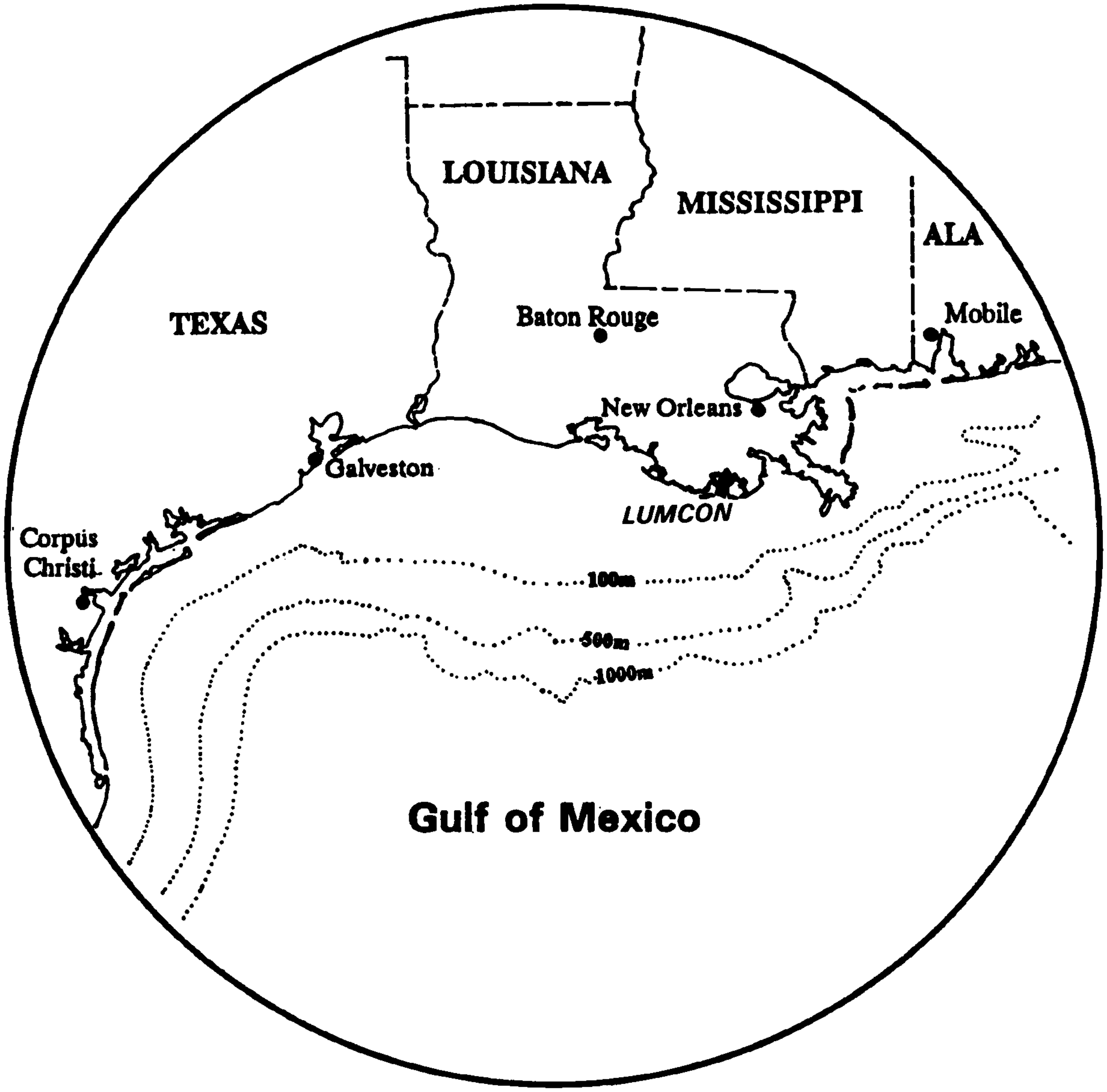
OCS Study
MMS 94-0054

University Research Initiative

Effects of Bottom Water Hypoxia on the Benthic Communities of the Southeastern Louisiana Continental Shelf



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

Cooperative Agreement
University Research Initiative
Louisiana Universities Marine Consortium

OCS Study
MMS 94-0054

University Research Initiative

Effects of Bottom Water Hypoxia on the Benthic Communities of the Southeastern Louisiana Continental Shelf

Authors

Nancy N. Rabalais
Lorene E. Smith
Louisiana Universities Marine Consortium
Chauvin, Louisiana

Donald E. Harper, Jr.
Texas A&M University
Galveston, Texas

and

Dubravko Justic'
Louisiana State University
Baton Rouge, Louisiana

January 1995

Prepared under MMS Contract
14-35-0001-30470
by
Louisiana Universities Marine Consortium
8124 Highway 56
Chauvin, Louisiana 70344

Published by

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

Cooperative Agreement
University Research Initiative
Louisiana Universities Marine Consortium

DISCLAIMER

This report was prepared under contract between the Minerals Management Service (MMS) and the Louisiana Universities Marine Consortium. This report has been technically reviewed by MMS and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Service, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. It is, however, exempt from review and compliance with MMS editorial standards.

REPORT AVAILABILITY

Extra copies of this report may be obtained from the Public Information Unit (Mail Stop 5034) at the following address:

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
Attn: Public Information Unit (MS 5034)
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394
Telephone Number: 1-800-200-GULF

CITATION

Suggested citation:

Rabalais, N. N., L. E. Smith, D. E. Harper, Jr., and Dubravko Justic'. 1995. Effects of Bottom Water Hypoxia on Benthic Communities of the Southeastern Louisiana Continental Shelf. OCS Study MMS 94-0054. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 105 pp.

ABSTRACT

The natural, temporal variability as caused by hypoxic bottom waters was examined for benthic communities on the southeastern Louisiana continental shelf. Study sites were near two platforms in the South Timbalier block area in 20 m water depth, 3 km apart, one production (ST53A) and one non-production (ST53B); and near a production platform in the West Delta block area (WD32E) in 20 m water depth, 74 km from ST53B. Benthic data from a gradient away from the platforms (20 to 1000 m or reference) were initially collected to examine the influence of both hypoxia and production activities (Rabalais et al. 1993). This study focused on the distal stations (500 or 1000 m) or a reference station (WD33) and expanded the temporal scale for an examination of the effects of hypoxia and benthic community recovery and recruitment.

The 1990 season of hypoxia at ST53A and ST53B was severe, in that hypoxia occurred early and persistently in the spring, hypoxia was severe in the summer, long periods of anoxia were documented, and the generation of hydrogen sulfide in bottom waters was often recorded. The oxygen record for WD32E showed incursions of hypoxic conditions, with no extremely low levels for prolonged periods. The continuous oxygen data for the South Timbalier area in 1991 indicated a period in late February and early March when hypoxia occurred. There were shorter periods of hypoxia in March-June followed by rapid re-aeration. For most of July and August and into early September, near-bottom waters were near-anoxic or anoxic. Beginning in early September, the water column was re-aerated by wind-induced mixing from a series of strong cold front passages. Grain size distributions were considerably different between the South Timbalier area (primarily sandy silts or silty sands, with higher variability) and the West Delta area (primarily silts, with lower variability).

There were significant decreases in summer and fall 1990 in species richness and abundance of organisms. Decreases were dramatic at ST53A and ST53B during the period of severe hypoxia/anoxia. The decline in benthic populations was gradual at WD32E throughout the summer and early fall. There was a slight recovery in the benthic community at ST53A and ST53B during October, but the decline in numbers of species and organisms continued at WD32E. Overall, abundance was greater at ST53B in the spring and early summer. As hypoxia/anoxia began in the South Timbalier area and benthic populations declined, abundance of organisms became significantly greater at WD32E. As populations continued to decline at WD32E into the fall along with the slight recovery at ST53B, ST53B became the study site with the greatest abundance of organisms. At ST53A and ST53B, the most dramatic reductions occurred when bottom water oxygen levels fell below 0.5 mg/l. Oxygen levels seldom approached this level at WD32E, and were never persistently low. Recruitment of more species and individuals occurred in February-May 1991, but not at the level observed in spring 1990. At ST53B there was a decline in number of species and individuals during the 1991 summer hypoxia similar to that observed in 1990 but not as severe.

The hypoxia-affected fauna on the southeastern Louisiana shelf followed many predictable patterns of other similar areas. The fauna was dominated primarily by polychaetes of smaller individuals, with overall less biomass, especially during the peak of severe hypoxia. The reduction in species richness, abundance, and biomass, however, was much more severe on the southeastern Louisiana shelf than documented in other hypoxia-affected areas. Longer-lived, larger, higher biomass organisms were virtually absent from the hypoxia-affected study sites.

TABLE OF CONTENTS

Appendices

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This research was funded as a Cooperative Agreement under the Minerals Management Service/Louisiana Universities Marine Consortium (MMS/LUMCON) University Research Initiative. Funds for collection of benthic samples and hydrographic data beyond the original MMS/LUMCON University Research Initiative were provided by the National Oceanic and Atmospheric Administration (NOAA), Coastal Ocean Program, Nutrient Enhanced Coastal Ocean Productivity program (NECOP) project through the Louisiana Sea Grant College Program NOAA Grant No. NA90AA-D-SG691, project number MAR24 to Drs. Nancy N. Rabalais, Louisiana Universities Marine Consortium (LUMCON) and Donald E. Harper, Jr., Texas A&M University at Galveston; and the Louisiana Sea Grant College Program, Grant No. NA89AA-D-SG226, project number R/HPX-1-PD to Drs. Rabalais and Harper for supplemental ship funds. Funds from the NOAA NECOP program NOAA Grant No. NA90AA-D-SG691, project number MAR31 supported the hypoxia studies and instrument mooring of Drs. Nancy N. Rabalais, R. Eugene Turner, Louisiana State University (LSU), and William J. Wiseman, Jr. (LSU). Additional support was provided during July 1990 and July 1991 by the NOAA National Undersea Research Center (NURC). Funding from the Louisiana Board of Regents, Louisiana Education Quality Support Fund (LEQSF), initiated the instrument mooring at South Timbalier 53B, monthly cruises in 1989 and 1990, and a shelfwide survey in 1990.

Benthic macroinfaunal analyses were performed by Lorene Smith, Larry Hyde, Michael Hosey, Danny Smith, June Tillett, Jin Hee Martin and Don Harper. In addition to those just listed, help in field collections was provided by Lori Brunet, Ann Neville, Amy Innes, Laura Bonvillain, and Darla Conner. Sediment grain size analyses were conducted by David DeLaune, Amy Gorman and Lorene Smith. Biomass determinations were completed by Jim Bolden and Corey Coffman. Statistical analyses were performed by Lorene Smith, Dubravko Justic' and Nancy Rabalais. Graphics are by Nancy Rabalais, Lorene Smith and Ben Cole. We thank the captains and crews of the R/V *Pelican* and R/V *Acadiana* for their help in completion of the research.

Dr. Robert Rogers served as Contracting Officer's Technical Representative for MMS, and Dr. Paul W. Sammarco served as LUMCON URI Program Manager during the study.

The research program could not have proceeded without the cooperation of the oil and gas industry. Companies that facilitated access to study areas were Shell Offshore, Inc. and Union Oil Company of California.

CHAPTER 1. EXECUTIVE SUMMARY

Natural variation in space and time often complicates assessments of the effects of petroleum production activities on ambient communities in a field setting. A major confounding effect in offshore regions of Louisiana is seasonally intense and widespread hypoxic (dissolved O_2 < 2 mg/l) bottom waters (Rabalais et al. 1991). Zones of hypoxia may cover up to 16,500 km^2 during mid-summer on the inner continental shelf from the Mississippi River delta to the upper Texas coast (Rabalais et al. 1994a). Several studies of the effects of offshore petroleum development have been unable to separate the effects of sediment contamination from oxygen stress because of a lack of knowledge of the natural variability in the system or knowledge of the history of oxygen stress.

We previously examined the multiple effects of production activities and hypoxia at three study sites on the southeastern Louisiana shelf during April-August 1990 (Rabalais et al. 1993). In the present study we focused exclusively on the effects of hypoxia to better define the variability in the benthic community. We examined varying degrees of oxygen stress, and expanded the temporal scale to define the variability in the community over several annual cycles of oxygen stress and benthic community recovery.

The study was conducted within the South Timbalier and West Delta lease blocks. Unocal South Timbalier 53A (= ST53A, UA) is in close proximity to the 1990 instrument mooring (with continuously recording oxygen meter) at Unocal's South Timbalier 53B platform (= ST53B, UB). The instrument mooring was moved to Unocal South Timbalier 53#3 (=ST53#3) in 1991. Shell's platform West Delta 32E (=WD32E, SH) is located closer to the Mississippi River and 74 km distant from the primary instrument moorings. An oxygen meter was deployed at WD32E during 1990. Sediments in West Delta 32 were predominantly silts (80 to 95%) while those of the South Timbalier area were predominantly silt and sand mixtures of extreme variability.

Monthly cruises along Transect C on the southeastern Louisiana continental shelf in 1990 documented widespread areas of lower water column hypoxia and very often anoxic or near-anoxic conditions in near-bottom waters from mid-May through mid-September (Rabalais et al. 1992a). Hypoxia occurred as late as mid-October. By comparison, hypoxia in the lower water column was patchy and ephemeral along Transect C in 1991 from mid-May through mid-July, was extensive and severe in mid-August, and had diminished substantially by mid-September (Rabalais et al. 1992a).

At Station ST53B off Terrebonne Bay, continuous oxygen records indicated that bottom waters were severely depleted in dissolved oxygen and often anoxic for most of the record from mid-June through mid-August 1990 (Rabalais et al. 1994b). Severe hypoxia also persisted for much of the month of September. There were no strong diurnal or diel patterns in the oxygen time series at ST53B (Rabalais et al. 1994b). In contrast, at Station WD32E hypoxia occurred for only 50% of the total record, hypoxic events were shorter in duration than at ST53B, and there was a strong diurnal pattern in the oxygen time series (Rabalais et al. 1994b). The record of dissolved oxygen was most coherent with the diurnal bottom water pressure signal, which suggested the importance of tidal advection in the variability of the oxygen record (Rabalais et al. 1994b).

The continuous oxygen data for station ST53#3 in 1991 indicated a period in late February and early March when hypoxia occurred (Rabalais et al. 1992a). There were other much shorter periods of hypoxia in March-June followed by rapid re-aeration. For most of July and August and into early September, near-bottom waters were near-anoxic or anoxic. Beginning in early September, the water column was re-aerated by wind-induced mixing from the beginning of a series of strong cold front passages. The early part of 1991 (March-June) was also characterized by a fairly continuous series of strong weather fronts with strong winds and subsequent wind-induced mixing. Bottom waters at WD32E were well-oxygenated during the months of benthic collections (February-May) in 1991.

There were significant decreases in summer and fall in species richness and abundance of organisms. Decreases were dramatic at ST53A and ST53B during the period of severe hypoxia/anoxia. The decline in benthic populations was gradual at WD32E throughout the summer and early fall. There was a slight recovery in the benthic community at ST53A and ST53B during October, but the decline in numbers of species and organisms continued at WD32E. Overall, abundance was greater at ST53B in the spring and early summer. As hypoxia/anoxia set up in the South Timbalier area and benthic populations declined, abundance of organisms became significantly greater at WD32E. As populations continued to decline at WD32E into the fall along with the slight recovery at ST53B, ST53B became the study site with the greatest abundance of organisms. At ST53A and ST53B, the most dramatic reductions occurred when bottom water oxygen levels fell below 0.5 mg/l. Oxygen levels seldom approached this level at WD32E, and were never persistently low.

Spring recruitment of 1991 replenished both species and number of individuals at all three sites, but not to the same level as in spring 1990. The timing and magnitude of spring recruitment varied from year to year. During mid-summer 1991, severe hypoxia drastically reduced the number of species and individuals at ST53B, but not as severely as in 1990. A comparison of the continuous oxygen records for the two years indicated that the number and duration of hypoxic and anoxic events were not as great in 1991 as in 1990. This demonstrates variable responses within degrees of severity of hypoxia, and not just a single response to hypoxic conditions.

The benthic communities at ST53A and ST53B were similar to each other with regard to taxonomic composition and changes in dominance of species through time. Polychaetes were the most common members of the community. The polychaetes *Ampharete* sp. A, *Paraprionospio pinnata*, and *Mediomastus ambiseta* were common in spring and early summer. As hypoxia progressed, the common species were reduced to the polychaetes, *Ampharete* sp. A and *Magelona* sp. H, and the sipunculan *Aspidosiphon* sp. During August, only *Magelona* sp. H and *Aspidosiphon* sp. maintained any significant population levels. Fall recruitment in 1990 was due primarily to the recruitment of *Paraprionosopio pinnata* and *Armandia maculata* and sustained population levels of *Magelona* sp. H and *Aspidosiphon* sp. Besides the common members of the fauna, spring recruitment in 1991 was accompanied by high numbers of *Sigambra tentaculata*. Recruitment in fall 1991 at ST53B was again due to sustained population levels of *Magelona* sp. H and *Aspidosiphon* sp. as well as the presence of *Sigambra tentaculata* and *Paraprionospio pinnata*.

A large component of the benthic community at WD32E was composed of polychaetes, with a much greater diversity of other major taxa than at stations in the South Timbalier area. The benthic community at WD32E was diverse, with a complement of pericaridean crustaceans, bivalves, gastropods, and other taxa, not usually representative of the silty sediments. *Mediomastus ambiseta* and *Paraprionospio pinnata* were dominant for most months. An increase in *Armandia maculata* was observed in August. Changes in several dominant species through time were evident with *Prionospio cristata*, *Nephtys incisa*, *Magelona* sp. I, *Magelona* sp. H, *Ampharete* sp. A, *Owenia fusiformis*, *Sigambra tentaculata* and *Cossura soyeri*.

Most individuals were distributed within the upper 2 cm of the sediments, especially during peaks in spring recruitment of both years. The smaller recruited individuals at the surface in spring of both years were *Paraprionospio pinnata* and *Ampharete* sp. A, which are surface deposit feeders. Other dominant spring recruits, *Mediomastus ambiseta*, are subsurface deposit feeders/opportunists. Individuals (low in abundance) were more evenly distributed during mid-summer hypoxia in July-August 1990 and August 1991. Although numbers increased in fall (September-October) of both years, they remained more evenly distributed through the sediments (with a few exceptions) as opposed to close to the sediment surface as in spring. Species were more evenly distributed throughout the sediments across seasons and years, than individuals.

Benthic community biomass at West Delta 32E displayed a positively linear relationship with abundance data (Figure 23). The relationships of biomass to abundance for South Timbalier 53A and South Timbalier 53B were fairly linear until abundances exceeded 200/replicate. These higher abundances were associated with recruitment events for *Paraprionospio pinnata* and *Mediomastus ambiseta* where the number of individuals increased dramatically, but biomass did not (i.e., smaller recruits).

The hypoxia-affected fauna on the southeastern Louisiana shelf followed many of the predictable patterns of previous studies (Holland et al. 1987, Santos and Simon 1980, Gaston 1985, Dauer et al. 1992). They were dominated primarily by polychaetes of smaller individuals, with overall less biomass, especially during the peak of severe hypoxia. The reduction in species richness, abundance, and biomass, however, was much more severe than documented in the above mentioned studies. Longer-lived, larger, higher biomass organisms were virtually absent from the hypoxia-affected study sites. Contrary to previous studies, the fauna was not restricted to shallow -dwelling organisms. Although most individuals were located within the upper 2 cm of the sediments, this was most dramatic during the period of spring recruitment, and organisms were more uniformly distributed throughout the remainder of the year, although drastically reduced during July-August (the most severe hypoxia/anoxia).

CHAPTER 2. INTRODUCTION

Natural variation in space and time often complicates assessments of the effects of petroleum production activities on ambient communities in a field setting. A major confounding effect in offshore regions of Louisiana is seasonally intense and widespread hypoxic (dissolved O_2 < 2 mg/l) bottom waters (Rabalais et al. 1991). The zones of hypoxic bottom water may cover up to 16,500 km^2 during mid-summer on the inner continental shelf from the Mississippi River delta to the upper Texas coast (Rabalais et al. 1994a). Several studies of the effects of offshore petroleum development have been unable to separate the effects of sediment contamination from oxygen stress because of a lack of knowledge of the natural variability in the system. The most notable examples are the Offshore Ecology Investigation (Ward et al. 1979), the Central Gulf Platform Study (Bedinger 1981), and a produced water discharge study (Neff et al. 1989). Knowledge that was lacking was the actual history of oxygen concentrations, the different responses of benthic communities to varying recorded oxygen concentrtaions, and the sequence of benthic community changes during and following severe hypoxia/anoxia.

We previously examined the multiple effects of production activities and hypoxia at three study sites on the southeastern Louisiana shelf during April-August 1990 (Rabalais et al. 1993). In the present study we focused exclusively on the effects of hypoxia to better define the variability in the benthic community. We examined varying degrees of oxygen stress, and expanded the temporal scale to define the variability in the community over several annual cycles of oxygen stress and benthic community recovery.

Previous studies of benthic macroinfaunal communities in areas of hypoxia on the Louisiana and Texas continental shelf (Harper et al. 1981, 1991, Gaston 1985, Gaston et al. 1985) have been situated within areas of intermittent or less severe hypoxia, with the exception of the preliminary studies of Boesch and Rabalais (1991) and Rabalais and Harper (1991, 1992), within the area of seasonally severe, persistent and extensive hypoxia. Low oxygen concentrations were either documented during the period of collections, or surmised from the structure of the benthic communities. The overall objective of our research program was to determine the effects of hypoxia on benthic community structure at two locations on the southeastern Louisiana continental shelf, where we also collected continuous dissolved oxygen concentrations. One area experiences severe oxygen depletion of the bottom waters most summers; the second was located in an area with intermittent hypoxia (Rabalais et al. 1994b). We also aimed to define the long-term variation in the benthic communities within these two areas over several seasonal cycles of hypoxia and community recovery.

2.1 Hypoxia on the Louisiana Continental Shelf

The largest, most severe, and most persistent zone of hypoxia (operationally defined by dissolved oxygen levels of < 2 mg/l, based on effects on local biota) in the U.S. coastal waters and the western Atlantic Ocean is found in the northern Gulf of Mexico on the continental shelf off Louisiana (Rabalais et al. 1991). The zones of hypoxic bottom water in the northern Gulf of Mexico may cover 16,5000 km^2 during mid-summer on the inner continental shelf, from the Mississippi River delta to the upper Texas shelf (Figure 1, Rabalais et al. 1991, 1992a, 1994a). The configuration of the area in most mid-summer surveys is a set of disjunct areas downfield of the Mississippi River birdsfoot delta and Atchafalaya Bay, although a continuous band was mapped in 1985 and 1990. More frequent sampling along a transect on the southeastern shelf and continuous time series data off Terrebonne Bay document hypoxic bottom waters as early as February and as late as October, with widespread, persistent and severe hypoxia/anoxia from mid-May through mid-September.

Hypoxia on the Louisiana Continental Shelf

1990 and 1991

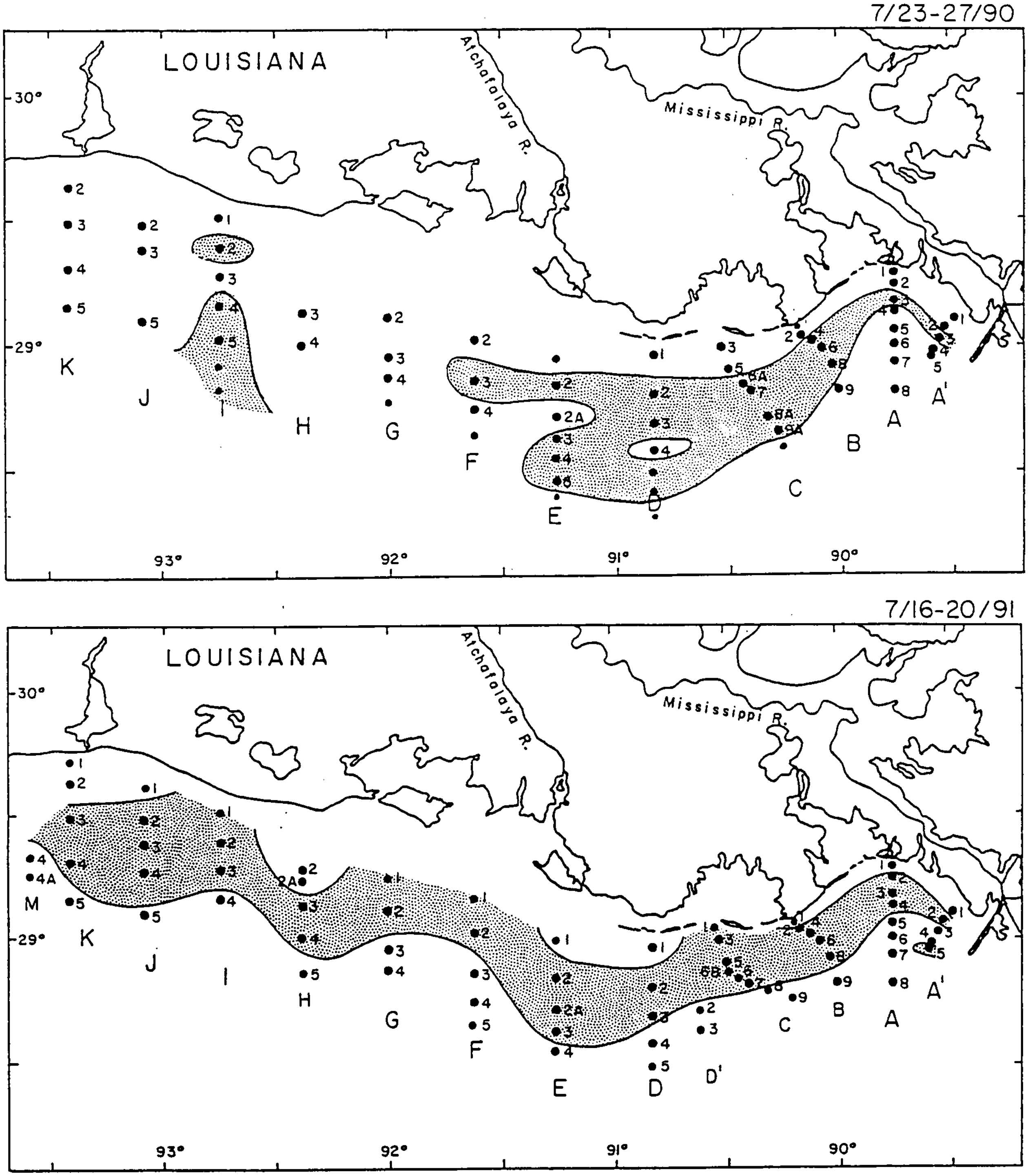


Figure 1. Areas of near-bottom water hypoxia on the Louisiana shelf (modified from Rabalais et al. 1992a). Transect (letters) and station (numbers) labels correspond to the studies of Rabalais et al. (1991, 1992a, 1994a).

The Mississippi River system, which empties onto the northern Gulf of Mexico continental shelf, ranks among the world's top ten rives in terms of freshwater and sediment inputs to the coastal ocean (Milliman and Meade 1983), drains 41% of the conterminous U.S., and contributes over 90% of the fresh water to the Gulf of Mexico (Dinnel and Wiseman 1986). High flow occurs in March-May. Although river flow is reduced in summer, seasonal wind reversals retain much of the fresh water on the shelf. A productive, stratified system is maintained for the majority of the year (Sklar and Turner 1981, Justic' et al. 1993). The vertical distribution of the hypoxic water mass is defined by water column stratification which is controlled by riverine freshwater inflow, large-scale circulation and wind-driven mixing (Rabalais et al. 1991).

High biological productivity in the immediate and extended plumes of the Mississippi River (Lohrenz et al. 1990, Sklar and Turner 1981) is mediated by high nutrient inputs and regeneration, and favorable light conditions. Subsequent carbon flux (via direct sinking, repackaging as fecal pellets, aggregate formation, or advection) is sufficient to deplete the lower water column within periods of days to weeks to months (Turner and Allen 1982, Dortch et al. 1994). Once hypoxic water masses have formed, they persist until mixing results from winds and/or thermal cooling, or the advection of oxygenated water during upwelling or downwelling favorable conditions and/or tidal oscillations. The highest net productivity in the adjacent shelf system lags one month after peak river flow; the most deficient bottom water oxygen lags two months behind peak river flow (Justic' et al. 1993).

2.2 Prior Studies

Regions of hypoxic bottom waters have been detected along portions of the Louisiana-Texas coast every summer since 1972 (see reviews of Dennis et al. 1984, Rabalais et al. 1985, 1991, Renaud 1985, 1986). Prior observations are few, but anecdotal evidence indicates hypoxia also developed during earlier years (W. Forman, G. Gunter, pers. comms., Gaston 1985). Until the systematic studies of Rabalais et al. (1991, 1992a) beginning in 1985, a comprehensive picture of the temporal and spatial distribution of shelf hypoxia was lacking. Most prior data were collected in regionally limited and short-term studies. Many of these earlier accounts of hypoxia were documented in conjunction with environmental assessments of oil and gas activities, oil offloading facilities (LOOP-Louisiana Offshore Oil Port), brine disposal sites of the Dept. of Energy Strategic Petroleum Reserve Program, and broadscale fisheries distributions (SEAMAP-Southeast Area Monitoring and Assessment Program of the Gulf States Marine Fisheries Commission).

The Gulf Universities Research Consortium (GURC) Offshore Ecology Investigation (OEI) was the first large investigation of the long-term impacts of oil and gas development in the coastal and offshore regions of Louisiana (Ward et al. 1979). Sampling was conducted between 1972 and 1974 in the Timbalier Bay and offshore areas of Louisiana. Extremely low levels of dissolved oxygen were found during the OEI-GURC study in 1973-1974 (Oetking et al. 1974) which confounded the interpretation of results. The benthic studies of the OEI-GURC program, however, were replete with methodological problems (outlined in Sanders 1981, Carney 1987).

The Central Gulf Platform Study was conducted during 1978-1979 to define the long-term cumulative impacts of extensive oil and gas development along the southeastern Louisiana coast in the region of offshore platforms (series of reports edited by Bedinger 1981). Bedinger (1981) mentioned frequently low dissolved oxygen levels in the study area, the limitations of the study to adequately define the long-term monthly or even seasonal variation in the levels, and the potential effects on the benthic fauna. Conclusions from the benthic studies were that oxygen depletion, the freshwater, sediments, natural organic materials and contaminants in the Mississippi River outflow, and tropical storms affect the study area to such an extent that showing significant population differences definitely attributable to platform operations could not be accomplished with the study. The study design, however, did not incorporate the temporal or spatial sampling necessary to identify the inherent variability of the system, nor were dissolved oxygen measurements sufficient to characterize the area. In fact, the protocol for hydrographic casts in the Central Gulf Platform Study was for surface and subsequent 10-m interval discrete samples that often left the near-bottom waters unmeasured.

The produced water discharge study of Neff et al. (1989) at Eugene Island Block 105 in approximately 8 m water depth characterized the benthic fauna as pioneer communities characteristic of disturbed environments. This community was dominated by one or a few species which were short-lived opportunistic species. Juvenile forms were very abundant, representing more than 50% of the total individuals of several species, yet species diversity was moderate to high at all stations. They deduced that the benthic community structure throughout the area was controlled in large part by factors such as high suspended sediment loads attributable to the Mississippi River outflow and periodic bottom water hypoxia. The study area was visited in late March and early October 1986, during which time the water column was well-mixed and dissolved oxygen concentrations were at or near saturation throughout. In our opinion, the benthic community composition described by Neff et al. (1989) indicates a relatively diverse community at both the specific and broader taxonomic levels, which captured a recruitment event of the capitellid polychaete *Mediomastus ambiseta*, especially in the spring collection. The dissimilarity of this community with those on the southeastern Louisiana shelf (Murrell and Fleeger 1989, Rabalais et al. 1989, Boesch and Rabalais 1991, Rabalais unpubl. data) indicates very little exposure of this community to severe or persistently low oxygen conditions. A candidate study site, Ship Shoal Block 114 in 12 m water depth, was omitted, because there was a strong indication in July 1985 of an extremely depauperate benthic infauna attributable to bottom water hypoxia, so that it would be difficult or impossible to detect any impacts attributable to produced water discharges.

A few benthic studies on the Louisiana and Texas shelves have benefited from adequate time series to identify benthic community impacts related to low oxygen events (Harper et al. 1981, 1991, Gaston 1985, Gaston et al. 1985, Murrell and Fleeger 1989, Rabalais et al. 1989, Boesch and Rabalais 1991, Rabalais and Harper 1991, Rabalais et al. unpubl.), but these studies were not conducted in conjunction with efforts to determine the impacts of production platform effluents. Two of the studies (those of Harper and colleagues and those of Gaston and colleagues) were designed for brine disposal sites of the Strategic Petroleum Reserve Program at Bryan Mound, offshore Texas and West Hackberry, offshore southwestern Louisiana, respectively. The Bryan Mound site off Freeport, Texas is located in an area where hypoxia occurs infrequently, but the event in June-July 1979 was prolonged and severe enough for the production of hydrogen sulfide into the water column above the sediment-water interface (Harper et al. 1981, 1991). During this period, benthic infauna declined precipitously. Other, less severe, hypoxic events may have occurred in 1982-1984. The 29-month study documented patterns of recovery in benthic communities in 15- and 21-m water depth following the initial impact, and provided an excellent documentation of the natural variability inherent in the system (Harper et al. 1991). The West Hackberry site, off Cameron, Louisiana is located in an area that experiences hypoxia, but in episodic events, less severe, less prolonged, and less extensive compared to the southeastern Louisiana coast where hypoxia is a severe, extensive, and prolonged annual occurrence (Gaston 1985, Pokryfki and Randall 1987, Rabalais et al. 1991, 1992b). The benthic infauna at West Hackberry was dramatically reduced for most species following hypoxia in June-August 1981, with the exception of the polychaete *Magelona* cf. *phyllisae* (= *Magelona* sp. H) which increased in numbers, compared to Bryan Mound where this species along with all polychaetes was severely reduced. As with the Bryan Mound study site, the amphipod crustaceans at the West Hackberry site (14-mo study) were dramatically reduced the year following the hypoxic event (Gaston 1985, Harper et al. 1991).

On the southeastern Louisiana shelf the meiofaunal and macrofaunal communities were examined at a single station for a 16-mo period encompassing two periods of hypoxia in 1985 and 1986 (Murrell and Fleeger 1989, Rabalais et al. 1989, Boesch and Rabalais 1991, Rabalais unpubl. data). In both cases, the communities were reduced, more severely in 1985 when oxygen levels fell lower than in 1986. Of the meiofaunal community, hypoxia virtually eliminated populations of benthic copepods and kinorhynchs, with extensive recovery not occurring until the following winter. Heavy mortalities occurred in the macroinfauna in both 1985 and 1986, with the persistence of a population of the polychaete *Magelona* cf. *phyllisae* (= *Magelona* sp. H) in 1986. Also, recruitment and increases in populations on the southeastern Louisiana shelf did not occur after the cessation of hypoxia, compared to the upper Texas coast and the southwestern Louisiana shelf, and did not begin until the following spring. The reason for this delay may be related to the fact that the southeastern Louisiana site lies within a large area which experiences persistent hypoxia virtually every year, compared to episodic and ephemeral events at the other sites. Also, at the southeastern Louisiana site, amphipod populations were very sparse at all times, compared to reductions with slow recoveries at the Bryan Mound and West Hackberry sites, perhaps again reflecting the persistent and widespread hypoxia on the southeastern Louisiana shelf.

2.3 Other Studies

A recent review by Diaz and Rosenberg (in press) compiled worldwide data on the effects of hypoxia and anoxia on benthic macrofauna. They noted that hypoxia is the most widespread, anthropogenically induced deleterious effect in the marine environment. It appears that oxygen stress is increasing in area, severity and duration, even within systems that historically are considered stressed. The ecological effects of hypoxia and anoxia on benthos are related to the temporal variation of events which fall below critical thresholds for specific organisms, the absolute oxygen concentration, the stability and duration of hypoxia, and the generation of hydrogen sulfide. There are few field studies with continuous oxygen data. Very often the hypoxia exposure is not known, and we should not presuppose a specific oxygen history based on infaunal community structure.

Long-term trends for the Skagerrak coast of western Sweden in semi-enclosed fjordic areas experiencing increased oxygen stress (Rosenberg 1990) showed declines in (1) total abundance and biomass, (2) abundance and biomass of mollusks, and (3) abundance of suspension feeders and carnivores. In pre-stressed communities, sensitive faunal groups were already lost from the community before severe hypoxic/anoxic events further depleted the benthic fauna (Josefson and Widbom 1988). Holland et al. (1987) examined recurring seasonal hypoxia in the mesohaline Chesapeake and found a reduction in long-lived benthos and dominance by smaller, short-lived species (also Mountford et al. 1977). Where hypoxia is periodic and intermittent, e.g., Rappahannock River of Chesapeake Bay, Llanso (1992) determined that the benthic community was related to the intermittent hypoxia. In York River, however, intermittent but less severe hypoxia, had no effect on benthic community changes (Llanso 1991, 1992) where the community may be long-term conditioned to hypoxic stress. Diaz and Rosenberg concluded that, in general, long-term reduction in macrofauna occurs as hypoxic stress increases (Ranchor 1985, Niermann et al. 1990, Friligos 1976, Friligos and Zenetos 1988).

CHAPTER 3. METHODS

This report supplements the work of Rabalais et al. (1993) which examined the multiple effects of production activities and hypoxia on benthic community structure. Data from the initial study were obtained in April and June-August 1990 at three platforms along a gradient of 20 m to 1000 m away from the structure (including a reference station at one study site). Supplemental data for fall 1990 and spring, summer and fall of 1991 focused on the 500 and 1000 m stations, as well as the reference station. Data include benthic community parameters and sedimentary and hydrographic characteristics for the 1991 collections; data for 1990 were reported previously (Rabalais et al. 1993). Supplemental data for the vertical distribution of the benthos (1990 and 1991) and benthic biomass (1990 and 1991) are provided in this report.

3.1. Study Areas

Our original project (Rabalais et al. 1993) focused on two oil and gas production platforms within 100 km of each other in a 20-m depth range off Terrebonne Bay and within the Mississippi River bight. They were located within the area of recurring hypoxia (based on 5 years of mid-summer surveys by Rabalais and colleagues), and near Station ST53B or ST53#3, where a mooring with hydrographic instruments was deployed.

Table 1. Study areas.

Company	Lease Block	Water Depth	Volume Discharged	Sediment Type
Shell Offshore	West Delta 32E (oxygen meter, 1990) = WD32E, SH reference station in WD33	20 m	19,000 bbl/d	silt
Unocal	South Timbalier 53A and A-Aux. = Unocal A and UA	20 m	5,550 bbl/d	sandy silt
Unocal	South Timbalier 53B (oxygen meter and instrument mooring, 1990) = Unocal B and UB	20 m	inactive	variable; sandy silt and silty sand
Unocal	South Timbalier 53#3 (new mooring, 1991)	21 m	satellite platform	

Unocal's South Timbalier 53A and A-Aux. is in close proximity (≤ 7 km) to the 1990 instrument mooring at Unocal's South Timbalier 53B platform (=C6A) and to the 1991 mooring at Unocal's South Timbalier 53#3 satellite (=C6B). The Shell platform in West Delta 32 was located closer to the Mississippi River effluent, in a different sedimentary regime, and 74 km distant from the primary instrument moorings at ST53B or ST53#3. The reference station for West Delta 32 E was located in West Delta 33, within 7 km of WD32E. Sediments in West Delta 32 were predominantly silts (85 to 90%) while those of the South Timbalier 53 lease block were predominantly silt and sand mixtures of extreme variability.

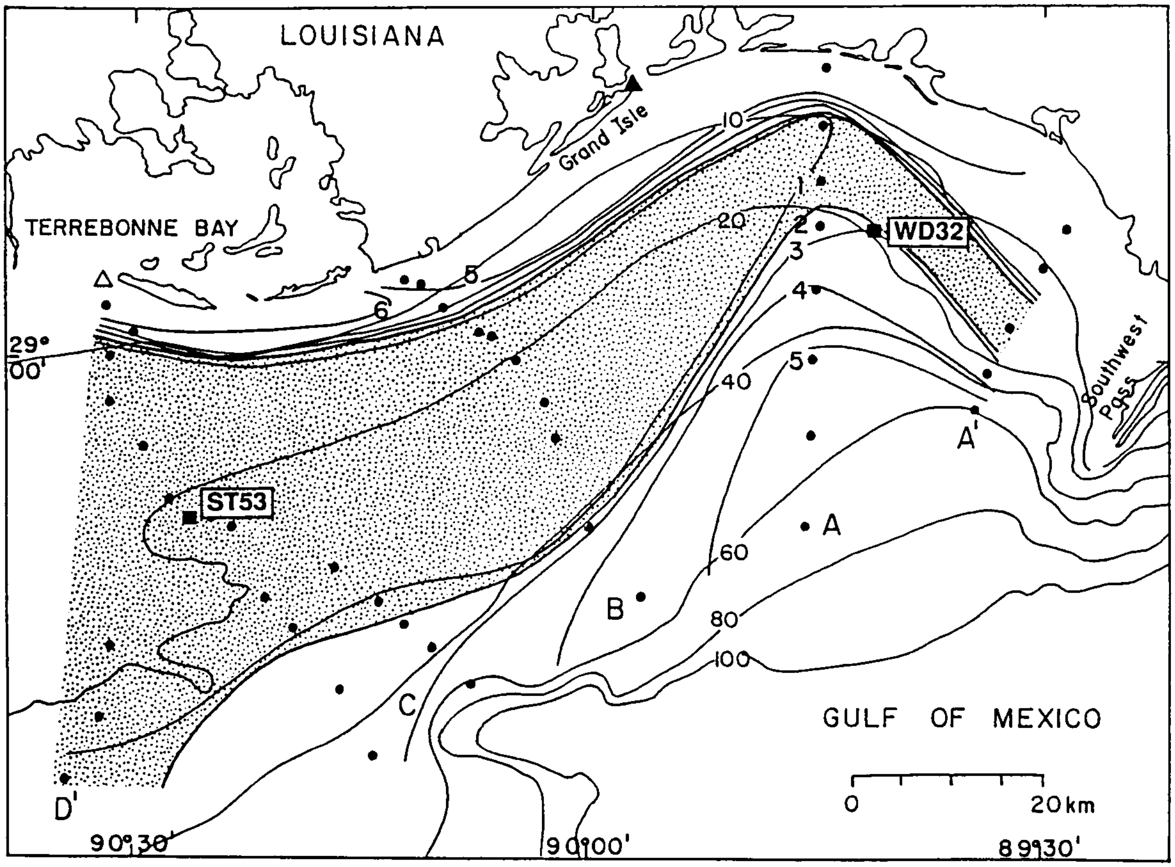


Figure 2. Map of study area with the location of South Timbalier Block 53 (ST53) and West Delta 32 (WD32) superimposed on locations of hydrographic survey stations along transects A' through D' of studies of Rabalais et al. (1991, 1992a, 1994a). Stippled area represents spatial extent of near-bottom water hypoxia (≤ 2 mg/l) during mid-July to late-July 1990. Isobaths in 10 m to 100 m; oxygen isopleths in 1 to 6 mg/l (modified from Rabalais et al. 1994b).

Supplemental funding from the NOAA NECOP program provided for follow-up of a selected number of stations from the three study sites through the spring recruitment period of 1991, and a single station through the 1991 hypoxia period. To avoid the potential interference of platform-related activities and/or discharges (see Rabalais et al. 1993), the stations selected for continuation were at the 500 m or 1000 m distance or, in the case of WD32E, the reference station in WD33. The station slated for continuation through the 1991 hypoxia season was Unocal ST53B at a distance of 500 m. The removal of the Unocal ST53B platform late in 1990 necessitated our moving the instrument mooring to Unocal ST53#3 in 1991 (=C6B).

3.2 Field Studies

Benthic collections (with ancillary data) were conducted during April - October 1990 and February - October 1991. Additional samples for hydrographic data were taken in the vicinity of the study sites at other times during 1990 and 1991, and on a broad-scale on the southeastern shelf during mid-July cruises of both years. Research cruises were conducted aboard the LUMCON vessels R/V *Pelican* or R/V *Acadiana*. Navigation was by Loran C of the respective vessels, which differed somewhat in their signals. Waypoints were recorded from both Loran C units for intercomparison of navigation data. Station distances from each platform were placed as closely as possible at 500 and 1000 m intervals away from the discharge point. A buoy was set at each distance, and the research vessel positioned as close as possible to the buoy during sample collections.

At all study sites, hydrographic profiles were obtained from at least one station during each sample period. With the exception of July 1990 shelfwide cruises, water column measurements were made at 1-m (sometimes 0.5-m) intervals with a Hydrolab Surveyor II CTD unit for water temperature, salinity, conductivity, pH and dissolved oxygen. Water samples for verification of conductivity measurements were taken for salinity determinations on an AGE "Minisal" Model 2100 salinometer. Pre- and post-cruise calibration of the Hydrolab over the previous four years of operation in various LUMCON research programs has verified it as a reliable instrument. The Hydrolab sonde unit is returned to the factory for a yearly maintenance and calibration check. During the shelfwide July cruises, hydrographic data were recorded as continuous profiles with the *Pelican* SeaBird CTD/DO system. Temperature and conductivity probes on the SeaBird system are factory-calibrated. The dissolved oxygen sensor is set on an estimated upper- and lower-end concentration prior to each cruise; actual concentrations are calculated based on Winkler titrations (Parsons et al. 1984) across the full range of values and conducted on board the vessel during the cruise. Water samples for Winkler titrations and conductivity were collected from 5-l Niskins taken to a known depth, or from bucket samples for surface waters.

Benthic samples were collected with an Ekman-type closure 0.1-m^2 box corer with an average penetration of 20 cm and a minimum penetration of 10 cm in sandy, well-sorted sediments. Surface grain size and total organic carbon (TOC) samples were taken using 60-cc piston core syringes down to a depth of 5 cm. Samples were bagged, frozen, and returned to the laboratory.

Sediment samples for benthic macroinfaunal analysis were taken with a small, hand-operated Ekman grab (0.023-m^2 surface area) from the larger box corer. The entire contents of the smaller Ekman grab were used. The volume of the sediments collected was noted, if the sample appeared not to have penetrated to a suitable depth. Five replicates per station, one from each of five separate box cores, were taken. Samples were sieved in the field through a 0.5-mm screen. If time or logistics did not allow, the samples were placed in buckets, preserved, and returned to the laboratory for sieving. The organisms retained on the sieve and debris were preserved in 10% buffered formalin in ambient water stained with Rose Bengal.

Vertical cores were taken at Unocal ST53A, 500 m distance for each month of the study. Acrylic core tubes (7.6-cm diameter) were used to subsample the box corer. They were extruded on a precision core extruder at 0-2 cm, 2-4 cm, 4-6 cm, etc. sections for the length of the core. The extruded sediments were preserved in 10% buffered formalin in ambient water stained with Rose Bengal and returned to the laboratory for sieving and enumeration.

3.3 Instrument Deployments

The instrument mooring with current meters, particle traps and near-bottom continuously recording oxygen meter as part of the Rabalais, Turner and Wiseman hypoxia studies was deployed in March 1990 at ST53B. Recovery of the oxygen meter in mid-May 1990 indicated a problem with the instrument and loss of the first 2-mo record. Data were recovered from mid-May through mid-October, when the mooring was taken out of the water prior to the scheduled removal of the ST53B platform by Unocal. The mooring was redeployed in early February through December at ST53#3 in 1991. At Shell's WD32E, continuous oxygen data were recovered from a near-bottom deployment from mid-June through mid-October 1990, when the instrument was taken out of the water. The oxygen meter was not re-deployed at this site in 1991.

Continuous oxygen measurements were recorded with Endeco 1184 oxygen meters deployed approximately 0.5- to 1-m from the bottom. The oxygen meter at Unocal ST53B/53#3 was supplemented with near-surface and near-bottom particle traps and current meters with CT probes. Probes, battery packs and data cartridges for the Endeco 1184 meters were replaced on monthly or bimonthly schedules. Probes were pre- and post-calibrated in the laboratory with the aid of an Endeco 1125 laboratory unit, temperature-controlled manifold, mixed gases of known concentrations, and supplemental Winkler titrations in accordance with specifications for the Endeco 1184 and 1125 (Endeco 1988). Post-calibration values and comparisons between Endeco 1184 recordings and Hydrolab measurements were made to correct Endeco 1184 data.

3.4 Laboratory Analyses and Quality Control

3.4.1 Sedimentary Characteristics

Grain size distributions were determined at LUMCON using a Coulter Multisizer with 256 channelizer capability. This instrument allows rapid processing of samples and accurate particle sizing down to 0.3 µm. Three aperture tube sizes were used in the analysis: 280 µm, 140 µm and 50 µm. Samples were sieved through a 63-µm Nitex screen before analysis with the 140-µm aperture tube, and through a 20-µm Nitex screen before analysis with the 50-µm aperture tube. Coulter Accucomp software was used to overlay distributions from each tube, and sand, silt and clay fractions were identified using the final combined distribution. Coarser samples were also sieved to isolate larger sand particles unsuitable for Coulter Multisizer analysis. Where appropriate these sand measurements were combined with the Coulter Multisizer data, assuming a constant particle density for the sand fraction, to produced a total grain size distribution. Grain size is described according to the sand, silt and clay fractions. In characterizing sediment grain size, silt and clay fractions are frequently combined and described as mud.

Sediment samples for TOC were ground and carbonate material was removed using hydrochloric acid. Subsamples for analysis were weighed on a Cahn micro-balance. The analysis was conducted at LUMCON using a Control Equipment Elemental Analyzer, Model 240XA with a multisampler injector. Duplicate samples for the maximum and minimum TOC readings for each study area were performed for quality control.

3.4.2 Benthos

Macroinfaunal samples were transferred to the sorting laboratory at LUMCON where they were logged into a laboratory record book by sample code, number of containers per sample, and date received. In the laboratory the formalin was decanted over a 0.5-mm sieve inside a fume hood. The samples were rinsed with water and decanted a second time after settling of the organisms. The samples were sorted in water from gridded dishes under a dissecting microscope. Organisms were counted and identified to the lowest possible taxon. Organisms normally considered part of the meiofauna (nematodes and harpacticoid copepods) were not included in the macroinfaunal analysis. Data were entered into dBase data files. A collection of voucher specimens from the benthic infaunal samples was retained in a Reference Collection. The debris from the sample was rechecked by another technician for any missed organisms. If organisms were found, the sample was resorted. For those samples identified by D. E. Harper, Jr. as part of the NOAA NECOP study of Rabalais and Harper, inter-laboratory coordination of taxonomy was conducted by the LUMCON taxonomists to ensure consistency in data.

3.4.3 Biomass

Biomass was determined on ethanol preserved organisms according to the dry ash-free organic method of Crisp (1984). Organisms from each replicate were separated into major taxonomic groupings. Organisms were filtered onto ashed GFC filters and dried for 12-24 h at 60°C to determine dry weight. The filters were then ashed in a muffle furnace at 500°C for 5 h to separate and account for inorganic material in the samples, and then weighed again. Ash-free dry weights were converted to equivalents of carbon with the conversion of 2 g AFDW $\approx$ 1 g C (Ryther 1956).

3.5 Statistical Methods

3.5.1 Descriptive Statistics

Standard benthic community parameters were determined for each station and included number of species per replicate, number of individuals per replicate, diversity (H') and evenness (J'). Diversity was calculated by the following formula:

$$H' = -\sum_{i=1}^{s} \frac{n_i}{N} \log_{10} \frac{n_i}{N}$$

where s = total number of species collected, n = number of individuals of each species, and N = total number of individuals. Evenness was calculated by the formula:

$$J' = \frac{H'}{\log_2 s}$$

Basic statistics were computed using procedures of the Statistical Analysis System (SAS Institute, Inc. 1982).

3.5.2 Analysis of Variance

Infaunal data were analyzed using the General Linear Models (GLM) procedures for analysis of variance (ANOVA) (SAS Institute, Inc. 1982). To meet the assumptions of homogeneity of variance and normal distribution, data were transformed to natural log(x+1). Duncan's multiple range test was performed to identify significantly different stations/months/sites within a group. The level of significance was established at $P < 0.05$.

3.5.3 Multivariate Methods

The results of the field assessments were consolidated into a multi-component data base to characterize the effects of hypoxia and other environmental variables on benthic biota. Hydrographic and sedimentological data were combined with standard benthic community parameters to relate species assemblage properties to location, date and environmental parameters. The data base for multivariate techniques was developed so that information on each station/sample date was consolidated. For the comparison of the three study sites, data were combined by season [1=winter (Feb-Mar); 2=spring (Apr-May); 3=summer (Jul-Aug); 4=fall (Sep-Oct)] to provide an even number of replicates and months within each category. For the ST53B site for which data were available from April 1990 - October 1991, a separate analysis was conducted for monthly data.

Q-type analysis is a standard method for classification and ordination of samples. The following is a short summary of methods that were used in this study. Computations were carried out using Numerical Taxonomy and Multivariate Analysis System (NTSYS-pc, ver. 1.8; Rohlf, 1993).

The biotic data consist of a matrix in which individual samples (columns) are described by average species densities (rows). A total of 51 species was selected for the analysis, which accounted for 98% of the total number of specimens collected during the course of the project. Individual species densities, however, provided a very skewed data. In order to obtain a better approximation of the population mean, average densities were computed from logarithmically transformed data (18-30 replicates per sample), and then backtransformed to the original scale.

In order to achieve normal distribution, the raw data were transformed using the 'root-root' transformation:

$$Y_{ij} = SQR(SQR\ X_{ij})$$

where SQR is the square-root, X_{ij} is the raw data score of the i^{th} species in the j^{th} sample, and Y_{ij} is the corresponding transformed score. This transformation, similar to the logarithmic transformation, has the effect of scaling down the scores of abundant species, so that they do not overwhelm the other data.

A variety of measures of distance, information, correlation, similarity and dissimilarity have been used in order to summarize the overall similarity between samples. Many of these measures and their properties are summarized in Clifford and Stephenson (1975). A frequent feature of marine survey data is that many of the species are absent from a considerable number of samples, so that a significant proportion of the data matrix entries are zero. Transformation of the data does not alter this. Thus, measures which take account of joint absences, including the product moment correlation coefficient which is based on deviations from the mean score, are not robust enough to be generally applicable.

We have adopted the Bray-Curtis dissimilarity (= distance) coefficient which is not affected by joint absences, and is therefore sufficiently robust for marine data. This measure has the form:

$$\delta_{jk} = [\Sigma\ |Y_{ij} - Y_{ik}|] \ /\ [S(Y_{ij} + Y_{ik})$$

where δ_{jk} is dissimilarity between the j^{th} and k^{th} samples summed over all species, Y_{ij} is the score for the j^{th} species in the j^{th} sample, and Y_{ik} is the score for the i^{th} species in the k^{th} sample. Values of δ_{jk} range from 0 (identical scores for all species) to 1 (no species in common). Application of the measure of similarity results in a triangular matrix whose entries compare each sample with every other sample.

Various hierarchical sorting strategies can be used in order to produce a dendrogram from the similarity matrix (Clifford and Stephenson, 1975). The most successful method appears to be the UPGMA method (Unweighted Pair-Group Method, Arithmetic Average), which was also used in the present study. This method joins two groups of samples together at the average level of similarity between all members of one group and all members of the other. In ordination of samples we used a technique known as Multi-Dimensional Scaling (MDS). This method produces an ordination of samples in a specified number of dimensions, usually 2 or 3.

Having obtained groups of samples by analysis of the biotic data, it is important to find the environmental factors that are likely to be responsible for patterns found. One approach is to do this in a separate statistical analysis of the environmental data. In the simplest possible case, values of environmental variables are superimposed on the abundance-based MDS plots. A variety of techniques is then available for further analysis, ranging from a simple t-test or its non-parametric counterpart, Mann-Whitney U-test, to analysis of variance and multiple discriminant analysis.

CHAPTER 4. CHARACTERIZATION OF ENVIRONMENTS

4.1 Conditions of Hypoxia

A comparison of the areal extent of near-bottom water dissolved oxygen levels that fell below 2 mg l^{-1} is shown in Figure 1. The size of the hypoxic water mass was larger in 1991 than 1990 (11,920 km^2 cf. 9260 km^2) (Rabalais et al. unpubl. data), and the configuration was very different. The extent of hypoxia on the southeastern Louisiana shelf in 1990 was much greater than previous years (1985 to 1989) and occurred in deeper water and farther offshore. The extent of hypoxia on the southwestern shelf, however, was reduced compared to previous years. In 1991 a continuous band of hypoxic bottom waters extended from the Mississippi River delta to the Calcasieu Estuary.

Monthly cruises along Transect C on the southeastern Louisiana continental shelf in 1990 documented widespread areas of lower water column hypoxia and very often anoxic or near-anoxic conditions in near-bottom waters from mid-May through mid-September (Figure 3) (Rabalais et al. 1992a). Hypoxia occurred as late as mid-October. Hydrogen sulfide was detected in the near-bottom water samples on several occasions in June, July and August and at one or more stations along Transect C in 1990. By comparison, hypoxia in the lower water column was patchy and ephemeral along Transect C in 1991 from mid-May through mid-July, was extensive and severe in mid-August, and had diminished substantially by mid-September (Figure 3) (Rabalais et al.

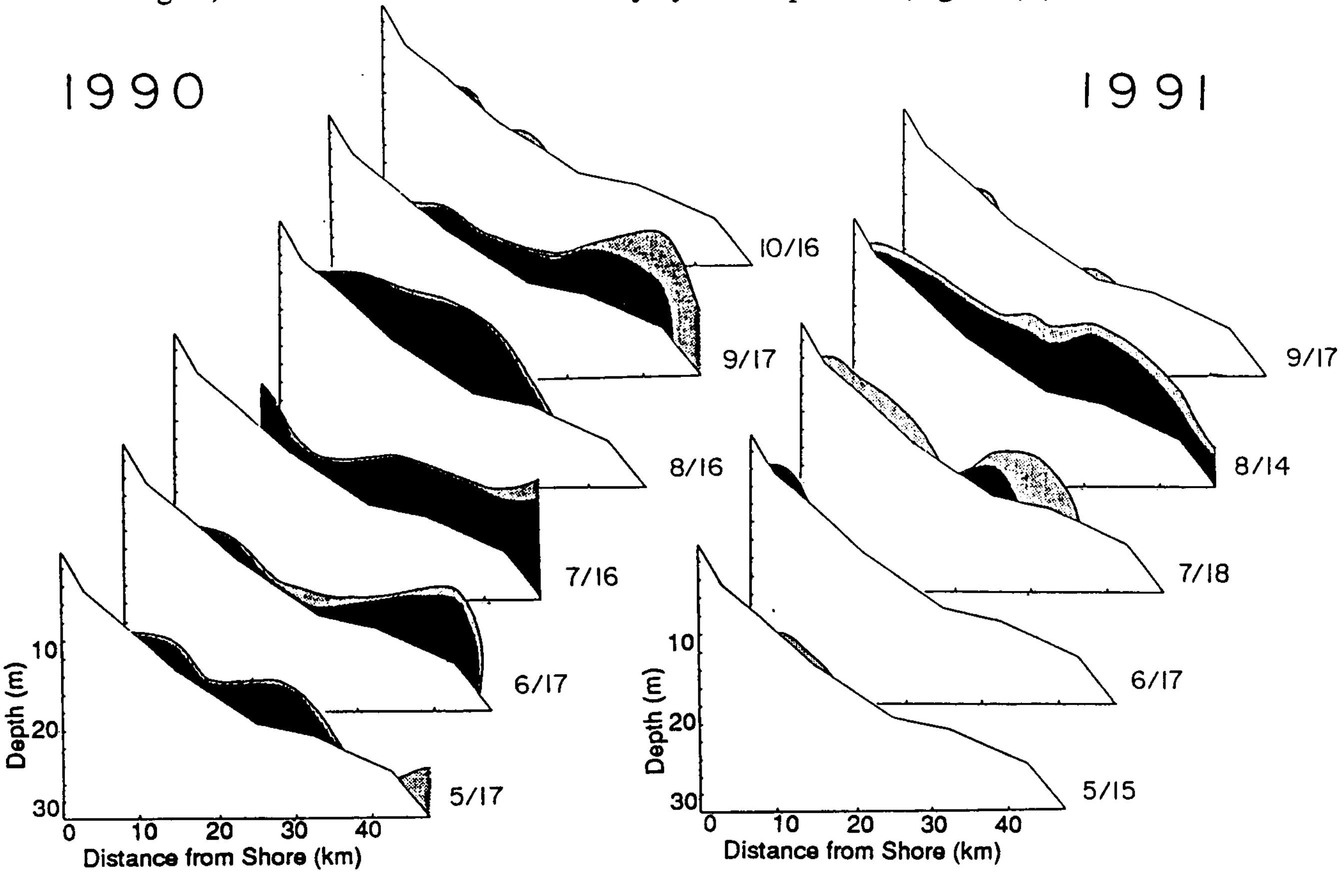


Figure 3. Time sequence of cross-shelf profiles for transect C in 1990 and 1991 with stippled area indicating values of oxygen < 2 mg/l and dark areas, values of oxygen < 1 mg/l (modified from Rabalais et al. 1992a).

1992a). Near-bottom water dissolved oxygen concentrations approached anoxia on few occasions during 1991, and there were no instances when hydrogen sulfide was detected.

At Station ST53B off Terrebonne Bay, continuous oxygen records indicated that bottom waters were severely depleted in dissolved oxygen and often anoxic for most of the record from mid-June through mid-August 1990 (Figure 4). Severe hypoxia also persisted for much of the month of September. There were no strong diurnal or diel patterns in the oxygen time series at ST53B (Figure 5, Rabalais et al. 1994b). In contrast, at Station WD32E hypoxia occurred for only 50% of the total record, hypoxic events were shorter in duration than at ST53B, and there was a strong diurnal pattern in the oxygen time series (Figure 6, Rabalais et al. 1994b). The record of dissolved oxygen was most coherent with the diurnal bottom water pressure signal, which suggested the importance of tidal advection in the variability of the oxygen record (Figure 5) (Rabalais et al. 1994b). A highly stratified water column was present during most of the periods of record. Wind-induced mixing was insufficient to reaerate the water column prior to the outbreak of cold air fronts in late September and early October at which time a relaxation in the stratification also occurred due to thermal cooling. Lack of strong winds capable of breaking down the stratification suggested that reoxygenation (at ST53B in late August and at WD32E for most of the record) resulted from lateral advection. The depth gradient is gradual at ST53B so that the hypoxic area is much broader in a cross-shelf direction and the oxygen meter was less likely to be impinged by a normoxic water mass during upwelling or downwelling favorable conditions. The steeper depth gradient in the Mississippi River Bight, and the occurrence of mid-water oxygen minima for several of the mid-month hydrographic surveys, indicated that the WD32E oxygen meter was often near the edge of a hypoxic water mass and was periodically exposed to hypoxia (Rabalais et al. 1994b).

The continuous oxygen data for station ST53#3 in 1991 indicated a period in late February and early March when hypoxia occurred (Figure 7) (Rabalais et al. 1992a). There were other much shorter periods of hypoxia in March-June followed by rapid re-aeration. For most of July and August and into early September, near-bottom waters were near-anoxic or anoxic. Beginning in early September, the water column was re-aerated by wind-induced mixing from the beginning of a series of strong cold front passages. The early part of the year (March-June) was also characterized by a fairly continuous series of strong weather fronts with strong winds and subsequent wind-induced mixing. Bottom waters at WD32E were well-oxygenated during the months of benthic collections (February-May) in 1991.

4.2 Sedimentary Characteristics

The sedimentary characteristics of the three study sites differed considerably from each other, and within some of the study sites there was considerable spatial and temporal variability. The grain size distributions of the study sites are shown in Figure 8 and detailed in Appendix B (and in Rabalais et al. 1993). Sediment TOC values (Appendix B) were consistently low across the study area, typically less than 1.0. Sediment chlorophyll *a* and phaeopigment concentrations were consistent with season and distance from the Mississippi River (as described by Rabalais et al. 1992b) (Appendix B).

Sediments at Shell's WD32E platform were composed primarily of silts with some clay and sand. Sediments at Unocal ST53A were predominantly sandy silts with little clay fraction, and the percentage of sand created most of the temporal and seasonal variability. Unocal ST53B was the most variable in space and time with regard to sediment grain size distribution. Non-uniform and high percentages of sand or clay were not consistent with distance from the platform nor sample period. Observations of SCUBA divers at this station and ROV videotape footage indicate that the seabed, while relatively unremarkable, was characterized by small hummocks and shallow

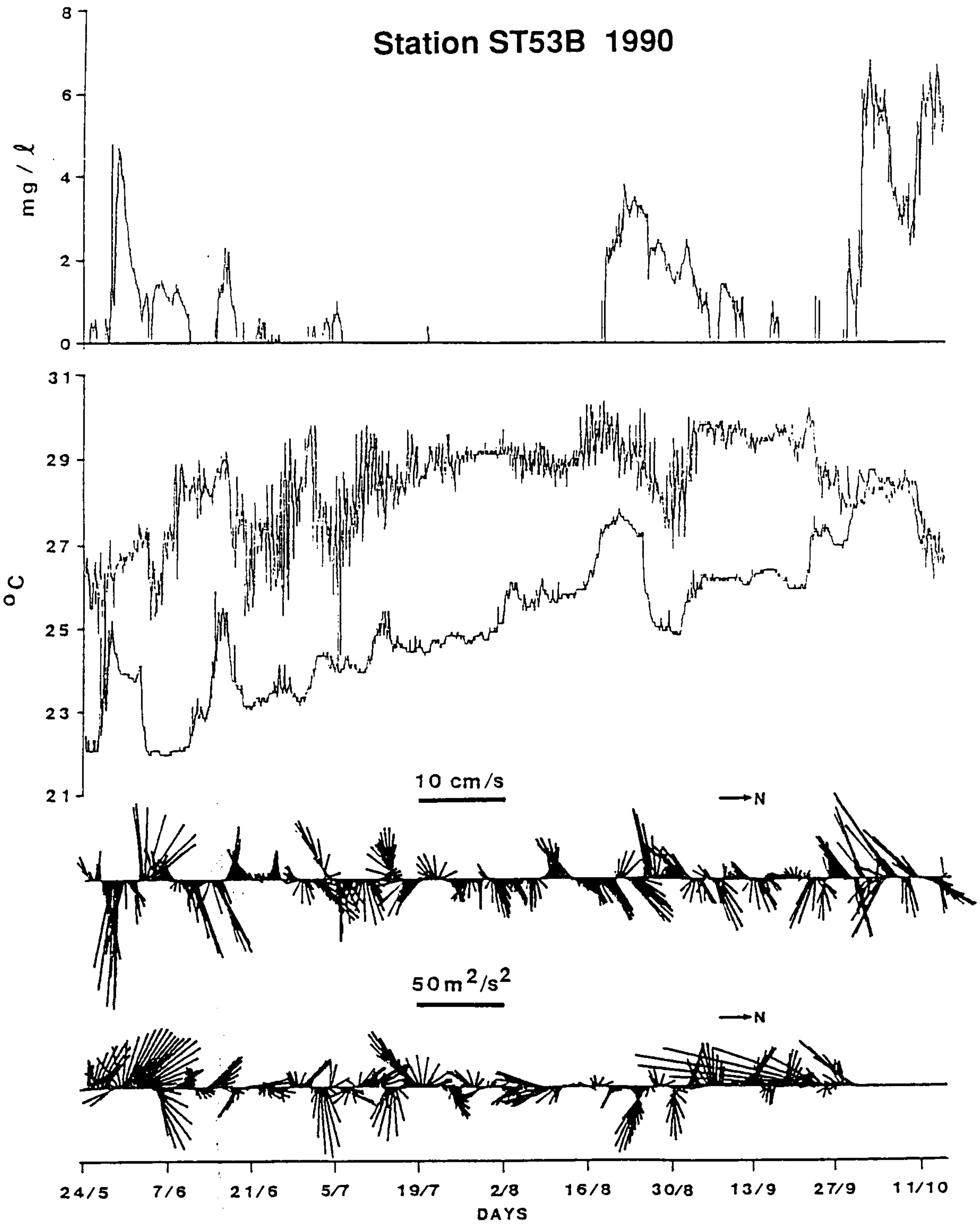


Figure 4. Time series (from top to bottom) of near-bottom dissolved oxygen, near-surface and near-bottom temperature, low-passed near-bottom currents and wind pseudo-stress. Stick diagrams have been rotated 90° clockwise. Period of record is May 24, 1990 - October 15, 1990 for ST53B (from Rabalais et al. 1992a).

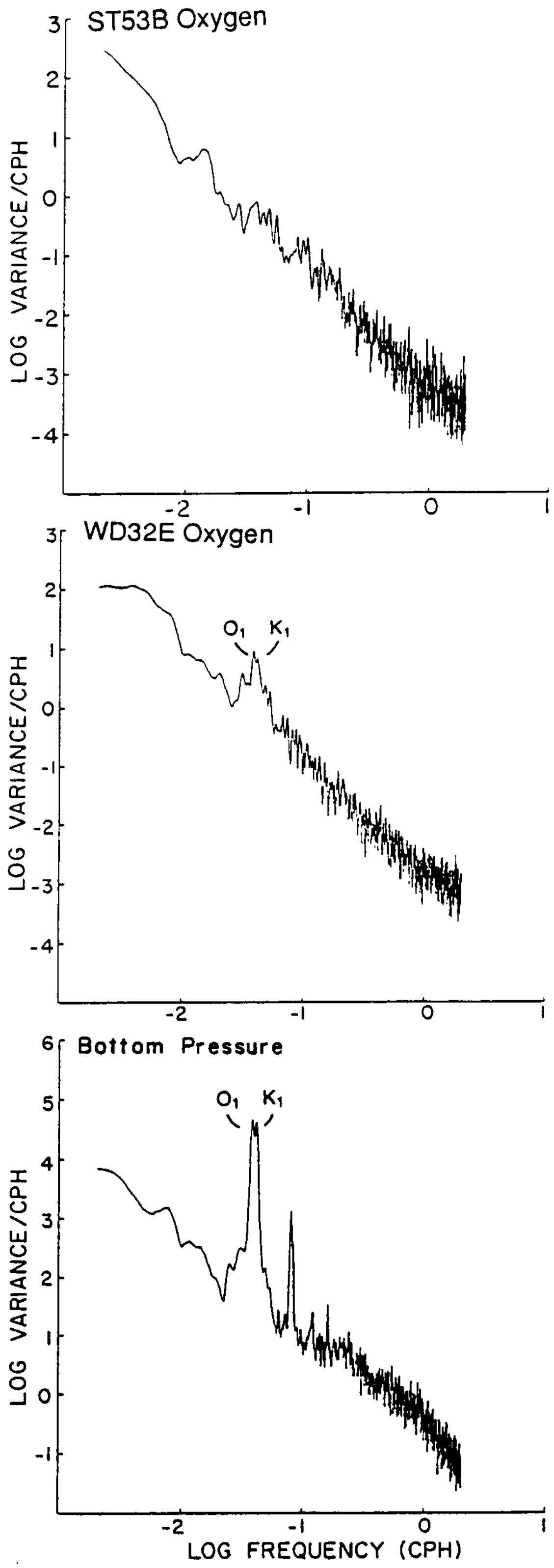


Figure 5. Smoothed periodograms of dissolved oxygen time series at ST53B (upper panel), dissolved oxygen time series at WD32E (middle panel), and bottom pressure at mouth of Terrebonne Bay (lower panel) (from Rabalais et al. 1994b).

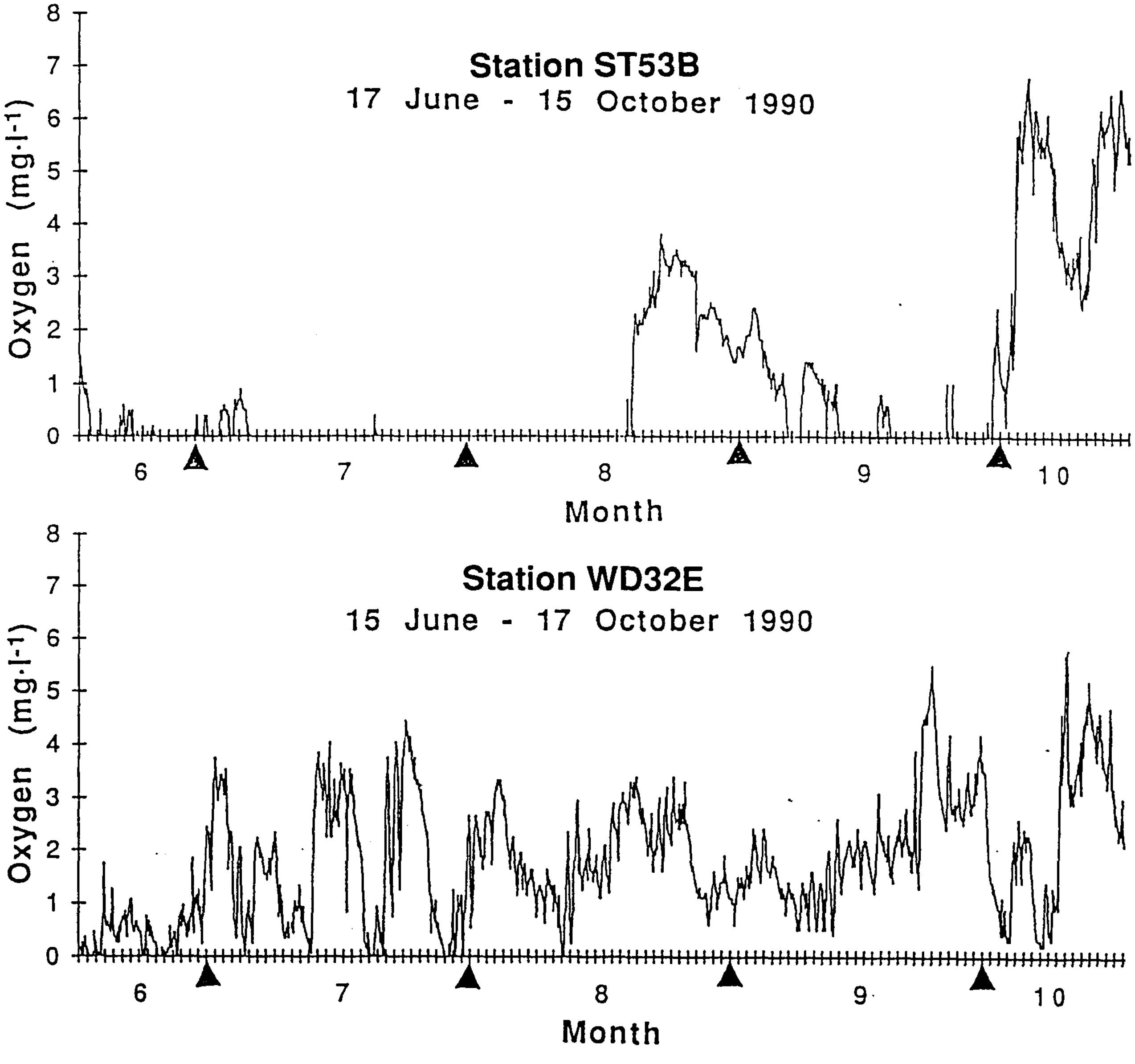


Figure 6. Time series plots of near-bottom dissolved oxygen concentration at Stations ST53B and WD32E (closed triangles indicate beginning of month indicated) (modified from Rabalais et al. 1994b).

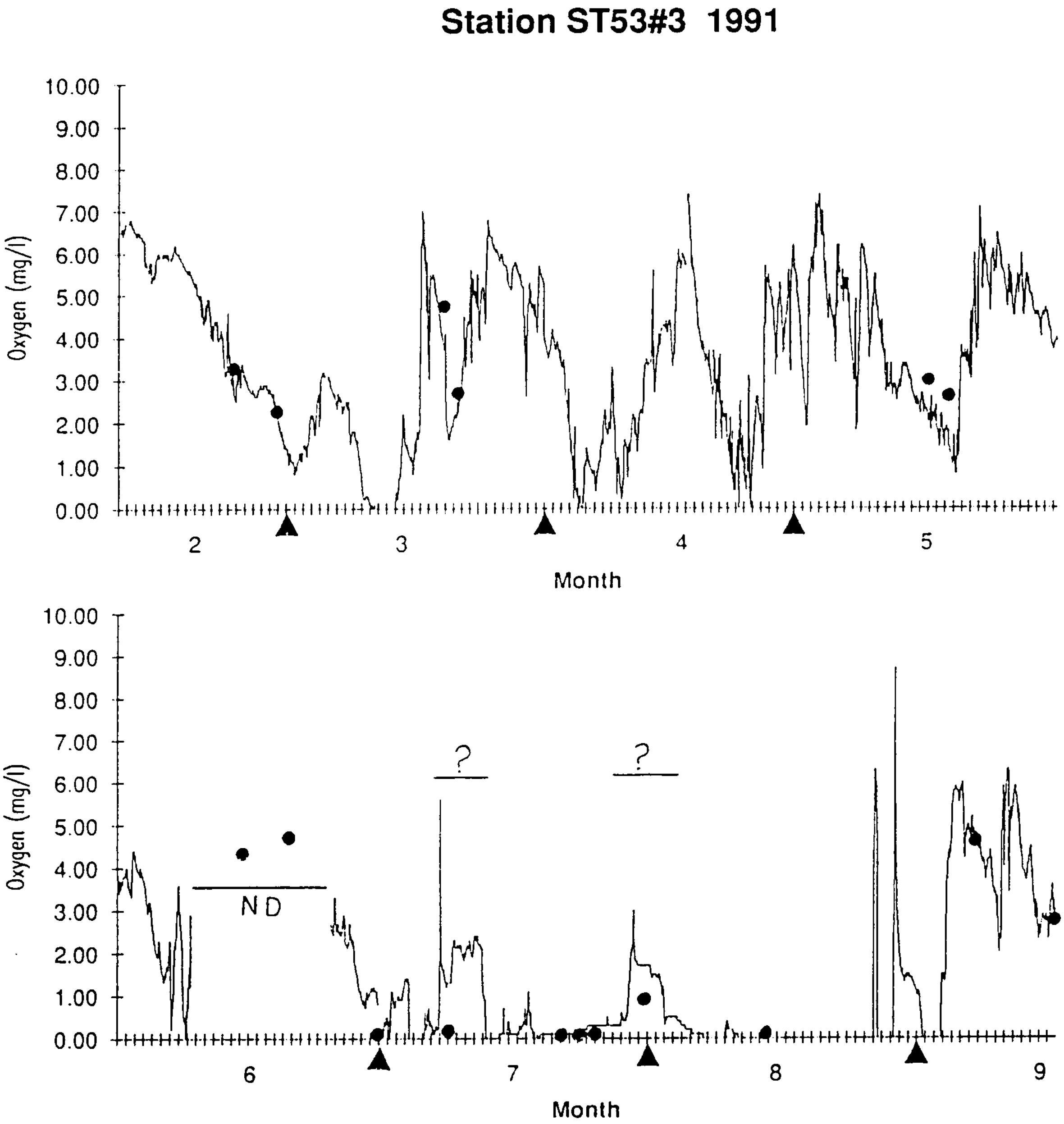


Figure 7. Time series of near-bottom dissolved oxygen for period indicated in 1991 for Station ST53#3. Black dots indicate discrete recordings from Hydrolab unit; lack of data indicated by ND; data problems indicated by "?" (from Rabalais et al. 1992a).

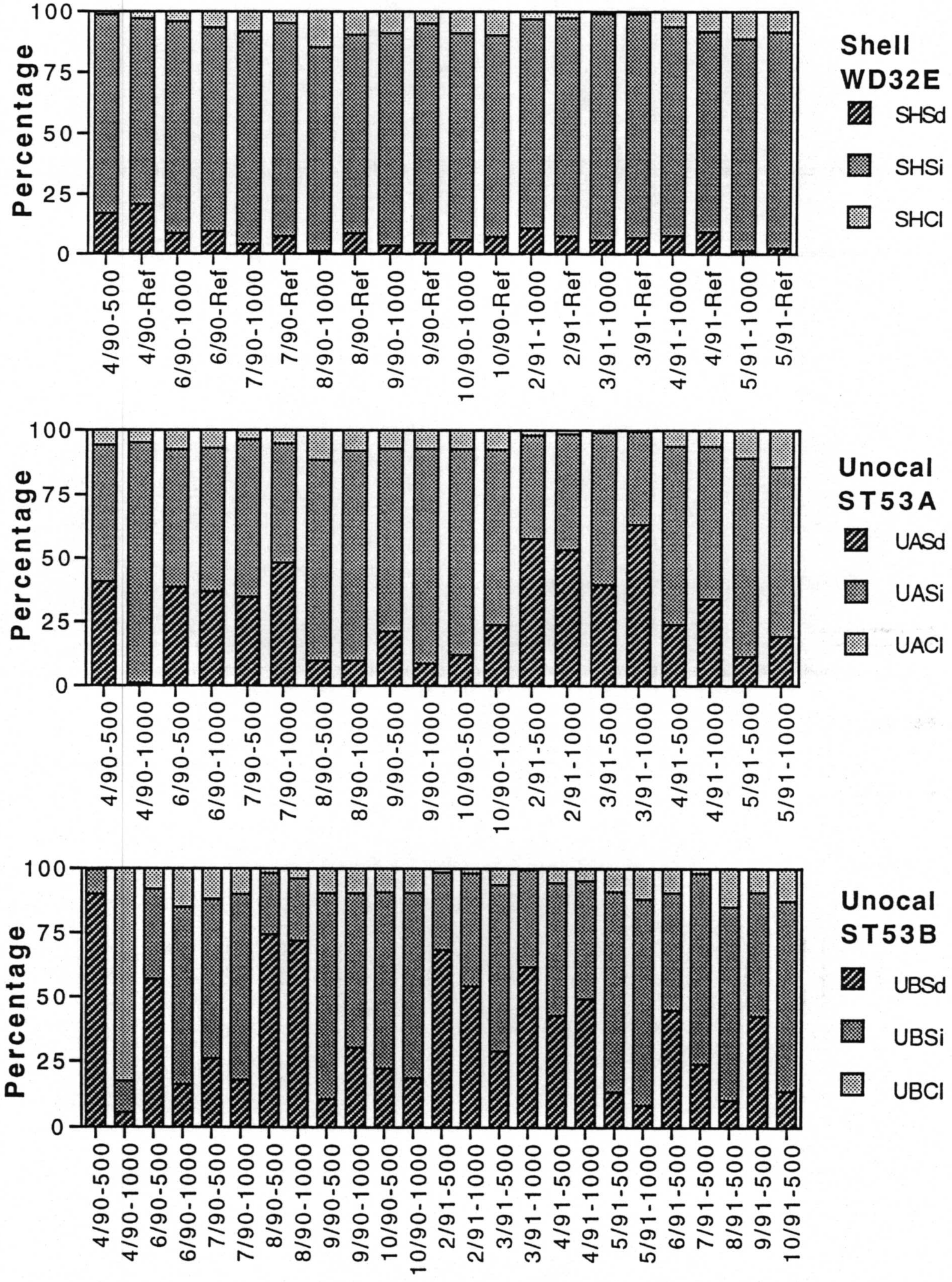


Figure 8. Percent composition of sand (Sd), silt (Si) and clay (Cl) for Shell WD32E, Unocal ST53A and Unocal ST53B for periods indicated.

depressions, subject to short-term deposition and erosional events, and quite variable on a small scale (< 1 m). Although a thin veneer of silt/clay, biogenic particles, and fine sand may be deposited in the area (N. N. Rabalais, pers. observ.), the long-term characterization for the area of South Timbalier 52 and 53 is that of little or no sediment accumulation (B. A. McKee, pers. comm.). A well-consolidated, dense clay is usually located at 10-14 cm below the sediment-water interface, but may become exposed to the surface or near-surface at times (e.g., 1000 m in April, Figure 8 and following Hurricane Andrew in August 1992, N. N. Rabalais, pers. observ.). Similar variability in sediment grain size distribution for the area was documented in the previous studies of Murrell and Fleeger (1989), Boesch and Rabalais (1991), Rabalais et al. (1989, unpubl. data).

4.3 Chemical Contaminants

The stations chosen for this integration were selected at the ends of the transects designed to identify in platform-related chemical contaminant pollutants (Rabalais et al. 1993). Details of the chemical contaminants can be found in Rabalais et al. (1993) and were for April-August 1990 only.

There were no clear gradients in concentrations of metals away from the Unocal ST53A or ST53B platforms. For Shell WD32E there were elevated levels compared to background for Zn and Pb within 50 to 100 m from the platform. There were no patterns in Fe, Al, Ba, Cu, Cd, and Ni with distance from the platform.

The sediments adjacent to the Unocal ST53A platform contained hydrocarbons in low concentrations of mostly a weathered petroleum or biogenic nature. Although the Fossil Fuel Pollution Index (FFPI) often exceeded 0.5 for sediments at ST53A, no analyte concentration was above 50 ppb, and the summed alkylated or parent polynuclear aromatic hydrocarbons (PAH) concentrations were all less than 400 ppb which is below the threshold level ($\geq$ 450 ppb) where negative impacts have been shown to affect the benthic infauna (Rabalais et al. 1993). There were no clear spatial nor temporal patterns evident in the distribution of hydrocarbons adjacent to the ST53A platform. Hydrocarbons of sediments adjacent to the reference station, Unocal ST53B, were similar in composition to those of Unocal ST53A, but in general were lower in concentration than samples from ST53A. There were no clear spatial nor temporal patterns evident in the distribution of hydrocarbons adjacent to the ST53B platform, nor any evident relationships in distributions with grain size variability, which was more evident for ST53B than other study sites in South Timbalier Blocks 52 and 53.

The sediments associated with the Shell WD32E platform contained hydrocarbons mostly of a mixed weathered petroleum and biogenic nature; there were certain stations, however, where the hydrocarbon composition was distinctly petrogenic. Most of these stations were within 500 m of the platform, but occasionally sediments at 750-m and 1000-m displayed primarily petrogenic with some biogenic components. There was a general trend for a greater predominance of petrogenic hydrocarbons at the 250-m station, and higher total concentrations of saturated hydrocarbons at the 750-m station; there are exceptions. There was also a trend at WD32E for a greater predominance of biogenic hydrocarbons with distance from the platform; exceptions were noted for the 1000-m station.

CHAPTER 5. BENTHIC COMMUNITIES

5.1 Comparison of Study Sites

Results of benthic macroinfaunal analyses are summarized in Appendix C for the community parameters of number of species, number of individuals, diversity and evenness for each study site/date/station combination for 1991 (1990 data are in Rabalais et al. 1993). Depending on the study site and month, there were isolated statistically significant differences among stations within each study site in the community parameters of number of individuals and number of species (see Section 5.2). Overall, however, there were enough similarities between the stations within any single study site to compare them on a broad scale. The variability within each study site will be detailed in Section 5.2.

A comparison of species richness and mean number of individuals for selected stations at each of three study sites (West Delta 32E, Unocal ST53A and Unocal ST53B) is shown in Figure 9. Healthy macroinfaunal communities existed at all sites in April 1990. Additional recruitment occurred in June. In July, there was a general seasonal decline in populations at all three study sites, but the decline was much more precipitous at ST53A and ST53B than at WD32E. The decline in populations at WD32E continued into September and October, but benthic communities at ST53A and ST53B showed slight recovery during that period. The duration and intensity of hypoxic conditions differed at the WD32E site in being neither as persistent nor as severe as in the South Timbalier study area. Recruitment of more species and individuals occurred in February-May 1991, but not at the level observed in spring 1990. The timing and magnitude of spring recruitment varied from year to year. At ST53B there was a decline in number of species and individuals during the 1991 summer hypoxia similar to that observed in 1990, but not as severe. A comparison of the continuous oxygen records for the two years indicated that the number and duration of hypoxic and anoxic events were not as great in 1991 as in 1990. This demonstrates variable responses within degrees of severity of hypoxia, and not just a single response to hypoxic conditions.

There were statistically significant differences between study sites with regard to both number of species and number of individuals, across all months (April 1990 - May 1991) and for most months alone (Table 2). During the period of severe hypoxia in 1990 (August-September), diversity was greater at WD32E; a similar trend may have been evident in 1991 if sampling had continued at WD32E. Across all months, number of individuals was greater at ST53B than at either WD32E or ST53A, which were statistically similar to each other. Exceptions in this pattern were seen again in August and September 1990, when the benthic infauna was more abundant at WD32E. In both comparisons of species richness and number of individuals across all months, ST53A and ST53B were statistically different from each other (Table 2), but variation was evident within any sample period. In any ranking scheme by sample period, ST53B was always greater in number of species and individuals than ST53A, but not always significantly.

5.2 Variability within Study Sites

Results of general linear model analysis of variance and Duncan's multiple range test indicated that within each study site there were isolated differences between stations within a sample period and once for all four sample periods combined. There were trends within each study site in the ranking of stations with regard to benthic community parameters, but these trends were not consistent across months. There were significant differences between months at each site.

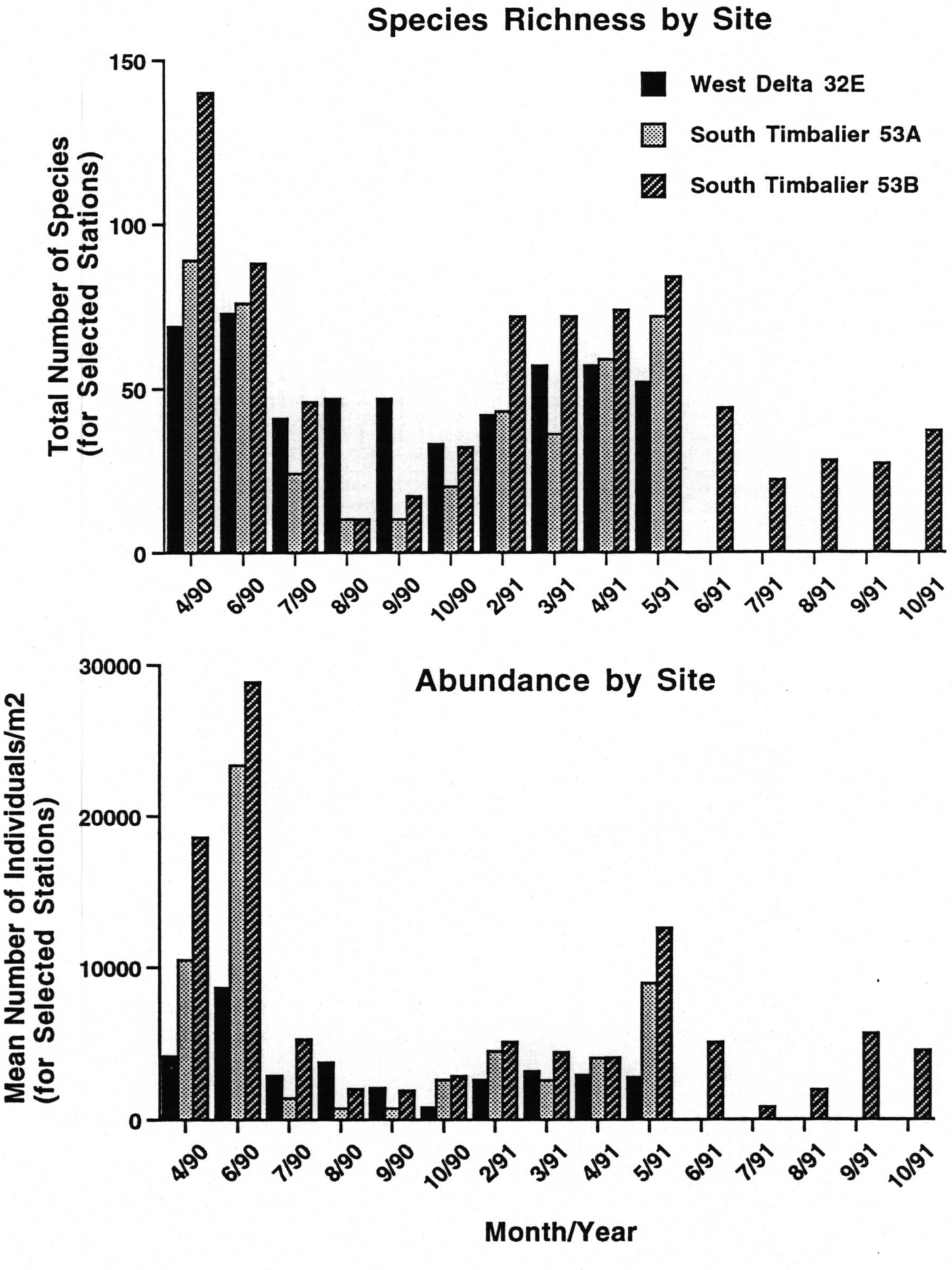


Figure 9. Comparison of species richness and mean number of individuals for each study site by month for selected stations (500 m and 1000 m for ST53A and ST53B; 1000 and Ref for WD32E, 500 m substituted for 1000 m in Apr 1990).

Table 2. Results of general linear model analysis of variance of natural log(x + 1) transformed data comparison of study sites for number of species and individuals by sample period (April 1990 - May 1991) and all months combined (stations 500 m and 1000 m for UA and UB; 1000 m and Ref for SH, 500 m substituted for 1000 m in Apr 1990; alpha = 0.05 for significance *; ns = not significant) and Duncan's multiple range test results. [Underlined sites are not significantly different from each other. *n* = number of replicates. ^ indicates fewer replicates than others. UA = Unocal South Timbalier 53A, UB = Unocal South Timbalier 53B, SH = Shell West Delta 32E.]

Month	Parameter	GLM *p* value	*n*	Duncan's Multiple Range Test
Apr 1990	Species	$p < 0.0001$*	10	$\overline{\text{SH}}\quad\overline{\text{UA}}\quad\overline{\text{UB}}$
	Individuals	$p<0.0001$*		$\underline{\text{SH}}\quad\underline{\text{UA}}\quad\underline{\text{UB}}$
Jun 1990	Species	$p<0.0041$*	10	$\overline{\text{SH}}\quad\overline{\text{UA}\quad\text{UB}}$
	Individuals	$p<0.0002$*		$\underline{\text{SH}}\quad\underline{\text{UA}\quad\text{UB}}$
Jul 1990	Species	$p<0.0001$*	10	$\overline{\text{UA}}\quad\overline{\text{SH}\quad\text{UB}}$
	Individuals	$p<0.0001$*		$\underline{\text{UA}}\quad\underline{\text{SH}}\quad\underline{\text{UB}}$
Aug 1990	Species	$p<0.0001$*	10,8	$\overline{\text{UA}^\wedge\quad\text{UB}^\wedge}\quad\overline{\text{SH}}$
	Individuals	$p<0.0001$*		$\underline{\text{UA}^\wedge}\quad\underline{\text{UB}^\wedge}\quad\underline{\text{SH}}$
Sep 1990	Species	$p<0.0001$*	10	$\overline{\text{UA}\quad\text{UB}}\quad\overline{\text{SH}}$
	Individuals	$p<0.0006$*		$\underline{\text{UA}}\quad\underline{\text{UB}\quad\text{SH}}$
Oct 1990	Species	$p<0.1527$ns	10	$\overline{\text{UA}\quad\text{UB}\quad\text{SH}}$
	Individuals	$p<0.0001$*		$\underline{\text{SH}}\quad\underline{\text{UA}\quad\text{UB}}$
Feb 1991	Species	$p< 0.0088$*	10,9	$\overline{\text{SH}^\wedge\quad\text{UA}}\quad\text{UB}$ $\text{SH}^\wedge\quad\overline{\text{UA}\quad\text{UB}}$
	Individuals	$p<0.0081$*		$\underline{\text{SH}^\wedge}\quad\underline{\text{UA}\quad\text{UB}}$
Mar 1991	Species	$p<0.0009$*	10	$\overline{\text{UA}}\quad\overline{\text{SH}\quad\text{UB}}$
	Individuals	$p<0.0791$ns		$\underline{\text{UA}\quad\text{SH}\quad\text{UB}}$
Apr 1991	Species	$p<0.3656$ns	10	$\overline{\text{SH}\quad\text{UA}\quad\text{UB}}$
	Individuals	$p<0.4016$ns		$\underline{\text{SH}\quad\text{UA}\quad\text{UB}}$
May 1991	Species	$p<0.0020$*	10	$\overline{\text{SH}}\quad\overline{\text{UA}\quad\text{UB}}$
	Individuals	$p<0.0001$*		$\underline{\text{SH}}\quad\underline{\text{UA}\quad\text{UB}}$
All Months Combined	Species	$p<0.0014$*	99,98	$\overline{\text{UA}^\wedge}\quad\overline{\text{SH}\quad\text{UB}^\wedge}$
	Individuals	$p<0.0001$*		$\underline{\text{SH}\quad\text{UA}^\wedge}\quad\underline{\text{UB}^\wedge}$
				—— increasing means ⟶

5.2.1 Shell WD32E

Stations 1000 m and Ref differed from each other in number of species across all months sampled (ANOVA, alpha = 0.05). This overall difference was due to significant differences in this parameter for June and July 1990; otherwise, the stations did not differ from each other in number of species. Overall, stations 1000 m and Ref did not differ from each other with regard to number of individuals (ANOVA, alpha = 0.05); for the month of September 1990, there was a difference. In general, station 1000 m had more species and individuals than did the reference station.

There were significant differences between months in number of species and number of individuals for both stations combined (Table 3). Species richness was similar in April and June 1990, decreased in July and August, then decreased further in September and October (Figure 10). There were no severe reductions in the benthic fauna in July and August, as seen at the South Timbalier study sites; however, hypoxia was intermittent at WD32E. The benthic community demonstrated a further reduction in species in February 1991. Spring recruitment in 1991 increased the number of species in April through May 1991, but not as high as the previous spring (Figure 10, Table 3). Peak abundance occurred in June 1990 followed by a seasonal mid-summer and fall decline (Figure 10). Numbers recruiting the following spring 1991 were not as high as spring 1990.

While polychaetes were a large component of the benthic community at WD32E, composition by other major taxonomic groups was greater than the polychaetes in April 1990 and August 1990 and 50:50 in June 1990 (Figures 11 and 12). Polychaete taxa dominated in July, September and October of 1990 and during February - May 1991. The number of taxonomic groups was fairly consistent with time indicating the lack of influence of severe hypoxia on the benthic community. The benthic community at WD32E was diverse, with a complement of pericaridean crustaceans, bivalves, gastropods, and other taxa, not usually representative of the silty sediments. The successive change in the abundance's of several dominants are shown in Figures 11 and 12. Dominant species for most months were *Paraprionospio pinnata* and *Mediomastus ambiseta*. An increase in *Armandia maculata* was observed in August. Changes in several dominant species through 1990 were evident with *Prionospio cristata*, *Nephtys incisa*, *Magelona* sp. I, *Magelona* sp. H, *Ampharete* sp. A, and *Owenia fusiformis* (Rabalais et al. 1993). *Armandia maculata*, *Ampharete* sp. A and *Magelona* sp. I, which were dominants in 1990, were replaced in spring 1991 by *Sigambra tentaculata* and *Cossura soyeri*.

5.2.2 Unocal ST53A

Stations 500 m and 1000 m did not differ from each other with regard to either number of species or number of individuals, across all months and for each month alone (ANOVA, alpha = 0.05). There were significant differences between months in number of species and number of individuals for both stations combined (Table 3).

Species richness was severely depressed in August and September 1990, and was also extremely low in July and October 1990 (Figure 13, Table 3). Species richness in June and April 1990 was similar and approximately six times greater than in July through October 1990. Species richness increased during the spring of 1991, but not to the level observed in spring 1990 (with the exception of May 1991). Abundance of individuals was high in April 1990, higher in June 1990 with additional recruitment of several species; then the number of individuals was very low from July through September (Figure 13). There was a slight recovery of individuals in October, and further recruitment in spring 1991, but not to the level observed in spring 1990 (with the exception of May 1991).

Table 3. Results of general linear model analysis of variance of natural log(x+1) transformed data comparison of months for number of species and individuals (alpha = 0.05 for significance) and Duncan's multiple range test results. [Underlined dates are not significantly different from each other. ^ indicates fewer replicates than others.]

West Delta 32E [Apr 90 - May 91, 1000 m and Ref (except 500 m for 1000 m in Apr 90), n = 10,9]

Species	p < 0.0001*	10/90	2/91^	7/90	9/90	4/91	3/91	8/90	5/91	6/90	4/90
Individuals	p < 0.0001*	10/90	9/90	2/91^	5/91	4/91	7/90	3/91	4/90	8/90	6/90

Unocal ST53A [Apr 90 - May 91, 500 m and 1000 m, n = 10,8]

Species	p < 0.0001*	8/90^	9/90	7/90	10/90	3/91	2/91	4/91	5/91	4/90	6/90
Individuals	p < 0.0001*	9/90	8/90^	7/90	3/91	10/90	4/91	2/91	5/91	4/90	6/90

Unocal ST53B [Apr 90 - May 91, 500 m and 1000 m, n = 10,8]

Species	p < 0.0001*	8/90^	9/90	10/90	7/90	2/91	4/91	3/91	5/91	6/90	4/90
Individuals	p < 0.0001*	9/90	8/90^	10/90	4/91	3/91	2/91	7/90	5/91	4/90	6/90

Unocal ST53B [Apr 90 - Oct 91, 500 m and 1000 m for Apr 90 - May 91, 500 m only for Jun 91- Oct 91, n = 10,5]

Species	p < 0.0001*	8/90	7/91^	9/90	10/90	8/91^	9/91^	7/90	6/91^	10/91^	2/91	4/91	3/91	5/91	6/90	4/90
Individuals	p < 0.0001*	7/91^	9/90	8/91^	8/90	10/90	4/91	6/91^	3/91	10/91^	2/91	7/90	9/91^	5/91	4/90	6/90

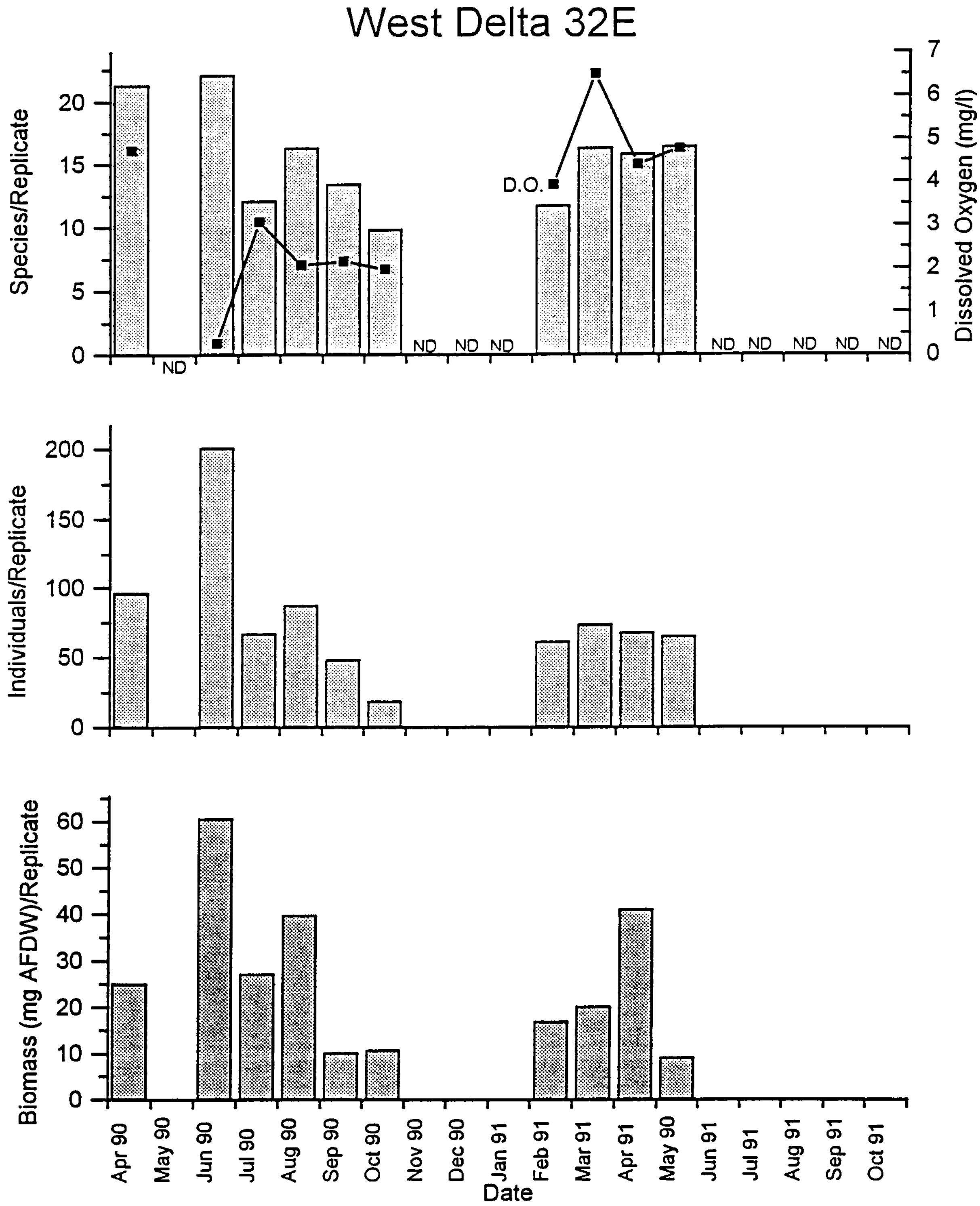
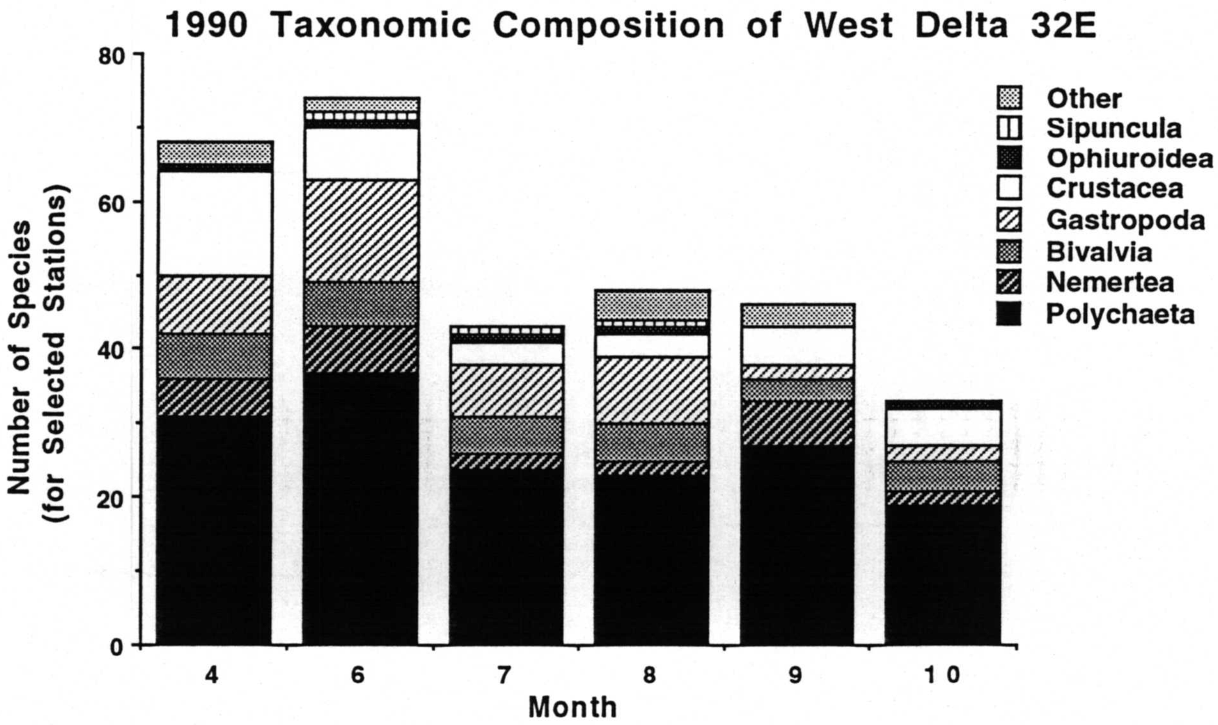


Figure 10. Mean number of species, individuals and biomass (mg AFDW) per replicate for West Delta 32E for dates indicated. Data are from stations 1000 m and Ref with the exception of April 1990, where 500 m was substituted for 1000 m. ND is no data.



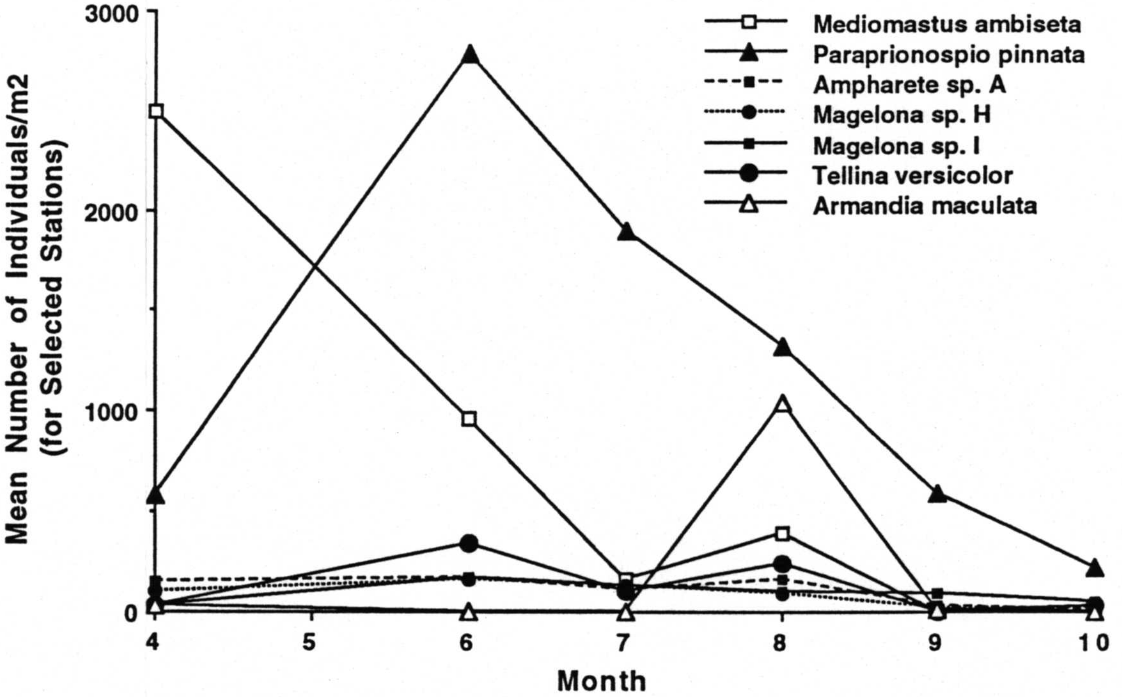
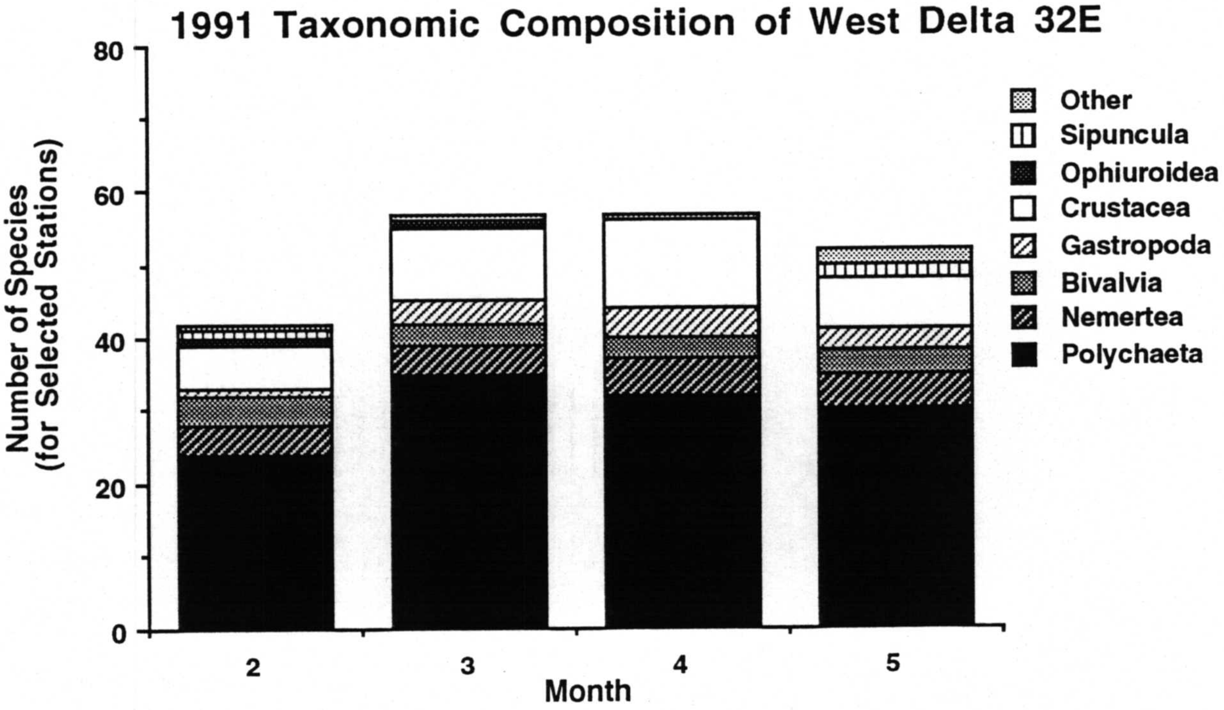


Figure 11. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Shell WD32E for months indicated in 1990 (from Rabalais et al. 1993).



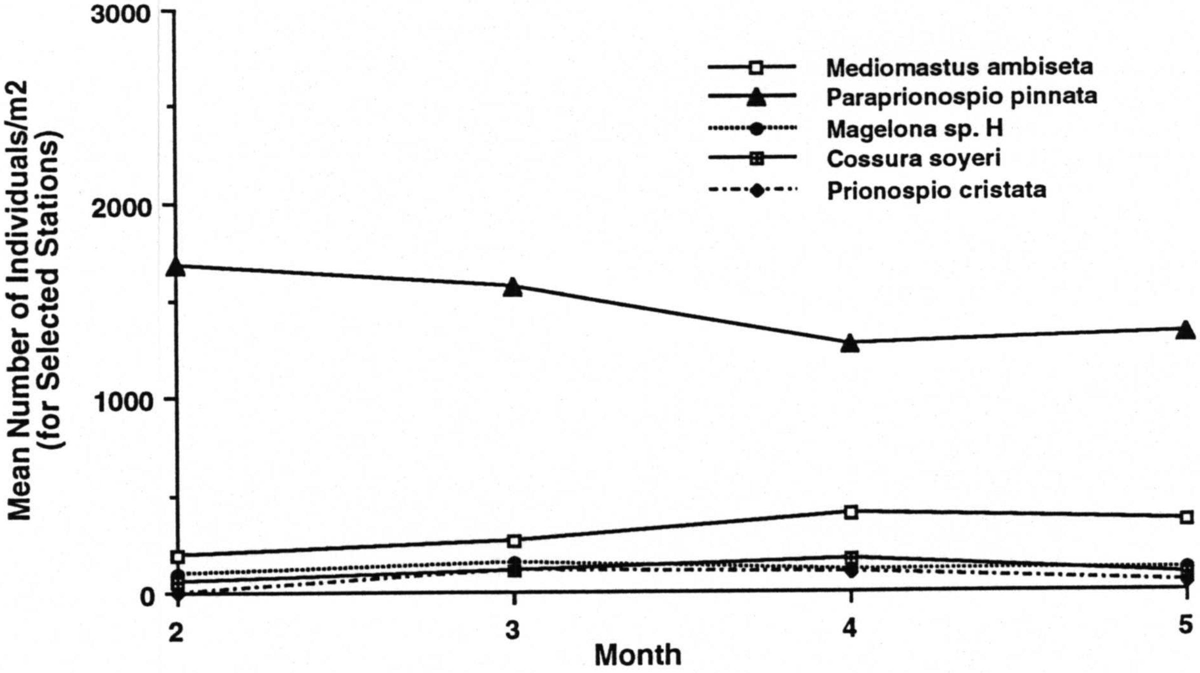


Figure 12. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Shell WD32E for months indicated in 1991.

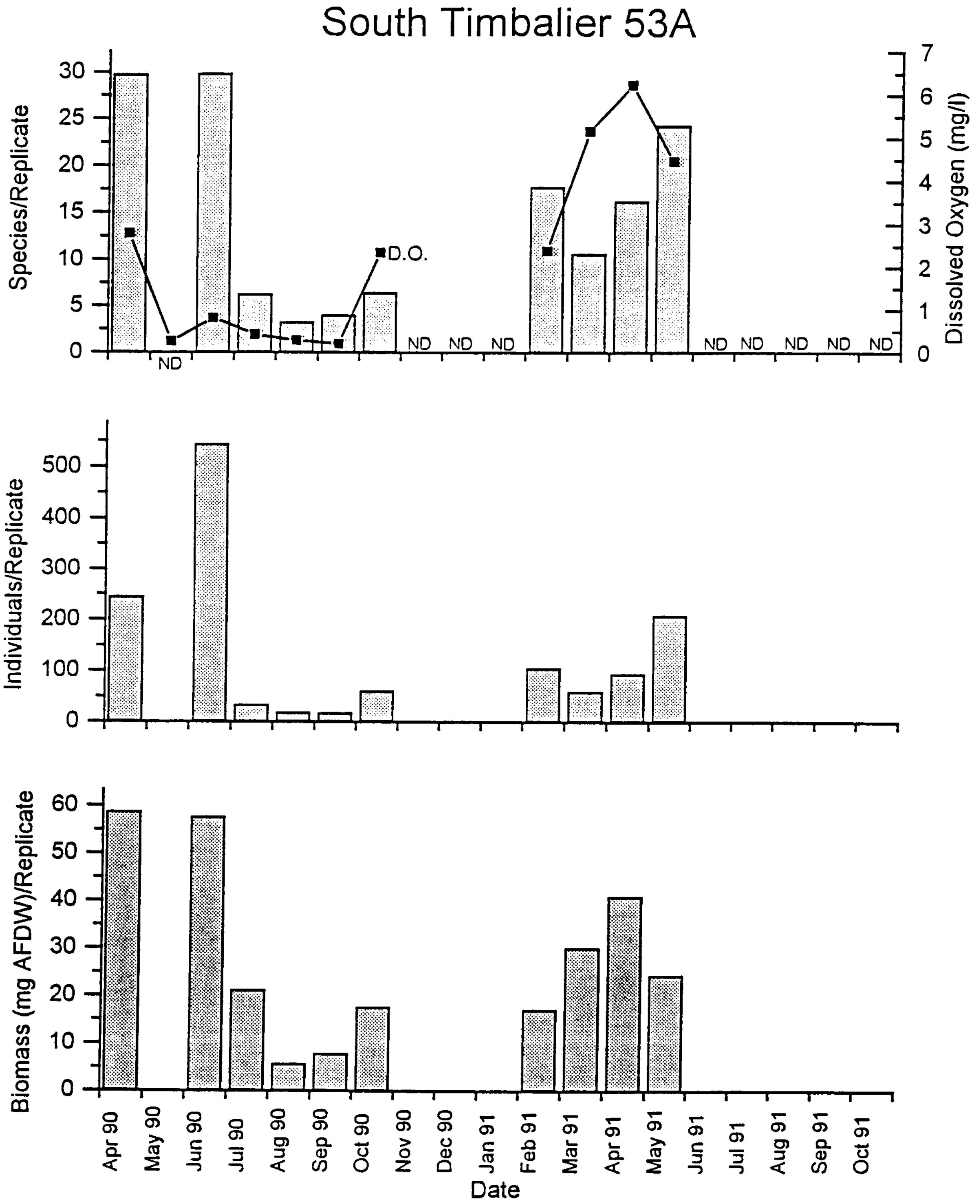


Figure 13. Mean number of species, individuals and biomass (mg AFDW) per replicate for South Timbalier 53A for dates indicated. Data are from stations 500 m and 1000 m. ND is no data.

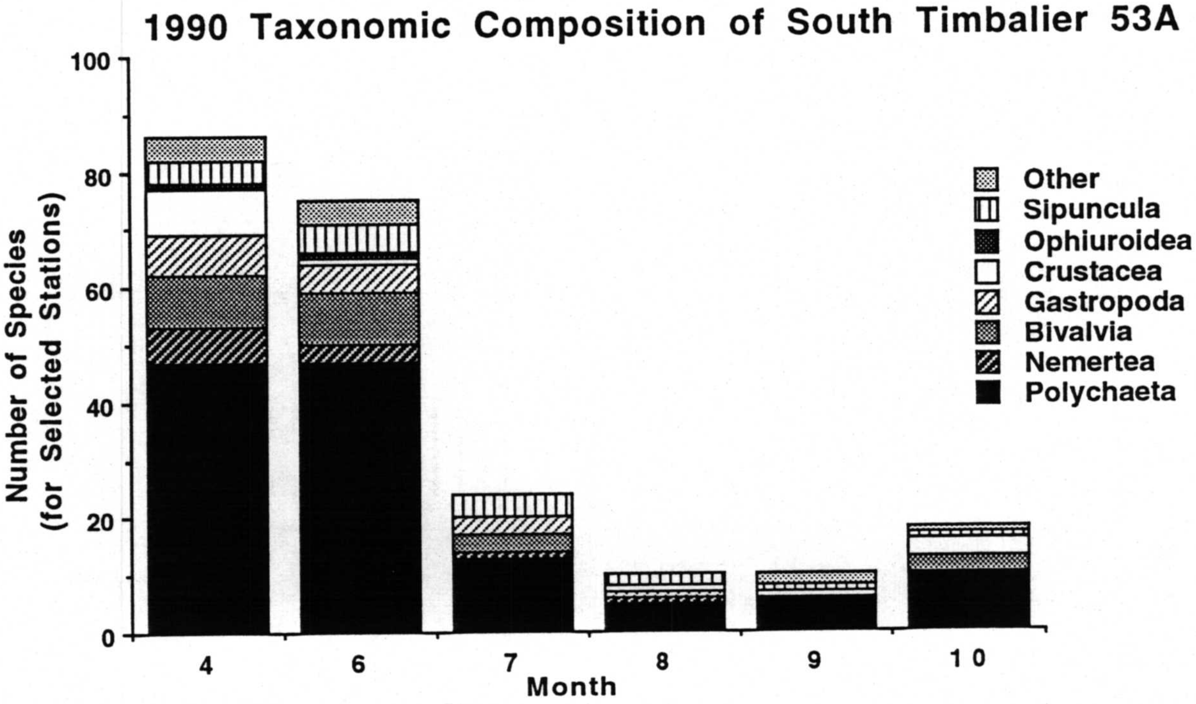
While polychaetes comprised most of the species at ST53A, composition by other major taxonomic groups was fairly high in April (13 taxa) and June (11 taxa) of 1990, then reduced to 4 to 6 major taxa in July through October 1990 (Figure 14). Polychaetes, by far, dominated the fauna in 1991 (Figure 15). The successive change in the abundances of several dominants is shown in Figures 14 and 15. The polychaetes *Ampharete* sp. A, *Paraprionospio pinnata*, and *Mediomastus ambiseta* were common in spring and early summer of 1990. As hypoxia progressed, the common species were reduced to the polychaetes *Ampharete* sp. A and *Magelona* sp. H and the sipunculan, *Aspidosiphon* sp. During August 1990, only *Magelona* sp. H and *Aspidosiphon* sp. maintained any significant population levels. During September and October 1990, the overall increase in number of individuals was due primarily to the recruitment of *Paraprionospio pinnata* and *Armandia maculata* and sustained population levels of *Magelona* sp. H and *Aspidosiphon* sp. Diversity again increased during the spring recruitment period of 1991, but polychaetes remained the dominant taxa. *Owenia fusiformis* which had been a dominant member of the community in 1990 was replaced by a population of *Sigambra tentaculata* in spring 1991.

5.2.3 Unocal ST53B

Stations 500 m and 1000 m did not differ from each other with regard to either number of species or number of individuals, across all months and for each month alone (ANOVA, alpha = 0.05). There were significant differences between months in number of species and number of individuals for both stations combined (Table 3).

Species richness was severely depressed in August 1990 with a slight recovery in September and October 1990 (Figure 16). Species richness increased in spring 1991, but not to the level observed in spring 1990. There was again a dramatic reduction in number of species in July 1991, but not as severe as in mid-summer 1990. There was an increase in species richness in August through October 1991. The increase in August 1991 was very different from the severely depressed fauna in August 1990 (Table 3). Abundance of individuals was high in April and June 1990, but dropped dramatically in July through September 1990 (Figure 16, Table 3). There was a slight recovery of individuals in October. Abundance recovered somewhat in February-April 1991, then increased substantially in May 1991. A seasonal decrease began in June 1991 with a significant reduction in abundance in July and August. Abundance increased in September and October 1991 to about the same level as early spring 1991.

While polychaetes were a large component of the benthic community at ST53B, composition by other major taxonomic groups was greater than the polychaetes in April, August and October. The number of major taxa decreased steadily from April through the period of hypoxia (April, 14 taxa; June, 9 taxa; July, 7 taxa; August, 4 taxa), then increased slightly in September (6 taxa) and more in October (10 taxa) (Figure 17). A diverse fauna was reestablished in February-April 1991, as a greater proportion of all taxa was composed of non-polychaetes. Polychaetes dominated the fauna from May through October 1991 (Figure 18). Dominant species by number of individuals for each sample period are shown in Figures 17 and 18. The polychaetes *Mediomastus ambiseta*, *Paraprionospio pinnata*, and *Ampharete* sp. A were common in spring and early summer of 1990. The retention of species during hypoxia was similar to ST53A; as hypoxia progressed, the common species were reduced to the polychaetes *Ampharete* sp. A, *Magelona* sp. H and *Clymenella torquata*, and the sipunculan, *Aspidosiphon* sp. During August, only *Magelona* sp. H and *Aspidosiphon* sp. maintained any significant population levels. During September and October 1990, the overall increase in number of individuals was due primarily to the recruitment of *Paraprionospio pinnata* in September and October and the additional recruitment of *Armandia maculata* in October, and maintained population levels of *Magelona* sp. H and *Aspidosiphon* sp. Diversity again increased during the spring recruitment



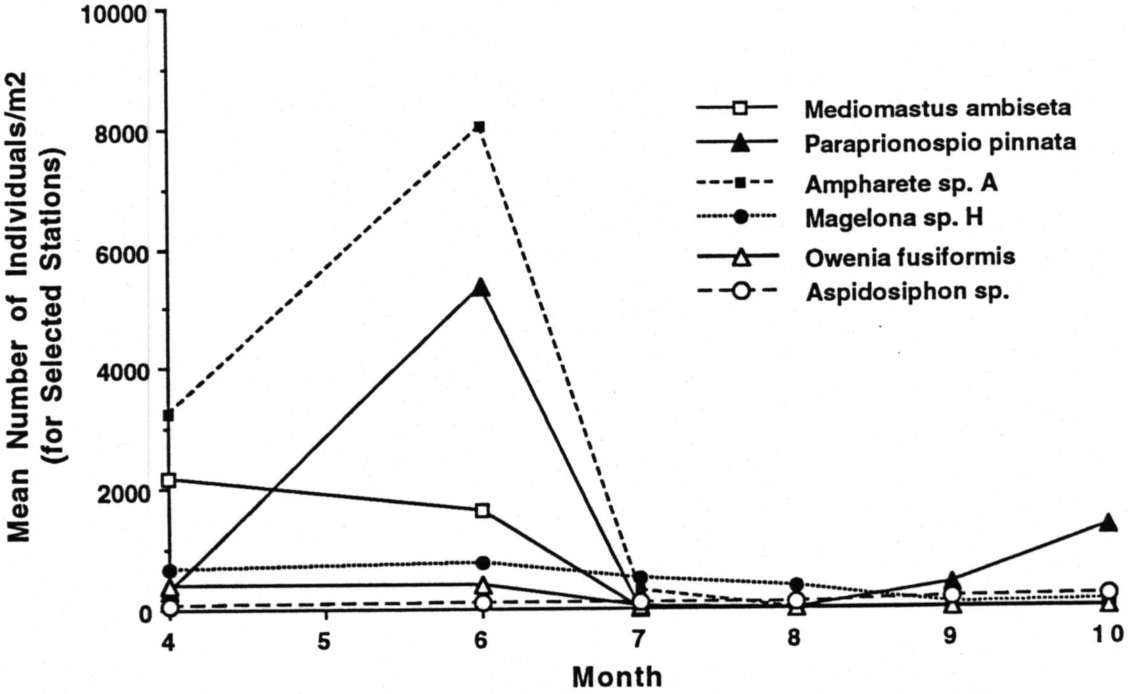


Figure 14. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Unocal ST53A for months indicated in 1990 (from Rabalais et al. 1993).

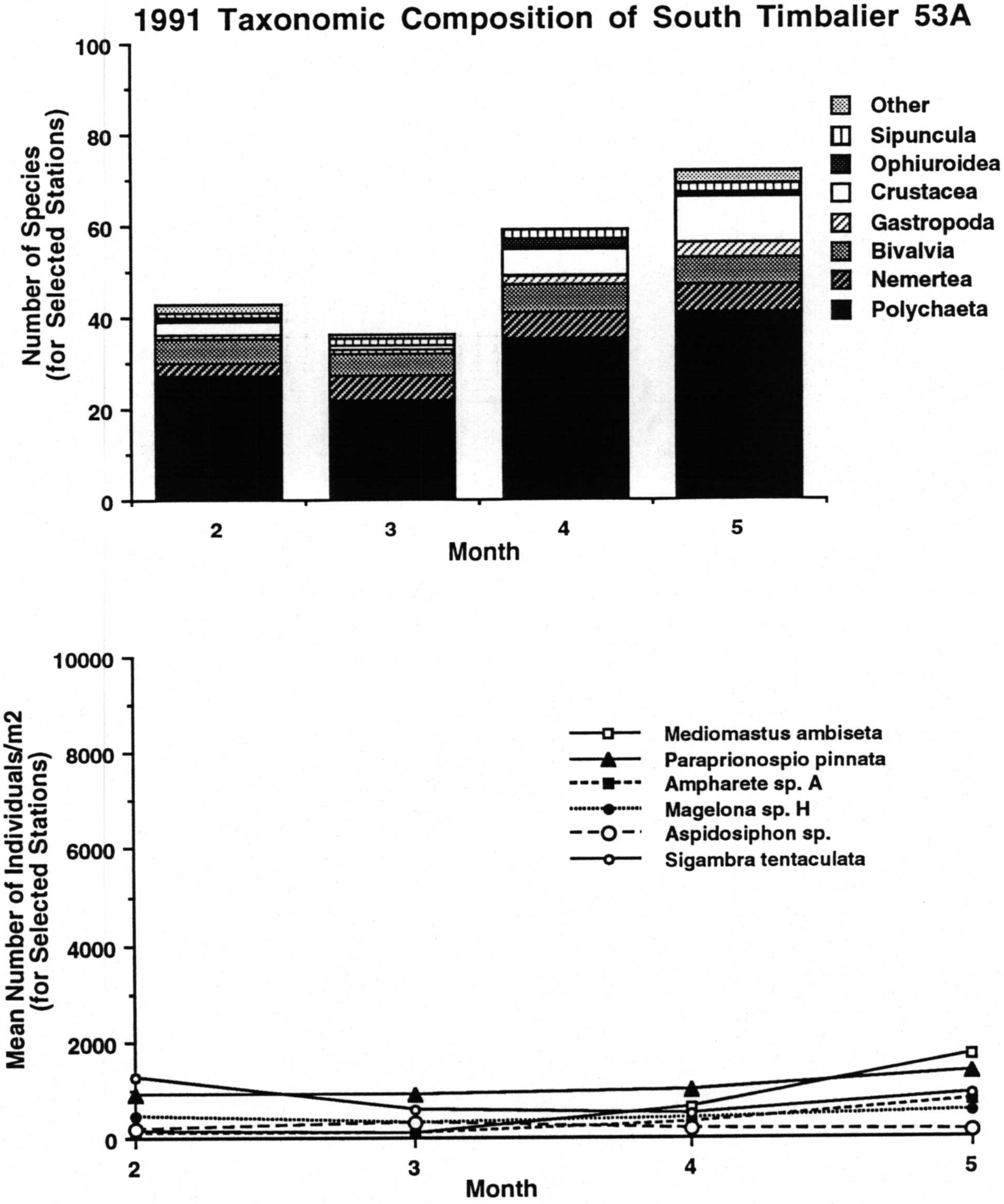


Figure 15. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Unocal ST53A for months indicated in 1991.

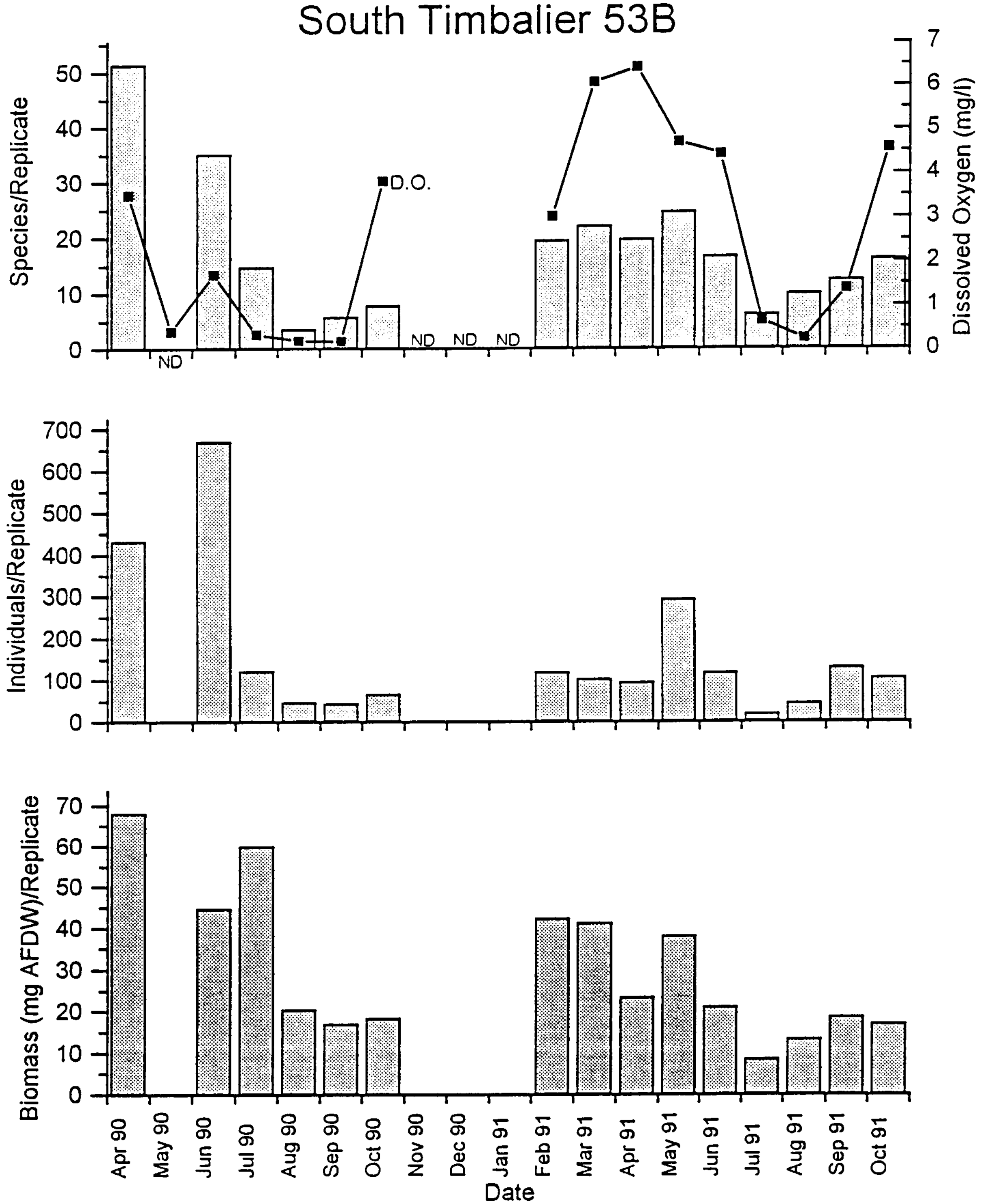
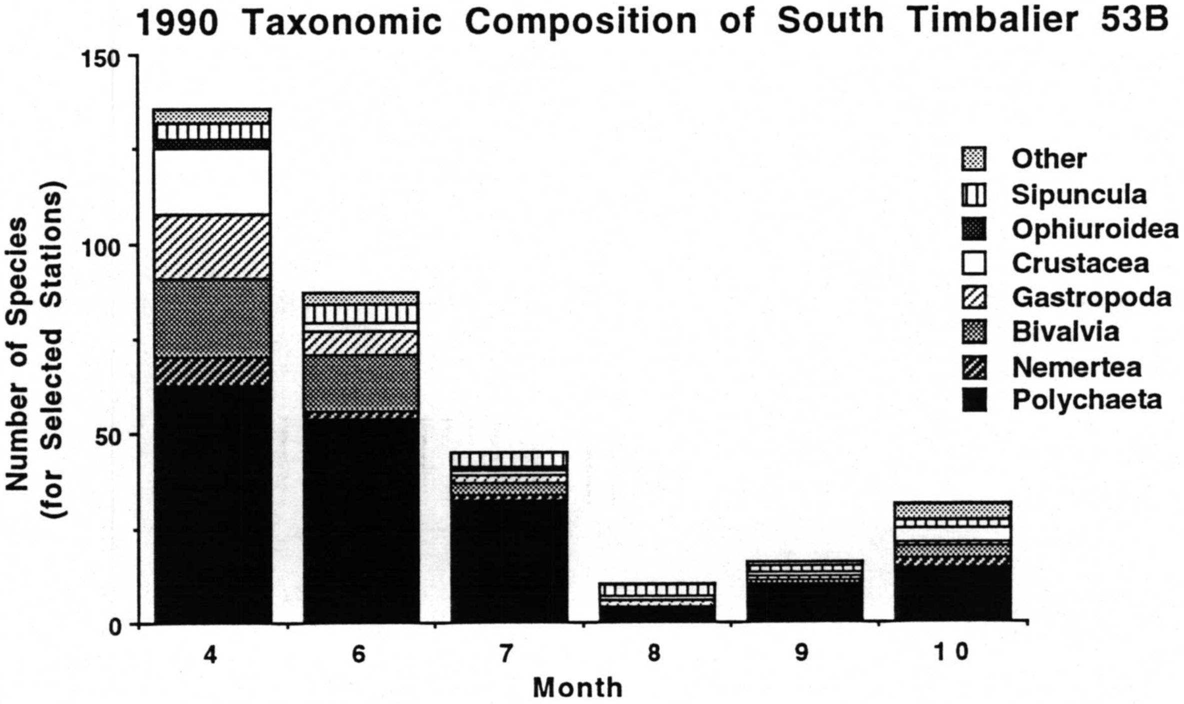


Figure 16. Mean number of species, individuals and biomass (mg AFDW) per replicate for South Timbalier 53A for dates indicated. Data are from stations 500 m and 1000 m. ND is no data.



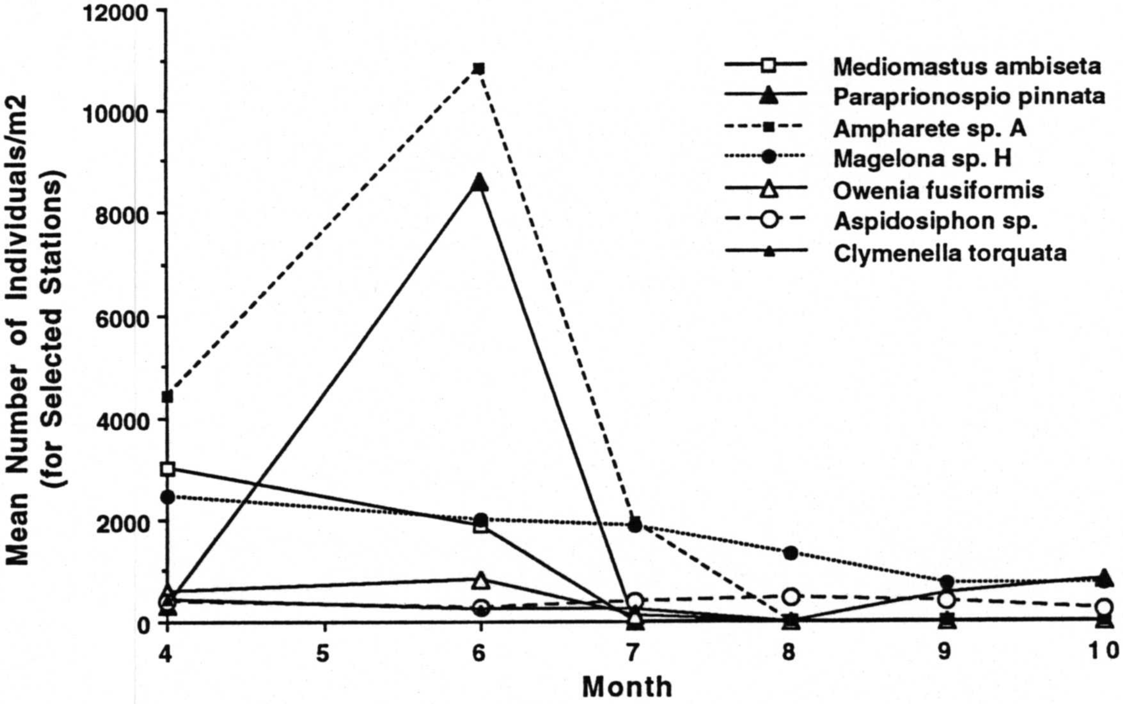
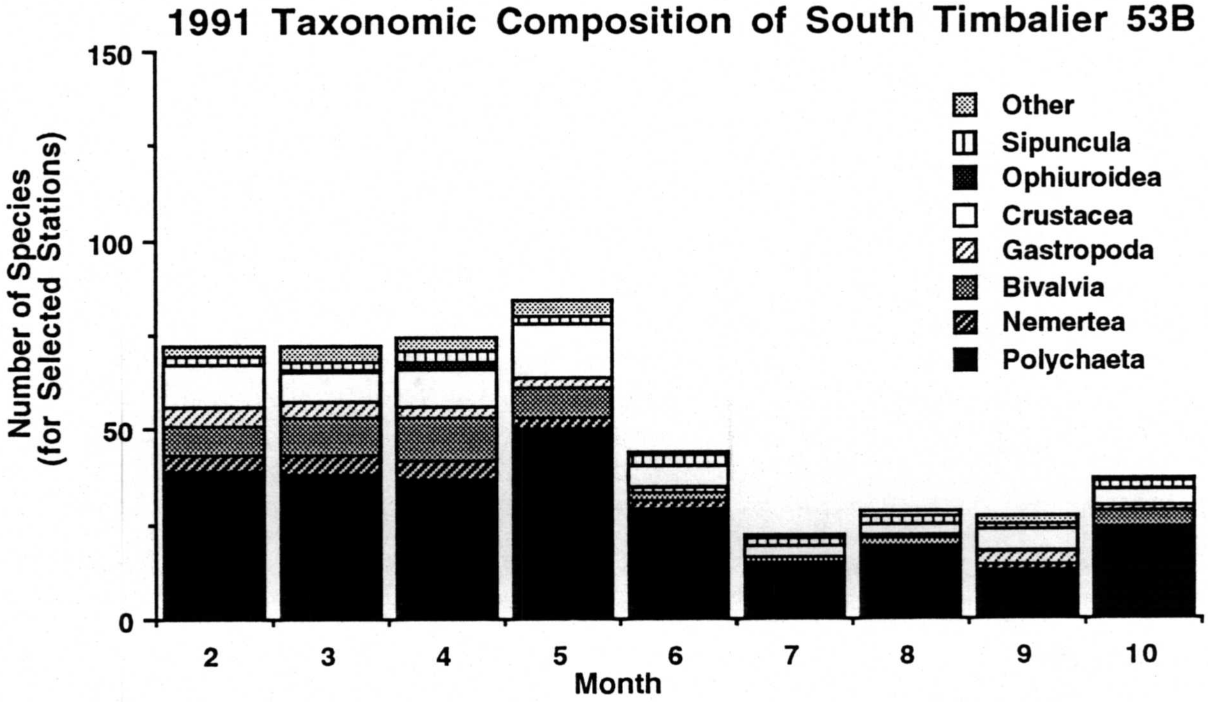


Figure 17. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Unocal ST53B for months indicated in 1990 (from Rabalais et al. 1993).



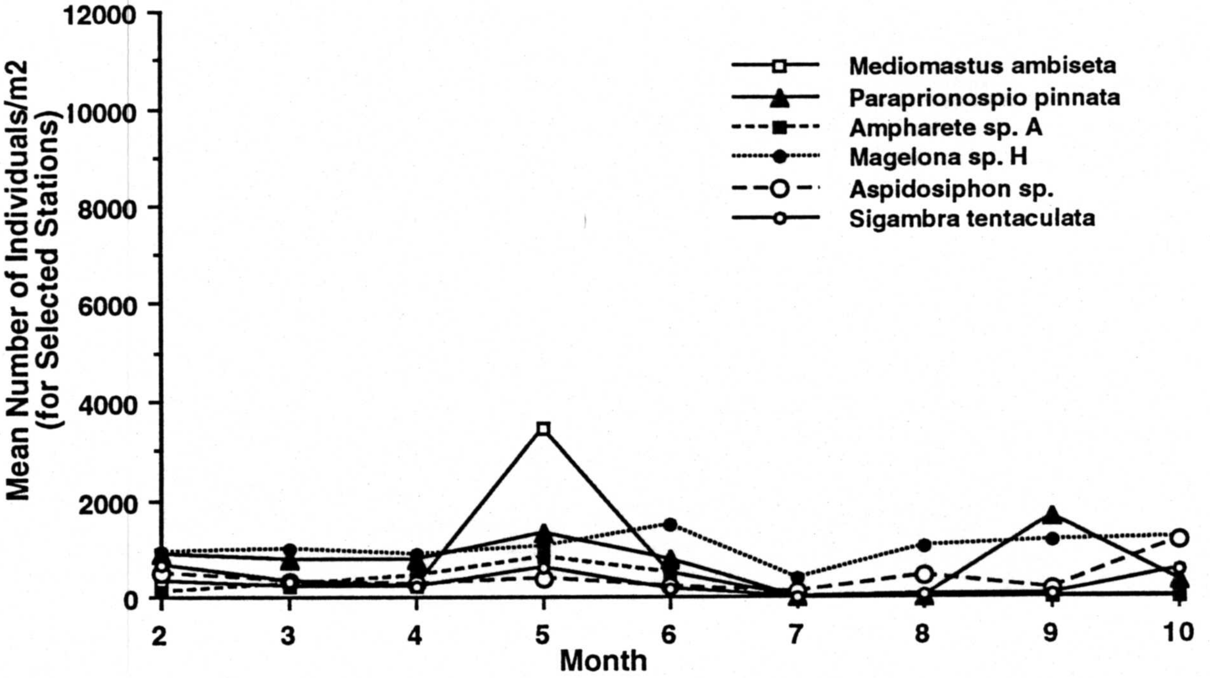


Figure 18. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Unocal ST53B for months indicated in 1991.

period of 1991, but polychaetes remained the dominant taxa. *Owenia fusiformis* and *Clymenella torquata* which had been dominant members of the community in 1990 were replaced by a population of *Sigambra tentaculata* in spring 1991. Recruitment in fall 1991 was again due to sustained levels of *Magelona* sp. H and *Aspidosiphon* sp., as well as the presence of *Sigambra tentaculata* and *Paraprionospio pinnata.*

5.3 Vertical Distribution

A series of subcores were taken from the Ekman box core (500 m at Unocal ST53B) monthly in 1990 and 1991 and sectioned to examine the vertical distribution of the macroinfauna, and in particular the effects of hypoxia on the vertical distribution (Figures 19 through 22).

Most individuals were distributed within the upper 2 cm of the sediments, especially during peaks in spring recruitment of both years. The smaller recruited individuals at the surface in spring of both years were *Paraprionospio pinnata* and *Ampharete* sp. A, which are surface deposit feeders. Other dominant spring recruits, *Mediomastus ambiseta*, are subsurface deposit feeders/opportunists. Individuals (low in abundance) were more evenly distributed during mid-summer hypoxia in July-August 1990 and August 1991. Although numbers increased in fall (September-October) of both years, they remained more evenly distributed through the sediments (with a few exceptions) as opposed to close to the sediment surface as in spring. Species were more evenly distributed throughout the sediments across seasons and years, than individuals.

Although it was not measured, we expect that the redox potential discontinuity (RPD) layer would move vertically up into the sediments towards the sediment surface as the dissolved oxygen in the overlying waters approached anoxia (Diaz and Rosenberg in press). The vertical distribution, however, other than spring recruitment benthos being mostly in upper 2 cm did not show a reduction in habitat as the RPD was expected to be closer to the surface of the sediments. In contrast, Dauer et al. (1992) found that there was a significant decrease in the biomass of deep-dwelling species (> 5 cm in sediments) during hypoxia.

5.4 Biomass

Benthic community biomass at West Delta 32E displayed a positively linear relationship with abundance data (Figure 23). The relationships of biomass to abundance for South Timbalier 53A and South Timbalier 53B were fairly linear until abundances exceeded 200/replicate. These higher abundances were associated with recruitment events for *Paraprionospio pinnata* and *Mediomastus ambiseta* where the number of individuals increased dramatically, but biomass did not (i.e., smaller recruits).

Species richness, density and biomass are typically reduced in hypoxia-affected environments. This was demonstrated in the Chesapeake Bay mainstem and its mesohaline tributaries (Dauer et al. 1992) and very clearly in this study (Table 4). The biomass data (as calculated in g C m^{-2}) for the hypoxia-affected stations of this study were much lower than those estimated by Cruz-Kaegi and Rowe (1992, unpubl. data) for some of the same stations in July 1991 (Table 4), although the number of individuals were similar. The "normal oxygen" stations sampled by Cruz-Kaegi and Rowe (1992, unpubl. data) in April 1992, however, failed to resemble either spring recruitment data for either ST53A or ST53B, or either spring recruitment or seasonally low fall values for WD32E. Abundance and biomass were unusually low in the Cruz-Kaegi and Rowe's samples compared to other data for the Louisiana inner shelf (this study and Rabalais et al. 1989). The reason for this is not clear. Biomass values obtained in this study (as calculated in g C m^{-2}) for "normal oxygen" environments were similar to those reported by Rowe

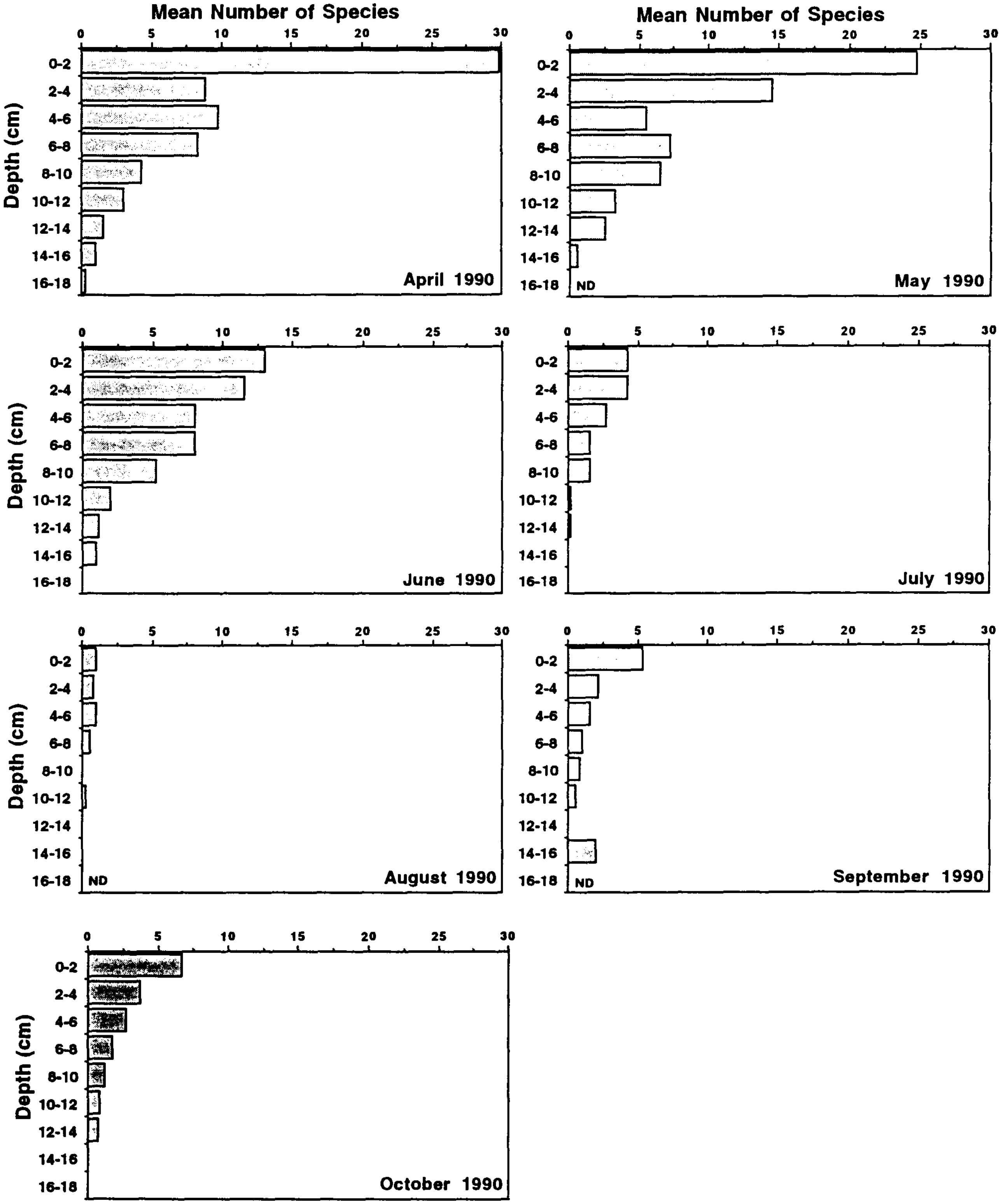


Figure 19. Vertical distribution of mean number of species per core section from replicate cores (n=2) taken from replicate box cores (n=3) at Unocal ST53B, 500 m during 1990. ND is no data, zeros are real values.

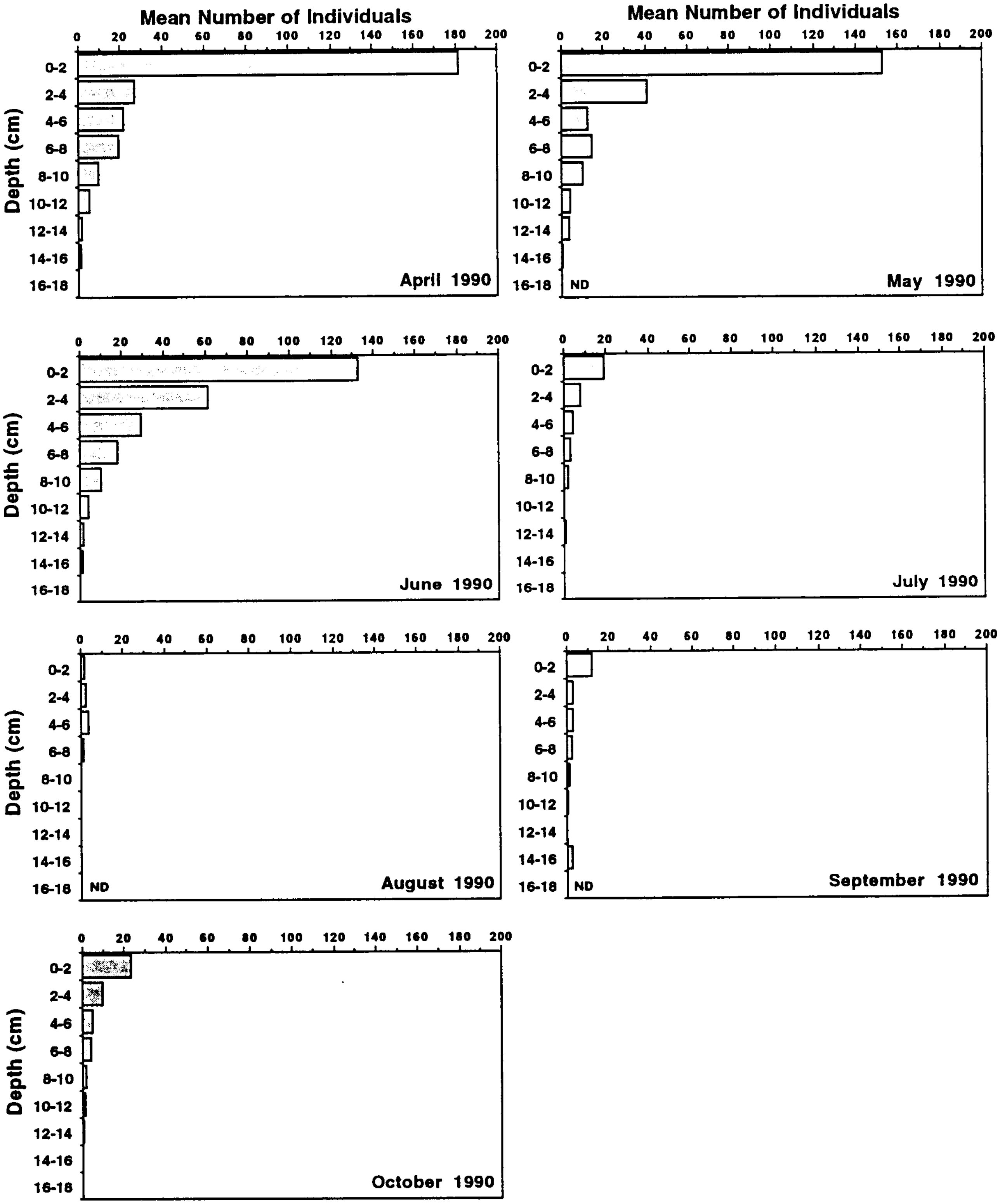


Figure 20. Vertical distribution of mean number of individuals per core section from replicate cores (*n*=2) taken from replicate box cores (*n*=3) at Unocal ST53B, 500 m during 1990. ND is no data, zeros are real values.

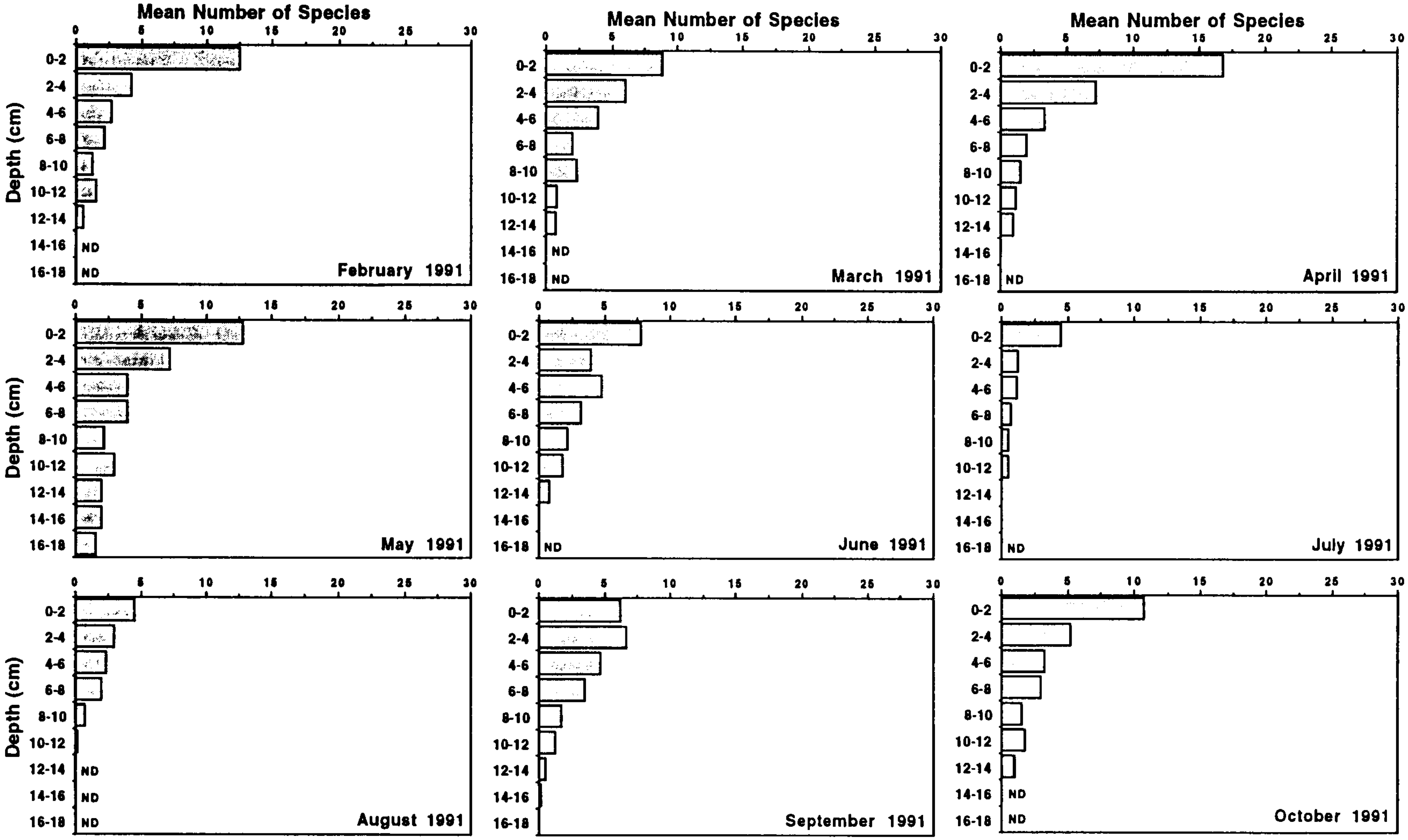


Figure 21. Vertical distribution of mean number of species per core section from replicate cores (*n*=2) taken from replicate box cores (*n*=3) at Unocal ST53B, 500 m during 1991. ND is no data, zeros are real values.

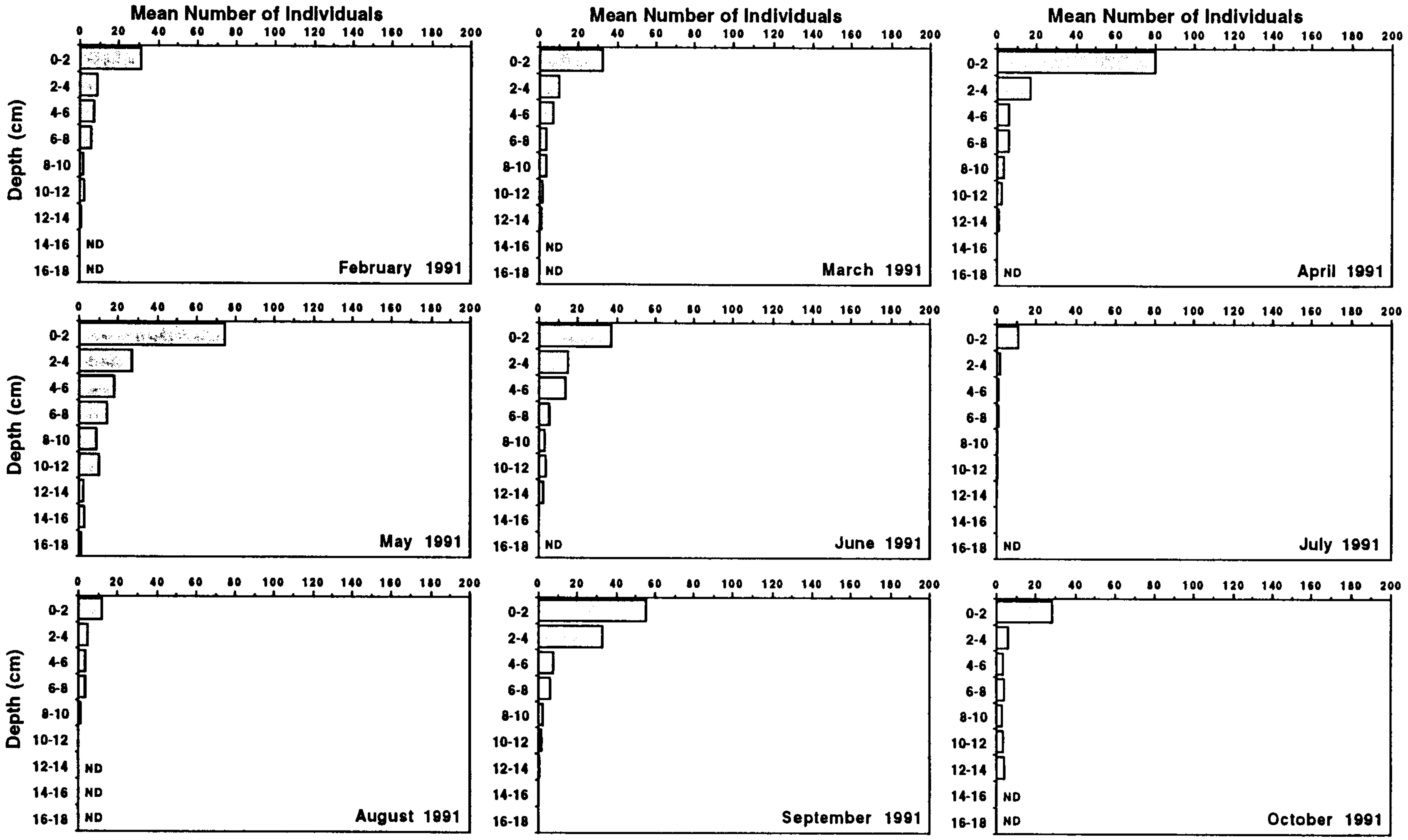


Figure 22. Vertical distribution of mean number of individuals per core section from replicate cores (*n*=2) taken from replicate box cores (*n*=3) at Unocal ST53B, 500 m during 1991. ND is no data, zeros are real values.

et al. (1988) for the continental shelf off southern New England in 50-m water depth; and, thus, we believe more representative of the Louisiana shelf in normoxic conditions.

An examination of the comparative date in Table 4 indicates that there are many more small individuals, especially during spring recruitment, on the southeastern Louisiana continental shelf than in the Chesapeake Bay mainstem and tributaries under normoxic conditions. During hypoxia-affected events, the numbers, species richness, and biomass are far more drastically reduced on the southeastern Louisiana shelf than in the affected environments of Chesapeake Bay.

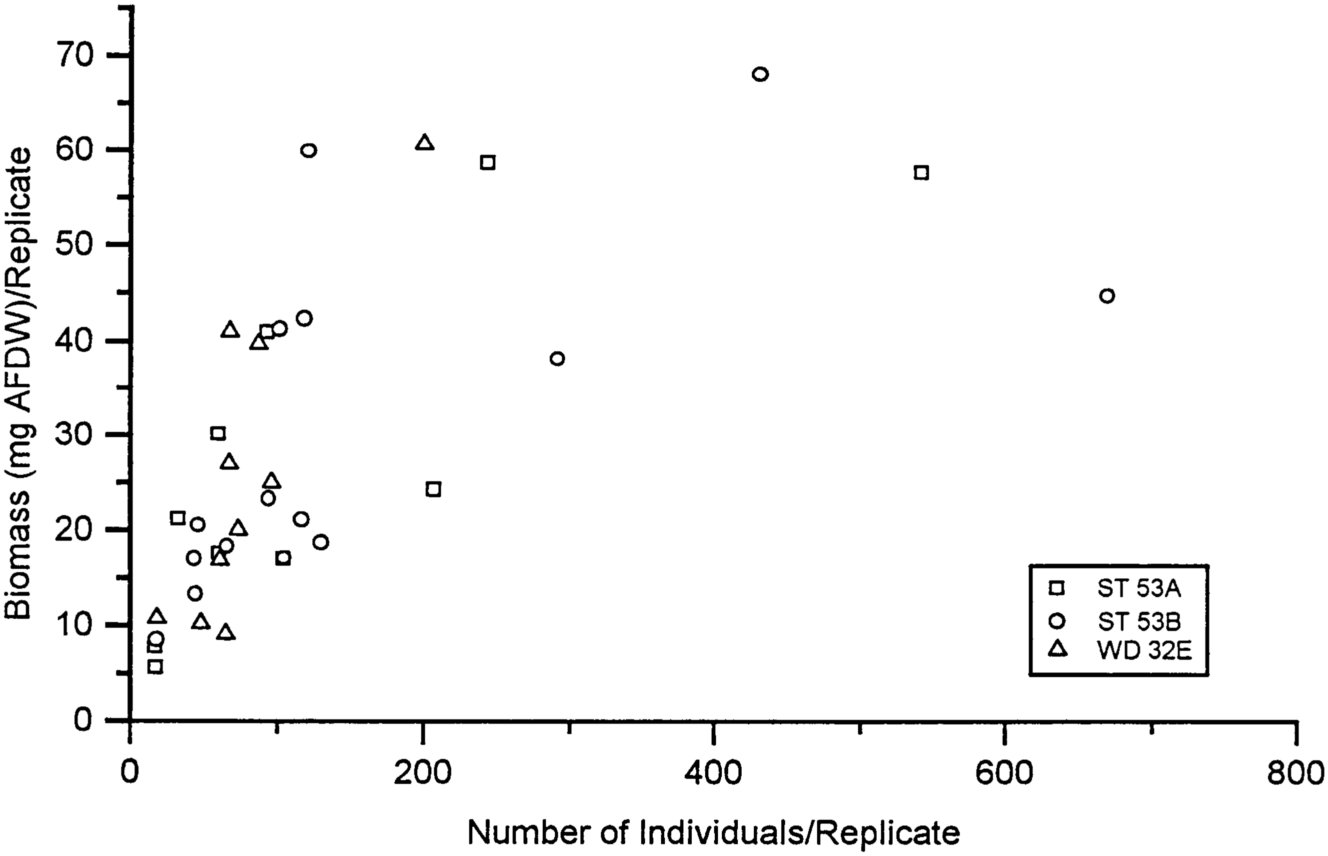


Figure 23. Comparison of benthic biomass (mg AFDW/replicate) and number of individuals/replicate for all three study sites for all individual month/year combinations from April 1990 - October 1991. Data composited from Figures 10, 13 and 16.

5.5 Environmental Variability

5.5.1 Correlation Analysis

Variability in the benthic community parameters of species richness and abundance was correlated with the environmental variables of dissolved oxygen, water temperature and salinity, and sedimentary characteristics (Table 5). Bottom water oxygen concentration was an important environmental variable only when data from all three sites were combined, and then only for species richness. In the case of ST53A and ST53B, there was more of a threshold effect, whereby

Table 4. Comparison of benthic community data and biomass values from selected publications, either inner shelf environments and/or hypoxia-affected environments.

Dauer et al. (1992)	Chesapeake Mainstem		Tributaries	
	Polyhaline Mud	Hypoxia-affected	Mesohaline Mud	Hypoxia-affected
Density (no. m^{-2})	1,978	1,723	3,065	902
Biomass (g AFDW m^{-2})	9.9	1.7	2.5	1.1
Species (no. $sample^{-1}$)	10.3	6.0	8.8	4.3
Cruz-Kaegi and Rowe (1992, unpubl. data)	Louisiana Continental Shelf			
	Normal Oxygen April 1992	Hypoxia-affected July 1991		
Density (no. m^{-2})	1,091	1,361		
Biomass (g C m^{-2})	0.38	0.49		
Rowe et al. (1988)	Continental Shelf off New England			
Biomass (g C m^{-2})	3.6			
This Study	West Delta 32E		South Timbalier	
	Spring Recruitment April 1990	Seasonal Low Fall Sep 1990	Spring Recruitment April 1990	Hypoxia-affected Jul-Aug 1990
Density (no. m^{-2})	8,637	1,431	18,437	730
Biomass (g AFDW m^{-2})	2.59	0.45	2.92	0.23
Biomass (g C m^{-2})	1.30	0.22	1.46	0.10
Species (no. $sample^{-1}$)	22.1	11.6	51.4	3.6
	Feb-May 1991		Feb-May 1991	Jul-Aug 1991
Density (no. m^{-2})	2,873		6,486	1,346
Biomass (g AFDW m^{-2})	0.93		1.55	0.46
Biomass (g C m^{-2})	0.46		0.77	0.23
Species (no. $sample^{-1}$)	16.2		21.5	8.1

numbers of species and individuals were dramatically reduced when the oxygen concentration fell below 0.5 mg/l. Also, the continuous oxygen record is more informative of the oxygen conditions at a site than discrete samples taken during collection of benthic samples. Contrary to many benthic studies, grain size distributions were not always paramount in explaining the variation observed in the benthos. Grain size was an important variable for all sites combined, and within ST53B where there was more sedimentary variability. Sediment characteristics were fairly uniform at both WD32E and ST53A. The high percentage of silt at WD32E likely contributed to the significant correlations of %Si(-) and Sd:Md(+) forall sites combined (Table 5).

Table 5. Environmental variables identified as significant ($p < 0.05$) in matrix of simple correlation coefficients against number of species and number of individuals. Mo = month, Sal = bottom water salinity, °C = bottom water temperature, %Si = percent silt, Sd:Md = sand:mud ratio, Ox = bottom water dissolved oxygen, TOC = sediment total organic carbon; sign indicates positive or negative relationship.

West Delta 32E		South Timbalier 53A		South Timbalier 53B		All Sites	
Species	#Indiv	Species	#Indiv	Species	#Indiv	Species	#Indiv
		Mo(-) Sal(-)		Mo(-) Sal(-) °C(-) %Si(-) Sd:Md(+) TOC(-)	TOC(-)	Mo(-) Ox(+) °C(-) Sal(-) %Si(-) Sd:Md(+) TOC(-)	%Si(-) Sd:Md(+) TOC(-)

5.5.2 Multivariate Results

Based on species abundance in a community, three groups of samples were distinguished at the hierarchical level of Bray-Curtis dissimilarity > 0.5 (Figures 24-26). Four groups of samples, however, were visible at the dissimilarity level of 0.37. Oxygen concentration correlated well with the above ordination when the data were superimposed on the multidimensional scaling analysis (Figures 25 and 26). Relationships with other environmental variables were less apparent when overlaid on the same plots. The obvious separation of the West Delta 32E samples (=SH in clustering results) likely relates to the differences in grain size mentioned above (i.e., higher percentage silt composition at WD32E), but these results were not obvious in the multivariate analyses.

Similar analysis of monthly data from ST53B indicates that the community structure is fairly stable during the period February - June (tight clusetering of month/year combinations in Figure 27). Major changes in species composition and species abundance, as evident from the distances between the individual samples in Figure 27, occur between the winter-spring months and July and August, and then again from mid-summer to the fall (October and September). These shifts are related to periods of recruitment in the spring, dramatic reductions of species and individuals with severe hypoxia/anoxia in mid-summer, and a recovery of the community in the fall after abatement of hypoxia. The separation of fall and spring samples indicates a difference in the community makeup by season and lower abundances in fall after hypoxia than during spring recruitment.

5.6 Effects of Hypoxia

There was a dramatic reduction in diversity, abundance and biomass of macroinfauna at sites exposed to severe and continuous hypoxia during mid-summer as opposed to the site exposed to intermittent and less severe oxygen depletion. The segregation of the three study sites into these two major groupings (ST53A and ST53B vs. WD32E) was evident in the multidimensional scaling plots (Figures 25 and 26). The further delineation of the South Timbalier area sites by season further emphasized the importance of severely low levels of dissolved oxygen in mid-summer. An examination of the continuous oxygen record and frequency of stressful events (Rabalais et al. 1994b) indicated that stations ST53A and ST53B were exposed to much lower dissolved oxygen concentrations over a much greater time period than WD32E which was intermittently exposed to hypoxia during mid-summer of 1990. The continuous oxygen record for WD32E is not known for 1991. For spring months, however, we can assume similar oxygen environments based on other April data on the southeastern shelf that correspond with the location of WD32E (i.e., values of 3 to 4 mg/l).

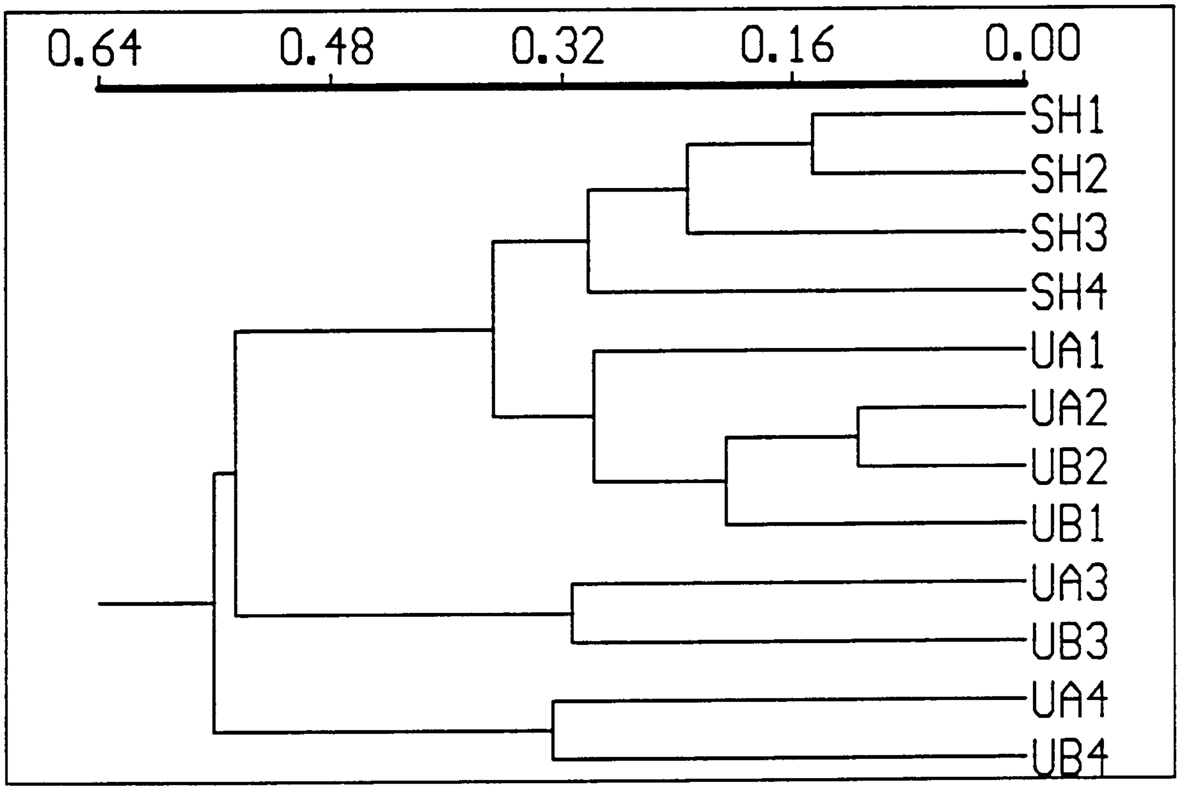


Figure 24. Results of unweighted pair-group method, arithmetic average clustering analysis of species abundance by site and season for Bray-Curtis Dissimilarity Index. SH=West Delta 32E, UA=South Timbalier 53A, UB=South Timbalier 53B. 1=winter (Feb-Mar), 2=spring (Apr-May), 3=summer (Jul-Aug), and 4=fall (Sep-Oct).

The benthic community was also composed of considerably different organisms at the South Timbalier sites compared to West Delta 32E. A more diverse fauna was found at WD32E including pericaridean crustaceans, bivalves, gastropods, and ophiuroids, mostly absent at ST53A and ST53B. The mid-summer "hypoxia" fauna at the South Timbalier sites was composed mostly of *Magelona* sp. H and the sipunculan, *Aspidosiphon* sp. Populations levels of these were maintained in the fall during recruitment of additional species, primarily individuals of *Owenia fusiformis* and *Clymenella torquata* in fall 1990 and *Sigambra tentaculata* in fall 1991. *Paraprionospio pinnata* was present in fauna with peaks during spring recruitment and some in the fall. *Mediomastus ambiseta* and *Ampharete* sp. A were also dominant spring recruits at the South Timbalier sites. Many of these same dominants were present at WD32E along with many other taxa. *Paraprionospio pinnata* dominated the macroinfauna at WD32E similar to other Louisiana-Texas inner shelf areas exposed to intermittent hypoxia (cf. Harper et al. 1981, 1991, Rabalais et al. 1989).

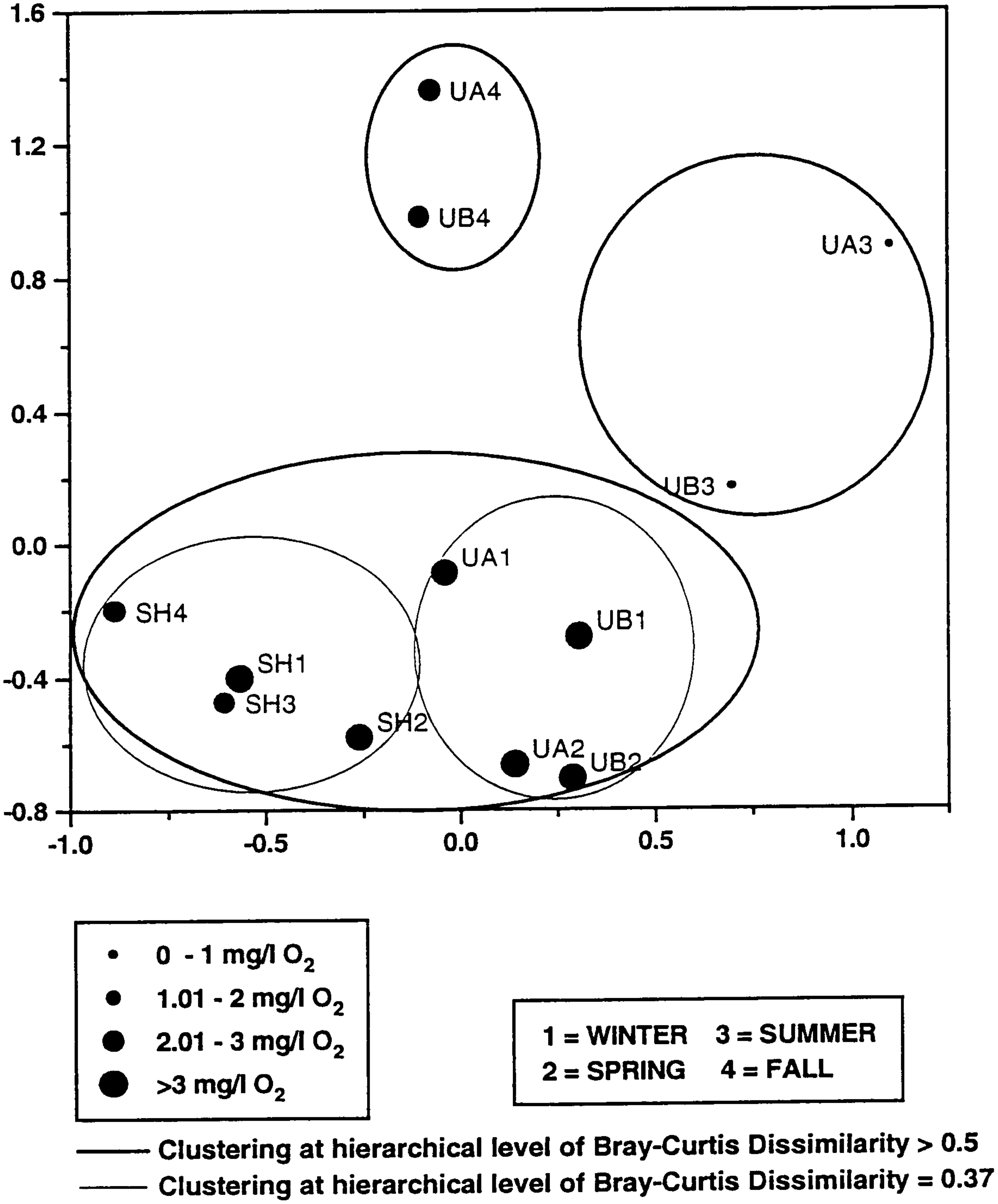


Figure 25. Two-dimensional results of the nonlinear multidimensional scaling analysis on matrix with site and season data for species abundances with bottom water dissolved oxygen concentrations superimposed.

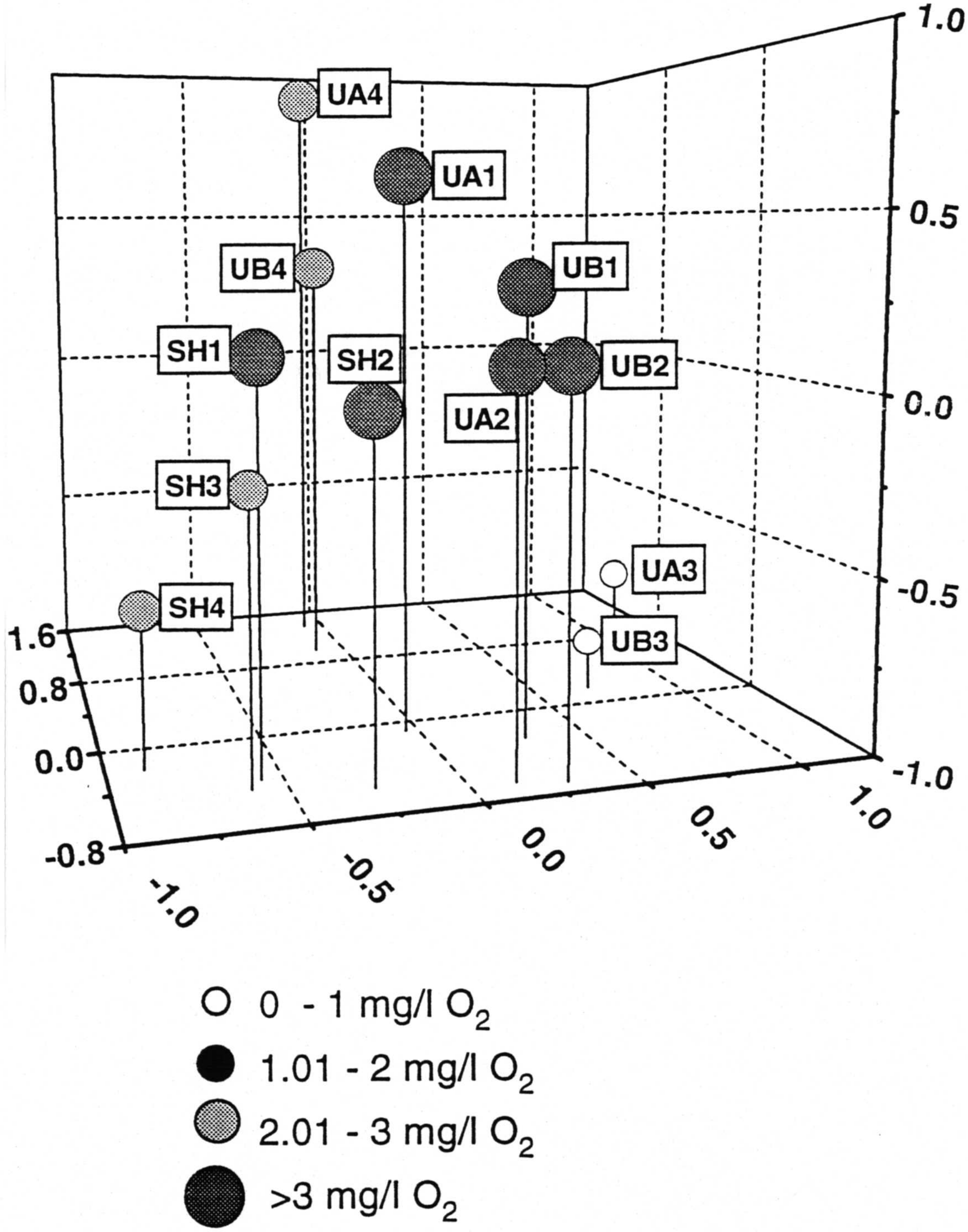


Figure 26. Three-dimensional results of the nonlinear multidimensional scaling analysis on matrix with site and season data for species abundances with bottom water dissolved oxygen concentrations superimposed.

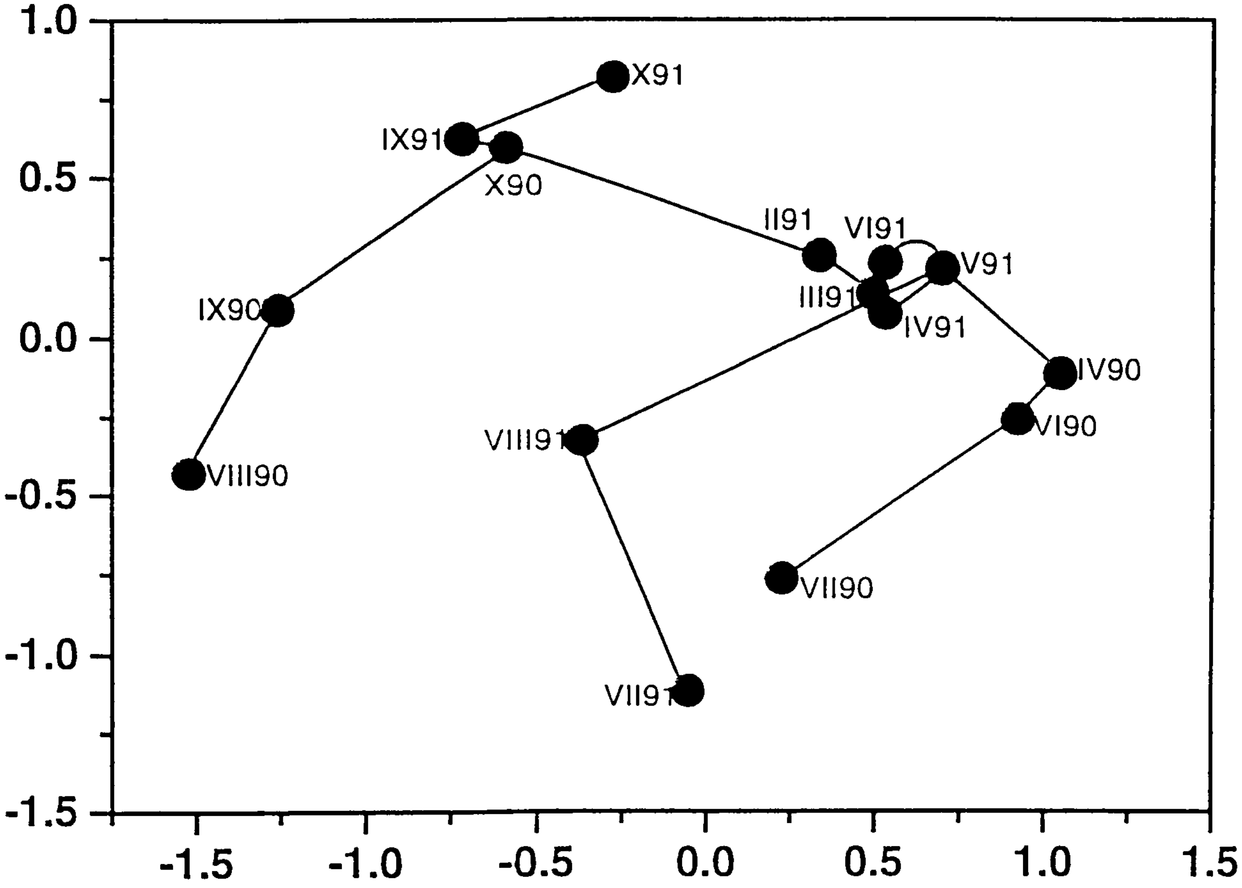


Figure 27. Results of the multidimensional scaling analysis for ST53B from April 1990 - October 1991. Months are connected with a minimum spanning tree that was calculated from the same Bray-Curtis dissimilarity matrix as the multidimensional scaling analysis.

The hypoxia-affected fauna on the southeastern Louisiana shelf followed many of the predictable patterns of previous studies (Holland et al. 1987, Santos and Simon 1980, Gaston 1985, Dauer et al. 1992). They were dominated primarily by polychaetes of smaller individuals, with overall less biomass, especially during the peak of severe hypoxia. The reduction in species richness, abundance and biomass, however, was much more severe than documented in the above mentioned studies. Longer-lived, larger, higher biomass organisms were virtually absent from the hypoxia-affected study sites. Contrary to previous studies, the fauna was not restricted to shallow-dwelling organisms during the peak of hypoxia. Although most individuals were located within the upper 2 cm of the sediments, this was most dramatic during the period of spring recruitment, and organisms were more uniformly distributed throughout the remainder of the year, although drastically reduced during July-August (the most severe hypoxia/anoxia). The more uniform vertical distribution of organisms during severe hypoxia would likely indicate that those survivors (e.g., *Magelona* sp. H or *Aspidosiphon* sp.) are physiologically adapted to severe hypoxia and/or high levels of hydrogen sulfide, and are, therefore, not restricted to the upper 2 cm of the sediments. When fall recruits enter the community, the low-oxygen tolerant species continue to maintain high levels in the community and are not restricted to the upper sediment layers.

The shift from more diverse, longer-lived, potentially deeper-dwelling organisms in the benthic community to smaller, opportunistic organisms in a continual state of recruitment may have implications for benthic-pelagic coupling and trophic dynamics. Although movement of benthic organisms to the surface of the sediments during hypoxia stress and the predominance of surface deposit feeders may expose more members of the community to demersal predators, the absence of finfish and larger crustaceans from the lower water column in the South Timbalier area when dissolved oxygen levels fall below 1.8 to 2.0 mg/l (Rabalais and Harper, pers. observ.) makes this an unlikely scenario. Also, the presence of intact moribund and stressed benthic organisms at the sediment surface (Rabalais and Harper, pers. observ.) provides evidence for the absence of larger predators. Biological processes of a community of smaller, lower biomass, surface deposit feeders has additional implications for physical alteration of sediments and chemical properties related to these sediment alterations (or lack thereof), such as nutrient fluxes, location of the RPD, and composition of the microbial community.

The admonition of Diaz and Rosenberg (in press) is relevant to the results of this study. They noted that "oxygen deficiency may very well be the most wide-spread anthropogenically induced deleterious effect in the marine environment that causes localized mortality of benthic macrofauna," and that the incidence of seasonal hypoxia in coastal areas is spreading rapidly. The main cause for this is suggested to be eutrophication. On the southeastern Louisiana continental shelf, especially in the Mississippi River Bight, there is well documented evidence of the effects of eutrophication in the form of carbon accumulation which parallels long-term changes in the nutrient concentrations and ratios of freshwater delivered by the Mississippi River (Turner and Rabalais 1991, 1994, Justic' et al. 1993, Justic et al. 1995). In addition, results from dated sediment cores indicate that the benthic community (as characterized by foraminiferans) has also changed as a result of an increase in oxygen stress which parallels the increase in eutrophication (Rabalais et al. submitted, Sen Gupta et al. submitted).

Benthic communities impacted by severe, persistent and extensive hypoxic bottom waters undergo a predictable sequence of community changes, which, now identified, can provide a general understanding within which to place results from studies of the effects of offshore petroleum development. We were able to document the annual cycle of benthic community responses to varying degrees of oxygen stress because we (1) expanded the temporal scale to monthly sampling over several annual cycles of oxygen stress and benthic community recovery, and (2) continuously measured the bottom water oxygen environment. We documented that (1) the larger, mobile fauna usually migrate from hypoxic bottom waters (Rabalais and Harper 1991, 1992), (2) the smaller, less mobile organisms die off in differential patterns depending, in part, on community structure, history of previous stresses, duration and intensity of exposure to oxygen deficient waters, and the physiological capabilities of the fauna, (4) some macroinfauna are physiologically capable of surviving extremely low dissolved oxygen concentrations and form part of the basis for the fall benthic community, (5) additional benthic recruits colonize the area when hypoxia abates, (6) the community is comprised of smaller, shorter-lived, opportunistic individuals and does not develop into a more diverse, longer-lived, potentially deeper-dwelling community, and (7) benthic communities continually exposed to seasonally severe hypoxia are distinguishable from other communities not exposed to such conditions or to ephemeral or less intense oxygen stress.

LITERATURE CITED

Bedinger, C. A., Jr. (ed.). 1981. Ecological investigations of petroleum production platforms in the central Gulf of Mexico. Report to the Bureau of Land Management, Contract No. AA551-CT8-17, Southwest Research Institute, San Antonio, Texas.

Boesch, D. F. and N. N. Rabalais (eds.). 1987. Long-term environmental effects of offshore oil and gas development. London: Elsevier Applied Science. 690 pp.

Boesch, D. F. and N. N. Rabalais. 1991. Effects of hypoxia on continental shelf benthos: comparisons between the New York Bight and the Northern Gulf of Mexico. Pages 27-34 in Tyson, R. V. and T. H. Pearson (eds.), Modern and Ancient Continental Shelf Anoxia. Geological Society Special Publication No. 58. London: The Geological Society.

Carney, R. S. 1987. A review of study designs for the detection of long-term environmental effects of offshore petroleum activities. Pages 651-690 in Boesch, D. F. and N. N. Rabalais (eds.), Long-Term Environmental Effects of Offshore Oil and Gas Development. London: Elsevier Applied Science.

Clifford, H.T. and W. Stephenson. 1975. An Introduction to Numerical Classification. Academic Press, New York.

Crisp, D. J. 1984. Energy flow measurements. Pages 284-372 in Holme, N. A. and A. D. McIntyre (eds.), Methods for the Study of Marine Benthos. London: Blackwell Scientific Publications.

Cruz-Kaegi, M. L. and G. T. Rowe. 1992. Benthic biomass gradients on the Texas-Louisiana shelf. Pages 145-149 in Nutrient Enhanced Coastal Ocean Productivity, Proceedings of a Workshop, Louisiana Universities Marine Consortium, October 1991, Publ. No. TAMU-SG-92-109, Texas A&M University Sea Grant College Program, College Station, Texas.

Dauer, D. M., A. J. Rodi, Jr. and J. A. Ranasinghe. 1992. Effects of low dissolved oxygen events on the macrobenthos of the lower Chesapeake Bay. Estuaries 15(3):384-391.

Dennis, G. D., T. J. Bright and C. A. Shalan. 1984. Offshore oceanographic and environmental monitoring services for the strategic petroleum reserve: annotated bibliography of hypoxia and other oxygen-depleted literature on the marine environment. Final Report to DOE, Strategic Petroleum Reserve Project Management Office, Contract No. DOE-AC96-83PO10850. Texas A&M University, Texas A&M Research Foundation, College Station, Texas. 46 pp.

Diaz, R. J. and R. Rosenberg. (in press). Marine benthic hypoxia - Review of ecological effects and behavioural responses of benthic macrofauna. Oceanogr. Mar. Biol. Ann. Rev.

Dinnel, S. P. and W. J. Wiseman, Jr. 1986. Fresh water on the Louisiana and Texas shelf. Continental Shelf Res. 6:765-784.

Dortch, Q., N. N. Rabalais, R. E. Turner and G. T. Rowe. 1994. Respiration rates and hypoxia on the Louisiana shelf. Estuaries 17(4):862-872.

Endeco. 1988. Operations manual for the Endeco type 1184 SSM pulsed dissolved oxygen and temperature recorder. Endeco, Inc., Marion, Massachusetts. 62 pp.

Friligos, N. 1976. Seasonal variations of nutrients around the sewage outfall in the Saronikos Gulf (1973). Thalassia Jugoslavica 12:441-453.

Friligos, N. and Zenetos, A. 1988. Elefsis Bay anoxia: nutrient conditions and benthic community structure. Mar. Ecl. 9:273-290.

Gaston, G. R. 1985. Effects of hypoxia on macrobenthos of the inner shelf off Cameron, Louisiana. Estuar. Coastal Shelf Sci. 20:603-613.

Gaston, G. R., P. A. Rutledge and M. L. Walther. 1985. The effects of hypoxia and brine on recolonization by macrobenthos off Cameron, Louisiana (USA). Contr. Mar. Sci. 28:79-93.

Harper, D. E., Jr., L. D. McKinney, R. R. Salzer and R. J. Case. 1981. The occurrence of hypoxic bottom water off the upper Texas coast and its effects on the benthic biota. Contr. Mar. Sci. 24:53-79.

Harper, D. E., Jr., L. D. McKinney, J. M. Nance and R. R. Salzer. 1991. Recovery responses of two benthic assemblages following an acute hypoxic event on the Texas continental shelf, northwestern Gulf of Mexico. Pages 49-64 in Tyson, R. V. and T. H. Pearson (eds.), Modern and Ancient Continental Shelf Anoxia. Geological Society Special Publication No. 58. London: The Geological Society.

Holland, A. F., A. T. Shaughnessy and M. H. Hiegel. 1987. Long-term variation in the mesohaline Chesapeake Bay macrobenthos: Spatial and temporal patterns. Estuaries 10:370-278.

Josefson, A. B. and B. Widbom. 1988. Differential response of benthic macrofauna and meiofauna to hypoxia in the Gullmar Fjord basin. Mar. Biol. 100:31-40.

Justic', D., N. N. Rabalais, R. E. Turner and W. J. Wiseman, Jr. 1993. Seasonal coupling between riverborne nutrients, net productivity and hypoxia. Mar. Pollut. Bull. 26(4):184-189.

Justic', D., N. N. Rabalais, R. E. Turner and Q. Dortch. 1995. Changes in nutrient structure of river-dominated coastal waters: Stoichiometric nutrient balance and its consequences. Estuar. Coastal Shelf Sci. 40:(in press).

Lohrenz, S. E., M. J. Dagg and T. E. Whitledge. 1990. Enhanced primary production at the plume/oceanic interface of the Mississippi River. Continental Shelf Res. 10:639-664.

Llanso, R. J. 1991. Tolerance of low dissolved oxygen and hydrogen sulfide by the polychaete *Streblospio benedicti* (Webster). J. Exper. Mar. Biol. Ecol. 153:165-178.

Llanso, R. J. 1992. Effects of hypoxia on estuarine benthos: the lower Rappahannock River (Chesapeake Bay), a case study. Estuar. Coast. Shelf Sci. 35:491-515.

Milliman, J. D. and R. H. Meade. 1983. World-wide delivery of river sediment to the ocean. J. Geol. 91:1-21.

Mountford, N. K., A. F. Holland and J. A. Mihursky. 1977. Identification and description of macrobenthic communities in the Calvert Cliffs region of the Chesapeake Bay. Chesapeake Sci. 14:160-369.

Murrell, M. C. and J. W. Fleeger. 1989. Meiofauna abundance on the Gulf of Mexico continental shelf affected by hypoxia. Continental Shelf Res. 9(12):1049-1062.

Neff, J. M., T. C. Sauer and N. Maciolek. 1989. Fate and effects of produced water discharges in nearshore marine waters. Final Report to American Petroleum Institute, API Publ. No. 4472, American Petroleum Institute, Washington, D.C. 300 pp.

Niermann, U., E. Bauerfeind, W. Hickel and H. V. Westernhagen. 1990. The recovery of benthos following the impact of low oxygen content in the German Bight. Netherlands J. Sea Res. 25:215-226.

Oetking, P., R. Back, R. Watson and C. Merks. 1974. Hydrography on the nearshore continental shelf of south central Louisiana. Final Report of Offshore Ecology Investigation for Gulf Universities Research Consortium, Galveston, Texas, by Southwest Research Institute, SwRI Proj. No. 03-3720.

Parsons, T. R., Y. Maita and C. M. Lalli. 1984. A manual of chemical and biological methods for seawater analysis. New York: Pergamon Press. 173 pp.

Pokryfki, L. and R. E. Randall. 1987. Nearshore hypoxia in the bottom water of the northwestern Gulf of Mexico from 1981 to 1984. Mar. Environmental Res. 22:75-90.

Rabalais, N. N. and D. E. Harper, Jr. 1991. Studies of the benthic oxygen depletion phenomenon off Louisiana. Pages 57-63 in Krock, H.-J. and D. E. Harper, Jr. (eds.), International Pacifica Scientific Diving...1991. Proceedings, American Academy of Underwater Sciences, Eleventh Annual Scientific Diving Symposium, 25-30 September 1991, Honolulu, Hawaii.

Rabalais, N. N. and D. E. Harper, Jr. 1992. Studies of benthic biota in areas affected by moderate and severe hypoxia. Pages 150-153 in Nutrient Enhanced Coastal Ocean Productivity, Proceedings of a Workshop, Louisiana Universities Marine Consortium, October 1991, Publ. No. TAMU-SG-92-109, Texas A&M University Sea Grant College Program, College Station, Texas.

Rabalais, N. N., M. J. Dagg and D. F. Boesch. 1985. Nationwide review of oxygen depletion and eutrophication in estuarine and coastal waters: Gulf of Mexico. Report to the U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Services, Ocean Assessments Division, Rockville, Maryland. 60 pp.

Rabalais, N. N., L. E. Smith and D. F. Boesch. 1989. The effects of hypoxic water on the benthic fauna of the continental shelf off southeastern Louisiana. Pages 147-151 in Proceedings: Ninth Annual Gulf of Mexico Information Transfer Meeting. OCS Study MMS 89-0060. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 430 pp.

Rabalais, N. N., R. E. Turner, W. J. Wiseman, Jr. and D. F. Boesch. 1991. A brief summary of hypoxia on the northern Gulf of Mexico continental shelf: 1985-1988. Pages 35-47 in Tyson, R. V. and T. H. Pearson (eds.), Modern and Ancient Continental Shelf Anoxia. Geological Society Special Publication No. 58. London: The Geological Society.

Rabalais, N. N., R. E. Turner and W. J. Wiseman, Jr. 1992a. Distribution and characteristics of hypoxia on the Louisiana shelf in 1990 and 1991. Pages 15-20 in Nutrient Enhanced Coastal Ocean Productivity, Proceedings of a Workshop, Louisiana Universities Marine Consortium, October 1991, Publ. No. TAMU-SG-92-109, Texas A&M University Sea Grant College Program, College Station, Texas.

Rabalais, N. N., R. E. Turner and Q. Dortch. 1992b. Louisiana continental shelf sediments: Indicators of riverine influence. Pages 77-81 in Nutrient Enhanced Coastal Ocean Productivity, Proceedings of a Workshop, Louisiana Universities Marine Consortium, October 1991, Publ. No. TAMU-SG-92-109, Texas A&M University Sea Grant College Program, College Station, Texas.

Rabalais, N. N., L. E. Smith, E. B. Overton and A. L. Zoeller. 1993. Influence of Hypoxia on the Interpretation of Effects of Petroleum Production Activities. OCS Study/MMS 93-0022. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 158 pp.

Rabalais, N. N., R. E. Turner and W. J. Wiseman, Jr. 1994a. Hypoxia conditions in bottom waters on the Louisiana-Texas shelf. Pages 50-54 in Dowgiallo, M. J. (ed.), Coastal Oceanographic Effects of Summer 1993 Mississippi River Flooding, Special NOAA Report, National Oceanic and Atmospheric Administration, Coastal Ocean Office, Silver Spring, Maryland.

Rabalais, N. N., W. J. Wiseman, Jr. and R. E. Turner. 1994b. Comparison of continuous records of near-bottom dissolved oxygen from the hypoxia zone of Louisiana. Estuaries 17(4):850-861.

Ranchor, E. 1985. Eutrophierung in der Nordsee-Bedrohung durch Sauerstoffmangel. Abhandlung Naturwitenschaftlichen Verein Bremen 40(3):283-292.

Renaud, M. L. 1985. Annotated bibliography on hypoxia and its effects on marine life, with emphasis on the Gulf of Mexico. NOAA Technical Report NMFS 21. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D.C. 9 pp.

Renaud, M. L. 1986. Hypoxia in Louisiana coastal waters during 1983: implications for fisheries. Fishery Bull. 84(1):19-26.

Rohlf, F.J. 1993. Numerical Taxonomy and Multivariate Analysis System, NTSYS-pc, version 1.80. Applied Biostatistics Inc., New York.

Rosenberg, R. 1990. Negative oxygen trends in Swedish coastal bottom waters. Mar. Pollut. Bull. 21:335-339.

Rowe, G. T., R. Theroux, W. Phoel, H. Quinby, R. Wilke, D. Koschoreck, T. E. Whitledge, P. G. Falkowski and C. Fray. 1988. Benthic carbon budgets for the continental shelf south of New England. Continental Shelf Res. 8(5-7):511-527.

Ryther, J. H. 1956. The measurement of primary production. Limnol. Oceanogr. 1:72-84.

Sanders, H. L. 1981. Environmental effects of oil in the marine environment. Pages 117-146 in Safety and Offshore Oil: Background Papers of the Committee on Assessment of Safety of OCS Activities. National Research Council, National Academy Press, Washington, D.C.

Santos, S. L. and J. L. Simon. 1980. Response of soft-bottom benthos to annual catastrophic disturbance in South Florida estuary. Mar. Ecol. Prog. Ser. 3:347-355.

SAS Institute, Inc. 1982. SAS user's guide. SAS Institute, Inc., Cary, North Carolina.

Sklar, F. H. and R. E. Turner. 1981. Characteristics of phytoplankton production off Barataria Bay in an area influenced by the Mississippi River. Contr. Mar. Sci. 24:93-106.

Turner, R. E. and R. L. Allen. 1982. Plankton respiration in the bottom waters of the Mississippi River Delta Bight. Contr. Mar. Sci. 25:173-179.

Turner, R. E. and N. N. Rabalais. 1991. Changes in Mississippi River water quality this century: implications for coastal food webs. BioScience 41(3):140-147.

Turner, R. E. and N. N. Rabalais. 1994. Coastal eutrophication near the Mississippi river delta. Nature 368:619-621.

Ward, C. H., M. E. Bender and D. J. Reish (eds.). 1979. The offshore ecology investigation: effects of oil drilling and production in a coastal environment. Rice Univ. Studies 65(4&5):1-589.

Appendix A. Hydrography

Table A.1. Hydrography, February 1991.

CRUISE DATA - TRANSECT C

Station: 6　Latitude: 28:51.44 N　Hydrolab cast time: 16:30
Date: 02/02/91　Longitude: 90:27.68 W　Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.9	16.40	15.67	7.70	10.92	9.10	101.8
2.1	16.41	24.16	7.71	17.38	8.61	101.3
4.1	16.42	24.50	7.69	17.65	8.60	101.5
6.1	16.44	24.64	7.68	17.75	8.53	100.8
8.0	16.46	25.06	7.69	18.06	8.43	99.9
10.0	16.54	24.72	7.69	17.78	8.36	99.0
12.0	16.65	25.35	7.69	18.24	8.27	98.5
14.2	17.03	26.21	7.70	18.82	8.22	99.2
16.0	17.66	28.51	7.70	20.42	7.91	98.0
17.1	18.38	30.20	7.69	21.54	7.40	94.0
18.5	18.78	31.17	7.67	22.18	7.25	93.3

CRUISE DATA - TRANSECT C

Station: 6B　Latitude: 28:52.18 N　Hydrolab cast time: 18:00
Date: 02/02/91　Longitude: 90:28.04 W　Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.7	16.20	16.26	7.72	11.41	8.95	100.0
2.3	16.19	21.75	7.71	15.59	9.80	113.2
4.0	16.18	24.07	7.70	17.37	8.57	100.3
6.3	16.18	24.00	7.70	17.32	8.57	100.3
8.2	16.19	23.93	7.70	17.26	8.53	99.8
9.7	16.18	24.42	7.70	17.63	8.51	99.9
12.4	16.15	24.07	7.70	17.37	8.44	98.8
14.3	16.40	24.71	7.70	17.81	8.26	97.5
16.0	17.70	28.37	7.69	20.31	7.45	92.3
17.0	18.25	29.91	7.68	21.35	7.15	90.4
18.9	18.55	30.72	7.66	21.89	7.20	92.0

[500m East of Platform]
Station: 6B　Latitude: 28:52.18 N　Hydrolab cast time: 12:55
Date: 02/03/91　Longitude: 90:28.04 W　Secchi disk depth (m): 2.9

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	15.51	21.57	7.71	15.59	9.10	103.5
2.5	15.51	21.63	7.71	15.64	9.09	103.4
4.1	15.46	21.70	7.71	15.70	9.03	102.7
5.9	15.66	22.66	7.70	16.40	8.74	100.4
8.2	16.55	25.20	7.70	18.15	8.37	99.4
10.2	17.40	28.14	7.70	20.20	7.81	96.1
12.1	17.87	29.38	7.72	21.03	8.15	101.9
14.0	18.50	30.36	7.71	21.63	7.56	96.3
16.8	19.03	31.76	7.70	22.57	7.12	92.4
17.9	19.04	31.91	7.70	22.68	7.11	92.4
18.6	19.03	31.84	7.69	22.62	7.13	92.6

Table A.1. Continued

CRUISE DATA - TRANSECT C

[New Mooring]
Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 15:00
Date: 02/08/91 Longitude: 90:28.04 W Secchi disk depth (m): 3.2

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	16.15	16.98	7.89	11.97	12.35	138.5
1.0	16.17	18.64	7.89	13.23	12.22	138.5
2.0	16.06	20.31	7.85	14.53	11.25	128.5
3.0	17.53	26.11	7.72	18.63	9.31	113.4
4.0	18.85	30.60	7.68	21.73	8.31	106.8
5.0	19.12	32.06	7.66	22.77	7.80	101.6
6.0	19.14	32.21	7.65	22.88	7.70	100.4
7.0	19.19	32.21	7.66	22.87	7.65	99.9
8.0	19.25	32.51	7.66	23.08	7.59	99.4
9.0	19.39	32.73	7.66	23.22	7.53	99.0
10.0	19.43	32.88	7.66	23.32	7.50	98.8
11.0	19.51	33.04	7.66	23.41	7.47	98.6
12.0	19.55	33.11	7.66	23.46	7.42	98.1
13.0	19.59	33.19	7.66	23.51	7.40	97.9
14.0	19.65	33.34	7.66	23.61	7.32	97.1
15.0	19.70	33.41	7.66	23.65	7.22	95.9
16.0	19.71	33.42	7.65	23.65	7.15	95.0
17.0	19.72	33.42	7.65	23.65	7.12	94.6
18.0	19.73	33.42	7.65	23.65	7.14	94.9
19.0	19.73	33.49	7.65	23.70	7.13	94.8
19.5	19.71	33.34	7.63	23.60	7.04	93.5

CRUISE DATA - TRANSECT C

Station: 6 Latitude: 28:51.44 N Hydrolab cast time: 15:15
Date: 02/21/91 Longitude: 90:27.68 W Secchi disk depth (m): 7.5

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	18.43	22.49	7.95	15.67	8.82	107.1
1.0	18.43	29.35	7.95	20.88	8.52	107.8
2.0	18.44	23.25	7.95	16.24	8.79	107.2
3.0	18.44	23.53	7.95	16.45	8.85	108.2
5.0	18.43	28.36	7.95	20.12	8.58	107.9
7.0	18.41	29.42	7.95	20.94	8.52	107.8
9.0	18.40	29.42	7.95	20.94	8.52	107.7
11.0	18.38	29.42	7.94	20.94	8.45	106.8
13.0	18.36	29.99	7.91	21.38	8.05	102.1
15.0	18.54	30.79	7.73	21.95	6.58	84.1
16.0	18.52	30.79	7.66	21.95	5.15	65.8
17.0	18.48	31.65	7.61	22.61	4.49	57.6
18.0	18.47	31.93	7.56	22.84	3.95	50.8
19.0	18.56	31.94	7.53	22.82	3.74	48.2

Table A.1. Continued

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 13:15
Date: 02/21/91 Longitude: 90:28.04 W Secchi disk depth (m): 8.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	18.45	19.49	7.96	13.39	9.10	108.6
1.0	18.45	29.50	7.98	20.99	8.60	108.9
3.0	18.45	29.57	7.96	21.04	8.60	108.9
5.0	18.45	29.64	7.96	21.09	8.58	108.7
7.0	18.45	29.57	7.96	21.04	8.58	108.7
9.0	18.44	29.57	7.96	21.04	8.61	109.1
11.0	18.40	29.78	7.96	21.21	8.54	108.2
13.0	18.37	29.99	7.92	21.38	8.23	104.4
15.0	18.35	30.13	7.77	21.49	6.37	80.8
16.0	18.34	30.27	7.70	21.60	5.41	68.7
17.0	18.40	30.85	7.68	22.03	5.14	65.5
18.0	18.47	30.93	7.65	22.07	4.98	63.6
19.0	18.62	31.51	7.54	22.48	4.01	51.6
19.5	18.67	31.66	7.62	22.58	4.00	51.5

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 09:30
Date: 02/27/91 Longitude: 90:28.04 W Secchi disk depth (m): 5.5

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	16.40	20.33	8.01	14.47	10.63	122.3
1.0	16.40	24.16	8.02	17.39	10.40	122.4
2.0	16.43	24.99	8.01	18.01	10.25	121.3
3.0	16.48	25.82	8.01	18.64	10.07	119.9
5.0	17.22	28.41	7.83	20.44	7.59	93.2
7.0	17.25	28.62	7.83	20.60	7.69	94.6
9.0	17.29	28.69	7.82	20.65	7.77	95.7
11.0	17.35	28.84	7.82	20.75	7.67	94.6
13.0	18.34	30.13	7.70	21.49	5.73	72.7
15.0	19.74	33.13	7.42	23.42	2.37	31.4
16.0	19.87	33.28	7.41	23.51	2.37	31.6
17.0	19.98	33.36	7.41	23.54	2.41	32.2
18.0	20.14	33.89	7.41	23.90	2.43	32.6
18.5	20.27	33.75	7.40	23.76	2.43	32.7

Table A.1. Continued

[1000m]
Station: 6 = UA Latitude: 28:51.44 N Hydrolab cast time: 12:10
Date: 02/27/91 Longitude: 90:27.68 W Secchi disk depth (m): 1.5

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	15.43	14.72	8.12	10.38	13.52	147.3
1.1	15.46	20.28	8.12	14.62	13.00	146.6
2.2	15.49	22.11	8.12	16.01	12.81	146.1
3.0	15.54	22.79	8.11	16.52	12.33	141.4
4.0	16.66	26.12	8.01	18.82	9.96	119.2
6.0	17.32	27.99	7.86	20.10	7.80	95.7
8.0	17.30	28.62	7.86	20.59	7.69	94.7
10.0	17.34	28.70	7.86	20.64	7.78	95.9
12.0	17.36	28.84	7.85	20.74	7.70	95.0
14.0	18.05	29.75	7.75	21.27	6.03	75.9
15.0	18.60	30.79	7.66	21.94	4.55	58.2
16.0	19.72	33.20	7.43	23.48	2.30	30.5
17.0	19.78	33.06	7.43	23.36	2.30	30.5
18.0	19.81	33.13	7.43	23.41	2.34	31.1
18.5	20.00	33.29	7.43	23.48	2.38	31.8

[500m]
Station: 6A = UB Latitude: 28:50.49 N Hydrolab cast time: 14:10
Date: 02/27/91 Longitude: 90:26.02 W Secchi disk depth (m): 1.6

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	16.37	17.65	8.04	12.44	11.33	128.1
1.0	16.40	24.23	8.04	17.44	11.51	135.5
2.0	17.22	26.58	7.94	19.05	8.99	109.2
3.0	17.49	28.29	7.87	20.29	7.91	97.6
5.0	17.50	28.57	7.86	20.50	7.81	96.5
7.0	17.51	28.22	7.86	20.23	7.76	95.7
9.0	17.52	28.29	7.86	20.29	7.75	95.6
11.0	17.57	28.36	7.86	20.33	7.66	94.7
13.0	18.48	30.35	7.70	21.63	5.47	69.7
15.0	19.80	33.28	7.47	23.52	2.85	37.9
16.0	20.07	33.59	7.46	23.69	2.94	39.4
17.0	20.30	33.83	7.44	23.81	2.87	38.7
18.0	20.36	33.83	7.42	23.80	3.01	40.6

Table A.1. Continued

[1000m]
Station: SH Latitude: 29:07.22 N Hydrolab cast time: 21:30
Date: 02/27/91 Longitude: 89:41.81 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	15.61	14.59	8.12	10.25	11.42	124.8
1.0	15.62	21.98	8.12	15.89	10.91	124.7
2.0	15.63	21.98	8.13	15.89	10.90	124.6
3.0	15.62	21.98	8.12	15.89	10.93	124.9
5.0	16.90	25.02	7.96	17.94	8.95	107.0
7.0	17.69	28.02	7.82	20.04	7.42	91.7
9.0	17.94	28.39	7.79	20.27	7.05	87.8
11.0	18.48	30.43	7.67	21.69	5.60	71.3
13.0	20.00	33.66	7.66	23.76	4.63	61.9
15.0	20.04	33.73	7.66	23.81	4.61	61.7
16.0	20.03	33.95	7.65	23.98	4.64	62.2
17.0	20.03	33.88	7.64	23.92	4.59	61.5
18.0	20.05	33.81	7.63	23.86	4.70	63.0
19.0	20.18	34.04	7.54	24.00	3.92	52.7

Table A.2. Hydrography, March 1991.

CRUISE DATA - TRANSECT C

Station: 6B   Latitude: 28:52.18 N   Hydrolab cast time: 09:50
Date: 03/18/91   Longitude: 90:28.04 W   Secchi disk depth (m): 2.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	17.75	16.45	7.53	11.24	7.85	90.7
1.0	17.75	25.71	7.54	18.27	7.70	94.0
2.0	17.76	25.85	7.54	18.37	7.71	94.2
3.0	17.75	25.85	7.54	18.37	7.68	93.8
4.0	17.75	25.78	7.54	18.32	7.65	93.4
6.0	17.70	25.91	7.54	18.44	7.65	93.4
8.0	17.81	26.34	7.54	18.74	7.53	92.4
10.0	17.92	26.98	7.55	19.20	7.38	91.1
12.0	18.20	27.84	7.56	19.79	7.25	90.5
14.0	18.45	28.71	7.56	20.39	7.25	91.4
15.0	18.62	29.51	7.56	20.95	6.79	86.3
16.0	18.85	31.03	7.53	22.05	6.00	77.3
17.0	19.14	31.70	7.52	22.49	5.80	75.4
18.0	19.24	32.07	7.50	22.75	5.39	70.4
19.0	19.23	32.00	7.49	22.70	5.46	71.3

CRUISE DATA - TRANSECT C

[1000m]
Station: 6=UA   Latitude: 28:51.44 N   Hydrolab cast time: 12:20
Date: 03/18/91   Longitude: 90:27.68 W   Secchi disk depth (m): 2.4

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	18.06	18.43	7.57	12.67	8.05	94.7
1.0	17.99	21.10	7.57	14.71	7.99	95.4
2.0	17.94	22.81	7.57	16.02	7.80	94.0
3.0	17.85	25.09	7.57	17.77	7.70	93.9
4.0	17.93	26.14	7.57	18.56	7.45	91.5
6.0	18.16	27.63	7.58	19.64	7.26	90.4
8.0	18.19	27.91	7.58	19.85	7.29	91.0
10.0	18.26	28.13	7.58	19.99	7.29	91.2
12.0	18.61	29.29	7.58	20.79	7.14	90.6
14.0	18.78	30.24	7.57	21.47	6.53	83.6
15.0	18.98	30.97	7.56	21.98	6.49	83.8
16.0	19.05	31.55	7.56	22.40	6.22	80.7
17.0	19.18	31.63	7.52	22.43	5.34	69.5
18.0	19.28	32.36	7.50	22.96	5.00	65.5
19.0	19.36	32.44	7.49	23.00	5.15	67.6

Table A.2. Continued.

CRUISE DATA - TRANSECT C

[500m]
Station: 6A=UB
Date: 03/18/91
Latitude: 28:50.49 N
Longitude: 90:26.02 W
Hydrolab cast time: 17:10
Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	18.44	21.80	7.60	15.15	7.95	96.2
1.0	18.44	23.18	7.60	16.19	8.00	97.6
2.0	18.32	20.43	7.60	14.14	7.97	95.4
3.0	18.01	24.47	7.60	17.27	7.76	94.5
4.0	18.12	25.45	7.61	17.99	7.45	91.5
6.0	18.32	27.71	7.60	19.66	7.11	88.9
8.0	18.57	29.15	7.58	20.69	6.62	83.9
10.0	18.64	29.44	7.60	20.90	6.57	83.5
12.0	18.77	30.02	7.61	21.31	6.84	87.4
14.0	18.93	30.82	7.60	21.88	6.40	82.5
15.0	19.10	31.63	7.58	22.45	5.92	76.9
16.0	19.30	31.86	7.55	22.57	5.46	71.3
17.0	19.40	32.45	7.55	22.99	5.61	73.7
18.0	19.51	32.67	7.56	23.14	5.90	77.7
19.0	19.52	32.75	7.56	23.19	6.07	80.0

CRUISE DATA - TRANSECT C

[1000m]
Station: SH
Date: 03/19/91
Latitude: 29:07.22 N
Longitude: 89:41.81 W
Hydrolab cast time: 00:50
Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	17.40	23.33	7.67	16.54	8.40	100.4
1.0	17.40	23.46	7.69	16.64	8.41	100.6
2.0	17.41	23.46	7.68	16.64	8.41	100.6
3.0	17.41	23.53	7.67	16.69	8.41	100.7
4.0	17.41	23.33	7.67	16.54	8.40	100.4
6.0	17.66	26.12	7.62	18.60	7.47	91.3
8.0	18.00	27.55	7.63	19.61	7.31	90.7
10.0	18.23	28.70	7.62	20.43	7.24	90.8
12.0	18.17	28.76	7.62	20.49	7.23	90.6
14.0	18.15	29.05	7.63	20.71	7.37	92.5
15.0	18.33	29.70	7.63	21.17	7.36	93.1
16.0	18.59	30.58	7.63	21.77	7.29	93.2
17.0	18.77	31.02	7.62	22.07	7.16	92.1
18.0	18.85	30.96	7.61	22.00	7.14	91.9
19.0	19.18	31.92	7.58	22.65	6.47	84.3
20.0	19.20	32.07	7.57	22.76	6.51	84.9

Table A.2. Continued.

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 10:50
Date: 03/20/91 Longitude: 90:28.04 W Secchi disk depth (m): 5.3

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	18.71	26.54	7.60	18.68	8.06	100.8
1.0	18.70	26.68	7.59	18.79	8.06	100.9
2.0	18.70	26.54	7.61	18.68	8.08	101.0
3.0	18.68	26.68	7.60	18.79	8.06	100.8
4.0	18.52	26.67	7.61	18.82	8.02	100.0
5.0	18.53	26.88	7.60	18.98	8.01	100.0
6.0	18.55	27.02	7.60	19.08	7.97	99.7
7.0	18.55	27.09	7.62	19.14	7.93	99.2
8.0	18.61	27.45	7.62	19.39	7.89	99.0
9.0	18.85	29.45	7.61	20.86	7.68	98.0
10.0	19.05	30.26	7.62	21.42	7.35	94.6
11.0	19.26	31.86	7.60	22.58	6.70	87.4
12.0	19.60	32.68	7.53	23.12	5.31	70.1
13.0	19.90	33.65	7.57	23.78	5.91	78.9
14.0	20.28	34.63	7.45	24.43	3.75	50.7
15.0	20.38	35.08	7.40	24.74	2.69	36.6
16.0	20.38	34.93	7.40	24.63	2.60	35.3
17.0	20.38	34.93	7.40	24.63	2.55	34.6
18.0	20.38	34.71	7.39	24.46	2.55	34.6
19.0	20.37	34.79	7.39	24.52	2.55	34.6
20.0	20.37	34.93	7.39	24.63	2.80	38.0

Station: 6 Latitude: 28:51.44 N Hydrolab cast time: 12:50
Date: 03/20/91 Longitude: 90:27.68 W Secchi disk depth (m): 4.7

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	19.08	27.13	7.62	19.03	8.11	102.5
1.0	19.08	27.06	7.60	18.98	8.12	102.6
2.0	19.06	27.27	7.61	19.15	8.11	102.6
3.0	19.05	27.48	7.63	19.31	8.12	102.8
4.0	19.01	27.26	7.64	19.16	8.10	102.4
5.0	18.99	27.69	7.64	19.48	8.12	102.8
6.0	18.90	27.96	7.64	19.71	8.10	102.6
7.0	18.82	28.10	7.63	19.84	7.89	99.8
8.0	18.81	28.03	7.62	19.78	7.74	97.9
9.0	18.85	28.81	7.62	20.37	7.56	96.1
10.0	19.18	30.41	7.62	21.50	7.13	92.1
11.0	19.50	32.16	7.61	22.75	6.70	88.0
12.0	19.72	32.83	7.60	23.21	6.29	83.3
13.0	20.35	35.08	7.40	24.75	2.80	38.0
14.0	20.49	35.09	7.36	24.72	2.38	32.4
15.0	20.50	35.17	7.37	24.77	2.33	31.7
16.0	20.50	34.94	7.37	24.61	2.33	31.7
17.0	20.50	35.17	7.37	24.77	2.35	32.0
18.0	20.50	35.09	7.37	24.72	2.35	32.0
19.0	20.50	35.02	7.37	24.66	2.37	32.3
20.0	20.51	35.31	7.36	24.88	2.37	32.3
21.0	20.51	35.09	7.37	24.72	2.41	32.8
22.0	20.52	35.39	7.36	24.94	2.41	32.9
23.0	20.52	35.09	7.37	24.71	2.44	33.2
24.0	20.52	34.80	7.37	24.49	2.60	35.4

Table A.3. Hydrography, April 1991.

CRUISE DATA - TRANSECT C

Station: 6B   Latitude: 28:52.18 N   Hydrolab cast time: 11:15
Date: 04/16/91   Longitude: 90:28.04 W   Secchi disk depth (m): 3.8

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	23.01	21.92	8.22	14.09	7.80	103.3
1.0	23.02	25.49	#.##	16.78	7.54	101.9
2.0	23.03	25.28	#.##	16.61	7.47	100.9
3.0	23.05	28.55	#.##	19.07	7.24	99.7
4.0	23.01	31.74	#.##	21.49	7.10	99.5
5.0	22.99	32.54	#.##	22.10	7.11	100.0
6.0	22.94	32.47	#.##	22.06	7.09	99.6
7.0	22.88	32.83	#.##	22.35	7.12	100.1
8.0	22.73	33.19	#.##	22.66	7.24	101.7
9.0	22.62	33.18	#.##	22.69	7.27	102.0
10.0	22.60	34.06	#.##	23.36	7.13	100.5
11.0	22.64	34.43	#.##	23.63	6.97	98.5
12.0	22.63	34.51	#.##	23.69	6.82	96.4
13.0	22.46	35.09	#.##	24.18	6.55	92.6
14.0	22.46	34.64	#.##	23.84	6.57	92.6
15.0	22.25	34.34	#.##	23.66	6.20	86.9
16.0	22.25	34.19	#.##	23.55	6.17	86.4
17.0	22.25	34.78	#.##	24.00	6.26	88.0
18.0	22.22	34.70	#.##	23.95	6.26	87.9
19.0	22.17	35.07	8.13	24.24	6.18	86.9
20.0	22.15	35.36	8.14	24.47	6.44	90.7

CRUISE DATA - TRANSECT C

Station: 6   Latitude: 28:51.44 N   Hydrolab cast time: 13:10
Date: 04/16/91   Longitude: 90:27.68 W   Secchi disk depth (m): 3.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	22.42	27.24	#.##	18.26	7.82	105.6
1.0	22.46	31.42	#.##	21.40	7.70	106.6
2.0	22.47	31.56	#.##	21.51	7.68	106.4
3.0	22.48	31.56	#.##	21.50	7.67	106.3
4.0	22.53	31.79	#.##	21.66	7.58	105.3
5.0	22.65	32.01	#.##	21.79	7.43	103.6
6.0	22.70	32.31	#.##	22.00	7.39	103.3
7.0	22.75	32.53	#.##	22.16	7.30	102.2
8.0	22.88	32.76	#.##	22.29	7.18	100.9
9.0	22.92	32.91	#.##	22.39	7.16	100.8
10.0	22.91	32.98	#.##	22.45	7.14	100.6
11.0	22.88	33.12	#.##	22.57	7.14	100.6
12.0	22.81	33.49	#.##	22.86	7.12	100.4
13.0	22.73	34.15	#.##	23.38	6.98	98.6
14.0	22.58	34.87	#.##	23.98	6.88	97.4
15.0	22.45	35.01	#.##	24.12	6.82	96.4
16.0	22.52	35.17	#.##	24.22	6.93	98.1
17.0	22.52	35.17	#.##	24.22	6.97	98.7
18.0	22.50	35.02	#.##	24.11	6.91	97.7
19.0	22.20	35.37	8.16	24.46	6.75	95.1
20.0	22.18	35.14	8.15	24.30	6.81	95.8

Table A.3. Continued.

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 16:00
Date: 04/17/91 Longitude: 90:28.04 W Secchi disk depth (m): 6.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	22.91	20.46	##.#	13.03	8.13	106.5
1.0	22.85	20.94	##.#	13.40	8.07	105.9
2.0	22.83	25.27	##.#	16.66	7.89	106.1
3.0	22.33	29.46	##.#	19.95	7.45	101.7
4.0	22.23	31.11	##.#	21.23	7.39	101.6
5.0	22.19	31.84	##.#	21.79	7.36	101.6
6.0	22.15	32.20	##.#	22.08	7.34	101.4
7.0	22.11	32.56	##.#	22.36	7.30	101.0
8.0	22.10	32.56	##.#	22.37	7.28	100.7
9.0	22.08	32.64	##.#	22.42	7.26	100.5
10.0	22.06	33.07	##.#	22.76	7.13	98.9
11.0	22.05	32.93	##.#	22.65	7.06	97.8
12.0	22.05	33.22	##.#	22.88	7.04	97.7
13.0	22.10	33.59	##.#	23.14	7.04	98.0
14.0	22.32	33.75	##.#	23.20	6.99	97.8
15.0	22.39	34.57	##.#	23.80	6.58	92.6
16.0	22.33	35.01	##.#	24.15	6.14	86.5
17.0	22.30	35.00	##.#	24.16	6.02	84.8
18.0	22.28	35.08	##.#	24.22	5.94	83.7
19.0	22.27	34.93	##.#	24.11	5.82	81.9
20.0	22.27	34.85	##.#	24.05	5.74	80.7

CRUISE DATA - TRANSECT C

[1000m]
Station: 6=UA Latitude: 28:51.44 N Hydrolab cast time: 18:45
Date: 04/17/91 Longitude: 90:27.68 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	22.79	20.26	##.#	12.90	8.24	107.6
1.0	22.80	32.31	##.#	21.98	7.70	107.8
2.0	22.80	32.24	##.#	21.92	7.68	107.5
3.0	22.79	32.38	##.#	22.04	7.71	108.0
4.0	22.75	32.31	##.#	21.99	7.68	107.4
5.0	22.73	32.38	##.#	22.05	7.62	106.6
6.0	22.59	32.52	##.#	22.19	7.58	105.8
7.0	22.25	32.57	##.#	22.33	7.46	103.5
8.0	22.10	33.00	##.#	22.70	7.28	101.0
9.0	22.04	33.29	##.#	22.93	7.11	98.7
10.0	22.13	33.52	##.#	23.08	7.07	98.4
11.0	22.22	33.45	##.#	23.00	7.06	98.4
12.0	22.28	33.31	##.#	22.88	7.08	98.7
13.0	22.26	33.67	##.#	23.16	7.06	98.6
14.0	22.35	33.53	##.#	23.03	7.03	98.3
15.0	22.37	34.20	##.#	23.52	6.91	97.0
16.0	22.37	34.79	##.#	23.97	6.73	94.8
17.0	22.44	34.87	##.#	24.01	6.48	91.5
18.0	22.41	35.01	##.#	24.13	6.26	88.4
19.0	22.41	35.23	##.#	24.30	6.23	88.1

Table A.3. Continued.

CRUISE DATA - TRANSECT C

[500m]
Station: 6A=UB Latitude: 28:50.49 N Hydrolab cast time: 20:30
Date: 04/17/91 Longitude: 90:26.02 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	22.77	20.19	##.#	12.86	8.57	111.8
1.0	22.77	21.22	##.#	13.63	8.48	111.3
2.0	22.77	23.02	##.#	14.99	8.15	108.1
3.0	22.77	26.54	##.#	17.64	8.10	109.6
4.0	22.73	29.40	##.#	19.80	8.12	111.6
5.0	22.64	30.85	##.#	20.92	8.08	111.8
6.0	22.41	31.56	##.#	21.52	7.83	108.3
7.0	22.39	31.92	##.#	21.80	7.64	105.9
8.0	22.39	32.29	##.#	22.08	7.48	103.9
9.0	22.32	32.43	##.#	22.20	7.42	103.0
10.0	22.24	32.43	##.#	22.22	7.36	102.0
11.0	22.22	32.50	##.#	22.28	7.34	101.8
12.0	22.27	33.01	##.#	22.66	7.37	102.6
13.0	22.27	33.01	##.#	22.66	7.35	102.3
14.0	22.14	33.01	##.#	22.69	7.21	100.1
15.0	22.41	33.83	##.#	23.24	7.06	99.0
16.0	22.36	35.08	##.#	24.20	6.45	91.0
17.0	22.36	35.38	##.#	24.42	6.34	89.6
18.0	22.36	34.86	##.#	24.03	6.37	89.8
19.0	22.37	35.31	##.#	24.36	6.42	90.7

CRUISE DATA - TRANSECT C

[1000m]
Station: SH Latitude: 29:07.22 N Hydrolab cast time: 03:20
Date: 04/17/91 Longitude: 89:41.81 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	23.02	17.27	##.#	10.60	9.09	117.2
1.0	23.02	17.13	##.#	10.50	9.14	117.7
2.0	23.02	17.00	##.#	10.40	9.18	118.1
3.0	22.95	17.13	##.#	10.51	9.19	118.2
4.0	22.71	17.80	##.#	11.08	8.74	112.3
5.0	22.43	18.81	##.#	11.91	8.10	104.1
6.0	22.34	21.41	##.#	13.89	7.62	99.3
7.0	22.37	21.48	##.#	13.94	7.60	99.1
8.0	22.33	21.90	##.#	14.26	7.54	98.5
9.0	22.33	22.03	##.#	14.36	7.69	100.5
10.0	22.28	22.80	##.#	14.95	7.46	97.9
11.0	22.09	21.96	##.#	14.37	7.14	92.9
12.0	20.76	30.52	##.#	21.18	5.01	66.8
13.0	20.53	32.53	##.#	22.77	4.52	60.7
14.0	20.50	32.75	##.#	22.94	4.65	62.5
15.0	20.50	32.60	##.#	22.83	4.72	63.4
16.0	20.50	32.53	##.#	22.77	4.70	63.1
17.0	20.52	32.68	##.#	22.88	4.63	62.2
18.0	20.52	32.82	##.#	22.99	4.52	60.8
19.0	20.53	32.53	##.#	22.77	4.39	58.9

Table A.4. Hydrography, May 1991.

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 17:00
Date: 05/15/91 Longitude: 90:28.04 W Secchi disk depth (m): 2.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	25.41	15.83	8.52	8.86	8.98	120.1
1.0	25.41	15.89	8.53	8.91	8.96	119.9
2.0	25.41	15.83	8.53	8.86	8.97	119.9
3.0	25.41	15.89	8.53	8.91	8.98	120.1
4.0	25.38	16.03	8.51	9.02	8.88	118.8
5.0	25.29	16.23	8.49	9.20	8.73	116.7
6.0	23.96	19.39	8.21	11.94	5.98	79.4
7.0	23.86	22.91	8.05	14.61	4.91	66.4
8.0	23.89	27.15	8.08	17.78	5.17	71.7
9.0	24.01	28.95	8.11	19.10	5.71	80.2
10.0	24.32	30.20	8.15	19.95	6.23	88.6
11.0	24.73	31.09	8.15	20.50	6.38	91.9
12.0	24.62	31.81	8.14	21.08	6.30	91.0
13.0	25.00	31.98	8.13	21.08	6.27	91.3
14.0	25.40	33.32	8.13	21.97	6.21	91.8
15.0	25.05	34.19	8.11	22.74	6.04	89.1
16.0	23.94	34.36	8.06	23.20	4.96	71.8
17.0	23.49	34.49	7.98	23.42	3.86	55.4
18.0	23.45	34.56	7.97	23.49	3.77	54.1
18.5	23.45	34.56	7.96	23.49	3.80	54.6

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 11:20
Date: 05/16/91 Longitude: 90:28.04 W Secchi disk depth (m): 2.8

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	24.71	18.31	8.38	10.92	8.24	110.3
1.0	24.71	19.20	8.39	11.58	8.53	114.8
2.0	24.64	19.20	8.38	11.60	8.51	114.4
3.0	24.66	19.27	8.38	11.65	8.44	113.5
4.0	24.36	23.00	8.22	14.53	6.67	91.1
5.0	24.33	24.12	8.20	15.38	6.30	86.6
6.0	24.27	24.26	8.19	15.50	6.11	83.9
7.0	24.25	25.03	8.17	16.09	6.05	83.5
8.0	24.23	25.46	8.16	16.41	5.90	81.6
9.0	24.21	26.31	8.15	17.06	5.86	81.4
10.0	24.30	27.17	8.15	17.67	5.95	83.2
11.0	24.49	28.11	8.16	18.32	6.14	86.6
12.0	24.25	29.90	8.13	19.75	5.82	82.6
13.0	24.24	32.16	8.09	21.45	5.47	78.6
14.0	24.26	32.75	8.08	21.89	5.34	77.0
15.0	23.86	33.77	8.02	22.77	4.47	64.4
16.0	23.74	33.91	8.00	22.91	4.20	60.4
17.0	23.56	34.05	7.97	23.07	3.82	54.8
18.0	23.53	34.04	7.95	23.08	3.56	51.0
19.0	23.53	34.12	7.95	23.13	3.53	50.6
20.0	23.52	34.04	7.92	23.08	3.57	51.2

Table A.4. Continued.

CRUISE DATA - TRANSECT C

Station: 6 Latitude: 28:51.44 N Hydrolab cast time: 18:50
Date: 05/15/91 Longitude: 90:27.68 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	25.22	15.36	8.58	8.57	9.29	123.4
1.0	25.22	15.36	8.57	8.57	9.32	123.8
2.0	25.21	15.36	8.57	8.57	9.27	123.2
3.0	25.23	15.42	8.58	8.61	9.26	123.1
4.0	25.19	15.76	8.53	8.87	8.89	118.3
5.0	25.11	16.96	8.46	9.80	8.18	109.5
6.0	24.35	23.07	8.23	14.58	6.25	85.4
7.0	24.09	26.87	8.13	17.52	5.65	78.5
8.0	23.97	27.80	8.11	18.25	5.45	76.0
9.0	23.90	30.11	8.12	20.00	5.77	81.4
10.0	23.75	30.90	8.08	20.64	5.61	79.3
11.0	24.12	31.43	8.11	20.93	5.97	85.2
12.0	25.00	32.86	8.14	21.75	6.28	91.9
13.0	25.40	33.54	8.14	22.14	6.23	92.2
14.0	25.44	34.06	8.13	22.52	6.20	92.1
15.0	25.21	34.05	8.12	22.58	6.00	88.7
16.0	24.33	34.16	8.08	22.93	5.31	77.3
17.0	23.52	34.41	8.00	23.36	4.08	58.6
18.0	23.48	34.41	7.98	23.37	3.94	56.5

CRUISE DATA - TRANSECT C

[500m]
Station: 6=UA Latitude: 28:51.44 N Hydrolab cast time: 12:55
Date: 05/16/91 Longitude: 90:27.68 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	25.20	18.73	8.45	11.09	9.33	126.4
1.0	25.17	18.93	8.45	11.25	9.31	126.2
2.0	25.05	19.14	8.44	11.44	9.13	123.6
3.0	24.59	20.02	8.35	12.23	8.54	115.2
4.0	24.40	22.16	8.27	13.89	6.81	92.7
5.0	24.35	24.68	8.22	15.79	6.49	89.5
6.0	24.40	25.25	8.22	16.21	6.39	88.5
7.0	24.56	26.75	8.21	17.28	6.47	90.7
8.0	24.62	26.82	8.21	17.32	6.46	90.7
9.0	24.69	27.39	8.21	17.73	6.41	90.4
10.0	24.79	28.69	8.21	18.68	6.47	92.1
11.0	24.77	29.20	8.21	19.06	6.41	91.4
12.0	24.70	29.99	8.18	19.68	6.26	89.6
13.0	24.98	31.39	8.16	20.65	5.92	85.9
14.0	24.54	33.50	8.09	22.37	5.23	76.2
15.0	24.20	33.93	8.06	22.80	4.84	70.2
16.0	24.00	33.92	8.03	22.85	4.57	66.0
17.0	23.94	33.99	8.02	22.92	4.43	64.0
18.0	23.87	33.91	8.02	22.88	4.40	63.4
19.0	23.87	34.06	8.01	22.99	4.46	64.3

Table A.4. Continued.

CRUISE DATA - TRANSECT C

[500m]
Station: 6A=UB Latitude: 28:50.49 N Hydrolab cast time: 14:55
Date: 05/16/91 Longitude: 90:26.02 W Secchi disk depth (m): 2.2

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	25.10	19.68	8.43	11.84	9.03	122.7
1.0	24.90	19.68	8.43	11.89	8.90	120.5
2.0	24.85	20.23	8.40	12.32	8.55	116.0
3.0	24.58	19.95	8.38	12.18	8.15	109.9
4.0	24.47	21.61	8.38	13.45	7.97	108.2
5.0	24.37	22.37	8.29	14.05	6.90	93.9
6.0	24.33	25.18	8.20	16.17	6.28	86.8
7.0	24.34	24.40	8.21	15.59	6.19	85.2
8.0	24.47	27.46	8.20	17.84	6.33	88.9
9.0	24.87	28.33	8.23	18.39	6.56	93.3
10.0	25.08	30.59	8.20	20.02	6.41	92.7
11.0	25.13	31.47	8.19	20.66	6.38	92.8
12.0	25.09	33.08	8.13	21.89	6.00	88.0
13.0	24.84	33.37	8.11	22.18	5.71	83.5
14.0	24.72	33.66	8.10	22.44	5.33	77.9
15.0	24.38	34.01	8.08	22.80	4.93	71.8
16.0	24.20	33.93	8.05	22.80	4.75	68.9
17.0	24.08	34.07	8.04	22.94	4.61	66.8
18.0	24.02	34.22	8.03	23.07	4.50	65.2
19.0	24.01	34.00	8.03	22.90	4.70	68.0

CRUISE DATA - TRANSECT C

[1000m]
Station: SH Latitude: 29:07.22 N Hydrolab cast time: 23:00
Date: 05/16/91 Longitude: 89:41.81 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	25.86	13.70	8.59	7.15	8.81	117.4
1.0	25.88	13.70	8.60	7.14	8.82	117.5
2.0	25.92	13.84	8.61	7.23	8.86	118.2
3.0	25.76	14.03	8.59	7.42	8.74	116.4
4.0	25.42	14.69	8.54	8.01	8.51	113.1
5.0	25.22	15.02	8.51	8.32	8.23	109.2
6.0	24.99	15.49	8.48	8.73	7.60	100.6
7.0	24.83	16.22	8.40	9.32	7.09	94.0
8.0	24.49	18.92	8.23	11.44	5.99	80.1
9.0	24.20	20.98	8.05	13.06	4.64	62.5
10.0	23.51	27.07	7.97	17.83	3.57	49.1
11.0	23.27	29.28	7.96	19.56	3.67	50.9
12.0	23.14	30.65	7.97	20.63	4.05	56.5
13.0	23.68	32.28	8.04	21.71	5.13	73.0
14.0	23.98	33.26	8.04	22.35	4.72	67.9
15.0	24.17	33.63	8.03	22.58	4.70	68.0
16.0	24.23	34.01	8.03	22.84	4.70	68.2
17.0	24.23	34.01	8.03	22.84	4.71	68.4
18.0	24.25	34.16	8.03	22.95	4.72	68.6
19.0	24.25	34.08	8.03	22.89	4.77	69.3

Table A.4. Continued.

CRUISE DATA - TRANSECT C

[500m]
Station: 6A=UB Latitude: 28:50.49 N Hydrolab cast time: 06:00
Date: 05/17/91 Longitude: 90:26.02 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	24.97	27.19	8.24	17.50	6.88	97.4
1.0	24.97	27.26	8.24	17.55	6.87	97.3
2.0	24.98	27.19	8.25	17.49	6.89	97.5
3.0	25.04	27.40	8.25	17.64	7.04	99.9
4.0	25.03	27.55	8.25	17.75	7.01	99.5
6.0	24.55	28.18	8.18	18.36	6.13	86.6
8.0	24.48	29.33	8.17	19.25	6.12	86.9
10.0	24.31	29.76	8.15	19.62	5.90	83.7
12.0	24.27	30.27	8.13	20.01	5.65	80.4
14.0	24.25	33.27	8.09	22.28	5.03	72.8
16.0	23.71	34.13	8.01	23.09	3.92	56.4
18.0	23.63	34.27	7.99	23.22	3.68	52.9
19.0	23.62	34.20	7.98	23.17	3.62	52.0
19.5	23.60	34.20	7.97	23.17	3.57	51.3

Table A.5. Hydrography, June 1991.

CRUISE DATA - TRANSECT C

Station: 6B
Date: 06/17/91
Latitude: 28:52.18 N
Longitude: 90:28.04 W
Hydrolab cast time: 11:00
Secchi disk depth (m): 4.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.2	28.41	21.86	8.46	12.47	7.67	112.1
1.0	28.40	21.93	8.47	12.52	7.64	111.7
2.0	28.39	22.14	8.45	12.68	7.65	112.0
3.0	28.25	29.72	8.16	18.38	6.35	96.8
4.0	28.12	31.11	8.11	19.46	6.21	95.2
5.0	28.16	32.07	8.07	20.16	6.01	92.7
6.0	27.99	32.06	8.07	20.22	6.05	93.0
7.0	27.84	32.06	8.07	20.26	6.11	93.7
8.0	27.66	32.43	8.07	20.59	6.02	92.2
9.0	27.44	32.49	8.06	20.72	5.96	91.0
10.0	27.29	32.56	8.06	20.82	5.91	90.0
11.0	27.31	32.79	8.05	20.98	5.89	89.8
12.0	27.33	33.16	8.05	21.25	5.88	89.9
13.0	27.35	33.23	8.05	21.30	5.84	89.4
14.0	27.34	33.46	8.04	21.47	5.70	87.3
15.0	27.30	33.53	8.05	21.54	5.67	86.8
16.0	27.15	33.75	8.04	21.75	5.62	85.9
17.0	26.67	33.73	8.01	21.89	5.03	76.2
18.0	25.99	33.78	7.97	22.14	4.07	61.0
19.0	25.98	33.78	7.94	22.15	4.18	62.6

CRUISE DATA - TRANSECT C

Station: 6
Date: 06/17/91
Latitude: 28:51.44 N
Longitude: 90:27.68 W
Hydrolab cast time: 13:20
Secchi disk depth (m): 3.1

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	28.91	21.80	8.44	12.26	7.78	114.7
1.0	28.87	21.73	8.46	12.22	7.76	114.3
2.0	28.68	23.62	8.43	13.69	7.55	112.0
3.0	28.49	27.91	8.26	16.95	7.01	106.2
4.0	28.23	30.16	8.15	18.71	6.41	97.9
5.0	28.13	31.77	8.08	19.95	6.12	94.2
6.0	27.90	32.14	8.08	20.30	6.06	93.1
7.0	27.92	32.36	8.07	20.46	6.04	92.9
8.0	27.74	32.43	8.07	20.57	6.00	92.0
9.0	27.74	32.50	8.07	20.63	6.07	93.1
10.0	27.61	32.57	8.07	20.72	6.05	92.7
11.0	27.49	32.79	8.06	20.92	5.95	91.0
12.0	27.36	32.86	8.06	21.02	5.93	90.6
13.0	27.31	33.16	8.05	21.26	5.88	89.9
14.0	27.24	33.30	8.04	21.39	5.76	88.0
15.0	27.08	33.45	8.03	21.55	5.57	84.9
16.0	26.67	33.66	8.01	21.84	5.08	77.0
17.0	26.43	33.80	7.99	22.02	4.66	70.4
18.0	26.33	33.65	7.98	21.93	4.54	68.4
19.0	26.19	33.72	7.97	22.03	4.31	64.8
19.4	26.20	33.72	7.96	22.03	4.42	66.4

Table A.5. Continued.

CRUISE DATA - TRANSECT C

Station: 6A
Date: 06/20/91
Latitude: 28:50.49 N
Longitude: 90:26.02 W
Hydrolab cast time: 10:44
Secchi disk depth (m): 3.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.2	28.34	21.79	8.48	12.44	7.56	110.3
1.0	28.33	21.72	8.48	12.39	7.60	110.9
2.0	28.23	22.00	8.47	12.63	7.59	110.7
3.0	28.13	22.84	8.43	13.28	7.45	109.0
4.0	27.95	23.12	8.36	13.55	7.23	105.6
5.0	27.43	25.45	8.18	15.45	5.52	80.9
6.0	27.01	27.88	8.01	17.40	4.42	65.2
7.0	26.88	29.69	8.03	18.79	5.65	84.0
8.0	27.14	30.06	8.04	18.99	6.20	92.8
9.0	26.17	30.70	7.97	19.77	4.84	71.5
10.0	26.74	32.18	7.98	20.70	5.62	84.5
11.0	27.12	32.71	7.98	20.98	5.90	89.6
12.0	27.36	33.23	7.97	21.30	5.71	87.4
13.0	27.21	33.60	7.95	21.62	5.33	81.5
14.0	27.16	33.82	7.94	21.80	5.20	79.6
15.0	27.08	33.82	7.92	21.83	4.95	75.6
16.0	27.01	33.89	7.91	21.90	4.81	73.4
17.0	26.99	33.74	7.91	21.80	4.76	72.6
18.0	26.95	33.82	7.90	21.86	4.67	71.2

Table A.6. Hydrography, July 1991.

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 13:34
Date: 07/01/91 Longitude: 90:28.04 W Secchi disk depth (m): 2.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.2	32.05	20.59	8.37	10.31	6.70	103.7
1.0	31.70	20.72	8.38	10.53	6.57	101.1
2.0	30.70	20.77	8.39	10.91	6.74	102.0
3.0	30.13	20.97	8.38	11.25	6.74	101.1
4.0	30.00	20.97	8.38	11.29	6.65	99.5
5.0	29.66	22.29	8.33	12.38	6.59	98.7
6.0	29.35	22.92	8.27	12.95	6.32	94.5
7.0	29.22	24.41	8.21	14.10	6.09	91.6
8.0	27.67	29.71	7.76	18.56	1.51	22.8
9.0	26.84	32.40	7.64	20.84	1.38	20.8
10.0	26.65	33.29	7.66	21.56	1.80	27.2
11.0	26.62	33.29	7.65	21.57	1.65	24.9
12.0	26.53	33.21	7.60	21.54	1.15	17.3
13.0	26.47	33.50	7.58	21.78	0.98	14.8
14.0	26.42	33.58	7.56	21.85	0.85	12.8
15.0	26.48	33.88	7.56	22.06	0.87	13.2
16.0	26.29	34.24	7.48	22.39	0.13	2.0
17.0	26.26	34.69	7.48	22.74	0.12	1.8
18.0	26.26	34.76	7.48	22.79	0.12	1.8
19.0	26.27	34.69	7.48	22.73	0.14	2.1
20.0	26.28	34.76	7.48	22.79	0.16	2.4

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 10:14
Date: 07/09/91 Longitude: 90:28.04 W Secchi disk depth (m): 3.8

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.2	29.05	24.48	8.12	14.21	6.30	94.5
1.0	29.00	24.40	8.11	14.17	6.31	94.6
2.0	28.98	24.69	8.12	14.39	6.28	94.2
3.0	29.00	24.76	8.12	14.43	6.25	93.9
4.0	28.93	25.47	8.11	14.99	6.14	92.5
5.0	28.76	27.19	8.07	16.32	5.95	90.2
6.0	28.67	28.13	8.04	17.05	5.80	88.3
7.0	28.62	28.27	8.03	17.18	5.72	87.0
8.0	28.57	28.56	7.99	17.41	5.54	84.4
9.0	28.49	29.65	7.95	18.25	5.09	77.9
10.0	28.25	29.72	7.92	18.38	4.74	72.2
11.0	27.09	31.89	7.63	20.38	1.69	25.5
12.0	27.03	33.00	7.62	21.23	1.62	24.6
13.0	26.92	33.44	7.61	21.59	1.55	23.6
14.0	26.38	33.80	7.49	22.03	0.37	5.6
15.0	26.41	34.32	7.47	22.41	0.18	2.7
16.0	26.43	34.77	7.48	22.75	0.31	4.7
17.0	26.44	34.92	7.49	22.85	0.39	5.9
18.0	26.45	35.07	7.50	22.96	0.49	7.5
19.0	26.46	35.14	7.50	23.02	0.50	7.6
20.0	26.46	35.07	7.49	22.96	0.53	8.1
20.3	26.48	35.07	7.48	22.96	0.63	9.6

Table A.6. Continued.

SHELFWIDE 1991 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6 Latitude: 28:51.35 N CTD time: 13:05
Date: 07/17/91 Longitude: 90:27.53 W Secchi disk depth (m): 2.1
Estimated total depth (m): 18.5

HYDROGRAPHIC DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.024		21.11	0.30	30.79	3.76	88.9	11.09	
1.076	7.08	21.88	0.39	30.16	3.84	89.0	11.87	106.8
2.045	6.59	23.90	0.49	30.32	4.17	92.6	13.33	100.8
3.011	6.79	24.64	0.25	30.10	4.27	94.2	13.95	103.9
4.027	6.69	25.18	0.17	30.15	4.36	94.6	14.34	102.8
5.009	6.65	25.78	0.14	30.19	4.46	95.0	14.77	102.6
6.014	6.63	28.04	0.06	30.15	4.80	95.2	16.47	103.5
7.006	6.51	30.32	0.02	29.63	5.10	96.2	18.35	102.0
8.005	6.14	30.83	0.23	29.39	5.15	96.1	18.81	96.2
9.024	5.05	33.52	0.29	28.16	5.43	96.0	21.23	78.5
10.001	4.13	34.18	0.19	27.83	5.49	96.4	21.83	64.1
11.001	3.50	34.34	0.51	27.55	5.48	96.7	22.05	54.1
12.015	2.23	34.51	0.16	27.29	5.48	94.4	22.26	34.3
13.007	1.81	34.55	0.17	27.26	5.48	94.5	22.30	27.8
14.007	1.61	34.57	0.15	27.23	5.48	94.2	22.32	24.8
15.025	1.56	34.57	0.13	27.06	5.46	93.8	22.37	23.9
16.006	0.82	34.58	0.11	26.40	5.39	91.9	22.59	12.4
16.105	0.78	34.70	0.09	26.13	5.38	91.4	22.77	11.7
16.300	0.72	34.66	0.05	25.94	5.36	92.1	22.80	10.8
16.417	0.38	34.70	0.05	25.78	5.35	91.6	22.88	5.7
16.684	0.41	34.91	0.04	25.31	5.33	92.1	23.18	6.1
16.802	0.45	35.21	0.02	25.05	5.34	92.1	23.49	6.6
16.877	0.35*	34.86	0.01	25.24	5.31	92.2	23.16	5.2
16.979	0.44	35.10	0.02	24.76	5.30	92.5	23.50	6.6

CRUISE DATA - NURC 1991 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6B-1 Latitude: 28:52.11 N CTD time: 11:25
Date: 07/25/91 Longitude: 90:28.13 W Secchi disk depth (m): 2.8
Estimated total depth (m): 18.5

SEABIRD DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.399		21.99	0.82	30.41	3.88	90.4	11.87	
0.998		22.01	0.90	30.39	3.88	90.4	11.89	
1.017		22.01	0.87	30.39	3.88	90.4	11.90	
2.016		22.17	0.91	30.46	3.91	90.4	11.99	
3.042		23.00	0.86	30.71	4.06	92.3	12.52	
4.002		23.87	0.72	30.62	4.19	92.9	13.20	
5.064		28.42	0.71	30.89	4.93	94.2	16.50	
6.076		30.97	0.54	29.55	5.19	94.8	18.86	
7.062		31.83	0.32	28.54	5.22	95.3	19.84	
8.016		33.33	0.53	27.64	5.35	93.1	21.25	
9.032		33.85	0.16	27.64	5.42	95.4	21.65	
10.024		33.93	0.02	27.37	5.41	95.8	21.80	
11.032		34.19	-0.01	27.38	5.44	95.9	21.99	
12.024		34.41	-0.04	27.36	5.47	96.0	22.16	
13.005		34.51	-0.06	27.28	5.48	95.9	22.26	
14.023		34.56	-0.07	27.21	5.48	95.7	22.32	
15.043		34.61	-0.05	27.09	5.47	95.5	22.40	
16.023		34.81	-0.01	26.51	5.44	94.7	22.73	
17.076		34.91	0.02	26.17	5.42	94.0	22.91	
17.672		34.87	-0.01	26.12	5.41	94.2	22.90	

Table A.6. Continued.

NURC 1991 - TRANSECT C

Station: 6B-1 Hydrolab cast time: 12:55
Date: 07/25/91

HYDRO-LAB DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Temp. (deg. C)	Conduct. (mmho/cm)	Sigma-t	pH	Percent Oxygen Saturation
0.2	6.22	22.10	31.16	39.49	11.74	8.19	95.6
1.0	6.24	22.03	31.13	39.35	11.70	8.19	95.8
2.5	6.35	22.17	30.64	39.22	11.96	8.19	96.7
4.1	6.22	22.37	30.49	39.45	12.17	8.17	94.6
4.9	6.02	23.57	30.60	41.42	13.02	8.12	92.4
6.0	5.44	29.11	30.77	50.18	17.08	7.99	86.4
6.8	5.22	30.05	30.19	51.08	17.98	7.96	82.5
8.0	1.90	32.44	28.22	52.71	20.42	7.67	29.4
8.7	2.24	33.69	27.72	53.99	21.52	7.62	34.6
9.7	3.06	33.99	27.69	54.38	21.76	7.72	47.3
10.9	2.25	34.28	27.42	54.51	22.06	7.66	34.7
11.7	1.83	34.42	27.33	54.63	22.20	7.64	28.2
13.0	1.77	34.57	27.29	54.79	22.32	7.64	27.3
13.9	1.63	34.65	27.25	54.85	22.39	7.62	25.1
14.5	1.48	34.64	27.20	54.80	22.41	7.60	22.8
16.1	0.73	34.86	26.80	54.67	22.69	7.53	11.2
17.1	0.16	34.98	26.21	54.23	22.98	7.45	2.4
18.1	0.17	34.91	26.20	54.12	22.92	7.44	2.6
19.1	0.20	34.91	26.19	54.11	22.93	7.44	3.0
19.5	0.26	35.05	25.94	54.04	23.11	7.43	3.9

CRUISE DATA - NURC 1991 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6B-2 Latitude: 28:52.11 N CTD time: 16:10
Date: 07/25/91 Longitude: 90:28.13 W Secchi disk depth (m): #.#
Estimated total depth (m): 18.5

SEABIRD DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.113		21.80	0.40	31.81	3.95	88.4	11.26	
0.968		21.91	0.46	31.49	3.94	88.5	11.45	
1.010		21.94	0.46	31.40	3.94	88.4	11.51	
1.945		22.05	0.61	30.69	3.91	88.4	11.83	
2.014		22.02	0.61	30.72	3.90	88.4	11.79	
3.002		22.09	0.69	30.46	3.90	88.2	11.93	
4.003		22.13	0.82	30.49	3.91	88.6	11.95	
5.009		23.17	0.65	30.66	4.08	89.8	12.67	
6.006		29.16	0.32	30.82	5.03	92.8	17.08	
7.021		30.53	0.43	29.71	5.14	93.0	18.48	
8.026		32.74	0.39	28.66	5.36	93.7	20.48	
9.001		33.62	0.04	28.06	5.43	94.4	21.34	
10.028		34.17	-0.03	27.49	5.45	94.7	21.94	
11.021		34.27	-0.13	27.36	5.45	94.8	22.05	
12.002		34.34	-0.13	27.31	5.46	94.8	22.12	
13.002		34.38	-0.15	27.31	5.46	94.8	22.16	
14.056		34.46	-0.15	27.25	5.47	94.7	22.23	
15.014		34.58	-0.16	27.10	5.47	94.3	22.37	
16.043		34.81	-0.14	26.54	5.44	93.0	22.72	
17.065		34.87	-0.11	26.30	5.43	92.7	22.84	
17.607		34.87	-0.13	26.28	5.42	92.7	22.85	

Table A.6. Continued.

CRUISE DATA - NURC 1991 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6B-3 Latitude: 28:52.11 N CTD time: 19:50
Date: 07/25/91 Longitude: 90:28.13 W Secchi disk depth (m): #.#
Estimated total depth (m): 18.5

SEABIRD DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.260	4.80	21.52	0.64	31.15	3.85	85.5	11.28	73.5
0.908	4.39	21.66	0.66	31.07	3.87	85.6	11.41	67.2
1.034	3.91	21.65	0.65	31.09	3.87	85.7	11.39	59.8
1.962	5.08	21.91	0.86	30.67	3.88	86.0	11.73	77.4
2.004	5.10	21.95	0.87	30.59	3.88	86.1	11.78	77.5
3.011	5.02	22.26	1.03	30.70	3.94	87.0	11.98	76.7
4.018	5.04	22.90	0.75	30.69	4.04	88.0	12.46	77.2
5.023	5.04	23.57	0.76	30.69	4.15	88.7	12.96	77.5
6.027	4.83	26.82	0.63	30.89	4.68	89.3	15.31	75.9
7.012	4.68	28.82	0.47	30.76	4.98	90.1	16.84	74.1
8.005	3.27	29.86	0.82	29.27	5.00	90.1	18.12	50.8
9.039	3.59	32.73	0.98	28.61	5.36	91.1	20.49	56.0
10.010	3.37	33.58	0.19	27.97	5.42	92.2	21.34	52.2
11.013	3.19	33.84	0.08	27.80	5.44	92.4	21.59	49.4
12.015	2.93	34.10	-0.01	27.64	5.46	92.4	21.84	45.3
13.007	2.50	34.24	-0.09	27.36	5.45	92.6	22.03	38.4
14.003	2.17	34.37	-0.13	27.32	5.46	92.7	22.14	33.4
15.003	1.80	34.56	-0.12	27.18	5.47	92.0	22.33	27.6
16.002	1.23	34.84	-0.07	26.45	5.44	91.3	22.77	18.6
17.022	0.92	34.88	-0.10	26.41	5.44	90.7	22.81	13.9
17.133	0.92	34.88	-0.10	26.42	5.44	90.4	22.82	14.0
17.206	0.91	34.89	-0.09	26.42	5.44	90.5	22.82	13.8
17.301	0.88	34.89	-0.10	26.42	5.44	90.6	22.82	13.4
17.419	0.84	34.89	-0.11	26.42	5.44	90.6	22.82	12.8
17.500	0.86	34.89	-0.11	26.44	5.44	90.6	22.82	13.0
17.656	0.68*	34.91	-0.09	26.44	5.45	90.6	22.83	10.3
17.682	0.70	34.92	-0.09	26.44	5.45	90.5	22.83	10.6

Table A.6. Continued.

Station: 6A-1 Latitude: 28:50.48 N CTD time: 10:40
Date: 07/26/91 Longitude: 90:25.99 W Secchi disk depth (m): #.#
Estimated total depth (m): 18.5

SEABIRD DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
1.083	6.62	21.70	0.47	30.67	3.85	87.9	11.57	100.6
2.043	6.58	21.69	0.43	30.64	3.85	87.7	11.58	100.0
3.007	6.43	22.25	0.63	30.86	3.95	88.5	11.92	98.4
4.002	6.15	24.69	0.44	30.80	4.33	90.0	13.75	95.3
5.012	5.92	25.61	0.42	30.69	4.47	91.0	14.48	92.0
6.036	5.06	29.82	0.34	30.36	5.09	91.9	17.73	80.1
7.017	4.17	30.44	0.35	29.86	5.14	92.2	18.36	65.7
8.007	1.15	32.16	0.80	28.41	5.26	89.8	20.13	17.8
9.023	4.90	33.89	0.04	29.14	5.58	92.9	21.18	77.6
10.010	5.22	34.16	-0.08	28.91	5.60	93.1	21.47	82.5
11.008	5.28	34.41	-0.13	28.86	5.63	93.1	21.67	83.6
12.034	5.16	34.62	-0.07	28.47	5.62	93.1	21.96	81.2
13.055	3.82	34.81	-0.13	27.58	5.55	92.9	22.39	59.2
14.002	2.93	34.92	-0.11	27.37	5.54	92.6	22.54	45.3
15.000	2.27	34.97	-0.11	27.24	5.54	92.1	22.62	35.0
16.019	1.64	34.99	-0.08	27.03	5.52	91.3	22.70	25.1
17.000	1.26	34.99	-0.07	26.95	5.51	90.8	22.73	19.4
17.104	1.26	34.99	-0.05	26.93	5.51	90.8	22.73	19.4
17.203	1.21	34.98	-0.05	26.93	5.51	90.8	22.73	18.6
17.310	1.19	34.97	-0.04	26.94	5.51	90.8	22.72	18.3
17.401	1.20	34.97	-0.04	26.91	5.50	90.7	22.73	18.3
17.504	1.12	34.98	-0.05	26.91	5.51	90.7	22.73	17.1
17.611	1.04	34.97	-0.05	26.91	5.50	90.7	22.73	15.9
17.760	1.04	34.96	-0.06	26.88	5.50	90.7	22.73	15.9
17.817	1.00	34.96	-0.06	26.90	5.50	90.6	22.72	15.3
17.917	0.90	34.97	-0.05	26.87	5.50	90.5	22.74	13.8
18.003	0.57*	34.95	0.01	26.88	5.50	90.6	22.72	8.8
18.042	0.64	34.96	-0.02	26.87	5.50	90.5	22.73	9.9

HYDRO-LAB DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Temp. (deg. C)	Conduct. (mmho/cm)	Sigma-t	pH	Percent Oxygen Saturation
0.3	6.40	21.70	31.83	39.29	11.21	8.21	99.3
1.0	6.47	21.70	31.82	39.28	11.22	8.21	100.4
2.0	6.45	21.76	31.69	39.31	11.31	8.21	99.9
3.2	6.46	21.76	31.43	39.12	11.39	8.21	99.6
4.1	6.56	21.75	30.93	38.76	11.56	8.22	100.2
5.0	6.45	21.89	30.70	38.82	11.74	8.21	98.2
5.9	6.03	24.36	30.82	42.83	13.53	8.11	93.3
7.1	5.39	28.30	30.42	48.63	16.60	7.98	84.7
8.1	5.24	34.57	29.80	57.41	21.49	7.92	84.4
9.1	5.93	31.94	29.25	53.01	19.71	7.86	93.2
9.9	5.37	33.28	29.24	54.96	20.72	7.86	85.0
11.3	5.32	34.24	28.88	55.98	21.56	7.84	84.1
12.1	5.18	34.46	28.67	56.08	21.79	7.83	81.7
13.0	3.15	34.81	27.76	55.62	22.35	7.71	49.0
14.0	2.28	34.88	27.43	55.36	22.51	7.64	35.3
15.0	1.87	34.95	27.31	55.34	22.60	7.61	28.9
16.0	1.60	34.79	27.23	55.04	22.51	7.59	24.6
17.0	1.52	34.94	27.20	55.22	22.63	7.58	23.4
17.9	1.35	34.94	27.14	55.15	22.65	7.57	20.8
19.0	0.52	35.00	26.78	54.86	22.81	7.51	8.0
19.5	0.28	34.85	26.52	54.37	22.78	7.46	4.3

Table A.6. Continued.

CRUISE DATA - NURC 1991 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6A-2 Latitude: 28:50.53 N CTD time: 08:00
Date: 07/27/91 Longitude: 90:26.02 W Secchi disk depth (m): #.#
Estimated total depth (m): 18.5

SEABIRD DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.239		21.82	0.32	31.10	3.90	88.5	11.52	
0.991	6.31	21.97	0.34	31.12	3.92	88.5	11.62	96.9
1.010	6.33	21.96	0.33	31.11	3.92	88.7	11.62	97.0
2.016	6.38	21.87	0.28	31.08	3.91	88.6	11.56	97.9
3.029	6.32	22.05	0.34	31.08	3.94	88.8	11.70	96.9
4.043	6.16	24.86	0.36	30.92	4.37	90.2	13.85	95.7
5.022	6.05	25.45	0.28	30.88	4.46	90.9	14.30	94.3
6.011	5.47	30.14	0.16	29.94	5.10	91.8	18.11	86.1
7.007	5.46	31.28	0.05	29.48	5.23	92.3	19.12	85.9
8.029	5.06	32.39	-0.02	29.04	5.35	92.7	20.10	79.4
9.055	5.43	33.85	-0.03	29.14	5.58	92.9	21.16	86.0
10.024	5.46	34.19	-0.09	28.98	5.61	93.0	21.47	86.5
11.029	5.47	34.30	-0.09	28.94	5.62	92.9	21.56	86.6
12.017	5.44	34.42	-0.08	28.77	5.62	92.9	21.71	86.0
13.010	4.02	34.80	-0.11	27.59	5.55	92.9	22.38	62.3
14.044	1.93	34.99	-0.09	26.83	5.50	91.8	22.76	29.6
15.008	1.56	34.97	-0.09	26.76	5.49	91.7	22.77	23.9
16.018	1.47	34.97	-0.09	26.75	5.49	91.7	22.78	22.4
17.000	1.42	34.98	-0.07	26.68	5.48	91.7	22.81	21.6
17.221	1.40	34.98	-0.09	26.64	5.48	91.7	22.82	21.3
17.339	1.36	34.98	-0.09	26.58	5.47	91.7	22.84	20.7
17.430	1.17*	34.99	-0.08	26.53	5.47	91.6	22.86	17.7
17.510	1.19	34.97	-0.09	26.49	5.46	91.6	22.86	18.1
17.567	1.21	34.96	-0.09	26.45	5.45	91.7	22.86	18.5

HYDRO-LAB DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Temp. (deg. C)	Conduct. (mmho/cm)	Sigma-t	pH	Percent Oxygen Saturation
0.3	6.24	21.69	31.51	39.06	11.32	8.21	96.3
1.0	6.22	21.62	31.50	38.94	11.27	8.21	95.9
2.0	6.22	21.62	31.44	38.90	11.29	8.21	95.8
3.0	6.22	21.62	31.46	38.91	11.28	8.21	95.8
4.0	6.14	22.38	31.02	39.84	12.00	8.19	94.3
5.0	6.02	24.78	30.83	43.51	13.84	8.14	93.4
5.9	5.56	28.67	30.66	49.41	16.79	8.05	87.9
7.0	3.71	30.84	29.43	51.55	18.83	7.88	58.1
7.9	3.71	31.57	28.94	52.15	19.53	7.88	57.8
9.1	3.19	33.33	28.19	53.96	21.10	7.74	49.6
10.0	5.10	34.17	28.88	55.87	21.50	7.91	80.6
11.0	4.96	34.54	28.70	56.22	21.84	7.89	78.3
11.9	4.85	34.61	28.55	56.16	21.94	7.88	76.4
13.0	4.48	34.68	28.32	56.02	22.07	7.86	70.3
14.1	2.19	34.65	27.42	55.04	22.34	7.72	33.8
15.0	1.65	34.94	27.17	55.18	22.64	7.66	25.4
15.6	0.97	34.94	27.07	55.07	22.67	7.63	14.9
16.0	0.71	34.93	26.92	54.91	22.71	7.59	10.9
16.9	0.38	34.93	26.70	54.67	22.78	7.55	5.8
17.9	0.13	34.77	26.57	54.32	22.70	7.53	2.0
19.0	0.09	34.89	25.78	53.66	23.04	7.52	1.4
19.6	0.18	35.10	25.38	53.52	23.32	7.50	2.7

Table A.6. Continued.

CRUISE DATA - NURC 1991 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6B-4 Latitude: 28:52.18 N CTD time: 16:20
Date: 07/27/91 Longitude: 90:28.04 W Secchi disk depth (m): #.#
Estimated total depth (m): 18.5

SEABIRD DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.058	6.84	21.46	0.15	31.57	3.87	89.1	11.09	105.4
1.015	6.85	21.46	0.15	31.58	3.87	89.2	11.09	105.7
2.009	6.80	21.46	0.15	31.58	3.87	89.3	11.09	104.9
3.013	6.74	21.45	0.15	31.58	3.87	89.3	11.08	104.0
4.018	6.68	24.50	0.48	30.98	4.32	89.8	13.55	103.7
5.006	6.19	27.01	0.42	30.83	4.70	90.6	15.48	97.2
6.009	5.60	29.13	0.37	30.39	4.99	90.9	17.20	88.3
7.018	4.47	29.68	0.58	29.86	5.03	90.1	17.79	70.0
8.024	1.80	31.32	0.50	28.94	5.18	91.9	19.33	28.0
9.017	3.26	33.92	0.30	28.74	5.54	91.2	21.34	51.3
10.019	5.04	34.60	-0.12	28.59	5.63	93.5	21.90	79.4
11.001	4.99	34.69	-0.11	28.37	5.62	93.5	22.04	78.4
12.006	4.45	34.72	-0.16	27.97	5.58	93.5	22.20	69.4
13.033	2.66	34.88	-0.13	27.34	5.54	92.8	22.52	41.0
14.035	1.78	34.91	-0.08	27.03	5.51	92.5	22.64	27.3
15.017	1.08	34.89	-0.09	26.87	5.49	92.1	22.68	16.5
16.036	0.67	34.89	-0.09	26.49	5.45	91.8	22.80	10.1
17.010	0.23	34.86	-0.14	26.22	5.42	90.8	22.87	3.5
17.103	0.18	34.94	-0.14	26.19	5.42	91.0	22.93	2.7
17.206	0.20	34.86	-0.14	26.20	5.41	91.1	22.86	3.0
17.305	0.17	34.93	-0.14	26.16	5.42	91.1	22.93	2.5
17.501	0.15	34.95	-0.15	26.07	5.41	91.1	22.98	2.2
17.547	0.14*	34.87	-0.16	26.04	5.40	91.1	22.93	2.0

Table A.6. Continued.

CRUISE DATA - NURC 1991 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6B-5
Date: 07/31/91
Latitude: 28:52.18 N
Longitude: 90:28.04 W
CTD time: 00:01
Secchi disk depth (m): #.#
Estimated total depth (m): 18.5

SEABIRD DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.000	6.14	21.89	0.11	31.07	3.91	90.6	11.58	94.1
1.111	6.16	21.89	0.11	31.07	3.91	90.6	11.58	94.4
2.045	6.11	21.89	0.07	31.08	3.91	90.6	11.58	93.7
3.036	6.05	21.90	0.09	31.07	3.91	90.6	11.59	92.7
4.044	6.13	22.15	0.14	30.57	3.91	90.6	11.94	93.3
5.010	5.73	27.45	0.12	30.57	4.75	91.8	15.89	89.9
6.037	5.09	29.63	0.05	30.01	5.03	92.4	17.70	80.1
7.010	4.89	30.30	0.21	29.80	5.11	92.2	18.28	76.9
8.024	5.17	32.98	0.06	29.30	5.46	92.5	20.46	81.7
9.089	3.73	34.18	0.16	28.53	5.56	92.6	21.61	58.5
10.009	4.12	34.70	0.23	28.03	5.58	92.5	22.16	64.4
11.044	3.63	35.02	0.24	27.15	5.54	92.5	22.68	56.0
12.056	2.12	34.96	0.19	26.63	5.47	92.6	22.81	32.3
13.025	1.51	34.99	0.13	26.41	5.45	92.3	22.90	22.9
14.035	1.36	35.08	0.13	26.35	5.46	92.5	22.99	20.7
15.022	1.62	35.17	0.10	26.44	5.48	92.5	23.03	24.7
16.026	1.94	35.27	0.09	26.45	5.50	92.6	23.09	29.5
17.105	2.08	35.23	0.03	25.87	5.43	92.5	23.25	31.3
17.516	1.16	35.21	0.06	25.74	5.41	92.0	23.28	17.4
17.794	0.52*	35.37	0.09	25.73	5.43	91.8	23.40	7.8
17.802	0.53	35.37	0.09	25.73	5.43	91.8	23.40	8.0
17.915	0.54	35.36	0.09	25.73	5.43	91.8	23.39	8.1

HYDRO-LAB DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Temp. (deg. C)	Conduct. (mmho/cm)	Sigma-t	pH	Percent Oxygen Saturation
0.3	6.47	22.05	31.92	39.93	11.44	8.21	100.7
1.0	6.40	22.03	31.02	39.27	11.74	8.21	98.1
2.0	6.40	22.03	31.02	39.27	11.74	8.21	98.1
3.0	6.39	22.03	31.02	39.27	11.74	8.21	97.9
4.0	6.40	22.03	30.93	39.21	11.76	8.21	97.9
4.9	6.80	21.67	30.54	38.37	11.63	8.21	103.1
5.9	5.49	22.16	30.58	39.18	11.98	8.02	83.5
7.0	5.13	27.13	29.73	46.24	15.96	7.99	79.1
8.0	5.07	29.82	29.65	50.23	17.99	7.98	79.3
8.9	5.38	30.76	29.23	51.25	18.84	7.98	83.9
10.0	4.60	32.74	28.53	53.46	20.55	7.89	71.7
11.0	4.53	33.93	28.31	54.94	21.51	7.87	70.8
12.0	3.51	34.35	27.51	54.72	22.09	7.81	54.2
13.0	1.95	35.08	26.79	54.97	22.87	7.71	29.8
14.0	1.24	35.22	26.44	54.79	23.08	7.60	18.9
15.0	1.29	35.21	26.35	54.69	23.11	7.66	19.6
16.0	1.64	35.44	26.42	55.08	23.25	7.68	25.0
17.0	2.09	35.44	26.49	55.16	23.23	7.71	31.9
17.7	2.12	35.52	26.45	55.22	23.30	7.71	32.3
17.9	1.36	35.35	26.05	54.57	23.30	7.66	20.6
18.0	0.93	35.66	26.17	55.11	23.50	7.67	14.1
19.3	0.85	35.19	25.82	54.11	23.26	7.65	12.8

Table A.7. Hydrography, August 1991.

CRUISE DATA - TRANSECT C

Station: 6B
Date: 08/13/91
Latitude: 28:54.88 N
Longitude: 90:29.35 W
Hydrolab cast time: 11:13
Secchi disk depth (m): 3.4

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	29.98	25.77	7.97	14.86	5.80	89.1
1.0	29.98	25.77	7.97	14.86	5.81	89.3
2.0	29.98	25.84	7.97	14.92	5.84	89.8
2.9	29.98	25.70	7.97	14.81	5.76	88.5
4.5	29.96	25.77	7.96	14.87	5.75	88.3
5.0	29.96	25.77	7.96	14.87	5.72	87.9
6.0	30.01	26.78	7.92	15.60	5.39	83.4
7.0	30.02	27.57	7.87	16.19	4.95	76.9
7.9	29.79	30.56	7.73	18.49	3.35	52.7
9.1	28.46	33.93	7.66	21.46	2.84	44.5
10.0	27.89	34.44	7.63	22.03	2.42	37.6
11.0	27.77	34.51	7.59	22.12	1.93	30.0
12.2	26.91	34.93	7.54	22.72	1.36	20.8
13.2	26.57	35.00	7.48	22.87	0.62	9.4
13.9	26.25	35.06	7.44	23.02	0.22	3.3
14.7	26.10	35.13	7.42	23.12	0.10	1.5
15.9	26.20	35.13	7.42	23.09	0.12	1.8
17.0	25.94	35.20	7.42	23.22	0.12	1.8
18.0	25.72	35.19	7.41	23.28	0.15	2.3
19.0	25.72	35.04	7.41	23.17	0.17	2.6
19.5	25.72	35.11	7.41	23.23	0.22	3.3

Station: 6
Date: 08/13/91
Latitude: 28:51.44 N
Longitude: 90:27.68 W
Hydrolab cast time: 14:50
Secchi disk depth (m): 3.5

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.2	30.08	25.70	8.04	14.78	5.83	89.7
1.0	30.08	25.70	8.03	14.78	5.82	89.6
1.9	30.08	25.70	8.04	14.78	5.83	89.7
3.0	30.07	25.70	8.03	14.78	5.79	89.1
4.0	30.07	25.84	8.03	14.89	5.77	88.9
5.0	30.06	25.70	8.03	14.78	5.74	88.3
6.0	30.02	26.34	8.01	15.28	5.38	83.0
7.0	29.81	29.68	7.88	17.83	4.01	62.8
7.9	29.09	32.83	7.77	20.43	3.25	51.2
9.0	28.50	34.08	7.77	21.56	3.31	51.9
10.0	28.19	34.52	7.75	22.00	2.99	46.8
11.0	27.72	34.73	7.70	22.31	2.28	35.4
12.0	26.95	35.16	7.61	22.87	1.13	17.4
13.0	26.59	35.22	7.53	23.04	0.23	3.5
14.1	26.54	35.22	7.52	23.05	0.17	2.6
14.9	26.53	35.29	7.52	23.11	0.18	2.7
16.0	26.46	35.29	7.52	23.13	0.21	3.2
17.0	26.33	35.29	7.52	23.17	0.20	3.0
17.7	25.83	35.34	7.50	23.37	0.15	2.3
19.0	25.82	35.12	7.50	23.20	0.19	2.9
19.4	25.83	35.12	7.51	23.20	0.23	3.5

Table A.7. Continued.

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 11:43
Date: 08/19/91 Longitude: 90:28.04 W Secchi disk depth (m): 2.7

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	28.71	24.90	8.03	14.63	6.60	98.7
1.0	28.71	24.90	8.05	14.63	6.57	98.2
2.0	27.71	24.96	8.05	14.99	6.53	95.9
3.0	28.72	25.11	8.04	14.79	6.44	96.4
4.0	28.75	25.83	8.02	15.31	6.24	93.9
5.0	28.80	26.83	8.01	16.04	6.01	91.0
6.0	29.00	27.84	7.94	16.73	5.24	80.1
7.0	29.00	29.08	7.88	17.65	4.27	65.7
8.0	27.68	34.88	7.67	22.43	2.26	35.1
9.0	27.09	35.09	7.60	22.78	1.27	19.5
10.0	26.30	35.21	7.55	23.12	0.81	12.3
11.0	26.21	35.21	7.53	23.15	0.66	10.0
12.0	26.17	35.66	7.55	23.50	0.92	14.0
13.0	25.90	35.50	7.52	23.46	0.59	8.9
14.0	25.48	35.40	7.48	23.52	0.24	3.6
15.0	25.39	35.40	7.47	23.54	0.13	1.9
16.0	25.38	35.40	7.47	23.55	0.15	2.2
17.0	25.38	35.40	7.47	23.55	0.18	2.7
18.0	25.37	35.40	7.47	23.55	0.20	3.0
19.0	25.38	35.40	7.46	23.55	0.26	3.9
20.0	25.41	35.25	7.46	23.43	0.44	6.6

Table A.8. Hydrography, September 1991.

CRUISE DATA - TRANSECT C

Station: 6B   Latitude: 28:52.18 N   Hydrolab cast time: 11:30
Date: 09/12/91   Longitude: 90:28.04 W   Secchi disk depth (m): 6.5

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	28.61	30.97	7.78	19.20	6.29	97.2
1.0	28.54	30.97	7.79	19.22	6.28	96.9
2.0	28.51	31.04	7.79	19.28	6.26	96.6
3.0	28.50	31.12	7.79	19.34	6.26	96.6
4.0	28.52	31.19	7.78	19.39	6.21	95.9
5.0	28.67	31.49	7.77	19.56	6.14	95.2
6.0	28.75	32.01	7.75	19.93	6.04	94.1
7.0	28.72	32.08	7.74	19.99	5.80	90.3
8.0	28.73	32.15	7.74	20.04	5.64	87.9
9.0	28.77	32.45	7.71	20.25	5.21	81.4
10.0	28.78	32.53	7.71	20.30	5.48	85.7
11.0	28.78	32.60	7.72	20.36	5.82	91.0
12.0	28.82	32.75	7.71	20.46	5.84	91.5
13.0	28.84	32.75	7.69	20.45	5.09	79.8
14.0	28.84	32.82	7.69	20.51	5.04	79.0
15.0	28.84	32.82	7.68	20.51	5.04	79.0
16.0	28.84	32.82	7.68	20.51	5.04	79.0
17.0	28.84	32.82	7.68	20.51	5.07	79.5
18.0	28.84	32.75	7.68	20.45	5.06	79.3
19.0	28.83	32.82	7.67	20.51	5.07	79.5
20.1	28.83	32.82	7.65	20.51	5.04	79.0

Station: 6B   Latitude: 28:52.18 N   Hydrolab cast time: 12:45
Date: 09/17/91   Longitude: 90:28.04 W   Secchi disk depth (m): 6.5

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	29.40	28.50	8.31	17.09	6.33	97.8
1.0	29.39	28.94	8.31	17.42	6.33	98.0
2.0	29.31	28.65	8.31	17.23	6.29	97.1
3.0	29.40	28.94	8.30	17.42	6.24	96.6
4.0	29.18	29.96	8.28	18.25	6.14	95.3
5.0	29.17	30.84	8.25	18.91	6.02	93.9
6.0	29.20	30.98	8.24	19.01	5.91	92.3
7.0	29.18	31.28	8.23	19.24	5.83	91.1
8.0	29.14	31.94	8.21	19.75	5.45	85.5
9.0	29.12	32.09	8.19	19.86	5.34	83.8
10.0	29.14	32.46	8.18	20.14	5.27	82.9
11.0	29.24	32.76	8.18	20.33	5.56	87.7
12.0	29.23	32.76	8.17	20.33	5.35	84.4
13.0	29.22	32.76	8.18	20.33	5.40	85.2
14.0	29.22	32.83	8.17	20.39	5.39	85.1
15.0	29.22	32.83	8.16	20.39	5.07	80.0
16.0	29.21	32.76	8.16	20.34	4.86	76.7
17.0	29.13	32.83	8.06	20.42	2.78	43.8
18.0	29.12	32.83	8.06	20.42	2.34	36.9
19.0	29.12	32.83	8.05	20.42	2.25	35.4
19.5	29.13	32.83	8.04	20.42	2.25	35.5

Table A.8. Continued.

CRUISE DATA - TRANSECT C

Station: 6 Latitude: 28:51.44 N Hydrolab cast time: 14:49
Date: 09/17/91 Longitude: 90:27.68 W Secchi disk depth (m): 6.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	29.75	27.42	8.35	16.17	6.70	103.5
1.0	29.76	27.78	8.34	16.43	6.66	103.1
2.0	29.62	28.14	8.35	16.75	6.49	100.5
3.0	29.58	28.80	8.34	17.25	6.41	99.5
4.0	29.34	30.03	8.29	18.25	6.07	94.5
5.0	29.28	30.99	8.25	18.99	5.82	91.0
6.0	29.17	31.43	8.25	19.35	5.62	87.9
7.0	29.16	31.87	8.20	19.69	5.62	88.1
8.0	29.14	32.09	8.23	19.86	5.40	84.8
9.0	29.13	32.61	8.20	20.25	5.41	85.1
10.0	29.12	32.76	8.21	20.36	5.23	82.4
11.0	29.12	32.76	8.18	20.36	5.00	78.7
12.0	29.13	32.76	8.18	20.36	5.01	78.9
13.0	29.14	32.68	8.16	20.30	4.95	77.9
14.0	29.14	32.76	8.15	20.36	4.96	78.1
15.0	29.14	32.91	8.15	20.47	4.97	78.4
16.0	29.14	32.91	8.14	20.47	4.87	76.8
17.0	29.14	32.91	8.14	20.47	4.77	75.2
18.0	29.06	32.90	8.11	20.49	4.30	67.7
19.0	28.95	33.27	7.97	20.81	2.07	32.6
20.0	28.95	33.57	7.91	21.03	1.37	21.6

Table A.9. Hydrography, October 1991.

CRUISE DATA - TRANSECT C

Station: 6B Latitude: 28:52.18 N Hydrolab cast time: 14:17
Date: 10/17/91 Longitude: 90:28.04 W Secchi disk depth (m): 9.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.4	24.59	31.81	8.05	21.08	6.28	90.6
0.9	24.59	31.81	8.06	21.08	6.34	91.5
1.9	24.60	31.81	8.06	21.08	6.32	91.2
3.0	24.59	31.81	8.05	21.08	6.34	91.5
3.9	24.58	31.81	8.05	21.09	6.28	90.6
5.0	24.57	31.81	8.05	21.09	6.36	91.8
6.0	24.55	31.74	8.05	21.04	6.34	91.4
6.7	24.53	31.74	8.05	21.04	6.37	91.8
7.8	24.50	31.81	8.05	21.11	6.35	91.5
8.7	24.49	31.81	8.05	21.11	6.31	90.9
9.9	24.47	31.73	8.05	21.06	6.36	91.6
11.2	24.46	31.81	8.05	21.12	6.30	90.7
12.0	24.46	31.81	8.05	21.12	6.30	90.7
13.0	24.47	31.81	8.05	21.11	6.34	91.3
14.0	24.47	31.81	8.05	21.11	6.34	91.3
15.0	24.55	31.88	8.05	21.15	6.18	89.2
16.0	25.46	32.80	7.94	21.57	3.77	55.6
17.0	25.61	33.03	7.94	21.69	3.73	55.2
18.0	25.68	33.18	7.92	21.78	3.55	52.7
19.0	25.70	33.25	7.91	21.83	3.40	50.5
19.8	25.70	33.18	7.90	21.78	3.34	49.6
20.3	25.67	33.25	7.88	21.84	3.23	47.9

Station: 6 Latitude: 28:51.44 N Hydrolab cast time: 15:36
Date: 10/17/91 Longitude: 90:27.68 W Secchi disk depth (m): 9.6

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	24.69	31.67	8.09	20.95	6.36	91.9
1.0	24.71	31.82	8.07	21.05	5.39	78.0
2.0	24.70	31.89	8.07	21.11	6.38	92.3
3.0	24.69	31.89	8.07	21.11	6.40	92.6
4.0	24.69	31.82	8.07	21.06	6.42	92.8
5.0	24.66	31.82	8.07	21.06	6.43	92.9
6.0	24.62	31.89	8.07	21.13	6.43	92.9
7.0	24.59	31.81	8.08	21.08	6.43	92.8
8.0	24.56	31.81	8.07	21.09	6.42	92.6
9.0	24.55	31.88	8.07	21.15	6.42	92.6
10.0	24.55	31.88	8.07	21.15	6.41	92.5
11.0	24.54	31.88	8.07	21.15	6.42	92.6
12.0	24.55	31.81	8.07	21.09	6.41	92.5
13.0	24.55	31.81	8.07	21.09	6.41	92.5
14.0	24.75	32.04	8.06	21.21	6.28	91.0
15.0	24.90	32.27	8.06	21.33	6.27	91.3
16.0	25.25	32.87	8.03	21.68	5.41	79.5
17.0	25.75	33.26	7.95	21.82	3.83	56.9
18.0	25.77	33.26	7.94	21.81	3.71	55.2
19.0	25.78	33.26	7.93	21.81	3.70	55.0
19.5	25.78	33.33	7.92	21.87	4.56	67.9

Appendix B. Sedimentary Characteristics

Table B.1. Surficial sediment characteristics, 1991.

Month	Station & Distance	% Sand	% Silt	% Clay	Sand:Mud Ratio	% TOC	Chlorophyll a (µg/g dry wt)	Phaeopigments (µg/ g dry wt)	Total Pigments (µg/ g dry wt)
2	SH1000	10.67	86.33	3.00	0.12	0.94	5.33	42.94	48.26
2	SHRef	7.45	89.8	2.75	0.08	0.98			
2	UA500	57.76	40.37	1.86	1.37	0.58			
2	UA1000	53.41	45.2	1.39	1.15	0.57	1.92	15.68	17.59
2	UB500	68.51	30.05	1.44	2.18	0.44	15.53	35.11	50.64
2	UB1000	54.3	43.98	1.72	1.19	0.38			
3	SH1000	5.79	93.44	0.77	0.06	0.73	2.45	41.89	44.38
3	SHRef	6.82	92.28	0.90	0.07	0.80			
3	UA500	39.21	60.04	0.75	0.64	0.60			
3	UA1000	63.2	36.34	0.46	1.72	0.36	1.18	17.53	18.7
3	UB500	29.02	64.9	6.08	0.41	0.58	1.51	10.83	12.33
3	UB1000	61.75	37.86	0.39	1.61	0.73			
4	SH1000	7.69	86.03	6.28	0.08	0.68	12.77	143.64	156.42
4	SHRef	9.19	82.49	8.32	0.10	1.01			
4	UA500	24.04	69.91	6.05	0.32	0.69			
4	UA1000	34.10	59.76	6.15	0.52	0.48	10.07	137.12	147.20
4	UB500	42.76	51.88	5.36	0.75	0.37			
4	UB1000	49.30	46.13	4.57	0.97	0.55			
5	SH1000	1.32	87.50	11.18	0.01	1.00	8.11	65.21	73.32
5	SHRef	2.45	88.94	8.61	0.03				
5	UA500	11.58	77.57	10.85	0.13				
5	UA1000	19.40	66.35	14.25	0.24	0.50	3.18	37.03	40.02
5	UB500	13.32	77.94	8.74	0.15	0.57	12.09	68.00	80.09
5	UB1000	8.59	79.64	11.77	0.09				
6	UB500	45.01	45.74	9.26	0.82		1.71	15.21	16.92
7	UB500.1	32.20	65.82	1.97	0.78	0.44	1.49	56.25	57.74
7	UB500.2	24.21	73.46	2.32	0.32				
7	UB500.3	39.36	58.90	1.74	0.65				
7	UB500	24.17	74.06	1.77	0.32	0.66	1.41	14.03	15.44
8	UB500	10.50	74.92	14.58	0.12				
9	UB500	42.61	48.31	9.08	0.74	0.32	1.28	29.79	31.07
10	UB500	13.82	73.75	12.42	0.16	0.50	1.31	15.18	16.49

Appendix C. Benthic Community Parameters

Table C.1. Benthic community parameters, Shell WD32E (=SH), 1991.

Month/ Station	No. Repl.	No. Species X±SD	No. Individuals X±SD	No. Calc.	Diversity X±SD	Evenness X±SD
February						
SH1000	4*	13.8±3.2	50.8±15.5	4*	0.82±0.24	0.22±0.05
SHRef	5	10.0±1.0	69.0±55.6	5	0.58±0.27	0.18±0.09
March						
SH1000	5	19.4±5.9	80.8±45.4	5	0.94±0.20	0.22±0.04
SHRef	5	11.8±5.0	62.6±39.1	5	0.56±0.23	0.16±0.05
April						
SH1000	5	18.4±3.8	83.4±25.8	5	0.96±0.10	0.23±0.02
SHRef	5	13.2±5.1	51.8±29.0	5	0.68±0.09	0.19±0.05
May						
SH1000	5	16.2±5.2	76.8±43.6	5	0.85±0.12	0.21±0.01
SHRef	5	16.6±4.1	53.2±22.3	5	0.80±0.07	.020±0.01

*Replicate E missing.

Table C.2. Benthic community parameters, Unocal ST53A (=UA, C6), 1991.

Month/ Station	No. Repl.	No. Species X±SD	No. Individuals X±SD	No. Calc.	Diversity X±SD	Evenness X±SD
February						
UA500	5	11.6±4.3	82.0±33.7	5	0.78±0.14	0.22±0.02
UA1000	5	17.8±4.1	96.4±15.3	5	0.89±0.11	0.22±0.02
March						
UA500	5	9.2±4.7	54.8±35.3	5	0.73±0.12	0.24±0.03
UA1000	5	12.0±3.4	64.4±27.4	5	0.75±0.13	0.21±0.02
April						
UA500	5	17.4±8.1	94.0±60.0	5	0.96±0.18	0.24±0.02
UA1000	5	15.0±5.2	92.6±57.8	5	0.84±0.12	0.22±0.02
May						
UA500	5	26.4±7.2	184.6±81.1	5	1.07±0.05	0.23±0.02
UA1000	5	22.2±6.5	229.4±112.8	5	0.99±0.10	0.22±0.02

Table C.3. Benthic community parameters, Unocal ST53B (=UB, C6A), 1991.

Month/ Station	No. Repl.	No. Species X±SD	No. Individuals X±SD	No. Calc.	Diversity X±SD	Evenness X±SD
<u>February</u>						
UB500	5	17.4±5.1	111.8±36.4	5	0.95±0.10	0.23±0.01
UB1000	5	21.6±9.8	124.6±64.6	5	1.08±0.14	0.25±0.01
<u>March</u>						
UB500	5	20.6±6.7	98.4±65.8	5	0.98±0.17	0.23±0.02
UB1000	5	23.6±8.4	105.8±43.7	5	1.07±0.17	0.24±0.01
<u>April</u>						
UB500	5	23.0±10.1	116.2±74.0	5	1.05±0.18	0.24±0.01
UB1000	5	16.4±2.7	72.6±15.4	5	0.93±0.07	0.23±0.01
<u>May</u>						
UB500	5	27.0±8.6	354.6±231	5	0.97±0.15	0.21±0.02
UB1000	5	26.6±5.7	171.6±57.1	5	1.08±0.11	0.23±0.02
<u>June</u>						
UB500	5	16.6±8.4	117.2±92.7	5	0.87±0.18	0.23±0.02
<u>July</u>						
UB500	5	6.2±4.3	18.4±17.0	5	0.51±0.32	0.24±0.04
<u>August</u>						
UB500	5	10.0±4.0	44.6±8.1	5	0.62±0.14	0.19±0.01
<u>September</u>						
UB500	5	12.4±1.1	130.4±23.6	5	0.71±0.03	0.20±0.02
<u>October</u>						
UB500	5	16.2±2.8	105±28.5	5	0.86±0.08	0.22±0.01

Table C.4. Benthic biomass data (mg AFDW/sample ± SD) for 1990 and 1991 (n = 5 replicates, except where indicated otherwise).

	West Delta 32E		Unocal ST53A		Unocal ST53B	
Month-Year	Station	Biomass	Station	Biomass	Station	Biomass
Apr-90	500 m	24.98±6.34	1000 m	58.70±24.40	1000 m	67.98±3.72^
Jun-90	1000 m	60.58±34.43	1000 m	57.62±24.07	1000 m	44.64±17.60
Jul-90	1000m	27.02±16.56	1000 m	21.22±20.20	1000 m	59.86±16.21
Aug-90	1000 m	39.74±32.34	1000 m	5.66±2.40	1000 m	20.46±11.56^
Sep-90	1000 m	10.18±7.86	500 m	10.58±6.52	500 m	14.62±6.04
			1000 m	5.04±4.63	1000 m	19.28±14.12
Oct-90	1000 m	10.74±10.44	500 m	17.58±11.20	500 m	15.16±6.38
			1000 m	17.50±8.77	1000 m	21.50±14.55
Feb-91	1000 m	16.85±8.73^	1000 m	17.04±3.78	1000 m	42.32±21.70
Mar-91	1000 m	20.04±10.32	1000 m	30.88±24.99	1000 m	41.26±21.85
Apr-91	1000 m	41.00±30.84	1000 m	40.98±26.44	1000 m	23.36±13.22
May-91	1000 m	9.1±6.48	1000 m	24.32±24.06	1000 m	38.1±25.27
Jun 199					1000 m	21.10±14.40
Jul-91					1000 m	8.5±10.83
Aug-91					1000 m	13.28±6.39
Sep-91					1000 m	18.70±2.47
Oct-91					1000 m	17.02±2.23

^ 4 replicates

Table C.5. Abbreviations for taxa designations in Tables C.6, C.7 and C.8.

Code	Species	Code	Species
Abr aeq	Abra aequalis (B)	Med cal	Mediomastus californiensis (P)
Albun A	Albuneidae sp. A. (D)	Mirc atr	Microphiopholis atra (O)
Ampel B	Ampelisca sp. B (Am)	Mono nyei	Monoculodes nyei (Am)
Amph A	Ampharete sp. A (P)	Mont A	Monticellina sp. A (P)
Anc jon	Ancistrosyllis jonesi (P)	Nat pus	Natica pusilla (G)
Arc A	Arcidae sp. A (B)	Nean micr	Neanthes micromma (P)
Aric frag	Aricidea fragilis (P)	Nemer A	Nemertea sp. A. (N)
Aric A	Aricidea sp. A. (P)	Nep inc	Nephtys incisa (P)
Arm Mac	Armandia maculata (P)	Nuc acut	Nuculana acuta (B)
Aspido	Aspidosiphon sp. (S)	Nuc conc	Nuculana concentrica (B)
Asy elon	Asychis elongatus (P)	Owe fus	Owenia fusiformis (P)
Autom	Automate sp. (D)	Palaeo	Palaeonemertea (N)
Biv L	Bivalvia L (B)	Para B	Paramphinome sp. B (P)
Cer irr	Ceratonereis irritabilis (P)	Para pin	Paraprionospio pinnata (P)
Cer lact	Cerebratulus lacteus (N)	Pinn A	Pinnixa sp. A (D)
Cerian	Ceriantharia (A)	Pir rob	Piromis roberti (P)
cf. Car	cf. Carinomella (N)	Pod lev	Podarkeopsis levifuscina (P)
Chaet D	Chaetozone sp. D (P)	Prio cris	Prionospio cristata (P)
Cirr	Cirratulidae (P)	Prio del	Prionospio delta (P)
Cirr A	Cirrophorus sp. A. (P)	Prio F	Prionospoio sp. F (P)
Cirr B	Cirrophorus sp. B (P)	Prio perk	Prionospio perkinsi (P)
Clym torq	Clymenella torquata (P)	Pseudo amb	Pseudoeurythoe ambigua (P)
Cos del	Cossura delta (P)	Sabel A	Sabellides sp. A (P)
Cos soy	Cossura soyeri (P)	Shrimp	Shrimp
Enter	Enteropneusta (H)	Sig bas	Sigambra bassi (P)
Golfin	Golfingia sp. (S)	Sig tent	Sigambra tentaculata (P)
Gyp vit	Gyptis vittata (P)	Sip X	Sipuncula X (S)
Hesion	Hesionidae (P)	Sthen	Sthenelais sp. (P)
Lepid A	Lepidasthenia sp. A (P)	Sync amer	Synchelidium americanum (Am)
Linei	Lineidae (N)	Tell vers	Tellina versicolor (B)
Mag H	Magelona sp. H (P)	Them	Thenaria (An)
Mag I	Magelona sp. I (P)	Vitr flor	Vitrinella floridana (G)
Med amb	Mediomastus ambiseta (P)	Vol tex	Volvulella texasiana (G)

Am - Amphipoda
An - Anthozoa
B - Bivalvia
D - Decapoda
G - Gastropoda
H - Hemichordata
N - Nemertea
O - Ophiuroidea
P - Polychaeta
S - Sipuncula

Table C.6. Dominant taxa by month (number/replicate) for Shell WD32E (=SH) for 1991.

Rank	Feb	Mar	Apr	May
1	Para pin 39.3	Para pin 36.7	Para pin 29.7	Para pin 30.9
2	Med amb 4.4	Med amb 6	Med amb 9.2	Med amb 8.4
3	Mag H 2.2	Mag H 3.4	Cos soy 3.8	Mag H 2.5
4	Prio del 1.7	Cos soy 2.5	Linei 2.7	Cos soy 2.0
5	Sig tent 1.7	Prio cris 2.5	Mag H 2.7	cf. Car 1.7
6	Cos soy 1.4	Nemer A 1.3	Prio cris 2.1	Linei 1.3
7	Nuc acut 0.8	cf. Car 1.3	cf. Car 1.4	Prio F 1.3
8	Nean micr 0.6	Vitr flor 1.3	Nuc acut 1.3	Nemer A 1.2
9	Pinn A 0.6	Sync amer 1.2	Tel vers 1.1	Mont A 1.1
10	Gyp vit 0.6	Sig tent 1.1	Mono nyei 1.0	Prio cris 1.1

Codes are located in Table C.5.

Table C.7. Dominant taxa by month (number/replicate) for Unocal ST53A (=UA) for 1991.

Rank	Feb	Mar	Apr	May
1	Sig tent 29.3	Para pin 20.9	Para pin 23.7	Med amb 39.9
2	Para pin 20.7	Sig tent 13.4	Med amb 15.2	Para pin 31.6
3	Mag H 10.6	Mag H 7.7	Sig tent 11.2	Arm mac 27.7
4	Prio cris 5.7	Aspido 6.9	Mag H 9.3	Sig tent 21.6
5	Aspido 3.8	Amph A 1.8	Amph A 7.2	Amph A 17.5
6	Med amb 3.6	Med amb 1.8	Sabel A 4.4	Mag H 13.0
7	Prio perk 2.3	Prio perk 1.0	Aspido 3.9	Sabel A 10.1
8	Amph A 1.8	Prio cris 0.8	Tell vers 2.9	Prio cris 8.5
9	Nean micr 1.0	cf. Car 0.6	cf. Car 1.5	cf. Car 3.5
10	Pseud amb 1.0	Nemer A 0.5	Anc jon 1.2	Aspido 3.4

Codes are located in Table C.5.

Table C.8. Dominant taxa by month (number/replicate) for Unocal ST53B (=UB) for 1991.

Rank	Feb	Mar	Apr	May
1	Mag H 21.8	Mag H 22.6	Mag H 21.1	Med amb 81.3
2	Para pin 19.9	Para pin 18.1	Para pin 17.5	Para pin 31.2
3	Sig tent 15.3	Sig tent 8.0	Amph A 9.8	Mag H 24.8
4	Prio cris 12.1	Aspido 7.2	Aspido 6.4	Prio cris 20.8
5	Aspido 11.3	Amph A 5.8	Med amb 5.6	Amph A 19.3
6	Med amb 7.2	Med amb 5.2	Tell vers 5.2	Sig tent 14.4
7	Prio perk 5.9	Prio perk 5.2	Sig tent 5.1	Aspido 9.4
8	Amph A 2.7	Prio crist 4.0	Owe fus 2.3	Tell vers 6.0
9	Vitr flor 1.7	Owe fus 2.3	Nean micr 1.2	Sabel A 6.0
10	Nean micr 1.2	Tell vers 2.1	Arc A 1.2	Arm mac 4.5

Codes are located in Table C.5.

Table C.8. Continued.

Rank	Jun	Jul	Aug	Sep	Oct
1	Mag H 34.6	Mag H 8.8	Mag H 23.8	Arm mac 44.0	Mag H 28.6
2	Para pin 17.8	Aspido 3.0	Aspido 9.8	Para pin 39.0	Aspido 27.2
3	Prio cris 12.8	Owe fus 1.4	Sig tent 1.8	Mag H 26.4	Sig tent 12.2
4	Med amb 12.0	Cirr 1.0	Pir rob 1.0	Enter 6.0	Para pin 7.8
5	Amph A 11.8	Ampel B 0.8	Cirr B 0.8	Aspido 4.4	Nean micr 7.0
6	Aspido 4.8	Amph A 0.4	Pseud amb 0.8	Nean micr 2.6	Enter 6.6
7	Sig tent 4.2	Sig tent 0.4	Para pin 0.6	Anc jon 1.2	Sthen 3.6
8	Cer irr 2.4	Para B 0.4	Owe fus 0.6	Sig tent 1.2	Arm mac 1.6
9	Arm mac 1.4	Asy elon 0.2	Cer irr 0.6	Shrimp 0.6	Sig bas 1.0
10	cf. Car 1.4	Cer irr 0.2	Amph A 0.4	Cirr B 0.4	Pseud amb 1.0

Codes are located in Table C.5.

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 **Royalty Management Program** 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.