitment in the spring and fall; growth from fall to winter can be traced (Figures 16 and 17). No significant correlations of mean length

TABLE 1
correlation coefficients of mean length of a species with benthic physical variables

| Optimum Depth Zone | Abundance <br> Rank in 1976 | Depth Range (m) | Species | Depth | Temperature | Salinity <br> ORRELATION | Mean Grain Size COEFFICIENTS | \% Sand | \% Clay | N |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Shallow to | 7 | 10-65 | Squilla empusa | .659* | . 228 | .402* | .477* | -. 451* | . 529* | 39 |
| Shallow- | 12 | 10-27 | Penaeus duoraman | . 142 | . 389 | . 084 | . 237 | -. 266 | . 253 | 14 |
| Intermediate | 22 | 10-35 | Penaeus aetiferus | . 065 | . 025 | . 143 | . 239 | . 262 | . 193 | 17 |
|  | 1 | 10-81 | Trachypenaeus similis | .800* | . 001 | .645* | .436* | -. 399* | .476* | 58 |
|  | 3 | 10-130 | Callinectes similis | .485* | . 191 | .517* | .417* | -.425* | .425* | 66 |
|  | 13 | 10-40 | Portunus gibbesii | . 112 | -. 262 | -. 279 | . 361 | -. 335 | . 341 | 17 |
| Intermediate | 10 | 22-131 | Squilla ohydaea | . 628* | -. 198* | . 307* | . $387 *$ | -. 316* | . 413 * | 67 |
|  | 4 | 10-131 | Penaeus aztecus | .789* | -.493* | . 582* | . $529 *$ | -.417* | .585* | 88 |
| Deep-Interasediate to Deep | e 5 | 42-130 | Amusium papyraceus | . $540 *$ | -.451* | . 291* | .448* | -. 383* | . $467 *$ | 53 |
|  | 8 | 27-134 | Portunus spinicarpus | . 718 | -.413* | .474* | .481* | -. 368* | .536* | 56 |



Figure 12．Width－Frequency Histogram afisigambra tentaculata Data， 1976.

Paralacydonia paradoxa
FALL


Figure 13. Width-Frequency Histogram of Paralacydonia paradoxa Data, 1976.


Figure 14. Length-Frequency Histogram of Nephtys incisa Data, 1976.



Figure 16. Length-Frequency Histogram of Armandia nazculata Data, 1976

with depth were found. All size classes were collected at a station. This would be expected of sedentary animals if the young can survive only in an area already inhabited by a successful population. Or to state it another way, if the populations of a species are inhabiting all "good habitat" the new recruits can only survive where they find that habitat. In some cases such as Ampelisca agassizi the young do not have a planktonic stage and remain in the area of the adult population. Generation time of many of the infauna species may be short and our sampling periods too far apart to follow their reproductive cycles.

One important aspect of the BLM-STOCS study is the potential for understanding the distribution of organisms in relationship to their total environment. An explanation of how such a system works depends oń understanding the behavior of the individual organisms. For this purpose, multi-variate analysis was undertaken and preliminary results of the analysis on three species of epifauna are presented. Linear correlations of species abundance with independent variables were not significant in most cases. The distribution of many organisms followed a curve with optimal conditions grading off on one or both ends to suboptimal conditions and finally to zero abundance. Non-linear functions can fit this type of distribution, whereas linear functions cannot. The multi-variate aspect allows combinations of independent variables which are based on conditions closely resembling those that constitute the animals environment. The value of this technique as a prediction of species distribution must be evaluated by using all three years of data. Only 1976 BLM data was used in this analysis. The technique is based on least squares fitting a non-linear function to the species data. The dependent variable was species abundance and independent variables were the benthic physical variable (i.e. temperature, salinity, time of day, etc.). The criterion for best fit was a reduction of the mean square.

Portunus gibbesii distribution was best explained by salinity. About $80 \%$ of the variation in abundance could be attributed to salinity; combination with other physical variables did not improve the best fit. $P$. gibbesii was most abundant at low salinity and was absent from high salinity water. Depth and salinity are significantly correlated. Analysis of other years of data should clarify the importance of salinity to this species.

The distribution of CaZZinectes simizis was $8 \%$ explained by temperature and $26 \%$ explained by seasonality. When both variables were combined the reduction in variation was $45 \%$. These two variables were the most important factors regulating $C$. similis abundance in 1976. .

Penaeus aztecus variation in abundance was best explained by seasonality, time of day and temperature. With time of day considered alone, the mean square was reduced $5 \%$ and with season considered alone, the mean square was reduced $26 \%$, but a combination of the two variables reduced the mean square $48 \%$. Including temperature as a third variable resulted in explaining $80 \%$ of the variability of this species. The nonlinear functions used were exponential sine curves (for season and time of day) and a Gaussian curve for temperature. These functions are considered to be biologically sound because they do not predict negative or infinite abundances, and allow gradual changes from optimal conditions such as can be seen in natural situations. A three dimensional plot of the best fit function for $P$. aztecus distribution is presented in Figure 18.

These preliminary results can be strengthened by the addition of the 1975 and 1976 BLM data to the analysis. The final result should be a function which can be used to predict the distribution of a species under known conditions. With an explanation of the distribution of major species of epifauna it should be possible to describe how epifauna fit into the


Figure 18. Abundance of Penaeus aztecus as a Function of Julian Day and Time of Day at a Constant Temperature of $25^{\circ} \mathrm{C}$.
physical, chemical and biological system of the STOCS.

CONCLUSIONS

## Epifauna

1. Temporal and spatial variations in abundance in 1976 collections were due to recruitment of young age classes.
2. Fall 1976 collections were low because of no recruitment at that time.
3. Large variations in abundance were confined to species with shallow shelf or estuarine connections.
4. In general species with life histories confined to the STOCS study area did not show great temporal variation.
5. There was a general tendency for young to be found in shallow water and for the adults to move offshore to deeper water.
6. Preliminary results of non-linear, multi-variate analysis confirm the suggestions that species abundance is significantly correlated with abiotic variables.

## Infauna

1. Recruitment and growth patterns in infauna data were not clear.
2. Prolonged or year round reproduction may be occurring in infaunal populations.
3. More frequent collections are necessary to trace reproductive cycles.

## CHAPTER SEVEN

BIOMASS MEASUREMENTS OF BEMTHIC INVERTEBRATES

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ABSTRACT

Biomass, measured as wet weight, of 19 epifaunal species and 14 infaunal species for nine monthly and seasonal collections during 1976, was assayed. Distribution of biomass spatially and temporally was analyzed and regression of biomass on numbers of individual by species was obtained.

Total sample biomass was distributed according to depth for both epifauna and infaunal organisms. Infauna exhibited a gradient in total biomass inversely proportioned to depth. Epifaunal biomass decreased precipitously in the deepest of the zones while remaining essentially the same in the two shallow zones. Analysis of variance on raw biomass and standing crop data showed no significant differences in total biomass with season or with transect. A great deal of within treatment (season or transect) variability was observed.

Biomass of individual species showed several interesting patterns. Infaunal species were either basically shallow-water species grading into deeper zones or the reverse. Epifaunal species exhibited several other biomass distribution patterns including apparent mid-depth species which exhibited decreased biomass in both shallower and deeper zones. Mean collection biomass exhibited possible recruitment periods for a limited number of species, with no significant pattern for most. Many species had little variation in collection mean biomass indicating possible continuous recruitment.

Biomass was significantly correlated with numbers for all species except Clymenella torquata. Regression equations are provided.

## INTRODUCTION

Biomass estimates for 19 epifaunal and 14 infaunal invertebrate species taken from the South Texas Outer Continental Shelf during 1976 have been made. These measurements are the first biomass estimates to be made on benthic invertebrates during the BLM funded STOCS study. Total sample biomass estimates were not made on the 1976 collections and could not be reconstructed during this study as specimens are archived by species rather than sample. Concomitant with this biomass study, however, total sample biomass for infaunal samples collected during the fall, 1977, cruise has been measured.

The species selected for biomass measurements were those that met one or more criteria that were felt to delimit biologically important species in a qualitative or at best, semi-quantitative way. We opted to select species based on our knowledge of numerical dominance, distribution patterns or individual size. Since numbers and size of individuals within a collection are dominant factors in the biomass within that collection, we chose species that had exhibited numerical dominance over the duration of the study and those species that we felt, due to their large individual size, would have significant impact on biomass even though their numbers may be relatively small. Some species were chosen because their distribution was limited to a portion of the study area (e.g. ParaZacydonia paradoxa in deep stations). It was felt that even though these species were neither numerically dominant nor relatively large, that they represented biomass to be found at localized areas and should be included.

Although there is a long-standing debate among community oriented ecologists concerning the relative efficacy of numbers and biomass as indicators of the "quantity" of a faunal association, we do not attempt to shed new light on that debate. We are aware of the many sources of
variability inherent in non-destructive biomass measurement techniques and acknowledge no control over some sources such as fragmentation of most infaunal specimens utilized (one species, Armandia maculata was consistently whole), but attempted to be as rigorous as possible in limiting other sources of variation (operator differences, varying amounts of wetness, etc.).

This study was divided between biomass measurements of individual benthic epifaunal species (epifauna defined as macro-invertebrates associated with the sediment water interface, collected with a trawl) and benthic infaunal species (infauna defined as macroinvertebrates associated with the sediment-water interface, collected with a Smith-McIntyre bottom sampler). Wèattempted to delimit spatial and seasonal patterns in biomass for each species and to evaluate the relation between numbers and biomass through regression of weights or numbers. Comparisons among the various destructive and non-destructive means of assessing biomass for a limited number of epifaunal species were attempted.

## METHODS

Specimens utilized in the biomass study were collected during the nine cruises of the 1976 study period. These included three seasonal cruises (spring, fall and winter) and six monthly cruises (March, April, July, August, November and December). Collection methods have been described in the 1976 final report. All infaunal and epifaunal invertebrates from 1976 were archived by species.

The following species of infaunal organisms were weighed to measure biomass: Cossura delta, Paraprionospio pinnata, MageZona phyllisae, Asychis elongata, Clymenella torquata, Armandia maculata, Sigombra tentaculata, Paralacydonia paradoxa, Nephtys incisa, Diopatra cuprea, Lumbrineris
parvapedata, Ninoe nigmipes, Abra equalis and Anpelisca agassizi. Lie (1968) suggested a drying time of $5-10$ minutes after which an asymptote would be reached for wet weights. This time limit would fluctuate depending on the size of the species examined. The drying time for the samples of infauna was one to three minutes since the majority of the species were very small. The samples were weighed on a SARTORIUS analytical balance with an accuracy to $1 \times 10^{-4} \mathrm{gm}$. Only one of the above species, Armandia maculata, contained samples with whole organisms. Anterior fragments comprised samples of the other species.

The following 19 species of epifauna were analyzed: Renilla mulleri, Amusium papyraceus, Polystira albida, Squilla chydaea, Squilla empusa, Penaeus aztecus, Penaeus duoramm, Penaeus setiferus, Trachypenaeus constrictus, Trachypenaeus similis, Acetes anericana, Sicyonia dorsalis, Solenocera vioscai, Anasimus latus, Callinectes similis, Portunus gibbesii, Portunus spinicarpus, Astropecten cingulatus, and Astropecten duplicatus. The drying time of each species was determined using the asymptote method described by Lie. The time varied from 10-20 minutes depending on the size and amount of alcohol retained by the individual. The measurements of weight were made on an OHAUS triple beam balance accurate to 0.1 gm .

Four species, Squilla chydaea, Penaeus aztecus, Trachypenaeus similis, and Sicyonia dorsalis were used to compare ash free dry weights to preserved weights. Fresh samples were obtained, fixed in $10 \%$ formalin, then preserved in $50 \%$ alcohol. The individuals of the particular species were weighed according to the above procedure for wet weight then dried in an oven at $90^{\circ} \mathrm{C}$ for 24 hours. This was taken to be dry weight. Finally, the samples were heated to $550^{\circ} \mathrm{C}$ for 24 hours to obtain the ash free dry weight (Buchanan and Warwick, 1974).

## RESULTS

## Epifauna

Biomass and numerical distribution data for epifauna are summarized in Tables 1 and 2. It is apparent (Table 1) that most of the epifaunal species analyzed exhibit distinctive biomass distribution patterns according to depth. This depth relationship can be used to divide epifaunal species into three basic groups; a shallow water group characterized by Renilla mulleri, SquilZa empusa, the penaeid shrimp, etc.; a moderate depth group characterized by SquilZa chydaea, Solenocera vioscai and Astropecten duplicatus; and a deep water group including Amusium papyraceus, Polystira albida, Anasimus Zatus and Portunus spinicarpus. The total biomass collected during the year showed little difference between depth zones 1 and 2 , but a considerable drop-off in total biomass in depth zone 3 (Table 1). The brown shrimp, Penaeus aztecus, the gulf crab, CaZlinectes similis, and the paper scallop, Amusium papyraceus, were the major contributors to the total annual biomass of the 19 species investigated. These three species contributed almost two-thirds (66.12\%) of the total epifaunal biomass measured.

The epifauna species showed very significant correlations between numbers and biomass (Table 2). This was seen also in the fact that four of the five numerical dominants were also in the top five species contributing to biomass.

Regression of weight on numbers utilizing the equation: $\mid y=m x$ where $y$ is weight ( $\bar{g}$ ); $x$ is the number of individuals and $m$ is a constant, is given in Table 2 for each species. This equation forces the origin to be zero. The standard linear regression $(y=a+b x)$ would allow for some weight to be present with no individuals present,

## TABLE 1

EPIFAUNA bIOMASS BY SPECIES. DEPTH RELATIONS, ANNUAL TOTALS, BIOMASS AND NUMERICAL COMPOSITION


Zone $1=39.8 \%$ of biomass total
Zone $2=45.3 \%$ of biomass total
Zone $3=14.9 \%$ of biomass total
Biomass (Total Wt. g/yr) of epifauna $=99.97 \%$ of combined infauna and epifauna biomass.
Total Epifaunal Individuals $=47 \%$ of combined total infaunal and epifaunal individuals.

TABLE 2
EPIFAUNA SEASONAL AND SPATIAL BIOMASS DATA. REGRESSION AND CORRELATION OF WEIGHT ON NUMBER OF EPIFAUNAL SPECIES

| Species | Winter Wt | (7) N | March Wt | $\begin{gathered} \text { (8) } \\ \mathrm{N} \end{gathered}$ | April <br> Wt | (9) $\mathrm{N}$ |  |  | $\mathrm{ng}(\underset{\mathrm{~N}}{(1)}$ |  | July Wt | (2) $\mathbf{N}$ | Augu Wt | $(3)$ |  | (4) ${ }_{\mathrm{N}}$ | November Wt | $\begin{gathered} (5) \\ N \end{gathered}$ | Decembe Wt | (6) N |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Renilla mulleri | 567.7 | 254 | 40.4 | 17 | 12.2 | 3 |  | 100.2 | 26 |  | 1.5 | 1 | - | - | 43.7 | 23 | 49.9 |  | 18.2 |  |
| Polystira albida | 250.4 | 95 | 40.1 | 5 | 39.1 | 5 |  | 3.6 | 1 |  | 2.2 | 1 | - | - | 479.9 | 61 | - |  | - |  |
| Amusium papyraceus | 1627.4 | 137 | 1725.3 | 148 | 859.9 | 63 |  | 963.9 | 111 |  | 399.1 | 28 | 492.1 | 28 | 3114.7 | 475 | 266.4 |  | 965.0 |  |
| Squilla chydaea | 618.2 | 146 | 396.4 | 92 | 127.8 | 26 |  | 385.2 | 89 |  | 125.3 | 13 | 17.7 |  | 395.2 | 59 | 74.3 |  | 179.4 |  |
| Squilla empusa | 1631.6 | 211 | 720.9 | 86 | 243.2 | 26 |  | 2357.8 | 246 |  | 16.1 | 2 | 26.7 | 3 | 193.9 | 12 | 23.7 |  | 29.3 |  |
| Penaeus aztecus | 5255.5 | 203 | 1117.3 | 41 | 1376.3 | 49 |  | 10207.7 | 922 |  | 648.5 | 47 | 12801.7 | 5 | 7241.9 | 278 | 1320.0 |  | 947.7 |  |
| Penaeus duorarwm | 593.8 | 38 | 35.2 | 2 | 21.5 | 1 |  | 2230.0 | 170 |  | - | - | - | 1105 | 253.3 | 12 | - |  | - |  |
| Penzeus setiferus | 797.0 | 43 | 272.9 | 13 | 302.8 | 10 |  | 411.7 | 10 |  | - | - | - | - | 56.6 | 3 | 70.4 |  | 552.3 |  |
| Sicyonia dorsalia | 952.6 | 788 | 331.1 | 256 | 13.6 | 39 |  | 1273.3 | 1615 |  | 104.0 | 86 | 35.1 | - | 747.6 | 258 | 71.0 |  | 88.6 |  |
| Solenocera vioscai | 460.5 | 217 | 281.0 | 154 | 182.7 | 145 |  | 656.1 | 280 |  | 67.0 | 15 | 81.0 | 20 | 322.2 | 99 | 106.2 |  | 11.3 |  |
| Trachypenaeus constrictus | 3.2 | 3 | - | - | - | - |  | 404.5 | 132 |  | - | - | . 3 | 19 | 1.5 | 1 | $7{ }^{-}$ |  | - ${ }^{-1}$ |  |
| Trachypenaeus aimilis | 3931.4 | 3405 | 1496.4 | 524 | 528.0 | 484 |  | 2433.3 | 1335 |  | 72.8 | 22 | 72.2 | 1 | 219.8 | 83 | 79.3 |  | 340.5 |  |
| Acetes americana | 4.8 | 173 | . 7 | 21 | . 7 | 27 |  | . 2 | 14 |  | - | - | - | 20 | - | - | - |  | - |  |
| Anasimus latus | 342.1 | 58 | 80.3 | 38 | 89.9 | 19 |  | 164.6 | 43 |  | 6.1 | 2 | 12.0 | - | 362.2 | 64 | 4.9 |  | 235.3 |  |
| Callinectes similis | 1581.0 | 122 | 750.2 | 52 | 34.2 | 2 |  | 11198.8 | 1509 |  | 956.8 | 94 | 1063.8 | 2 | 4597.8 | 234 | 192.0 |  | 704.1 |  |
| Portunua gibbesii | 195.6 | 62 | 32.7 | 5 | 1.0 | 1 |  | 398.7 | 138 |  | - | - | - | 60 | 34.6 | 10 | 30.7 |  | 5.9 |  |
| Portunus spinicarpus | 935.2 | 139 | 299.9 | 39 | 341.2 | 50 |  | 732.8 | 113 |  | 56.8 | 12 | 95.4 | - | 1097.7 | 185 | 17.2 |  | 200.6 |  |
| Astropesten cingulatus | 221.2 | 29 | 173.9 | 40 | 38.6 | 7 |  | 106.3 | 25 |  | 4.0 | 5 | 5.1 | 13 | 237.7 | 49 | 7.7 |  | 169.8 |  |
| Astropecten duplicatus | 83.4 | 130 | 10.5 | 31 | 2.0 | 4 |  | 25.0 | 56 |  | 7.2 | 15 | - | - | 76.9 | 88 | 4.0 |  | 13.8 |  |
| Species | Transect Wt |  | Transect Wt | $\begin{aligned} & \mathbf{t} \quad \mathrm{II} \\ & \mathbf{N} \end{aligned}$ | $\begin{array}{cc} \text { Transect } & \text { II } \\ \mathrm{Wt} \end{array}$ |  |  | $\begin{array}{ll} \text { I } & \text { Transect } \\ \text { Wt } \end{array}$ |  | $\begin{aligned} & \text { IV } \\ & \mathbf{N} \end{aligned}$ |  | Regression <br> Plot ( $\mathrm{y}=\underline{\mathrm{m}} \mathrm{m}$ ) |  | : | - |  |  |  |  |  |
| Renilla mulleri | 16.9 | 5 | 297.9 | 94 | 523.9 |  | 45 |  | 5.1 | 3 | 3 | 2.24 | . 955 |  | $N=$ Number of Individuals |  |  |  |  |  |
| Polystira albida | 34.0 | 8 | 92.7 | 13 | - |  | - |  | 8.6 | 147 |  | 3.92 | . 839 |  |  |  |  |  |  |  |
| Amusium papyraceus | 389.8 | 50 | 6785.1 | 535 | 411.6 |  | 36 |  | 7.3 | 461 |  | 6.48 | . 916 |  |  |  |  |  |  |  |
| Squilla chydaea | 98.6 | 16 | 1408.1 | 305 | 507.8 |  | 89 |  | 5.0 | 85 |  | 4.20 | . 911 |  |  |  |  |  |  |  |
| Squilla empusa | 1991.4 | 270 | 1474.0 | 177 | 432.4 |  | 36 |  | 5.4 | 109 |  | 8.06 | . 971 |  |  |  |  |  |  |  |
| Penaeus astecus | 2112.4 | 121 | 24928.2 | 1806 | 5423.5 |  | 55 | -845 | 2.5 | 558 |  | 1.26 | . 805 |  |  |  |  |  |  |  |
| Fenaeus duoramon | 1018.3 | 67 | 56.7 | 3 | 607.1 |  | 37 | 145 | 1.7 | 116 |  | 2.59 | . 959 |  |  |  |  |  |  |  |
| Penaeus setiferus | 862.3 | 37 | 1442.2 | 58 | 81.4 |  | 4 | 47 | 7.8 | 3 | 32 | 2.49 | . 943 |  |  |  |  |  |  |  |
| Sicyonia dorealis | 297.3 | 430 | 1968.6 | 2015 | 400.6 |  | 69 |  | 0.4 | 450 |  | . 74 | . 895 |  |  |  |  |  |  |  |
| Solenocera vioscai | 183.5 | 64 | 1394.7 | 658 | 383.2 |  | 48 |  | 6.6 | 87 |  | 2.09 | . 880 |  |  |  |  |  |  |  |
| Trachypenaeus constrictus | 2.5 | 1 | . 3 | 1 | - |  | - |  | 6.7 | 135 |  | 2.97 | . 589 |  |  |  |  |  |  |  |
| Trachypenaeus similis | 1278.2 | 1598 | 4636.0 | 2886 | 1290.9 |  | 42 | 196 | 8.6 | 944 |  | 1.26 | . 805 |  |  |  |  |  |  |  |
| Acetes conericana | 4.9 | 183 | 1.4 | 50 | $>.1$ |  | 2 | 2 | - | - |  | $>.1$ | . 975 |  |  |  |  |  |  |  |
| Anasimus latus | 56.0 | 12 | 574.4 | 131 | 524.6 |  | 86 |  | 2.4 | 33 |  | 4.81 | . 930 |  |  |  |  |  |  |  |
| Callinectes similis | 5796.5 | 736 | 8729.0 | 965 | 2770.7 |  | 02 | 278 | 2.5 | 222 |  | 6.58 | . 883 |  |  |  |  |  |  |  |
| Portunus gibbesii | 522.3 | 181 | 70.3 | 15 | 44.4 |  | 11 |  | 2.2 | 18 |  | 2.81 | . 977 |  |  |  |  |  |  |  |
| Portunus spinicarpus | 292.9 | 52 | 1470.0 | 232 | 883.4 |  | 30 | 106 | 0.5 | 169 |  | 6.44 | . 974 |  | - |  |  |  |  |  |
| Astropecten cingulatus | 124.3 | 16 | 528.1 | 98 | 297.2 |  | 53 |  | 4.7 | 10 |  | 5.63 | . 884 |  |  |  |  |  |  |  |
| Astropecten duplicatus | 47.8 | 95 | 50.2 | 100 | 41.2 |  | 48 |  | 3.6 | 104 |  | . 72 | . 934 |  |  |  |  |  |  |  |

Total biomass of the 19 epifaunal species varied between seasons with winter and fall being approximately equal with nearly 20 kg per sample period. The spring sample was over 34 kg . A one-way analysis of variance was run on the seasonal data. Differences in biomass between seasons were not significant at the $.05 \%$ level. Numbers of individuals were similar (approximately 6500) in the winter and spring collections with a decrease to less than 2000 in the fall. No significant difference at the . $05 \%$ level of significance was seen.

Total biomass varied between transects with Transect II and IV yielding approximately 55 and 23 kg , respectively, total biomass for the year. Transects I and III had less biomass with approximately 15 kg each for the 1976 collections. Again no significant differences were seen with a one-way ANOVA on biomass between transects. Numbers of individuals varied between transects with Transect II producing over 10,000 individuals and the remaining transects between 2,000 and 4,000 individuals. A one-way ANOVA test indicated a significant difference (at the . $05 \%$ level of significance) for numbers of individuals between transects.

Mean weights of each epifaunal species for each collection and for the year are presented in Table 3. Recruitment of smaller individuals into the population should result in lowering the mean weights. Some fluctuations as in Solenocera vioscai, Penaeus aztecus and Astropecten cingulatus showed definite trends for seasonal occurrence of smaller individuals. Other species had several periods in which smaller individuals occurred, interspersed with periods in which onIy relatively large individuals occurred.

## Infauna

Biomass and numerical distribution data are summarized in Tables 4

TABLE 3
EPIFAUNAL SPECIES COLLECTION MEANS AND ANNUAL MEAN BIOMASS

| Species | Winter | March | April | Spring | July | August | Fall | November | December | $\underset{\bar{x}}{\text { Annual }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Renilla mulleri | 2.24 | 2.38 | 4.07 | 4.24 | 1.5 | - | 1.90 | 2.77 | 3.64 | 2.43 |
| Polystira albida | 2.64 | 8.02 | 7.82 | 3.6 | 2.2 | - | 7.83 | - | - | 4.84 |
| Amusium papyraceus | 11.88 | 11.66 | 13.65 | 8.68 | 14.25 | 17.58 | 6.56 | 12.58 | 13.40 | 9.61 |
| Squilla chydaea | 4.23 | 4.31 | 4.92 | 4.33 | 9.64 | 5.90 | 6.70 | 3.23 | 4.08 | 4.69 |
| Squilla empusa | 7.73 | 8.38 | 9.35 | 9.58 | 8.05 | 5.34 | 16.16 | 11.85 | 14.65 | 8.86 |
| Penaeus aztecus | 25.89 | 27.25 | 28.09 | 11.07 | 13.80 | 11.59 | 26.05 | 20.63 | 30.57 | 14.93 |
| Penaeus duorarum | 15.63 | 17.60 | 21.5 | 13.12 | - | - | 21.11 | - | - | 14.08 |
| Penaeus setiferus | 18.53 | 20.99 | 30.28 | 41.17 | - | - | 18.87 | 23.47 | 27.62 | 24.15 |
| Sicyonia dorsalis | 1.21 | 1.29 | 0.35 | 0.79 | 1.21 | 1.76 | $\frac{2.90}{}$ | 2.03 | 1.32 | 1.14 |
| Solenocera vioscai | 2.12 | 1.82 | 1.26 | 2.34 | 4.47 | 4.26 | 3.25 | 4.25 | 3.77 | 2.27 |
| Trachypenaeus constrictus | 1.07 | - |  | 2.95 | - | . 3 | 1.5 | - | - | 2.99 |
| Trachypenaeus similis | 1.15 | 2.86 | 1.09 | 1.82 | 3.31 | 3.61 | $\frac{1.5}{2.65}$ | 2.40 | 2.08 | 1.51 |
| Acetes americana | 0.03 | 0.03 | 0.03 | 0.01 | - | - | - . | - | - | 0.03 |
| Anasimus latus | 5.90 | 2.11 | 4.73 | 3.83 | 3.05 | 6.0 | $5.66^{\circ}$ | 4.9 | 6.72 | 4.95 |
| Callinectes similis | 12.96 | 14.43 | 17.10 | 7.09 | 10.18 | 17.73 | 19.65 | 17.45 | 17.17 | 9.92 |
| Portunus gibbesii | 3.17 | 6.54 | 1.0 | 2.89 | - | - | 3.46 | 4.39 | 2.95 | 3.11 |
| Portunus spinicarpus | 6.73 | 5.89 | $\overline{6.82}$ | 6.48 | 4.73 | 7.34 | 5.93 | 5.73 | $\frac{6.92}{}$ | 6.36 |
| Astropecten cingulatus | 7.63 | 4.35 | 5.51 | 4.25 | 0.80 | 1.70 | 4.85 | $\frac{5.7}{7.7}$ | 9.43 | 5.45 |
| Astropecten duplicatus | 0.64 | 0.34 | 0.5 | 0.45 | 0.48 | - | 0.87 | $\underline{1.0}$ | 0.73 | 0.64 |

TABLE 4
INFAUNAL bIomass by species. depth relations, annual totals, biomass and numerical composition

and 5. Again, it is apparent that most infaunal species showed a distinct biomass distribution according to depth (Table 4). The majorrity of the 14 species assayed showed greatest biomass in the shallow zone. Several (Sigambra tentaculata and Cossura delta) showed little depth preferences. Paralacydonia paradoxa had a decided preference for the deepest zone. No species of infauna assayed showed highest biomass at the middepth zone.

The three infaunal species having the greatest total biomass during the 1976 collection year were Diopatra cuprea, Paraprionospio pinnata and Abra equalis. They accounted for $69.91 \%$ of the total assayed infaunal biomass collected during 1976. Numerical dominants among infaunal species were MageZona phyllisae, Paraprionospio pinnata and Lumbrineris parvapedata accounting for $62 \%$ of the total number for the 14 infaunal species assayed (Table 4).

Regression of weight on numbers of individual infaunal organisms data is given in Table 5. The calculated correlation values ( $r$ ) were generally smaller than those for epifauna but all were significant at the 0.01 level except ClymenelZa torquata in which weight was not significantly correlated to numbers.

Seasonal values for total biomass were not significantly different (ANOVA). Spring values were the highest and fall values the lowest but statistically significant differences were not seen. Several species showed seasonal abundance extremes. Diopatra cuprea had a much lower biomass in the fall collection although the number of individuals was not much lower. Abra equalis showed peak biomass and numbers in the spring collection. Biomass of most species varied relatively little during the various seasonal collections, however, numbers of individuals varied for a few species (Lumbrineris parvapedata, Magelona phyZZisae,

TABLE 5
infaina seasonal. and spatial biomass data. regression and correlation of weigit on numbers of infaunal species

| Spectes | Winter Wt | $\begin{gathered} (7) \\ N \end{gathered}$ | March Wt | (8) <br> N | April <br> Wt | (9) $\mathrm{N}$ | Spring Wt | $(1)$ | July <br> Wt | 2) N | Auguat Wt | (3) N | Fall <br> Wt | (4) $\mathbf{N}$ | November Ht | (5) $\mathbf{N}$ | December Wt | (6) <br> N |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Siguombra tentaculata | . 0806 | 102 | . 0218 | 42 | . 0197 | 28 | . 0860 | 235 | . 0323 | 71 | . 0348 | 39 | . 0633 | 220 | . 0263 | 54 | . 0197 | 67 |
| Faralacydonia paradoxa | . 0115 | 19 | . 0058 | 11 | . 0023 | 6 | . 0202 | 42 | . 0074 | 11 | . 0022 | 7 | . 0228 | 62 | . 0037 | 11 | . 0071 | 11 |
| Nephtys inciea | . 5108 | 106 | . 2874 | 50 | . 3398 | 38 | . 6995 | 143 | . 0692 | 36 | . 4445 | 92 | . 4745 | 242 | . 2129 | 96 | . 2958 | 97 |
| Diopatra cuprea | 6.7862 | 89 | . 0050 | 7 | . 0178 | 3 | 9.1949 | 96 | . 1309 | 2 | . 3669 | 4 | 1.6435 | - 68 | . 0039 | 2 | . 29 | 97 |
| Lumbrineris parvapedata | . 3909 | 475 | . 0072 | 34 | . 0083 | 24 | . 1768 | 575 | . 0056 | 28 | . 0116 | 34 | . 2783 | 1579 | . 0080 | 37 | . 0072 | 27 |
| Ninoe nigripes | . 1850 | 44 | . 0634 | 17 | . 0496 | 9 | . 3242 | 63 | . 1239 | 19 | . 0924 | 21 | . 0880 | 37 | . 0394 | 10 | . 0183 | 10 |
| Paraprionospio pinnata | 1.2791 | 705 | . 7855 | 507 | 1.3032 | 486 | 1.2162 | 1009 | . 1884 | 189 | . 1258 | 213 | . 5718 | 630 | . 5709 | 425 | . 7913 | 363 |
| Magelona phyllisae | . 1137 | 755 | . 0167 | 58 | . 0077 | 38 | . 2814 | 2518 | . 0059 | 25 | . 0105 | 38 | . 2468 | 2909 | .0078 | 29 | . 0105 | 38 |
| Cossura delta | . 0366 | 130 | . 0232 | 81 | . 0095 | 51 | . 0491 | 231 | . 0129 | 62 | . 0138 | 51 | . 0469 | 224 | . 0105 | 48 | . 0107 | 43 |
| Armandia maculata | . 1283 | 21 | . 0180 | 5 | . 0138 | 7 | . 0334 | 42 | . 0056 | 10 | . 0535 | 39 | . 0360 | 54 | . 0412 | 21 | . 0554 | 20 |
| clymenella torquata | 1.2019 | 21 | - | - | . 0441 | 1 | . 1996 | 136 | . | 10 | . 05 | 3 | . 3052 | 215 | r | 21 | -05S | 20 |
| Asychia elongata | . 7079 | 16 | - | - | . 0564 | 3 | 1.1378 | 1076 | . 0322 | 1 | . 0017 | 2 | . 1726 | 67 | - | - | - | - |
| Abra equalis | . 0791 | 3 | - | - | . 0020 | 1 | 4.5795 | 1228 | . 0016 | 11 | . 0104 | 64 | . 2610 | 46 | . 0015 | 12 | . 0028 | 22 |
| Ampelisca agassiai | . 5180 | 489 | . 1101 | 117 | . 0577 | 28 | . 4583 | 576 | . 0163 | 24 | . 0468 | 47 | . 7388 | 615 | . 0605 | 44 | . 0347 | 31 |


| Species | Transect I |  | Tranmect 11 |  | Transect Wt | $\operatorname{III}_{N}$ | Transect Wt | $\begin{gathered} \text { IV } \\ \mathbf{N} \end{gathered}$ | Regression Plot |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | N |  | N |  |  |  |  | y |  |
| Sigambra tentaculata | . 0419 | 128 | . 2652 | 427 | . 0420 | 161 | . 0354 | 142 | $3.87 \times 10^{-4}$ | . 560 |
| Paralacydonia paradoxa | . 0207 | 49 | . 0390 | 76 | . 0110 | 25 | . 0129 | 30 | $4.36 \times 10^{-4}$ | . 781 |
| Nephtys incisa | . 5242 | 129 | 2.4872 | 558 | . 1616 | 108 | . 1614 | 105 | $3.05 \times 10^{-3}$ | . 490 |
| Diopatra cuprea | 12.0048 | 95 | . 7581 | 24 | 1.1492 | 41 | 4.2370 | 111 | $7.64 \times 10^{-2}$ | . 775 |
| Lumbrineris parvapedata | . 2298 | 671 | . 0688 | 239 | . 3224 | 1038 | . 2737 | 865 | $2.13 \times 10^{-}$ | . 669 |
| Ninoe nigripes | . 2507 | 44 | . 5483 | 118 | . 0879 | 39 | . 0973 | 29 | $4.93 \times 10^{-3}$ | . 549 |
| Paraprionospio pinnata | . 7576 | 635 | 5.6764 | 3271 | . 2047 | 237 | . 1935 | 384 | $1.91 \times 10^{-5}$ | . 887 |
| Magelona phyllisae | . 2488 | 2622 | . 0939 | 323 | . 2706 | 2378 | . 0923 | 1088 | $9.80 \times 10^{-5}$ | . 921 |
| Cobrura delta | . 0353 | 154 | . 1148 | 480 | . 0284 | 116 | . 0347 | 171 | $1.93 \times 10^{-3}$ | . 769 |
| Armandia maculata | . 0237 | 24 | . 3208 | 133 | . 0270 | 43 | . 0137 | 19 | $1.59 \times 10^{-3}$ | . 490 |
| Clymenella torquata | . 2680 | 6 | . 0441 | 1 | . 1894 | 128 | 1.2496 | 238 | $1.12 \times 10^{-3}$ | . 182 |
| Asychis elongata | 1.8218 | 1117 | . 1536 | 10 | . 0002 | 5 | . 1330 | 33 | $6.04 \times 10^{-5}$ | . 511 |
| Abra equalis | 4.2018 | 506 | . 0199 | 116 | . 3965 | 650 | . 3197 | 115 | $2.81 \times 10^{-3}$ | . 578 |
| Anpelisca agasnizi | . 0409 | 53 | .3912 | 396 | 1.5486 | 1458 | . 0605 | 64 | $1.05 \times 10^{-9}$ | . 959 |

TAbLE 6

INFAUNAL SPECIES COLLECTION MEANS AND ANNUAL MEAN HiOMASS*

| Spectes | Winter | March | April | Spring | July | August | Fall | November | Decembèr | Annual |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Siganbra tentaculata | 0.7902 | 0.5190 | 0.7036 | 0.3660 | 0.4549 | 0.8123 | 0.2877 | 1.4130 | 0.2940 | 0.45 |
| Raralaoydonia paradoxa | 0.6053 | 0.5273 | 0.3833 | 0.4810 | 0.6727 | 0.3143 | 0.3677 | 0.3364 | 0.7000 | 0.46 |
| Nephtys incisa | 4.8189 | 5.7480 | 8.9421 | 4.8916 | 1.9222 | 4.8315 | 1.9607 | 2.2177 | 3.0495 | 3.7 |
| Diopatra cuprea | 76.2494 | 0.7143 | 5.933 | 95.7802 | 65.45 | 91.7250 | 24.1691 | 1.95 | - | 66.97 |
| Lundrineris parvapedata | 0.8229 | 0.2088 | 0.3458 | 0.3075 | 0.2000 | 0.3412 | 0.1763 | 0.2162 | 0.2667 | 0.32 |
| Ninoe nigripes | 4.2045 | 3.7294 | 5.5111 | 5.1460 | 6.5211 | 4.4000 | 2.3784 | 3.9400 | 1.8300 | 4.28 |
| Paraprionospio pinnata | 1.8143 | 1.5493 | 2.6815 | 1.2054 | 0.9968 | 0.5906 | 0.9076 | 1.3433 | 2.1799 | 1.51 |
| Nagelona phyllisae. | 0.1506 | 0.2879 | 0.2026 | 0.1118 | 0.2360 | 0.2763 | 0.0848 | 0.2690 | 0.2763 | 0.11 |
| Cossura delta | 0.2815 | 0.2864 | 0.1863 | 0.2126 | 0.2081 | 0.2706 | 0.2094 | 0.2188 | 0.2488 | 0.23 |
| Arnandia maculata | 6.1095 | 3.6000 | 1.9714 | 0.7952 | 0.5600 | 1.3718 | 0.6667 | 1.9619 | 2.7700 | 1.76 |
| Clymenella torquata | 57.2333 | - | 44.1000 | 1.4676 | - | - | 1.4195 | 1. | 2.770 | 4.69 |
| Asychis elongata | 44.2438 | - | 18.8000 | 1.0574 | 32.2000 | 0.8500 | 2.5761 | - | - | 1.81 |
| Abra equalis | 26.3667 | - | 2.0000 | 37.3923 | 0.1455 | 0.1625 | 5.6739 | 0.1250 | 0.1273 | 3.56 |
| Ampelisca agassizi | 1.0593 | 0.9410 | 2.0607 | 0.7957 | 0.6792 | 0.9957 | 1.2013 | 1.3750 | 1.1194 | 1.04 |

*Weight in milligrams

Abra equalis) but remained relatively unchanged for others (Armandia maculata, Anpelisca agassizi).

Table 6 gives collection mean biomass and annual mean biomass for each species. Many of these species trad: a decided tendency to fragment, thus many of these data were based on anterior portions only. Even so, for several species (Paraprionospio pinnata, Armandia maculata), there seemed to be definite periods in which the mean biomass is diminished indicating the probable periods of recruitment. In others, mean biomass fluctuated very little (Sigambra tentaculata) or without interpretable pattern (Asychis elongata).

Tables 7 and 8 provide comparisons of fresh and preserved wet weights with dry weights and ash free dry weights for selected epifaunal species. These comparisons were not attempted on infaunal species due to the lack of precision caused by fragmentation and the extremely small weights of the organisms. Dry weights and ash free dry weights were consistent within a species and varied slightly between species: The one species common to both analyses, P. aztecus, showed siightly higher values for the dry weight and ash free dry weights of fresh specimens expressed as a percentage of fresh weights than for preserved weights.

## DISCUSSION

The most apparent pattern for biomass of both epifaunal and infaunal species assayed was that the summed biomass of both groups decreased with depth. The infauna species showed a gradient across the shelf while the epifaunal species remained similar within the two shallowest zones but dropped precipitously in the deepest zone. This general finding, decrease of biomass with depth, agrees with results found by other investigators of marine benthic organisms. The reason for the epifaunal biomass con-

TABLE 7
COMPARISON OF ALCOHOL PRESERVED, DRY AND ASH-FREE DRY WEIGHTS OF FOUR EPIFAUNAL SPECIES

\begin{tabular}{|c|c|c|c|c|c|c|}
\hline Spectes \& Preserved Weight \& Dry
Weight \& Percent Preserved Weight \& $$
\begin{aligned}
& \text { Ash } \\
& \text { Weight }
\end{aligned}
$$ \& Ash-Free Dry Weight \& Percent Preserved Weight <br>
\hline \multirow[t]{6}{*}{Squilla chydaea} \& 5.1841 \& 1.0429 \& 20.12 \& . 4102 \& . 6417 \& 12.38 <br>
\hline \& 5.3486 \& . 8552 \& 15.99 \& . 3373 \& . 5179 \& 9.68 <br>
\hline \& 4.6242 \& . 9206 \& 19.91 \& . 2999 \& . 6207 \& 13.42 <br>
\hline \& 4.6015 \& . 7883 \& 17.13 \& . 2918 \& . 4965 \& 10.79 <br>
\hline \& 4.7620 \& . 8792 \& 18.46 \& . 3163 \& . 5757 \& 12.09 <br>
\hline \& 4.9040 \& . 8972 \& 18.29 \& . 3293 \& . 5705 \& 11.63 <br>
\hline \multirow[t]{6}{*}{Trachypenaeus similis} \& 4.3243 \& . 9542 \& 22.07 \& . 2190 \& . 7352 \& 17.00 <br>
\hline \& 5.3231 \& 1.1628 \& 21.84 \& . 2478 \& . 9150 \& 17.19 <br>
\hline \& 3.8654 \& . 7185 \& 18.59 \& . 1873 \& . 5312 \& 13.74 <br>
\hline \& 4.7609 \& . 9951 \& 20.90 \& . 2738 \& . 7213 \& 15.15 <br>
\hline \& 4.7577 \& 1.0386 \& $\frac{21.18}{21.14}$ \& . 2435 \& . 7951 \& 16.71 <br>
\hline \& 4.6062 \& . 9738 \& 21.14 \& . 2342 \& .7396 \& 16.06 <br>
\hline \multirow[t]{4}{*}{Penaeus aztecus

$\overline{\mathrm{x}}$} \& \& \& 27.01 \& . 4571 \& 2.9424 \& <br>

\hline \& $$
12.1354
$$ \& 2.9329 \& 24.17 \& . 3863 \& 2.5466 \& 20.98 <br>

\hline \& 11.9341 \& 2.9537 \& $\underline{24.75}$ \& . 3239 \& $\underline{2.6298}$ \& 22.04 <br>
\hline \& 12.2185 \& 3.0953 \& $\frac{25.33}{}$ \& .3891 \& $\frac{2.7063}{}$ \& $\frac{22.04}{22.15}$ <br>
\hline \multirow[t]{6}{*}{$\begin{array}{ll}\text { Sicyonia dorsalis } \\ \\ & \overline{\mathbf{x}}\end{array}$} \& 1.8355 \& . 4473 \& 24.37 \& . 1390 \& . 3083 \& 16.80 <br>
\hline \& 1.8047 \& . 5038 \& 27.92 \& . 2092 \& . 2946 \& 16.32 <br>
\hline \& 1.8207 \& . 5003 \& 27.48 \& . 2290 \& . 2713 \& 14.90 <br>
\hline \& 1.8561 \& . 4794 \& 25.83 \& . 2007 \& . 2787 \& 15.02 <br>
\hline \& 1.6849 \& . 4394 \& $\frac{26.08}{26.33}$ \& . 1938 \& . 2456 \& 14.58 <br>
\hline \& 1.8003 \& . 4740 \& 26.33 \& .1943 \& .2797 \& 15.52 <br>
\hline
\end{tabular}

TABLE 8

## COMPARISON OF FRESH, DRY AND ASH-FREE DRY WEIGHTS OF FIVE EPIFAUNAL SPECIES

| Species | Fresh Weight | $\begin{aligned} & \text { Dry } \\ & \text { Weight } \end{aligned}$ | Percent <br> Fresh <br> Weight | Ash-Free Dry Weight | Percent <br> Fresh <br> Weight |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Squilla empusa | 19.9516 | 4.9635 | 24.88 | 2.9663 | 14.87 |
|  | 25.8436 | 6.3546 | 24.59 | 4.0223 | 15.56 |
|  | 27.6591 | 6.4730 | 23.40 | 4.2921 | 15.52 |
|  | 28.7706 | 7.9102 | 27.49 | 5.4198 | 18.84 |
|  | $\overline{\mathrm{x}} \overline{25.5562}$ | $\overline{6.4253}$ | 25.14 | 4.1751 | $\overline{16.34}$ |
| Portunus gibbesii | 9.0595 | 3.0736 | 33.93 | 1.6328 | 18.02 |
|  | 5.9583 | 2.2724 | 38.14 | . 9826 | 16.75 |
|  | 5.4382 | 1.9720 | 36.26 | 1.0543 | 19.39 |
|  | 5.9591 | 2.3240 | 39.00 | 1.3552 | 22.74 |
|  | 7.1596 | 2.4174 | 33.76 | 1.2746 | 17.80 |
|  | $\overline{\mathrm{x}} \mathbf{6 . 7 1 4 9}$ | $\frac{2.4119}{}$ | 35.92 | 1.2599 | 18.76 |
| Squilla chydaea | 3.7059 | 1.1749 | 31.70 | . 8328 | 22.47 |
|  | 3.9858 | 1.1450 | 28.73 | . 8122 | 20.38 |
|  | 5.0489 | 1.4135 | 28.00 | . 9217 | 18.26 |
|  | 5.8993 | 1.5855 | 26.88 | 1.1720 | 19.87 |
|  | 6.2009 | 1.7958 | 28.96 | 1.2194 | 19.66 |
|  | 6:8814 | 2.1121 | 30.69 | 1.5645 | 22.73 |
|  | $\overline{\mathrm{x}} 5.2870$ | 2.5378 | 29.09 | 1.0871 | 18.91 |
| Penaeus duoramm | 8.7066 | 2.6120 | 30.00 | . 9839 | 11.30 |
|  | 9.3402 | 2.8020 | 30.00 | . 9735 | 10.42 |
|  | -12.3231 | 3.6969 | 30.00 | 1.1013 | 8.94 |
|  | 16.7986 | 5.8397 | 34.76 | 1.3505 | 8.04 |
|  | 7.9660 | 2.3898 | 30.00 | . 9087 | 11.41 |
|  | - 14.7322 | 4.4196 | 30.00 | 1.2459 | 8.46 |
|  | $\overline{\mathrm{x}} 11.64$ | 3.6267 | 31.16 | 1.0939 | 9.40 |
| Penaeus aztecus | 16.7934 | 4.6416 | 27.64 | 3.7871 | 22.50 |
|  | 16.2394 | 4.7639 | 29.34 | 3.9252 | 24.17 |
|  | 18.1461 | 5.3829 | 29.66 | 4.4617 | 24.59 |
|  | 11.7938 | 3.3037 | 28.01 | 2.6974 | 22.87 |
|  | 16.6240 | 4.8609 | 29.24 | 4.0209 | 24.19 |
|  | 17.2840 | 5.1339 | 29.70 | 4.1175 | 23.82 |
|  | 28.2576 | 7.8407 | 27.75 | 6.3978 | 22.64 |
|  | 26.6066 | 7.0508 | 26.50 | 5.8119 | 21.84 |
|  | 24.6449 | 7.4693 | 30.31 | 6.3348 | 25.70 |
|  | 26.2751 | 8.0899 | 30.79 | 6.7502 | 25.69 |
|  | x 20.2665 | 5.8538 | 28.89 | 4.8277 | 23.82 |

stancy within the first two depth zones is the fact.; that several epifaunal species (Squilla chydaea, Sicyonia dorsalis and Callinectes similis) show a decided preference for the mid-depth zone. Other epifaunal species (e.g., Penaeus aztecus, Trachypenaeus similis) have similar biomass distributions in both shallow zones. Almost all of the infaunal species show a true decreasing gradient across the shelf from shallow to deep. Only a few infaunal species: (Paralacydonia paradoxa which showed a reverse gradient and Cossura delta which showed no gradient) did not show the decreasing biomass gradient across the shelf. No infaunal species showed a decided preference for the mid-depth region.

The depth pattern for epifaunal organisms was more complex than that of the infauna. The assayed infaunal species had two basic types of species, the shallow and deep groups. In our area, there were many more shallow species gading into deep zones than the reverse. Epifaunal species had at least four distribution patterns relative to depth. Perhaps the most common was the shallow grading to deep species which actually was of two types, the continuous gradient across the three zones and the precipitous drop in the deepest zone after remaining fairly constant in the two shallow zones. The third type contained species which are truly mid-depth species, showing a peak biomass in the mid-depth zone. There were no similar species in the infauna assayed. The fourth epifaunal biomass distribution pattern was exhibited by the deep species which showed a biomass decrease as depth decreased.

The difference between the apparent depth distribution types of epifaunal and infaunal organisms may be explained in that the "depth relation" may not be only the effect of depth per se on the various organisms. but probably includes many depth related factors such as sediment type, nutrient availability, stability of hydrographic parameters,
etc. The infauna species, selected because they were biologically important to our area, being far less motile have adapted to fewer distribution patterns.

The regression of weights on numbers for epifaunal and infaunal species indicated, as might be expected, a generally significant correlation between weights and numbers. Epifaunal species generally had less variation in data plots of weights on numbers and had higher correlation coefficients ( $r$ ). This stemmed from the greater fragmentation of infaunal species and from the greater numbers of infaunal specimens analyzed. All species analyzed except the polychaete, Clymenella torquata, showed highly significant correlations between weight and numbers. Notes made during the weighing procedure indicate a greater than normal percentage of fragments of varying sizes and many individuals of various sizes in the samples of this species. The prediction of weight from number of individuals of a given epifaunal species will be somewhat more accurate than for infaunal species within the ranges sampled.

The apparent lack of statistically significant differences between biomass (and numbers) of both epifaunal and infaunal species for seasons and transects remains somewhat dubious, Biomass totals for both epifauna and infauna showed differences between seasons and transects but due to the very great variability within a given treatment (season or transect) the one-way ANOVA test was unable to detect difference between transects (season or sample), Spring samples for both epifauna and infauna showed the highest biomass of the seasons sampled. The epifauna winter and spring samples had similar numbers but the spring sample was much heavier. This may indicate growth of prevalent species between February (winter) and May (spring) sampling periods. Fall samples were similar in biomass to the winter samples but far fewer in numbers of individuals, indicating
larger individuals; stock for reproduction in the winter-spring. These generalizations would seem to apply to the total sample but individual species did not necessarily follow this pattern (or any obvious pattern of seasonal biomass). Mean weights of individual epifaunal species (Table 3) showed a variety of patterns of average weight patterns through time. Some patterns, such as that of $P$. aztecus, may be safely interpreted as recruitment of smaller individuals leaving the bays for the continental shelf in the spring and summer. However, many species 'hads no such pattern and may actually be reproducing more or less continuously through the year (or major portion of the year). This is thought to be true of some estuarine invertebrates (e.g. Callinectes sapidus Rathbun) in the South Texas area and may well be true for some outer continental shelf species as well, particularly those species having no known usage of bays and estuaries for nursery grounds. Infaunal species showed even less evidence for distinct reproductive periods than did the epifauna. It may well be that many, if not most, of the smaller infaunal species have a very short life span in the relatively warm waters of the STOCS region and are indeed reproducing during most of the year.

Biomass between transects varied with epifaunal annual biomass being greatest along Transects II and IV. Infaunal annual biomass was greatest on Transects I' and II. It must be remembered that Transect II data includes the six monthly samples while all other transects have only seasonal data. This then negated the importance of Transect II in biomass and numbers of individuals, making it similar to Transects I and III for the epifauna and to Transects III and IV for infauna. The difference in epifaunal biomass for Transect IV was primarily due to several species including Polystira albida, Amusium papyraceus and Penaeus aztecus. Infaunal biomass on Transect I was highest due to the presence of the
polychaete, Diopatra cuprea, which had more biomass on Transect I than the total biomass on each of the other transects. Thus 95 individuals of one species ( $D$, cuprea) collected during the year, primarily winter and spring cruises on Transect $I$, weighed more than the annual summed weights of 14 infaunal spectes ( 3000 to 6000 individuals) on each of the other transects. Without this preponderance of Diopatra, the biomass on each transect would have been very similar.

As wet weights are known to be fraught with sources of variability, dry weights and ash-free dry weights were investigated on several epifaunal specíes. As all regularly collected specimens were archived for future reference work, a selected group of species was: collected on an ancillary cruise to be utilized in the destructive (dry and ash-free dry weight) biomass measures. Dry weight averaged less than $25 \%$ of the preserved weight of four species and slightly over $25 \%$ of the fresh weight of five epifaunal species. Apparently, some of the fresh weight was lost to the preservative. Ash-free dry weight was more similar averaging $16-18 \%$ of the preserved or fresh weight except in Penaeus aztecus which had $22.2 \%$ and $23.8 \%$ respectively. Unfortunately, there was only one species, P. aztecus common to both biomass measurement (fresh and preserved weights) analyses. The percentage dry weight and ash-free dry weights were very similar for this species, both being slightly higher for the fresh weight analysis, Again a loss of carbon weight in the preserving process was indicated.

Biomass for the infauna was, as expected, fairly low. Other investigators had reported low biomass for infauna (Rowe, 1974) in the Gulf of Mexico. The 14 species selected probably comprised a major portion of the total biomass available. Sanders (1960) reported the top ten species comprising about $95 \%$ of the total in one of his study areas. We have no way of
knowing the actuaz percentage but".wouldestimate at leäst $\mathbf{7 5 \%}$ af thènfaunal biomass was contributed by these 14 species. The maximum seasonal biomass of 18.4559 grams for the 14 assayed species would then estimate 24.6078 total biomass for the 150 samples collected on the spring cruise, or an average of 1,6403 grams of wet weight per square meter over the study area. This estimate is slightly lower than fall samples from 1977 which are being weighed whole and are averaging slightly less than four grams per square meter. These whole samples are utilizing all fragments and therefore are more accurate than the present extrapolations but are still only about twice the present estimate. The low biomass figures calculated give added strength to the hypothesis of continuous infaunal reproduction, i.e., a high turnover rate, if the infaunal organisms are indeed contributing, as we feel they are to the energetics of the STOCS ecosystem.

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ADDENDUM TO HISTOPATHOLOGY OF DEMERSAL FISHES
Histopathology of Micropogon undulatus (Atlantic croaker)
Exposed to Water Soluble Fractions of South Louisiana Crude Oil

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#### Abstract

Histopathologic analyses of approximately 100 Micropogon unduZatus (Atlantic croaker) exposed to water soluble fractions of South Loulsiana crude oil were made. Five fish were exposed to two solutions (5 and $10 \%$ of a stock solution) for $1,3,7,14$ and 21 days. Samples of liver, kidney, heart, skeletal muscle, stomach, gonad and gill were collected following the various periods of exposure.

Most of the organ samples obtained from fish exposed to varying concentrations of water soluble fractions of South Louisianacrude oil did not show lesions that could be attributed to the oil. Two of the organs, gill epithelium and liver, and possibly a third organ, the subcutaneous areas, did show a response to the crude oil. The fact that some organs did not demonstrate a response and that others showed a minimal response suggests that the lengths of exposure, the concentrations used, or both exposure and concentrations, were too low to permit severe lesions to occur.


This special report is concerned with the histopathologic analyses of Micropogon undulatus (Atlantic croaker) exposed to water soluble fractions of South Louisiana crude oil. Organ and tissue responses to crude oil exposure were compared to the normal status of selected organs currently being characterized in demersal fishes, South Texas OCS Monitoring Study, 1976 and 1977.

## MATERIALS AND METHODS

## Experimental Animal

Approximately 100 Micropogon undulatus were collected by otter trawl in Galveston Bay, Texas. The fish were transported in tanks by truck to the Aquatic Animal Medicine Laboratory, Texas A $\alpha M$ University, College Station, Texas. Temperature during transport was maintained with block ice. Temperature and salinity of the laboratory holding tanks were adjusted to approximate bay conditions. The fish were allowed to adjust to laboratory conditions for one week. Both treated and control fish were maintained on a diet of live shrimp.

## Crude Oil

A water soluble fraction of crude oil was prepared by mixing, with a magretic stirring apparatus, one liter of South Louisiana crude oil ${ }^{1}$ with nine liters of distilled water for 24 hours. The distilled water containing water soluble portions of the crude oil was drawn from beneath the oil layer. This was designated the stock solution. The stock solution was diluted with synthetic sea water (INSTANT OGEAN) to 5 and $10 \%$

[^0]working solutions in 35-1iter aquaria.

## Experimental Design

Five fish were exposed to each of the two working solutions for five periods of time: $1,3,7,14$ and 21 days. Fish were maintained in the working solutions with aeration only. The working solutions were changed daily to insure a constant concentration of the volatile portions of the water soluble fraction of crude oil. Five untreated fish served as controls for each exposure period. The experimental design is presented in Table 1.

## Organ Samples

Samples of liver, kidney, heart, skeletal muscle, stomach, gonad and gill were collected following the various periods of exposure. The tissues were fixed in• $10 \%$ buffered neutral formalin and Helly solution. Following fixation the tissues were washed, dehydrated with ethyl alcohol and embedded in paraffin. Blocks of tissues were sectioned at six micra and stained with hematoxylin and eosin. In addition, liver, stomach and kidney sections were stained according to the alcian blue - periodic acid - Schiff procedure (AB-PAS).

Tissue sections were evaluated qualitatively for histopathologic disturbances. Liver samples were further evaluated using a subjective quantitative procedure. Duncan's Multiple Range procedure was used to test for significance between means.

All organ sections were evaluated using a blind procedure in which the observer did not know the fish, the treatment or the length of exposure from which the section was taken,

## TABLE 1

NUMBERS OF FISH EXPOSED TO WATER SOLUBLE FRACTIONS OF SOUTH LOUISIANA CRUDE OIL

| Length of Exposure $\qquad$ | Control | $\begin{aligned} & \text { Working } \\ & 5 \% \\ & \hline \end{aligned}$ | $\begin{gathered} \text { Solutions } \\ 10 \% \\ \hline \end{gathered}$ | Total |
| :---: | :---: | :---: | :---: | :---: |
| 1 | 5 | 5 | 5 | 15 |
| 3 | 5 | 5 | 5 | 15 |
| 7 | 5 | 5 | 5 | 15 |
| 14 | 5 | 4 | 5 | 14 |
| 21 | 5 | 5 | 5 | 15 |
| Total | 25 | 24 | 25 | 74 |

Kidney, gonad, heart and stomach did not show any lesions that could be attributed to exposure to the water soluble fractions of crude oil. Occasional parasitism was observed, but this was consistent with observations in the control fish and in organ samples obtained from fish on the Texas Outer Continental Shelf. The mucin content of the gastric superficial epithelial cells appeared to be unchanged, as determined by the $A B-P A S$ procedure.

Muscle tissue did not appear to be disturbed by the crude oil exposure. During the collection procedure some skin was occasionally left attached to the muscle to help maintain muscle compactness. When the muscle slides were being read, it was observed that some sections contained a lipid or a fatty subcutaneous layer between the skin and muscle. The sections with subcutaneous lipid areas were mainly from untreated or control fish.

Gill tissue sections demonstrated a separation of lamellar epithelium when exposed to both the 5 and $10 \%$ concentrations of the crude oil. This lesion was first observed after 14 days exposure and was also present after 21 days. The degree of epithelial separation did not vary between 14 and 21 days of exposure. No other gill lesions were observed.

In the liver, hepatocytes had numerous round cytoplasmic vacuoles. The degree of vacuolation increased with length of exposure and concentration of the working solution (Table 2). Degree of vacuolation was subjectively evaluated from 1 (no vacuolation) to 6 (extreme vacuolation). Significant increases in vacuolation ( $P<0.05$ ) occurred in the liver of fish exposed seven days or longer to the 5 and $10 \%$ concentrations of

TABLE 2

## average degree of hepatocyte vacuolation in fish EXPOSED TO WATER SOLUBLE FRACTIONS OF SOUTH LOUISIANA CRUDE OIL

| Length of Exposure <br> (Days) | Contro1 | $\cdots$ | Working Solutions <br> $5 \%$ |
| :---: | :---: | :---: | :---: |
| 1 | $1.6 *$ | 2.2 | $10 \%$ |
| 3 | 2.2 | 1.8 | 3.0 |
| 7 | 2.0 | 3.5 | 4.4 |
| 14 | 2.4 | 4.0 | 4.4 |
| 21 | 1.2 | 4.2 | 4.8 |

[^1]crude oil.

## DISCUSSION

Most of the organ samples obtained from fish exposed to varying concentrations of water soluble fractions of South Louisiana crude oil did not show lesions that could be attributed to the oil. Two of the organs, gill epithelium and liver, and possibly a third organ, the subcutaneous areas, did show a response to the crude oil. The fact that some organs did not demonstrate a response and that others showed a minimal response suggests that the lengths of exposure, the concentrations used, or both exposure and concentrations, were too low to permit severe lesions to occur.

Epithelial tissue has high regenerative capacity. It is expected that gill epithelium would continually be replaced while under constant irritation from petroleum elements. After prolonged exposure to a foreign substance, however, replacement of gill epithelium may not be able to keep pace with cell loss, and erosion of the epithelium would begin to take place. This erosion of epithelium was beginning to take place between 14 and 21 days of exposure to crude oil as demonstrated in this study. It is expected that with exposures greater than 21-days there would be ulceration followed by sloughing of gill lamina. The latter lesions would cause severe respiratory depression.

It has been stated that the gill membranes are one major pathway by which exogenous hydrocarbons enter the body of aquatic animals (Stegeman, 1977). Such hydrocarbons would be transported to the liver for metabolism. In the present study an increase in hepatic vacuoles occurred with increase in time of exposure, an apparent response to crude oil uptake. The exact nature of the hepatocyte vacuolation cannot
be determined without employing histochemical procedures. It is believed, however, that these vacuoles probably are lipid concentrations. Longer exposures to crude oil could lead to irreversible degenerate processes, primarily in the liver and secondarily in other organs, especially the heart and kidneys,

The lack of subcutaneous adipose tissue in the fish exposed to the crude oil suggests that lipids may be depleted.through the skin. This would be an important aspect of hydrocarbon pollution, especially for use in a monitoring system. The observations presented here, however, are not conclusive since skin was not collected routinely as part of this study.

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## CHAPTER NINE

# KARYOTYPE OF DEMERSAL FISHES AND INVERTEBRATE EPIFAUNA 

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#### Abstract

A variety of techniques have been developed over the past few years for the study of chromosomes. Many of these techniques are mainly for mamals and a few for other animals. These techniques have been modified for marine invertebrates and fishes in this study with good success.

The rationale for chromosome analysis and components of the techniques are outlined. The protocol for fish tissues, blue crab, squid and paper scallop are outlined in detail. Some problems still exist in converting protocols to marine organisms and in the response of marine tissues to the various treatments. The squash technique and modifications to this technique have proven the most successful for invertebrates and fishes. Invertebrate tissues do not respond well to pre-treatment, therefore direct squashes have provided the best material:


## INTRODUCTION

Chromosomes have been studied in a variety of ways and from a variety of tissues for many years. The primary method for chromosome preparation was the squash technique (Seryer, 1950; Ohno, et al., 1965; Sharma and Sharma, 1972) but this did not always produce analyzable chromosomes. In the 1950's, Ford and Hamerton (1956) introduced a technique for human chromosome preparation that revolutionized the field of cytogenetics. As a result of this, newer and better techniques were developed. Pre-treatment with mitotic inhibitors were introduced to increase the number of metaphase chromosomes. Hypotonic solution pre-treatment to aid in the separation and spreading of chromosomes was also introduced in addition to the air-drying method which improved the scatter of chromosomes. These and other modifications have been introduced and are being employed in the study of chromosomes.

In this study, the modification of these techniques have been applied to the study of chromosomes of marine fishes and marine invertebrates. Few studies have been made of marine organisms. Techniques have not been fully developed and are in need of refinement.

Some of the problems that had to be solved were (1) the choice of tissue, (2) choice of technique, (3) type and length of pre-treatment, (4) method of preparation, and (5) fixation. A variety of techniques were employed, modificationsmade and several techniques combined in developing techniques that were applicable for chromosome analysis. Different marine fishes and marine invertebrates were used (Table 1) some With relatively good results, others with poor results. Some of the techniques were arrived at through a trial and error approach while others were as described previously in the literature.

Table 1. Species Sampled and Chromosome Counts.

| Species | Chromosome Number |
| :---: | :---: |
| Fish: |  |
| 1. Sand Seatrout - Cynoscion arenarius | 48 |
| 2. Vermillion Snapper - Rhomboplites aurorubens | -- |
| 3. Barred Grunt - Condon nobilis | -- |
| 4. Silver Perch - Bairdiella chrysura | 48 |
| 5. Gulf Butterfish - Peprilus burti | -- |
| Invertebrates: |  |
| 1. Blue Crab - Callinectes sapidus | 24 |
| 2. Squid - Lolliguncula brevis | 24 |
| 3. Brown Shrimp - Penaeus aztecus | 22 |
| 4. Paper Scallop - Amusium papyraceus | 12 |

## METHODS AND MATERIALS

Sampling
Organisms used (Table 1) were obtained from trawl samples along Transect II in the South Texas Outer Continental Shelf study area and along the offshore areas near the University of Texas Marine Science Institute at Port Aransas. Some animals were kept alive in holding tanks with continuous running filtered seawater at the Institute. The other animals were transported to the University of Texas at San Antonio and kept in aquaria with Instant Ocean.

## Sources of Chromosomes

Invertebrates
Chromosomes from some of the marine invertebrates were obtained from the gills, hepatopancreas, liver and other glandular tissues.

## Vertebrates

Fish chromosomes were obtained from both external epithelium and from internal organs with varying degrees of success. External sources that provided tissue for analysis were fin and scale epithelium and gill epithelium. Internal tissue sources for chromosomal analysis were the liver, spleen, and kidney.

## Chromosome Techniques

The specific techniques used were either a modification of the squash technique or the air-dry method. The advantages and disadvantages, as well as the specific method used are, discussed in the RESULTS/DISCUSSION section of this report. The tissues were either used directly, with no pre-treatment and squashed, or given a colchicine (mitotic arresting agent) pretreatment, hypotonic pretreatment and squashed or air-dried. The actual
technique used varied from tissue to tissue and from organism to organism. Treatment time also varied greatly with the type of organism, and size of organism.

## Solutions

Solutions employed in this study were:

1. Colchicine: $0.25 \%$ solution in physiological saline;
2. Marine invertebrate physiological saline;
3. Marine crustacean physiological saline;
4. Teleost physiological saline;
5. Hypotonic solution
a. 0.075 M KCL
b. 1\% Na-Citrate
c. Distilled water;
6. Fixatives
a. Methanol: Acetic acid (3 parts to 1 part)
b. 50\% Acetic acid;
7. Stains
a. Aceto-orcein, $2 \%$
b. Giemsa,

RESULTS AND DISCUSSION
In order to develop techniques for the different organisms sampled from the South Texas Outer Continental Shelf it was necessary to modify existing techniques (1), for marine organisms and (2) to the specific tissues. The basic principle as described in the literature (Denton, 1973; Sharma and Sharma, 1972) was employed as an initial approach to each organism. For some animals these techniques yielded satisfactory
material, while in others the material was lost completely. The primary approach was to handle the tissue as described in the literature and monitor the tissue or cells periodically under the microscope in an attempt to establish the best time, treatment and/or technique. As changes to the basic protocol were made, new material would be so treated and again monitored at specific time intervals. Some of the tissues were treated and again monitored at specific time intervals. Some of the tissues were treated simultaneously with different solutions and treatments and the results compared for best results.

The basic protocol employed is basic to most chromosomal techniques. The elements in the protocol are as follows:
a. Colchicine pre-treatment. Colchicine is an alkaloid that is used as a mitotic inhibitor. As a result of this inhibitor, it is possible to increase the number of metaphase figures and increase the number of analyzable chromosome spreads. The concentrations normally used range from 0.01 to $0.5 \%$ for periods from one to six hours and sometimes for as long as 12 to 18 hours. The colchicine is usually administered by injecting the fish in the dorsal musculature or peritoneal cavity and by injecting the coelomic cavity of the invertebrates. For the smaller fish, where injection is not possible, it is suggested that the fish be allowed to swim in dilute colchicine solution. One of the major problems with the use of a mitotic inhibitor is that if the treatment is too long, it may cause the chromosomes to become overcontracted. It is possible to obtain a good material without any mitotic inhibitor, but the number of chromosome spreads may be small.
b. Hypotonic pre-treatment, The hypotonic pre-treatment is a procedure that causes the cells to swell and as a result the chromosomes will
scatter when squashed or splattered on the slide. This treatment is done immediately after the tissue is removed from the animal. The hypotonic solution can be any solution that has a lower fonic concentration than the contents of the cell. Solutions used with varying success are distilled water, sodium citrate, potassium chloride and dilute saline solutions. The effectiveness of the hypotonic pre-treatment depends on length of treatment and the delicacy of the tissue. Therefore, the treatment time may vary from a few minutes up to an hour. Over-treatment will result in the cells swelling too much and breaking open with the subsequent loss of material. The type of solution used will often affect the quality of the preparation; thus, some solutions are preferred over others for certain tissues. Some invertebrates produced excellent material with no hypotonic pre-treatment suggesting that their cells were very fragile.
c. Fixation. After the cells have been treated hypotonically, it is necessary to stop the swelling process. This is accomplished by chemically fixing the material. The most common fixative used is a $3: 1$ solution of methanol and acetic acid. Another fixative often employed is a $50 \%$ solution of acetic acid. Care in handling the cells must be exercised since even after fixation it is possible for the cells to burst and result in the loss of chromosomes. Fixation is normally from 5 to 30 minutes.
d. Chromosome preparation, The air-drying technique is the newest method and produces excellent material when it can be used. The tissue is dissociated into a slurry of cells and the cells are then pre-treated and fixed in this condition. A few drops of thefixed slurry of cells is deposited on a clean slide and allowed to air dry. Spreading of the chromosomes may be aided by blowimg straight down on the slide or by splat-
tering the drop of slurry onto the slide from a short distance. The squash technique, the oldest method, is the most widely used for flattening metaphase chromosomes. A small piece of fixed tissue is placed on the slide, covered with a cover glass and gentle pressure applied with the thumb.
e. Staining. Air dried preparations may be stained in Giemsa or other suitable stain after they have dried thoroughly. Squash preparations may be stained during the squashing procedure. This is accomplished by placing the tissue in a drop of aceto-orcein for a few minutes before squashing. The tissue is then squashed and the excess stain blotted. This produces a temporary slide that is ready for examination. Temporary slides can be converted into permanent slides by the Conger-Fairchild (1953) dry-ice method.

The techniques developed for marine organisms from the STOCS were adapted from the above basic protocol. These will be outlined below with modifications described for each type of organism or tissue.

Tissues used from the fishes were gill epithelium, scale and fin epithelium, liver, spleen and kidney. The liver, spleen and kidney tissues were homogenized to make a slurry of cells. The squash technique was used for the chromosome preparations. The homogenization method has been used successfully in some laboratories (Gold, 1974; Gold and Avise, 1977) and reportedly provided good analyzable spreads in fresh water fish. This technique did not prove satisfactory in our study as the mitotic cells were lost in the process, Since the number of animals was limited, it was not possible to adjust the technique until the proper combination was obtained,

The squash technique proved to give best results. The pre-treatment was adjusted for the various fishes, based on size and previous experience.

The basic squash technique employed was that of Ohno et $a l$. (1965) and Denton (1972). The main changes were in the treatment times and solutions used. The protocol was as follows:

1. Two to three hours prior to sacrifice, 0.1 to 0.5 ml of $0.25 \%$ colchicine was injected into the dorsal musculature directly behind the gill arch and operculum.
2. The spleen, kidney and gonads were removed, minced into small cubes and placed in hypotonic solution for 20 to 30 minutes. Hypotonic solutions used were $0.075 \mathrm{M} \mathrm{KC1}$ and $1 \% \mathrm{Na}$ Citrate. The distilled water treatment did not work effectively.
3. The tissues were fixed in $50 \%$ acetic acid for 5 to 30 minutes and squashed.
4. The cover glass was removed by the Conger-Fairchild dry ice method and the slide passed through $100 \%$, ice cold ethanol and air dried.
5. Slides:were stained in Giemsa.

This technique proved to be satisfactory with countable chromosome spreads. The major problem was obtaining a high enough number of dividing cells for analysis. The gill epithelium provided a much higher mitotic index and better chromosome spreads. The technique used was a modification of the Lieppman and Hubbs (1969) and McPhail and Jones (1966) techniques for freshwater fish. Protocol was as follows:

1. 0.2 ml of $0.25 \%$ colchicine was injected into the dorsal musculature directly behind the gill arch and operculum one to three hours prior to sacrificing the animal. The animals were kept in well aerated water.
2. The gill arches were removed, washed in physiological saline to remove blood and mucous and incubated in hypotonic solution. A 0.075

M KC1 hypotonic solution as well as a $1.0 \% \mathrm{Na}$ Citrate pre－treatment for 30 minutes proved effective．

3．The gills were then fixed in $50 \%$ acetic acid for 15 to 30 min－ utes．

4．With jeweler＇s forceps，the gills were removed from the fixative， allowed to air dry for a minute，and the tissue dabbed on the slide to loosen the cells onto the slide．

5．The cells were covered with a cover glass and the slide placed between filter paper and pressure applied．

6．The slide could be checked directly if the cells were dabbed onto a drop of aceto－orcein，or the slide processed through the dry ice method and subsequently stained with Giemsa．

Previous techniques recommended distilled water for the hypotonic treatment．This treatment causes the cells to explode with loss of material．

Chromosomes from scales also provided adequate material with the exception of dividing cells．Denton $(1969,1973)$ suggests that the fish be placed in a $0.01 \%$ colchicine solution for five to six hours．However， the amount of colchicine for this treatment may be prohibitive．The advantage of this technique is that the animal does not have to be sacrificed and the same fish can be used several times．A modification developed for this technique was as follows：

1．Scales or fin epithelium were collected and placed in physiologi－ cal saline．Colchicine was added to the saline to make a $0.025 \%$ concen－ tration and scales and fin epithelium incubated at room temperature for three hours．Any dividing cells were arrested which gave an adequate amount of．material，
2. The saline was carefully aspirated without disturbing the tissue and gently replaced with a $0.075 \mathrm{M} \mathrm{KC1}$ hypotonic solution. The cells were allowed to swell for 30 minutes at room temperature,
3. Fixation was accomplished by adding an equal amount of concentrated acetic acid to the hypotonic solution to make the final concentration $50 \%$. Tissues were fixed for 15 to 30 minutes.
4. Scales were picked with fine jeweler's forceps and the scale tapped on the slide to transfer epithelial cells onto the slide. The material was either air dried or placed in: a drop of aceto-orcein for a few minutes and then covered with a coverglass and squashed.
5. The slide could be examined immediately or made into a permanent preparation by the dry ice method of Conger and Fairchild (1953).

This technique enables the use of the same animal repeatedly without requiring the sacrifice of the fish or the colchicfne injection, The disadvantage of this technique is the low number of dividing cells found on the scale epithelium plus the low number of overall cells available. Otherwise, very good results have been obtained.

The invertebrates did not prove as easy to work with as the vertebrates. Many of the techniques necessary to work with the invertebrates are so varied or dependent on the animal that a general protocol was not available, Several studies have been published on invertebrates (Ahmed and Sparks, 1967, 1970; Longwell et al., 1967; Menzel, 1965, 1968). The majority of these studies have been for embryonic material where a large number of dividing cells can be found. In this study, adult animals were used and normal tissues used for chromosomal analysis. Tissues used were the gills, hepatopancreas, liver and/or coelomic fluid, Some of these were very poor for chromosomal analysis. Invertebrates used in this study were blue crab, squid, brown shrimp and paper scallop (Table 1).

Some of the techniques developed that provided adequate chromosomal material are as follows:
A. Blue Crabs.

1. 0.2 ml of $0.25 \%$ colchicine was injected into the coelomic cavity. Varying times were tried ranging from 6 to 60 hours. The most effective treatment time was 18 hours.
2. The animal was sacrificed and gills and hepatopancreas were either given a hypotonic treatment or squashed directly.
a. Tissues were given a hypotonic treatment with either 0.075 M KCl or dilute ( $1: 10$ ) physiological saline, for 30 minutes. Tissues were then fixed in $50 \%$ acetic acid and squashed.
b. Tissues squashed directly were rinsed briefly and kept in physiological saline. The tissues were dabbed directly onto slides or small pieces squashed directly. A small drop of aceto-orcein was used as a fixative (approximately $50 \%$ acetic acid) and a stain.
3. Permanent slides were made using the Conger-Fairchild dry ice method.

The blue crab has provided good countable chromosomal spreads, but the morphology of the chromosomes is not good. The chromosomes tend to clump or become sticky since the colchicine and hypotonic pre-treatments have not been fully worked out.

B, Squid,

1. Colchicine was injected into the mantle-coelomic cavity of the squid with treatment lasting from one to six hours. A one to two hour treatment of $0,05 \mathrm{ml}$ of $0.25 \%$ colchicine in well aerated water gave the best results,
2. Gills, gonads and hepatopancreas were used for chromosomal
analysis using the hypotonic treatment and direct squash procedures as in the blue crab. The direct squash provided the best results. The tissue was dabbed onto the slide and a drop of aceto-orcein added and squashed.
3. Slides were restained with Giemsa and made permanent by the dry ice method.
C. Paper Scallop.
4. Paper scallops were injected with 0.1 ml of $0.25 \%$ colchicine in the area of the digestive gland-heart region. A colchicine pre-treatment from one to three hours was used with good results.
5. 'Gills, mantle, gonads and digestive gland were tested for effectiveness in chromosomal preparation. The gills and digestive gland provided the best material.
6. Direct squash and hypotonic pre-treatment were tried with poor results. The modification for this animal's tissues was immediate fixation in $50 \%$ acetic acid for 10 minutes prior to squashing.
7. Material was dabbed onto the slide, coverglass applied and gentle pressure applied.
8. Permanent slides were stained with Giemsa.

The above procedures incorporate the basic protocol for chromosomal analysis. In some, minor modifications were necessary, while in others wide deviation from normal procedures was necessary.

Among the fishes, the main modification has been in pre-treatment times in order to obtain analyzable material plus minor changes in the handling of the cells. In general, the invertebrate tissues did not respond to colchicine and hypotonic pre-treatment as well as vertebrate cells. Invertebrate cells are also more fragile and tend to be lost in handling. As a result, direct squash, or dabbing plus squash gave best
results．Since the tissues／cells do not respond to pre－treatments as well as fish cells，the chromosomes do not spread as well and tend to clump．Further work will be continued to establish better treatment to improve the handling of chromosomes of marine organisms．

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# VARIANCE OF SEDIMENT TEXTURE WITHIN GRAB SAMPLES 

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#### Abstract

In order to determine the variability of sediment textural para－ meters within grab samples，replicate subsamples were taken from each of three grab samples taken from Stations 1－3，all transects，during the winter，1976，cruise．An analysis of variance was used to compare intra－ grab and intergrab variations for the following parameters；mean grain size；standard deviation；skewness；kurtosis；percent sand，silt and clay；sand／mud ratio；silt／clay ratio；and percent finer than 10.6 phi（ $\varnothing$ ）．

Of the 12 stations，seven are considered to fit a model of no significant difference between grab samples．At the other five stations real differences between grab samples are indicated．


## In:TRODUCTION

Variation between replicate grab samples taken at a sampling station is large for many parameters (e.g., infaunal abundance). A question arises: do these represent only random variations in that parameter, or are they due to variations in a controlling factor? In order to answer this question, the variance of the possibly controling factor must be known. The factor examined in this report is sediment texture.

Different models of textural variability may be used to compare textures with other parameters they may affect. One model is that each grab sample has unique textural characteristics. This model would require that any other parameter be correlated with the texture of the grab sample from which it was determined. A second model could be that at any given sampling station, the sediment texture is uniform at the volume of a grab sample, but non-uniform at the smaller volume of a subsample. Observations of sedimentary structures in cores and box samples strongly support this small scale variability. If this model were true, better correlations between textures and other parameters would be obtained by using pooled estimates of textural values. According to this model, the estimate of the true population of grain sizes would improve as more samples were taken at a given station. Furthermore, it would not matter if the replicates were from a single grab sample or from many. This model is depicted graphically in Figure 1.

BLM sampling of the Texas OCS from 1975 to 1977 was done assuming that model 1 is correct. If model 2 is actually the case, use of the data from these samples according to model 1 will introduce unneces-


If textures at a station are uniform so that the true grain size distributions in all grab samples (e.g., 1-6) are identical, then subsample groups la-6a, $3 \mathrm{a}-3 \mathrm{e}$, and $\mathrm{f}-\mathrm{j}$ are equally good estimators of that population; but smaller scale variations (within grab samples) and laboratory analytical errors would make each individual grab sample analysis a less accurate estimator of that population.
sary noise or scatter in the results. However, if it can be shown that model 2 is more accurate for some stations, the use of pooled estimates of the true sediment textures will enhance the analysis of benthic parameters measured at those stations.

Even where sediment texture for a given grab sample is better estimated by a single analysis of subsample from that grab, correlation with other parameters may be put into better perspective by knowIng the range of variability of textures that a single analysis may represent.

## METHODS

In order to determine the variability within grab samples, replicate subsamples were taken from each of the three grab samples taken during the winter 1976 cruise. These were analyzed by the same rapid sediment analyzer and pipette methods used for all other BLM samples.

An analysis of variance was used to compare intragrab and intergrab variations for three grab samples from Stations 1-3 on each of the four transects sampled seasonally. The analysis was applied to the following parameters: mean grain size, standard deviation, skewness, kurtosis, percent sand, silt and clay, sand/mud ratio, silt/clay ratio, and percent finer than 10,6 phi ( $\varnothing$ ). This analysis was applied to three replicates from each grab for convenience in programming the computations. However, of the 36 grab samples analyzed, 29 had 5 replicates, 6 had 4 replicates, and 1 only had 3. All the replicates were used to make further comparisons of mean grain size.

The analysis of variance tests the hypothesis that based on the variability within grab samples, there is no evidence of variability between grab samples. At 9 of the 12 stations tested, this hypothesis is accepted at least at the $95 \%$ confidence level. At Station $1 / I$ the hypothesis is rejected for skewness at $95 \%$ and for kurtosis.at $99 \%$ confidence. At Station $2 /$ II it is rejected for kurtosis at $95 \%$ and for the silt/clay ratio at $99 \%$ confidence. At Station 2/IV the hypothesis is rejected for standard deviation, percent sand, and sand/mud ratio at $95 \%$ confidence. Thus, this analysis suggests that for Stations $2 / \mathrm{I}, 3 / \mathrm{I}, 1 / \mathrm{II}, 3 / \mathrm{II}, 1 / \mathrm{III}, 2 / \mathrm{III}$, 3/III, I/IV and 3/IV any correlation with a textural parameter should be made with a pooled estimate from all grab samples.

Although the analysis of variance of mean grain sizes indicated that analysis at all stations should use pooled estimates, some considerable differences (of $\frac{3}{2} \emptyset$ or more) suggested that further investigation of the significance of these differences should be made. It was reasoned that if model 2 were the case, true variability of mean grain size could be estimated two ways: 1) as the standard deviation of means of all subsamples taken at a station, and 2) as the average of intragrab standard deviations (calculated from 3 to 5 replicates). If no intergrab variability existed, these estimates should be identical. A plot of these averages (Figure 2) shows that the values approach each other for many, but not all stations.

For stations $2 / I, 3 / I, 1 / I I, 3 / I I, 1 / I I I, 3 / I I I$, and $1 / I V$ the standard deviations are essentially the same (see Table 1 columns 1 and 2). A further examination of possible differences was done by


FIGURE 2. ESTIMATORS OF STANDARD DEVIATION of mean grain size.

Abscissa is average standard deviation of means of groups of replicate subsamples from three grab samples, e.g., ( $2 / I / 1+2 / I / 2+$ 2/I/3)/3. Ordinate is standard deviation of means for all subsamples from that station. Solld dots are for all replicate subsamples from three grab samples (11-15); open squares are for one subsample from each of seven grab samples. Model 1 assumes unique values for each grab sample; Model 2 assumes true values for all grab samples are the same.

TABLE 1
STANDARD DEVIATIONS OF MEAN GRAIN SIZE

| station | grab | 1 | 2 | 3 | station | grab | 1 | 2 | 3 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1/I | 1 |  | . 21 |  | 1/III | 1 |  | . 28 |  |
|  | 2 |  | . 69 |  |  | 2 |  | . 62 |  |
|  | 3 |  | . 20 |  |  | 3 |  | . 58 |  |
|  |  | . 70 | . 37 | . 86 |  |  | . 50 | . 49 | . 46 |
| 2/I | 1 |  | . 44 |  | 2/III | 1 |  | . 34 |  |
|  | 2 |  | . 34 |  |  | 2 |  | . 14 |  |
|  | 3 |  | . 59 |  |  | 3 |  | . 33 |  |
| - |  | . 45 | . 46 | . 87 |  |  | . 42 | . 27 | . 40 |
| 3/I | 1 |  | . 22 |  | 3/III | 1 |  | . 23 |  |
|  | 2 |  | . 18 |  |  | 2 |  | . 19 |  |
|  | 3 |  | . 19 |  |  | 3 |  | . 14 |  |
|  |  | . 19 | . 20 | . 09 |  |  | . 19 | . 19 | . 16 |
| 1/II | 1 |  | . 87 |  | 1/IV | 1 |  | . 26 |  |
|  | 2 |  | . 38 |  |  | 2 |  | . 24 |  |
|  | 3 |  | . 49 |  |  | 3 |  | . 33 |  |
|  |  | . 60 | . 58 | . 64 |  |  | . 29 | . 28 | . 18 |
| 2/II | 1 |  | . 24 |  | 2/IV | 1 |  | . 42 |  |
|  | 2 |  | . 42 |  |  | 2 |  | . 32 |  |
|  | 3 |  | . 10 |  |  | 3 |  | . 52 |  |
|  |  | . 47 | $\overline{.25}$ | . 51 |  |  | . 50 | . 42 | . 33 |
| 3/II | 1 |  | . 18 |  | 3/IV | 1 |  | . 36 |  |
|  | 2 |  | . 13 |  |  | 2 |  | . 45 |  |
|  | 3 |  | . 24 |  |  | 3 |  | . 31 |  |
|  |  | . 17 | . 18 | . 11 |  |  | . 41 | .37 | . 47 |

Column 1. Standard deviations of all subsamples from grabs 1-3.
Column 2. Standard deviations of replicates within each grab sample and averages of these three values.

Column 3. Standard deviations of one subsample from each of seven grab samples taken at each station.
applying a $t$ test to the hypothesis that the mean grain sizes of the groups of replicates from the grab samples were the same（Table 2）． At all of the above stations except $1 / I V$ ，there was no evidence for a rejection of this hypothesis at the $95 \%$ confidence level．At $1 /$ IV the $t$ tests are somewhat equivocal in that they reject the similarity hypothesis at between 90 and $95 \%$ confidence．

At station 3／IV the difference in standard deviations was only $0.04 \emptyset$ ，but grab 2 was about $\frac{1}{2} \emptyset$ coarser than the two other grab sam－ ples．In this case the $t$ test hypothesis was rejected at the moderately high confidence level of $95 \%$ ．

At station $2 /$ IV the difference between standard deviation esti－ mates was 0.08 and，again，grab 2 was coarser than the others by about $\frac{1}{2} \emptyset$ ．In this case，tests show greater than $97.5 \%$ confidence that the mean grain sizes are not the same in all grabs．

At Station 2／III the difference in standard deviation estimates was 0.15 ，and $t$ tests showed differences between means at greater than 99\％confidence．

At the two remaining stations（1／I and $2 / I I$ ）differences in stan－ dard deviation estimates were greater than $0.2 \emptyset$ ，and means differed by from 0.6 to $1.2 \emptyset$ ．These differences were significant well beyond the $99 \%$ confidence limit．

So far only three of the seven grab samples taken at each station have been considered．Standard deviations between mean grain sizes deter－ mined from one subsample from each of the seven grab samples should be an equally good estimator of station standard deviation if model 2 is true（Figure 1）．These values are tabulated in Table 1 （Column 3）， plotted in Figure 2 （open squares），and an indication of their support

TABLE 2
dLfferences in mean grain size

| Station | $\begin{aligned} & \text { Grab } \\ & \text { Samples } \end{aligned}$ | $t$ | Confidence Level of Sigaificant Difference |  | $\begin{aligned} & \text { Data } \\ & \text { Fits } \\ & \text { Sodel } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Low | High |  |
| 1/I | 1-2 | 3.76 |  | >99.5. |  |
|  | 2-3 | . 32 | $<75$ |  | 1 |
|  | 3-1 | 8.50 |  | >99.95 |  |
| 2/I | 1-2 | 1.16 |  |  |  |
|  | 2-3 | . 77 | $<90$ |  | 2 |
|  | 3-1 | . 16 | $<60$ |  |  |
| 3/I | 1-2 | . 24 | $<60$ |  |  |
|  | 2-3 | . 24 | $<60$ |  | 2 |
|  | 3-1 | . 87 | $<90$ |  |  |
| 1/II | 1-2 | . 24 | $\bigcirc$ |  |  |
|  | 2-3 | 1.20 | $\xrightarrow[90]{ }$ |  | 1 |
|  | 3-1 | . 98 | $\xrightarrow{\text { 90 }}$ |  |  |
| 2/II | 1-2 | 3.53 |  | $>99$ |  |
|  | 2-3 | 1.26 | <90 |  | 1 |
|  | 3-1 | 3.72 |  | $>99.5$ |  |
| 3/II | 1-2 | . 44 | $<75$ |  |  |
|  | 2-3 | 1.24 | $<90$ |  | 2 |
|  | 3-1 | . 73 | $\bigcirc$ |  |  |
| 1/III | 1-2 | . 22 | $<60$ |  |  |
|  | 2-3 | . 70 | $<75$ |  | 2 |
|  | 3-1 | . 60 | $<75$ |  |  |
| 2/III | 1-2 | 4.26 |  | >99.5 |  |
|  | 2-3 | . 50 | <75 |  | 1 |
|  | 3-1 | 2.91 |  | >99 |  |
| 3/III | 1-2 | . 13 | $<60$ |  |  |
|  | 2-3 | 1.16 | $<90$ |  | 2 |
|  | 3-1 | . 86 | $<90$ |  |  |
| 1/IV | 1-2 | 1.49 | 290 |  |  |
|  | 2-3 | . 28 |  |  | 2 |
|  | 3-1 | 1.45 | 29 |  |  |
| 2/IV | 1-2 | 2.39 |  | 297.5 |  |
|  | 2-3 | 2.47 |  | 297.5 | 2 |
|  | 3-1 | . 34 | $<75$ |  |  |
| 3/IV | 1-2 | 1.20 | $<90$ |  |  |
|  | 2-3 | 2.03 |  | >95 | 1 |
|  | 3-1 | . 04 | $<60$ |  |  |

*Underlines indicate significance suggested by variability of seven grab samples with one analysis each. Arrows show auggested change in interpretation.
or nonsupport of previous significant differences is given in Table 2 (by underlining and arrows). Of the seven stations that seem to fit model 2 according to the analysis of variance, comparison of standard deviations, and $t$ tests, six still fit that model according to the additional data from grabs four through seven.

The equivocal $t$ tests at Station $1 / I V$ are apparently not significant. However, at Station $1 / I I$, the difference between intra- and intergrab stan- dard deviations is increased by $0.04 \emptyset$ by considering the additional grab samples and is increased further by considering the spring and fall samples. Thus grabs f́rom this station probably have real differences and should be considered to fit model 1.

At the three stations (1/I, 2/II and 3/III) already apparently conforming to model 1 (at $>99 \%$ confidence) significant differences between grab samples are clearly supported by data from grabs four through seven. At Station 2/IV the additional evidence from all seasonal samples reduces the intergrab variance to equal or less than the intragrab variance and thus suggests that the station fits model 2. Finally, at Station 3/IV where $t$ tests suggest at least one intergrab difference significant at more than $95 \%$ confidence, the additional samples support real intergrab differences and indicate that model 1 is appropriate.

CONCLUSIONS

Of the 12 stations where intragrab sample variance was compared to intergrab sample variance seven $(2 / I, 3 / I, 3 / I I, 1 / I I I, 3 / I I I, 1 / I V$, and 2/IV) are considered to fit a model of no significant difference between grab samples. Textural data from these stations would be better compared with other benthic parameters by using pooled values from all grab samples. At the other five stations (I/I, $1 / I I, 2 / I I, 2 / I I I$ and $3 / I V$ ) real differences
between grab samples are indicated, and textural data should be compared on a grab by grab basis.

If there were no real variations between any station subsamples, all variation in textural data would come from analytical error. Therefore, the minimum observed variance is the maximum experimental error. From this it can be concluded that standard deviations of mean grain size due to experimental errors are less than $0.2 \emptyset$.

## CHAPTER ELEVEN

AN INTENSIVE STUDY OF THE HEAVY HYDROCARBONS
IN THE SUSPENDED PARTICULATE MATTER OF SEAWATER

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#### Abstract

Samples of particulate matter taken at three stations along Transect II were analyzed by GC and GC/MS/Data System. Total particulate hydrocarbon concentrations were found to decrease with distance offshore. The concentration of higher molecular weight hydrocarbons ( $C_{28}-C_{30}$ ) however, remained relatively constant. Such a distribution could be explained by production/introduction of hydrocarbons inshore with subsequent movement offshore. Preferential retention of higher molecular weight hydrocarbons during weathering could account for their more uniform concentration.

Polycyclic aromatic compounds were found in benzene eluates of each sample. Among the compounds identified were: alkyl naphthalenes, phenanthrenes and dibenzothiophenes. Fluoranthene and pyrene were also found. A petroleum origin for the aromatics is likely.


## INTRODUCTION

This study was undertaken to investigate more closely, the heavy hydrocarbon fraction of particulate matter suspended in the water column overlying the South Texas Outer Continental Shelf. The main purposes of the study were to identify further the components of the hydrocarbon fraction and to seek information regarding the source of the material. Previous studies have indicated higher concentrations of hydrocarbons in particulate matter of inshore stations but these materials were still exceedingly low in concentrations which made identification and quantification difficult.

METHODS
Sampling
Three stations were established (Figure 1) for the study: two previously monitored stations of the BLM-STOCS study area (Stations 1 and 3, Transect II ; and a third station (Station A, Transect II) half-way between shore and Station 1. At each station 100 gallons (390 liters) of subsurface seawater were collected and immediately filtered. The filters were then frozen until analysis in the laboratory. Each "filter" consisted of a Millipore glass fiber $2.7 \mu \mathrm{~m}$ prefilter and a Millipore glass fiber . $5 \mu \mathrm{~m}$ filter. The filters were washed with chloroform, methanol and hexane before use in the Millipore stainless steel filter apparatus.

## Analytical

The filters were placed in a flask and allowed to reflux in a methanol:hexane mixture (1:1 vol.) for three hours. This extract was

decanted off and replaced with chloroform for another two hours. The extracts were combined and concentrated in a Kuderna-danish apparatus under reduced pressure. The concentrate was fractionated by column chromatography on a twin bed micro-column of silica gel overlain with alumina (volume ratio $2: 1$ ). The column was eluted with hexane, followed by benzene, then methanol. Because of poor separation in the benzene eluate this fraction was re-chromatographed on a one centimeter diameter column using the same bed ratio. The eluates were placed in a hood and allowed to evaporate to near dryness, at which time the volumes were adjusted to $100 \mu l$. Analysis of the concentrates was by gas chromatography using a $0.32 \mathrm{~cm}(1 / 8 \mathrm{in}$.$) by 183 \mathrm{~cm}$ ( $6 \mathrm{ft}$. ) stainless steel column of $5 \%$ FFAP on Gas Chrom Q $80 / 100$ mesh.

No total lipid weight was taken for either the hexane or the benzene fraction since loss of volatiles occurs in samples taken to dryness.

## RESULTS

## Hexane Eluate

A suite of normal alkanes along with pristane and phytane was clearly established in all of the stations (Tables 1-3). Total hydrocarbon concentrations decreased with distance offshore. In general, concentrations of individual $n$-alkanes varied from $.01 \mu \mathrm{~g} / \ell$ to $.2 \mu \mathrm{~g} / \mathrm{l}$ seawater. In almost all cases a clear decrease in each of the normal alkanes can be seen (Figure 2) with distance offshore. Concentrations of the lower weight compounds (1600-2000) decreased between Stations A/II and $1 /$ II while higher weight compounds ( $2500-2800$ ) tended to stay more constant in the inshore stations and decline at Station 3/II. The highest weight compounds (2900 and above) were nearly constant at all stations, at a low level (. $02 \mu \mathrm{~g} / \ell$ ).

## TABLE 1

hydrocarbon analysis from station a/II: hexane eluate

| Retention Index | $\mu \mathrm{g} / \ell$ |
| :---: | :---: |
| 16.00 | .08416667 |
| 16.70 | .02319002 |
| 17.00 | .06710163 |
| 17.80 | .06665742 |
| 18.00 | .08033619 |
| 19.00 | .13136097 |
| 20.00 | .15627582 |
| 21.00 | .19143122 |
| 22.00 | .19353954 |
| 23.00 | .20014981 |
| 24.00 | .19660663 |
| 25.00 | .16080310 |
| 26.00 | .13853007 |
| 27.00 | .09488266 |
| 28.00 | .08223306 |
| 29.00 | .01931188 |
| 30.00 |  |

TOTAL $\quad 1.91$

## TABLE 2

HYDROCARBON ANALYSIS FROM STATION 1/II: HEXANE ELUATE

| Retention Index | $\mu \mathrm{g} / \ell$ |
| :---: | :---: |
| 16.00 | $\cdot .06781422$ |
| 16.70 | .01783814 |
| 17.00 | .05719077 |
| 17.80 | .04908906 |
| 18.00 | .03947384 |
| 19.00 | .05508538 |
| 20.00 | .06892846 |
| 21.00 | .10552931 |
| 22.00 | .14023399 |
| 23.00 | .15898554 |
| 24.00 | .17730477 |
| 25.00 | .16420670 |
| 26.00 | .13823249 |
| 27.00 | .09844748 |
| 28.00 | .07705358 |
| 29.00 | .02457029 |
| 30.00 | .02136738 |

TOTAL $\quad 1.46$

## TABLE 3

HYDROCARBON ANALYSIS FROM STATION 3/II: HEXANE ELUATE

| Retention Index | $\mu \mathrm{g} / \ell$ |
| :---: | :---: |
| 16.00 | .04854914 |
| 16.70 | .01528983 |
| 17.00 | .07392924 |
| 17.80 | .05494314 |
| 18.00 | .04236468 |
| 19.00 | .03915189 |
| 20.00 | .03776490 |
| 21.00 | .05707923 |
| 22.00 | .07705920 |
| 23.00 | .07824026 |
| 24.00 | .10956185 |
| 25.00 | .10803500 |
| 26.00 | .09314170 |
| 27.00 | .07587807 |
| 28.00 |  |
| 29.00 |  |
| 30.00 |  |
|  |  |
|  |  |



Figure 2. Concentration of Normal and Isoprenoid Hydrocarbons at Each Station. Hydrocarbons are Identified by Retention Index: $1600=n-C 16$, etc.; $1670=$ pristane; $1780=$ phytane.


Pristane/phytane ratios (Table 4) varied only slightly among the stations, and the OEP curves were almost identical for the three stations, with values near unity (Tables 5-7, Figures 3-5). A typical gas chromatogram of a hexane eluate is shown in Figure 6.

## Benzene Eluate

Analyses of benzene eluates were hampered by the presence of alkanes which had not been completely removed with hexane. The retention index and concentration of each major component other than $n$-alkanes are given in Table 8. In addition to these major components, which appear to be natural marine hydrocarbons, each sample was found to contain detectable quantities of polycyclic aromatic compounds. A list of these aromatics and their relative concentration in each sample is given in Table 9. The notation "probable" in Table 9 indicates the presence of significant counts of ions with $m / e$ equal to that of the molecular ion of a given aromatic compound at the proper retention time (scan number) for the occurrence of that compound. Data of this nature were obtained by generation of mass chromatograms such as Figures 7-10. Compounds for which both a recognizable mass spectrum and a positive mass chromatogram were obtained, were termed "trace" compounds in Table 9. Examples of mass spectral data are given in Figures 11 and 12.

## Methanol Eluate

No quantitative data for individual compounds in this fraction were obtained. A typical methanol fraction is shown in Figure 13, and Table 10 gives the total dry weight of each sample. Methyl esters of C-14, C-16 and C-18 fatty acids were identified in each sample.

## TABLE 4

## PRISTANE/PHYTANE RATIOS

| Stations | A/II | $1 /$ II | $3 /$ II |
| :--- | :---: | :---: | :---: |
|  |  |  | . |
| PR/17 | .3456 | .3117 | .2068 |
| PR/PH | .3479 | .3632 | .2783 |
| PH/18 | .8298 | 1.243 | 1.297 |

## TABLE 5

ODD/EVEN PREFERENCE DATA, STATION A/II


TABLE 6

ODD/EVEN PREFERENCE DATA, STATION 1/II


## TABLE 7

ODD/EVEN PREFERENCE DATA, STATION 3/II

| No. of Carbons | Percent Relative $\qquad$ Weight | Percent Smooth $\qquad$ Weight | OEP Value |
| :---: | :---: | :---: | :---: |
| 16 | 5.096 |  |  |
| 17 | 7.761 |  |  |
| 18 | 4.447 | 5.202 | 1.328 |
| 19 | 4.110 | 4.504 | 1.142 |
| 20 | 3.964 | 4.796 | 1.112 |
| 21 | 5.992 | 6.031 | 1.001 |
| 22 | 8.089 | 7.552 | . 888 |
| 23 | 8.214 | 9.062 | . 850 |
| 24 | 11.502 | 10.319 | . 900 |
| 25 | 11.342 | 10.585 | . 990 |
| 26 | 9.779 | 9.563 | 1.019 |
| 27 | 7.965 | 7.752 | 1.016 |
| 28 | 5.605 | 5.718 | . 981 |
| 29 | 3.362 |  |  |
| 30 | 2.771 |  |  |




Figure 4. Plot of Relative Percent and Odd/Even Preference of n-alkanes at Station 1/II.



## TABLE 8

MAJOR COMPONENTS OF BENZENE ELUATES OTHER THAN n-ALKANES*

| Retention Index | Station A/II |  | Station 1/II |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Station 3/II |  |  |  |
| 1861 | N.D. | .074. | .100 |  |
| 1949 | .105 | .103 | .098 |  |
| 2071 | N.D. | N.D. | .145 |  |
| 2149 | .121 | .031 | .033 |  |
| 2242 | .071 | .022 | .060 |  |
| 2365 | .246 | N.D. | .082 |  |
| 2453 | N.D. | N.D. | .010 |  |

*Concentration is $\mu \mathrm{g} / \ell$
N.D.-not detected

## TABLE 9

POLYCYCLIC AROMATIC COMPOUNDS PRESENT IN THE BENZENE ELUATES

| Compound | Molecular <br> Weight |  | STATIONS |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: |
|  |  |  | A/II | I/II |  | 3/II

N.D. = not detected

P = probably present as indicated by mass chromatogram
$T \quad=$ trace quantities present indicated by mass chromatogram and mass spectrum




,

$1^{2}$

 Dimethylphenanthrene, MW=206, Station $1 / \mathrm{II}$.

13

| 5:- | 87 | PASE | 3 |
| :---: | :---: | :---: | :---: |
| - M MAT | IN | H BGOO9 | 10-5-77 T8 |


| HFESES | 74, | 0 |
| :--- | :---: | :---: | :---: |
| \#SCANS | 255 | HRDCPY NO |
| FCALE | 100 | REZERO VE |

EHSE 6327*て** 0


Figure 13. Mass Chromatogram of $m / e=74$, Indicates Presence of Methyl Esters of Fatty Acids. $1=C_{14}$ Acid, $2=C_{16}$ Acid, and $3=C_{18}$ Acid. Phtalates (4) are Also Evident. Station 1/II Methanol Eluate.

## TABLE 10

METHANOL ELUATE DRY WEIGHTS

| Stations | Weight |  |
| :--- | :--- | :--- |
|  |  |  |
| A/II | $.02237 \mathrm{~g} / \ell$ |  |
| 1/II | .01305 g | .057 |
| $3 / \mathrm{II}$ | .00846 g | .033 |
|  |  | .022 |

The data from this mini-study has confirmed and extended previous data obtained on smaller samples during regular BLM studies. The decrease in total particulate hydrocarbons offshore was confirmed and an interesting pattern of more or less constant concentration of higher molecular weight ( $C_{28}-C_{30}$ ) hydrocarbons was observed. Such a distribution could be explained if one assumes production/introduction of hydrocarbons inshore and subsequent movement offshore. Preferential retention of heavy hydrocarbons during weathering would explain their more uniform concentration.

The detection of polycyclic aromatic compounds in the benzene eluates was a first for the STOCS seawater studies. Concentrations of these compounds were less than that required for quantification yet sufficient for unequivocal mass spectra in same samples. A petroleum origin for these aromatics is suggested. The concentrations of polycyclics appeared to be highest at Station I/II and lowest at Station A/II. These results do not favor Corpus Christi Bay - Port Aransas as a major source. This possibility cannot, however, be ruled out on the basis of only three samples since variation between water masses on the shelf resulting from tidal cycles is well documented.

## CBAPTER TWELVE

# FATE OF PETROLEUM-DERIVED AROMATIC COMPOUNDS IN SEAWATER HELD IN OUTDOOR TANKS 

## Principal Investigator:

J. Kenneth Winters

## ABSTRACT

Two simulated oil spills ( 300 and 100 PPM) were conducted in 7000 \& outdoor tanks. A mixture of aromatic compounds was added to a tank in a third experiment. Dissolved and particulate fractions of seawater were analyzed by gas chromatography and combined gas. chromatography-mass spectrometry.

Results showed that the concentration of petroleum derived alkanes was approximately ten times greater in particulate fractions. Aromatics were generally at least five times more concentrated in dissolved fractions. Aromatic compounds were partioned between dissolved and particulate fractions with parent and mono-methyl compounds enriched in dissolved fractions while more highly methylated compounds were enriched in particulate fractions.

## INTRODUCTION

When a crude oil is spilled or discharged into the marine environment a portion of that oil is dissolved and another portion is adsorbed onto the particulate matter present. The subsequent fate of these petroleum derived compounds in the sea is not well known. Biodegradation, evaporation and photochemical reaction are the most of ten mentioned processes which alter or remove petroleum compounds from" the water column. The rates at which different classes of compounds are removed vary greatly. Identification of classes of petroleum compounds which have relatively long residence times in the water column could be an important step in detection of low-level chronic petroleum pollution as might be expected in BLM lease areas. While the division of organic matter in seawater into dissolved or particulate fractions is simply an operational definition, enrichment of petroleum compounds in either fraction could aid in their detection in BLM OCS studies. Such information is necessary to the understanding of the potential impact of oil spills in the oceans.

Objectives to this study were 1) to identify components of crude oil (or degradation products thereof) which enter the water column from an oil slick weathered under "natural" conditions in an outdoor tank; 2) to filter water collected from the experimental tank and determine which petroleum-derived compounds are associated with particulate matter and which compounds are "dissolved"; and 3) to observe changes in concentration of dissolved and particulate petroleum-derived compounds with time. MATERIALS AND METHODS

Two identical circular fiberglass tanks ( 3 m diameter, 1.1 m deep) were used for the study. The tanks ( 7000 \& capacity) were fully exposed to natural sunlight and wind conditions. A cylinder ( 1 m diameter, 30 cm
deep) was constructed from galvanized sheet metal and suspended from a wooden frame over the experimental tank (Figure 1). The cylinder was submerged to one half of its depth ( 15 cm ) and maintained at that depth by adjusting the length of the suspension lines (Figure 1, D). Tanks were filled with seawater from the laboratory's seawater and allowed to stand at least ten days before the experiments were begun.

Samples were taken on days $1,2,3,4$ and on or about days 7 and 12. Additional samples were taken weekly. Control samples were taken weekly from a control tank which had been filled at the same time as the experimental tank. Two spills of an Alaskan crude oil were conducted. Spill I and Spill II had oil-seawater ratios of 300 ppm and 100 ppm (volume:volume) respectively. Another experiment was carried out by adding a mixture of aromatic compounds to one of the tanks.

Water samples ( 40 l) were obtained from the tanks about 35 cm below the surface at a point equidistant from the outside wall of the tank and the cylinder containing crude oil. Samples were obtained by siphon through a 1.5 cm outside diameter (O.D.) copper pipe suspended over the tank. The pipe remained in place at all times with the lower end outside the tank sealed between samplings by a rubber stopper covered with Tefion film. Samples were filtered immediately after collection through glass fiber filters (Millipore AP152935).

Methodology used in sample preparation was identical to that described in the STOCS benchmark studies (1976) except that an additional fraction was eluted from silica gel with methanol. The methanol fraction was concentrated and analyzed by the same methods used for hexane and benzene fractions.

Quantitative gas chromatography analyses were carried out on a PERRIN-


ELMER 900 chromatography interfaced to a HEWLETT-PACKARD 3352B data system. Columns packed with $5 \%$ FFAP on $60 / 80$ Gas Chrom $Q(0.3 \mathrm{~cm} \times 1.8 \mathrm{~m}$ ) were used for quantitation and a similar column was used in the gas chromatographymass spectrometer for peak identification. Temperature was programmed from $80-270^{\circ} \mathrm{C}$ at $6^{\circ} /$ minute. A VARIAN 2700 gas chromatograph, DUPONT 21-491 mass spectrometer and DUPONT 21-094B data system comprised the GC/MS/DS employed for this study.

Spill I was begun October 18,1977 by addition of $2.1 \ell$ of an Alaskan crude oil to the cylindrical enclosure. This volume of oil was calculated to have produced a slick with an average thickness of about 2.8 mm within the enclosure. The Alaskan crude oil used in this study was selected primarily because it was available in sufficient quantity and some limited analyses of its composition had been completed. Experimental results obtained with this oil would not be expected to differ greatly from results obtained with a typical Gulf Coast crude. The tank contained about 7000 \& of seawater with a salinity of 28.4 ppt . Air and water temperature were $30^{\circ}$ and $26^{\circ}$, respectively.

Spill II was begun by addition of 675 mls of Alaskan crude to about $6750 \ell$ of seawater. This volume produced a slick with an average thickness of about 0.9 mm . The water temperature and salinity were $21^{\circ} \mathrm{C}$ and 31.2 ppt .

The aromatic compounds experiment was conducted as follows. The mixture of aromatics composed of thirteen compounds which had previously been identified as water soluble components of crude or fuels oils, was prepared. The compounds were chosen to be: 1) representative of various classes of compounds; 2) readily separated by gas chromatography; and 3) easily identified by mass spectrometry. Components of the mixture in their order of elution by gas chromatography on FFAP can be found in Table 1.

A 125-250 mg amount of each compound was weighed out and dissolved in

TABLE 1

COMPONENTS OF THE AROMATIC MIXTURE PREPARED AND ADDED TO THE EXPERIMENTAL TANK


* Figure 16 shows a gas chromatogram of the mixture with peaks identified as indicated above.
$1.0 \ell$ of isopropyl alcohol. This mixture was slowly added to the pond ( 6000 l) through 0.3 cm stainless steel tubing which was continually moved throughout the water column. After addition the pond water was gently stirred with a wooden paddle for a few minutes. The temperature and salinity of the water were $21^{\circ} \mathrm{C}$ and 30.8 ppt .

Between each experiment both fiberglass tanks were drained and cleaned. The walls and bottom were scrubbed with a stiff bristle broom which has been dipped in a detergent (ALCONOX). The tanks were then rinsed with copious amounts of seawater prior to refilling for the next experiment.

During the first week, after Spill I, air temperature remained rather warm and water temperatures rose to $28^{\circ} \mathrm{C}$ during the afternoon. Water temperature dropped to a low of about $24^{\circ} \mathrm{C}$ at night during this period. Temperatures cooled considerably the second and third week with the lowest afternoon temperature, $14^{\circ} \mathrm{C}$, recorded on day 23 . Winds were generally light for the first four to five days averaging $10-12$ miles per hour. A heavy rain, which lasted several hours on the morning of day 3, proved to have a significant influence on hydrocarbon concentration in the water. Rain fell with sufficient force to splash oil as high as the wooden support over the tank which held the sheet metal cylinder. A small amount of oil did splash over the cylinder. Most of this oil, however, was stranded on the sides of the tank above normal water level by wave action during high wind associated with the storm. The increase in volume due to addition of rainwater was less than two percent.

RESULTS AND DISCUSSION

## Spill I

## Dissolved Hexane Fraction

Results of analyses of dissolved hexane eluates are presented in Table 2. Day 1 and 2 samples contained very low levels of alkanes which

## TABLE 2

CONCENTRATION OF DISSOLVED n-ALKANES AND ISOPRENOID HYDROCARBONS DURING SPILL $I, \mu \mathrm{~g} / \ell$


TABLE 2 CONT.'D

| RETENTION |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| INDEX | Day 7 | Day 13 | Day 20 | Day 27 |
| 1670 | . 001 | . 005 | . 003 | T |
| 1700 | . 008 | . 003 | . 001 | ND |
| 1782 | . 008 | . 005 | . 003 | T |
| 1800 | . 012 | . 003 | . 002 | ND |
| 1900 | . 015 | . 008 | . 006 | . 002 |
| 2000 | . 013 | . 006 | . 004 | . 003 |
| 2100 | . 020 | . 014 | . 010 | . 003 |
| 2200 | . 011 | . 007 | . 008 | '. 003 |
| 2300 | . 020 | . 016 | . 013 | . 004 |
| 2400 | . 011 | . 010 | . 008 | . 003 |
| 2500 | . 012 | . 012 | . 010 | . 004 |
| 2600 | . 010 | . 011 | . 009 | . 003 |
| 2700 | . 008 | . 008 | . 008 | . 002 |
| 2800 | . 005 | . 003 | . 004 | . 001 |
| 2900 | . 005 | . 005 | . 002 | . 001 |
| 3000 | . 006 | . 004 | ND | ND |
| Total | . 175 | . 120 | . 091 | . 029 |

were odd carbon number and apparently biogenic in origin. The significant increase in alkanes on day 3 suggested their addition as a result of the heavy rain previously mentioned. An odd carbon preference was still present, however, in day 3 and 4 samples when oil derived alkanes were present at maximum concentration. Alkanes containing odd numbered carbon atoms between $C_{19}$ and $C_{23}$ were generally the most abundant in all samples taken during Spill I .

## - Dissolved Benzene Fraction

The identification and concentration of major components of the dissolved benzene fraction are reported in Table 3. A gas chromatogram of a sample analyzed on packed columns used for quantitative analysis is shown in Figure 2. Representative GC/MS data used for identification given in Table 3 are shown in Figures 3 through 6. Analysis of the same sample on a glass capillary column ( 20 m SP1000), yielded the chromatogram shown in Figure 7. Concentration data for each component of Table 3 was normalized to the highest concentration found for that component.

More soluble compounds reached their maximum concentration on day 3 with the others reaching a maximum by day 7. Highest absolute concentrations ( $1 \mu \mathrm{~g} / \mathrm{l}$ ) were attained by substituted naphthalenes. The amount of naphthalenes present in the water even at their highest concentration represented only a small fraction of the amount of naphthalenes originally present in the added oil. Table 3 indicated the concentration of methylnaphthalenes on day 3 was $1.91 \mu \mathrm{~g} / \ell(0.88+1.03)$. The $7000 \ell$ of seawater contained about 13.4 mg of methylnaphthalenes ( $7000 \ell+1.91 \mu \mathrm{~g} / \ell$ ). Previous work in our laboratory found the concentration of methylnaphthalenes in the Alaskan crude oil to be $1.4 \mathrm{mg} / \mathrm{ml}$ (Batterton et $\mathrm{al} ., 1978$ ) or about 2.94 g for the $2.1 \ell$ of oil added. Therefore, the water contained less than $0.5 \%$ of the methylnaphthalenes originally present in the added oil

## TABLE 3

CONCENTRATION OF DISSOLVED AROMATICS DURING SPILL I

| Figure 2 Identifier | A | B | C | D | E |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Major Component | Naphthalene | 2-Methyl <br> Naphthalene | 1-Methyl Naphthalene | $\mathrm{C}_{2}$-Naphthalene | $\mathrm{C}_{2}$-Naphthalene |
| Secondary Component |  |  |  |  | Biphenyl |
| Day 1 Conc. $\mu \mathrm{g} / \ell$ (Normalized) | $\begin{aligned} & .16 \\ & (.30) \end{aligned}$ | $\begin{gathered} .18 \\ (.21) \end{gathered}$ | $\begin{aligned} & .22 \\ & (.21) \end{aligned}$ | $\begin{aligned} & .05 \\ & (.13) \end{aligned}$ | $\begin{gathered} .14 \\ (.11) \end{gathered}$ |
| Day 2 | $\begin{aligned} & .27 \\ & (.52) \end{aligned}$ | $\begin{aligned} & .31 \\ & (.35) \end{aligned}$ | $\begin{aligned} & .42 \\ & (.41) \end{aligned}$ | $(.11$ | $\begin{gathered} .26 \\ (.20) \end{gathered}$ |
| Day 3 | $(1.0)$ | $\begin{gathered} .88 \\ (1.0) \end{gathered}$ | $\begin{aligned} & 1.03 \\ & (1.0) \end{aligned}$ | $\begin{gathered} .40 \\ (1.0) \end{gathered}$ | $\begin{aligned} & 1.27 \\ & (1.0) \end{aligned}$ |
| Day 4 | $\begin{aligned} & .35 \\ & (.67) \end{aligned}$ | $\begin{gathered} .61 \\ (.70) \end{gathered}$ | $\begin{aligned} & .72 \\ & (.70) \end{aligned}$ | $\begin{aligned} & .28 \\ & (.70) \end{aligned}$ | $\begin{gathered} .92 \\ (.72) \end{gathered}$ |
| Day 7 | $\begin{gathered} .02 \\ (.04) \end{gathered}$ | $\begin{gathered} .19 \\ (.21) \end{gathered}$ | $\begin{aligned} & .24 \\ & (.23) \end{aligned}$ | $\begin{gathered} .19 \\ (.47) \end{gathered}$ | $\begin{gathered} .56 \\ (.44) \end{gathered}$ |
| Day 13 | $(.11$ | $\begin{gathered} .24 \\ (.27) \end{gathered}$ | $\begin{aligned} & .30 \\ & (.29) \end{aligned}$ | $\begin{gathered} .17 \\ (.41) \end{gathered}$ | $\begin{aligned} & .15 \\ & (.40) \end{aligned}$ |
| Day 20 | - | - | - | - | - |
| Day 27 | $\begin{gathered} .05 \\ (.09) \end{gathered}$ | $\begin{gathered} .07 \\ (.07) \end{gathered}$ | $\begin{gathered} .09 \\ (.08) \end{gathered}$ | $\begin{gathered} .03 \\ (.07) \end{gathered}$ | . - |

TABLE 3 CONT. 'D

| Figure 2 Identifier | F | G | H | I | J |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Major Component | $\mathrm{C}_{2}$-Naphthalene | $\mathrm{C}_{3}$-Naphthalene | $\mathrm{C}_{3}$-Naphthalene ${ }^{\text {- }}$ | $\mathrm{C}_{3}-$ Naphthalene | $\mathrm{C}_{3}$-Naphthalene |
| Secondary Component |  | $\mathrm{C}_{3}$-Naphthalene | Methyl-Bipheny 1 |  |  |
| Day 1 Conc. $\mu \mathrm{g} / \ell$ (Normalized) | $\begin{aligned} & .04 \\ & (.08) \end{aligned}$ | $\begin{gathered} .01 \\ (.05) \end{gathered}$ | $\begin{aligned} & .11 \\ & (.26) \end{aligned}$ | $\begin{gathered} .25 \\ (.59) \end{gathered}$ | $\begin{gathered} .04 \\ (.08) \end{gathered}$ |
| Day 2 | $. .11$ | $\begin{gathered} .05 \\ (.21) \end{gathered}$ | $\begin{gathered} .13 \\ (.30) \end{gathered}$ | - | - |
| Day 3 | $\begin{gathered} .48 \\ (1.0) \end{gathered}$ | $\begin{gathered} .24 \\ (1.0) \end{gathered}$ | $\begin{gathered} .41 \\ (1.0) \end{gathered}$ | $\begin{gathered} .42 \\ (1.0) \end{gathered}$ | $\begin{gathered} .22 \\ (.44) \end{gathered}$ |
| Day 4 | $\begin{aligned} & .35 \\ & (.73) \end{aligned}$ | $\stackrel{.18}{(.73)}$ | $\begin{gathered} .30 \\ (.73) \end{gathered}$ | $\begin{gathered} .32 \\ (.78) \end{gathered}$ | $\stackrel{.49}{(1.0)}$ |
| Day 7 | $\begin{aligned} & .24 \\ & (.50) \end{aligned}$ | $\stackrel{.16}{(.65)}$ | $\stackrel{.28}{(.67)}$ | $\begin{gathered} .42 \\ (1.0) \end{gathered}$ | $\begin{gathered} .15 \\ (.31) \end{gathered}$ |
| Day 13 | $\begin{gathered} .19 \\ (.39) \end{gathered}$ | $\stackrel{.10}{(.43)}$ | $\begin{gathered} .16 \\ (.39) \end{gathered}$ | $\stackrel{.28}{(.67)}$ | $\begin{aligned} & .10 \\ & (.20) \end{aligned}$ |
| Day 20 | - | - | - | - | - |
| Day 27 | $\begin{aligned} & .03 \\ & (.07) \end{aligned}$ | $\begin{gathered} .01 \\ (.05) \end{gathered}$ | $\begin{gathered} .03 \\ (.07) \end{gathered}$ | $\begin{gathered} .06 \\ (.14) \end{gathered}$ | $\text { . } 01$ |

TABLE 3 CONT. ${ }^{\text {D }}$

| Figure 2 Identifier | K | L | M | N | 0 | P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Major Component | $\mathrm{C}_{3}$-Naphthalene | Methyl <br> Biphenyl | $\mathrm{C}_{3}$-Naphthalene | Fluorene | $\mathrm{C}_{2}$-Bipheny1 | Methyl <br> Fluorene |
| Secondary Component |  |  |  |  | C3-Bipheny1 |  |
| Day 1 Conc. $\mu \mathrm{g} / \ell$ (Normalized) | $(.003$ | $(.01$ | $(.003$ | $(.01$ | - | - |
| Day 2 | $\begin{gathered} .01 \\ (.09) \end{gathered}$ | $\begin{gathered} .01 \\ (.10) \end{gathered}$ | $\begin{aligned} & .005 \\ & (.05) \end{aligned}$ | $\text { . } 01$ | - | $\begin{aligned} & .001 \\ & (.01) \end{aligned}$ |
| Day 3 | $\begin{gathered} .11 \\ (.92) \end{gathered}$ | $\begin{gathered} .10 \\ (.80) \end{gathered}$ | $\begin{aligned} & .05 \\ & (.53) \end{aligned}$ | $\underset{(1.0)}{.16}$ | $(.11$ | $\begin{gathered} .03 \\ (.40) \end{gathered}$ |
| Day 4 | $\stackrel{.12}{(.97)}$ | $\begin{gathered} .10 \\ (.80) \end{gathered}$ | $\begin{gathered} .04 \\ (.42) \end{gathered}$ | $(.11$ | $.(.07$ | $\begin{aligned} & .05 \\ & (.64) \end{aligned}$ |
| Day 7 | $\underset{(1.0)}{.12}$ | $\underset{(1.0)}{.12}$ | $\underset{(1.0)}{.10}$ | $\stackrel{.12}{(.77)}$ | $\begin{gathered} .13 \\ (1.0) \end{gathered}$ | $\begin{gathered} .08 \\ (1.0) \end{gathered}$ |
| Day 13 | $\begin{gathered} .07 \\ (.60) \end{gathered}$ | $\begin{gathered} .09 \\ (.70) \end{gathered}$ | $\begin{aligned} & .06 \\ & (.60) \end{aligned}$ | $\begin{aligned} & .09 \\ & (.55) \end{aligned}$ | $\begin{gathered} .08 \\ (.60) \end{gathered}$ | $\begin{aligned} & .06 \\ & (.73) \end{aligned}$ |
| Day 20 | - | - | - | $\begin{aligned} & .01 \\ & (.07) \end{aligned}$ | $\begin{gathered} .01 \\ (.07) \end{gathered}$ | - |
| Day 27 | - | $\begin{gathered} .01 \\ (.11) \end{gathered}$ | $\text { . } 01$ | $\begin{gathered} .02 \\ (.14) \end{gathered}$ | $\begin{gathered} .02 \\ (.15) \end{gathered}$ | $\begin{gathered} .002 \\ (.03) \end{gathered}$ |

TABLE 3 CONT. ${ }^{\prime}$ D

Figure 2 Identifier
Q
R
S

Major Component $\quad$| Methyl |
| :--- |$\quad$ Fluorene

Secondary Component

| Day 1 | Conc. $\mu \mathrm{g} / \ell$ (Normalized) | $\begin{gathered} .01 \\ (.03) \end{gathered}$ |  | $\begin{aligned} & .005 \\ & (.03) \end{aligned}$ | $\begin{gathered} .01 \\ (.05) \end{gathered}$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Day 2 |  | $\begin{aligned} & .01 \\ & (.04) \end{aligned}$ | $\begin{aligned} & .004 \\ & (.03) \end{aligned}$ | $\begin{aligned} & .01 \\ & (.06) \end{aligned}$ | $\begin{gathered} .02 \\ (.08) \end{gathered}$ | - | $\begin{gathered} .004 \\ (.04) \end{gathered}$ |
| Day 3 |  | $\begin{gathered} .23 \\ (1.0) \end{gathered}$ | $\begin{gathered} .07 \\ (.47) \end{gathered}$ | $\begin{gathered} .13 \\ (.75) \end{gathered}$ | $\begin{gathered} .22 \\ (1.0) \end{gathered}$ | $\begin{gathered} .08 \\ (.77) \end{gathered}$ | $\begin{aligned} & .05 \\ & (.44) \end{aligned}$ |
| Day 4 |  | $\begin{gathered} .12 \\ (.52) \end{gathered}$ | $\begin{gathered} .07 \\ (.47) \end{gathered}$ | $\begin{gathered} .17 \\ (1.0) \end{gathered}$ | $\begin{gathered} .20 \\ (.92) \end{gathered}$ | $\begin{gathered} .07 \\ (.67) \end{gathered}$ | $\begin{aligned} & .06 \\ & (.57) \end{aligned}$ |
| Day 7 |  | $\begin{gathered} .17 \\ (.73) \end{gathered}$ | $\begin{gathered} .14 \\ (1.0) \end{gathered}$ | $\begin{gathered} .15 \\ (.87) \end{gathered}$ | $\begin{gathered} .20 \\ (.90) \end{gathered}$ | $\begin{gathered} .10 \\ (1.0) \end{gathered}$ | $\begin{gathered} .10 \\ (1.0) \end{gathered}$ |
| Day 13 |  | $(.10$ | $\begin{gathered} .07 \\ (.49) \end{gathered}$ | $(.12$ | $\begin{gathered} .12 \\ (.55) \end{gathered}$ | $\begin{gathered} .05 \\ (.49) \end{gathered}$ | $\begin{aligned} & .05 \\ & (.45) \end{aligned}$ |
| Day 20 |  | $\begin{aligned} & .02 \\ & (.08) \end{aligned}$ | $\begin{aligned} & .006 \\ & (.05) \end{aligned}$ | $\begin{aligned} & .02 \\ & (.13) \end{aligned}$ | $\begin{gathered} .03 \\ (.15) \end{gathered}$ | $\begin{gathered} .02 \\ (.17) \end{gathered}$ | $\begin{gathered} .02 \\ (.17) \end{gathered}$ |
| Day 27 |  | $\begin{gathered} .02 \\ (.09) \end{gathered}$ | $\begin{aligned} & .015 \\ & (.10) \end{aligned}$ | $\begin{aligned} & .04 \\ & (.21) \end{aligned}$ | $\begin{gathered} .04 \\ (.19) \end{gathered}$ | $\begin{gathered} .02 \\ (.17) \end{gathered}$ | $\begin{aligned} & .01 \\ & (.12) \end{aligned}$ |

```
TABLE 3 CONT.'D
```

| Figure 2 Identifier | W | X | Y | z |
| :---: | :---: | :---: | :---: | :---: |
| Major Component | Methyl <br> Phenanthrene | Methy1 <br> Phenanthrene | $\mathrm{C}_{2}$-Phenanthrene | $\mathrm{C}_{2}$-Phènanthrene |
| Secondary Component | $\mathrm{C}_{2} \text {-Dibenzo- }$ thiophene |  |  |  |
| Day 1 Conc. $\mu \mathrm{g} / \ell$ (Normalized) | - | $\begin{aligned} & .004 \\ & (.02) \end{aligned}$ | - | - |
| Day 2 | $(.002$ | $\begin{aligned} & .004 \\ & (.02) \end{aligned}$ | $(.002$ | $\begin{gathered} .004 \\ (.03) \end{gathered}$ |
| Day 3 | $\begin{aligned} & .18 \\ & (.86) \end{aligned}$ | $\begin{aligned} & .21 \\ & (.85) \end{aligned}$ | $\stackrel{.12}{(.70)}$ | $\stackrel{.12}{(.80)}$ |
| Day 4 | $\begin{aligned} & .15 \\ & (.72) \end{aligned}$ | $\begin{gathered} .17 \\ (.69) \end{gathered}$ | $\begin{gathered} .09 \\ (.53) \end{gathered}$ | $\begin{gathered} .09 \\ (.64) \end{gathered}$ |
| Day 7 | $\stackrel{.21}{(1.0)}$ | $\underset{(1.0)}{.24}$ | $\stackrel{.17}{(1.0)}$ | $\stackrel{.14}{(1.0)}$ |
| Day 13 | $\begin{aligned} & .11 \\ & (.55) \end{aligned}$ | $\begin{gathered} .19 \\ (.79) \end{gathered}$ | $\begin{gathered} .08 \\ (.47) \end{gathered}$ | $\begin{gathered} .09 \\ (.60) \end{gathered}$ |
| Day 20 | $\begin{aligned} & .04 \\ & (.20) \end{aligned}$ | $\begin{gathered} .05 \\ (.21) \end{gathered}$ | $\begin{aligned} & .04 \\ & (.22) \end{aligned}$ | $\begin{aligned} & .04 \\ & (.28) \end{aligned}$ |
| Day 27 | $\begin{aligned} & .04 \\ & (.21) \end{aligned}$ | $\begin{gathered} .05 \\ (.19) \end{gathered}$ | $\begin{aligned} & .03 \\ & (.18) \end{aligned}$ | $\begin{aligned} & .09 \\ & (.59) \end{aligned}$ |



Figure 2. Gas Chromatogram of Spill I, Day 3, Dissolved, Benzene Eluate on a $3 \mathrm{~cm} \times 1.8 \mathrm{~m}$ FFAP Packed Column. For Peak Identification see Table 3.

Spill I, Day 3, Benzene Praction, Dissolved


Figure 3. Total Ion Chromatogram of Spill I, Day 3, Dissolved Fraction, Benzene Eluate. Identification of Peaks $A-Z$ is Given in Table 3.

## Spill I，Day 3，Benzene Fraction，Dissolved

 Masses 184

Spill I，Day 3，Benzene Fraction，Dissolved Masses 192


Figure 4．Mass Chromatograms From Spill I，Day 3，Dissolved Fraction， Benzene Eluate．Mass Chromatogram of $m / e=184$ ，Dibenzothio－ phene（above），m／e＝192，methylphenanthrenes（below）．Scan Numbers in Figs． 3 and 4 are the same．

Spill 1, Day 3, Benzene Fraction, Dissolved Scan 75
BKGRND 72


Spill 1, Day 3, Benzene Fraction, Dissolved Scan 106
BKGRND 103


Figure 5. Mass Spectra From Spill I, Day 3, Dissolved Fraction, Benzene Eluate. Mass Spectrum of Scan 75 (Component N), Fluorene (above); Scan 106 (Component S), Dibenzothiophene, (below).

FILL 1 DAYG BEM. FRAC., DISS. TIPEAT


FPILL 1 DAYG BEY. FPAC., DISS. REPEAT

SCAM : 136
BKGTND 133
67


Figure 6. Mass Spectra From Spill I, Day 3, Dissolved Fraction, Benzene Eluate. Mass Spectrum of Scan 112 (Component T) Phenanthrene (above); Scan 136 (Component Y), Dimethylphenanthrene (below).


Figure 7. Gas Chromatogram of Spill I, Day 3, Dissolved, Benzene Eluate on a 20 m SP1000 Glass Capillary Column. For Peak Identification see Table 3.
( $0.0134 \mathrm{~g} / 2.94 \mathrm{~g}$ ) on day 3 . Two major factors in this low percentage were the non-turbulent mixing conditions of the experiment and a high evaporation rate of naphthalenes from oil and water.

Normalized concentrations of several representative compounds have been plotted in Figure 8. Naphthalene and dimethylnaphthalene, respectively, reached 52 and $23 \%$ of their maximum concentration on day 2. Phenanthrene and dibenzothiophene had only reached 8 and $6 \%$ maximum concentration by day 2. The concentration of naphthalenes, however, also decreased more rapidly than the three ring compounds. By day 27 naphthalenes were present at about $10 \%$ of their maximum concentration while dibenzothiophene and phenanthrene were present at about $20 \%$. Absolute concentrations of all four compounds, however, were similar (Table 3).

## Dissolved Methanol Fraction

A representative chromatogram of dissolved methanol fractions is illustrated in Figure 9. Identification and concentration range of some of the compounds in Figure 9 are presented in Table 4. GC/MS data which support these identifications are shown in Figures 9 and 10. Acetophenone, $\alpha$-methyl benzyl alcohol and most of the phthalates are derived from resin material used in the manufacture of the fiberglass tanks and were also seen in the control tank. Several unidentified biogenic compounds were found in the samples.

## Particulate Hexane Fraction

The concentration and relative weight percent of n-alkanes, pristane and phytane found in particulate samples are given in Tables 5 through 15. The data indicated an increase in n-alkanes in the particulate fraction from $\sigma .02 \mu \mathrm{~g} / \ell$ on day 2 to more than $3 \mu \mathrm{~g} / \ell$ on day 3 . The composition of particulate hydrocarbon in the water was also drastically altered between


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ETF. POND DAY 3. MEOH
\begin{tabular}{|c|c|c|c|}
\hline -simaris & 250 & HRECFY & No \\
\hline \(\because\) OCmLE & 183 & RETERO & 5 \\
\hline PASE & 2576 & ** & \\
\hline
\end{tabular}
```


E.MP. PCND DAY 3. MEOH
BKERN $8 \quad$ SCAN $\quad 12$


Figure 9. Total Ion Chromatogram of Spill I, Day 3, Dissolved Fraction, Methanol Eluate (above). Mass Spectrum of Scan 11, (Component A) Acetophenone (below).

## TABLE 4

IDENTIFICATION AND CONCENTRATION RANGE OF MAJOR COMPONENTS IN DISSOLVED METHANOL FRACTIONS, SPILL I

Figure 9
Identifier
Compound
Concentration Range ( $\mu \mathrm{g} / \ell$ )

| I | Acetophenone | $0.3-0.8$ |
| :--- | :--- | :--- |
| II | a-methylbenzyl alcohol | $0.3-0.8$ |
| III | Unknown biogenic, MW $=286$ | $0.0-1.2$ |
| IV | Unknown biogenic, $\mathrm{MW}=286$ | $0.0-1.0$ |
| V | Dioctyl phthalate | $0.7-24.6$ |

F．FF．POMD DAY 3，MEOH


E．A．P．POND DAY 3，MECH
EKGRND $159 \quad$ SCAN $\$ 163$


Figure 10．Mass Spectra from Spill I，Day 3，Dissolved Fraction， Methanol Eluate．Mass Spectrum of Scan 38 （Component B）， $\propto$－Methyl Benzyl Alcohol（above）；Scan 163 （Component C） （below）．

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TARLE 7
HEAY FYOunCGRAMA AMALYSIS－STICS－ 1977

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$20 \cdots$
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$31 \therefore 1$
$32 \pi 4$
$33 \because$

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TMT」

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.236047 .63
.233 日a 7.53
．2円य日に 6.59
$.165 \cdots 14.33$
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－ 118 ver 3.91
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## TARLE 8

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HEAVY HYOZOCAEROO ANALYSIS = STOCS - 1977
PARTICULATE
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－ $1374 a$
－ 1534
.1911
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RELATIVE AT． PERCENT

4.77
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4.45
8.85
9.67
7.73
h． 55
6.9 in
6.55
5.62
4.39

5．17
3.53
2.61
2.56
3.85

2．21
.97
1.13

TABLE 9
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$27 \% \%$
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$33 \therefore$

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（UG．／L．）

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.1790 .7
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| :---: | :---: | :---: |
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| $17 \% 1$ | －a4320 | 2.52 |
| 177 ？ | 0.76363 | 3．3？ |
| 1493 | .26770 | 3.54 |
| 17．4 | － 96610 | 3.45 |
| 2．19 | ．9684a | 3.57 |
| 214.3 | ． 9 ¢ 150 | 3.21 |
| 2291 | ． 27517 | 3.92 |
| 23014 | ． 27890 | 4.12 |
| 24．3） | ．18483 | $4.2 ?$ |
| $253 \%$ | ． 29580 | 4.43 |
|  | .49629 | 5.13 |
| 27\％ | ． 10204 | 5.33 |
| 2 Cin | － 16150 | 3.21 |
| 29－：9 | ． 88700 | 4.59 |
| 引いうの | .17110 | 8.93 |
| $31^{19}$ | .23109 | 12.07 |
| 32．11 | ．164\％ | 8． 57 |
| $330 \%$ | ． 23737 | 12.38 |
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## TARLE 11

HEAVY GYOROCARHOAB ANALYSIS－STOCS－ 1977 PARTICULATE

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－0183a 2．24
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TABLE 12
HEAVY HYORORARROA ANALYSIS－STOCS－ 1977
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hexane eluate

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TUTAL
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CONCENTRATION （UG．／L．）

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$.12510 \quad 4.56$
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7.84
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5． 21
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table 13
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.274914 .22
$.65178 \quad 2.78$
－ 481304.37
.1390 a 7.47
.19 RBG $1 \lambda .64$
$.1740 \pi \quad 9.35$
.189204 .79
1.26140
a．danana

TABLE 14
heavy hyorocafeon analyeis－stocs－ 1977
PARTICULATE
SAMPLE TYPE ：MAT
SAMDE CODE ：CP14，Control Pond Day 14 PERIOD：MINI－STD LOCATID：STATIOM－ 1 LIME－I
heyane eluate
－－－－－－－－－－－－－－

RETEVTION
IVOEX
－

1008
17 ／月
177 ？
18.0

1934
210 e
$211 \%$
22i11
2317
24月：
25．月4
2 hum
$27:$
241
29！
$31^{1.1}$
329
TOTAL

CONCENTRATION （UG．ル．）

－ 14337
．A1月478
－Av512
.03782
.90743
. $\operatorname{ABP}_{13}$
－ 0911
.01270
$.90872 \quad 7.34$
－M1072
－． 572
.04544 .71
．113386 3.37
－an7an 6．11
－ $\sin 6215.42$
－4080 7.51
$.04784 \quad 0.84$
．जिय4 4.13
.11454

RELATIVE NT． PERCENT
－－－－－－－－
2.94
4.17
4.47
6.83
6.49
7.10
7.95
9.34
7.61

1 Tital
a．Mivina

$$
1
$$

table 15
heavy hyowocaragn analysis－Stocs－ 1977
PARTICULATE


179
190．3
104.4

2n An
2191
231

24．
2514
2717
TUTAL

Tだ

CHMCENTRATION （UG．ル．）

－$\pi 17824$
.31610
．N1， 555
－ 1 － 1549
．． 457 a
－A1042？
－त1527
－जの323
－i5ヶ2ス
.90329
.11379
2.141907
felative nt． DERCENT
－ーーーーーーーが
7.24
14.15
4.88
4.82
5.21
3.6 ？
4.63
3.37
49.39
2.99
days 2 and 3. Presumably these data reflected addition of small particles of crude oil as a result of the heavy rainfall.

Samples from days 7 and 14 apparently showed some biogenic hydrocarbon input at $C_{13}$ and $C_{33}$ superimposed on a background of petrogenic hydrocarbons. Samples on days $7,14,20$ and 27 exhibited concentrations of pristane which were similar or greater than $n-C_{17}$. Pristane and phytane values are identified in Tables 5 through 26 by retention index of 1668 and 1772, . respectively. Phytane $/ n-C_{18}$ ratios were also greater than that of the crude oil added. Preferential microbial biodegradation of straight chain hydrocarbons was suspected as being responsible for enrichment of the isoprenoids.

## Particulate Benzene Fraction

Retention times and concentrations of major components in the benzene fraction of Spill I samples are given in Tables 16 through 26. These tables also include data on components of the hexane fraction not reported in Tables 5 through 15. Compounds in the benzene fraction reported in Tables 16 through 26 all appeared to be biogenic hydrocarbons according to mass spectral data. The concentration of petroleum derived aromatics was too low to be measured by electronic integrators. Aromatic compounds were however detected by the GS/MS/DS technique of searching each scan for ions with $m / e$ equal to the molecular ion of certain aromatic compounds (i.e. mass chromatograms).

Figures 11 and 12 demonstrate this technique as applied to the day 7 particulate sample. This sample was found to contain the largest amount of aromatics. Although no peaks were apparent in the reconstructed total ion chromatogram, use of mass chromatograms indicated the presence and relative amounts of substituted naphthalenes, phenanthrenes and dibenzo-
table 16
HEAVY HYOROCLPBON ANALYSIS - STUCS - 1977 PARTICULATE

| HExANE | eluate | bevzene eluate |  |
| :---: | :---: | :---: | :---: |
| NETEATIDN [VOEX | CONCENTRATION | heTENTION <br> INDEX | CONCENTRATION (UG. L.) |
| 1751 | . 01520 | 1795 | - 27578 |
| 24.10 | . $0^{\text {a }}$ 221 | 2153 | . 06468 |
| 2.34 | . 01360 | 2172 | .24898 |
| 2134 | -0.0524 | 2896 | . 11147 |
| ? $2.1 \%$ | -014416 | 3167 | - 12520 |
| 231. | . 94527 | 3246 | . 14520 |
| 29:8 | . 04307 | 3296 | . 90920 |
| $3 \times 59$ | . 01231 |  |  |
| 3154 | - aftara |  |  |
| 3340 | .25390 |  |  |
| total | . 12378 | TOTAL | . 47938 |

tarle 17
meavy hy joicarron analysis－Stocs－ 1977
PARTICULATE

| Sandle type | ：vat |  |
| :---: | :---: | :---: |
| sample code | ：Ex＾入2，Experimental Day 2 | PERIDO ：MINI－STD |
| Loratiju | statiori－ 1 LINE－I |  |

hexaive eluate


RETENTION
IVDEX


17 Av
1751
2191
23 3
2うら1
29ヵ9
3109
TOTAL

CONCENTRATION
（UG．／L．）
－a－－－－－－0－
－n9427
－H215
－Tn4ar
． 14488
－ay211
－cual
． 11819
.05889 TOTAL
1847
1981
2160
3074
3175
3371
benzene eluate


| RETEMTIUN | CONCENTRATION |
| :---: | :---: |
| INDEX | （UG．IL．） |

． 21320
－カヘ8日7
.01047
－ 94060
．． 15806
.33040
.11933
table 18
HEAVY HYDROCARBOA ANALYSIS - STOCS - 1977
PARTICULATE


## TABLE 18 （CONTIMIED）

> 2553
> 2ヶ4:
> 2から4
> 2751
> 2496
> 240
> 3.1.1
> $31+1$
> 3101
> 32 n
> 3340
> 3572

TOTAL
.12185
.135 na
$.0295 \pi$
－ 1050 ？
－ $47 \times 10$
－11ヶ6a
－118ar
.1364 ？
.25450
.145 an
－ 19964
.40346
4.13410

TOTAL
.04529

TARLE 19
HEAVY HYONOCADRON ANALYSIS－STOCS＝ 1977
PARTICULATE

```
SAMPLE TYPE: yAT
SAWPLE CODE:EX^A, Experimental Day 4 PERIOD:MINI-STD
LOCATIOM: STATIO| - 1 LINE = I
```

mEXAVE ELUATE

RETEMTION
TUDEX

15．30
1515
1ヵらタ
17413
1753
1772
$18 \lambda$
1ヵらう
1903
1941
$1+55$
23.13
2.134
2.149
2.31

2141
2133
2214
ここう．
23.1

235
$24.1 x$
2152
$25 \%$
263．j
2650
2714
277 \％
24．9
2ヶ75
2714
$3 \therefore \therefore 1$
$31 \therefore 2$
3151
324
330 ．

COMCENTRATION

.27969
－ 10510
$-1.406$
.12900
.83470
－ $4755 \pi$
$.1502 a$
－ $1944 a$
.14794
－ 13757
－na98？
.131 1a
－ 10645
－ 1730
－ 0 の2か
－111aa
－ 12100
－ 117 万ad
$.0504 \pi$
.11103
.11981
$.1053 \%$
－につち80
－へ744
－$\because 848$
$\therefore \therefore 22 \pi 9$
. ． 5990
－30671
－ 14422
． 111452
－ 64514
－いちら2゙
.23749
－ 136
.91530
.2910

TARLE 20

HEAVY HYIRROCARRON ANALYSIS－STOCS－ 1977

## PARTICULATE

```
Sa%pLE TYPE : AAT
S4%PLE COJE : EXv7, Experimental Day 7 PERIOD : MINI-STD
LOCatTNA: STATION - 1 LINE -I
```

| RETENTION IVREX | CONCERTRATION （UG．／L．） | $\begin{aligned} & \text { RETENTION } \\ & \text { INDEX } \end{aligned}$ | COVCENTRATION <br> （UG．IL．） |
| :---: | :---: | :---: | :---: |
| 1519 | ． 01380 |  |  |
| 10.10 | －い7710 |  |  |
| 1617 | .44920 |  |  |
| 1904． | .15200 |  |  |
| 170.1 | ． 14804. |  | ， |
| 1753 | ． 07898 |  |  |
| 1772 | ． 12508 |  |  |
| 1814 | ． 1790 A |  |  |
| 1350 | ．1769a |  |  |
| $19 \%$ | ． 19298 |  |  |
| 1941 | ．94710 |  |  |
| 1955 | ． 2174 |  |  |
| 20.35 | ．1896at |  |  |
| 2034 | ． 04370 |  |  |
| 2ma9 | ． 15248 |  |  |
| 2109 | ． 17500 |  |  |
| 2131 | ． 01590 |  |  |
| 2244 | ． 18530 |  |  |
| 2240 | ． 63918 |  |  |
| 23 ch | ．17500 |  |  |
| $\geq 327$ | ． 1578 |  |  |
| 235＾ | － 3 万人a |  |  |
| $24 \%$ \％ | ．16180 |  |  |
| 2434 | ． 18880 |  |  |
| 2451 | ． 1277 |  |  |
| 25.31 | ． 15 ama |  |  |
| 2521 | ． 11254 |  |  |
| 2555 | .$\times 319 n$ |  |  |
| ？ 50 | ． 179 and |  |  |
| 2658 | ． 03750 |  |  |


|  | taele 20 | （CONTINUED） |  |
| :---: | :---: | :---: | :---: |
| 2708 | ． 15739 |  |  |
| 2and | ． 1090 |  |  |
| 2976 | ． 13388 |  |  |
| 203\％ | ．136a才 |  |  |
| 3AD．） | ． 123 na |  |  |
| 3＾ちを | .05240 |  |  |
| 3103 | ． 24 ¢月可 |  |  |
| 31 万力 | ．07617 |  |  |
| 32.9 | ． 23 ana |  |  |
| 33.17 | ． $3760 \%$ | － |  |
| TOTAL | 4.26129 | total | 0.09008 |

tarle 21

```
    HEAVY HYDAOCARHON aNALYSIS - STOCS - 1977
        PARTICULATE
SAMPLE TYPE : NAT
SAPIFE CJDE : EXIA, Experimental Day 14 PERIDO : MINI-STD
LOCatiOM: STATION - 1 LINE - I
```

hexane eluate
－－－－－－－－－－－－－－
aETEvTIOA TYEX

## －－－－－－－－－－

1ヶ13
1563
$17 \times 1$
1753
177 ？
1401
1836
$1 \times 57$
1895
1700
1943
2901
2.155

21An
2134
2？ 14
234
235 A
24．3．
2434
2451
25．
この碞
26か？
2713
2700
2．0．0
2876
2．t．
3A．ic
3：4
31 1．
31 ヶう
324
3318
TOTAL

## CONCENTRATION （UG．$L$ ．）

RETENTION INDEX
． $4292 \pi$
． 067 万象
－B4820
－Hal4D
－ $2 \in 300$
－${ }^{\circ} 6770$
$.8142 \pi$
． 1333 a

－ 10610
－na712
－ $1084 \pi$
．． 3430
－an 150
－ 20.918
$.0751 \%$
． 27890
． 11174
－28a80
－905？ 5
.04296
.48580
.09620
． $1155{ }^{\circ}$
.1920 A
－an7ba
.9615 a
． $1162 \%$
.0879 u
.17100
.03690
.23170
.28400
.16480
－ 2370 ar

TOTAL
CONCENTRATION
（UG．／L．）
－－－－－－－－

TARLE 22
HEAVY HYORICARPON $\triangle N A L Y S I S ~-~ S T O C S ~-~$
PARTICULATE
SAMPLE TYPE：NAT
SAWPLE CJDE：EXZA，Experimental Day 20 PERIOO：MINI－STD LDCATIJV：STATIDN－1 LINE－I

HEXAVE ELUATE
－－－－－－－－－－－－－

RETEUTION I MIDEX


1519
1647
1659
1724
1754
1772
1931
1848
1900
1957
2331
2349
214
2234
225.1

23：14
$235 \%$
2401
2452
2510
2547
261才
2ち56
27月
2769
2むうA
2957
$29 \lambda \lambda$
2949
3＾の
3450 $31 \therefore$ a
3242
$33: 1$
3117

TOT4L

CONCENTRATION
（UG．／L．）

－ 217 ：
.10521
.05910
.04160
－ 92173
． 14680
.16790
.13202
－ $4874 a$
.05510
－v64h：
$.106 a 3$
$.0429 \Rightarrow$

－ $0625 \pi$
－ 04548
－N11ヵの － 03120 － 0383 ？ － 12240 － 0 5299 .03040 $.0272 \pi$ －0246 － $0 \Delta 266$ .91832 .48428 －M2581 .00399 .4398 ？ －Vi27日 ．4392？ －in 449 ？ .142619 － 2916
$1.3481^{\circ}$
TOTAL
genzene eluate


| RETENTEON | CONCENTRATION |
| :---: | :---: |
| INDEX | （UG．／L．） |

－ 11140
.02218
－90712
.02308
.04970
.01150
.80642
.08792
－DV635
－ロ1018

HEAVY HYDROCAREOM：$\triangle A_{A L Y S I S ~-~ S T O C S ~-~}^{\text {O }}$－ 1977 PARTICULATE
SAVPLE TYPE：AAT
SiMPLE CODF：EX27，Experimental Day 27 DERIOD：MINI－STD LICATTON：STATION－ 1 LINE－I

HEXANE ELUATE


PETFUTION
I MDEX

COMCEMTRATION （UG．／L．）

1611
1619
10ヶら
17.4

1751
1772
1がが，
1851
19月9
1937
195A

$213 \pi$
2645
$21 \pi A$
2129
2？．4
224.

23月，
2327
2349
？ 4 ．
245
25：
2ヶ！ 4
2555
$27 \therefore 6$
2757
2201
24．7
3：A：
5•12
3124
3151
3237
32月5
1GTAL
－
$.7447 \lambda$
$.2493 n$
.14000
.14502
$.1692 \pi$
－ $1264 a$
．196ad
$.140 \pi a$
－？ 15 na
－ $0165 \pi$
－ 1330
.20509
－44150
.16368
.174 勿
－119

.03410
－1ヵ3ar
－ 11490
.11560
.14300
－ 14350
.11 ers
.12500
－ 02924 － 19240
－ 21640
． 175 ui
－ 7110
－164an
.19790
.2390 ar
.07620
.12304
－ 3777
3.51310

GENZENF ELUATE

RETENTION
INDEX
（UG．／L．）

CONCENTRATION
－EAVY MYOPOCARGOMi ANALYSTS－STOCS－ 1977 PARTICULATE
SANPLE TYPE：AAT SAPLE CJDE：CPAT，Control Day 7 PERIDD：MINI－STD LicaTIOA：STATIO：1－9 LINE－I

HEXANE ELUATE


SETE：TIGN TMDFス

1ヶう3
17へタ
1742
1772
1 ล1ด
$185 \%$
1483
19.14

1742
1757
2． 1.1
$215 \%$
219
2133
22：－1
2231
23.1

2320
255 ？
24ヶ4
2453
วら：．
2らファ
このダ1
？○ 57
27.1

2771
2が，
2ヵ96
274！
3．4．14
$316)$
；1 3
3103
32 14
33：4
33．4

「「「4L

COMCENTRATION （UG．／L．）

－ 3 万иの
－い4わ9
－M12品
－ 151880
－ 19140
－4889a
.01364
.127 EO
. $\operatorname{sen} 794$
－वt1014
$.115 a^{\circ}$
－02か7い
$.164 a!$
－ind 743
$.100 \pi$
$.4273:$
－Ma98
－いけR日？
.91949
－19134
－ 13189
． 28864
－ 1980
.9945
－ 2146
.17400
． $1117 \%$
.25171
．170月1
$.2813:$
.13904
.14300
．192いの
－17くろ2
.17440
－ 08920
． 12 为里

2． $3 \times 547$

RETENTEON
INDEX

2252
2449
2585
3399

CONCENTRATION （UG．／L．）
－－ー－ー－ー－
－ 01264
.12700
－ $0451 \pi$
.83402
tafle 25

tafle 26
reavy hyorocargon analysis－stocs－ 1977 PARTICULATE
SAMFLE TYPE ：AAT
SムTLLE CJJE ：CP2A，Control Day 28 PERIOD ：MINI－STD LOCATIGU ：STATION－ 1 LINE－I
hexane eluate


RETEvTIOA：
I voex
－－－－ッロー－
134
17 A
19.9

1440
$19: 4$
20．As
2 143
21An
22913
？25：
$23 ;$
2351
240）
2453
$25: 8$
2549
2554
$27 \mathrm{n} \%$
2745
2855
272．1
3.155

3119
3339

TOTAL
． 73.12
CONCENTRATION
（UG．／L．）
－－－－－－－－－－
．Aगतz
.11613
.19307
－ 10555
． 20459
.19030
.010570
.00412
． $124 \times 1$
－94527
－ 170428
－ロの3 33
． 197650
－15620
． 20763
． 05072
． 10329
． 14484
.0273 五
.14490
.03189
$.01967 n$
.15960

1．Phegru

RETENTION
INDEX
－－－－－－
1798
1849
1899
2092
2052
2072
2115
2127
2162
2209
2233
2262
2312
2352
2416
2439 2482
2557
2624
2655
2827
2867
3053
3157
3293
TOTAL

CONCENTRATION （UG．ル．） －－－－－－－－－－
.24548
$.0253 \pi$
． 80409
.31890
－． 94790
－ 1810
.02440
.02647
.83527
1.21902
$.157 a \pi$
．2290か
． $9164 \pi$
.06370
． 8650 ？
．461スス
.21930
－ $1196 \pi$
． 92531
.91647
$.13331 \%$
． 08579
．$\lambda 2907$
.32108
$.8115 \%$
2.97886

FFILL 1 DAY 7. PART. BENZERE

| sscarts | 200 | HRDCPY | NO |
| :---: | :---: | :---: | :---: |
| $\because S C H E$ | 100 | RECERO | YES |
| EASE | 12385 | x* |  |



APILI 1 DAY 7. PART. BEMZERE

| 1\%ASSES | i73. | $\theta$. | 0. |
| :---: | :---: | :---: | :---: |
| 5 SCHN | 280 | HRDCeY | NO |
| OSCALE | 100 | RETERO | YES |
| EASE |  | * |  |



Figure 11. Total Ion Chromatogram of Spill I, Day 7, Particulate Fraction, Benzene Eluate (above). Mass Chromatogram of $\mathrm{m} / \mathrm{e}=178$, Phenanthrene (below).

SPILL 1 DAY 7. PART. BEMZERE



SPILL 1 DAY 7. PART. BENZBNE

| HMESES | 206. | 0. | 0 |
| :---: | :---: | :---: | :---: |
| EECAMS | 200 | HFIDCPY | NO |
| :SSALE | 103 | RESERO | YES |
| EASE | 478 | \% |  |



Figure 12. Mass Chromatograms from Spill I, Day 7, Particulate Fraction Benzene Eluate. Chromatogram of $\mathrm{m} / \mathrm{e}=192$, Methylphenanthrene (above); m/e=206, Dimethylphenanthrene (below)
thiophenes. The relative proportions of parent compound, methyl-, and dimethyl- and trimethyl- substituted compounds were quite different to that seen in the dissolved fraction. Parent and methyl substituted compounds are the more prominant in water solubles, while in particulates di- and tri- substituted compounds are dominant. Day 3, 4 and 14 particulate benzene samples also contained aromatics in similar relative proportions but at lower concentrations.

## Particulate Methanol Fraction

Particulate methanol fractions were characterized by a single large phthalate peak and one or two much smaller peaks which were also identified as phthalates on the basis of their mass spectra (base peak $m / e=149$ ).

## Spill II

Spill II was begun by addition of 675 mls of Alaskan crude oil to about 6750 l of seawater. This volume of oil produced a slick within the cylindrical enclosure with an average thickness of about 0.9 mm . Afternoon water temperature was $27^{\circ} \mathrm{C}$ the day of Spill II and rose to as high as $31^{\circ} \mathrm{C}$. Salinity of the water was 31.2 ppt . Water column sampling was terminated after a hard rain drove oil over and under the enclosure and into the water column on day 28. A tarball-1ike sample of residual oil within the enclosure was taken for analysis on day 43. Another tarball was sampled on day 79 .

Dissolved Hexane Fraction
Results of analyses of the dissolved benzene fraction are presented in Table 27. The components identified and quantified for Spill II were given the same identifiers, A-Z, previously used for Spill I. Selected data from Table 27 have also been plotted in Figure 13.

CONCENTRATION OF DISSOLVED AROMATICS DURING SPILL II

| Figure 2 Identifiers | A | B | C | D | E | F |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Major Component | Naphthalene | Methyl <br> Naphthalene | Methyl <br> Naphthalene | $\begin{aligned} & \mathrm{C}_{2} \\ & \text { Naphthalene } \end{aligned}$ | $\begin{aligned} & \mathrm{C}_{2} \\ & \text { Naphthalene } \end{aligned}$ | $\begin{aligned} & \mathrm{C}_{2} \\ & \text { Naphthalene } \end{aligned}$ |
| Secondary Component |  |  |  |  | Biphenyl |  |
| Day 1 Conc. $\mu \mathrm{g} / \ell$ <br> (Normalized) | $\begin{gathered} .063 \\ (1.0) \end{gathered}$ | $\underset{(1.0)}{.106}$ | $\underset{(.96)}{.118}$ | $\stackrel{.037}{(51)}$ | $(.102$ | $\begin{aligned} & .037 \\ & (.41) \end{aligned}$ |
| Day 2 | $\begin{aligned} & .008 \\ & (.13) \end{aligned}$ | $\begin{aligned} & .023 \\ & (.22) \end{aligned}$ | $\begin{aligned} & .038 \\ & (.31) \end{aligned}$ | $\begin{aligned} & .015 \\ & (.21) \end{aligned}$ | $\begin{aligned} & .045 \\ & (.23) \end{aligned}$ | $\begin{aligned} & .017 \\ & (.19) \end{aligned}$ |
| Day 3 | $\begin{aligned} & .045 \\ & (.71) \end{aligned}$ | $\underset{(1.0)}{.105}$ | $\begin{gathered} .123 \\ (1.0) \end{gathered}$ | $\begin{gathered} .072 \\ (1.0) \end{gathered}$ | $\begin{gathered} .198 \\ (1.0) \end{gathered}$ | $\begin{array}{r} .090 \\ (1.0) \end{array}$ |
| Day 4 | $\begin{aligned} & .028 \\ & (.44) \end{aligned}$ | $\begin{aligned} & .076 \\ & (.72) \end{aligned}$ | $\begin{aligned} & .086 \\ & (.70) \end{aligned}$ | $\begin{aligned} & .062 \\ & (.86) \end{aligned}$ | $\begin{aligned} & .198 \\ & (.85) \end{aligned}$ | $\begin{gathered} .079 \\ (.88) \end{gathered}$ |
| Day 9 | $\begin{aligned} & .005 \\ & (.08) \end{aligned}$ | $\begin{array}{r} .019 \\ (.18) \end{array}$ | $\text { . } 022$ | $\begin{gathered} .021 \\ (.29) \end{gathered}$ | $(.081$ | $\begin{gathered} .045 \\ (.50) \end{gathered}$ |
| Day 15 | - | - | - | - | $(.011$ | - |
| Day 23 | - | - | - |  |  |  |

TABLE 27 CONT. 'D

| Figure 2 Identifiers | G | H | I | J | K | L |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Major Component | $\begin{aligned} & \mathrm{C}_{2} \\ & \text { Naphthalene } \end{aligned}$ | $\begin{aligned} & \mathrm{C}_{3} \\ & \text { Naphthalene } \end{aligned}$ | $\begin{aligned} & \mathrm{C}_{3} \\ & \text { Naphthalene } \end{aligned}$ | $\begin{aligned} & \mathrm{C}_{3} \\ & \text { Naphthalene } \end{aligned}$ | $\mathrm{C}_{3}$ <br> Naphthalene | Methyl <br> Biphenyl |
| Secondary Component | $\begin{aligned} & \mathrm{C}_{3} \\ & \text { Naphthalene } \end{aligned}$ | Methy1 <br> Diphenyl |  |  |  |  |
| Day 1 Conc. $\mu \mathrm{g} / \ell$ <br> (Normalized) | $\begin{aligned} & .013 \\ & (.32) \end{aligned}$ | $.022$ |  |  | $\begin{aligned} & .016 \\ & (.26) \end{aligned}$ | $\begin{gathered} .018 \\ (.64) \end{gathered}$ |
| Day 2 | $\begin{aligned} & .007 \\ & (.17) \end{aligned}$ |  | - |  | $\begin{aligned} & .013 \\ & (.21) \end{aligned}$ |  |
| Day 3 | $\begin{gathered} .041 \\ (1.0) \end{gathered}$ | $059$ | $.044$ | $.143$ | $\begin{aligned} & .057 \\ & (.92) \end{aligned}$ | $\begin{aligned} & .020 \\ & (.71) \end{aligned}$ |
| Day 4 | $\begin{aligned} & .040 \\ & (.98) \end{aligned}$ | $057$ | $.048$ | $.070$ | $\begin{aligned} & .058 \\ & (.94) \end{aligned}$ | $(.021$ |
| Day 9 | $\begin{aligned} & .026 \\ & (.63) \end{aligned}$ | $.065$ | $.043$ | $.072$ | $\begin{gathered} .062 \\ (1.0) \end{gathered}$ | $\left(\begin{array}{c} .028 \\ (1.0) \end{array}\right.$ |
| Day 15 | - | - | - | - | $\begin{aligned} & .018 \\ & (.29) \end{aligned}$ |  |
| Day 23 | - | - | - |  |  |  |

TABLE 27 CONT.D

| Figure 2 Identifiers | M | N | 0 | P | Q | R | S |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Major Component | $C_{4}$ <br> Naphthalene | Fluorene | $\mathrm{C}_{2}$ <br> Biphenyl | Methyl Fluorene | Methyl <br> Fluorene | $\begin{aligned} & \mathrm{C}_{2} \\ & \text { Fluorene } \end{aligned}$ | Dibenzothiophene |
| Secondary Component |  |  | $\begin{aligned} & \mathrm{C}_{3} \\ & \text { Bipheny1 } \end{aligned}$ |  |  |  |  |


| Day 1 | Conc. $\mu \mathrm{g} / \ell$ (Normalized) |  | $\begin{aligned} & .008 \\ & (.17) \end{aligned}$ | $\begin{aligned} & .005 \\ & (.16) \end{aligned}$ |  | $\begin{aligned} & .028 \\ & (.35) \end{aligned}$ |  | $\begin{aligned} & .008 \\ & (.15) \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Day 2 |  | - | . 016 | . 003 | - | . 034 | - | . 010 |
|  |  | - | (.35) | (.10) | - | (.43) | - | (.19) |
| Day 3 |  | . 032 | . 038 | . 019 | . 014 | . 059 | . 027 | . 019 |
|  |  | - | (.83) | (.61) | - | (.75) | - | (.35) |
| Day 4 |  | . 033 | . 042 | . 022 | . 016 | . 057 | . 015 | . 034 |
|  |  | - | (.91) | (.71) | - | (.72) |  | (.63) |
| Day 9 |  | . 031 | . 046 | . 031 | . 031 | . 079 | - | . 054 |
|  |  | - | (1.0) | (1.0) | - | (1.0) | - | (1.0) |
| Day 15 |  | - | . 009 | - | - | . 042 | - | . 029 |
|  |  | - | (.20) | - | - | (.53) | - | (.54) |
| Day 23 |  | - | - | - | - | . 038 | - | . 015 |
|  |  | - | - | - | - | (.48) | - | (.28) |

TABLE 27 CONT. ${ }^{\prime} D$

| Figure 2 Identifiers | T | U | V | W | X | Y | Z |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Major Components <br> Secondary Components | Phenan- <br> threne | Methy1 <br> Dibenzo- <br> thiophene | Methyl <br> Dibenzo- <br> thiophene | Methyl <br> Phenan- <br> threne <br> $\mathrm{C}_{2}$ Dibenzo- <br> thiophene | Methyl <br> Phenan- <br> threne $\mathrm{C}_{2}$ Dibenzothiophene | $\mathrm{C}_{2}$ <br> Phenanthrene | $\mathrm{C}_{2}$ <br> Phenanthrene |
| $\text { Day } 1 \underset{\text { (Normalized) }}{\text { Conc. } \mu \mathrm{g} / \ell}$ | $\begin{aligned} & .012 \\ & (.20) \end{aligned}$ | - |  | $\begin{aligned} & .009 \\ & (.21) \end{aligned}$ | $\begin{array}{r} .009 \\ (.32) \end{array}$ | - | $\text { . } .011$ |
| Day 2 | $\begin{aligned} & .015 \\ & (.25) \end{aligned}$ | - | - | $\begin{aligned} & .008 \\ & (.19) \end{aligned}$ | $\begin{aligned} & .010 \\ & (.36) \end{aligned}$ | $\begin{aligned} & .003 \\ & (.27) \end{aligned}$ | $\begin{aligned} & .003 \\ & (.10) \end{aligned}$ |
| Day 3 | $\begin{aligned} & .037 \\ & (.62) \end{aligned}$ | $.010$ | $.008$ | $\text { (. } .017$ | $\begin{aligned} & .020 \\ & (.71) \end{aligned}$ | $\begin{aligned} & .008 \\ & (.73) \end{aligned}$ | $\begin{array}{r} .030 \\ (1.0) \end{array}$ |
| Day 4 | $\begin{gathered} .041 \\ (.68) \end{gathered}$ | $.009$ | $.005$ | $\begin{aligned} & .017 \\ & (.40) \end{aligned}$ | $\begin{aligned} & .017 \\ & (.61) \end{aligned}$ | $\begin{aligned} & .008 \\ & (.73) \end{aligned}$ | $\begin{aligned} & .015 \\ & (.50) \end{aligned}$ |
| Day 9 | $\stackrel{.06}{(1.0)}$ | $.015$ | $.008$ | $\begin{gathered} .043 \\ (1.0) \end{gathered}$ | $\begin{gathered} .028 \\ (1.0) \end{gathered}$ | $\underset{(1.0)}{.011}$ | $\underset{(.50)}{.015}$ |
| Day 15 | $\underset{(.53)}{.032}$ | - | - | $\begin{aligned} & .027 \\ & (.63) \end{aligned}$ | $\begin{gathered} .018 \\ (.64) \end{gathered}$ | - | $(.017$ |
| Day 23 | $\underset{(.37)}{.022}$ | - | - | $\begin{aligned} & .020 \\ & (.47) \end{aligned}$ | $\begin{aligned} & .015 \\ & (.54) \end{aligned}$ | - | - |



Figure 13. Concentration of Various Compounds, Spill II, Dissolved Fraction, Benzene Eluate. Concentrations Expressed as Percent of Maximum Value Attained by Each Compound A=Naphthalene, $K=C_{3}$-Naphthalene, $S=D i b e n z o$ thiophene, $\mathrm{T}=$ Phenanthrene.

Although only a third as much oil was added for Spill II concentrations of most aromatics present on day 1 were similar to those measured on day 1 of Spill I. The only compounds which had significantly lower concentrations on day 1 were naphthalene and methylnaphthalenes. Concentration of naphthalenes on day 2, Spill II, were inordinately low and assumed to be indicative of loss during sample preparation.

Concentrations of fluorenes, dibenzothiophenes and phenanthrenes, however, were similar on day 2 for the two spills. Apparently the concentration of naphthalene and the methylnaphthalenes was at a peak on day 2 because by day 3 concentrations were similar to or less than day 1 concentrations. $\mathrm{C}_{2}$-naphthalenes reached their highest concentration on day 3 while most higher molecular weight compounds had highest concentrations on day 9.

## Dissolved Methanol Fraction

Spill II samples contained the same compounds discussed for Spill I except for one new phthalate derivative, dimethyl phthalate.

## Particulate Hydrocarbons

Due to calm weather conditions during Spill II very little particulate matter was present in the water column. The amount of material extracted was so low that it was not possible to obtain reliable quantitative data. All samples were processed and analyzed by gas chromatography and a few were analyzed by GC/MS/DS. An inventory of all samples analyzed by GC/MS/DS is given in Table 28.

## Particulate Hexane Fractions

The trace amounts of $n$-alkanes seen in a few samples were primarily odd carbon numbered hydrocarbons in the $C_{18}-C_{23}$ range.

TABLE 28

## INVENTORY OF FRACTIONS ANALYZED BY GC-MS-DS

| Experiment |  | Day | Part. | Diss | Hex. | Benz . | MEOH |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Spill I |  | 2 |  | X |  | X |  |
|  |  | 3 | X |  | X | X | X |
|  |  | 3 |  | X |  |  | X |
|  |  | 4 | X |  | X | X | X |
|  |  | 4 |  | X |  | X |  |
|  |  | 7 | X |  |  | X |  |
| - |  | 7 |  | X | X |  | X |
|  |  | 14 | $X$ |  |  | X |  |
|  |  | 14 |  | X |  |  | X |
|  |  | 27 | X |  | X | X | X |
|  |  | 27 |  | X |  | X | X |
|  | Control | 7 | X |  | X | X |  |
|  | Control | 14 |  | X |  | , | X |
| Aromatic Mix |  | 24 | X | X |  |  |  |
| Aromatic Mix, Sediment |  | 24 | X |  | X | X |  |
| Spill II |  |  |  |  |  |  |  |
|  |  | 9 | X |  |  | X |  |
|  |  | 15 | X |  |  | X |  |
|  |  | 23 |  | X |  | X | X |
|  | Residual Oil | 43 |  |  |  | X |  |
|  | Residual Oil | 79 |  |  |  | X |  |

## Particulate Benzene Fractions

GC/MS/DS analyses of the day 4,9 and 15 samples indicated day 9 contained the largest amounts of aromatic compounds. $\mathrm{C}_{2}$ - and $\mathrm{C}_{3}$ - substituted compounds were present in the highest concentration.

## Particulate Methanol Fractions

The only identifiable compounds present in the methanol fractions were phthalates.

Residual Oil (Tarba11) Samples, Spill II
Hexane Fraction
The day 43 and 79 hexane fractions gave similar chromatograms with n-alkanes prominent from $\mathrm{C}_{17}$ to $\mathrm{C}_{31}$ (Figure 14). The pristane/n- $\mathrm{C}_{17}$ ratio on day 43 and 0.6 and near unity on day 79 .

## Benzene Fraction

Figure 15 gives the reconstructed total ion chromatogram of the day 43 sample. Dominant peaks were identified as substituted phenanthrenes and dibenzothiophenes. Di- and trimethylnaphthalenes were present in trace amounts. The day 79 samples had no discernible peaks above the baseline and only trace quantities of substituted phenanthrenes were found via the mass chromatogram technique.

## Aromatic Compounds Mixture Experiment

Afternoon water temperature was $21^{\circ} \mathrm{C}$ at the start of this experiment and rose to $26^{\circ} \mathrm{C}$ by the fourth week. Salinity of the water was 30.8 ppt . The first sample was taken one hour after addition of the mixture was begun. Figure 16 shows a chromatogram of the mixture before addition and the one hour dissolved sample. Results of analyses of the dissolved and particulate samples are given in Table 29. Data from these samples


SPILL 2 RESIELAL GIL, DAY 43. BENZENE



SPILL 2 RESIDUAL OIL, DAY 43. BETCIENE

$$
\text { ASCALE } 100 \text { REYERO YES }
$$

efse
3641 天еस 0


Figure 15. Total Ion Chromatogram of Spill II, Day 43, Residual Oil, Benzene Eluate (above). Mass Chromatogram of $m / e=$ 192, Methylphenanthrenes (below).


TABLE 29

VARIATION IN CONCENTRATION OF ADDED AROMATICS

| $\substack{\text { Dissolved } \\ \mu \mathrm{g} / \ell \% \text { of } 1 \mathrm{H} \\ \text { Sample }}$ | Particulate <br> $\mu \mathrm{g} / \ell \%$ of 1 H |
| :--- | :--- |

o-Toluidine

| $1 \mathrm{H}^{1}$ | 10.0 | 98 | 0.2 | 2 |  | 10.2 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| $0.5 \mathrm{D}^{2}$ | 8.7 | 85 | - | - | 8.7 | 100 |
| 1 D | 9.0 | 88 | - | - | 9.0 | 88 |
| $2 . \mathrm{D}$ | 4.5 | 44 | - | - | 4.5 | 44 |
| 4 D | 3.0 | 29 | - | - | 3.0 | 29 |
| 8 D | 1.4 | 14 | - | - | 1.4 | 14 |
| 24 D | T |  | - | - | T |  |

2, 4-Dimethylphenol

| 1 H | 12.3 | 100 | - | - | 12.3 | 100 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 8.7 | 71 | - | - | 8.7 | 71 |
| 1 D | 9.2 | 75 | - | - | 9.2 | 75 |
| 2 D | 3.7 | 30 | - | - | 3.7 | 30 |
| 4 D | 2.8 | 23 | - | - | 2.8 | 23 |
| 8 D | 0.4 | 3 | - | - | 0.4 | 3 |
| 24 D | - | - | - | - | - | - |

## Indole

| 1 | H | 18.6 | 100 | - | - | 18.6 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 8.9 | 48 | - | - | 8.9 | 48 |
| I D | 7.6 | 41 | - | - | 7.6 | 41 |
| 2 | D | 0.5 | 3 | - | - | 0.5 |
| 4 | D | - | - | - | - | - |

## 2-Methylnaphthalene

| 1 H | 29.1 | 92 | 2.5 | 8 | 11.6 | 31.6 | 100 |
| :--- | ---: | :---: | :---: | :---: | ---: | ---: | ---: |
| 0.5 D | 29.0 | 92 | 0.9 | 3 | 32.2 | 29.9 | 95 |
| 1 D | 28.9 | 91 | 0.8 | 3 | 36.1 | 29.7 | 94 |
| 2 D | 18.3 | 58 | 0.2 | 1 | 91.5 | 18.5 | 59 |
| 4 D | 20.5 | 65 | 0.2 | 1 | 102.5 | 20.7 | 66 |
| 8 D | 8.6 | 27 | 0.1 | 0 | 86 | 8.7 | 28 |
| 24 D | 0.2 | 0.6 | - | - | - | 0.2 | 0.6 |

## 2,6-Dimethylnaphthalene

| 1 H | 27.5 | 82 | 6.0 | 18 | 4.6 | 33.5 | 100 |
| :--- | ---: | :---: | :---: | ---: | ---: | ---: | ---: |
| 0.5 D | 27.4 | 82 | 2.3 | 7 | 11.9 | 29.7 | 89 |
| 1 D | 26.1 | 78 | 2.2 | 7 | 11.9 | 28.3 | 85 |
| 2 D | 16.4 | 49 | 0.6 | 2 | 27.3 | 17.0 | 51 |
| 4 D | 16.9 | 50 | 0.7 | 2 | 24.1 | 17.6 | 52 |
| 8 D | 7.3 | 22 | 0.3 | 1 | 24.3 | 7.6 | 23 |
| 24 D | 0.2 | 0.6 | - | - | - | 0.2 | 0.6 |

TABLE 29 CONT. 'D


## 2,3,6-Trimethylnaphthalene

| 1 H | 23.5 | 64 | 13.4 | 36 | 1.8 | 36.9 | 100 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 23.8 | 64 | 5.4 | 15 | 4.4 | 29.2 | 79 |
| 1 D | 20.2 | 55 | 4.7 | 13 | 4.3 | 24.9 | 68 |
| 2 D | 12.5 | 34 | 2.3 | 6 | 5.4 | 14.8 | 40 |
| 4 D | 12.2 | 33 | 2.6 | 7 | 4.7 | 14.8 | 40 |
| 8-D | 4.9 | 13 | 1.1 | 3 | 4.4 | 6.0 | 16 |
| 24 D | 0.3 | 0.8 | - | - | - | 0.3 | 0.8 |

## Fluorene

| 1 H | 34.0 | 82 | 7.5 | 18 | 4.5 | 41.5 | 100 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 33.6 | 81 | 2.7 | 7 | 12.4 | 36.3 | 88 |
| 1 D | 30.5 | 73 | 2.2 | 5 | 13.9 | 32.7 | 78 |
| 2 D | 20.3 | 49 | 1.3 | 3 | 15.6 | 21.6 | 52 |
| 4 D | 23.3 | 56 | 1.5 | 4 | 15.5 | 24.8 | 60 |
| 8 D | 10.8 | 26 | 0.9 | 2 | 12.0 | 11.7 | 28 |
| 24 D | 0.9 | 2.2 | - | - | - | 0.9 | 2.2 |

1-Methylfluorene

| 1 H | 14.2 | 65 | 7.6 | 35 | 1.9 | 21.8 | 100 |
| :--- | ---: | :---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 16.8 | 77 | 3.4 | 16 | 4.9 | 20.2 | 93 |
| 1 D | 14.7 | 67 | 3.0 | 15 | 4.9 | 17.7 | 81 |
| 2 D | 10.2 | 47 | 2.0 | 9 | 5.1 | 12.2 | 56 |
| 4 D | 10.5 | 48 | 2.5 | 11 | 4.2 | 13.0 | 59 |
| 8 D | 5.5 | 25 | 1.1 | 5 | 5.0 | 6.6 | 30 |
| 24 D | 1.0 | 4.6 | - | - | - | 1.0 | 4.6 |

## Phenanthrene

| 1 H | 26.3 | 65 | 14.3 | 35 | 1.8 | 40.6 | 100 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 31.1 | 77 | 7.0 | 17 | 4.4 | 38.1 | 94 |
| 1 D | 27.4 | 67 | 6.1 | 15 | 4.5 | 33.5 | 83 |
| 2 D | 18.5 | 46 | 4.0 | 10 | 4.6 | 22.5 | 56 |
| 4 D | 17.6 | 43 | 4.8 | 12 | 3.7 | 22.4 | 55 |
| 8 D | 8.8 | 22 | 2.2 | 5 | 4.0 | 11.0 | 27 |
| 24 D | 1.0 | 2.5 | - | - | - | 1.0 | 2.5 |

1-Methylphenanthrene

| 1 H | 7.3 | 39 | 11.6 | 61 | 0.6 | 18.9 | 100 |
| :--- | :---: | :---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 9.8 | 52 | 6.0 | 32 | 1.6 | 15.8 | 84 |
| 1 D | 7.6 | 40 | 4.8 | 25 | 1.6 | 12.4 | 65 |
| 2 D | 5.2 | 28 | 3.2 | 17 | 1.6 | 8.4 | 45 |
| 4 D | 5.0 | 26 | 3.5 | 19 | 1.4 | 8.5 | 45 |
| 8 D | 2.3 | 12 | 1.6 | 8 | 1.4 | 3.9 | 20 |
| 24 D | 0.2 | 1.1 | - | - | - | 0.2 | 1.1 |

TABLE 29 CONT. 'D

| Dissolved | Particulate |  |  | Total |
| :---: | :---: | :---: | :---: | :---: |
| $\mu \mathrm{g} \ell$ \% of 1 H | $\mu \mathrm{g} / \ell \%$ of 1 H | Diss/Part | $\mu \mathrm{g} / \ell$ | \% of 1 H |

Sample
Dibenzothiophene

| 1 H | 24.5 | 70 | 10.6 | 30 | 2.3 | 35.1 | 100 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 26.0 | 74 | 5.5 | 16 | 4.7 | 31.5 | 90 |
| 1 D | 23.8 | 68 | 4.9 | 14 | 4.9 | 28.7 | 82 |
| 2 D | 15.0 | 43 | 3.3 | 9 | 4.5 | 18.3 | 52 |
| 4 D | 15.1 | 43 | 4.1 | 12 | 3.7 | 19.2 | 55 |
| 8 D | 7.6 | 22 | 2.2 | 6 | 3.4 | 9.8 | 28 |
| $24^{\circ} \mathrm{D}$ | 0.9 | 2.6 | - | - | - | 0.9 | 2.6 |

Fluoranthene

| I H | 9.7 | 27 | 26.8 | 73 | 0.4 | 36.5 | 100 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 15.2 | 42 | 16.1 | 44 | 0.9 | 31.3 | 86 |
| 1 D | 11.0 | 30 | 12.2 | 33 | 0.9 | 23.2 | 63 |
| 2 D | 7.3 | 20 | 9.2 | 25 | 0.8 | 16.5 | 45 |
| 4 D | 6.7 | 18 | 8.3 | 23 | 0.8 | 15.0 | 41 |
| 8 D | 2.5 | 7 | 3.3 | 9 | 0.8 | 5.8 | 16 |
| 24 D | 0.6 | 1.6 | - | - | - | 0.6 | 1.6 |

## Pyrene

| 1 H | 7.8 | 22 | 27.6 | 78 | 0.3 | 35.4 | 100 |
| :--- | :---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 0.5 D | 7.3 | 21 | 10.7 | 30 | 0.7 | 18.0 | 51 |
| 1 D | 5.0 | 14 | 6.5 | 18 | 0.8 | 11.5 | 32 |
| 2 D | 1.6 | 5 | 2.2 | 6 | 0.7 | 3.8 | 11 |
| 4 D | 0.5 | 1 | 0.6 | 2 | 0.8 | 1.1 | 3 |
| 8 D | - | - | 0.2 | 0.6 | - | 0.2 | 0.6 |
| 24 D | - | - | - | - | - | - | - |

$$
\begin{aligned}
& { }^{1} H=\text { hour } \\
& { }^{2} \mathrm{D}=\text { day }
\end{aligned}
$$

were used to prepare the graphs of Figures 17 through 20 which show less of the various compounds from the water column with time.

Addition of aromatic compounds to the tank appeared from the data to proceed rather well with the exception of three compounds: methylphenanthrene, fluoranthene and pyrene. Table 29 indicates one hour after addition that more than $60 \%$ of the methylphenanthrene and more than $70 \%$ of the fluoranthene and pyrene in the water column was present in the particulate fraction. Apparently, these compounds were largely precipitated upon addition. The data indicated an increase in concentration of dissolved methylphenanthrene and fluoranthene between the 1 and 12 hour samples which suggested these compounds did redissolve to some extent. A similar phenomenon was suggested to a lesser degree for the following: trimethylnaphthalene, methylfluorene, dibenzothiophene, and phenanthrene.

The data indicated a rapid disappearance of indole from the water column and no association with particulate matter. The pattern of change in concentration suggested a photolytic decomposition. Photolysis of indole in aqueous solutions has indeed been reported (Arce et al., 1975). Loss of dimethylphenol and o-toluidine was most likely attributed to autooxidation by atmospheric oxygen through light catalyzed reactions. Although concentrations of dimethylphenol and toluidine were too low to quantify, trace amounts were present in the day-24 dissolved fraction and recognizable mass spectra were obtained for both compounds. These two compounds were not detected in the day-24 particulate sample.

Loss of methyl-, dimethyl- and trimethylnaphthalene from the water column occurred at similar rates. The data suggested retention of less volative di- and trimethyl compounds via reduced evaporation was offset by greater adsorption to particulate matter and subsequent loss of sedimentation.



Figure 18, Concentration of Various Compounds After Addition of Aromatic Mixuter. Concentrations Expressed as Percent of 1.Hour Value. $\mathrm{X}=$ Dissolved, $0=$ Dissolved + Particulate.



The dissolved／particulate ratio for most compounds is reported in Table 20．The ratios remained rather constant over an eight day period and as much as a five fold change in concentration which indicated an equilibrium existed between dissolved and particulate fractions．The dis－ solved／particulate ratio for trimethylnaphthalene reached a rather stable value of $4-5$ by the 12 hour sample．Similar values were observed for methylfluorene，phenanthrene and dibenzothiophene．The only compounds which maintained dissolved／particulate ratios less than one were fluoran－ thene and pyrene．

Results of the aromatic mixture experiment and those of Spill I and II suggest that the classes of aromatic compounds most likely to be indi－ cative of petroleum pollution include：naphthalenes，fluorenes，phenan－ threnes and dibenzothiophenes．These classes of compounds were present in measurable quantities three to four weeks after each spill．Frankenfeld （1973）studied the weathering of a Venezuelan crude oil in a laboratory simulator and reported that the classes of aromatics present in highest concentration in the aqueous extract after two months were indenes，naph－ thalenes，acenaphthalenes，acenaphthenes，fluorenes and phenanthrenes．

In each of the three experiments aromatic compounds were generally three to five times more concentrated in the dissolved fraction than in the particulate fraction．Data from each experiment suggested that aromatic compounds were partioned between dissolved and particulate fractions with parent and mono－methyl compounds enriched in dissolved fractions while more highly methylated compounds were enriched in particulate fractions．

Data obtained from the three experiments described a rather limited set of weathering conditions imposed on a specific crude oil．The weathering conditions in the experimental tanks included very little turbulent mixing of the oil and seawater which resulted in minimal incorporation of petroleum
hydrocarbons into the water column (less than $0.5 \%$ methylnaphthalenes in Spill I).

## RECOMMENDATIONS

In view of the limited scope of weathering conditions and crude oil tested in this study it is recommended that further studies be carried out before any management decisions are made based on these results alone.

## SUMMARY

Data presented herein indicated the following:

1. The concentration of petroleum-derived $n$-alkanes in the water column was approximately ten times higher in particulate fractions than in dissolved fractions.
2. Aromatic compounds were generally at least five times more concontrated in dissolved fractions than in particulates.
3. Aromatic compounds were partioned between dissolved and particulate fractions with parent and mono-methyl compounds enriched in dissolved fractions while more fighly methylated compounds were enriched iń particulate fractions.
4. A very small percentage of the naphthalenes originally present in the crude oil was found in the water column under the experimental conditions employed (less than $0.5 \%$ of the methylnaphthalenes).

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## CHAPTER THIRTEEN

DEVELOPMENT OF MINI-COMPUTER PROGRAMMING TO AID IN INTERPRETATION OF MASS SPECTRAL DATA

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## ABSTRACT

- The GC/MS data system includes a library of mass spectra stored on magnetic disc cartridge assessible through online software. In order to make this library more useful, programs have been written to list, search, and modify this library. The programs are already useful as an interpretative aid and future programs are contemplated to be of further assistance.


## INTRODUCTION

A part of the integrated STOCS baseline study is the measurement and characterization of higher molecular weight hydrocarbons by the analytical techniques of combined gas chromatography and mass spectrometry．The combined analysis involves the use of a digital data acquisition and data synthesis system having a＂library＂of mass spectra with which unknown mass spectra may be compared to assist in identification．

The total system in use at this laboratory is a DuPont ${ }^{1}$ Model 21－491 GC－Mass Spectrometer（GC／MS）with a DuPont Model 21－094B data acquisition system．The library associated with this system contains 7054 mass spec－ tra，most of which are derived from Stenhagen et al．（1974）．＇The spectra from the＂Atlas＂is supplemented with DuPont＇s unpublished library of drugs， pesticides and metabolites．The library search and retrieval software used is that developed by DuPont and has been found useful but somewhat limiting in this laboratory．

In practice，the search algorithm selects five library entries which most resemble the unknown mass spectrum，but lists the names of the com－ pounds of only the first two＂hits＂．The remaining three compounds are listed by an identification number only．Because the library spectra were not obtained by the same instrument as the unknown spectrum，inten－ sity differences are present which may preclude the selection of one as the＂most likely＂spectrum．Thus，identification of the remaining three compounds is desirable to allow closer comparison of compound types and， to determine that the unknown is not one of the alternate，unidentified entries．

[^2]Frequently an unknown spectrum does not compare well with any library spectra. Other, more classical, mass spectral interpretation schemes must be employed for identification. In many instances the base peak of the mass spectrum (i.e. the fragment ion having the greatest intensity) is characteristic of the compound type. For example: a base peak of $\mathrm{m} / \mathrm{e}=$ 149 ( $\mathrm{m} / \mathrm{e}$ is mass to change ratio given in atomic mass units) is usually indicative of phthalate esters; $m / e=74$ base peak is characteristic of methyl esters of fatty acids; etc. A listing of compounds as a function of base peak mass would be useful information for compound identification.

A base peak of a compound analyzed by one instrument may be a major peak but not necessarily the base peak when analyzed by a different instrument. This lack of correspondence between acquired data and library data suggests that a list of compounds as function of "predominant" peaks would be useful.

Data stored within the library spectra do not include the compound's molecular weight although such data are available in the original "Atlas". The molecular weight of a compound can frequently be obtained from mass spectral data and is very useful information to assist in compound identification.

## PROGRAM DEVELOPMENT

Both high level (FORTRAN IV) and low level (ASSEMBLER) programming languages are available for program development. Using these languages programs were written to:

1) generate a listing of every spectrum identification in numeric sequence to allow ready identification of those spectra listed by number only;
2) generate a listing of spectra arranged in sequence of the "basepeak" of the mass spectrum to assist in identification of unknown spectra;
3) generate a listing of spectra arranged in sequence of their "most significant peaks" (including the base peak); and
4) permit manual entry of the molecular-weight of a compound into the data-base of each compound spectrum to permit future development of search algorithms involving this parameter.

## Numeric Sequence Listing

The first of these programs was written in FORTRAN with a program listing given in Section A, Appendix I. The result of program execution is a 221 page listing of spectral entries in the library. A representative page of this listing is reproduced in Section A, Appendix II.

The program is quite simple, using standard calls to the Disc Operating System (DOS) executive subroutines to access the information on the magnetic disc. The program will, at the option of the user, either list all spectra in sequence or merely count the number of spectra in the library.

## Base Line and Significant Peak Listings

The second and third aspects of this study were accomplished with a single program written in ASSEMBLER language. The program listing is given in Section B, Appendix I. The results of execution vary with option specified by the user at the time of execution.

The user may specify the listing be made on the basis of base peaks or on "significant" peaks. For the purpose of this program "significant" peaks are those with intenstties $25 \%$ or greater than the base peak intensity, The $25 \%$ level was selected because such mass fragments are already flagged in the spectral library thus easing the programming effort required.

The user also has the option of making a listing for any given mass
number or for any sequence of mass numbers selected by input.
The result of a sequential listing of base peaks is a 435 page 1ist. A representative page of this listing is reproduced in Appendix II, Section $B$. The sequence started at $m / e=1$ and extended through $m / e=700$, although no spectra were found with base peaks greater than $m / e=450$.

A similar listing of all "significant" peaks would be excessively long, 1437 pages would be required. A listing of the number of spectra as a function of mass is given in Table 1 . Since the program can be executed for any given mass or range of masses there is little convenience in having the complete listing. That portion of the listing required can be generated as needed. An example of the listing is given in Section $C$, Appendix II through $\mathrm{m} / \mathrm{e}=20$.

## Addition of Molecular Weight to Data Base

A program has been written in ASSEMBLER language to permit manual entry of molecular weights of compounds as a part of the basic data in the mass spectral library. A listing of this program is given in Section C, Appendix $I$.

Since no programs have been written to make use of this type data, the laborious task of executing the program has not been undertaken except for a few test entries to assure the program is functional. Future programs are contemplated to allow library search by molecular weight and by peak intensities combined with molecular weight data.

The library data file is a compact one leaving little room for additions of data without expanding the file size. This can only be done at the expense of considerable programming effort. To avoid this effort, the last two alphameric characters of the compound identification were sacrificed to make room for the new data. This is, for the most part,

LISTING OF THE NUMBER OF SPECTRA CONTAINING SIGNIFICANT PEAKS OF A GIVEN MASS

| Mris ${ }^{\text {a }}$ | *SPEC | Mass | \#SPEC | MASS | \%SPEC | MAss | FSPEC | MASS | ASPEC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0 | 34 | 8 | 67 | 603 | 100 | 44 | 133 | 167 |
| 2 | $\bigcirc$ | 35 | 17 | 68 | 264 | 101 | 141 | 134 | 106 |
| 3 | 0 | 36 | 32 | 69 | 913 | 102 | 44 | 135 | 150 |
| 4 | 0 | 37 | 8 | 70 | 440 | 103 | 165 | 136 | 138 |
| 5 | 0 | 38 | 44 | 71 | 657 | 104 | 138 | 137 | 76 |
| 6 | 0 | 39 | 1014 | 72 | 104 | 105 | 412 | 138 | 74 |
| 7 | 0 | 40 | 80 | 73 | 278 | 106 | 117 | 139 | 78 |
| 8 | 0 | 41 | 2363 | 74 | 157 | 107 | 275 | 140 | 48 |
| 9 | 0 | 42 | 529 | 75 | 216 | 108 | 147 | 141 | 129 |
| 10 | 0 | 43 | 2087 | 76 | 83 | 109 | 189 | 142 | 61 |
| 11 | 0 | 44 | 268 | 77 | 46 c | 110 | 95 | 143 | 88 |
| 12 | 1 | 45 | 548 | 78 | 93 | 111 | 192 | 144 | 44 |
| 13 | 1 | 46 | 68 | 79 | 320 | 112 | 99 | 145 | 108 |
| 14 | 10 | 47 | 166 | 80 | 97 | 113 | 71 | 146 | 66 |
| 15 | 158 | 48 | 34 | 81 | 511 | 114 | 34 | 147 | 133 |
| 16 | 16 | 49 | 52 | 82 | 353 | 115 | 171 | 148 | 63 |
| 17 | 15 | 50 | 76 | 83 | 545 | 116 | 51 | 149 | 104 |
| 18 | 114 | 51 | 212 | 84 | 252 | 117 | 186 | 156 | 80 |
| 19 | 3 | 52 | 48 | 85 | 492 | 118 | 106 | 151 | 44 |
| 20 | 1 | 53 | 199 | 86 | 75 | 119 | 243 | 152 | 62 |
| 21 | 0 | 54 | 170 | 87 | 22a | 120 | 128 | 153 | 49 |
| 22 | 0 | 55 | 1483 | 88 | 74 | 121 | 278 | 154 | 34 |
| 23 | 0 | 56 | 616 | 89 | 97 | 122 | 111 | 155 | 75 |
| 24 | 1 | 57 | 1179 | 90 | 54 | 123 | 97 | 156 | 46 |
| 25 | 3 | 58 | 443 | 91 | 565 | 124 | 56 | 157 | 45 |
| 26 | 75 | 59 | 293 | 92 | 154 | 125 | 82 | 158 | 51 |
| 27 | 1324 | 60 | 130 | 93 | 310 | 126 | 45 | 159 | 77 |
| 28 | 460 | 61 | 155 | 94 | 133 | 127 | 74 | 160 | 42 |
| 29 | 1333 | 62 | 64 | 95 | 362 | 128 | 89 | 161 | 68 |
| 30 | 148 | 63 | 121 | 96 | 195 | 129 | 121 | 162 | 75 |
| 31 | 3086 | 64 | 58 | 97 | 365 | 130 | 82 | 163 | 47 |
| 32 | 37 | 65 | 121 | 98 | 176 | 131 | 143 | 164 | 54 |
| 33 | 27 | 66 | 55 | 99 | 97 | 1.32 | 99 | 165 | 63 |

TABLE 1 CONT.'D

| Mfiss | *SPEC | MAss | *SPEC | MASS | *SPEC | Mass | \%SPEC | MASS | \#SPEC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 166 | 47 | 199 | 24 | 232 | 17 | 265 | 12 | 298 | 7 |
| 167 | 67 | 200 | 36 | 233 | 11 | 266 | 12 | 299 | 18 |
| 168 | 58 | 201 | е2 | e34 | 20 | 267 | 23 | 300 | 5 |
| 169 | 63 | 202 | 32 | 235 | 20 | 268 | 19 | 301 | 3 |
| 176 | 54 | 203 | 28 | 236 | 13 | 269 | 7 | 302 | 2 |
| 171 | 36 | 204 | 43 | 237 | 10 | 270 | 10 | 303 | 3 |
| 172 | 36 | 205 | 22 | 238 | 30 | 271 | 9 | 304 | 4 |
| 173 | 53 | 206 | 17 | 239 | 28 | a72 | 12 | 305 | 2 |
| 174 | 34 | 207 | 28 | 240 | 23 | 273 | 3 | 306 | 3 |
| 175 | 45 | 208 | 35 | 241 | 20 | 274 | 1 | 307 | 2 |
| 176 | 28 | 209 | 18 | 242 | 33 | 275 | 6 | 308 | 5 |
| 177 | 36 | 210 | 30 | 243 | 12 | 276 | 0 | 309 | 2 |
| 178 | 32 | 211 | E7 | 244 | 10 | 277 | 3 | 310 | 8 |
| 179 | 29 | 212 | 23 | 245 | 10 | 278 | 5 | 311 | 6 |
| 186 | 43 | 213 | 24 | 246 | 23 | 279 | 3 | 312 | 8 |
| 181 | 31 | 214 | 28 | 247 | 18. | 280 | 9 | 313 | 5 |
| 182 | 26 | 215 | 23 | 248 | 13 | 281 | 10 | 314. | 13 |
| 183 | 35 | 216 | 27 | 249 | 10 | 282 | 13 | 315 | 4 |
| 184 | 56 | 217 | 19 | 250 | 12 | 283 | 15 | 316 | 3 |
| 185 | 27 | 218 | 41 | 251 | 9 | 284 | 20 | 317 | 5 |
| 186 | 34 | 219 | 11 | 258 | 14 | 285 | 25 | 318 | 3 |
| 187 | 23 | 220 | 17 | 253 | 6 | 286 | 13 | 319 | 4 |
| 188 | 46 | 221 | 23 | 254 | 10 | 287 | 3 | 320 | 2 |
| 189 | 37 | 2e2 | 25 | 255 | 16 | 288 | 4 | 3 L 1 | 0 |
| 190 | 31 | 223 | 36 | 256 | 19 | 289 | 0 | 322 | 1 |
| 191 | 51 | 224 | 16 | 257 | 17 | 290 | 7 | 323 | E |
| 192 | 19 | 225 | 11 | 258 | 15 | 291 | 2 | 324 | 3 |
| 193 | 31 | 226 | 12 | 259 | 3 | 292 | 0 | 325 | 4 |
| 194 | 18 | 2e? | 9 | 260 | 6 | 293 | 1 | 326 | 9 |
| 195 | 32 | 228 | 25 | 281 | 4 | 294 | 1 | 327 | 9 |
| 196 | 21 | 229 | 22 | 262 | 17 | 295 | 7 | 328 | 2 |
| 197 | 31 | 230 | 14 | 26.3 | 7 | 296 | 10 | 329 | 1 |
| 198 | 34 | 231 | 19 | 264 | 14 | 297 | 2 | 330 | 5 |

TABLE 1 CONT.'D

| 14H5S | \#SPEC | MASS | \#SPEC | MASS | \#SPEC | MASS | \#SPEC | MASS | \#SPEC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 331 | 1 | 364 | 己 | 397 | 己 | 430 | 1 | 463 | 0 |
| $332$ | 5 | 365 | 2 | 398 | 0 | 431 | 0 | 464 | 0 |
| 333 | 2 | 366 | 2 | 399 | E | 432 | 0 | 465 | 0 |
| 334 | 4 | 367 | 0 | 400 | 3 | 433 | 0 | 466 | 0 |
| 335 | 2 | 368 | 5 | 401 | 0 | 434 | 0 | 467 | 0 |
| 336 | 0 | 369 | 4 | 402 | 0 | 435 | 0 | 468 | 0 |
| 337 | 1 | 370 | 2 | 403 | 0 | 436 | 0 | 469 | 0 |
| 338 | 5 | 371 | 6 | 404 | 0 | 437 | 1 | 470 | 6 |
| 339 | $\boldsymbol{L}$ | 972 | 7 | 405 | 0 | 438 | 0 | 471 | 0 |
| 340 | 4 | 373 | e | 406 | 1 | 439 | 0 | 472 | 0 |
| 341 | 5 | 374 | 0 | 407 | 0 | 440 | 0 | 473 | 8 |
| 342 | 9 | 375 | 0 | 408 | 1 | 441 | 0 | 474 | 0 |
| 343 | 8 | 376 | 2 | 409 | 4 | 442 | E | 475 | 0 |
| 344 | 8 | 377 | 0 | 410 | 4 | 443 | 0 | 476 | 0 |
| 345 | 2 | 378 | 0 | 411 | 1 | 444 | 1 | 477 | 0 |
| 346 | 5 | 379 | 0 | 412 | 1 | 445 | E | 478 | 1 |
| 347 | 1 | 380 | 1 | 413 | 0 | 446 | 0 | 479 | 0 |
| 348 | 4 | 381 | 0 | 414 | 1 | 447 | 1 | 480 | 0 |
| 349 | 1 | 382 | 5 | 415 | 0 | 448 | 0 | 481 | 0 |
| 350 | 2 | 383 | 5 | 416 | 0 | 449 | 0 | 48 c | 0 |
| 351 | 2 | 384 | 2 | 417 | 0 | 450 | 1 | 483 | 1 |
| 352 | 1 | 385 | 2 | 418 | 0 | 451 | 0 | 484 | 1 |
| 353 | 6 | 386 | 3 | 419 | 0 | 452 | 0 | 485 | 1 |
| 354 | 9 | 387 | 1 | 420 | 1 | 453 | 0 | 486 | 1 |
| 355 | 5 | 388 | 0 | 421 | 0 | 454 | 0 | 487 | 1 |
| 356 | 5 | 389 | 0 | 42 L | 0 | 455 | 0 | 488 | 0 |
| 357 | 4 | 390 | 0 | 423 | 0 | 456 | 0 | 489 | 0 |
| 358 | 10 | 391 | 0 | 424 | E | 457 | 0 | 490 | 0 |
| 359 | 0 | 392 | 0 | 425 | 3 | 458 | 0 | 491 | 0 |
| 360 | 3 | 393 | 0 | 426 | 0 | 459 | 0 | 492 | 0 |
| 361 | 1 | 394 | 3 | 427 | 2 | 460 | 0 | 493 | 6 |
| 362 | 0 | 395 | 1 | 428 | 1 | 461 | 0 | 494 | 0 |
| 363 | 0 | 396 | B | 429 | 1 | 4E2 | 0 | 495 | 0 |

of little consequence since in most instances the last two characters are blank spaces anyway. An example of the computer-user "dialogue" is given in Figure 1.

## LITERATURE CITED

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```
            1 BLR-6001 2501 MEPERIDINE
GIVE MOL.WT. (0-STOP)1000
    | 1000 OKP) 1
            Z BLR-0002 2501 NOR-MEPERIDINE
GIUE MOL.IJT. (0=STOP)1001
    (1001 OKP) 1
            3 BLR-0003 25O1 MEPERIDINIC ACID METHYL ESTER
GIUE MOL.WT. (0-STOP)1002
    (1002 OKP)0
            4 ELR-0004 250己 NOR-MEPERIDINIC ACID TMS ESTER
GIUE MOL.WT.(0mSTOP)9OGS
    (9999 OK') 1
            5 BLR-0005 2502 MEPERIDINIC ACID TMS ESTER
GIVE MOL.WT.(0wSTOP)O
    (0 OKr) 1
    THTS PROGRAM ALLOLS ENTRY OF THE MOLECULAR WEIGHT IN CPD <IDS
GIIJE THE STARTING SPECTRUM NO.
    , 9999 FOR PROGRAM HALLT.
9999
M
```

Figure 1. Example of Entry of Molecular Weight Data into the Mass Spectral Library.
1

## APPENDIX I

PROGRAM LISTINGS
A. A Fortran Program For: Sequential Listing of Entries in the Mass Spectral Library.
B. An Assembler Program For: Listing of Entries in the Mass Spectral Library According to Base Peaks or Significant Peaks.
C. An Assembler Program for: Addition of Compound Molecular Weight to the Mass Spectral Library Data Base.

APPENDIX I

A

A FORTRAN PROGRAM FOR:
SEQUENTIAL LISTING OF ENTRIES IN THE MASS SPECTRAL LIBRARY

FTH14, L
C
PROGRAM LIBRL
c
\% THIS PROGRAM GALLS A SUBROUTINE TO LIST THE
c
"ID" PORTION OF THE MASS SPECTRAL LIBRARY
IF NO LIST IS DESIRED IT WILL COLNTT THE ENTRIES
URITE (6,100)
READ (1.110) J
CALL IDLST(J)
STOP 1
100 FORMAT(1H1, "LIST ID'S 7 " 1 " 1 - YES"/" 0 = NO")
110 FORMAT(I1)
END
** NO ERRORS*

WITH J = 1 GIUES ENTIRE LIST OF MASS SPECTRAL LIBRARY ID'S WITH J < OR 21 GIUES ONLY THE NUMBER OF SPECTRA

SUBROUTINE IDLST( $(\checkmark)$
DIMEMSION IOBUF(128), ITREUF(4096), IBLFFR(128), IERPT(6). 1 LIBR(3). NOTRB(2). ITMP(32)

DATA LIBR/2HLI, $2 H B R, 2 H 1 \%$ NOTRB $/ 1,1 \%$ IERPT/1,2,3,4,5,6\% DEFINE TABLES, BLFFERS, ETC.

CALL EXEC (24, 1, IOBUF, 128, ITRBUF, NOTRB, 32, IER)
LCNT $=0$ ten
MAXLDD $\mathrm{MO}_{\mathrm{C}}$

OPEN THE FILE <LIBR〉
CALL EXEC(24,4, LIBR,111, 1,0,1,IER)
IF (IER.NE, (0) WRITE(6,100) IER, IERPT(2)

```
IF ID LIST, WRITE HEADER
```

CLEAR THE PAGE
IF(J.EG.1) CALL EXEC (2,65,6924, - 2 )
IF(J.EQ.1) LCNT = 4
IF(J.EG.1) $\operatorname{WRITE}(6,110)$

IFL $=0$
IPT $=1$
ICNT $=0$
TRANSFER THE FIRST RECORD (SECTOR) TO BLFFER
CALL EXEC(24,6,LIBR,0,IBUFFR, IER) IF (IER .NE, 0) WRITE (6,100) IER. IERPT(3)

NUJDS = THE NUMBER OF WORDS IN THIS SPECTRLM

IF THERE ARE NO MORE SPECTRA NWDS = 0
ICNT = ICNT + 1
$\operatorname{IF}(J, E G .1)$ WRITE(6,120) ICNT, (IBUFFR(I),I=2,33)
IF(J.EQ.1) LCNT $=$ LCNT +1
INITIATE HARDCOPY AFTER 35 LINES
IF (LCNT.GT.33) IPAGE - IPAGE +1

IF(LCNT .GT. 33) WRITE(6,121) IPAGE
121 FORMAT (1H 。/ G0X,"PAGE ", I3)
IF (LCNT.GT. 33 ) GALL EXEC ( $2,65,6935,-\mathrm{Z})$

IF (LCNT .GT. 33) LCNT $=0$
clear the page
IF(LCNT.EG.e.AND.J.EQ.1) CALL EXEC(2,65,6924,-Z)
IPT = IPT + IBUFFR(1)
80 IF (IPT . LE. 128) GO TO 10
IPT - IPT - 128
IF (IFL.EG.1) GO TO 10
CALL EXEC(24, 5, LIBR, 0, IBLJFFR, IER)
IF(IER .NE. ©) WRITE(6,100) IER, IERPT (4)
GO TO 80
10 NWDS = IBLFFFR(IPT)
IF (NHDS .GE. MAXWD) MAXWD = NWDS
IFL = 0
IF (MWDS .EG. 0) GO TO 30
INCREMENTT THE COUNTER FOR THIS SPECTRLM

THE ID PORTION CAN BE EITHERः ALL IN THIS SECTOR; PART IN THIS SECTOR \& PART IN THE NEXT: OR, AT THE START OF THE NEXT SECTOR.

WLIB IS THE NUMEER OF WORDS LEFT IN THE BLFFER
WLIB = 129 - IPT
IT IS ALL IN THIS SECTOR IF WLIB > = 33

IF(WLIB .LT. 3e) GO TO 70
DO 60 I - 1. 32
$60 \operatorname{ITMP}(I)=I B 1 f F R(I P T+I)$
GO TO 20

```
#己 CALL EXEC (24,6,LIBR,0,IBLFFR,IER)
    IF (IER.NE.0)LWRITE(6.100) IER
    DO 23 I = 1, 32
23 ITMP(I) - IELFFFR(I)
    IFL = 1
    GO TO20
IT IS PART IN THIS SECTOR AND PART IN THE NEXT
70 IDIFF = 128 - IPT
IF (IDIFF .EQ. 日) GO TO Ze DO 90 I =1, IDIFF
\(90 \operatorname{ITMP}(I)=I B L F F R(I P T+I)\)
CALL EXEC(24,6,LIBR,0, IBUFFR, IER)
IF (IER .NE, 0) WRITE(6,100) IER, IERPT(5)
IPT = IPT - 128
NREST - 32 - IDIFF
DO 15 I = 1. NREST
```

$c$

15 ITMP(IDIFF+I) - IBUFFR(I)
20 ICNT = ICNT +1 IPT = IPT + NWDS IF (J.EQ. 1) WRITE(6.120) ICNT, (ITMP (I), I=1,3E) IF (J .EG. 1) LCNT = LCNT +1
IF (LCNT. GT. 31 ) IPAGE $=$ IPAGE +1
IF (LCNT. GT, 31) URITE(6,121) IPAGE
IF (LCNT .GT. 31) CALL EXEC(2,65,6935,-Z )
IF (LCNT .GT. 31) LCNT =0
IF(LCNT.EG.O.AND.J.EO. 1) CALL EXEC(2,65,6924,-2)

```
    GO TO }8
        30 WRITE(6,130) ICNT
        WRITE(6,131) MAXWID
        CALL EXEC (2,65,6935,-2)
C
C ClOSE THE FILE TO MAKE BlFFERS AUAILABLE
    CALL EXEC(24,5,LIBR,0,IER)
    IF(IER .NE. Q) WRITE(6,100) IER . IERPT(6)
C
RETURN
    100 FORMAT(1H " EFMP ERROR NO. "I3, "AT LOC. NO. "I3N)
    110 FORMAT(1H ,17X,"GG/MS MASS SPECTRAL LIBRARY LISTING"//)
    120 FORMAT(1H . I5. 2X, 32AE)
    130 FORMAT(1HI, // * THE TOTAL NLMBER OF SPECTRA IS *,IE//)
C
    131 FORMAT(1H " THE MAXIMLUM SPECTRUM SIZE IS ",IG," WORDS"/)
        END
** NO ERRORS*
```

APPENDIX I
B
AN ASSEMBLER PROGRAM FOR:
LISTING OF ENTRIES IN THE MASS SPECTRAL LIBRARY ACCORDING TO BASE PEAKS OR SIGNIFICANT PEAKS

0001 0002 0003 0004 0005 0006 0007 0008 0009 0010 0011 0012 0013 0014 0015 0016 START NOP
0017 A EOU O 0018 B EOU 1 NXBAS JSE 0020 0021 002e 0023 0024 0025 0026 0027 0028 0029 0030 0031

```
ASMB,L,F,C
*
* THIS PROGRAM SEARCHES THE SPECTRAL LIBRARY FOR
* SPECTRA LHHICH HAUE A GIUEN BASE-PEAKK
*
NAM BASEN
    EXT EXEC
    EXT .DIO.
    EXT .IOI.
    ENT BASGN
*
*
BASGN DEF START
*
*
NXBAS JSE WTTY URITE AN INPUT MESSAGE
    DEF STMSG MASS MLMMBER AS SEARCH PARAMETER
    CLA
    STA INDXE CLEAR THE SEQUENTIAL SEARCH INDEX
    ISE RDTTY READ A MLMBER FROM THE TTY
    JSE IPTER ERROR ON INPUT
    CPA SIGNO SEARCH FOR SIGNF. PKS ?
    JSB SIGST YES - SIGNIFICANT (\E5%)
    SZA,RES
    ISE WTTY 
    CPA EXTHYO EXIT FROPM PROGRAM P
    JMP ESTOP YES - USE ERROR EXIT
    MASOK STA MMASNO
```



0067 0068 0069 0076
0071
0072
0073
0074
0075
0076
0077
0078
0079
0080
0081
0082
0083
0084
0085
0086
0087
0088
0089
0090
0091
0092
0093
0094
0095
0096
0097
0098
0099
0100
0101

```
    DEF ENDMS END OF OUTPLST LIST
    LDA MASNO ONLY ITEM IN THE LIST
    JSB .IOI.
ENDMS NOP
    JSB WTTY WRITE A HEADING
    INCREMENT FOUR LINES IN COUNTER
    LDA FOUR INCREMENT FOUR LINES IN COUNTER
    STA LNCNT
    CLA
    STA SPCNT CLEAR THE SPECTTRLM COUNTER
*
    JSB EXEC READ THE FIRST SECTOR
    DEF RETNG
    DEF RCODE
    DEF EFMPG
    DEF FNAME
    DEF RCDNO
    DEF BUFFR
    DEF ERRNO
*
RETNYS JSB ERMOH
NXSPC LDA IPT
    ADA M1
    ADA BUFFA GET THE BLFFFER ADDRESS AND SUM
    STA BLFAD STORE THE POINTER ADDRESS
    LDA BLFAD,I GET THE NUMBER OF WORDS IN THIS SPECTRLM
    STA NHIDS STORE IT
    SZA,RSS IF IT'S ZERO, THAT'S ALL
    JMP ENDDD QUIT
    ADA IPT IF NON-ZERO, THERE'S MORE
    STA NEXPT THIS IS THE REL. ADDR. OF NEXT SPECTRUM
    LDA ARRAD GET THE ADDRESS OF ARRAY
    STA INDXA SAUE FOR INCREMENT IN TXFER
    LDA NWDSS GET THE NO. OF WORDS IN THIS SPECTRUM
    CMA, INA MAKE IT NEGATIUE
GET THE LOCATION OF THE POINTER
```

0102 0103 0104 0105 0106 0107 0108 0109 0110
0111
0112
0113
0114
0115
0116
0117
0118
0119
0120
0121
012 E 0123 0124 0125
0126
$012 ?$
0128
0129 0130 0131 0132
0133
0134
0135 0136

STA TXUADS SAVE IT FOR COLMT
LDA IPT GET THE STARTING POINT IN BUFFER
JSE TXFER－TRANSFER WORDS FROM EUFFR TO ARRAY LDA TXWDS CHECK TO SEE IF TRANSFER COMPLETE
SSA，RSS
JMP INARR ALL TRANSFERRED
JSB EXEC
DEF RETN4
DEF RCODE
DEF EFMPG
dEF FMAME
DEF RCDMO
DEF BLFFR
DEF ERRNO
RETNA JSB ERMON LDA NEXPT ADA M128 STA NEXPT
CLAA，INA
JSB TXFER TRANSFER FROM SIPT〉 TO 〈NEXPT〉
＊
＊
＊
＊
INARR LDA NEXPT SET LP FO NEXT SPECTRUM
STA IPT
＊
＊
AS OF $2 / 13 / 77$ THE LARGEST SPECTRUM HAD ONLY 127 LORDS THEREFORE THIS RETLIRN HAS TO BE WITH TXWDS－ 0

```
```

            STA IPT
    ```
```

```
```

            STA IPT
    ```
```

THIS IS THE STARTING POINT FOR THE SEARCH OF THIS SPECTRUM．THE SPECTRUM HAS BEEN TRAMSFERRED FROM＜BLFFRS INTO＜ARRAY〉．

ISZ SPCNT INCREMENT THE SPECTRUM COUNTER． CLB
FROM＜BUFR INTO＜ARRAY．

0137
0138
0139
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015 e
0153
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0166
$016 ?$
0168
0169
0171

```
    STB HITFL CLEAR INTENSITY OF <MASNO>
    STB MAX CLEAR \MAX>
    STB NOMES CLEAR COUNTER OF >ES PEAKS
    LDA C34
    ADA ARRAD CALCLLLATE THE ADDRESS OF >25 PEAKS
    STA IDXES SAUE FOR USE IN CASE OF HIT
    STA INDEX FOR INCREMENT
MORES LDA INDEX, I GET THE FIRST PEAK
    SSA IS THIS ALL
    JMP NOMOR YES
    CPA MASNO NO - IS THIS ONE OF INTEREST ?
    CMB YES - SET "B" TO -1 AS A FLAG
    CPB SIGFL SIGNIFICANT PEAK SEARCH ?
    STB SGNFL
    ISZ INDEX IMCREMENT THE INDEX
    ISZ NOME5 INCREMENT THE COUNTER
    JMF MORDS GO BACK FOR MORE
NOMOR SSB,RSS WAS <MMASNO\ ONE OF THE >25 ?
    JMP NXSPC NO - SKIP THIS ONE
    LDA NOMES YES - PREPARE TO CHECK FOR BASE PEAK
    CMA, IMA GET NEG. OF THE NO. OF >2S PEAKS
    STA NGESS SAVE FOR COLNT DOLN
    STA NEGE5
    STA REP25
    ISZ INDEX POINT TO 15T OF MASS-INTENSITY PAIRS
NXTPR LDA IDXES ADDRESS OF >2S PEAKS
    STA INDES SAUE FOR INCREMENT
    LDA INDEX, I GET THE FIRST PAIR
    SSA CHECKED ALL PAIRS P
    JMP ENDSP YES - CLEAN UP THIS SPECTRLM
    AND HIMSK GET RID OF THE LOLd }6\mathrm{ BITS
    CLB CLEAR "B" FOR ROTATE
    LSR 6
COMPR CPA INDE5,I
    JMP POHIT
\begin{tabular}{|c|c|c|c|}
\hline & STB & HITFL & CLEAR INTENSITY OF <MASNO> \\
\hline & STB & MAX & CLEAR (MAX) \\
\hline & STB & NOM25 & CLEAR COUNTER OF 7 IS PEAKS \\
\hline & LDA & C34 & \\
\hline & ADA & ARRAD & CALCULATE THE ADDRESS OF >2S PEAKS \\
\hline & STA & IDXE5 & SAUE FOR USE IN CASE OF HIT \\
\hline & STA & INDEX & FOR INCREMENT \\
\hline MORES & LDA & INDEX, I & GET THE FIRST PEAK \\
\hline & S5A & & IS THIS ALL \\
\hline & JMP & NOMOR & YES \\
\hline & CPA & MASNO & NO - IS THIS ONE OF INTEREST ? \\
\hline & CMB & & YES - SET "B' TO - 1 AS A FLAG \\
\hline & CPB & SIGFL & SIGNIFICANT PEAK SEARCH ? \\
\hline & STB & SGNFL & \\
\hline & ISZ & INDEX & INCREMENT THE INDEX \\
\hline & 152 & NOM25 & INCREMENT THE COUNTER \\
\hline & JMF & MOR25 & GO BACK FOR MORE \\
\hline NOMOR & SSB. & RSS & WAS SMASNO ONE OF THE >25 ? \\
\hline & JMP & NXSPC & NO - SKIP THIS ONE \\
\hline & LDA & NOMES & YES - PREPARE TO CHECK FOR BASE PEAK \\
\hline & CMA. & INYA & GET NEG. OF THE NO. OF 325 PEAKS \\
\hline & STA & NGESS & SAVE FOR COLUNT DOUN \\
\hline & STA & NEGE5 & \\
\hline & STA & REP25 & \\
\hline & ISZ & INDEX & POINT TO 15T OF MASS-INTENSITY PAIRS \\
\hline NXTPR & L.DA & ID×25 & ADDRESS OF >25 PEAKS \\
\hline & STA & INDES & SAUE FOR INCREMENT \\
\hline & LDA & INDEX, I & GET THE FIRST PAIR \\
\hline & SSA & & CHECKED ALL PAIRS ? \\
\hline & JMP & ENDSP & YES - CLEAN UP THIS SPECTRUM \\
\hline & AND & HIMSK & GET RID OF THE LOU 6 BITS \\
\hline & CLB & & CLEAR "B" FOR ROTATE \\
\hline & LSR & 6 & SHIFT RIGHT G BITS (MASS \# OK) \\
\hline COMPR & CPA & IND25, I & IS THIS ONE OF THE \(>25\) 'S ? \\
\hline & JMP & POHIT & YES - CHECK FOR MAX \\
\hline
\end{tabular}
```

0172 0173 0174 0175 0176 0177 0178
0179
0180
0181
0182
0183
0184
0185
0185
0187
0188
0189
0190
0191 0192 0193 0194 0195 0196 0197
0198
0199 0200 0201 0202 0203 0204 0205 0206

|  | ISZ | INDES | NOT YET |
| :---: | :---: | :---: | :---: |
|  | ISZ | NEGES | CHECKED ALL 325'S P |
|  | JMP | COMPR | NOT YET |
|  | ISZ | INDEX | -INCREMENT THE INDEX TO |
| NXXPR1 | LDA | REP25 | RESTORE THE NO. OF 325 PEAKS |
|  | STA | MEG25 | FOR NEXT PAIR SCAN |
|  | JMP | NXTPR | CHECK THE NEXT PAIR |
| POHIT | CLB |  | CLEAR "B" FOR FLAG |
|  | CPA | MASNO | IS THIS THE ONE WE WANT ? |
|  | CMB |  | YES = SET FLAG (B) TO -1 |
|  | LDA | INDEX, I | NO - GET THE PEAK AGAIN |
|  | ISZ | INDEX | GET READY FOR NEXT PAIR |
|  | AND | LOMSK | GET RID OF HIGH BITS |
|  | STA | TEMP |  |
|  | CMA. | INA | GET NEG. UALLUE OF INTENSITY |
|  | ADA | MAX | PREUIOLS MAXIMLMM UALUE |
|  | SSA | RSS | NEW MAX ? |
|  | JMP | CNTNU | NOT YET |
|  | LDA | TEMP | LARGEST YET |
|  | STA | MaX | UPDATE MAX |
| CNTNU | SSB |  | WAS IT <MASMOS ? |
|  | STA | HITFL | YES - SAUE IT FOR FUTURE COMP. |
|  | CLB |  |  |
|  | ISZ | NG25S | FOUND ALL $>$ Es's |
|  | JMP | NXPR1 |  |
| ENDSP | LDA | HITFL. | YES - GET \MASNO〉 INTENSITY |
|  | CPA | MAX | WAS IT THE MAXIMLM VALUE $P$ |
|  | JMP | PRTIT | YES - PRINT THIS ID |
|  | LDB | SGNFL |  |
|  | SZB |  | SIGNIF. PEAK P |
|  | RSS |  |  |
|  | JMP | NXSPC | NO - SKIP THIS ENTRY |
|  | LDA | BLANK | GET A BLANK |
|  | STA | OLITPT+2 | PUT IT IN THE LITE FOR SIGNF. PK. |
| PRTIT | LDA | M3a |  |

0207
0208
0209
6210
0211
0212
0213
0214
0215
0216
0217
0218
0219
0220
oe21
02e2
02 O
0224
0225
o2eg
02e7
0228
0229
0230
0231
0 032
0233
0234
0235
0236
0237
0238
0239
0240
Qe41

STA INDXP
LDA ARRAD STA INDEX
ISZ INDEX
LDA OUTAD
STA IDOUT
IS2 IDOUT
ISZ IDOUT
ISZ IDOLT
MORID LDA INDEX. I
STA IDOUT. I LOAD ID INTO COUTPLIT
ISZ INDEX
ISZ IDOUT
ISZ INDXE
JMP MORID
CLA
CLE
JSB .DIO.
DEF OUTPT
DEF FORMT
DEF ELIST
LDA SPCNT
JSB .IOI.
ELIST
OP
JSB WTTY LIRITE THE OUTPUT
DEF OUTPT
LDA ASTER
STA OLTPT+Z
CLA

LDA M33
ADA LNCNT
SZA
JMP NXSPC

GET THE ARRAY ADDRESS
POINT TO 1 ST WORD OF ID GET THE OUTPUT BUFFER ADDRESS

SKIP 3 HORDS FOR SPECTRLM
LOC. 1 ST WORD OF ID ON OUTPUT

ALL TRAMSFERED ${ }^{9}$
NO - DO MORE
YES - SET UP FOR INTERNAL CONU.

STA SGMFL ZERO OUT THE SIG PK FLAG
ISZ LNCNT INCREMENT THE LINE COUNTER
GET AN ASTERISK
RESTORE THE OUTPUT LINE

33 LINES WRITTEN ?
MO - DO IT SOME MORE !

| 0242 | FNLOP | JSB | WTTY | YES - TURN ON HARDCOPY LNIT |
| :---: | :---: | :---: | :---: | :---: |
| 0243 |  | DEF | HDCPY |  |
| 0244 | MOL.ST | JSB | UTTY | CLEAR THE SCREEN |
| 0245 |  | DEF | CLRSC |  |
| 0246 |  | LDA | HDNOS | GET THE ASCII MASS MO. |
| 0247 |  | STA | TPAGE+28 |  |
| 0248 |  | LDA | HDNOS+1 |  |
| 0249 |  | STA | TPAGE+CS |  |
| 0250 |  | JSB | WTTY |  |
| 0251 |  | DEF | TPAGE | WRITE THE MASS NO. AT THE TOP OF Page |
| 925e |  | CLA. | INA |  |
| 0253 |  | INA |  |  |
| 0254 |  | STA | LNCNT | CLEAR THE LINE COUNTER |
| 0255 |  | LDB | FINAL | AT END OF LIERARY |
| 0256 |  | S2B | RSS |  |
| 0257 |  | JMP | NXSPC | GO DO SOME MORE |
| 0258 |  | ISZ | MASNO | INCREMENT THE MASS FOR SECLIONTIAL SEARCH |
| 0259 |  | LDA | ECODE | AT UPPER LIMIT OF SEARCH MASS 7 |
| 0260 |  | CPA | masno |  |
| 0261 |  | JMP | NXBAS | YES - START AGAIN <NO WAY TO END THIS PROG ! |
| 0262 |  | LDA | IMDXE | GET THE SEQUEMTIAL FLAG |
| 0263 |  | SSA, | RSS | IS THIS SEQLENTIAL 3 |
| 0264 |  | JMP | NXBAS | NO - go BAck to start |
| 0265 |  | LDA | MASNO | GET THE MASS |
| 0266 |  | JMP | MASOK | YES - GO BACK FOR SEQLEMTIAL |
| 0267 | EADDD | CLB, | INB |  |
| 0268 |  | STB | FINAL |  |
| 0269 |  | LDA | FOUR |  |
| 0270 |  | CPA | LINCNT | COMPARE WITH LINE COUNTER - IF 4 |
| 0271 |  | JMP | NOLST | THEN NO HARDCOPY |
| 0こ72 |  | JMP | FNLOP | PRINT THE LAST PAGE |
| 0273 | * |  |  |  |
| 0274 | * |  |  |  |
| 0275 | * |  |  |  |
| 0276 | TXFER | NOP |  |  |



0452 0453 0454 0455 0456 0457 0458 6459 0460 0461
0462
0463
0464 0465 0466 0467 0468
0469 0470 0471 0472 0473 0474 0475 0476 0477 0478 0479 0480 0481 0482

```
    DEF EFMPG
```

    DEF EFMPG
    NOP
    NOP
    * 
* 

ERROP OCT 0
ERROP OCT 0
ASC 8, PROGRAM HALT
ASC 8, PROGRAM HALT
OCT 8
OCT 8
FRMT ASC 2.(I2)
FRMT ASC 2.(I2)
*
*
*
*

* WORK AREA FOR PROGRAM
* WORK AREA FOR PROGRAM
* 
* 

STMSG OCT 15437
STMSG OCT 15437
OCT 15414
OCT 15414
OCT 6412
OCT 6412
OCT 641E
OCT 641E
ASC 13.THIS PROGRAM SEARCHES THE
ASC 13.THIS PROGRAM SEARCHES THE
ASC 12,MASS SPECTRAL LIBRARY BY
ASC 12,MASS SPECTRAL LIBRARY BY
ASC 5. BASE PEAK
ASC 5. BASE PEAK
OCT 6412
OCT 6412
OCT 6412
OCT 6412
ASC 1R,GIUE THE SEARCH MASS NO.
ASC 1R,GIUE THE SEARCH MASS NO.
OCT 6412
OCT 6412
ASC 18,0 ON ENTRY GIUES SEGLIENTIAL SEARCH
ASC 18,0 ON ENTRY GIUES SEGLIENTIAL SEARCH
OCT 6412
OCT 6412
ASC 22, 8888 MAKES A SIGNIFICANT PEAK (>25%) SEARCH
ASC 22, 8888 MAKES A SIGNIFICANT PEAK (>25%) SEARCH
OCT 6412
OCT 6412
ASC 12, }9999\mathrm{ GIUES PROGRAM HALT
ASC 12, }9999\mathrm{ GIUES PROGRAM HALT
OCT 6412
OCT 6412
OCT O
OCT O
TXWDS OCT O
TXWDS OCT O
FINAL OCT D FLAG AT END OF LIBRARY
FINAL OCT D FLAG AT END OF LIBRARY
MASNO OCT O SEARCH PARAMETER
MASNO OCT O SEARCH PARAMETER
RCODE OCT 30 EFMP TYFE EXEC CALLS
RCODE OCT 30 EFMP TYFE EXEC CALLS
EFMP1 OCT 1 DEFINE FILES
EFMP1 OCT 1 DEFINE FILES
OPNT\& BSS 128 OPENED FILES TABLE

```
OPNT& BSS 128 OPENED FILES TABLE
```

| 0487 | OPNSE | DEC 128 |  |
| :---: | :---: | :---: | :---: |
| 0488 | NOTRB | DEC 1 | NO. OF TEMP. RECD. BLIFFERS |
| 0489 |  | DEC 1 |  |
| 0490 | TRBSZ | DEC 10 |  |
| 6491 | TRBLF | BSS 1280 |  |
| 0492 | ERRMO | BSS 1 | LOC. FOR ERROR NUMBER |
| 0493 | EFMP4 | OCT 4 | OPEN FILES |
| 0494 | FNAME | ASC 3.LIER |  |
| 0495 | PAKNO | DEC 111 |  |
| 0436 | RCDNO | DEC 0 | SEQUENTIAL ACCESS |
| 0497 | SCODE | DEC 0 | SECURITY CODE |
| 0498 | * |  |  |
| 0499 | CLRSC | OCT 15437 | CLEAR THE SCREEN |
| 0500 |  | OCT 15414 |  |
| 0501 |  | DEC 0 |  |
| 0502 | * |  |  |
| 0503 | HEAD | OCT 6412 | CR / LF |
| 0504 |  | OCT 6412 | CR / LF |
| 8505 |  | ASC 12, THE | FOLLOLING SPECTRA HA |
| 0506 |  | ASC 12, VE A | PROMINANT PEAK AT |
| 0507 | HDNOS | ASC 3. |  |
| 0508 |  | ASC 9.r * | - BASE PEAK) |
| 0509 |  | OCT 6412 | CR / LF |
| 0510 |  | OCT G412 | EXTRA LINE SPACE |
| 0511 |  | OCT 0 |  |
| 0512 | FOUR | OCT 4 |  |
| 0513 | TPAGE | ASC 28, |  |
| 0514 |  | ASC 1. |  |
| 0515 |  | ASC 1. |  |
| 0516 |  | OCT 6412 |  |
| 0517 |  | OCT 0 |  |
| 0518 | BLANKK | OCT 20040 |  |
| 0519 | ASTER | OCT 25040 |  |
| 0520 | SGTFL | OCT 0 |  |
| 05 Cl | LNCNT | OCT 0 | LINE COUNTER FOR PRINT OUT |

```
0522 SPCNT OCT O
0523 EFMP6 OCT 6 READ A SECTOR
0524 BLFFR ESS 128
0525 IPT OCT 1
GSEG BLFFA DEF BUFFR
0527. BLFAD OCT 0
O528 NWDS OCT 0.
052G NEXPT OCT O
0530 EXTNO DEC 9999
0531 SIGNO DEC 8888
0532 M128 DEC -128
0533 INDEX OCT ©
0534 LOMSK OCT 7T
0535 HIMSK OCT 177700
0536 TEMP OCT O
0537 MAX OCT D
0538 HITFL OCT © 
0539 M32 DEC -32
0540 INDXE OCT O
0 5 4 1 ~ A R R A Y ~ B S S ~ 1 2 8 ~
0542 ARRAD DEF ARRAY
0543 IDOUST OCT O
0544 OUTPT ASC 3. *
0545 BSS 3己
0546 OCT 6412 RETLHN/LINE FEED
0547 OCT O
0548 OLTAD DEF OLTPT
0549 FORMT ASC 2,(I4)
0550 M33 DEC -33
0551 HDCPY OCT 154Z"?
0552 OCT E
0553 ECODE OCT 1442 UPPER LIMIT OF SEQU. SEARCH (702)
0554 M1 OCT -1
0 5 5 5 ~ I N D X S ~ O C T ~ 0 , ~
0556 INDXE OCT 0
```

```
0557 INDXA OCT O
0558 TEMP1 OCT 0
0559 TEMPE OCT O
0560 IDX25 0CT 0
0561 INDE5 OCT 0
0562 NOMES OCT 0
0563 NEG25 OCT 0
0564 NG25S OCT O
0565 REPES OCT 0
0566 C34 OCT 42
0568 *
0569 *
05?0 *
0571 *
0572 IPTER NOP
0576
0577
0578
0579
0580
0581
0582
0583
0584
0585
0586
0587
0588
0589
0 5 9 0
0591
```

```
0567 RUBO OCT 177 RUBPOU
```

0567 RUBO OCT 177 RUBPOU
0573 JSB WTTY URITE AN ERROR MESSAGE
0573 JSB WTTY URITE AN ERROR MESSAGE
0574 DEF IPMSG LOC, OF THE MESSAGE
0574 DEF IPMSG LOC, OF THE MESSAGE
0575 LDA IPTRRA, I GET THE RETURN ADDRESS
0575 LDA IPTRRA, I GET THE RETURN ADDRESS

```
*
```

* 
* 
* NOP
NOP
ADA M1
ADA M1
ADA M1
ADA M1
STA IPTER SET UP TO TRY AGAIN
STA IPTER SET UP TO TRY AGAIN
JMP IPTER,I
JMP IPTER,I
IPTRA DEF IPTER
IPTRA DEF IPTER
IPMSG OCT 6412 CR/LF
IPMSG OCT 6412 CR/LF
ASC 13,INPUT ERROR - TRY AGAIN
ASC 13,INPUT ERROR - TRY AGAIN
OCT -
OCT -
* 
* 
* 
* 

SIGST NOP ROUTINE TO INITIATE SIG. PK. SEARCH
SIGST NOP ROUTINE TO INITIATE SIG. PK. SEARCH
CCA LUSE -1 AS A FLAG
CCA LUSE -1 AS A FLAG
STA SIGFL
STA SIGFL
JSB WTTY
JSB WTTY
DEF SIGMS ASK FOR SEARCH MASS NO.

```
    DEF SIGMS ASK FOR SEARCH MASS NO.
```

```
    JSB RDTTV READ THE MASS NO
```

    JSB RDTTV READ THE MASS NO
    JSB IPTER
    JSB IPTER
    JMP SIGST,I RETURN
    JMP SIGST,I RETURN
    **
**
SIGMS ASC 1Z,gIUE THE.SEARCH MASS MO.
SIGMS ASC 1Z,gIUE THE.SEARCH MASS MO.
OCT G41E
OCT G41E
ASC 13,0 GIUES SEQUENTIAL SEARCH
ASC 13,0 GIUES SEQUENTIAL SEARCH
OCT G412
OCT G412
OCT O END OF MESSAGE
OCT O END OF MESSAGE
*
*
SIGFL OCT O
SIGFL OCT O
*
*
*
*
MSINC NOP
MSINC NOP
JSB WTTY WRITE MESSAGE FOR SEGU. MASS IMPUT
JSB WTTY WRITE MESSAGE FOR SEGU. MASS IMPUT
DEF SEOMS
DEF SEOMS
JSB RDTTY
JSB RDTTY
JSE IPTER
JSE IPTER
STR MASNO GET THE STARTING MASS NO.
STR MASNO GET THE STARTING MASS NO.
JSB WTTTY
JSB WTTTY
DEF NDMSO
DEF NDMSO
JSE RDTTY
JSE RDTTY
JSB IPTER
JSB IPTER
STA ECODE GET THE UPPER LIMIT MASS MO.
STA ECODE GET THE UPPER LIMIT MASS MO.
CLA SET UP FOR SEOU. SEARCH FLAG
CLA SET UP FOR SEOU. SEARCH FLAG
CMA
CMA
STA INDXE SEQLENTIAL SEARCH FLAG
STA INDXE SEQLENTIAL SEARCH FLAG
ldA mASNO gET THE START MASS
ldA mASNO gET THE START MASS
JMPP MASOK USE IT FOR THE FIRST MASS IN THE SEO.
JMPP MASOK USE IT FOR THE FIRST MASS IN THE SEO.
*
*
SEQMS ASC 18,SEQUENTIAL SEARCH - STARTING MASS P
SEQMS ASC 18,SEQUENTIAL SEARCH - STARTING MASS P
OCT G412
OCT G412
OCT 0
OCT 0
NDMSQ ASC 1G,SEQUENTIAL SEARCH - FINAL MASS ?
NDMSQ ASC 1G,SEQUENTIAL SEARCH - FINAL MASS ?
OCT 6412

```
    OCT 6412
```

```
0627 OCT 0
0628 *
GE29 END BASGN
**** LIIST END ****
```

e

## APPENDIX I

## C

AN ASSEMBLER PROGRAM FOR:

ADDITION OF COMPOUND MOLECULAR WEIGHT
TO THE MASS SPECTRAL LIBRARY DATA BASE

```
0001 ASMB,L,F,C
409己 *
0003 * THIS PROGRAM LISTS A LIBRARY ENTRY <ID> AND WAITS
0004 * FOR INPUT OF INTEGER MOLECULAR WEIGHT.. THIS UALLEE
0005 * REPLACES THE LAST "WORD" OF THE <ID>
0006 *
0007 *
0008 NAM MOLLT
0009 EXT EXEC
0010 EXT .DIO.
0011 EXT + IOI.
0012 ENT MOLLT
0013 *
0014 *
0015 MOLWT DEF START
0016 *
0017 *
0018 START NOP
0019 A EQU O
0020 B EQU 1
00E1 NXBAS JSE WTTYY URITE AN INPUT MESSAGE
00R2 DEF STMSG GIUE SPECTRUM NO. FOR START
0023 JSB RDTTY READ A NUMBER FROM THE TTY
0024
    JSB IPTER
    SZA,RSS
    JMP ESTOP STOP ON O ENTRY ALSO
    CPA EXTNO EXIT FROM PROGRAM ?
    JMP ESTOP YES - USE ERROR EXIT
    STA MASNO SANE THE STARTING SPEC NO.
    CLA, INA GET A 1
    STA IPT INITIALIZE <IPT>
```

|  | JSB | EXEC | DEFINE TABLES, BLIFFERS, ETC |
| :---: | :---: | :---: | :---: |
|  | DEF | RETM1 | RETURN POINT |
|  | DEF | RCODE | ADDRESS OF REQUEST CODE FOR EFMP |
|  | DEF | EFMP1 | ADDRESS OF EFMP FUNCTION CODE |
|  | DEF | OPNTB | ADDRESS OF. OPEMED-FILE TABLE |
|  | DEF | OPNSE | ADDRESS OF OPENED-FILE TABLE SIZE |
|  | DEF | TRELF | ADDRESS OF TEMPORARY RECORD BLIFFER |
|  | DEF | NOTRB | ADDRESS OF NUMBER OF TRB'S |
|  | DEF | TRESZ | ADDRESS OF SIZE OF TRB'S |
|  | DEF | ERRNO | PDDRESS OF RETURNED ERROR NLMBER |
| RETN1 | JSE | ERMON | GO CHECK FOR EFMP ERROR |
|  | JSB | EXEC | OPEN FILE <LIBR> IN <PN111> |
|  | DEF | RETNE |  |
|  | DEF | RCODE |  |
|  | DEF | EFMP4 | OPEN FILE |
|  | DEF | FNAME | ADDRESS OF FILE NAME <LIBR> |
|  | DEF | PAKNO | ADDRESS OF PACK NLMBER <PN111> |
|  | DEF | EFMP1 | START AT RECORD NO. 1 |
|  | DEF | SCODE | ADDRESS OF SECLRITY CODE |
|  | DEF | NOTRB | BUFFER NUMBER 1 |
|  | DEF | ERRNO |  |
| RETNE | JSB | ERMON |  |
|  | JSB | WTTY | CLEAR THE CRT SCREEN |
|  | DEF | CLRSC |  |
|  | CLA |  |  |
|  | STA | SPCNT | CLEAR THE SPECTRLMM COUNTER |
|  | STA | LNCNT | CLEAR THE LINE COLANT |
|  | STA | FINAL | CLEAR THE FIMAL OP FLAG |
|  | CMA |  |  |
|  | STA | ENDFL | MAKE END FLAG NON-ZERO |
|  | STA | NWDS | NEGATIUE NO. TO PARTIAL WRITE FLAG |
| * | J58 | EXEC | READ THE FIRST SECTOR |

```
    DEF RETNS
```

    DEF RETNS
    DEF RCODE
    DEF RCODE
    DEF EFMPG READ CODE
    DEF EFMPG READ CODE
    DEF FNAME
    DEF FNAME
    DEF RCDNO
    DEF RCDNO
    DEF BUFFR. IT IS IN <BUFFRS
    DEF BUFFR. IT IS IN <BUFFRS
    DEF ERRNO
    DEF ERRNO
    JSB ERMOM
    JSB ERMOM
    * 
* 

NXSPC LDA IPT
NXSPC LDA IPT
ADA M1
ADA M1
ADA ELIFFA
ADA ELIFFA
STA BUFAD
STA BUFAD
INA
INA
STA BLFID
STA BLFID
LDA ELFFAD
LDA ELFFAD
ADA C.32
ADA C.32
STA MOLAD
STA MOLAD
LDA BLFAD,I
LDA BLFAD,I
ISZ SPCNT
ISZ SPCNT
SZA,RSS
SZA,RSS
STA ENDFL
STA ENDFL
SZA,RSS
SZA,RSS
IMP LIRITE
IMP LIRITE
ADA IPT
ADA IPT
STA NEXPT
STA NEXPT
CLA
CLA
CLB
CLB
J5B .DIO.
J5B .DIO.
DEF SPOUT ASCII SPECTRLMM COUNT
DEF SPOUT ASCII SPECTRLMM COUNT
DEF FORMT
DEF FORMT
DEF ENDSP
DEF ENDSP
LDA SPCNT
LDA SPCNT
JSB .IOI.
JSB .IOI.
ENDSP NOP

```
ENDSP NOP
```

0105 0106 0107 0108 0109 6110
0111
0112
0113
0114
0115
0116
0117
0118
0119
0120
0121
0122 0123 0124 0125
0126 0127
0128
0129 0130 0131
0132
0133
0134
0135
0136
0137

```
```

* 

```
```

```
*
```

WRITE TO EFMP FILE
THE FILENAME IS "LIBR" BACKSPACE A RECORD

AT END OF LIBRARY P

```
LDA MASNO GET THE STARTIMG SPECTRLM NO.
```

LDA MASNO GET THE STARTIMG SPECTRLM NO.
CMA, INA . MAKE IT NEGATIVE
CMA, INA . MAKE IT NEGATIVE
ADA SPCNT - ADD THE SPECTRLM COLNT
ADA SPCNT - ADD THE SPECTRLM COLNT
SSA,RSS
SSA,RSS
CLA SINDEX SET TO O ST START POINT
CLA SINDEX SET TO O ST START POINT
STA INDEX <INDEX> SET TO NEG NO. BEFORE START
STA INDEX <INDEX> SET TO NEG NO. BEFORE START
LDA IPT . GET THE POINTER RELATIUE ADDRESS
LDA IPT . GET THE POINTER RELATIUE ADDRESS
ADA M1 DECREMENT
ADA M1 DECREMENT
ADA C32 ADD 32
ADA C32 ADD 32
ADA M128 SUBTRACT 128
ADA M128 SUBTRACT 128
SSA ALL <ID> IN THE BLJFFER ?
SSA ALL <ID> IN THE BLJFFER ?
JMP ALLIN YES - PRINT IT
JMP ALLIN YES - PRINT IT
STA NLIDS + MEANS PART IN NEXT BUFFER
STA NLIDS + MEANS PART IN NEXT BUFFER
LDA INDEX
LDA INDEX
SSA TO STARTING POINT YET ?
SSA TO STARTING POINT YET ?
JMP READR NO - SKIP WRITING <ID>
JMP READR NO - SKIP WRITING <ID>
JSB WTTMY
JSB WTTMY
DEF SPOUT
DEF SPOUT
JSB WRTID
JSB WRTID
DEF BUFID
DEF BUFID
*
*

* THIS SECTOR HAS BEEN MODIFIED - LRITE IT BACK
* THIS SECTOR HAS BEEN MODIFIED - LRITE IT BACK
* 
* 

WRITE JSB EXEC
WRITE JSB EXEC
DEF RETNS
DEF RETNS
DEF RCODE
DEF RCODE
DEF EFMP8
DEF EFMP8
DEF FNAME
DEF FNAME
DEF M1
DEF M1
DEF RLFFR
DEF RLFFR
DEF ERRNO
DEF ERRNO
RETNS JSB ERMON
RETNS JSB ERMON
LDA ENDFL
LDA ENDFL
SZA,RSS AT END OF LIBRARY ?

```
    SZA,RSS AT END OF LIBRARY ?
```

| 0138 | READR | JMP | EMDDD | YES - PROCESS FOR PROG. END <br> NEED MORE - READ THE NEXT SEGTOR |
| :---: | :---: | :---: | :---: | :---: |
| 0139 |  | JSB | EXEC |  |
| 0140 |  | DEF | RETM4 |  |
| 0141 |  | DEF | RCODE |  |
| 0142 |  | DEF | EFMPG |  |
| 0143 |  | DEF | FNAME |  |
| 0144 |  | DEF | RCDNO |  |
| 0145 |  | DEF | BUFFR |  |
| 0146 |  | DEF | ERRHO |  |
| 0147 | RETN4 | JSB | ERMOM |  |
| 0148 |  | LDA | NEXPT |  |
| 0149 |  | CPA | - B200 | WAS THE NEXT SPEC. AT THE LAST WORD $P$ |
| 0150 |  | JSB | BFADJ | PUT NO, WORDS NEXT SPEC IN BFADD |
| 0151 |  | ADA | M128 |  |
| 8152 |  | STA | IPT |  |
| 0153 |  | STA | NEXPT |  |
| 0154 |  | LDA | MOLAD | LPDATE THE STORE ADDRESS |
| 0155 |  | fDA | M128 |  |
| 0158 |  | STA | MOLAD |  |
| 0157 |  | LDA | INDEX |  |
| 0158 |  | SSA |  | TO STARTING POINT YET P |
| 0159 |  | JMP | NXSPC | NO - GO FOR MORE |
| 0160 |  | LDA | NWDS |  |
| 0161 |  | SSA |  | NEED TO URITE MORE ID ? |
| 0162 |  | JMP | NXSPC | NO - GO FOR NEXT SPECTRUM |
| 0163 |  | CCA |  |  |
| 0164 |  | STA | NWDS | YES - RESET THE FLAG |
| 0165 |  | JSB | WTTY |  |
| 0166 |  | DEF | BUFFR | FINISH WRITING 〈ID> AT START OF <ELIFFR〉 |
| 0167 |  | JSB | LNCTR |  |
| 0168 |  | JMP | MOLIN |  |
| 0169 | ALLIN | LDA | INDEX | STARTING FLAG |
| 0170 |  | SSA |  |  |
| 0171 |  | JMP | INCPT | NO START |
| 8172 |  | JSB | UTTY |  |

```
    DEF SPOUT
    JSB WRTID
    DEF EUFID
    JSB LNCTR CHECK THE LINE COLNTER
MOLIN JSB WTTY
    DEF INPTM WRITE A MESSAGE TO INPUT MOL. WT.
    JSE RDTTY READ FROM THE TTYY
    DEF IPTER
    STA MOLWE
    CLA
    CL.B
    JSB .DIO. INTERNAL CONUERSION TO ASCII
    DEF OUTIIW CONUERTED NO. LOC.
    DEF FORMT
    DEF ENDMS
    LDA MOLlUE UALLIE TO BE CONUERTED
    JSB .IOI.
ENDMS NOP
    JSB WTTY
    DEF OPTMLI ECHO UALLJE AND GLESST. UALIDITY
    JSB RDTTY O FOR NO 1 FOR YES
    JSB IPTER
    JSB LNCTR CHECK THE LINE COUNTER
    SZA,RSS ECHOED UALUS OK ?
    JSB LNCTR
    SZA,RSS
    JMP MOLIN NO - TRY IT AGAIN
    LDA MOLWE YES
    SZA,RSS IF ZERO ENTERED, QUIT
    JMP EMDDD
    STA MOLAD, I IT WAS OK - PUT IN THE BUFFER
IMCPT LDA NEXPT SET LIP FOR THE NEXT SPECTRUM
    STA IPT
    ADA M128
    S5A
```

0208 0 OO9
6210 0211 0212 0213 0214 0215 0216 0 륵
0218 0219 0220 0221 ロอออ 02 e 3 02 a 4 0225 oees 02er? 0228 0e29 0230 -231 0232 0233 0234 0235 0236 0237 0238 0239 0240 0241 0242

```
    JMP NXSPC
```

    JMP NXSPC
    STA IPT
    STA IPT
    JMP INRITE
    JMP INRITE
    * 
* 

LNCTR NOP
LNCTR NOP
ISZ LNCNT ..INCREMENT THE LINE COLMTER
ISZ LNCNT ..INCREMENT THE LINE COLMTER
LDA M33
LDA M33
ADA LNCNT
ADA LNCNT
SZA 33 LINES WRITTEN ?
SZA 33 LINES WRITTEN ?
JMP. LNCTR, I. NO - RETURN
JMP. LNCTR, I. NO - RETURN
FNLOP JSB WTTY YES - TURN OM HARDCOPY LNIT
FNLOP JSB WTTY YES - TURN OM HARDCOPY LNIT
DEF HDCPY
DEF HDCPY
NOLST JSB WTTY CLEAR THE SCREEN
NOLST JSB WTTY CLEAR THE SCREEN
DEF CLRSC
DEF CLRSC
CLA
CLA
STA LNCNT CLEAR THE LINE COUNTER
STA LNCNT CLEAR THE LINE COUNTER
LDB FINAL AT END OF LIBRARY
LDB FINAL AT END OF LIBRARY
SZB,RSS
SZB,RSS
JMP NXSPC GO DO SOME MORE
JMP NXSPC GO DO SOME MORE
JMP NXBAS
JMP NXBAS
JMP LNCTR,I
JMP LNCTR,I
ENDDD CLB,INE
ENDDD CLB,INE
STB FINAL
STB FINAL
CLA
CLA
CPA LNCNT COMPARE WITH LINE COLNTER - IF 4
CPA LNCNT COMPARE WITH LINE COLNTER - IF 4
IMP NOLST THEN MO HARDCOPY
IMP NOLST THEN MO HARDCOPY
JMF FNLOP PRINT THE LAST PAGE
JMF FNLOP PRINT THE LAST PAGE
*
*
BFADJ NOP
BFADJ NOP
STA TEMP1 SAUE THE A REGISTER
STA TEMP1 SAUE THE A REGISTER
LDA IPT-E GET UALUE CONTAINED IN LAST WORD <BLLFFR>
LDA IPT-E GET UALUE CONTAINED IN LAST WORD <BLLFFR>
STA BFADD STORE IT IN WORD PRECEEDING (BLIFFR)
STA BFADD STORE IT IN WORD PRECEEDING (BLIFFR)
LDA TEMPI RESTORE THE A REGISTER
LDA TEMPI RESTORE THE A REGISTER
JMP BFADJ,I RETURN

```
    JMP BFADJ,I RETURN
```

0323 0384 0325 0.386 038 ? 0.388 0389 0390
0391
0392
0393
0394
0395
0396 0397
0398 0399 0400 0401 0402 0403 0404 0405 0406 0407 0408 0409 0410 0411
0412 0413 0414 0415 0416 041 '

```
        STATEMENTS 243 THROUGH 385 ARE SUBROUTIMES 'WITY' AND 'RDTTY'
        TELETYPE SUPPORT ROUTINES COPIED FROM GC/MS SOFTWARE. THIS
        CODING IS PROTECTED BY AGREENENT BETWEEN E.I.DU PONT CO. AND
        THE UNIVERSITY OP IEXAS.
ERMON HOP . CHECK FOR ERRORS IN EFMP CALLS
    LDA ERRNO GET ERROR TYPE NO.
    SZA,RSS
    JMF ERMON. I IF ZERO RETURN
    CLA
    CLB
    JSB .DIO. SET LP FOR INTERNYAL COMNERSION
    DEF ERROP ERROR OUJTPUT BUFFER
    DEF FRMT
    DEF ESTOP
    LDA ERRNO
    JSB .IOI.
ESTOP MOP
    JSB WTTY
    DEF ERROP LTRITE THE ERROR MESSAGE
    JSB EXEC EXEC PROGRAM TERMINATION
    DEF *+己
    DEF EFMPG
    NOP
*
ERROP OCT O
            ASC 8, PROGRAM HALT
            OCT D
            ASC E.(IE)
FR
*
* WORK AREA FOR PROGRAM
STMSG OCT 15437
    OCT 15414
    OCT 6412
```



```
0453 LNCNT OCT 0
SPCNT OCT D
0454 SPCMPG OCT E
0456 BFADD OCT 0
045% BUFFR BSS 128
0458 OCT 0
0459 IPT OCT 1
0460 BLFFA DEF BLFFR
04E1 BUFAD OCT 0
0462 NWDS OCT 0
0463 NEXPT OCT Q
0464 EXTNO DEC 9999
0465 M128 DEC -1E8
0466 INDEX OCT O
0467 OPTMLN ASC 2, (
0468 OUTMW ASC 1,
0469 ASC 1.
0470 ASC 3. OKP)
0471 OCT O
0472 FORMT ASC E.(I4)
0473 M33 DEC -33
0474 HDCPY OCT 154Z?
0475 MOLAD OCT O ADDRESS OF MOL. WT. IN BUFFER
0476 M1 OCT -1
0477 ENDFL OCT Q
0478 BLFID OCT E
0479 EFMPY OCT 10
0480 TEMP1 OCT O
0481 TEMPC OCT D
0482 MOLWE OCT 0
0 4 8 3 ~ C 3 L ~ O C T ~ 4 0 ~
0484 RUBO OCT 177 RLJBPOU
0485 *
0486 *
*487 ;
```

0482
0489
0490
0491
0492
6493 0494 0495 0496 0497 0.498 0499 0500 0501 0502 0503 0504 0505
0506 0507 0508 0509 0510
0511
0512
0513
0514
0515
0516
0517
0518
0519
0520
0521
052 E

```
*
IPTER NOP
    JSB WTTY WRITE AN ERROR MESSAGE
    DEF IPMSG - LOC. OF THE MESSAGE
    LDA IPTRA,I GET THE RETURN ADDRESS
    NOP
    ADA M1:
    ADA M1
    STA IPTER SET UP TO TRY AGAIN
    JMP IPTER, I
IPTRA DEF IPTER
IPMSG.OCT 6412 CR/LF
    ASC 13,INPUT ERROR - TRY AGAIN
    OCT 0
*
*
WRTID NOP
*
* ALLOWS USE OF 〈LTTY\ INDIRECT
*
    LDA WRTID,I
    STA IDAD SAUE THE <ID> ADDRESS
    ISZ LRTID SET LJP FOR RETURN
    LDA JBUJFF
    STA INBFF
MORID LDA IDAD,I
    LDA A,I
    STA INBFF,I TRANSFER THE ID
    ISZ INBFF
    ISZ IDAD.I
    SZA
    JMP MORID
    JSB WTTY'
    DEF INBUF WRITE OUT THE ID
    JMP WRTID.I
```

| 0.523 | * |  |  |
| :---: | :---: | :---: | :---: |
| 0524 | INBLIF | BSS |  |
| 0525 |  | OCT |  |
| 0526 | IDAD | OCT | 0 |
| 0527 | JBLFF | DEF | INEUF |
| $05 \pm 8$ | INBFF | OCT | 0. |
| 0529 | * |  |  |
| 0530 | SPOUT | ASC | 3. |
| 0531 |  | OCT |  |
| 0532 |  | END | MOLJT |
| **** | LIST EN | VD | ** |

## APPENDIX II

PROGRAM EXECUTION OUTPUT
A. A Representative Sequential Listing of Entries in the Mass Spectral Library.
B. A Representative Listing of Entries in the Mass Spectral Library

- According to the Mass of the Base Peaks.
C. A Partial Listing of Entries in the Mass Spectral Library According to the Mass of Significant Peaks.


## APPENDIX II

A
A REPRESENTATIVE SEQUENTIAL LISTING OF ENTRIES IN THE MASS SPECTRAL LIBRARY

```
    1 BLR-0001 2501 MEPERIDINE
    # BLR-000己 ES01 NOR-MEPERIDINE
    3 BLR-0003 2501 MEPERIDINIC ACID METHYL ESTER
    4 BLR-0004 2502 NOR-MEPERIDINIC ACID TMS ESTER
    5 BLR-0005 250E MEPERIDINIC ACID TMS ESTER
    G BLR-0006 2EOE NOR-MEPERIDINIC ACID TMS ESTER N-TMS DERIUATIUE
    7 BLR-0007 2503 NOR-MEPERIDINIC ACID ETHYL ESTER M-TMS DERIUATIUE
    8 BLR-0008 2503 MOR-MEPERIDINIC ACID METHYL ESTER
    9 BLR-0009 2503 ACETOPHENETIDIN
    10 BLR-0010 2564 ACETAMINOPHEN METHYL ESTER
    11 BLR-0011 2504 ACETAMINOPHEN TMS ESTER
    12-BLR-0012 2505 ACETAMINOPHEN GLUCLIRONIDE METHYL ESTER TMS ETHER
    13 BLR-0013 2505 INDOMETHACIN METHYL ESTER
    14 BLR-0014 250E INDOMETHACIN TMS ESTER
    15 BLR-0015 2506 4-CHLOROBENZOIC ACID METHVL ESTER RFROM INDOMETHAC
    16, BLR-0016 250B 4-CHLOROBENZOIC ACID TMS ESTER (FROM INDOMETHACIN
    17 BLR-0017
    18 BLR-0018
    19
    20 BLR-0020
    21 BLR-0021
    22 BLR-0022
    23 BLR-0023
    24 BLR-0024
    25 BLR-0025
    26 BLR-002G
    E'7 BLR-0027
    28 BLR-0028 2510 SALICYLIC ACID METHYL ESTER TMS ETHER
```


## APPENDIX II

C

A PARTIAL LISTING，THROUGH MASS 20，OF ENTRIES IN THE MASS SPECTRAL LIBRARY ACCORDING TO THE MASS OF SIGNIFICANT PEAKS

582 LRL-0012 0051 CARBON SUBOXIDE

THE FOLLOWING SPECTRA HAUE A PROMIMANT PEAK AT 13 ( $*$ - BASE PEAK
6088 API-1345 $16728,9,10,11-T E T R A H Y D R O M A P H T H O(2,1-B) T H I A N A P H T H E N E ~$

THE FOLLOLING SPECTRA HAUE A PROMINANT PEAK AT
14 (* - BASE PEAK)
4E2* LRL-0034 0009 KETENE
470 LRL-0933 0011 HYDRAZOIC ACID (AZOIMIDE)
478 API-0760 0012 ETHYLENE OXIDE (GAS)
T51 GCC-0035 0066 BETA-PROPIOLACTONE
1854 API-0773 033㕕 METHYL CHLOROACETATE (GAS)
2449 DOU-2257 0492 ACETYL BROMIDE
3235 MOR-0113 0713 METHYL NICOTINATE
5664 AST-1935 149 E GLYCOL DIMERCAPTOACETATE
5665 COC-1935 1493 GLYCOL DIMERCAPTOACETATE 5873 MOR-0160 1575 FARNESOL

```
402* MIT-0207 2645 DIMETHYLSULPHONE
403 API-0110 0001 METHANE(GAS)
4 0 4 ~ A P I - 0 0 6 0 ~ 0 0 0 1 ~ M E T H A N E ( G A S ) ~
405 API-0001 0001 METHANE (GAS)
4 0 6 ~ D O W - 0 0 0 3 ~ 0 0 0 1 ~ M E T H A N E ~
4 7 0 ~ L R L - 0 0 3 3 ~ 0 0 1 1 ~ H Y D R A Z O I C ~ A C I D ~ ( A Z O I M I D E ) ~
4 7 2 ~ A P I - 0 7 6 3 ~ 0 0 1 1 ~ E T H Y L E N E ~ I M I N E ( G A S ) ~
4 7 8 ~ A P I - 0 7 6 0 ~ 0 0 1 2 ~ E T H Y L E N E ~ O X I D E ~ ( G A S ) , ~
4 8 1 ~ D O U - 0 2 3 9 ~ 0 0 1 2 ~ A C E T A L D E H Y D E ~
482 DOW-0240 0012 ETHYLENE OXIDE
506 API-0761 0016 DIMETHYL ETHER (GAS)
516 API-0088 0018 CHLOROMETHANE(METHYL CHLORIDE)(GAS)
560 API-1141 0DEZ7 N-METHYLETHYLENIMINE (GAS)
564 API-0768 0028 1,己-EPOXYPROPANE(PROPYLENE OXIDE) (GAS)
573* LRL-0047 0029 UINYL METHYL ETHER
576 API-0085 0030 E-PROPANONE(ACETONE)(GAS)
581* LRL-0009 0031 AZOMETHANE
592 GRC~0028 0033 ACETAMIDE (ETHANAMIDE)
597 API-1127 0034 TRIMETHYLAMINE (GAS)
617 API-6770 0038 METHYL ETHYL ETHER (GAS)
631 GDC-0001 0040 1,1-DIMETHYL HYDRAZINE
634 API-0836 0041 NITROMETHANE (GAS)
649 API-0762 0044 DIMETHYL PEROXIDE (GAS)
676* API-1874 0049 METHYL-N,M-DIFLLOROAMINE
751 GCC-0035 00E6 BETA-PROPIOLACTONE
753 SCL-0013 006E UINYL FORMATE
756 DOW-2602 0067 PYRUUALDEHYDE
757 MOR-0005 0067 PYRUUALDEHYDE
759 AST-0902 0067 METHYL UINYL CARBINOL
```

API-6779 0068 ETHYL ETHENYL ETHER(ETHYL UINYL ETHER) (GAS)
LRLL-0030 0074 FORMALLDEHYDE DIMETHYL HYDRAZONE
GCC-0041 0076 METHYLTHIOCYANATE
API-1133 0076 N, N -DIMETHYLFORMAMIDE (GAS)
DOT-0158 0080 GLVCIDOL
API-0781 0082 METHYL ISOPROPYL ETHER (GAS)
LRL-0045 0087 TRIMETHYL HYDRAZINE
API-0771 0094 Z-METHOXY-1-ETHANOL (ETHYLENE GLYCOL MONOMETHYL ETH
API-1089 0095 DIMETHOXYMETHANE (DIMETHYL FORTMAL) (GAS)
CCC-0010 0097 ACETYL CHLORIDE
DOW-1456 0097 ACETYL CHLORIDE
GCC-0030 0097 CHLOROACETALDEHYDE
ARC-0019 0098 DIMETHYL SULFOXIDE
LRL-001G e105 CHLOROMETHYL ETHER
GRC-0038 0106 METHYLMALONONITRILE
API-1875 0109 ETHYL-N, N-DIFLUOROAMINE
LRL-0036 0121 METHYL ISOPROPENYL KETONE
AST-1216 012e CIS-METHYL PFROPENYL KETONE
API-0794 0124 ACETALDAZINE (GAS)
DOS-0019 0131 ACETOME CYAMOHYDRIN
MOR-0086 0132 N-METHYLPYRROLIDINE
API-0782 0134 2,3-BLTANEDIONE(DIACETYL)(GAS)
KOP-0016 0135 BLTADIENE DIOXIDE
API-0783 0137 METHYL E-PROPENOATE(METHYL ACRYLATE) (GAS)
API-6796 0140 ETHENYL ISOPROPYL ETHERCUIMYL ISOPROPYL ETHER)(GAS
GDC-0004 0151 N,N-DIMETHYLACETAMIDE
AST-1218 0151 N, M-DIMETHYLACETTAMIDE
DOU-1352 0153 CYCLIC ETHYLENE CARBONATE
MOR-0010 0154 PYRUUIC ACID
DOT-0130 0154 ETHYLENE CARBONATE
DOW-2345 0156 ALDOL

1173 BIE-0612 0160 ACETOIN
$12 己 7$ QUA-0004 0172 ETHYL CARBAMATE (LRETHANE)
1230 CYA-0004 0173 3-METHOXY PROPYLAMINE
1237* API-0769 0174 METHYL CARBONATE (GAS)
1238 DOW-1318 0175 DIMETHYL CARBONATE
1256 API-0784 0179 DIETHYL PEROXIDE (GAS)
1258 API-1113 0179 1,1-DIMETHOXYETHANE (DIMETHYL ACETAL) (GAS)
1265 API-11450181 1.E-DIMETHOXYETHANECETHYLEME GLYCOL
1269 API-1090 018己 1.1-DIMETHOXYETHANE (DIMETHYZ ACETAL) (GAS)
1321* MOR-6074 0195 METHYL BROMIDE
132 C DOU-0422 0195 BROMOMETHANE
1329* AST-1653 0197 DIMETHYLSULPHONE
1366 COC-0005 0206 2,5 DIMETHYLFURAN
1368 API-0815 020G 2,5-DIMETHYLFURAN (GAS)
1490 DOS-0029 0240 METHYL CYANOACETATE
1491 GDC-0013 0240 N,N-DIMETHYL ACRYLAMIDE
1492 GDC-0011 0240 N-ETHYL ACRYLAMIDE
1493 MOR-0021 O241 E-METHYLPYRROLIDONE
15et? MOR-0091 0249 2,3-PEMTANEDIONE
1529 COC-4484 0250 4-METHYL-Z-PENTANONE
1533 COC-4560 0251 ISOBUTYL UINYL ETHER
1614 API-0810 0271 Z-METHOXYETHYL ETHENYL ETHER
1624 DOU-1343 01273 2-METHOXYETHYL UINYL ETHER
1631 DOT-0027 0275 METHYL ISO-BUTYRATE
1715 GRC-0007 0295 METHYL HYDRACRYLATE
1758 AST-0021 0307 E, Z-DIMETHOXYPROPANE
1761 LRL-0021 0307 Z, Z-DIMETHOXYPROPANE (ACETONE DIMETHYL ACETALI
1809 MOR-0093 0319 TRIMETHYL ORTHOFORMATE
1854 API-0773 0332 METHYL CHLOROACETATE (GAS)
1900 MOR-0095 0344 2-METHOKYPYRIDINE
1911 AST-1143 0348 DIMETHYL SLLFITE


3235 MOR－0113 0713 METHYL NICOTINATE
326e MOR－0114 072己 UINYLCYCLOHEXENE DIOXIDE
3303 MOR－0115 0733 2．6－DIMETHOXYPYRIDINE
3338 BIE－0595 0744 FURFURYL ACETATE
3385 MOR－0037 0757 METHYL DICHLOROACETATE
3608 ARC－0002 0820 DIMETHYL SUCCINATE
3803 AST－0932 0881 BENZYZ ACETATE
3814 API－0834 0889 1－PHENOXY－Z－PROPANONE
3877 DOW－1949 0960 METHYL BROMOACETATE
3893 MOR－0123 0905 UANILLIN
3979 MOR－0126 0931 METHYL E－OCTYNOATE（METHYL HEPTYNE CARBONATE
4081 AST－1244 0961 METHYL 4－METHYLCYCLOHEXANECARBOXYLATE
4193 MOR－0132 099己 METHYL CAPRYLATE
4223＊DOT－0188 1001 1，1，1－TRICHLORO－PROPANONE
424己 USI－1900 1007 DIMETHVL GLUTARATE
4350 DOT－0073 1041 METHYL ORTHO N－UALERATE
4351 MOR－0080 1041 TRIETHYL ORTHOACETATE
4415 MOR－0138 106E EUGENOL
4475 MOR－0142 1082 3，4－DIMETHOXY BENZALDEHYDE
4553 MOR－0143 1110 METHYL Z－NOMYNOATE（METHYL OCTYNE CARBONATE）
4588 AST－1246 1121 METHYL ALFA，BETA－DICHLOROISOBLTYRATE
4754＊API－1997 1173 DIMETHYL HEXANE－1，6－DIOATE（GAS）
4755 USI－1901 1173 DIMETHYL ALFA－METHYL GLUTARATE
4757 RYS－0030 1174 METHYL HEXANE－1，6－DIOATE
4762＊API－1396 1175 1，6－DIMETHYL HEXANEDIOATE（GAS）
4803 DOS－0090 1187 METHYL TRICHLOROACETATE
4853 DOT－0071 1203 BIS－（2－METHOXYETHYL）CARBONATE
5443 DOW－0518 1408 1，己－DIBROMOPROPANE
5498 USI－1903 1427 DIMETHYL SUBERATE
5591 MOR－0158 1464 METHOXYTRIGLYCOL ACETATE
5609 COC－0683 1470 3－METHYL－1－〔2，4，6－TRIMETHYLPHENYL）－1－BLTAMOL

5664 AST-1935 1492 GLYCOL DIMERCAPTOACETATE
5665 COC-1935 1493 GLYCOL DIMERCAPTOACETATE
5785 USI-1904 1539 DIMETHYL AZELATE
6008 USI-1906 1637 DIMETHYL ALFA-ETHYL SUBERATE
6023 DOLJ-4692 1643 1,1,1-TRIMETHOXY-2-CHLORO-Z-BROFHO-ETHANE

```
403* API-01100001 METHANE(GAS)
404* API-0060 0001 METHANE(GAS)
405* API-0001 0001 METHANE (GAS)
406* DOW-0003 0001 METHANE
4 0 7 ~ A P I - 0 0 9 0 ~ 0 0 0 1 ~ A M M O N I A ( G A S ) ~
4 0 8 ~ A P I - 0 4 5 8 ~ 0 0 0 1 ~ M O N O D E U T E R O M E T H A N E ~ ( G A S ) ~
410 API-0457 0002 DIDEUTEROMETHANE (GAS)
4 4 5 ~ R O C - 0 0 0 1 ~ 0 0 0 7 ~ H Y D R A Z I N E ~
446 API-1110 0007 HYDRAZINE (GAS)
5 2 4 ~ R O C - 0 0 0 3 ~ 0 0 1 9 ~ O X Y G E N ~ B I F L U O R I D E ~
666 DOW-1294 0047 1,1-DIFLLOOROETHYLENE-2,2-D2
910 LRL-0003 0100 AMMONIUM CARBAMATE
1705 DOW-E017 0293 SILICON TETRAFLUORIDE
2129 API-1559 0408 CIS-E,5-DIMETHYLPIPERAZINE
3235 MOR-0113 0713 METHYL NICOTIMATE
6996 ARC-0051 己己己己 METHYL GREEN
```



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\begin{tabular}{|c|c|c|c|}
\hline 407* & API-0090 & 0001 & A \\
\hline 408* & API-0458 & 0001 & MOHODEUTEROMETHANE (GAS) \\
\hline 410 & API-0457 & 0002 & DIDEUTEROMETHANE (GAS) \\
\hline 411 & API-0456 & 0002 & TRIDEUTEROMETHANE (GAS) \\
\hline 445 & ROC-0001 & 0007 & HYDRAZINE \\
\hline 446 & API-1110 & 0007 & HYDRAZINE (GAS) \\
\hline 910* & LRL-0003 & 0100 & AMMONILM CARBAMATE \\
\hline 1143 & DOT-0130 & 0154 & ETHYLENE CARBONATE \\
\hline 1332 & KOP-0017 & 0198 & 3-CHLORO-1-PROPANOL \\
\hline 1705 & DOW-2017 & 0293 & SILICON TETRAFLUORIDE \\
\hline 2129* & API-1559 & 0408 & CIS-E,5-DIMETHYLPIPERAZIN \\
\hline 2277 & ARC-0032 & 0447 & SUCCINIC ACID \\
\hline 2784* & DOW-2348 & 0588 & ALPHAHYDROXYYADIPALDEHYDE \\
\hline 3803 & AST-0932 & 0881 & BENZYL ACETATE \\
\hline 6996 & ARC-00 & 2222 & METHYL GREEN \\
\hline
\end{tabular}
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    409* DOW-0己3己 0001 WATER
    410* API-0457 0002 DIDEUTEROMETHANE (GAS)
    411 API-0456 0002 TRIDEUUTEROMETHANE (GAS)
    412 API-0455 0002 TETRADEUTEROMETHANE (GAS)
    428* DOW-0234 0004 FORMALDEHYDE
    452 DOW-1099 0008 METHAN-D3-OL
    488* GRC-0035 0013 FORMAMIDE (METHANAMIDE)
    498 DOW-0242 0015 FORMIC ACID
    537 DOW-0244 0022 ACROLEIN
    558* DOT-0021 0026 GLYCOLONITRILE
    562* DOW-2719 0027 GLYOXAL
    6 3 1 ~ G D C - 0 0 0 1 ~ 0 0 4 0 ~ i . 1 - D I M E T H Y L ~ H Y D R A Z I N E ~
    G36* DOS-0003 0041 ETHANOLAMINE
    756 DOL-2602 0067 PYRLUALDEHYDE
    759 AST-0902 0067 METHYL UINYL CARBINOL
    786 SIK-1226 0073 TRANS-E-BUTEN-1-OL
    817 DOT-0158 0080 GLYCTDOL
    854 LRL-0045 0087 TRIMETHYL HYDRAZINE
    860* DOS-0007 0089 1-AMINO-Z-PROPANOL
    861 DOS-0008 0089 Z-AMINO-1-PROPANOL
    870* DOW-Z718 0091 GLYCOLIC ACID
    887 MOR-0007 0095 PROPYLENE GLYCOL
    899* DOS-0012 0098 FLUOROACETIC ACID
    9己T* DOW-3879 0104 HYDROGEN BROMIDE
1143* DOT-0130 0154 ETHYLENE CARBONATE
1154 DOLW-2345 0156 ALDOL
1157* DOT-0132 0157 ALDOL
1230 CYA-0004 0173 3-METHOXY PROPYLAMINE
1233* DOS-002Z 0173 己-AMINO-1-BLTANOL
```

| 1235 | D0w-1960 | 0174 | OXALIC ACID |
| :---: | :---: | :---: | :---: |
| 1243 | MOR-0011 | 0176 | LACTIC ACID |
| 1268 | GDC-0008 | $018{ }^{\text {0 }}$ | 1,2-BUTANEDIOL |
| 1293 | MOR-0012 | 0188 | GLYCEROL |
| 1332* | KOP-0017 | 0198 | 3-CHLORO-1-PROPANKL |
| 1515* | DOt-206? | 0246 | GLUTARALDEHYDE |
| 1629 | DOT-0160 | 0274 | TRIMETHYLACETIC ACID (PIUALIC ACID) |
| $170 \%$ | DOW-2477 | 0293 | 2-CHLOROCROTOMALDEHYDE |
| 1718 | DOT-0152 | 0296 | ETHOXYACETIC ACID |
| 1783 | ARC-0007 | 0313 | DIETHANOLAMINE |
| 1864 | GRC-0006 | 0334 | DELTERATED MALONIC ACID |
| 1890* | DOS-0043 | 0341 | 2-AMINO-3-METHYLPYRIDINE |
| 1931 | SCL-0002 | 0353 | DIMETHYL (UINYL-ETHINYL) CARBINOL |
| 2070 | DOS-0053 | 0394 | TRIFLLOROACETIC ACID |
| 2079 | DOW-4526 | 0397 | 2-HYDROXYCYCLOHEXANONE |
| 2158 | DOW-5059 | 0416 | MALEIC ACID |
| 2159* | ARC-002 | 0416 | MALEIC ACID |
| 2251 | SCL-0012 | 0440 | 2, 4-DIAMINO-Z-METHYLPENTANE |
| 2276 | D01-2e32 | 0447 | SUCCINIC ACID |
| 2277* | ARC-0032 | 0447 | SUCCIMIC ACID |
| 2433* | DOS-0058 | 0488 | BENZALDEHYDE OXIME |
| 2519 | API-1349 | 0513 | 2,4-DIMETHYL-3-ETHYLPYRROLE (GAS) |
| 2540 | DOU-2653 | 0520 | O-HYDROXYBENZYL ALCOHOL |
| 2542* | DOU-5243 | 0520 | P-HYDROXYBENZYL ALCOHOL |
| 2643 | D0S-0070 | 0550 | 2,3-DICHLOROPROPANOL-1 |
| 2672 | DOW-4570 | 0559 | Z(HYDROXYMETHYL )CYCLOHEXANONE |
| 2764 | ARC-0449 | 0582 | 己-AMIMO-G-METHYLHEPTANE |
| 2784 | DOW-2348 | 0588 | ALPHAHYDROXYADIPALDEHYDE |
| 2918 | DOW-1665 | 0623 | 己-METHYL-3,4-DIHYDROXYTETRAHYDROPYRAN |
| 3355 | SIK-1080 | 0749 | NOMADIENOL |
| 3384 | DOU-2054 | 0757 | E, 2 -DICHLOROPROPIONIC ACID |


| 3499 | DOU-2738 | 0790 | 2-HYDROXYCYCLOHEXANEC |
| :---: | :---: | :---: | :---: |
| 3635* | D05-0081 | 0845 | 1,3-BIS (DIMETHYLAMINO)-E-PROPANOL |
| 3803* | AST-0932 | 0881 | BENZYL ACETATE |
| 3888 | SIK-5049 | 0903 | ISOUANILLIN |
| 3893 | MOR-0123 | 0905 | UAMILLIN |
| 3945* | DOW-2634 | 0920 | 己-DIETHYLAMINOETHANOL HYDROCHLORIDE |
| 4170 | WLR-1819 | 0986 | N-HEXYL PROPIONATE |
| 4204 | SIK-2054 | 0995 | 1-DECANOL |
| 4389* | DOW-1482 | 1054 | CHLORAL HYDRATE |
| 4454 | DOW-1785 | 1075 | A-BROMOBLTVRIC ACID |
| 4463* | DOW-1850 | 1079 | ISOPHTHALIC ACID |
| 4464* | DOW-1902 | 1079 | TEREPHTHALIC ACID |
| 4466 | DOW-4560 | 1079 | PHTHALIC ACID |
| 4553 | MOR-0143 | 1110 | METHYL E-NONYNOATE (METHYL OCTYAE CARBONATE) |
| 4679 | WUR-1823 | 1156 | N-HEPTYL PROPIONATE |
| 4699 | WLR-1826 | 1156 | 2-METHYLBLTYL ISOPENTANOATE |
| 4719* | SIK-2055 | 1161 | 1-UNDECANOL |
| 5028 | DOU-2479 | 1265 | O-BENZYLPHENOL |
| 5080 | DOT-0198 | 1279 | 1,2-BIS (2-CHLOROETHOXY) ETHANE |
| 5085 | DOW-1975 | 1281 | 4-PHENYLPYROCATECHOL |
| 5142 | LUR-1835 | 1299 | DIETHYL DIMETHYLMALONATE |
| 5143 | AST-1835 | 1300 | DIETHYL DIMETHYLMALONATE |
| 5280 | DOU-5157 | 1351 | METHYL AR-( 2 -HYDROXYETHYL)PHENYLACETATE |
| 5330* | DOL-4046 | 1370 | 2-HYDROXY-5-ISOPROPYL M-XYLENE-A, A DIOL |
| 5369* | D0T-0023 | 1384 | 1,3-DICHLOROTETRAFLUOROACETONE |
| 5502 | RYS-0035 | 1429 | METHYL 4-METHYLHEPTANE-1,7-DIOATE |
| 5582 | DOU-2843 | 1460 | Z-BROMOMAPHTHALEME |
| 5664 | AST-1935 | 1492 | GLYCOL DIMERCAPTOACETATE |
| 5665 | coc-1935 | 1493 | GLYCOL DIMERCAPTOACETATE |
| 5666* | DOW-1804 | 1493 | 1,2, 4-BENZENETRICARBOXYLIC ACID |
| 5678* | DOW-4048 | 1498 | 5-SEC-ELTYY-Z-HYDROXY-M-XYLENE-ALPHA, ALPHAPRIM |

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5787 API-1400 1540 己,5-DICYCLOPENTYLIDENE-1-CYCLOPENTANYNE (GAS)
5ERT DOL-2454 1556 3,4-DICHLOROPHENOXY ACETIC ACID
5 8 8 3 ~ S I K - 2 4 8 6 ~ 1 5 8 0 ~ C I S - T R A N S - F A R N E S O L ~
5912* GRC-0033 1594 DIBENZOYLMETHANE
5983 RYS-0009 162G METHYL N-TRIDECANOATE
E014 DOW-3798 1639 1,己-TETRADECANEDIOL
6051 DOU-CT42 1653 ALPHA-(2,4-DICHLOROPHENOXY)PROPIONIC ACID
6164 RY'S-0039 1719 ETHYL 4,4-DIMETHYLHEPTANE-1,7-DIOATE
G261 WLUR-1838 1767 GAMMA-PALMITOLACTONE
6己6己 AST-1838 1767 GAMMA-PALMITOLACTONE
6 3 9 0 ~ D O W - 1 4 0 3 ~ 1 8 3 6 ~ O C T A D E C A N O L ~
G428 DOW-1946 1857 3,12-OCTADECADIENOIC ACID (LIMOLEIC ACID)
6437 AST-1839 1862 GAMMA-STEAROLACTONE
6467 DOLH-371G 1880 ב-HEXADECYLOXYETHANOL
6504 MOR-0165 1900 METHYL STEARATE
6514 DOW-3T17 1906 1-HEXADECYLOXY-Z-PROPANOL
6559 DOL-1928 1931 METHYL ABIETATE
6 5 6 5 ~ D O W - 2 8 3 9 ~ 1 9 3 4 ~ D I P H E N Y L ~ P H T H A L A T E ~
6895 RYS-00Z1 2154 METHYL N-PENTACOSANOATE
6898 RYS-0034 2156 METHYL DOCOSANE-1,姩-DIOATE
6940 DOL-4380 2187 DIMONYL PHTHALATE
6975 RYS-0025 2213 N-DOCOSYL N-HEPTANOATE
6996* ARC-0051 2ב己己 METHYL GREEN
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THE FOLLOWING SPECTRA HAUE A PROMINANT PEAK AT
411* API-0456 0003 TRIDEUTEROMETHANE (GAS) 1807 DOW-2534 0319 1, 2, 4-BUTANETRIOL 2287 SIK~1432 8449 ETHYL LAC'TATE

THE FOLLOWING SPECTRA HAUE A PROMINANT PEAK AT 412* API-0455 0002 TETRADEUTEROMETHANE (GAS)
fHE FOLLOWIMG SPECTRA HAUE A PROMIMANT PEAK AT

19 ( * BASE PEAK

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,
20 ( * - BASE PEAK)
420 DOU-4383 0003 ACETYLENE-DE

## CHAPTER FOURTEEN

DEVELOPMENT OF A CHELATING/CO-PRECIPITATION PROCEDURE
FOR MATRIX-FREE ANALYSIS OF VARIOUS METALS IN ORGANISMS
FROM THE SOUTH TEXAS OCS BY ATOMIC ABSORPTION SPECTROPHOTOMETRY

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Department of Oceanography

## Principal Investigators:

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Paul N. Boothe


#### Abstract

A procedure is described using ammonium pyrrolidine dithiocarbamate (APDC) for the co-precipitation and preconcentration of trace metals in organism digests for subsequent determination using flameless atomic absorption spectrophotometry (AAS). The procedure ultimately developed involves co-precipitation of $\mathrm{Cd}, \mathrm{Ni}$ and Pb by a precipitated APDC-Co complex in the presence of added $\mathrm{S}^{-1}$ and NaCl . A single correction factor accounting-for the combined effects of pH and analyte concentrations on recovery was accomplished using multiple linear regression. STOCS organism digests of shrimp muscle, fish muscle, liver and gill, and NBS bovine liver comprise the three basic matrix types tested; muscle, gill and liver. Paired $t$ tests comparing results obtained by direct analysis and after the co-precipitation procedure indicated both measures are comparable, except for Cd and Ni in flesh.

The variability in the procedure is such that its results are semiquantitative estimates, but these provide a useful comparison when evaluating direct analysis data obtained at low levels in samples with complex matrices. The advantage of the method lies in the five to ten-fold pre-concentration obtained which tends to offset the disadvantage implicit in the higher variability of the method.


## INTRODUCTION

The low levels of $\mathrm{Cr}, \mathrm{Cd}, \mathrm{Ni}$ and Pb in marine organisms from the South Texas Outer Continental Shelf (STOCS) prompted this examination of a co-precipitation procedure as a means of achieving lower detection limits for these elements than is possible by flameless atomic absorption spectrophotometric (AAS) analysis of untreated samples. It was hoped this procedure would both ameliorate the problem of sample matrix interferences during AAS analysis and result in a significant preconcentration of the elements investigated. Both of these effects would contribute to improved detection limits.

Analytical procedures for trace metal preconcentration and matrix removal utilizing co-precipitation with ammonium pyrrolidine dithiocarbamate (APDC) have been applied to seawater by Boyle and Edmond (1975 and 1977). Modifications of these procedures have been used in our laboratory for the determination of $\mathrm{Cd}, \mathrm{Cu}, \mathrm{Ni}, \mathrm{Pb}$ and Zn in seawater. Work on procedures for $\mathrm{Cr}, \mathrm{Mn}$ and V have also been conducted. This experience was applied to this current study of APDC co-precipitation as a trace metal preconcentration procedure for digests of tissues from STOCS organisms.

Recoveries of $\mathrm{Cd}, \mathrm{Cr}, \mathrm{Ni}$ and Pb were initially studied in a dilute seawater matrix. Recoveries were acceptable except for Cr (Table 1). Further work failed to yield acceptable Cr recoveries. Van der Sloot (1976), using an APDC-activated carbon preconcentration procedure, found that recovery of Cr was strongly dependent upon its oxidation state. Only cationic Cr could be recovered with this procedure and dilute Cr solutions were unstable with respect to oxidation state. This conclu-

## TABLE 1

## RECOVERIES OF Cr, Cd, Ni AND Pb FROM SEAWATER <br> BY APDC CO-PRECIPITATION AT pH 4

| Concentration Added (ppb) | Percent Cr | Recovery of Cd | Element Ni | Indicated Pb |
| :---: | :---: | :---: | :---: | :---: |
| 50 | 16\% | 89\% | 75\% | 120\% |
| 100 | 16\% | 93\% | 103\% | 80\% |
| 150 | 5\% | 96\% | 113\% | 100\% |

sion explains our low Cr recoveries since Cr would most likely exist in the form of chromate or dichromate in the strong oxidizing conditions used in our digestion procedure. Because of this situation, no further work on Cr determinations in organism digests was conducted.

METHODS

## Procedure Development

The co-precipitation of trace metals using APDC involves using a carrier metal to produce a precipitate. The precipitate binds the metals via mechanisms not yet clarified but probably involving absorption of dissolved and colloidal chelated trace metals. In this study Co was used as the carrier metal.

Considerable preliminary work was done to optimize the co-precipitation procedure for the organism tissue digests to be analyzed. All samples for this work were prepared with standards added to a fish flesh digest. Results of these preliminary tests are summarized in Table 2. Each aspect of the procedure that was investigated during this initial development phase is discussed briefly below.

## Sulfide Addition and pH Selection

At pH 3.5 recoveries for all three elements were high while at pH 1.8 Cd and Pb recoveries were reduced. The lowest possible pH was desired because it would minimize the amount of buffered titrant needed to raise the pH of the highly acidic digests and thus reduce the contamination from that source. A pH of 2.5 was selected as a compromise between risks of contamination at higher $\mathrm{pH}^{\prime}$ s and the problem of partial recoveries at suboptimal pH values. Addition of sulfide enhanced the recoveries of the metals at pH 1.8 . Thus, this step was included in

TABLE 2

SUMMARY OF PRELIMINARY DEVELOPMENT WORK ON APDC CO-PRECIPITATION PROCEDURE

| Co-Precipitation Procedure |  | Peak Height Change, Relative to Reference Procedure, Resulting from Modification |  |  |
| :---: | :---: | :---: | :---: | :---: |
| Reference Procedure | Modification to Procedure | Cd | Ni | Pb |
| No sulfides ( pH 1.8) | Sulfide Addition ( pH 1.8 ) | +70\% | +20\% | +50\% |
| No salt ( pH 3.5 ) | Salt Added <br> 35\% NaCl <br> (pH 3.5) | -10\% | +20\% | 0\% |
|  | $\begin{aligned} & 150 \% \mathrm{NaCl} \\ & (\mathrm{pH} 3.5) \end{aligned}$ | -20\% | +20\% | - 0\% |
| $\mathrm{NaC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ <br> Titrant | $\mathrm{NH}_{4} \mathrm{C}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ <br> Titrant | not tested | -30\% | 0\% |
| pH 1.8 | pH 3.2 | +230\% | 0\% | +70\% |
| pH 1.8 | pH 4.5 | not tested | -20\% | -30\% |
| $\mathrm{pH}, 1.8$ | pH $4.5+$ salt | not tested | -20\% | +60\% |

the final procedure to lessen the problem of partial recoveries at the suboptimal pH used.

## Salt Addition

Boyle and Edmond (1975) report higher recoveries of Cd and Zn from seawater than from deionized water solutions. This observation prompted tests involving the addition of sodium chloride ( NaCl ) to samples prior to co-precipitation. It is possible that the NaC1 produces more uniform conditions for co-precipitation by moderating the differences in ionic strength among the different sample types. The addition of NaCl to the fish flesh matrix appeared to increase slightly the recovery of Ni and to decrease Cd recovery. Its effect on Pb recovery was variable. At pH 3.4 additional NaCl had no obvious effects. However, at pH 4.5 where Pb recovery was poor, NaCl appeared to improve recovery. Thus, this salt addition step was included in the final procedure as a possible means of improving Pb recovery at the suboptimal pH (2.5) used.

## Buffered Titrant Selection

A sodium acetate $\left(\mathrm{NaC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}\right)$ buffered titrant was used initially in this study. However, the Ni concentration in this solution was too high to permit adequate correction by procedural blanks. APDC co-precipitation of this titrant prior to use on samples did not reduce the Ni content to an acceptable level.

Because of its low trace metal content, an attempt was made to use ultrex ammonium hydroxide ( $\mathrm{NH}_{4} \mathrm{OH}$ ) alone as a titrant. This attempt failed because a flaky APDC precipitate was produced which failed to adhere to the NUCLEPORE filter. As a result significant amounts of the precipitate were lost during handling. Addition of acetic acid ( $\mathrm{HC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ )
to the $\mathrm{NH}_{4} \mathrm{OH}$ reversed this effect producing a well-consolidated precipitate.

Finally, an amonium acetate $\left(\mathrm{NH}_{4} \mathrm{C}_{2} \mathrm{H}_{3} \mathrm{O}_{2}\right)$ buffered titrant was prepared using reagent acetic acid and ultrex $\mathrm{NH}_{4} \mathrm{OH}$. Both of these compounds had relatively low levels of $\mathrm{Cd}, \mathrm{Ni}$ and Pb contamination. Also APDC co-precipitation was successful in removing these metals from this buffered titrant prior to its use on samples. As a result the levels of $\mathrm{Cd}, \mathrm{Ni}$ and Pb in this solution were sufficiently low to be corrected for adequately by procedural blanks. Previous work had established that $\mathrm{NH}_{4} \mathrm{C}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ was an acceptable buffered titrant for use in co-precipitating Cd using APDC. Thus further tests with this solution were conducted only on Ni and Pb . The decrease in Ni recovery in the titrant test (see Table 2) was apparently due to a lack of Ni contamination in the $\mathrm{NH}_{4} \mathrm{C}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ titrant.. Lead recoveries were acceptable using this solution.

## Indicator

Preliminary trials indicated that the color variation exhibited by meta-cresolsulfonephthalein permitted accurate pH matching in the range pH 1.8 - 2.7. The indicator, after purification by APDC co-precipitatión, also yielded blanks with no detectable $\mathrm{Cd}, \mathrm{Ni}$ and Pb .

## Time Before Filtration

The influence of the time interval between co-precipitation and filtration on metal recovery was studied. After 10 minutes, no increase in metal uptake occurred and losses did not occur prior to 45 minutes. Thus it was decided to perform filtration on samples in batches small enough to begin 10 minutes after co-precipitation and finish before 30 minutes.

## Filtration Apparatus

PLASTIPACK disposable syringes were used to drive the co-precipitated samples through $13 \mathrm{~mm} \times 0.4 \mu \mathrm{~m}$ polycarbonate NUCLEPORE filters contained in a 13 mm Swinnex-type Millipore filter holder. The silicone rubber washer of the holder was fixed inside the polypropylene housing with GE silicone sealer. Otherwise, it would adhere to filters and dislodge part of the precipitate from them upon disassembly. The syringe filtration system was convenient for the number of samples processed, but with more samples a vacuum manifold would be preferred.

## Sample Analysis

Subsequent sections describe the final APDC co-precipitation procedure developed from the preliminary work detailed above. This procedure was used to determine the levels of $\mathrm{Cd}, \mathrm{Ni}$ and Pb in 35 organism samples from the STOCS study area. The types of samples analyzed were fish flesh (21 samples), shrimp flesh (3), fish gill tissue (4), fish liver (4) and NBS bovine liver (3). These samples were prepared for AAS analysis in the same way as all STOCS BLM organism samples. The concentration of $\mathrm{Cd}, \mathrm{Ni}$ and Pb were first determined directly by flameless AA using standardized procedures adopted for the analysis of BLM samples. These preparative anc AA analytical techniques are described fully in the Final Report of the 1976 BLM STOCS Trace Metals Project (Presley and Boothe, 1977). These analyses were made using a PERKINELMER Model 306 AA spectrophotometer equipped with an HGA- 2100 graphite furnace atomizer. The remainder of each digested sample was then used to determine the levels of these same three metals by the APDC-co-precipitation method described below. This phase of the study was conduc' ted "blind" with samples being identified only by an arbitrary code number.

Reagent Preparation
pH Indicator: Meta-cresolsulfonephthalein, $0.8 \%$ in ethanol, was diluted $1 / 5$ with distilled water and co-precipitated with APDC, as described later.

1000 ppm Co: Titrasol 1000 ppm cobalt standard was made up to volume with deionized water.

2\% APDC: $\quad$ Fisher analytical reagent grade APDC was dissolved in water, $2 \% \mathrm{w} / \mathrm{w}$, and aged 1 hour before use.

Saturated NaC1: Excess Mallinckrodt NaCl was added to deionized water and stirred magnetically three hours, stored in 40 dram PLASTAINER snap cap vials, buffered to pH 3.5 and co-precipitated with APDC before use.

Ammonium acetate buffered titrant: Mallinckrodt $36 \% \mathrm{HC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$, analytical reagent grade, was adjusted to pH 3.5 using ultrex $\mathrm{NH}_{4} \mathrm{OH}$. The solution was co-precipitated with APDC prior to use.

Sulfide Solution: Hydrogen sulfide was generated from FeS and HCI in an $\mathrm{H}_{2} \mathrm{~S}$ generator and bubbled through ultrex $\mathrm{NH}_{4} \mathrm{OH}$ for two hours.

## Co-Precipitation

Strongly acidic sample solutions were stored in polyethylene centrifuge tubes until analyses could be performed. For this analysis sample solutions were weighed into 13 dram PLASTAINER snap cap vials. Each vial received, with stirring between additions, one drop pH indicator, 1.0 ml saturated NaCl solution, 0.1 ml sulfide solution, and .05 ml 1000 ppm Co. At this point, the pH was adjusted to 2.5 using the buffered titrant and matching colors with a color standard vial, containing indicator, at pH 2.5. Each sample then received 0.2 ml of a $2 \%$ APDC solution previously aged for an hour. Filtration began 10 minutes after APDC addition and was concluded within 20 minutes.

## Filter Leaching

PLASTAINER 5 dram snap cap vials received 0.1 ml ultrex concentrated
$\mathrm{HNO}_{3}$ and were set aside. After filtration each filter containing the APDC precipitate was transferred to one of these vials into the droplet of acid. The filter was allowed to leach five minutes before 1.0 ml aliquot of ultrex $0.1 \mathrm{NHNO}_{3}$ was added.

## Flameless AA Analysis

The concentrations of $\mathrm{Cd}, \mathrm{Ni}$, and Pb in the acid leachate of each sample were determined by flameless $A A$ analysis. The procedures used were the same as those described above for the direct determinations. To accurately correct for any non-linearity, the standard curves used to quantify these samples were calculated using a fourth degree polynomial curve fitting procedure.

## Calculation of Co-Precipitation Data

The method of standard additions was used to determine the percentage of $\mathrm{Cd}, \mathrm{Ni}$ and Pb recovered from the sample solutions by the APDC co-precipitation procedure. Two separate standard addition series (6 spiked aliquots) were prepared using aliquots from a single, large fish muscle sample. The perc̣ent recoveries of all three metals were generally not quantitative. The ranges were $64-97 \%$ for $\mathrm{Cd}, 31-112 \%$ for Ni and $32-87 \%$ for Pb . Recovery was affected strongly by the analyte concentration in the sample and to a lesser degree by the pH of the solution in which the co-precipitation was performed. Analyte concentrations varied as much as two to four orders of magnitude among different sample types. The pH was much less variable (i.e. $\mathrm{X}=2.5 \pm 0.25$ ).

To calculate the final results, it was necessary to correct the raw co-precipitation AA data for the incomplete recovery observed. However, as noted above, the percent recovery was not the same for each sample.

Rather it varied as a function of pH and analyte concentration. Thus a different correction factor (s) based on these two parameters was needed for each sample. The use of two separate correction factors (one based on pH and a second on analyte concentration) was ruled out because this approach ignores effects on recovery resulting from interactions between pH and analyte concentration. It was finally decided to use multiple linear regression (MLR) analysis to determine the correction factor. This approach permits a quantitative evaluation of the relationships between the dependent variable (percent recovery) and independent variables ( pH , analyte concentrations) as well as any interactions between the independent variables themselves.

MLR analysis was conducted on the standard additions data for all three elements. Equations were calculated by regressing percent recovery against both pH and observed analyte concentration. The percent recovery for each metal in each sample was determined by substituting the sample pH and analyte concentration into the appropriate MLR equation. Since the MLR equations were computed from only six observations for each metal, the validity of this approach cannot be proven statistically. However, the MLR model is logical and permits calculation of an objective correction factor that accounts for two major factors affecting recovery, pH and analyte concentration.

## RESULTS AND DISCUSSION

Results of direct flameless atomic absorption (AA results) and those of analyses following APDC co-precipitation and application of a correction term derived using multiple linear regression (MLR coprex results) appear in Table 3.

## TABLE 3

CADMIUM, NICKEL AND LEAD LEVELS OBTAINED BY CONVENTIONAL AAS (AA) ANALYSIS AND BY APDC CO-PRECIPITATION FOLLOWED BY AA ANALYSES (MLR COPREX) UNITS ARE TOTAL ng METALIN DIGEST ANALYZED

| Sample No. |  | Cadmium |  | Nickel |  | Lead <br> MLR Coprex |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Mg | 3 |  | 25 | 280 | 89 | 97 | 120 |
|  | 4 | 12 | 15 | 190 | 110 | 91 | 150 |
|  | 5 |  | - | 42 | <38 | 13 | 8 |
|  | 6 |  | $<8$ | 42 | $<59$ | 52 | 36 |
|  | 7 | 16 | 43 | 34 | <86 | 86 | 107 |
| U | 8 |  | 4 | 10 | 48 | 19 | <30 |
| S | 10 | 12 | 10 | 450 | 63 | 180 | 40 |
| C | 12 |  | 1.4 | 39 | <32 | 30 | 12 |
| C | 13 |  | 0.7 | 26 | <33 | 22 | 17 |
| E | 14 | 56 | 68 | 420 | 180 | 200 | 350 |
|  | 16 | 9 | $<21$ | 87 | < 110 | 53 | 53 |
|  | 17 | 3 | 4 | 5 | <50 | 27 | <30 |
| I | 18 | 11 | 12 | N.D. | <55 | 160 | 120 |
|  | 20 | 9 | 31 | 54 | <100 | 53 | 170 |
| S 22 |  | 3 | 2.9 | 44 | <68 | 23 | 46 |
| U | 23 | 23 | 36 |  | 240 | 100 | 320 |
|  | 24 | 45 | 41 |  | 130 | 88 | 85 |
|  | 25 | 15 | 30 |  | $<82$ | 97 | 120 |
|  | 27 | 140 | 180 |  | 230 | 270 | 270 |
|  | 28 | 14 | 84 |  | <70 | 74 | 67 |
|  | 29 | 21 | 45 |  | - | 290 | 260 |
|  | 30 |  | 21 | N.D. | $<56$ | 67 | 110 |
|  | 31 |  | <9 | 80 | $<91$ | 65 | $<54$ |
|  | 35 | 8 | 7 | 2 | $<30$ | 13 | <23 |
| 1320 |  | 6 | 7 | 38 | <30 | 13 | <23 |
| G 2 |  | $1500 \quad 1300$ |  | 600 | 600 | 1610 | 1600 |
| I | 9 | 4300 | 7600 | 830 | 560 | 980 | 1400 |
| L | 21 | 650 | 1200 | 500 | 720 | 440 | 830 |
| L | 26 | 310 | 430 | 240 | 470 | 270 | 1400 |
| L 1 |  | 10104 | 6300 | 420 | 190 | 260 | 230 |
| I | 11 | 2000 | 3800 | 45 | <130 | 140 | 240 |
| V | 15 | 2100 | 1100 | 48 | <53 | 59 | 100 |
| E | 19 | 140 | 88 | 120 | 40 | 96 | 130 |
| R | 32 | 190 | 220 | 76 | $<70$ | 300 | 380 |
|  | 33 | 2400 | 3200 | 130 | 260 | 190 | 400 |
|  | 36 | 550 | 300 | 240 | 110 | 420 | 420 |

N.D. - Not detectable

In order to reduce the detection limit for the metals studied using the MLR coprex procedure, direct AA and MLR coprex must be compared at levels detectable by both procedures to ensure comparable results are obtained. Scatterplots illustrating these comparisons for each metal and tissue type appear in Figures 1 through 9. A summary of quantitative differences between the results from both procedures is given in Table 4. Ratios of the means resulting from each method were computed. Expected deviations were calculated using the standard error of the differences between the means of each data set (Snedecor and Cochran, 1967). Results of these computations appear in Table 4.

The comparisons indicate the following:
Only Cd and Ni in muscle tissue appeared to yield different results by the different methods based on the $t$ test results.

The lack of significant $t$ values for the other elements and tissues is due at least in part to the large variance in the MLR coprex results which obscures differences.

Nickel results were variable to an unsatisfactory degree except perhaps in gill tissue. Lead appears to be estimated adequately in all tissues, though the results are low but not to a statistically significant degree. Thus, MLR coprex most successfully estimates the following: Pb in all tissues studied, Cd in liver tissue and Ni in gill tissue.

The analyses of NBS bovine liver by each method (Table 5) verify the trends noted above. The MLR coprex values were quite variable and generally higher than those from the direct $A A$ analyses. The only large discrepancy is that of Cd in liver tissue. However, the result is within three standard deviations ( $95 \%$ confidence interval) of the expected value. This emphasizes the variability intrinsic in the method. For the other






Figure 5. Scatterplot of Nickel in Gills Comparing Results of Flameless AA Analysis Before and After APDC Co-Precipitation. Data Points Represent Total Amount of Metal in Each Sample (ngms) with the Line of Perfect Agreement Appearing in the Figure.




Figure 9. Scatterplot of Lead in Liver Comparing Results of Flameless AA Analysis Before and After APDC Co-Precipitation. Data Points Represent Total Amount of Metal in Each Sample (nmgs) with the Line of Perfect Agreement Appearing in the Figure.

COMPARISONS OF ANALYSIS MEANS OBTAINED BY FLAMELESS ATOMIC ABSORPTION WITH AND WITHOUT APDC CO-PRECIPITATIVE PRECONCENTRATION

| Tissue | Element | Ratio of means | Results of paired $t$ tests comparing analyses with and without APDC preconcentration |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | (APDC AA/Direct AA x 100) | df | t value* | Probability |
| Muscle | Cd | $61 \pm 16 \%$ | 19 | 3.15 | <. 05 |
|  | Ni | $299 \pm 93 \%$ | 3 | 3.55 | <. 05 |
|  | Pb | $83 \pm 18 \%$ | 19 | 1.24 | $>0.4$ |
| Liver | Cd | $116 \pm 45 \%$ | 6 | 0.5 | $>0.5$ |
|  | Ni | $150 \pm 84 \%$ | 3 | 0.98 | >0.4 |
|  | Pb | $78 \pm 15 \%$ | 6 | 2.09 | >0.1 |
| Gil1 | Cd | $64 \pm 50 \%$ | 3 | 1.18 | >0.4 |
|  | Ni | $93 \pm 33 \%$ | 3 | 0.36 | $>0.5$ |
|  | Pb | $64 \pm 27 \%$ | 3 | 2.13 | $>0.2$ |

[^3]TABLE 5

COMPARISONS OF CONVENTIONAL ATOMIC ABSORPTION VERSUS MLR COPREX RESULTS ON NBS STANDARD BOVINE LIVER. RESULTS ARE REPORTED As ngms OF METAL IN THE SAMPLE ALIQUOTS DIGESTED

| Sample No. |  | Cadmium |  |  | Nickel |  |  | Lead |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | MLR <br> Coprex | AA | NBS | MLR <br> Coprex | AA | NBS | $\begin{aligned} & \text { MLR } \\ & \text { Coprex } \end{aligned}$ | AA | NBS |
| Mg | 19 | 137 | 88 | 87 | 116 | $<40$ | <64 | 96 | 130 | 109 |
|  | 32 | 186 | 216 | 204 | 76 | $<70$ | <151 | 303 | 378 | 256 |
|  | 36 | 546 | 280 | 298 | 235 | 110 | <220 | 420 | 420 | 375 |

elements the agreement is closer, being much better than expected for Ni . Coprex data for the analysis of the samples found to be below the detection limit for direct AA analysis appear in Table 6. It should be noted that samples 23 through 29 in the muscle tissue section of Table 3 were obviously contaminated by Ni. They were co-precipitated sequentially and apparently some contaminating event occurred. The values they represent are from 0.6 ppm to 1.6 ppm Ni and so are many times normal values. They are not included in the calculations of the means in Table 6 and were omitted from Table 3.

Coprex analysis of previously undetectable levels of $\mathrm{Cd}, \mathrm{Ni}$ and Pb in the STOCS organism digests confirms the low levels reported by the direct AA analysis for these tissues. The observed values expressed as a percent of the direct $A A$ detection limit also appear in Table 6 . For Cd this is $51 \%$ of the detection limit, for Ni it is $48 \%$ and for Pb it is $82 \%$. The detection limit is reduced 5 to 10 fold using the MLR coprex procedure since a 10 to 1 preconcentration is affected and most of the sample matrix is removed. The high variability noted must be weighed against this greatly increased sensitivity. The procedure is of value in verifying evidence concerning low levels of metals in complex sample matrices, since it results inea virtually matrix-free sample which shows none of the severe supression effects noted in ordinary organism digests. In this capacity it is a semi-quantitative check. Lead analyses in complex matrices are subject:to severe supression effects and frequently result in false positive signals due to absorption at the Pb line which is not corrected by the deuterium arc. The dilemma of simultaneous supression and enhancement can occur, and a small dilution may remove completely the observed signal, while addition of a strong standard solu-

TABLE 6
MLR COPREX ASSAY OF METAL LEVELS IN SAMPLE TYPES STANDARD FOUND TO BE BELOW DETECTION LIMITS OF DIRECT AA ANALYSIS. RESULTS REPORTED ARE IN UNITS OF ng ANALYTE PER GRAM OF TISSUE

| Sample | Tissue Type | cd |  |  | Ni |  | Pb |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | ```Detection Limit AA``` | MLR Coprex Analysis |  | Detection Limit AA | MLR Coprex Analysis | $\begin{gathered} \text { Detection } \\ \text { Limit } \\ A A \end{gathered}$ | MLR Coprex Analysis |  |
| Mg 5 | muscle | 9.5 | 6.3 |  | 75 | 82 |  |  |  |
| 6 | muscle |  |  |  | 70 | 50 |  |  |  |
| 7 | muscle |  |  |  | 40 | 16 |  |  |  |
| 8 | muscle |  |  |  |  |  | 57 | 36 |  |
| 11 | fish liver |  |  |  | 26 | 32 |  |  |  |
| 13 | muscle |  |  |  | 97 | 76 |  |  |  |
| 15 | fish liver |  |  |  | 70 | 63 |  |  |  |
| 16 | muscle |  |  |  | 50 | 42 |  |  |  |
| 17 | muscle |  |  |  | 89 | 9 | 54 | 48 |  |
| 18 | muscle |  |  |  | 70 | nd |  |  |  |
| 20 | muscle |  |  |  | 57 | 31 |  |  |  |
| 22 | muscle |  |  |  | 111 | 72 |  |  |  |
| 30 | muscle |  |  |  | 48 | nd |  |  |  |
| 31 | muscle |  |  |  | 49 | 43 | 29 | 35 |  |
| 32 | bovine liver | 4.8 | 1.8 |  | 93 | 101 |  |  |  |
| 1320 | muscle |  |  |  | 22 | 28 |  |  |  |
|  |  |  |  |  |  |  | $39.3$ | $32.3$ | 82\% |
|  | le Tissue | 9.75 | 5.3 | 54\% | $64.83$ | $37.457 \%$ | $39.3$ | $32.3$ | 82\% |
|  | ne Liver Liver | 4.8 | 1.8 | 38\% | 93 48 | 10148 <br> $100 \%$ | -- | -- | -- |

tion may fail to increase peak height at all. Such a situation prevents a conclusive analysis, leaving the analyst with no idea of the levels in his sample.

The analyses of Cd and Ni can be plagued by similar problems when examining marginally detectable levels in complex matrices.

CONCLUSIONS

1. The MLR coprex procedure described provides greatly increased sensitivity at the expense of increased variability. Therefore, it is a highly sensitive but semi-quantitative procedure for the study of certain trace metals in biological tissues.
2. The method best measures Pb in all sample types, Ni in gill and Cd in liver tissue; and it is least effective in estimating Ni levels in muscle and liver.
3. Application of the procedure to STOCS samples with previously undetectable metal levels generally confirms the low levels of Cd and Ni reported and indicates that Pb levels in these samples are only slightly below the detection limit.

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#### Abstract

A single station (near STOCS 4/II) was sampled for 24 hour periods on 29-30 June, 24-25 July, 25-26 September and 8-9 November 1978. Samples surveyed turbidity, light transmission, temperature, salinity, ${ }_{1}$ plant nutrients, plant biomass, species abundances, and near bottom ${ }^{14} \mathrm{C}$ uptake. A variable nepheloid layer was encountered during each cruise; only the first two cruises had associated phytoplankton abundances. These phytoplankton accumulations were composed of both pelagic and benthic species. Net ${ }^{14} \mathrm{C}$ uptake was detected within these layers under in situ conditions. Evidence suggests that this layer may be especially vulnerable to energy related activities.


## INTRODUCTION

Near－bottom increases in suspended sediments（nepheloid layer by analogy to deep sea terminology）are readily observed on world shelf areas when sought with appropriate techniques．In general，however， a detailed understanding is lacking because 1）marine geologists have only recently appreciated the need of defining the role of the nepheloid layer in sediment transport；2）sampling problems exist in maintaining the integrity of field particles during laboratory measurements；and 3） the three－dimensional problem of diffusion－advection is complex（Drake， 1976）．

The South Texas Outer Continental Shelf（STOCS）is a prime area for observing nepheloid layer dynamics due to the general availability of fine sediment，the extensive shallow shelf，and the suspension energy supplied by strong wind and measurable tidal forcing．Berryhill et $a Z$ ． （1977）summarize the spatial variability of the STOCS nepheloid layer as observed during three cruises dated November 1975，March 1976 and May 1976．They conclude that nearshore，inner shelf and outer shelf bottom water turbidity is variable in thickness and in distribution and is related in a complex way with the thermal structure．Nearshore suspen－ sion is caused by wave surge and tidal mixing．The offshore structure is generally two－layered with a nepheloid layer below a less turbid layer；it is thickest toward the outer shelf．Rezak（1977）provides additional profiles from the STOCS area．

The present study（NEPHY）investigates phytoplankton associations within the nepheloid layer as observed at a single station（near Station 4／II）over a 24 hour period on four separate cruises．Among the physical and chemical variables that must be considered are suspension mechanisms，
available light and nutrients. Suspension is aided by the same shear mechanisms that generate the nepheloid layer. In addition, phytoplankton have the ability to control their density (Smayda, 1970) and are thus less dependent on shear forces than inert particles. Since phytoplankton require about 8 uein $\mathrm{m}^{-2} \mathrm{sec}^{-1}$ of incident light (400-700 nannometers) to balance photosynthesis and respiration (Strickland, 1958), the available light penetrating through the water column to the nepheloid layer and then through the nepheloid layer itself is vital. Finally, nutrients must be supplied to the suspended phytoplankton for growth to continue. Rowe et al (1975) and Hartwig (1976) both provide information on the flux of nutrients across the sediment-pelagic interface. Their studies are especially interesting as they relate to the STOCS area because of the frequent appearance of the nepheloid layer between the sediment interface and a thermocline. Nutrients from the sediments are then mixed into a relatively thin water layer that concentrates the results of benthic regeneration. Additional nutrients may be obtained within the nepheloid layer itself through the activity of bacteria-colonized inorganic particles.

The following report is a beginning toward clarifying some of the complex relationships outlined above. Basic information is provided on the seasonality of a photosynthetically active nepheloid layer and on the environmental conditions associated with its occurrence.

METHODS
A station at about 33 m water depth along Transect II was occupied for 24 -hour periods on 29-30 June (NEPHY I), 24-25 July (NEPHY II), 25-26 September (NEPHY III), and 8-9 November (NEPHY IV) 1978. The depth was chosen based on Figures 1 and 2 which demonstrate the relationships


Figure 1. Comparison of Water Depth and Photic Zone Depth at All Stations Occupied Along Transect II During 1976.
(Numbers on Graph Denote Months of Year.)


Figure 2. Comparison of Water Depth and Photic Zone Depth at All Stations Occupied Along Transect II During 1977. (Numbers on Graph Denote Months of Year.)
between the photic zone depth and the water depth as determined during the STOCS program cruises along Transect II during 1976 and 1977. These figures suggest that the nepheloid layer can be within the photic zone between the shore and 30 nautical miles offshore ( 60 m depth) during July, August and September. The chosen station was thus near mid-depth within this bend.

Samples were collected at 4 -hour intervals except when prohibited by equipment failure. A sample set was missed during both NEPHY I and NEPHY III. The general sampling program consisted of successive profiles with a transmissometer (MARTEK), STD (PLESSEY 9060), submarine photometer (LAMBDA), and pump-fed fluorometer (TURNER DESIGNS, Source: F4T5 Fluorescent lamp, Excitation filter: 5-60 filter: Emission filter: 2-64 filter; photomultiplier: R446 infrared sensitive) blanked with distilled water. Discrete samples were collected from a second pump profile for determinations of plant nutrients $\left[\mathrm{NO}_{3}, \mathrm{NO}_{2}, \mathrm{NH}_{4}, \mathrm{PO}_{4}, \mathrm{Si}(\mathrm{OH})_{4}\right]$, chlorophyll a and phytoplankton species abundances at selected depths. Plant nutrients (except $\mathrm{NH}_{4}$ ), chlorophyll a and phaeopigments (Trichromatic technique on a spectrophotometer, SCOR-UNESCO Equation for chlorophyll a; Strickland and Parsons' equation for phaeopigments) were analyzed according to the techniques described in Strickland and Parsons (1968). $\mathrm{NH}_{4}$ was determined according to Solorzano (1969). Phytoplankton species were determined according to the Utermöh1 (1931) procedure on an inverted microscope. The STD profile was calibrated with discrete samples taken at the top and bottom of the water column. Salinity was determined on a BECKMAN salinometer. During NEPHY I and II, the nepheloid layer was found within the photic zone. In situ ${ }^{14} \mathrm{C}$-uptake experiments were performed on water collected at 0300 with a $30-\ell$ Niskin triggered within the nepheloid layer. Water from the Niskin was distributed into 36125 ml bottles, 18 1ight and 18 dark. These bottles were divided into three groups of six light and six
dark, inoculated with $2.5 \mu \mathrm{Ci}$ of $\mathrm{NaH}^{14} \mathrm{CO}_{2} / 125 \mathrm{ml}$ bottles, placed on three separate racks and suspended from the ship before sunrise at the sample depth. The incubations lasted from sunrise to local noon. From each group, three light and three dark bottles were filtered through $0.45 \mu \mathrm{~m}$ MILLIPORE filters and three light and three dark bottles were filtered through both a $20 \mu \mathrm{~m}$ NYTEX mesh and a $0.45 \mu \mathrm{~m}$ MILLIPORE filter. The $0.45 \mu \mathrm{~m}$ MILLIPORE filters were counted on a PACKARD liquid scintillation counter. Since alkalinities were not determined on a sample from the NISKIN bottle, a reasonable estimate of $\mathrm{W}=24000$ was made in the calculation of $\mathrm{mgC} \mathrm{m}^{-3} \mathrm{hr}^{-1}$ (Strickland and Parsons, 1968).

Selected equipment and sampling problems arose on some of the cruises. These are outlined below:

NEPHY I - the pump-fed fluorometer malfunctioned during the first three profiles;

- the transmissometer malfunctioned during the fourth profile;
- phytoplankton species abundance data were collected only during the last two profiles;

NEPHY II - no problems;
NEPHY III - Secchi depth determination was missed during profile 5;
NEPHY IV - the pump-fed fluorometer malfunctioned during all profiles;

- the temperature record was missed during the STD cast representing profile 5;
- the transmissometer calibration was erratic, the highest reading obtained in air was arbitrarily taken at $85 \%$, the underwater values were adjusted by the ratio for each profile.

Analytical problems also occurred in some laboratory techniques. The phosphate, silicate and ammonia values were blanked by the lowest determination within a cruise. The reported values may thus slightly underestimate the actual concentrations.

## RESULTS

The data collected during the four NEPHY cruises are listed in Appendices A through C．Appendix A contains depth distribution of measured factors；Appendix B contains phytoplankton species abundances in the near bottom sample；and Appendix C contains the ${ }^{14} \mathrm{C}$－uptake by nepheloid layer phytoplankton．Each cruise will be discussed in turn．

## NEPHY I

This cruise encountered a fluctuating nepheloid layer（ $1-6$ meters thick）that averaged about 3 meters in thickness（Figure 3）．The sur－ face waters were sufficiently clear to allow greater than $1 \%$ of the incident light（400－700 nannometers）to reach the sediment interface （Figure 4）．The thermocline depth（Figure 5）was not directly related to the nepheloid layer；at certain times the nepheloid layer was well below the thermocline or the nepheloid layer extended through the thermo－ cline．Figure 6 showed that a shallow halocline occurred in the water column at a depth well above the thermocline．The plant nutrients analyses demonstrated unstructured profiles for $\mathrm{PO}_{4}, \mathrm{NO}_{3}$ ，and $\mathrm{NO}_{2}$ ； $\mathrm{Si}(\mathrm{OH})_{4}$ and $\mathrm{NH}_{4}$ （Figure 7）showed a tendency to increase near the sediment interface． In vivo fluorescence（Figure 8）was uniformly low in the upper 10 meters， gradually increased to a maximum at about 26 m and slightly decreased to the sediment interface．Chlorophyll a concentration（Figure 9）showed a much more even distribution throughout the water column except for the increase in the bottom sample．The C／P ratio increased somewhat with depth suggesting a decreased grazing pressure compared to the upper water column．

Appendix B－1 provides a species list that had an even mix of pennate and centric diatoms．The former was dominated by the Nitzschia sps．；the




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M
Figure 6. Plot of Salinity (ppt) vs. Depth (meters) for cruise NEPHY I. The different profiles according to time of day measured for each selected parameters are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.
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Figure 7. Plot of $\mathrm{NH}_{4}$ Concentration ( $\mu \mathrm{g}-\mathrm{at} \mathrm{N} \ell^{-1}$ ) vs. Depth (meters) for cruise NEPHY I. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.

Figure 9. Plot of Chlorophyll a Concentration ( $\mu \mathrm{g} \ell^{-1}$ ) vs. Depth (meters) for cruise NEPHY I. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.
latter was dominated by Rhizosolenia sps. and Hemiaulus sps.
Appendix C-1 shows that net carbon fixation occurred in both the net (> $20 \mu \mathrm{~m}$ ) and the nanno ( $<20 \mu \mathrm{~m}$ ) size fractions under in situ light conditions.

## NEPHY II

During the first six profiles, this cruise encountered a fluctuating nepheloid layer ( $8-18$ meters thick) that averaged about 10 meters in thickness (Figure 10). The last profile in the series drastically deviated from this pattern with an intermediately turbid water column extending from 4 meters below the surface to the sediment interface, a distance of 29 meters. Figure 11 showed that $5-10 \%$ of the incident light (400-700 nm ) penetrated to the sediment interface under the conditions of the first six profiles; the value increased to $20 \%$ under conditions of the seventh profile. A sharp thermocline (surface $29^{\circ} \mathrm{C}$, bottom $24^{\circ} \mathrm{C}$ ) with the maximum gradient at about 19 meters acted as an effective cap to the nepheloid layer except during profile seven (Figure 12). The water column was isohaline during this cruise (Figure 13) with values generally around 36.4 ppt . $\mathrm{PO}_{4}, \mathrm{NO}_{3}$, and $\mathrm{NO}_{2}$ showed little structure in the water column; $\mathrm{NH}_{4}$ concentration (Figure 14) was erratic, but occasionally increased toward the bottom. Si(OH) 4 drastically increased throughout the water column beginning with profile 4. In vivo fluorescence (Figure 15) appeared similar to the transmission profiles in all cases, but did not exactly follow them. Chlorophyll a concentration (Figure 16) also followed the transmission profiles in all cases. The deviant turbidity profile (seven) was substantiated by both the in vivo fluorescence and the chlorophyll a data. The C/P ratio increased toward the bottom again suggesting decreased grazing activity.


Figure 12. Plot of Temperature ( ${ }^{\circ} \mathrm{C}$ ) vs. Depth (meters) for Cruise NEPHY II. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.


Figure 14. Plot of $\mathrm{NH}_{4}$ Concentration ( $\mu \mathrm{g}-\mathrm{at} \mathrm{N}^{-1}$ ) vs. Depth (meters) for cruise NEPHY II. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.
Figure 15. Plot of in vivo fluorescence (relative units) vs. Depth (meters) for cruise NEPHY II. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.


Figure 16. Plot of Chlorophyll a concentration ( $\mu \mathrm{g} \ell^{-1}$ ) vs. Depth (meters) for cruise NEPHY II. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.

Appendix B-2 demonstrates a complex shift in the class dominance patterns; centrics dominated all but the first and last profiles; dinoflagellates appeared in the last three profiles. The dominant species in each class were: Pennates - Nitzschia sps.; Centrics - Hemiaulus sps., Rhizosolenia sps.; Dinoflagellates - Gonyaulax polygramma.

Appendix C-2 shows the carbon fixation attained by a phytoplankton community collected just prior to the fifth profile when the silica concentrations drastically increased. Both net (> $20 \mu \mathrm{~m}$ ) and nanno ( $<20 \mu \mathrm{~m}$ ) fractions had significant carbon uptake under in situ light conditions.

## NEPHY III

This cruise encountered a developing nepheloid layer that attained a thickness of 5 meters (Figure 17). The first profile was characterized by a turbid near surface layer that was 13 meters thick and by a relatively clear lower layer; the remaining five profiles were clearer at the surface than near the sediment interface. An anomalously clear band of water centered at 25 meters depth gradually dec1ined over the sample interval. The increased turbidity in the surface waters resulted in a reduced photic zone with the $1 \%$ light level ( $400-700 \mathrm{~nm}$ ) centered around 1'6 meters depth (Figure 18). Water temperature structure (Figure 19) was nearly isothermal; profile three, which had extraordinarily clear surface water, was about $1^{\circ} \mathrm{C}$ warmer in the upper 12 meters than the other profiles. Salinity (Figure 20) increased with depth (surface ~ 32 ppt; bottom $\sim 34 \mathrm{ppt}$ ); the halocline occurred at $\sim 20$ meters. Generally all plant nutrients increased with depth. $\mathrm{NH}_{4}$ (Figure 21) was highest in those profiles related to the best developed nepheloid layer. In vivo fluorescence (Figure 22) was relatively unstructured with depth; there was some tendency for higher values in the upper half of the water column.

Figure 18. Plot of Percent Light (\%) vs. Depth (meters) for cruise NEPHY III. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.



Figure 22. Plot of in vivo Fluorescence (relative units) vs. Depth (meters) for cruise NEPHY III. The different profiles according to time of day measured for each selected parameters are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.

Chlorophyll a concentration (Figure 23) showed similar trends except for an increase near bottom in a few profiles. The C/P ratio generally decreased with depth suggesting increased grazing activity.

Appendix B-3 demonstrates the pennate dominance of the generally low population abundances. Nitzschia sps. were the most abundant pennates.

## NEPHY IV

This cruise encountered a developed nepheloid layer (Figure 24) about 10 meters thick that disappeared and then redeveloped to a thickness of 10 meters. . The surface waters were sufficiently turbid to 1 imit the $1 \%$ level of incident light ( $400-700 \mathrm{~nm}$ ) to about 24 meters (Figure 25), the top of the nepheloid layer at its thickest. The water temperature structure (Figure 26 ) showed an inversion with warmer water ( $\sim 25^{\circ} \mathrm{C}$ ) below the colder water $\left(\sim 23.5^{\circ} \mathrm{C}\right)$. The top of the thermocline accurred at about 17 meters depth. Salinity (Figure 27) also showed a two-layer structure (surface ~ 33 ppt; bottom ~ 35 ppt ) that changed at about 17 meters depth. $\mathrm{Si}(\mathrm{OH})_{4}$ and $\mathrm{PO}_{4}$ were generally unstructured with depth; $\mathrm{NO}_{3}$ and $\mathrm{NO}_{2}$ both increase within five meters of the bottom. $\mathrm{NH}_{4}$ (Figure 28) was erratic but generally increased in the near bottom samples. Chlorophyll a (Figure 29) was relatively high in the upper 12 meters of the water column during the first three profiles; the remaining profiles were less distinguished in this upper layer. The C/P ratio generally decreased with depth suggesting increased grazing activity.

Appendix B-4 demonstrates fluctuating dominance of pennate and centric diatoms. The former were dominated by Thalassionema nitzschioides; the latter by Chaetoceros sps.

## Specific

All cruises demonstrated the dynamic state of the nepheloid layer.
Figure 23. Plot of Chlorophyll a concentration ( $\mu \mathrm{g} \ell^{-1}$ ) vs. Depth (meters) for cruise NEPHY III. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.




#### Abstract

Figure 26. Plot of Temperature ( ${ }^{\circ} \mathrm{C}$ ) vs. Depth (meters) for cruise NEPHY IV. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.


Figure 27. Plot of Salinity (ppt) vs. Depth (meters) for cruise NEPHY IV. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.
Figure 28. Plot of $\mathrm{NH}_{4}$ concentration ( $\mu \mathrm{g}-\mathrm{at} \mathrm{N} \ell^{-1}$ ) vs. Depth (meters) for cruise NEPHY IV. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.

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Figure 29. Plot of Chlorophyl1 a concentration ( $\mu \mathrm{g} \ell^{-1}$ ) vs. Depth (meters) for cruise NEPHY IV. The different profiles according to time of day measured for each selected parameter are all plotted on the same graph. The profiles are distinguished by the profile numbers (1-6) corresponding to the profile order in Appendix A.

The thickness and density of the layer changed within a few hours providing an indirect index of the water motions involved. The physical conditions under which the nepheloid layer existed differed during each cruise:

NEPHY I - strong deep thermocline ( $\sim 8^{\circ} \mathrm{C}$ ); shallow weak halocline ( 2 ppt ); surface water clear (Secchi depth $\approx 22$ meters).

NEPHY II - strong intermediate thermocline ( $\sim 5^{\circ} \mathrm{C}$ ); no halocline; surface water clear (Secchi depth $\approx 22$ meters).

NEPHY III - weak shallow thermocline ( $<1^{\circ} \mathrm{C}$ ), weak deep halocline ( 2.5 ppt ); surface water turbid (Secchi depth $\sim 4$ meters).

NEPHY IV - weak inverted mid-depth thermocline ( $2.5^{\circ} \mathrm{C}$ ); weak middepth halocline ( 2 ppt ); surface waters somewhat turbid (Secchi depth $\approx 12$ meters).

Oxidized plant nutrients most consistently increased with depth during NEPHY III and IV. Silica showed an abrupt increase throughout the water column during NEPHY II that might be related to the appearance of dinoflagellates in the species sample. The unusual turbidity profile at the end of NEPHY II could be related to the vertical migration of a dense dinoflagellate population. This is especially likely since the temperature and salinity did not change significantly at that time. $\mathrm{NH}_{4}$ appeared to increase near the sediment interface during most profiles supporting the hypothesis of a benthic source for required nitrogen. More data is required for a definitive conclusion. In vivo fluorescence and chlorophyll a data demonstrate the association of phytoplankton biomass with the nepheloid layer during NEPHY I and II. The turbid surface waters during NEPHY III and IV apparently prohibited a deep phytoplankton maximum in the respective nepheloid layers. The species composition observed in the nepheloid layer derived both from pelagic and benthic sources suggesting a zone conducive to the maintenance of phytoplankton. The ${ }^{14} \mathrm{C}$ uptake data showed that the nepheloid layer supports net production during the summer months.

## General

Based on the results of the four NEPHY cruises, the role of the nepheloid layer as a reservoir of primary production during the summer months is maintained as a viable hypothesis. As shown in Kamykowski and Van Baalen (1978), the surface waters in the STOCS area during July can become warm (> $27^{\circ} \mathrm{C}$ ), saline (> 36 ppt ), and clear (chlorophyll a < 0.5 $\left.\mu \mathrm{g} \ell^{-1}\right)$. The Secchi depth across the shelf is greater than 20 m and the water column is thermally stratified. As seen in the present data under these conditions, a chlorophyll maximum appears below the thermoc1ine that is closely associated with the nepheloid layer. The species composition ( $>20 \mu \mathrm{~m}$ ) is a mixture of pelagic and benthic types suggesting that both settled oceanic forms and resuspended benthic forms contribute to the phytoplankton community. The production is maintained by light levels observed as high as $20 \%$ of surface radiation and by measurable concentrations of plant nutrients. Net carbon uptake is observed. Using the classical dark subtraction calculation as the standard, the nannophytoplankton are responsible for $37 \%$ of the total carbon fixed in June, and for $57 \%$ of the total carbon fixed in July. Based on average chlorophyll a concentration of $2.9 \mu \mathrm{~g} \ell^{-1}$ in June, and of $1.9 \mu \mathrm{~g} \ell^{-1}$ in July, a C/Chl a ratio of 60 and no cell carbon losses; a doubling of cell carbon in the nepheloid layer would require about 50 days in June and about 28 days in July. This calculation is only useful as a general index since it is based on community averages. Some species may contribute substantially to community chlorophyll a but little to community production while other species contribute little to community chlorophyll a, but may dominate the carbon uptake. The latter species would obviously double considerably faster than the community average computed above.

The primary production in the nepheloid layer is ultimately dependent on the clarity of the overlying water column. In some years, the clarity of the surface waters may be delayed beyond June thus delaying the initiation of a deep productive zone (Kamykowski et al., 1977). The return of turbid surface waters after a few months of clear conditions may occur in late summer due to hurricane activity or perhaps later in the year due to the passage of "northers". The longest anticipated season for a deep productive zone would probably be between early June and late September, a period of about four months.

The purpose of this research is to obtain basic information on the phytoplankton in the nepheloid layer and to speculate on the potential impact that petroleum related activities may have on this layer and its dependents. Various studies (Gordon and Prouse, 1973; Pulich et al., 1974; Winters et al., 1976; and Batterton et al., 1978) have investigated the effect of both fuel oils and crude oils on phytoplankton. Generalizations are difficult because different oils vary in toxicity and different species in the same class vary in response. It seems evident that both lipophilic and water soluble fractions of some oils are toxic to some algae; fuel oils are more toxic than crude oils. It seems probable that oil introduced into this environment would directly affect some species. Whether the decline of these species would affect other organisms in the food web is uncertain. Alternately, the whole phytoplankton community could be indirectly affected by oil if nutrient regeneration from the sediments were inhibited over a sufficiently broad area, if the light transmission properties of the overlying water were decreased, or if selected grazers were reduced below effective levels.

1. The nepheloid layer corresponds to a zone of concentrated phytoplankton biomass and active phytoplankton production during the summer months in the STOCS area. This zone extends from nearshore to about 30 nautical miles offshore.
2. The phytoplankton community is composed of both pelagic and benthic species.
3. The layer varies in thickness and intensity within the 24 hour sampling periods.
4. We can speculate that oil introduced into the near bottom layer will probably affect the species composition and net production of the phytoplankton community either through direct toxicity or through detrimental effects on light conditions, nutrient conditions or grazers.
5. The ecosystem impact of changes in this phytoplankton reservoir will depend on the alternate choices available to grazers.

APPENDIX A

Data summaries from four cruises of the NEPHY series providing date of cruise, cruise number, profile number, local time of profile, and secchi depth (meters), with a table of values for the following parameters:

```
water depth (meters);
transmission (percent);
salinity (ppt);
temperature ( }\mp@subsup{}{}{\circ}\textrm{C}\mathrm{ );
surface and subsurface light between 400-700 nm
    (\muein. m-2 sec-1);
light percent at depths;
in vivo relative fluorescence;
PO
Si(OH)4 (\mug-at Si \ell l ' );
NO
NO
NH4(\mug-at N \ell-1);
chlorophyll a ( }\mu\textrm{g}\mp@subsup{\ell}{}{-1}\mathrm{ );
chlorophy11-phaeopigment ratio.
```



DATE: GヵZ97A CHUISE NUMAER: 1- PROFILE NUMBER: 3 TIME: 13 AG SECCHI DEPTH: 23.75



| DEPTH | IHAMS． | SAL． | TEMP． | $\begin{gathered} \text { LIFHT } \\ \text { SURF. SIIR. } \end{gathered}$ | $\begin{gathered} \text { LIGHT } \\ 0 / 0 \end{gathered}$ | FLIJOR． | P04 | 31 | NO3 | NO2 | NH4 | CHLA | C／P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Hn | Hin．A | 32.75 | 29.32 |  | － | 1.3 | ＊ | － | － | － | － | － | － |
| （1） | カи．${ }^{\text {¢ }}$ | － | － |  | － | 1.3 | － | － | － | － | － | － | $\bullet$ |
| $\lambda 2$ | Hn．${ }^{\text {H }}$ | － | － |  | － | 1.3 | － | － | － | － 1 － | － 46 |  | 209 |
| 13 | H4．${ }^{\text {H }}$ | 32.85 | 29.32 |  | － | 1.3 | .58 | 2.8 | H．40 | .18 | .46 | ． 188 | 1.200 |
| $n 4$ | R14． 4 | － | ． |  | － | 1.3 | － | － | － | － | － | － | － |
| 45 | 44．い | － | － |  | － | 1.3 | － | － | － | － | － | － | － |
| H6 | 79．4 | 33.43 | 29.31 |  | － | 1.4 | － | － | － | － | － | － | － |
| 17 | 7A．U | ． | ， |  | － | 1.5 | － | － | － | － | － | 211 | －30 |
| 04 | 7H．U | － | － |  | － | 1.5 | ． 57 | 9.2 | B．0日 | .10 | － | .211 | 1.304 |
| n4 | 7H．U | 34.44 | 28.94 |  | － | 1.6 | － | － | － | － | － | － | － |
| 10 | 7R．N | － | ． |  | － | 1.7 | － | － | － | － | － | － | － |
| 11 | 74．И | － | － |  | － | 2．a | － | － | － | － | － | － | － |
| 12 | 7R．入 | 34.10 | 2日．月． |  | － | 2.1 | － | － | － | － | － | － |  |
| 13 | 74．4 | ， | － |  | － | 2.3 | ． 51 | 1.2 | 0．日月 | － 18 | ． 48 | .192 | 1.240 |
| 14 | 74．1 | － | － |  | － | 2.5 | － | － | ＊ | － | － | － | － |
| 15 | 7月．a | 34．54 | 28.78 |  | － | 2.7 | － | － | － | － | － | － | － |
| 16 | 78．И | － | － |  | － | 3.6 | － | － | － | － | － | － | － |
| 17 | 78.4 | － | － |  | － | 3.5 | － | － | － | － | － |  |  |
| if | 76．4 | 34．AR | 28.49 |  | － | 3.8 | ． 50 | U． 0 | O．Ba | .11 | ． 55 | .246 | 1.250 |
| 19 | 76.11 | － | － |  | － | 4.2 | － | － | － | － | － | － | －． |
| 24 | 7n．${ }^{7}$ | － | － |  | － | 5.2 | － | － | － | － | － | － | － |
| 21 | 16．4 | 35．4u | 28．74 |  | － | 6．${ }^{\text {¢ }}$ | － | － | － | － | － | － | － |
| 22 | 7n． 0 | － | － |  | － | 7．月 | － | － | － | － | － | － |  |
| 23 | 76．4 | － | － |  | － | 8.5 | ． 52 | 5．8 | A．AB | ． 11 | －5a | .266 | 1.333 |
| 24 | 15．4 | 35.22 | 28．44 |  | － | 10.7 | － | － | － | $\bullet$ | － | － | － |
| 25 | 75.1 | － | － |  | － | 12.0 | － | － | － | － | － | － | － |
| 26 | 75.4 | ． | － |  | － | 13.3 | － | － | － | － | － | － | － |
| 27 | 74.4 | 55．65 | 25.29 |  | － | 14.5 |  | － | － |  | － 39 | － |  |
| 2 H | 74.14 | － | － |  | － | 14.2 | ． 84 | 2.3 | Q．an | .11 | ． 39 | .497 | 1．454 |
| 29 | 74．4 | － | － |  | － | 13.9 | － | － | － | － | － | － | － |
| 34 | カи． 5 | 35.95 | 23.24 |  | － | 13.6 | － | － | － | － | － | － | － |
| 31 | 6．．4 | － | － |  | － | 12.6 | － | － | － | － | － | － | － |
| $3 ?$ | 6n．ll |  | － |  | － | 12．n |  |  |  |  |  |  |  |
| 33 | 2H．4 | 35.95 | 21.62 |  | － | － | .57 | 4.3 | 0.90 | ．14 | ． 85 | 3.586 | 1.538 |


| OEPTH | IHANS． | SAL． | TEMP． | $\begin{gathered} \text { LIGHT } \\ \text { SURF. SUB. } \end{gathered}$ | $\begin{gathered} \text { LIGHT } \\ \text { O/0 } \end{gathered}$ | FLUOR． | P04 | SI | NO3 | NO2 | NHA | CHLA | C／P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 161 | Ai4．H | 32.57 | 29．30 |  | － | 1.3 | － | － | － | － | － | － | － |
| 41 | カи．${ }_{\text {a }}$ | － | － |  | － | 1.3 | － | － | － | － | － | － | － |
| 42 | 8 81． 9 | ， | － |  | － | 1.3 |  | $5 \cdot 7$ | － 54 | －1a | － | 172 |  |
| 43 | HCH | 32.58 | 29．39 |  | － | 1.3 | .22 | 5.7 | .54 | ． 10 | － | .172 | 1．222 |
| 44 | Hu．${ }^{\text {H }}$ | － | － |  | － | 1.3 | － | － | － | － | － | － | － |
| 85 | Ha．h | － | － |  | － | 1.4 | － | － | － | － | － | － | － |
| H6 | 7H．A | 54．9n | 29.15 |  | － | 1.5 | － | － | － | － | － | － | － |
| d 7 | 1月．） | － | － |  | － | 1.5 | － | － | － | － | － |  |  |
| 14 | 7月．V | － | － |  | － | 1.6 | ． 16 | 10.3 | .75 | －99 | － | .160 | 1.259 |
| 09 | 7R．A | 34.54 | 29.95 |  | － | 1.7 | － | － | － | － | － | － | － |
| 14 | 7R．1 | － | － |  | － | 1.9 | － | － | － | － | － | － | － |
| 11 | 7R．D | － | － |  | － | 2.1 | － | － | － | － | － | － | － |
| 12 | 7R．H | 34.98 | 28.94 |  | － | 2.3 |  |  |  | －19 | － |  |  |
| 13 | 7R．H | 3． | 20．9 |  | － | 2.5 | .12 | 7.2 | 0.018 | .149 | － | .172 | 1.222 |
| 14 | 7～．И | － | － |  | － | 2.7 | － | － | － | － | － | － | － |
| 15 | 7R．4 | 34.95 | 26.99 |  | － | 2.9 | － | － | － | － | － | － | － |
| 16 | 79．4 | － | － |  | － | 3.2 | － | － | － | － | $\bullet$ | － | － |
| 17 | 7月．U |  |  |  | － | 3.6 |  |  |  |  | － |  |  |
| 1 H | 7h． 1 | 35.15 | 28.99 |  | － | 4.4 | .78 | 1.9 | .07 | .11 | － | .227 | 1.273 |
| 19 | 76．4 | ． | － |  | － | 5.2 | － | － | － | － | － | － | － |
| 24 | 7ヵ．4 |  | － |  | － | 5.8 | － | － | － | － | － | － | － |
| 21 | 75．4 | 35.25 | 28.78 |  | － | 6． 1 | － | － | － | － | － | － | － |
| 22 | 75．0 | － | － |  | － | 7.6 | － 08 | －${ }^{\circ}$ | －66 |  | － |  |  |
| 23 | 75.4 | 35.45 | 24＊ 6 |  | － | 9.5 | － 18 | 4．a | .66 | .12 | － | －282 | 1.348 |
| 24 | 74.4 | 35.45 | 28．62 |  | － | 11.4 | － | － | － | － | － | － | － |
| 25 | 74.9 | － | － |  | － | 14.2 | － | － | － | － | － | － | － |
| 26 | 74.14 | 35 | P8． |  | － | 15.8 | － | － | － | － | － | － | － |
| 27 | 73.1 | 35.55 | 28.48 |  | － | 17.1 |  | $6 \cdot 1$ |  |  | － |  |  |
| 2\％ | 73.4 | － | － |  | － | 16.4 | .03 | 6.1 | ． 14 | .13 | － | .282 | 1.308 |
| 29 | 13.6 | － | － |  | － | 16.4 | － | － | － | － | － | － | － |
| 31 | 42.4 | 35.68 | 28．94 |  | $\bullet$ | 15．8 | － | － | － | － | － | － | － |
| 31 | 42.11 | － 76 | － |  | － | 15.2 | － | － | － | － | － | ＊ | － |
| 32 | 42.4 | 35.76 | 23.20 |  | － | 14.5 |  |  |  |  | － |  | $\therefore 580$ |
| 33 | 5．n | － | － |  | － | ． | Q．AO | 15.2 | ． 81 | ．10 | － | 2.340 | 1.580 |

## CRUISE NUMBER 2

| DEPTH | IRANS． | SAL． | IEMP． | SIIRF | 11 SUR． | $\begin{gathered} \text { LIGHT } \\ 0 / 0 \end{gathered}$ | FLUNR． | POA | 31． | NO3 | NO2 | NH4 | CHLA | $C / P$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| na | 85.5 | 3n．5n | 27.24 | 1750 | 154n | 85.7 | 1.7 | － | － | － | － | － | － | － |
| 01 | 85.5 | － | － |  |  | － | 1.6 | － | ． | － | － | － | － | ． |
| in | A 5.5 | － | － |  |  | － | 1.2 | － | － | － | － | ． | － | － |
| 03 | 85.5 | 36．5n | 27.15 | 1740 | 1197 | 10．1 | 1.2 | － 19 | 7.2 | の．ค日 | .31 | ． 58 | .240 | 1.250 |
| 34 | 85． 5 | ． | ． |  |  | － | 1.2 | － | － | － | － | － | － | － |
| 15 | 85． 5 | － | － |  |  | － | 1.3 | － | － | － | － | － | － | － |
| 06 | 85.5 | 36.54 | 27．14 | 1740 | 498 | 58.7 | 1.2 | － | － | － | － | － | － | － |
| 07 | A5．${ }^{\text {a }}$ | ． | － |  |  | ． | 1.2 | － | － | － | － | － | － | － |
| ars | 84．010 | － | － |  |  | － | 1.3 | － | － | － | － | － | .188 | 1．246 |
| 19 | H4．${ }^{\text {H }}$ | 36．54 | 27.45 | $17 n n$ | 765 | 45．01 | 1.3 | － | － | － | － | － | － | － |
| 14 | H4．n | － | － |  |  | － | 1.3 | － | － | － | － | － | － | － |
| 11 | 84.9 | － | － |  |  | － | 1.4 | － | － | － | － | － | － | － |
| 12 | 84.0 | 36．43 | 26.98 | 1890 | 599 | 33.3 | 1.3 | － | － | － | － | － | － | － |
| 13 | A3． 11 | － | － |  |  | ． | 1.4 | ． 87 | 1.5 | .43 | .21 | .42 | .211 | 1．3日a |
| 14 | 73.4 | － | － |  |  | － | 1.4 | － | － | － | － | － | － | － |
| 15 | A3．4 | 36.44 | 26.91 | 1775 | 545 | 28．4 | 1.4 | － | － | － | － | － | － | － |
| 16 | A3．A | － | － |  |  | － | 1.5 | － | － | － | － | － | － | － |
| 17 | 83.1 | － | － |  |  | － | 1.6 |  | － |  | － | － | － |  |
| 18 | 82．${ }^{4}$ | 36.46 | 26.75 | 1790 | 432 | 25．4 | 1.7 | .19 | 2.3 | .18 | .11 | .24 | .298 | 1.286 |
| 19 | H2．${ }^{\text {a }}$ | － | － |  |  | ． | 1.8 | － | ， | － | － | － |  | －${ }^{\text {－}}$ |
| ？ 1 | 82.4 | － | － |  |  | － | 2.8 | － | － | － | － | － | ．668 | 1.583 |
| 21 | 81.4 | 36.41 | 26.36 | 1750 | 372 | 21.3 | 2.1 | － | － | － | － | － | － | － |
| 22 | An． 4 | ． | － |  |  | － | 2.3 |  | － | － | － | － | － | ＊ |
| 23 | 515.4 | － | － |  |  | － | 2.6 | .23 | .4 | .11 | ． 105 | .42 | 1.788 | 1.515 |
| 24 | 3R．4 | 36．3A | 23.75 | 1 ваи | 333 | 18． 5 | 3.3 | － | － | － | － | － | － | － |
| 25 | 2R．4 | － | ． |  |  | － | 5．9 | － | － | － | － | － | 。 | ， |
| 26 | 22．4 | － | 3． |  |  | － | 6.6 | － | － | － | － | － | － | － |
| 27 | 2い．n | 36． 39 | 23.22 | 1 ваи | 290 | 11.1 | 9.2 |  | － |  |  |  |  |  |
| 24 | 1月．0 | ， | ． |  |  | － | 11.4 | .24 | 1.4 | .22 | .05 | 1.77 | 2．368 | 1.535 |
| 29 | 11.11 |  | － |  |  | － 7 | 12.3 | － | － | － | － | － |  |  |
| 34 | 16．n | 3b． 39 | 23.21 | 184日 | 120 | 6.7 | 13.3 | － | － | － | － | － | 2.516 | 1.556 |
| 31 | 15.11 | 36.39 | 23.20 |  |  | － | 13.3 | － | － | 11 | 01 | 7 A |  |  |
| 32 | 15.9 | 36．39 | $23.2 n$ |  |  | ， | 13.3 | .20 | 2．01 | .11 | － 01 | ． 78 | 2.463 | 1.568 |
| 33 | 15．a | － | － | 18 HH | 49 | 5．9 |  |  | － | － | － | － | － | － |


| DEPTH | TRAMS． | SAL． | IEMP． | SIIRF | SUR. | $\begin{gathered} \text { LIGHT } \\ \text { O/O } \end{gathered}$ | FlUNR． | PO4 | 91 | NO3 | N02 | NHA | CHLA | C／P | $\vdots$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $0 \cdot 1$ | 45．4 | 36.52 | 29．044 | 1604 | 1340 | 81． 3 | 1.4 | － | － | － | － | － | － | － | ！ |
| $n 1$ | 85.9 | － | － |  |  | － | 1.3 | － | － | － | － | － | $\bullet$ | － |  |
| 42 | H4． 4 | － | － |  |  | － | 1.3 | － | － | － | － | － | － |  | 1 |
| 03 | 83.4 | 36.514 | 28.74 | 1694 | 865 | 54．0］ | 1.8 | .28 | 1.6 | .13 | .10 | .92 | .259 | 1.333 |  |
| a 4 | A3．${ }^{\text {a }}$ | ． | － |  |  | － | 1.8 | － | － | － | － | － | － | － | ！ |
| H5 | 83.4 | － | － |  |  |  | 1.9 | － | － | － | － | － | － | － | ！ |
| an | H2． 5 | 36.44 | 2R． 14 | 1650 | 333 | 215.2 | 1.9 | － | － | － | － | － | － | － | ； |
| 07 | 82． 5 |  | － |  |  | － | 1.8 | － | － | － | － | － | － | － |  |
| AH | A3． 1 | － | － |  |  | － | 1.8 | － | － | － | － | － | .227 | 1.166 | ！ |
| 49 | ${ }^{3} 3.4$ | 36.48 | 27．89 | 16 Wい | 319 | 19.9 | 1.6 | － | － | － | － | － | － | － |  |
| 113 | A3．4 | － | － |  |  | － | 1.4 | － | － | － | － | － | － | － | ！ |
| 11 | 84.4 | －${ }^{\circ}$ | －${ }^{\circ}$ |  |  | －${ }^{-1}$ | 1.4 | － | － | － | － | － | － | － |  |
| 12 | H3．4 | 36．4H | 27.39 | 1605 | 359 | 22.4 | 1.4 | $\bullet$ | － | － | － | － |  |  | $\stackrel{\square}{\square}$ |
| 13 | H3．4 | － | － |  |  | － | 1.5 | .48 | 1.9 | .18 | .09 | .74 | .243 | 1.250 | Y |
| 14 | 83.6 | ． | － |  |  | － | 1.5 | － | － | － | － | － | － | － | $\checkmark$ |
| 15 | A4．4 | 36.54 | 27.149 | 1650 | 333 | 20．2 | 1.6 | － | － | － | － | － | － | － | － |
| 1 t | 83.4 | ． | ． |  |  | ， | 1.6 | ． | － | － | － | － | ． | － |  |
| 17 | 83.8 | － | － 79 |  |  | － | 1.7 | － | － | － | － | ＊ | － |  |  |
| 18 | 83． 4 | 36.54 | 26.79 | 1650 | 333 | 28.2 | 1.7 | .18 | の．0 | － 29 | ． 12 | .61 | ． 301 | 1.345 |  |
| 19 | H2．n | ． | ． |  |  | － | 1.8 | － | － | － | － | － | － |  |  |
| 24 | A3．4 | － | － |  |  | － | 2.1 | － | － | － | － | － | 1.071 | 1．599 |  |
| 21 | H2．${ }^{\text {a }}$ | $36.4 n$ | 23.94 | 16146 | 346 | 21.6 | 2.4 | － | － | － | － | － | － | － |  |
| 22 | H2．4 | － | － |  |  | － | 2.6 |  | － |  | － |  |  |  |  |
| 23 | H1．${ }^{\text {H }}$ | ${ }^{-}$ | － |  |  | － | 3.1 | ． 30 | 1.6 | .26 | ． 08 | ． 52 | 2.283 | 1.524 |  |
| 24 | 8 ACH | 36.39 | 23.47 | 17 ns | 346 | 26.4 | 6.3 | － | 1． | － | － |  | －283 | － |  |
| 25 | 7ッ．か | － | － |  |  | － | 13.3 | － | － | － | － | － | － | － |  |
| 2 h | 52.4 |  |  |  |  | － | 15.8 | － | － | － | － | $\bullet$ | － | － |  |
| 27 | 28.4 | 36.39 | 23.44 | 1790 | 293 | 17.2 | 16.7 |  | － | － |  |  |  |  |  |
| 2 H | 21.6 | － | － |  |  | － | 17.4 | .37 | 1.5 | .16 | ． 14 | .74 | 2.626 | 1.521 |  |
| 29 | 19.4 | 36．4n | 23.44 |  |  |  | 17.1 |  | － | － | － | － |  |  |  |
| 3 H | $1 \mathrm{H.N}$ | 36．4n | 23.44 | 1659 | 2иa | 12.1 | 18.3 | － | － | － | － | － | 2.650 | 1.542 |  |
| 31 | 17.19 | ， | ， |  |  | － | 18.3 |  | － |  |  |  |  |  |  |
| 32 | 16．4 | 36.44 | 23.44 |  |  | － | 18.6 | .79 | 1.7 | .22 | .09 | .74 | 2.541 | 1.511 |  |
| 33 | 16.4 | － | － | 1768 | 163 | 9.4 | － | － | － | － | － | － | － | － |  |






| DEPTH | IHANS. | SAL. | TEMP. |  | ST | $\begin{gathered} \text { LIGHT } \\ \text { D/0 } \end{gathered}$ | FLUOR. | PO4 | SI | NO3 | NO2 | NH4 | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 04 | 85.5 | 36.48 | 20.58 | 9 90 | 767 | 85.2 | 1.8 | - | - | - | - | - | - | - |
| H1 | H5. 5 | - | . |  |  | - | 2.1 | - | - | - | - | - | - | - |
| 02 | H5. 5 | - | - |  |  | - | 1.7 | - | - | - | - 7 | - 7 |  | - |
| 43 | 85.5 | 36.48 | 2H.58 | 900 | 433 | 4R.1 | 1.7 | .18 | 18.8 | . 45 | . 87 | .27 | .294 | 1.2n0 |
| 14 | H5. 5 | . | . |  |  | - | 1.8 | - | - | - | - | - | - | - |
| 15 | 85.5 | - | - |  |  | - | 2. 1 | - | - | - | - | - | - | - |
| 06 | A5. 5 | 36.49 | 28.55 | 875 | 333 | 38.1 | 1.6 | - | - | . | - | - | - | - |
| 07 | 85.5 | . | - |  |  | . | 1.6 | - | - | - | - | - |  | - |
| ab | 85.5 | - | - |  |  | - | 1.6 | - | - | - | - | - | .263 | 1.231 |
| 09 | 85.5 | 36.47 | 28.15 | 960 | 307 | 34.1 | 1.6 | - | - | - | - | - | - | - |
| 10 | A5. 5 | - | . |  |  | - | 1.6 | - | - | - | - | - | - | - |
| 11 | 85.5 | - | * |  |  | - | 1.7 | $\bullet$ | - | - | - | - | - | - |
| 12 | 85.5 | 36.49 | 27.85 | 875 | 280 | 32.4 | 1.7 | - | - | - | - | , |  |  |
| 13 | 45.5 | . | - |  |  | - | 2. $\square^{1}$ | .11 | 19.2 | .53 | - 89 | .13 | . 243 | 1.154 |
| 14 | 85.5 | - | -78 |  | - 3 | - | 2.1 | - | - | - | - | - | - | - |
| 15 | A5. 5 | 36.59 | 27.75 | 909 | 253 | 28.1 | 2.2 | - | - | - | - | - | - | - |
| 16 | H4. ${ }^{\text {a }}$ | . | - |  |  | - | 2.8 | - | - | $\bullet$ | - | - | - | $\bullet$ |
| 17 | 82. ${ }^{\text {A }}$ | - | - | ${ }^{\circ}$ |  | - | 3.3 | - | - | - |  | - | - |  |
| $1{ }^{\text {H }}$ | 7A.И | 36.46 | 25.95 | A 75 | 297 | 23.7 | 3.3 | .13 | 19.9 | .23 | .13 | -3a | .658 | 1.310 |
| 19 | 14.4 | - | . |  |  | - | 3.7 | - | - | - | - | - | - |  |
| 26 | 6い. 1 | - | - |  |  | - | 4.2 | - | - | - | - | - | .918 | 1.35a |
| 21 | 42.14 | 30.42 | 24.75 | 875 | 167 | 19.1 | 5.3 | - | - | - | $\bullet$ | - | - | - |
| 22 | 36.4 | - | - |  |  | - | 5.8 | - | * | - | - | - 7 | - |  |
| 23 | 33.0 | - | - |  |  | - | 6. ${ }^{\text {a }}$ | .20 | 12.5 | .32 | .11 | .27 | 1.ana | 1.381 |
| 21 | 30.13 | 36.39 | 24.75 | 675 | 133 | 15.2 | 6.6 | - | . | - | - | - | - | - |
| 75 | 27.n | - | . |  |  | - | 7.3 | - | - | - | - | - | - | - |
| 26 | 20.4 | 31.39 | 24.75 |  |  | 11.9 | 7.6 | - | - | - | - | - | - | - |
| 27 | $2 川 .4$ | 36.39 | 24.75 | 9018 | 107 | 11.9 | 7.3 | 13 | 3 | 27 | -14 | 39 | 40 |  |
| 2H | 2?.4 | . | . |  |  | - | 7.6 | .13 | A. 3 | .27 | .14 | . 39 | 1.403 | 1.481 |
| 29 | 25.14 | - 39 | 24.75 |  |  | - | 7.6 | - | - | - | - | - |  |  |
| 3.1 | 22.n | 36.39 | 24.75 | 919 | 101 | 11.2 | 7.9 | - | - | - | - | - | 1.668 | 1.424 |
| 31 | 17.И | , | , |  |  | - | 8.2 | - 13 | - | - | , | , | , |  |
| $3 ?$ | 15.4 | 36.46 | 24.75 |  |  |  | 8.8 | .13 | 5.9 | .18 | .15 | .42 | 1.845 | 1.495 |
| 33 | 14.9 | - | - | 910 | 99 | 11.0 | - | - | - | - | - | - | - | - |



## cruise number 3



| DEPIH | IRAMS. | SAL. | TENP. | SURF | 17 SUR. | $\begin{aligned} & \text { LIGHT } \\ & \text { O/O } \end{aligned}$ | FLJOR. | PO4 | 31. | NO3 | NO2 | NHA | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (1) | 13.4 | 31.62 | 24.34 | 1300 | 426 | 32.8 | 7. $\square$ | - | - | - | - | - | - | - |
| 01 | 13.4 | . | - |  |  |  | 6.9 | - | - | - | - | - | - | - |
| 42 | 13.4 | - | - |  |  |  | 7.9 |  |  |  |  |  |  |  |
| 23 | 13.4 | 31.62 | 29.34 | ASa | 86 | 19.2 | 6.9 | .29 | 3.3 | .50 | .36 | .96 | 1.446 | 1.519 |
|  | 12.1 | - | - |  |  | - | 7.9 | - | - | - | - | - | - | - |
| 45 | 13.4 | - | - |  |  | . | 6.8 | - | - | - | - | - | - | - |
| 16 | 14.4 | 31.62 | 29.14 | 771 | 30 | 3.9 | 6.5 | - | - | - | - | - | . | - |
| 17 | 15.月 | - | - |  |  | . | 6.5 | - | - | - | - | - | - | - |
| an | 1月.4 | - | - |  |  | - | 5.2 | .29 | 3.7 | .46 | .35 | - | 1.188 | 1.478 |
| 19 | 16.8 | 31.64 | 29.14 | 770 | 44 | 5.2 | 3.8 | - | . | - | - | - | - | - |
| 14 | 15.8 | - | - |  |  | - | 3.6 | - | - | - | - | - | - | - |
| 11 | 15.8 | 31 | - |  |  | - | 3.4 | - | - | - | - | - | - | . |
| 12 | 16.8 | 31.68 | 29.49 | 840 | 73 | .9 | 3.5 | - | - | - | - | - | - | - |
| 13 | 17.9 | , | - |  |  | - | 3.8 | . 36 | 4.4 | .45 | .32 | .89 | .868 | 1.389 |
| 14 | 3.1 .14 | 3102 | - |  |  | - | 3.7 | - | - | - | - | - | - | - |
| 15 | 37.4 | 31.92 | 29.44 | 1300 | 60 | . 5 | 3.8 | - | - | - | - | - | - | - |
| 1 l | 47.5 | - | - |  |  |  | 3.7 | - | - | - | - | - | - | - |
| 17 | 47.5 | - | - |  |  | - | 3.6 | - | - | - | - | - |  | - |
| 18 | 49.A | 32.22 | 29.24 |  |  | - | 3.5 | .18 | 2.5 | .44 | .41 | .71 | .765 | 1.364 |
| 19 | 49.H | - | - |  |  | - | 3.4 |  | - |  |  | - |  | - |
| 24 | 49.4 | - | - |  |  | - | 3.3 | .25 | 2.9 | .25 | .23 | - | .575 | 1.435 |
| 21 | 52.2 | 32.62 | 29.34 |  |  | - | 3.2 | - | - | - | - | - | - | - |
| 22 | 5P.? | - | - |  |  | - | 3.1 |  | - | - |  |  |  |  |
| 23 | 619.1 | - | - |  |  | - | 3. ${ }^{\text {a }}$ | .43 | 4.6 | . 23 | .27 | .75 | .461 | 1.273 |
| 24 | 64.6 | 32.72 | 29.24 |  |  | - | 2.9 | - | - | - | - | - | - | - |
| 25 | 6H. 6 |  | . |  |  | - | 2.8 | - | - | - | - | , | - | - |
| 36 | 6P. 7 | * | - |  |  | - | 2.8 | - | - | - | - : | - | - | - |
| 21 | 62.7 | 33.52 | 29.24 |  |  | - | 2.7 | - | - | - 7 |  | $\bullet$ | - 525 | - 3 |
| 2 H | 62.7 | . | . |  |  | - | 2.7 | .43 | 4.6 | .27 | .47 | . 56 | .525 | 1.333 |
| 29 | 45.2 | - | - |  |  | - | 2.7 |  |  | - |  | - |  |  |
| 34 | 2.6 | 34.12 | 29.24 |  |  | - | , | .40 | 4.4 | 2.26 | . 48 | - | .454 | 1.273 |
| 31 | - | - | - |  |  | - | - | . 25 | 2.1 | . 89 | .55 | .62 | .499 | 1.254 |
| 32 | - | - | - |  |  | - | - |  | - | - | - | - | - | - |
| 33 | - | - | - |  |  | - | - | - | - | - | - | - | - | . |


| DFPTH | IMANS. | SAL. | IEMP. | $\begin{gathered} \text { LIIIHT } \\ \text { SIJRF. SUR. } \end{gathered}$ | $\begin{gathered} \text { LIGHT } \\ 0 / 0 \end{gathered}$ | FLUOR | POA | 51 | N03 | NO2 | NH4 | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $a_{1}$ | 45.2 | $32.4 n$ | 29.29 |  | - | 6.6 | - | - | - | - | - | - | - |
| (1) | 45.2 | - | - |  | . | 6.6 | . | . | - | - | - | - | $\bullet$ |
| 42 | 45.2 | - | - |  | - | 6.9 | - | - | - | - | - | - |  |
| n 3 | 45.2 | 32.40 | 29.20 |  | - | 7.0 | .36 | 2.8 | .66 | 0.月n | .22 | 1.227 | 1.458 |
| 44 | 47.5 | - | - |  | - | 6.6 | - | - | - | - | - | - | - |
| 05 | 47.5 | - | - |  | - | 6.6 | - | - | - | - | - | - |  |
| Wh | 47.5 | 32.41 | 29.20 |  | - | 6.6 | - | - | - | - | - | . | - |
| 47 | 47.5 | - | - |  | - | 6.6 | - | - | - | - | - | - |  |
| 88 | 45.2 | , | , |  | - | 6.7 | .36 | 2.6 | .45 | 0.90 | - | 1.150 | 1.435 |
| 69 | 47.5 | 32.41 | 29.24 |  | - | 6.5 | - | - | - | - | - | - | - |
| 1 H | 49.2 | - | - |  | - | 6.6 | - | - | - | - | - | - | - |
| 11 | 45.2 | , | - |  | - | 6.6 | , | - | - | - | - | - | - |
| 12 | 45.2 | 32.44 | 29.20 |  | - | 6.6 | - | - | - | - | - | - |  |
| 13 | 45.? | - |  |  | - | 6.5 | .32 | 2.9 | .62 | 日.00 | . $\quad$ ar | 1.110 | 1.454 |
| 14 | $45 . ?$ | 32041 | 290 |  | - | 6.6 | - | - | - | - | - | - | - |
| 15 | $45 . ?$ | 32.41 | 29.20 |  | - | 6.4 | - | - | - | - | - | - | - |
| 16 | 43.1 | - | . |  | - | 5.9 | - | - | - | - | - | - | - |
| 17 | 43.2 |  |  |  | - | 5.8 |  |  |  |  | - |  |  |
| 18 | 45.2 | 32.48 | 29.34 |  | - | 5.1 | .36 | 2.8 | .56 | .06 | - | .960 | 1.448 |
| 14 | 47.5 | - | - |  | - | 4.B | - | - | - | - | - | - |  |
| 24 | 19.8 | - |  |  | - | 4.5 | .14 | 1.6 | .71 | . .20 | - | .673 | 1.333 |
| 21 | 54.7 | 32.70 | 29.29 |  | - | 4.6 | - | - |  | - | - | - | - |
| $2 ?$ | 57.3 | - | - |  | - | 3.7 | - | - |  | - |  | - |  |
| 23 | 64.9 | $3{ }^{\bullet}$ |  |  | - | 3.5 | .36 | 4.9 | .42 | .13 | .33 | .476 | 1.267 |
| 24 | 7R. 1 | 33.14 | 29.29 |  | - | 3.4 |  | , | - | . | - | - | - |
| 25 | A1. 5 | $\bullet$ | - |  | - | 3.1 | - | - | - | - | - | - | - |
| 26 | H4.9 |  | 29* |  | - | 3.2 | - | - | - | - | - | - | - |
| 27 | 71.6 | 33.An | 29.24 |  | - | 3.4 |  | - |  | - |  |  |  |
| 2 H | 24.14 | - | - |  | - | 3.7 | .43 | 5.8 | .32 | .20 | .49 | . 581 | 1.385 |
| 29 | 3 nc 4 | - | - |  | - | 5.2 |  | , |  |  | - |  |  |
| 319 | 16.8 | 34.20 | 29.2.14 |  | - | 4.13 | .47 | 5.4 | .65 | . 35 | .62 | .712 | 1.312 |
| 31 | H. 5 | - | - |  | - | - | - | - | - | - | - |  |  |
| 32 | - | - | - |  | - | - | - | - | - | - | - | - | - |
| 33 | - | * | - |  | - | - | - | - | - | - | - | - | - |


| DAIE：MU267A | CHUISE FHIMHER： 3 | PROFILE NIJMAERE 3 | TIME：HARA | SECCHI DEPIH： |
| :---: | :---: | :---: | :---: | :---: |


| DFPPIH | IHAMS． | SAL． | IETIP． | $\begin{gathered} \text { LIGHT } \\ \text { SURF. } 31 J A . \end{gathered}$ | $\begin{aligned} & \text { LIGHT } \\ & 0 / 0 \end{aligned}$ | FLUOR． | P04 | 51. | NO3 | NO2 | NH4 | CHLA | $C / P$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| いい | AH．6 | 32.38 | 24.96 |  | － | 6.2 | － | － | － | － | － | － | － |
| い1 | 6H．h | ． | ． |  | － | 6.3 | － | － | － | － | － | － | － |
| 42 | 71.6 | － | － 7 |  | － | 6.3 |  |  |  | 0．90 |  |  |  |
| ， 3 | 11．6 | 32.38 | 29.97 |  | － | 6.2 | .65 | 7.0 | －30 | 0．00 | .42 | 1.678 | 1.499 |
| 41 | 71.6 | － | － |  | － | 6.1 | － | － | － | － | － | － | － |
| 45 | 71.6 | － | ， |  | － | 6.3 | － | － | － | － | － | － | － |
| ：19 | 11．0 | 32.38 | 29.97 |  | － | 6.1 | － | － | － | － | － | － | － |
| n 7 | 6H．6 | ． | － |  | － | 6.6 |  |  |  |  | － |  |  |
| 14 | bH． H | － | － |  | － | 6.1 | ． 25 | 3.5 | ． 82 | .05 | － | 1.150 | 1.435 |
| 14 | bS． 6 | 32.38 | 29.97 |  | － | 6． 0 | － | － | － | － | － | － | － |
| 14 | 69．6 | ． | ． |  | － | 6.1 | － | － | － | － | － | － | － |
| 11 | 65．h | － | － |  | － | 6.0 | － | － | － | － | － | － | － |
| 12 | 65．6 | 32.43 | 29.97 |  | － | 6.1 | －76 |  |  |  |  |  |  |
| 13 | 65.6 | 32.4 | 29. |  | － | 6.1 | 1.76 | 40．n | .33 | ． 07 | － 27 | 1.154 | 1．5月の |
| 14 | 64.6 | － | － |  | － | 6.1 | － | － | － | － | － | － | － |
| 15 | 05.6 | 32.53 | 29.16 |  | － | 5.4 | － | － | － | $\bullet$ | － | － | － |
| 16 | 6H．4 | － | ． |  | － | 4.8 | － | ＊ | $\bullet$ | － | － | － | － |
| 17 | カい．ひ | ． | － |  | － | 4.6 | 25 | 3.7 | 36 | 16 | －22 | 1．078 |  |
| 18 | 57.3 | 32.63 | 29.20 |  | － | 4.2 | .25 | 3.7 | .26 | .16 | .22 | 1.878 | 1.499 |
| 19 | 52.2 | － | － |  | － | 4．8 | ． 43 | 5.6 | － 34 | － 2 a | － | .647 | 1.409 |
| 20 | 49.8 | － | － |  | － | 3.8 | .43 | 5.6 | ． 34 | － 2 号 | － | ． 647 | 1.409 |
| 21 | 19．H | 33.10 | 29.26 |  | － | 3.6 | － | － | － | － | － | － | － |
| 22 | 52.2 | － | － |  | － | 3.4 | －36 | 3.5 | .41 | .24 | .26 | ．642 | 1.386 |
| 23 | $74 . \mathrm{H}$ | － | － |  | － | 3.2 | ． 36 | 3.5 | .41 | ． 24 | ． 26 | ．6n2 | 1.8 .86 |
| ？ 4 | 7H． 1 | 33.58 | 29.16 |  | － | 3.3 | － | － | － | － | － | － | － |
| 25 | 68．6 | ． | － |  | － | 3.5 | － | － | － | － | － | － | － |
| 26 | 41.0 | － | － |  | － | 3.9 | － | $\bullet$ | － | － | － | － | － |
| 27 | 314.11 | 33.93 | 29.16 |  | － | 4.9 |  | $3 \cdot 1$ | －76 | －16 |  | ． 634 | 1.267 |
| 2 H | 2.4 .2 | － | － |  | － | 4.3 | －18 | 2.1 | ． 76 | .16 | ． 85 | .634 | 1.267 |
| 29 | 11.3 | $34 \cdot 33$ | 29.16 |  | $\bullet$ | 4.3 | 18 | $2 \cdot 1$ | ． 63 | ． 39 | ． 64 | ． 673 | 1.333 |
| 34 | 4.1 | 34.33 | 29.16 |  | － | 4.2 | .18 | 2.1 | .63 | － 39 | ． 64 | －673 | 1.333 |
| 31 | － | － | － |  | － | － | － | － | － | － | － | － | － |
| 32 | － | － | － |  | － | － | － | ＊ | － | － | － | － | － |
| 33 | － | － | － |  | － | － | － | ， | － | － | － | － | － |

$t$
1
$i$

| OEPIH | IHANS. | SAL. | TEMP. | $\begin{gathered} \text { LIGHT } \\ \text { SUAF. } 3 U R . \end{gathered}$ | $\begin{gathered} \text { LIGHT } \\ 0 / 0 \end{gathered}$ | FLUOR. | PO4 | SI | NO3 | NO2 | NHa | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| An | 6H.H | 32.22 | 2A.84 |  | - | 5.0 | - | * | $\bullet$ | - | $\bullet$ | $\bullet$ | - |
| W1 | OM. ${ }_{\text {c }}$ | - | - |  | - | 5.月 | - | - | - | $\bullet$ | - | - | - |
| 02 | 57.3 |  | - |  |  | 5.a |  |  |  |  |  |  |  |
| a 3 | 57.3 | 32.22 | 28.H4 |  | - | 5.n | .43 | 3.2 | .35 | .27 | . 56 | .892 | 1.30日 |
| 44 | 57.3 | - | . |  | - | 5.9 | - | - | - | - | - | - | - |
| 35 | 57.3 | - | - |  | - | 5.1 | - | - | - | - | - | - | - |
| not | 57.3 | 32.22 | 28.811 |  | - | 5.9 | - | - | - | - | - | - | - |
| 07 | 57.3 | - | - |  | $\bullet$ | 5.1 |  |  |  |  | - |  |  |
| UH | 57.3 | - | . |  | - | 5.1 | .29 | 2.1 | .29 | .26 | - | .814 | 1.333 |
| 69 | 54.7 | 32.23 | 28.84 |  | - | 5.1 | . | - |  | - | - | - | - |
| 10 | 54.7 | 3.23 | - |  | - | 5.1 | - | - | - | - |  |  | - |
| 11 | 57.3 | * | - |  | - | 5.1 | - | - | - | - | - | - | - |
| 12 | 57.3 | 37.27 | 28.94 |  | - | 5.1 |  |  |  |  |  |  |  |
| 13 | 57.3 | 32. | - |  | - | 5.2 | .32 | 2.8 | . 36 | .28 | . 66 | . 924 | 1.350 |
| 11 | 54.7 |  |  |  | - | 5.2 | - | - | , | - | - | - | . |
| 15 | 54.7 | 32.36 | 29.96 |  | - | 5.3 | - | - | - | - | - | - | - |
| 15 | 54.7 | - | . |  | - | 5.7 | - | - | - | - | - | - | - |
| $11$ | 52.? |  |  |  | - | 5.6 |  |  |  |  |  |  |  |
| 18 | 511.7 | 32.72 | 29.44 |  | - | 5.7 | .14 | 1.8 | .37 | .34 | .62 | .962 | 1.273 |
| 19 | 57.5 | - | - |  | - | 5.8 | - | - | - 7 | - 7 | - |  |  |
| 2.1 | 62. 7 | - |  |  | - | 5.1 | .29 | 3.2 | .27 | . 27 | - | . 962 | 1.333 |
| 21 | 65.6 | 32.87 | 29.12 |  | - | 5.5 | - | - | - | - | - | - | $\bullet$ |
| $22$ | -2. 7 | - | - |  | - | 5.5 |  |  |  |  |  |  |  |
| $23$ | $62.7$ |  |  |  | - | 5.1 | .43 | 4.9 | .29 | .54 | .60 | .853 | 1.316 |
| 24 | 54.7 | 33.47 | 29.149 |  | - | 4.9 | - | . | - | - | - | - | . |
| 25 | 41.11 | - | - |  | - | 4.4 | - | - | - | - | - | - | - |
| $26$ | 31.6 |  |  |  | - | 0.1 | - | - | $\bullet$ | - | - | - |  |
| 27 | 34.0 | 34.47 | 29.49 |  | - | 4.0 | - |  |  |  | - 6 |  |  |
| $2 H$ | 21.4 | - | - |  | - | 4.0 | .22 | 3.5 | .55 | 1.50 | .60 | .251 | 1.294 |
| 24 | 17.1 | - | - |  | - | 4.3 |  |  |  |  |  |  |  |
| $34$ | 0.7 | 35.12 | 29.99 |  | $\bullet$ | 4.6 | .29 | 4.4 | .68 | 1.32 | .62 | .962 | 1.217 |
| 31 | - | - | - |  | - | - | - | - | - | - | - | $\bullet$ |  |
| $32$ | - | - | - |  | - | $\bullet$ | - | - | - | - | - | - | - |
| 33 |  | - | - |  |  |  | - | - | - | - | - | - |  |


| DEPrH | inams. | SAL. | TFMP. | SIIRF | UR. | $\begin{aligned} & \text { LIGHT } \\ & \text { ח/O } \end{aligned}$ | FLUOR. | POA | 91 | NO3 | NO2 | NH/1 | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H4 | 47.5 | 32.12 | 2A.84 | 250 | 93 | 37.2 | 6.6 | - | - | - | - | - | - | - |
| 111 | 15.? | - | - |  |  | . | 6.5 | - | - | - | - | - | - | - |
| 12 | 47.5 | - | - |  |  | . | 6.5 | - | - | - | - | - | - |  |
| 13 | 47.5 | 32.12 | 28.84 | 230 | 33 | 10.3 | 6.5 | .43 | 4.9 | .33 | .27 | .94 | 1.142 | 1.380 |
| 14 | 47.5 | - | - |  |  | . | 6.6 | - | - | - | - | - | - | - |
| 15 | 47.5 | , | - |  |  | , | 6.4 | - | - | - | - | - | - | - |
| 46 | 47.5 | 32.12 | 2R.84 | 254 | 19 | 7.6 | 6.9 | - | - | - | - | - | - | - |
| A 7 | 47.5 | - | - |  |  | - | 6.5 | - | - | - | - | - | - | - |
| $\wedge \mathrm{H}$ | 47.5 | - | - |  |  | - | 6.1 | . 40 | 3.9 | .34 | . 22 | - | 1.472 | 1.34A |
| 19 | 47.5 | 32.11 | 2A. H4 $^{\text {a }}$ | 240 | 11 | 4.6 | 6.1 | - | - | - | - | - | - | - |
| 14 | 47.5 | - | - |  |  | . | 6.1 | - | - | - | - | - | - | - |
| 11 | 47.5 | - | - |  |  | - | 5.9 | - | - | - | - | - | - | - |
| 12 | 47.5 | 32.11 | 2R.94 | 249 | 7 | 2.9 | 6.9 |  | * |  |  |  |  |  |
| 13 | 47.5 | - | - |  |  | . | 6. 1 | .90 | 13.7 | .31 | .22 | .99 | 1.065 | 1.499 |
| 14 | 47.5 | - | - |  |  | - | b. 0 | - | - | - |  | - | , | . |
| 15 | 47.5 | 32.11 | 29.96 | 246 | 5 | 2.1 | 5.9 | - | - | - | - | - | - | - |
| 16 | 45.2 | - | . |  |  | - | 6.1 | - | - | - | - | - | - | - |
| 17 | 45.2 |  | - |  |  |  | 5.5 |  |  |  |  |  |  |  |
| 18 | 47.5 | 32.12 | 28.94 | 270 | 4 | 1.5 | 5.5 | .47 | 5.6 | - 29 | .12 | .89 | .885 | 1.368 |
| 19 | 47.5 | - | - |  |  | - | 5.6 |  | - |  |  | - |  |  |
| 24 | $45 . ?$ | - | - |  |  | - | 5.6 | .43 | 4.9 | .45 | . .39 | - | .853 | 1.316 |
| 21 | 43.4 | 32.57 | 2月.94 | 275 | 3 | 1.1 | 5.4 | - | - | . |  | - | - | . |
| $2 ?$ | 43.19 | - | - |  |  | - | 5.3 |  | - |  | - | - | - |  |
| 23 | 49.4 | - | - |  |  | - | 5.3 | .47 | 4.9 | . 36 | .62 | .94 | . 175 | 1.278 |
| 24 | 45.2 | 32.82 | 29.149 | 275 | 3 | 1.1 | 5.1 | - | . | - | - | - | - | . |
| 25 | 24. ${ }^{4}$ | - | - |  |  | - | 4.6 | - | - | - | - | - | - | - |
| 26 | 4.8 | * | - |  |  | - | 4.4 | - | - | - | - | - | - | - |
| 27 | A. 5 | 33.42 | 29.09 |  |  | - | 4.2 | , | - | - | - | - | - | - 19 |
| 28 | 5.3 | 3.4 | 2. |  |  | - | 4.6 | .65 | 10.2 | .65 | 1.46 | - 89 | . 782 | 1.210 |
| 29 | 4.5 | - | - |  |  | - | 4.8 |  | - |  | - 1 | - 5 | - 3 - |  |
| 30 | - | 34.17 | 29.69 |  |  | - | 4.6 | .58 | A. 8 | - 84 | 1.41 | 1.54 | 1.384 | 1.171 |
| 31 | - | - | - |  |  | - | - | - | - | - | - | - | - | - |
| 37 | - | - | - |  |  | - | - | - | - | - | - | - | - | - |
| 33 |  |  |  |  |  |  |  |  |  |  | - |  |  |  |



## CRUISE NUMBER a

| NEPTH | IKANS. | SAL. | TEMP. | SIIRF | SUA. | $\begin{gathered} \text { LIGHT } \\ 0 / 0 \end{gathered}$ | FLUOR. | PO4 | SI | NO3 | NO2 | NH4 | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| nи | 71.3 | 33.44 | 23.42 | 1750 | 99月 | 57.0 | - | - | - | - | - | - | - | - |
| $n 1$ | 14.14 | - | - |  |  | , | - | - | - | - | - | - | - | - |
| $n 2$ | 74.4 | - | - |  |  | , | - |  | - |  |  |  |  |  |
| 43 | 711.4 | 33.84 | 23.42 | I AGA | 499 | 27.7 | - | .52 | 9.3 | .31 | .19 | .35 | 2.412 | 1.552 |
| 14 | 74.4 | - | - |  |  | - | - | - | - | - | - | - | - | - |
| 45 | 74.4 | - | - |  |  | - | - | - | - | - | - | - | - |  |
| H6 | 74.0 | 33.144 | 23.42 | 1700 | 266 | 15.6 | - | - | - | - | - | - | - | - |
| 47 | 74.11 | - | - |  |  | . | - | - | - | - | - | - |  |  |
| 48 | 74.11 | - | - |  |  | - | - | . 52 | 9.3 | .31 | .17 | .33 | 2.549 | 1.514 |
| 149 | 74.10 | 33.44 | 23.44 | IRAS | 128 | 6.7 | - | - | - | - | - | - | - | - |
| 10 | 74.4 | - | - |  |  | - | - | - | - | $\bullet$ | - | - | - | - |
| 11 | 75.4 | 33. | ** 45 |  |  | - | - | - | - | - | - | - | - | - |
| 12 | 75.1 | 33.84 | 23.45 | 6009 | 27 | 4.5 | - |  | - 3 |  |  |  |  |  |
| 13 | 7 7. 1 | \% | - |  |  |  | - | . 55 | 9.3 | .31 | .17 | .31 | 2.715 | 1.462 |
| 11 | 79.5 | 3** | 2** |  |  |  | - | - | - | - | - | - | - | - |
| 15 | АИ. 9 | 33.16 | 23.52 | 440 | 13 | 2.9 | - | - | - | - | - | - | - | - |
| 16 | H11.9 | - | - |  |  | - | - | - | - | - | - | - | - | - |
| 17 | H0.9 |  | - |  |  | - | - |  | * |  |  |  |  |  |
| 18 | 82. 3 | 33.42 | 23.96 | 950 | 9 | 1.6 | - | . 55 | 9.5 | .95 | .74 | .75 | 2.153 | 1.452 |
| 19 | 82.3 | . | - |  |  | - | - | - | - | - | - | - |  |  |
| 24 | 79.5 | ${ }^{\circ} 7$ | - |  |  | - | - | - | - | - | - | - | 1.606 | 1.394 |
| 21 | 74.2 | 34.78 | 25.32 | 5an | 6 | 1.1 | - | - | - | - | - | - | - | . |
| 22 | 74.6 | - | - |  |  | - | - |  | - | - | - |  |  |  |
| 23 | 68.5 | - | - |  |  | - | - | .55 | B. 7 | 1.59 | 1.14 | .57 | 1.200 | 1.4n9 |
| 24 | 57.6 | 35.17 | 25.72 | 1650 | 11 | . 7 | - | . | . | - | - | - |  |  |
| 25 | 27.4 | - | - |  |  | - | - | . 72 | 11.3 | 3.54 | 1.65 | - | .988 | 1.318 |
| 26 | 14.9 |  | 20.05 |  |  | - | - |  | - | - | - | - |  | - |
| 27 | 114.9 | 35.52 | 26.145 |  |  | - | - | - | - | -87 | - 25 | - |  |  |
| 28 | 114.9 | - | - |  |  | - | - | .65 | 11.5 | 2.87 | 1.25 | .49 | .910 | 1.35n |
| 29 | 9.6 | 35.74 | 26.29 |  |  | - | - | - | - | - | - | - | - | - |
| 36 | 4.2 | 35.74 | 26.20 |  |  | - | - | - | - | - | - | - | - | $\bullet$ |
| 31 | 6.9 | - | - |  |  | - | - | , |  |  |  |  |  |  |
| 32 | h. 9 | - | - |  |  | - | - | .62 | 10.2 | 2.23 | .96 | .71 | .665 | 1.357 |
| 33 | - | $\bullet$ | - |  |  | - | - | - | - | - | - | - | - | - |

DAIE: IIHATA CRUISE NUMREK: 4 PROFILE NIJMAER: 2 TIME: 1GAG SECCHI OEPTH: 9 -AR


| DFPTH | THANS. | SAL. | TFMP. | $\begin{gathered} \text { LIGHT } \\ \text { SURF. SIIR. } \end{gathered}$ | $\begin{gathered} \text { LIGHT } \\ 0 / 0 \end{gathered}$ | FLUOR. | PO4 | 31 | NO3 | NO2 | NH4 | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| na | bata | 33.25 | 23.47 |  | - | - | - | - | - | - | - | - |  |
| A1 | 61.0 | - | - |  | - | - | . | - | - | - | - | - |  |
| 02 | 61.0 | - | - |  | - | - |  | - | - | - | - | - |  |
| $\mathrm{HO}_{3}$ | 61.17 | 33.25 | 23.54 |  | - | - | .52 | 9.8 | .31 | .42 | .19 | 2.1198 | 1.439 |
| Ha | 01.4 | - | - |  | - | - | - | - | - | - | - | - | - |
| 05 | 61.4 | - | - |  | - | - | - | - | - | - | - | - | - |
| Q6 | 01.4 | 33.36 | 23.74 |  | - | - | - | - | - | - | - | - |  |
| U7 | 61.4 | - | - |  | - | - | - | - | - | - | - | - |  |
| 88 | H1.4 | - | - |  | - | - | .48 | 11.6 | .63 | . 54 | .09 | 1.948 | 1.410 |
| 19 | 59.4 | 33.65 | 23.93 |  | - | - | - | - | - | - | - | - | - |
| 14 | 61.14 | - | - |  | - | - | - | - | - | - | - | - | - |
| 11 | 6P., | - | - |  | - | - | - | - | - | - | - | - | - |
| 12 | 64.9 | 33.80 | 23.93 |  | - | - | - | - | - | - | - | - |  |
| 13 | 6h. ${ }^{\text {b }}$ | - | - |  | - | - | .42 | 10.2 | .63 | . 48 | .107 | 1.464 | 1.450 |
| 14 | 66.4 | - | - |  | - | . | - | - | - | - | - | - | - |
| 15 | 66. ${ }^{\text {a }}$ | 34.404 | 23.93 |  | - | - | - | - | - | - | - | - | - |
| 16 | 69.4 | - | - |  | - | - | - | - | - | - | - | - | . |
| 17 | 74.4 | - | - |  | - | - | - | - | - | - | - | - |  |
| 1 H | 714.4 | 30.20 | 24.nи |  | - | - | . 45 | 9.1 | .31 | . 28 | .11 | 1.496 | 1.387 |
| 19 | HR. ${ }_{\text {H }}$ | - | - |  | - | - | - | - | - | - | - | - |  |
| 24 | 6R. ${ }^{\text {ch }}$ | - | - |  | - | - | . 39 | 9.1 | .31 | . 28 | - | 1.504 | 1.387 |
| 21 | 6H. ${ }^{\text {ch }}$ | 34.42 | 24.16 |  | - | - | - | - | - | - | - | - | - |
| 22 | 48.1 | - | - |  | - | - |  | . | , | - | - | . |  |
| 23 | 65.:1 | - | - |  | - | - | .37 | 9.5 | .31 | . 28 | .03 | 1.389 | 1.497 |
| 24 | $6 \mathrm{H.H}$ | 34.55 | 24.35 |  | - | - | - | - | - | - | - | - | - |
| 25 | 69.6 | - | - |  | - | - | - | - | - | - | - | - | - |
| 26 | 62. ${ }^{\text {a }}$ | , | - |  | - | - | - | - | - | - | - | - | - |
| 21 | 58.H | 34.85 | 24.77 |  | - | - | - 37 | , | - | , | - | - 155 |  |
| 28 | 56.14 | - | - |  | - | - | .37 | A. 3 | .95 | . 57 | .94 | 1.155 | 1.478 |
| 29 | 24.4 | - | - |  | - | - |  |  |  | - |  |  |  |
| 34 | 16.n | 35.74 | 26.24 |  | - | - | .45 | 9.1 | 2.23 | 1.98 | - | . 949 | 1.877 |
| 31 | 14.4 | - | - |  | - | - |  | - | - | - |  |  |  |
| 32 | H. ${ }^{\text {n }}$ | - | - |  | - | - | .45 | 9.3 | 2.23 | .82 | .31 | . 881 | 1.263 |
| 33 | - | - | - |  | - | - | - | - | - | - | - | - | . |




| DEPTH | THANS. | SAL. | TEMP. | SURF | $T$ <br> SUA. | $\begin{gathered} \text { LIGHT } \\ \text { O/O } \end{gathered}$ | FIUOR. | PO4 | SI. | NO3 | NO2 | NH4 | CHLA | C/P |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Ab | 62.5 | 32.99 | 23.18 | 764 | 466 | 61.3 | - | - | - | - | $\bullet$ | - | - | - |
| H1 | 63.5 | . | - |  |  | . | - | - | - | - | - | - | - | - |
| a? | 63.5 | - | - |  |  | - | - | - | - | - |  | - |  |  |
| (1) 3 | 6 3.5 | 32.99 | 23.18 | 770 | 2и\% | 26.9 | - | .42 | 14.6 | .31 | .25 | .30 | 1.574 | 1.451 |
| ${ }^{4} 4$ | 63.5 | - | 。 |  |  | - | - | - | - | - | - | - | - | - |
| 45 | 63.5 | - | - |  |  | - | - | - | - | - | - | - | - | - |
| U6 | 64.S | 33.44 | 23.18 | 770 | 156 | 13.8 | - | - | - | - | - | - | - | - |
| Q 7 | 61.6 | . | - |  |  | - | - |  | - | - | - | - |  |  |
| UA | 6,8.6 | - | - |  |  | - | - | .48 | 13.5 | .31 | - 28 | . 26 | 1.394 | 1.429 |
| 09 | 74.7 | 33.39 | 23.68 | 770 | 65 | 8.4 | - | - | - | - | - | - | - | - |
| 1 A | 71.7 |  | - |  |  | - | - | - | - | - | - | - | - | - |
| 11 | 71.7 | - | - |  |  | - | - | - | - | * | - | - | - | - |
| 12 | 710.7 | 33.89 | 23.88 | 770 | 41 | 5.3 | - |  | $1{ }^{\circ}$ |  |  |  |  |  |
| 13 | 69.6 | . | - |  |  | . | - | . 48 | 13.8 | . 31 | .28 | . 49 | 1.380 | 1.379 |
| 14 | 68.6 | - | , |  |  | - | - | - | - | - | - | - | - | - |
| 15 | 61.5 | 33.99 | 24.48 | 770 | 29 | 3.8 | - | - | - | - | - | - | - | - |
| 1 l | 61.5 | - | - |  |  | - | - | - | - | - | - | - | - | - |
| 17 | 63.5 | 34.49 | ${ }^{\bullet}$ |  |  | $\cdots$ | - |  |  |  |  |  |  |  |
| 1 A | 6h.t | 34.49 | 24.61 | 780 | 21 | 2.7 | - | .45 | 9.3 | .63 | .37 | .44 | 1.419 | 1.464 |
| 19 | 67.6 | - | - |  |  | - | - |  | * | - | - | - | - 355 |  |
| 24 | h*. 6 | - | - |  |  | - | - | .42 | 9.1 | .31 | . 34 | - | 1.355 | 1.393 |
| 21 | 6R.O | 34.69 | 24.78 | 7A日 | 16 | 2.1 | - | - | - | - | - | - | - | - |
| 22 | 68.6 | - | - |  |  | - | - | - 39 | -7 | - 31 | - 37 | - | 1.504 | 1.433 |
| 23 | 67.6 | 34*7 | - 78 |  |  | $\stackrel{\square}{6}$ | - | .39 | 8.7 | .31 | .37 | .44 | 1.504 | 1.433 |
| 24 | 67.6 | 34.74 | 24.7A | 784 | 12 | 1.6 | - | - |  |  | - | - | - | - |
| 25 | 67.6 | - | - |  |  | - | - | - | - | - | - | * | - | - |
| 26 | 6t. 6 | 34. ${ }^{\text {a }}$ | - |  |  | - | - | - | - | - | - | - | - | - |
| 21 | 63.5 | 34.A4 | 24.98 | A90 | 10 | 1.3 | - | - | - | - | * |  |  |  |
| 2 2 | 44.4 | - | . |  |  | - | - | .42 | 10.9 | 2.23 | 1.14 | .26 | .919 | 1.350 |
| 24 | ? A .1 |  |  |  |  |  | - |  |  |  |  | - |  |  |
| 36 | 21.6 | 34.9n | 25.75 | HOH | 8 | 1.0 | - | . 52 | 19.6 | 2.23 | 1.088 | - | .917 | 1.350 |
| 31 | $2 ? .5$ | 35*49 | - |  |  | - | - | - | - | - | - | - 49 | . 71 |  |
| 32 | 22.5 | 35.49 | 26.18 |  |  | - | - | . 52 | 10.2 | 2.23 | 1.92 | .49 | .871 | 1.238 |
| 33 | h. 1 | - | - |  |  | - | - | - | - | - | - | - | - | - |



## APPENDIX B

Phytoplankton species abundances estimated from 5 mls of settled sample collected within the nepheloid layer on each of the four NEPHY cruises. The species are in alphabetical order within the divisions; Pennate Diatoms, Centric Diatoms and Dinoflagellates.

TABLE B-1

SPECIES ABUNDANCE FOR NEPYY I, JUNE 29, 1978


TABLE B-2
SPECIES ABUNDANCE FOR NEPHY II, JULY 24, 1978

| Species | Times | - | 80 | \% | 8 | $\begin{aligned} & 8 \\ & 0 \\ & 0 \end{aligned}$ | O | $\stackrel{8}{\text { ¢ }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

## Pennate

| Achnanthes sp. |  |  | 1 |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Amphiprora gigantea |  | 2 |  |  |  |  | 1 |
| Diploneis sp. | 5 | 3 | . 5 | 3 | 9 | 15 | 1 |
| Eunotia sp. | 2 |  |  |  |  |  |  |
| Gramatophora oceanica | 12 | 5 |  | 3 |  | 3 | 1 |
| Gyrosigma spencerii | 14 | 6 | 4 |  | 7 | 7 | 17 |
| Navicula membranacea | 16 | 3 | 1 | 1 | 3 | 3 | 3 |
| Nitzschia bilobata |  |  |  |  |  |  | 2 |
| Nitzschia clostenum | 32 | 22 | 2 | 3 | 4 | 1 | 3 |
| Witzschia delicatissima |  | 8 |  |  | 11 | 4 |  |
| Nitzschia longissima | 7 | 6 | 1 |  |  | 1 | 4 |
| Nitzschia paradoxa |  | 13 | 25 | 11 | 13 | 15 | 2 |
| Nitzschia pungens |  |  |  |  |  | 5 |  |
| Pseudoeunotia doliolus |  |  |  |  |  |  | 1 |
| Sumirella fastuosa v. recedens |  |  |  |  | 2 | 1 | 8 |
| Thalassiothrix longissima | 2 |  |  |  |  |  |  |
| Thalassiothrix meditteranea | 6 | 7 | 12 | 5 |  |  | 2 |
| Unidentified Pennate | 46 | 26 | 7 | 11 | 10 | 2 | 13 |
| Total (cells/5 ml) | 142 | 101 | 57 | 37 | 60 | 57 | 58 |

Centric

| Asteromphalus heptactis |  |  |  |  |  | 1 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Bacteriastrum hyalinum |  | - |  | 1 |  |  |  |
| Biddulphia sp. |  |  |  |  | 1 | 1 |  |
| Ceratculina bergonii | 6 |  |  |  |  |  |  |
| Chaetoceros affinis |  | 3 |  | 1 |  |  |  |
| Chaetoceros atlanticus | 2 |  |  |  |  |  |  |
| Chaetoceros decipiens | 1 |  |  |  |  |  |  |
| Chaetoceros didymus | 2 |  |  |  |  |  |  |
| Chaetoceros gracile | 3 |  |  |  |  |  | 1 |
| Chaetoceros laciniosus |  | 8 |  |  |  | 4 |  |
| Chaetoceros pelagicus |  |  |  |  |  |  | 2 |
| Chaetoceros peruvianus |  |  |  | 2 | 1 |  |  |
| Chaetoceros tetrastichon |  | 7 |  |  |  |  |  |
| Coscinodiscus sp. |  |  |  |  | 6 | 8 |  |
| Coscinodiscus excentricus |  | 1 |  |  |  |  |  |
| Coscinodiscus granii |  |  |  |  | 3 | 1 |  |
| Coscinodiscus radiatus | 3 | 3 | 2 | 1 | 19 | 5 | 4 |
| Ditylum brightwelli | 1 |  |  |  | 4 | 4 |  |
| Guinamdia flaccida | 32 | 38 | 12 | 3 | 5 | 6 | 2 |
| . Hemiaulus hauckii |  | 31 | 36 | 12 |  | 4 | 9 |

TABLEB-2 CONT: 'D


TABLE B-3
SPECIES ABUNDANCE FOR NEPHY III, SEPTEMBER 25, 1978

Species

Times | $\underset{7}{\sim}$ | 8 | 8 | 0 | 8 | 0 | 0 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |

Pennate
Climacosphenia moniligera Diploneis sp.
$\begin{array}{ll} & 1 \\ 1 & 8\end{array}$
Grammatophora marina
Gyrosigma spencerii
Navicula sp.
Navicula membranacea
Nitzschia sp.
Nitzschia bilobata
Nitzschia clostenum
Nitzschia Zongissima
Nitzschia paradoxa

| 13 | 2 | 6 |
| :--- | :--- | :--- | :--- |
| 13 | 16 | 13 |


| 13 | 16 | 8 | 16 | 13 |
| :--- | :--- | :--- | :--- | :--- |

$\begin{array}{lllll}.1 & 2 & 5 & 3 & 15\end{array}$

Plagiograrma sp.
Surirella fastuosa v. recedens Synedra sp.
Thallassionema nitzschoides
Thallassiothrix meditemonea
Unidentified Pennates
Total (cells/5 ml) 6
Centric

| Bacteriastrum hyalinum |  | 2 | 3 |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Coscinodiscus granii |  |  |  |  |  | 3 |
| Coscinodiscus lineatus |  |  |  |  | 1 |  |
| Coscinodiscus radiatus | 1 | 4 | 2 | 3 | 4 | 3 |
| Ditylum brightwelli |  |  |  | 1 |  |  |
| Melosira sulcata |  |  |  |  | 5 |  |
| Rhizosolenia castracanei |  |  | 1 |  |  |  |
| Thalassiosira aestivalis |  |  |  | 4 |  | 8 |
| Thalassiosira rotula |  | 1 | - | - | - |  |
| Total (cells/5 ml) | 1 | 7 | 6 | 8 | 10 | 14 |

Dinoflagellates

| Dinochysis caudata |  |  |  | 2 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gonyaulax polygramma |  |  |  | 1 |  |  |
| Gymnodinivm sp. | 2 | 4 |  | 2 | 3 |  |
| Peridinium sp. |  | 4 |  |  | 2 | 2 |
| Prorocentrum gracile | - | - |  | 2 | - | - |
| Total (cells/5 ml) | 2 | 8 |  | 7 | 5 | 2 |
| TOTAL (cells/5 mi) | 9 | 57 | 36 | 37 | 50 | 60 |
| Cells/Liter | 1800 | 11400 | 7200 | 7400 | 000 | 000 |

TABLE B－4
SPECIES ABUNDANCE FOR NEPHY IV，NOVEMBER 8， 1978

| Species | Times | － | $\begin{aligned} & 0.8 \\ & 0 \\ & \hline 1 \end{aligned}$ | 8 | 8 | 8 | 8 | － |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

Pennate

| Diploneis sp． | 6 | 3 | 3 | 3 | 3 | 14 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gyrosigma spencerii | 3 | 2 | 2 | 3 | 5 | 3 | 1 |
| Navicula membranacea | 1 |  |  |  |  |  |  |
| Nitzschia bilobata | 2 |  | 1 |  |  |  |  |
| Nitaschia closterium |  | 1 | － 3 | 6 | 2 | 4 | 1 |
| Nitzschia delicatissima |  | 1 | 1 | 8 | 4 | 4 | 6 |
| Nitzschía longissima | 6 |  | 3 | 2 | 1 | 2 | 2 |
| Nitzschia membranacea |  | 3 | 3 |  | 1 | 3 | 3 |
| Nitzschia paradoxa |  | 1 | 1 | 3 | 6 | 2 | 2 |
| Nitzschia pungens |  |  |  | 4 | 3 | 1 |  |
| Surirella fastuosa v．recedens | 1 | 1 |  |  |  | 2 |  |
| Thatassionema nitzschioides | 34 | 38 | 21 | 25 | 25 | 62 | 19 |
| Thalassiothrix frauenfeldii |  |  | 2 |  | ． |  |  |
| Thalassiothrix mediterranea | 1 |  |  |  |  |  |  |
| Unidentified Pennates | 13 | 5 | 4 | 13 | 11 | 10 | 7 |
| Total（cells／5 ml） | 67 | 55 | 44 | 67 | 61 | 107 | 41 |

Centric
Bacteriastrum delicatulum 2
Biddulphia mobiliensis
Chaetoceros sp． 2
Chaetoceros affinis
Chaetoceros brevis 3
Chaetoceros decipiens
Chaetoceros didymus
Chaetoceros holsaticus
Chaetoceros Zaciniostis
Chaetoceros vanheurcki
Coscinodiscus lineatus
Coscinodiscus radiatus
Dityluon brightwelli
Guinardia flaccida
Leptocylindme donicus
Melosira moniliformis
Rhizosolenia delicatula
Rhizosolenia hebetata
Rhizosolenia stolterfothii
Rhizosolenia styliformis
Skeletonema costatiom
Thalassiosira sp．
Thalassiosira aestivalis
Tofal（cells／5 ml）

4
12
11

| 2 | 2 | 2 | 11 | 5 |
| ---: | ---: | ---: | ---: | ---: |
|  |  |  | 3 | 3 |

1
3
$1 \quad 2$

3
$\begin{array}{ccccccc}- & \frac{44}{7} & - & - & - & & \\ 7 & 76 & 13 & 73 & 102 & 64 & 30\end{array}$

TABLE B-4 CONT. 'D

| Species | Times 윽 | 8 | - | 8 | O | - | $\stackrel{\text { - }}{\text { - }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Dinoflagellates |  |  |  |  |  |  |  |
| Gymmodinizon sp. |  |  |  | 6 |  | 2 | 1 |
| Caytoxzm scolopax |  |  |  | 9 | 4 | 7 | 4 |
| Prorocentrum micans |  |  |  | - | - | 1 | 1 |
| Total (cells/5 mi) |  |  |  | 15 | 4 | 10 | 6 |
| TOTAL (cells/5 ml) | 74 | 131 | 57 | 155 | 167 | 181 | 77 |
| Cells/Liter | 14800 | 200 | 00 | 000 | 3400 | 200 | 400 |

## APPENDIX C


#### Abstract

${ }^{14} \mathrm{C}$ uptake determinations made on populations collected from the nepheloid layer prior to sunrise and incubated in situ from sunrise to noon during those cruises in the NEPHY series that found the photic zone extending through the nepheloid layer．The counts per minute are the raw counts，the channel ratio is the technique used to compute the counting efficiency，and the disintegrations per minute represent the actual activity．The final column gives the average result for each treatment． Calculation A uses the classical dark subtraction；calculation B eliminates the dark subtraction．Total presents the result for the complete sample； Nanno presents the result for the size fraction less than $20 \mu m$ ．The result for the size fraction greater than $20 \mu m$ may be obtained by sub－ traction．


TABLE C－1

CARBON UPTAKE FOR NEPHY I；June 29， 1978

|  | Counts per Minute | Channe1 Ratio | Efficiency | Disintegrations per Minute | $\overline{\text { DPM }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Light | 820 | ． 961 | ． 65 | 1262 |  |
| Incubation | 614 | ． 923 | ． 67 | 916 |  |
|  | 701 | ． 945 | ． 65 | 1078 |  |
|  | 878 | ． 944 | ． 65 | 1351 |  |
|  | 617 | 1.089 | ． 62 | 995 |  |
|  | 653 | ． 971 | ． 65 | 1005 |  |
|  | 536 | 1.311 | ． 55 | 976. | 1040 |
| Light | 472 | ． 913 | ． 67 | 704 |  |
| Incubation | 376 | ． 921 | ． 67 | 561 |  |
| $20 \mu \mathrm{~m}$ | 556 | ． 923 | ． 67 | 830 |  |
| Filter | 473 | ． 915 | ． 67 | 706 |  |
|  | 534 | ． 914 | ． 67 | 797 |  |
|  | 518 | ． 894 | ． 67 | 773 | 729 |
| Dark | 443 | 1.336 | ． 71 | 624 |  |
| Incubation | 446 | 1.121 | ． 67 | 666 |  |
|  | 443 | 1.021 | ． 65 | 682 |  |
|  | 405 | 1.014 | ． 64 | 633 |  |
|  | 363 | 1.159 | ． 67 | 542 | － |
|  | 435 | 1.321 | ． 71 | 613 | 627 |
| Dark | 360 | ． 967 | ． 65 | 554 |  |
| Incubation | 395 | ． 892 | ． 67 | 590 |  |
| 20 mm | 360 | ． 955 | ． 65 | 554 |  |
| Filter | 372 | ． 989 | ． 65 | 572 |  |
|  | 416 | ． 921 | ． 67 | 621 | 578 |

A．$\quad \mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr}=\frac{\left(R_{\mathrm{L}}-R_{\mathrm{D}}\right) \times 24000 \times 1.05 \times \frac{1}{7}}{2.5\left(2.2 \times 10^{6}\right)}$
$\cdot \mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr} \quad \frac{\text { Total }}{0.27} \quad \frac{\text { Nanno }^{1}}{0.10}$
$\mathrm{mgC} / \mathrm{m}^{3} / 14 \mathrm{hr} \quad 3.78 \quad 1.40$
B．$\quad \mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr}=\frac{\mathrm{R}_{\mathrm{L}} \times 24000 \times 1.05}{2.5\left(2.2 \times 10^{6}\right)} \times \frac{1}{7}$
$\mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr} \quad \frac{\text { Total }}{.68} \quad \frac{\text { Nanno }}{.48} \quad{ }^{1}$ Nanno $=$ less than $20 \mu \mathrm{~m}$

## TABLE C-2

CARBON UPTAKE FOR NEPHY II, JULY 24, 1978.

A. $\mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr}=\frac{\left(\mathrm{R}_{\mathrm{L}}-\mathrm{R}_{\mathrm{D}}\right) \times 24000 \times 1.05}{2.5\left(2.2 \times 10^{\circ}\right)} \times \frac{1}{7}$ B. $\quad \mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr}=\frac{\mathrm{R}_{\mathrm{L}} \times 24000 \times 1.05}{2.5\left(2.2 \times 10^{6}\right)} \times \frac{1}{7}$

| $\mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr}$ | $\frac{\text { Total }}{0.29}$ | $\frac{\text { Nanna }}{0.17}$ | $\mathrm{mgC} / \mathrm{m}^{3} / \mathrm{hr}$ | $\frac{\text { Total }}{.86}$ | $\frac{\text { Nanna }}{.57}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{mgC} / \mathrm{m}^{3} / 14 \mathrm{hr}$ | 4.06 | 2.38 | $\mathrm{mgC} / \mathrm{m}^{3} / 14 \mathrm{hr}$ | 12.01 | 8.03 |

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## The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

## The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the Offshore Minerals Management Program administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS Minerals Revenue Management meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.


[^0]:    ${ }^{1}$ Supplied by Shell Oil Company, Houston, Texas.

[^1]:    *Degree of vacuolation: $1=1 i t t l e$ or no vacuolation; 2-3 = slight vacuolation; $4-5=$ moderate vacuolation; 6 = extreme vacuolation

[^2]:    ${ }^{1}$ Use of trade names does not constitute endorsement of a product．

[^3]:    * From paired $t$ tests performed comparing $A A$ values on each sample with or without coprecipitation.

