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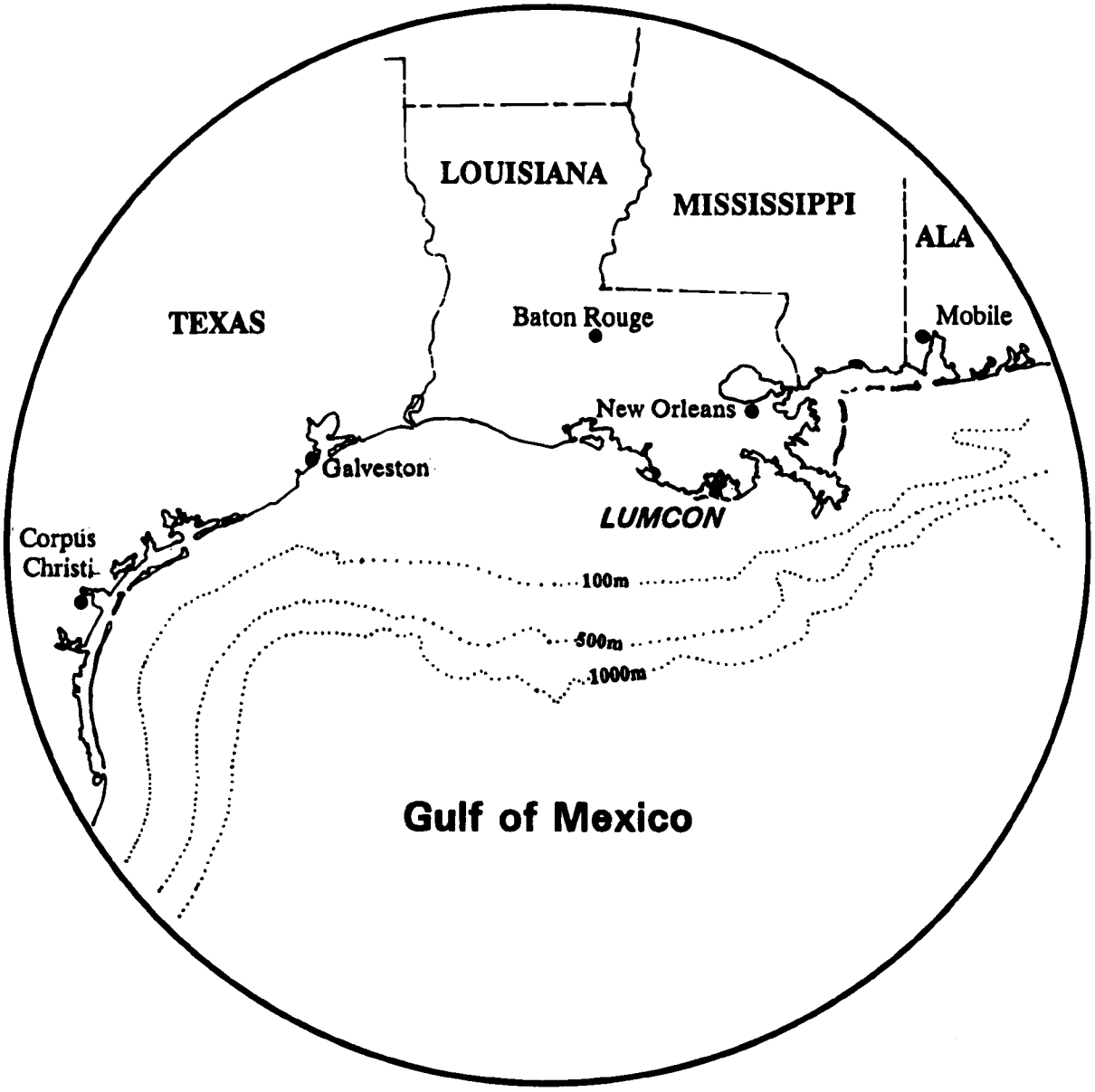
Influence of Hypoxia on the Interpretation of Effects of Petroleum Production Activities



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LUMCON Cooperative Agreement
University Research Initiative
Louisiana Universities Marine Consortium

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Influence of Hypoxia on the Interpretation of Effects of Petroleum Production Activities

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ABSTRACT

Two production platforms and one non-production platform were studied to determine if the effects of offshore petroleum development in the form of a produced water discharge could be identified on the Louisiana continental shelf and placed in the context of natural, temporal variability as caused by hypoxic bottom waters. Study sites were 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 a production platform in the West Delta block area (WD32E) in 20 m water depth, 74 km from ST53B. The reference site for WD32E was an open water station in West Delta Block 33. A fourth platform (production, ST52C) was dropped from the study design in July 1990. A reconnaissance cruise was conducted in April 1990, and field studies were conducted mid-month in June through August 1990. Additional sampling was conducted in September and October with ancillary funding from another agency. Continuously recording oxygen meters were located in each study area (ST53B and WD32E).

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 recorded often. The oxygen record for WD32E showed incursions in and out of hypoxic conditions, with no extremely low levels for prolonged periods. The grain size distributions were considerably different between the South Timbalier area (primarily silty sands) and the West Delta area (primarily silts). The degree of variability among stations within a single study site was high, and not always consistent with time.

The range of hydrocarbon concentrations was greatest at WD32E, and there were obvious indicators of petrogenic origin hydrocarbons at selected stations during some months. In a few instances at WD32E, analyte concentrations and summed PAH concentrations approached or exceeded the threshold level where negative impacts on benthic infauna have been shown previously. Hydrocarbon concentrations, in general, however, were low for most study sites (even where sediments were silty) and were characterized as weathered petrogenic or biogenic in nature. In general, there were no consistent spatial or temporal trends in hydrocarbon chemistry at the three study sites.

There were significant and dramatic decreases in summer and fall in species richness and abundance of organisms at ST53A and ST53B (severe hypoxia), but a more gradual decline in benthic populations at WD32E (ephemeral hypoxia). 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; these communities were distinct from those of WD32E. Differences in the benthic communities could be attributed to sediment characteristics and oxygen environments.

There were some indications of gradients in benthic community parameters at the two production platforms, but these gradients were not always consistent in time, nor consistent with distance from the platform, nor significant. However, there were no clear environmental signals at any of the platforms with distance from the platform. There were indications that hydrocarbon composition and concentrations at the two production platforms were different from the non-production platform. Multiple regression analysis identified oxygen concentration, bottom water temperature and salinity, and sediments as important environmental factors that explained the variation in benthic community parameters of species richness and abundance. Production discharge hydrocarbon concentrations were not significant in any of the models, but there were no clear environmental signals related to these contaminants at any of the study sites.

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CHAPTER 1. EXECUTIVE SUMMARY

Natural variation in space and time has been one of the greatest problems encountered in assessments of effects of petroleum production activities in a field setting. In the extensively developed oil and gas production areas of the northern Gulf of Mexico, a major confounding effect is seasonally intense and widespread hypoxic (dissolved $O_2 < 2$ mg/l) bottom waters (Rabalais et al. 1991b). The zones of hypoxic bottom water may cover 8000 to 9500 km^2 during mid-summer on the inner continental shelf from the Mississippi River delta to the upper Texas coast. 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. Critically depressed dissolved oxygen conditions may occur in near-bottom waters nearly continuously from April through October on the inner shelf of southeastern and southwestern Louisiana. On the southeastern shelf, the zones of hypoxia are continuous, widespread, and persistent, and may include up to 40% of the lower water column in 10-30 m water depth.

Several investigations of the impacts of oil and gas development in the coastal and offshore regions of Louisiana have been complicated by the effects of hypoxia on the benthos. 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). Other studies of either the impacts of operational discharges (e.g. Middleditch 1981, Bedinger 1981, Neff et al. 1989, Rabalais et al. 1991a, 1992a) or the effects of hypoxia (e.g. 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, 1992, Rabalais unpubl. data) have demonstrated that the effects of either hydrocarbon contamination or hypoxia can be identified in the sediments and associated communities. One additional study of produced water discharges in a shallow, erosive water column on the Louisiana inner shelf off Atchafalaya Bay (Rabalais et al. 1991a) indicated that production platform effects were detectable even where large-scale natural processes (albeit not hypoxia) were expected to obscure patterns. Based on these prior investigations and concerns related to confounding effects on impacts studies, we hypothesized that the effects of offshore petroleum development in the form of a production platform discharge could be identified on the Louisiana continental shelf and placed in the context of natural, temporal variability as caused by hypoxic bottom waters.

Several assumptions guided our research. First, it is highly probable that an area of the southeastern Louisiana inner continental shelf, where there are extensive oil and gas production activities, will experience hypoxic bottom waters during the summer season. Second, the dissolved oxygen levels at two or more sites will be similar throughout the season of hypoxia in concentration and duration. Third, benthic communities can be identified as being impacted by hypoxia. Fourth, concentrations of contaminants can be identified in the sediments adjacent to a production platform, and should be correlated with distance from the discharge.

As a result of these assumptions, we hypothesized that differences in the benthic fauna can be identified as a gradient in distance from the production platform, that these differences will be consistent across time, and that the relative importance of environmental variables that affect benthic community variability can be identified.

A substantial problem evolved early in the determination of adequate study sites (see Table 1 in Section 3.1) that would provide the suitable experimental setting to answer the original research questions. The eventual selection was two platforms in the South Timbalier area in 20 m water depth, 3 km apart, one production (Unocal ST53A) and one non-production (Unocal ST53B); and a production platform in the West Delta area (WD32E) in 20 m water depth, 74 km from ST53B. The South Timbalier area was characterized by sandy silty sediments (less likely to adsorb hydrocarbon contaminants), and the produced water discharge volume from ST53A was

5,550 bbl/d. The West Delta area was characterized by silty sediments (more likely to adsorb hydrocarbon contaminants) and a produced water discharge volume of 20,000 bbl/d. ST53B was the site of a permanent instrument mooring with a continuously recording oxygen meter; a continuously recording oxygen meter was placed at the WD32E platform for a portion of the study period (mid-June through mid-October).

Results from the reconnaissance cruise in April 1990 indicated that the original study design was complicated by 1) dramatic variability in sediment characteristics with distance from the platform at two potential study sites, and 2) the lack of a clear chemical contaminant signal (concentration and expected gradient away from the platform) at two study sites. One platform (Chevron ST52C) was dropped from the study design in July 1990. At this point, however, we were compelled to continue focusing on the three selected platforms because of limitations of time to complete the study and be underway for the 1990 summer hypoxia season and limitations of resources to conduct further reconnaissance cruises. With data from the three sites, we assumed it would be possible (in the event of minimal chemical signals and confounding effects of sediment variability) to at least characterize the benthic communities from a variety of sedimentary regimes where hypoxia is persistent and severe during the summer months.

Field studies were conducted in mid-month of April through August at three or four study sites (additional collections were made in September and October under the auspices of another funding agency). The focus of the study was refined in July to three study sites (ST53A, ST53B, and WD32E as described above and listed in Table 1, see Section 3.1). Station distances from each platform were placed as closely as possible to 20, 50, 100, 250, 750 and 1000 m intervals. The ST53B platform served as a reference station for ST53A; an open-water station in West Delta block 33 served as the reference station for WD32E. Standard collections at each study site were hydrographic profiles, sediment samples for chemical analyses, and benthic organisms. Sediments were analyzed in all months for grain size, total organic carbon; in April-August for saturated hydrocarbons, semi-volatile hydrocarbons and trace metals; in selected months and stations for radionuclides. Standard benthic community analyses were conducted on 0.023-m^2 hand-operated Ekman grabs taken from a larger box corer (five replicates for each station each month). Statistical techniques used were analysis of variance general linear model, Duncan's multiple range test, and multiple regression techniques.

The 1990 season of hypoxia, as monitored off Terrebonne/Timbalier Bays and at 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 recorded often. Dissolved oxygen concentrations in bottom waters at ST53A were similar to those at ST53B, where the instrument mooring was located. The oxygen record for WD32E located 74 km away, on the other hand, showed incursions in and out of hypoxic conditions, with no extremely low levels for prolonged periods. Oxygen conditions, therefore, were substantially different between the South Timbalier and West Delta areas. Conditions at South Timbalier could be characterized as severe and persistent, with effects expected on the benthic community. On the other hand, conditions at West Delta could be characterized as ephemerally hypoxic and not severe, with little impact expected on the benthic community. Thus, another original assumption, that hypoxia would be similar at distant locations on the southeastern shelf, was also not met, and we were unable to characterize the benthic communities from a variety of sedimentary regimes where hypoxia was persistent and severe during the summer.

These numerous problems in appropriate study sites, lack of chemical contaminant signal and lack of a gradient and consistent chemical signal when found, meant that we would be unable to adequately test our original hypothesis. The unexpected differences in the oxygen environment between WD32E and the South Timbalier area also complicated those comparative aspects of the study. However, we did further document, under a set of environmental conditions, the signals of

production platforms in various habitats, and the effect of variable conditions of hypoxia on the benthos. Further, we were able to identify the relative differences in environmental factors with regards to explaining the variability in benthic community parameters.

The grain size distributions, as expected, were considerably different between the South Timbalier area (primarily sandy silts) and the West Delta area (primarily silts). The degree of variability among stations within a single study site was high, and not always consistent with time. For example, sediments at ST53A were predominantly sandy silts with little clay fraction, but substantially different sediments were often observed (e.g., anomalously low sand percentage at 1000 m in April and 100 m in June, or extremely high sand percentage at 50 m in July (see Section 5.2). There were no consistent gradients in sand/silt/clay percentages with time at ST53A. ST53B was the most variable in space and time with non-uniform and high percentages of sand or clay that were not consistent with distance from the platform nor sample period. Variability in sediments at ST53A and ST53B complicated the interpretation of benthic community data. Sediments at WD32E were composed primarily of silts, with the exception of stations closest to the platform (0, 20 and 50 m) where the sediment surface was impacted by sandblasting operations. At these times, anomalously high percentages of coarse-grained sands were present. These sediment differences so close to the platform complicated the interpretation of both chemical contaminant and benthic infaunal data.

Minimal informative data were gleaned from the sediment radionuclide and trace metal samples. Limited surficial sediments analyzed for the radionuclides Pb-210, Ra-226 and Ra-228, indicated concentrations at or below typical coastal sediments. Elevated concentrations of Ra-226 at a few stations were not found in sediments associated with higher levels of petrogenic hydrocarbons. There were no clear gradients in concentrations of metals away from the ST53A or ST53B platform for the four months sampled. Values, in general, were lower for sediments at ST53B than at ST53A. Metal concentrations clearly outside the limits of normalized Al concentrations (Schropp et al. 1990) (Pb > 100 ppm and Zn > 100 ppm) were evident within 100 m of the WD32E platform, and were likely related to a platform activity or discharge.

Sediments at ST53A contained hydrocarbons in low concentrations of mostly a weathered petroleum or biogenic nature. There were no clear spatial nor temporal patterns evident in the distribution of hydrocarbons adjacent to the ST53A platform. Sediment hydrocarbons adjacent to ST53B were similar in composition to those of ST53A, but generally lower in concentration. Hydrocarbon concentrations had a greater range at WD32E than the study sites in the South Timbalier area. The sediments at WD32E contained hydrocarbons mostly of a mixed weathered petroleum and biogenic nature; there were certain stations, however, where the hydrocarbon composition was distinctly petrogenic. There was also a trend for a greater predominance of biogenic hydrocarbons with distance from the platform. With the exception of the June sampling period, total saturated hydrocarbon concentrations for WD32E were similar to concentrations in South Timbalier, despite the higher percentage of fine sediments at WD32E and the larger volume discharge. There was a general decrease in the concentration of specific analytes and in summed PAHs from April through August. The summed alkylated PAH concentrations at 50 and 100 m in June exceeded the threshold level where negative impacts on benthic infauna have been shown previously (Rabalais et al. 1991a).

In summary, the greatest range in hydrocarbon concentrations was observed at WD32E, and there were obvious indicators of petrogenic origin hydrocarbons at selected stations during some months. In a few instances at WD32E, analyte concentrations and summed PAH concentrations approached or exceeded the threshold level where negative impacts on benthic infauna have been shown previously. Hydrocarbon concentrations, in general, however, were low for most study sites (even where sediments were silty) and were characterized as weathered petrogenic or biogenic in nature. In general, there were no consistent spatial or temporal trends in hydrocarbon chemistry at the three study sites.

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.

Although ST53A was consistently lower in number of species and individuals than ST53B, these differences were not always significant. It is tempting to attribute these differences to the consistently higher concentrations of produced water hydrocarbons at ST53A; however, a multiple regression model with both study sites combined indicates that only the environmental variables of oxygen concentration, temperature, salinity, sediments, and total saturated hydrocarbon concentrations were significant in explaining the variation in species richness and abundance in the South Timbalier study area.

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. During September and October the overall increase in number of individuals was due primarily to the recruitment of *Paraprionosopio pinnata* and *Armandia maculata* and sustained population levels of *Magelona* sp. H and *Aspidosiphon* sp.

A large component of the benthic community at WD32E, on the other hand, was composed of polychaetes, but there was a much greater diversity of other major taxa than at the 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, and *Owenia fusiformis*.

There were some gradients in benthic community parameters that were consistent through time. For example, species richness and abundance were generally lower at the 20 m station at ST53A. The remainder of the stations grouped with 250 m, 500 m, 750 m and 1000 m having the most species and individuals, and with stations at 50 m and 100 m being intermediate. These trends were not always significant, nor consistent through time. Also, no environmental variable analyzed showed the same consistent pattern with distance from the platform. No gradient with distance from the platform was evident in the benthic community at the non-production platform, ST53B, and there were usually no significant differences with distance from the platform. Hydrocarbon concentrations were also lower at this study site. Benthic community parameters were significantly different (in most cases) by station at the WD32E platform, but these differences were not related to distance from the platform and were not consistent across time. Stations at 20 m and 50 m, in general, has more species and individuals than the other stations, but these differences were probably related to platform effects based on the type of fauna in the samples. In

April, higher values for number of individuals at 20 m, 50 m and 100 m were related to abundances of *Mediomastus ambiseta* and Tubificidae A, both indicators of organic enrichment. Tubificids were uncommon in the remainder of the study and at the other study sites.

Variability in the benthic community parameters of species richness and abundance was explained by differing combinations of the environmental variables of oxygen and related water temperature and salinity, sediments, and total saturated hydrocarbons. The environmental variable of bottom water oxygen concentration was important in both models for ST53A and one each for ST53B and WD32E. In the case of ST53A and ST53B, there was more of a threshold effect, whereby numbers of species and individuals were dramatically reduced when the oxygen concentration fell below 0.5 mg/l. Sediment characteristics were incorporated in the models for ST53B but were inconsistent with benthic community paradigms (i.e., percent sand was negatively correlated to diversity and abundance). Contrary to many benthic studies, grain size distributions were not always paramount in explaining the variation observed in the benthos (e.g., Unocal ST53A); however, the relationship with oxygen was strong for that study site and sediment variability was minimal at ST53A. At only one study site, ST53B, were any hydrocarbon variables significant in the models that explained variability in species richness and abundance. The variable of total saturated hydrocarbons was positively related to species richness and abundance, perhaps indicating an enhancement effect of the biogenic-type hydrocarbons present in the sediments at the distal ends of the ST53B transect. As noted earlier, however, the concentration of saturated hydrocarbons at the ST53B study site (non-production platform), was much less than the other two study sites (both production platforms). Neither of the variables that would indicate the presence of produced water origin hydrocarbons (summed alkylated PAH and FFPI) were significant in any of the models. The potential for effects within 100 m of the WD32E platform were masked by the platform-related grain size distribution differences and other potential platform effects that would increase diversity and abundance.

Thus, there were some indications for gradients in benthic community parameters at the two production platforms, but these gradients were not always consistent in time, nor consistent with distance from the platform, nor significant. However, there were no clear environmental signals at any of the platforms with distance from the platform. There were indications that hydrocarbon composition and concentrations at the two production platforms were different from the non-production platform. Multiple regression analysis identified oxygen concentration, bottom water temperature and salinity, and sediments as important environmental factors that explained the variation in benthic community parameters of species richness and abundance. Production discharge hydrocarbon concentrations were not significant in any of the models, but there were no clear environmental signals related to these contaminants at any of the study sites.

CHAPTER 2. INTRODUCTION

Natural variation in space and time has been one of the greatest problems encountered in assessments of effects of petroleum production activities in a field setting. In the extensively and intensively developed oil and gas production areas of the Gulf of Mexico, several studies of the effects of offshore petroleum development have suffered from lack of knowledge of the natural variability in the system, as well as 1) inadequate sample design and 2) the confounding effects of the Mississippi River as a source of turbid fresh water and anthropogenic pollutants, seasonally intense and widespread hypoxic bottom waters (dissolved $O_2 < 2$ mg/l), and storm events (Boesch and Rabalais, 1987). Still, within this area, differences in hydrocarbon contamination of sediments are evident, particularly where there are large amounts of operational discharges, i.e., produced waters (Middleditch 1981, Bedinger 1981, Neff et al. 1989, Rabalais et al. 1991a, 1992a). Also, 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, Boesch and Rabalais 1991, Rabalais and Harper 1991, 1992) have shown that we can identify the effects of hypoxia. These effects vary with the duration and intensity of low oxygen concentrations. The overall objective of our research program was to test whether the effects of hypoxia could be separated from the effects of petroleum production contaminants incorporated in the sediments.

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. 1991b). The zones of hypoxic bottom water in the northern Gulf of Mexico may cover 8000 to 9500 km^2 during mid-summer on the inner continental shelf, from the Mississippi River delta to the upper Texas shelf (Figure 1). 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 July 1985. Critically depressed dissolved oxygen conditions may occur in near-bottom waters nearly continuously from April through October on the inner shelf off southeastern (Turner and Allen 1982a, Rabalais et al. 1991b, 1992b) and southwestern Louisiana (Pokryfki and Randall 1987). The zones of hypoxia are continuous, widespread, and persistent, and may include up to 40% of the lower water column in 10-30 m water depth.

The Mississippi River system discharge creates strongly stratified nearshore waters, which flow westward and southward along the Louisiana and Texas coasts. A strong seasonal correlation is apparent between Mississippi River discharge and coastal hydrographic variability (Geyer 1950, Dinnel and Wiseman 1986, Wiseman et al. 1990). The resulting stratification is strongest in spring, during high river runoff, and summer, when wind mixing is weak and solar heating is strong. The summer insolation contributes to a seasonal thermocline. The halocline and thermocline, together, form a seasonal pycnocline. The relationships between surface salinity and sigma-t gradients on the inner to middle Louisiana shelf are positive and strong (Rabalais et al. 1991b). Low oxygen conditions in bottom waters on the Louisiana shelf are coincident with strong density stratification. As the differences in density from the surface-to-bottom become greater through the warmer months, the differences in oxygen concentration from surface-to-bottom also increase (Figure 2). Very often, the near-bottom seasonal pycnocline that is thermally controlled caps off the most severely oxygen-depleted bottom waters (Wiseman et al. 1992). The importance of strong stratification in the buildup and maintenance of low oxygen bottom waters was evident in 1988 during record low flow of the Mississippi River, when areas of bottom water seriously depleted in oxygen were minimal in mid-summer (Rabalais et al. 1991b). Stratification over the inner shelf can be readily broken down by storm driven mixing (Wiseman et al. 1986). This process, dominant in winter or during tropical storms and hurricanes, effectively reaerates the

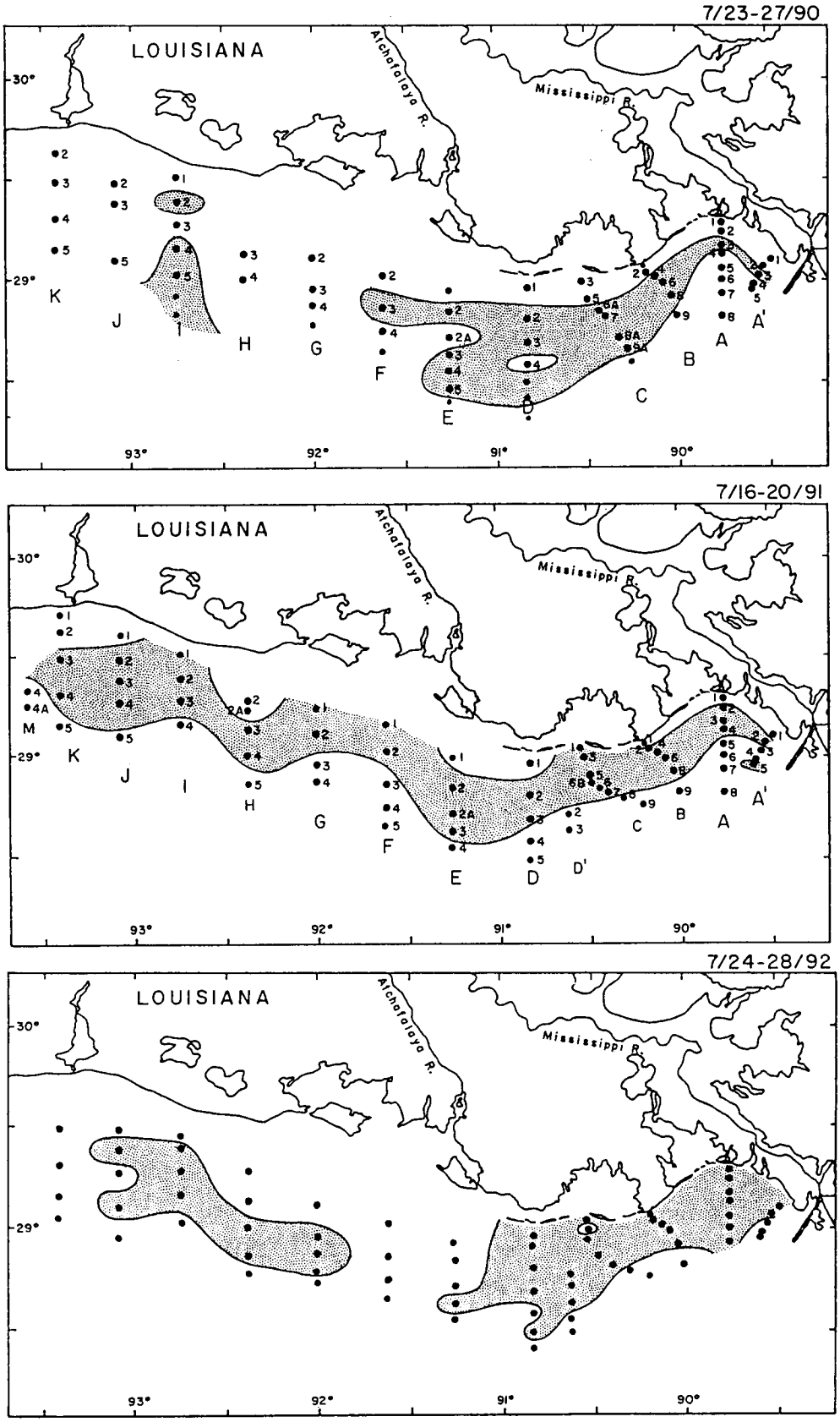

Figure 1. Areas of hypoxia on the Louisiana shelf (modified from Rabalais et al. 1992b).

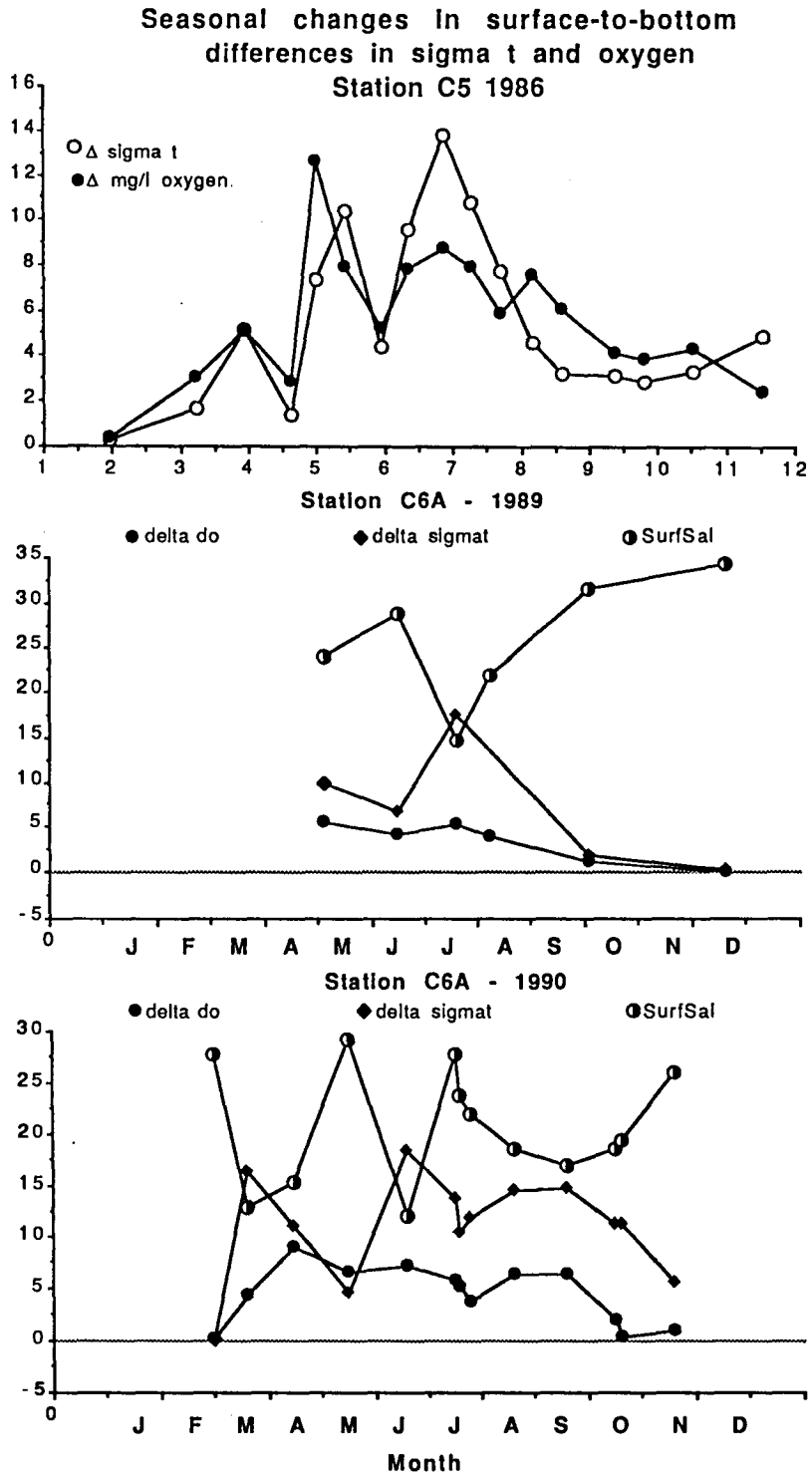

Figure 2. Changes in intensity of stratification and surface-to-bottom oxygen differences in three years (modified from Rabalais et al. 1991b).

deeper waters. Weaker mixing events, which do not fully destroy the stratification, are also reflected as increased bottom oxygen concentrations.

The principal source of organic matter in the bottom waters and sediments of the northern Gulf of Mexico shelf is from phytoplankton production in surface waters (Gearing et al. 1977, Thayer et al. 1983, Rabalais et al. 1992c). Whether the phytoplankton production originates in situ on the continental shelf, or is derived from the coastal boundary layer, from the Mississippi and Atchafalaya River plumes, or a combination of these is not clear, nor is there a straightforward relationship between surface chlorophyll *a* levels and bottom water hypoxia. We would not expect a close coupling in time and space because the surface distribution of water masses, including phytoplankton biomass, responds to freshwater inflow, currents, and winds over short time scales. Cross-correlation analysis shows a significant correlation of oxygen deficit in the bottom waters with river flow, implying a time-lag of two months (Justić et al. submitted). Further, net production in the surface waters shows a strong one-month lag with river flow, implying that fluxes of organic matter resulting from "new" primary production are potentially high, and may be sufficient to induce hypoxia in a highly stratified water column. The net primary productivity is highly dependent on nutrients coming from the river (Justic et al. submitted), and it is likely that riverine water quality changes will ultimately change the frequency, extent and duration of hypoxic events (Justic' et al. submitted, Turner and Rabalais 1991).

Irrespective of the source, the amount of phytoplankton biomass in the water column across the Louisiana inner and middle continental shelf is high. There are some indications of the coupling of surface production with the accumulation of organic material in the bottom waters (Rabalais et al. 1991b) and the sediments (Rabalais et al. 1992c). In addition, the respiration rate in these waters is proportional to phytoplankton pigment concentration (Turner and Allen 1982b), and respiration rates within the lower water column where hypoxia is prevalent are sufficient to drive the dissolved oxygen concentration to zero within a short period (Dortch et al. 1992). The consumption of oxygen far exceeds the reaeration rates from the surface layers, especially in the presence of strong stratification during the summer months. The fact that anoxia (or no oxygen) is seldom documented, suggests that mechanisms exist for resupply of oxygen to the bottom layer.

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, 1991b, 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. (1991b, 1992b) 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 including lack of replication, different methodologies for various taxonomic groups, omission of important taxonomic groups, poor

coordination with measurements of critical environmental factors, especially hydrocarbons, insufficient sampling to encompass the variability of the system, and poor study design (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). Much improved over the predecessor OEI-GURC study, the Central Gulf Platform Study successfully linked faunal and environmental data, but conducted and presented a bewildering series of sampling methodologies and statistical analyses that voided conclusions 1) that any faunal variation due to petroleum activity could not be separated from that due to periodic, major environmental fluctuations, and 2) there were effects due to chronic levels of some chemicals (Carney 1987). A sampling design existed that was conducive to the use of analysis of variance, but the possible differences were not tested (Carney 1987). Extremely sensitive techniques for resolving hydrocarbons in the sediments, allowed several general conclusions for the study area: 1) absolute levels of contaminants were higher in areas with very fine sediments vs. sandy, 2) platforms with high levels of contaminants associated with multiple and long-term discharges of produced waters showed definite trends of decreasing hydrocarbon contamination up to 2000 m from the platform, 3) where concentrations were lower, increased contaminant concentrations were confined closer to the platform, 4) even where absolute levels of hydrocarbons were extremely low, it was possible to discern polluting platforms, and 5) the entire region is contaminated with pollutants from man's activities (Bedinger 1981). With regard to hypoxia, 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. Still, they were able to say that there was an indication that benthic communities within about 20 m were influenced by sediment contamination, probably derived from produced water discharges. 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 my 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. Because

of the focus of the program to identify impacts of produced waters on benthic communities, there was no opportunity to examine the interaction of chemical contaminants and hypoxia, nor to resolve the temporal variability necessary to identify the impacts of hypoxia alone.

A few benthic studies on the Louisiana and Texas shelves have benefitted 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 cf. the southeastern Louisiana coast where hypoxia is a severe, extensive, and prolonged annual occurrence (Gaston 1985, Pokryfki and Randall 1987, Rabalais et al. 1991b, 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, cf. 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, cf. 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, cf. episodic and ephemeral events at the other sites. Also, at the southeastern Louisiana site, amphipod populations were very sparse at all times, cf. 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.

Results from the Eugene Island Block 18 study area of the produced water discharge studies of Rabalais et al. (1991a), indicated that even in a shallow, erosional environment under the direct influence of the sediment-laden freshwater effluent of the Atchafalaya River, produced water hydrocarbon contamination was detectable out to 200 m from the platform. Also, statistically significant differences in benthic communities extended to 300 m from the platform and were consistent across time (the May and November 1989 sample dates). Large-scale natural processes i.e., shallow, erosive water column and high flushing potential of the Atchafalaya River flow,

were expected to dilute and transport the produced water contaminants and obscure patterns of impact. The high silt content of the sediments, large volume discharge, and high volatile loadings at the site may be factors in the larger area of impact. Regardless, impacts were observed where features of the environment (albeit not hypoxia, but similar in expectations) were predicted to obscure patterns.

2.3 Guiding Hypotheses

The continental shelf of the southeastern Louisiana coast is the site of extensive oil and gas production activities as well as the largest area of seasonal near-bottom hypoxic waters in the coastal United States and the western Atlantic (Rabalais et al. 1991b). Studies of the environmental effects of offshore oil and gas development on the Louisiana shelf have been confounded by natural phenomena such as seasonal hypoxia (Ward et al. 1979, Bedinger 1981, Neff et al. 1989). We hypothesized that the effects of offshore development could be identified and placed in the context of natural, temporal variability, in this case as caused by hypoxic bottom waters. Several assumptions guided our research:

1. It is highly probable that an area of the southeastern Louisiana inner continental shelf, where there are extensive oil and gas production activities, will experience hypoxic bottom waters during the summer season.

1.a. The near-bottom dissolved oxygen levels at two sites on the southeastern continental shelf in similar water depths will be similar throughout the season of hypoxia, in concentration, and

1.b. in duration.

2. Benthic communities can be identified as being affected by low oxygen conditions, by

2.a. abundance,
2.b. number of species,
2.c. taxonomic composition and
2.d. age and size class structure.

3. Concentrations of contaminants can be identified in the sediments adjacent to an offshore production platform and should be correlated with distance from the discharge

As a result of these assumptions, we hypothesized that differences in the benthic fauna can be identified as a gradient in distance from the production platform, that these differences would be consistent across time, and that the relative importance of the environmental variables that explain benthic community variability can be identified.

CHAPTER 3. STUDY DESIGN

3.1. Study Areas

Our original project goals were to locate two oil and gas production platforms within 50 to 100 km of each other in a 20- to 30-m depth range off Terrebonne and Timbalier Bays as study sites. The intent was for the two sites to have dissimilar volume discharges and for each to have an oxygen meter deployment. A third, nearby site was to serve as a "reference" point. An initial reconnaissance of study sites during the summer of 1989 was to be made to determine general patterns of variance in faunal, chemical and environmental parameters. A reduced scope of the original research plan called for a concentration of effort on a single production or "primary" site with a reduced effort at a "reference" site. During the second year, monthly surveys during the period of hypoxia (June, July and August) were to be conducted at the two study sites. Several complicating factors compromised the original study design. The resulting selection of study sites was less optimal than needed to answer the questions raised in the original proposal; however, a broader understanding of the fate of pollutants and the impacts of hypoxia were obtained for a range of study sites.

3.1.1 Selection of Sites

The selection process for suitable study areas began in the fall of 1989 with a request to the U.S. Minerals Management Service, Gulf of Mexico OCS Regional Office, for information on oil and gas platforms on the southeastern Louisiana continental shelf within the depth range of interest, within the area of recurring hypoxia (based on 5 years of mid-summer surveys by Rabalais and colleagues), and within a suitable distance from the proposed reference site. The reference site, Station C6A (Figure 3) of the hypoxia studies of N. N. Rabalais, R.E. Turner and W.J. Wiseman, Jr., was dictated by an instrument deployment with oxygen meter funded from other sources (LEQSF and NOAA NECOP). This is the location of an inactive Unocal platform (South Timbalier Block 53B) at which an instrument deployment was in place from March through December 1989, and again deployed in March 1990 for the remainder of the year. Hydrographic profiles at C6A and adjacent stations of the hypoxia studies of Rabalais and colleagues indicated similar dissolved oxygen levels in the near-bottom waters at adjacent stations (C5 and C6, see Figure 3). These stations were also the sites of production platforms, and, thus, candidates for a discharge site.

The MMS Gulf of Mexico OCS Regional Office provided a computer printout of platforms in the lease blocks requested of block, platform name, year installed, latitude, longitude, and water depth, along with a map of the platforms by lease block. A subsequent request was made for information concerning the discharges of the platforms on the original listing. Cross-listings of the platforms in the two printouts was complicated by the fact that one listing was by lease block and platform name and the second was by lease number. The lists were narrowed to approximately 50 platforms as potential study sites. We then needed to determine whether a produced water discharge was actually occurring at the platform and the volume of the discharge. This information was sought from the U.S. Minerals Management Service, Denver office, and confirmed by the oil companies which operated the platforms. All parties concerned (MMS, Conoco, Mobile, Shell, Exxon, Unocal, Chevron and Kerr-McGee) were most helpful in providing information; however, we were delayed in final selection of potential study sites until April 1990 by the disjunct sources of information and non-conformity of site information.

The next step was to focus on those platforms of primary interest and request oil company permission for conducting our study and for the deployment of an additional oxygen meter at the base of a platform. The potential study areas are listed in Table 1 and shown in Figure 3.

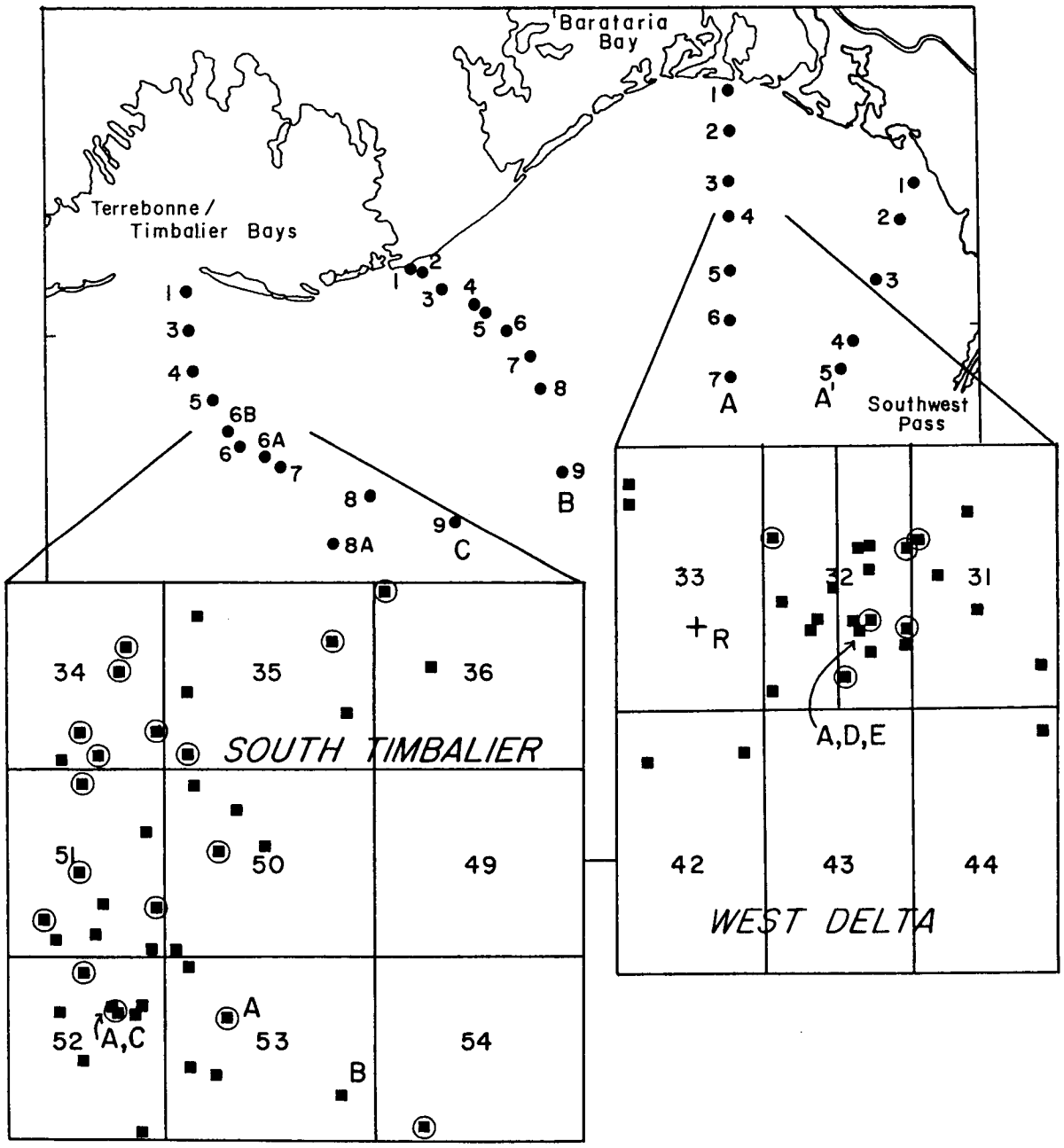

Figure 3. Location of Shell's West Delta 32A&D complex with platform E, a reference station (R) in WD33 block, Unocal's South Timbalier 53A complex and ST53B, and Chevron's South Timbalier 52A complex with platform C. Platforms indicated by dark squares; circled platforms are those with produced water discharges. MMS lease blocks are set within the general area of hypoxia studies (Transects A'-C) of Rabalais et al.

Table 1. Study areas.

Company	Lease Block	Water Depth	Volume Discharged	Sediment Type
Shell Offshore	West Delta 32E (oxygen meter) = WD32E	20 m	19,000 bbl/d	silt
Unocal	South Timbalier 53A and A-Aux. =Unocal A and C6	20 m	5,550 bbl/d	sandy silt
Unocal	South Timbalier 53B (oxygen meter and instrument mooring) = Unocal B and C6A	20 m	inactive	variable; sandy silt and silty sand
Chevron USA	South Timbalier 52 A and C complex =ST52C	20 m	20,000 bbl/d	sandy silt

Two of the above named platforms, Unocal's South Timbalier 53A and A-Aux. and Chevron's South Timbalier 52A complex, are in close proximity (≤ 7 km) to the ongoing instrument mooring at Unocal's South Timbalier 53B platform (=C6A of hypoxia studies). One of the two (Chevron's ST52A complex) had a much larger produced water discharge (20,000 bbl/d versus 5,000 bbl/d). The Shell platform in West Delta 32, while significant in produced water discharged, was located closer to the Mississippi River effluent and in a different sedimentary regime than those of the South Timbalier area. The WD32E platform was also located 74 km distance from the primary instrument mooring at ST53B. Sediments in West Delta 32 are predominantly silts (85 to 90%) while those of the South Timbalier 52 and 53 lease blocks were predominantly silt and sand mixtures of extreme variability. Thus, a dilemma was posed in a tradeoff between a large discharge that may provide more of an environmental signal in sediments of smaller size fraction (Shell's West Delta 32E platform) versus a large discharge (Chevron's ST52A complex) or a smaller discharge (Unocal's ST53A and A-Aux.) in a sedimentary environment that would be less likely to record chemical contaminants, but that was located close to an existing instrument mooring and where similar oxygen levels has been recorded in near-bottom waters.

A second dilemma was posed with the information from Unocal that the ST53A and A-Aux. was scheduled for exploratory drilling in the area in 1990, and that the ST53B inactive platform was scheduled for removal in 1991. An additional problem, not related to study design, was in the delay in obtaining final approvals for conducting the studies around the various platforms.

In our initial study design, we envisioned a primary study site with four quadrats and seven radii each. The reference site was to have two quadrats and three radii each. The primary and reference sites were to be in close proximity to each other. Because of constraints placed on our sampling design around Chevron's ST52A complex, the dilemma posed by two suitable but different study areas, and limitations in ship funding for the initial survey; we chose to sample a

single quadrat with seven radii each on four separate platforms. The platforms were each of those listed in Table 1.

3.1.2 Initial Reconnaissance Cruise

The research cruise was conducted on 17-19 April 1990 aboard the LUMCON R/V *Pelican*. Aside from the usual problems encountered at sea during research cruises, this cruise was hampered in several ways. The R/V *Pelican* had difficulty at times in obtaining Loran C fixes while in the shadow of the platform and at certain times of the day. The research vessel also had difficulty in maintaining a buoy on the location and in maintaining the ship next to the buoy while the box coring was in progress. All of these difficulties were magnified by a cold front passing through the study area during the first night's operations and then backing up onto the study area and staying there during the second and third day's operations. Position of the ship close to the platforms for stations at 20- and 50-m from the structure were also hampered by the sea conditions.

Stations at Chevron's ST52A complex were confined by Chevron to a single transect at 15°NNE. This was to avoid the pipelines entering the complex. Unfortunately, this was not in the direction of the supposed dispersion of an effluent from the ST52C production platform. Current meter measurements at ST53B during mid-April through June 1989 indicated strong surface currents (mean of 3 cm/s) from the east for a majority of the record with speeds approaching 30 cm/s for several days in the record. This would indicate a steady current from the east at that time and potential dispersion towards the west from the platform. Sampling at Chevron's ST52A complex was further complicated by the shell hash that covered the bottom at stations 50- and 100-m distance from the platform. Box coring was difficult at the 100-m station and impossible at the 50-m station. Because of the sea state and the seabed conditions, samples were not attempted at the 20-m station. The benthic community at the 100-m station was more typical of a hard substrate than the soft bottom benthic community that was collected at the 250-m station. Thus, while the Chevron ST52A complex had a large produced water discharge, the substrate and the quadrat limitations did not make it a suitable study area.

Sampling around ST53A and A-Aux. was successful in that all samples were collected. Sediments were more uniform around this platform that at Chevron's ST52A complex. This platform, however, had a much smaller produced water discharge.

Sampling around the reference area, ST53B, was conducted on a quadrat to the SW in order to avoid the instrument mooring off the NE leg of the platform. There were no difficulties encountered in obtaining samples from around this platform; although there was considerable variability in the sediment texture for the three stations sampled.

Sampling around the Shell WD32E platform was complicated by activities on the platform. Sandblasting and painting were in progress on the platform while we were on station. Sediments from the stations closest to the platform indicated that the sand from the sandblasting operations were the predominant sediments on the seabed. Sediments beyond 50 m were more typical of the silts expected. There were also indications of hydrocarbon contamination at the 50-m station (oily sheen seen while washing the benthic samples). Only five stations were sampled at WD32E rather than seven. The 750-m and 1000-m stations were dropped, due to time limitations. A reference station for this platform was taken in the West Delta lease block 33, about 2.6 km to the west of the WD32E platform in an area where there were no other platforms currently located. A suitable reference station would have been difficult to locate in the West Delta 32 block which had several platforms with discharges.

3.1.3 Final selection

Preliminary chemical analyses for hydrocarbons and trace metals were completed for the samples collected during the April reconnaissance cruise so that changes in study design could be implemented before or during the hypoxia cruises. The time frame of the season of hypoxia and logistical constraints, however, did not allow for a complete redesign in sampling strategy.

As a result, a substantial problem evolved in the determination of adequate study sites in order to answer the original research questions. As noted above, four study sites were sampled in the original reconnaissance cruise. One (ST53B) was the reference area for two platforms (ST53A and A-Aux. and ST52A and C complex) with substantially different volumes of produced water discharged. These three platforms are located within an area of the continental shelf where background information existed, where an instrument mooring was located, but where the surficial sediments were less likely to incorporate a chemical contaminant signal. The fourth platform (WD32E) had a substantial discharge, was located within a sedimentary environment where contaminants were more likely to be adsorbed to the sediments, but was located at a considerable distance and in a different sedimentary environment than the preferred reference station with the instrument mooring. It is possible that another platform complex other than those surveyed in the initial reconnaissance cruise may have been a better study area. Other platforms considered, however, were not in the correct depth range or had smaller produced water discharge volumes. We did not consider any platforms west of the South Timbalier lease blocks.

Limitations of time and resources led us to continue focusing on the originally selected four platforms. With data from these, it would be possible (in the event of minimal chemical signals) to at least characterize the benthic communities from a variety of sedimentary regimes where hypoxia is persistent and severe during the summer months.

After the initial reconnaissance which showed the lack of a contaminant gradient along the 15°NNE heading from the Chevron ST52C production platform, and after examining a pipeline drawing, we obtained permission from Chevron to conduct sampling along a different quadrat in June. Results from the June sampling along the 270°W heading at ST52C indicated hydrocarbon contaminants at the 50-m and 100-m stations with a decrease away from the platform and with change from petrogenic to biogenic hydrocarbons. Sediments at the 20-, 50- and 100-m stations, however, were also different in sediment texture from those farther removed from the platform. Shell hash at the 20-m station prevented successful box coring. Difficulty in reoccupying the same sediment types during July at the Chevron platform and the gradient of sediment types caused us to drop this platform from the study. Details of this study site as obtained through June 1990 are provided in this report.

Sampling during the mid-June, mid-July and mid-August hypoxic period was continued at Shell WD32E, Unocal ST53A and Unocal ST53B as previously planned. These study sites were the foci for this and other research programs related to hypoxia dynamics.

3.2 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-month's record. Problems with the meter were not anticipated, nor could they be corrected after the fact. The meter had been deployed from June through December 1989 without any problems in the machinery. Our retrieval and maintenance schedule was changed from bi-monthly to monthly, in order to minimize data loss due to instrument failure. Data was 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.

We had expected the second oxygen meter to be deployed by mid-May 1990 at Shell's WD32E but we were delayed until mid-June. Data were recovered from mid-June through mid-October, when the mooring was taken out of the water. The delay in receipt of the second meter caused problems in that not as complete an oxygen record was available as anticipated or desired for the WD32E area.

Oxygen meter data for all study sites was supplemented with CTD/DO casts (conductivity/temperature/depth and dissolved oxygen) at monthly intervals during the study, or during other hypoxia studies of Rabalais and colleagues.

3.3 Ancillary Studies

Several additional sources of funding and activities related to the distribution and dynamics of hypoxia were conducted concurrently and subsequently to this MMS/LUMCON University Initiative project. Funding from the Louisiana Board of Regents LEQSF initiated the instrument mooring at ST53B, monthly cruises during 1989 and 1990, and a shelfwide survey in 1990. Funding from the NOAA NECOP program to Drs. Rabalais, Turner and Wiseman continued the primary instrument mooring and monthly and shelfwide cruises in 1990 and 1991. N. N. Rabalais collaborated with Dr. Donald E. Harper, Jr. of Texas A&M University of Galveston, under auspices of the NOAA NECOP program to follow the post-hypoxia recovery period and the spring recruitment period of the stations sampled for the MMS-University Initiative study and to continue a single station into the subsequent hypoxic period. We further proposed to compare the results of the ongoing investigation with previous studies from the southeastern Louisiana shelf to areas off the southwestern Louisiana coast and the upper Texas coast, where hypoxia is more of an ephemeral event, not necessarily occurring every year. Additional projects were funded by the NOAA NURC program (with remotely operated vehicle (ROV) and diving experiments and observations) to study benthic and demersal communities in relationship to hypoxic bottom waters during mid-summer 1990. Supplemental vessel rental funds were obtained from the Louisiana Sea Grant College program to support the extra collections of benthos during post-hypoxia and the following recruitment period. An unfunded ancillary project was conducted at a single station (C6A) to examine the vertical distribution of foraminiferans and macroinfauna through time in 1990 and 1991.

These various programs provide a much more informative and broader description of the effects of hypoxia on benthic fauna over a 2-year period. Several of these other programs are nearing completion or are still in analyses phases. The focus of this report will be upon those samples collected as part of the MMS/LUMCON University Initiative, at the four designated platforms, for the collections in 1990 during hypoxia, with some additional information provided for post-hypoxia recovery (NOAA NECOP work of Rabalais and Harper).

CHAPTER 4. METHODS

4.1 Field Studies

Field surveys were conducted during 16-18 April, 15-17 June, 16-18 July, 14-16 August, 17-20 September, and 15-18 October at the three or four study sites. Additional samples for hydrographic data were taken in the vicinity of the study sites at other times during 1990, and on a broad-scale on the southeastern shelf during two cruises in July 1990. 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, or TDs, were recorded from both Loran C units for intercomparison of navigation data. Station distances from each platform were placed as closely as possible at 20, 50, 100, 250, 500, 750 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. The platform and station configurations are shown in Figures 4-6.

At all study sites, hydrographic profiles were obtained from at least one station during each sample period. With the exception of July synoptic 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 broad-scale 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.

Continuous oxygen measurements were recorded with Endeco 1184 oxygen meters deployed approximately 0.5- to 1-m from the bottom at Unocal ST53B and Shell WD32E. The oxygen meter at Unocal ST53B was supplemented with near-surface and near-bottom particle traps and current meters with CT probes; the heavily instrumented mooring was part of the hypoxia studies of Rabalais, Turner and Wiseman. 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 values as needed or to delete any suspect data.

Sediment 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. Similar samples were taken for surficial sediment radionuclides, but refrigerated for return to the laboratory. Sediment samples for hydrocarbon and trace metal analyses were taken in triplicate (60-cc piston core down to 5 cm) from a single box core and combined in a solvent-cleaned glass jar, refrigerated, and returned to the laboratory for analysis.

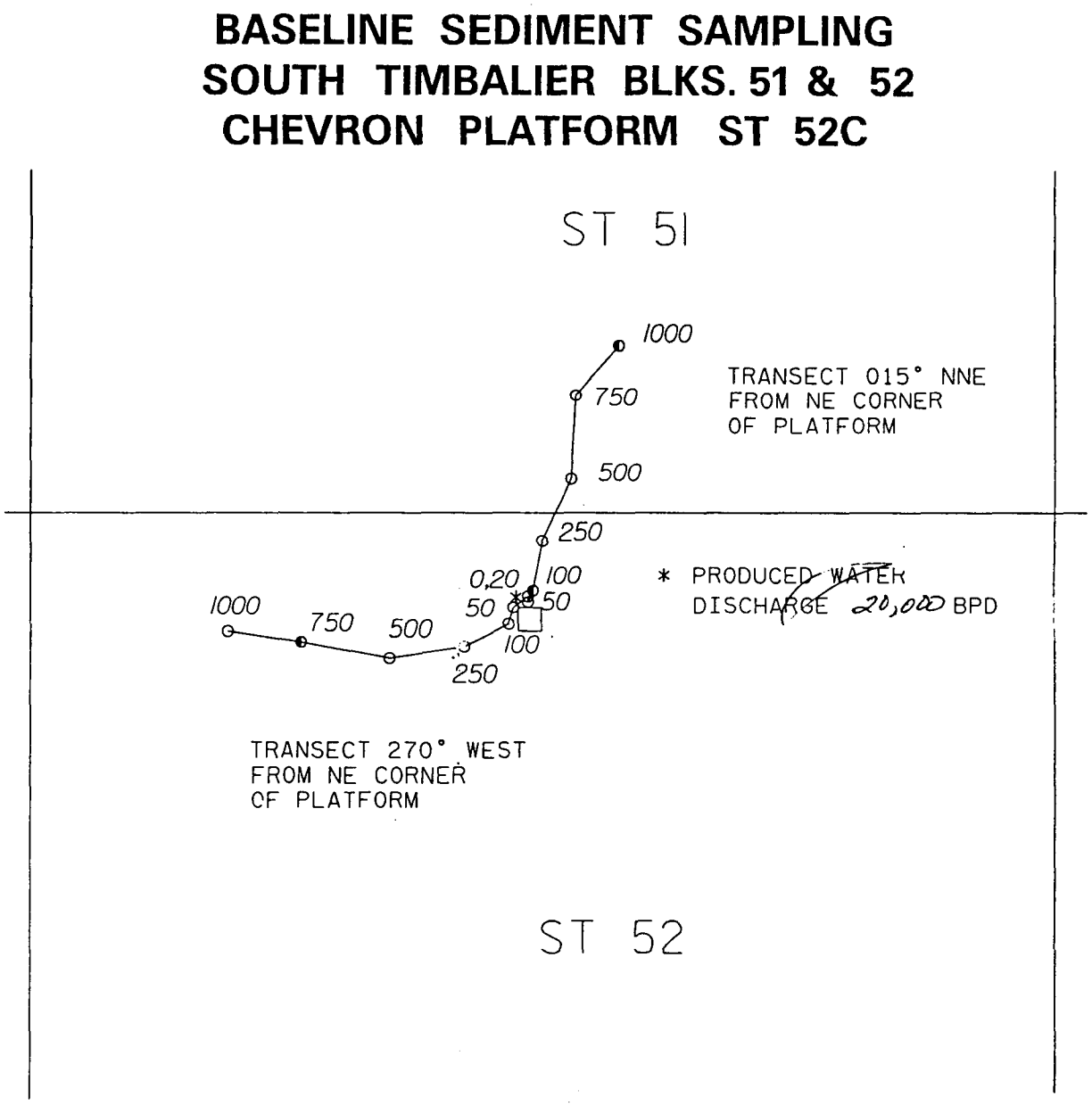

Figure 4. Location of transects and stations away from Chevron U.S.A., Inc. South Timbalier 52 A complex, "C" platform (=CV).

BASELINE SEDIMENT SAMPLING
SOUTH TIMBALIER BLK. 53
UNOCAL PLATFORMS ST 53, A/A AUX AND ST 53 B

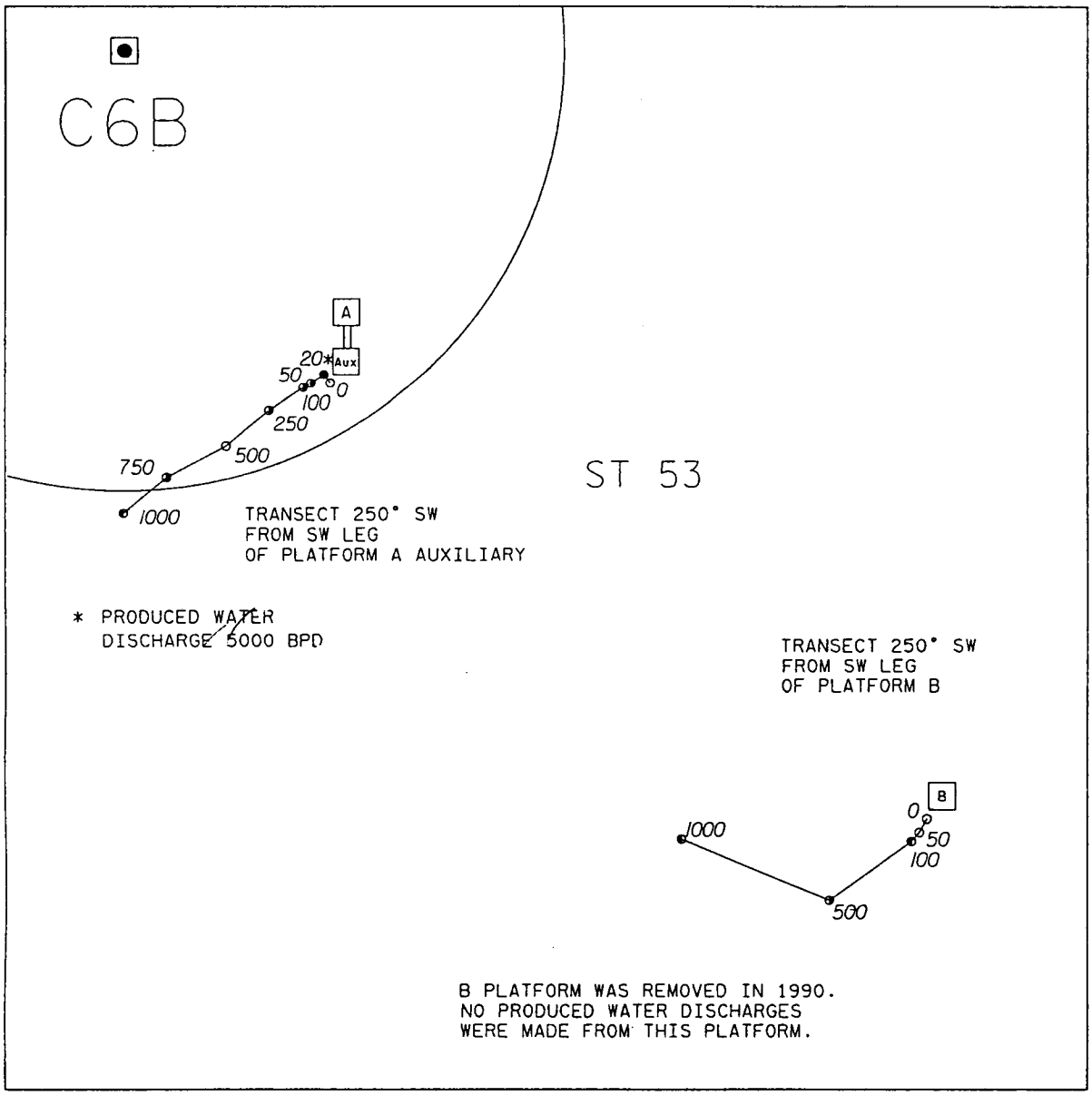

Figure 5. Location of Unocal South Timbalier 53A and A-Aux. and 53B, transects and stations.

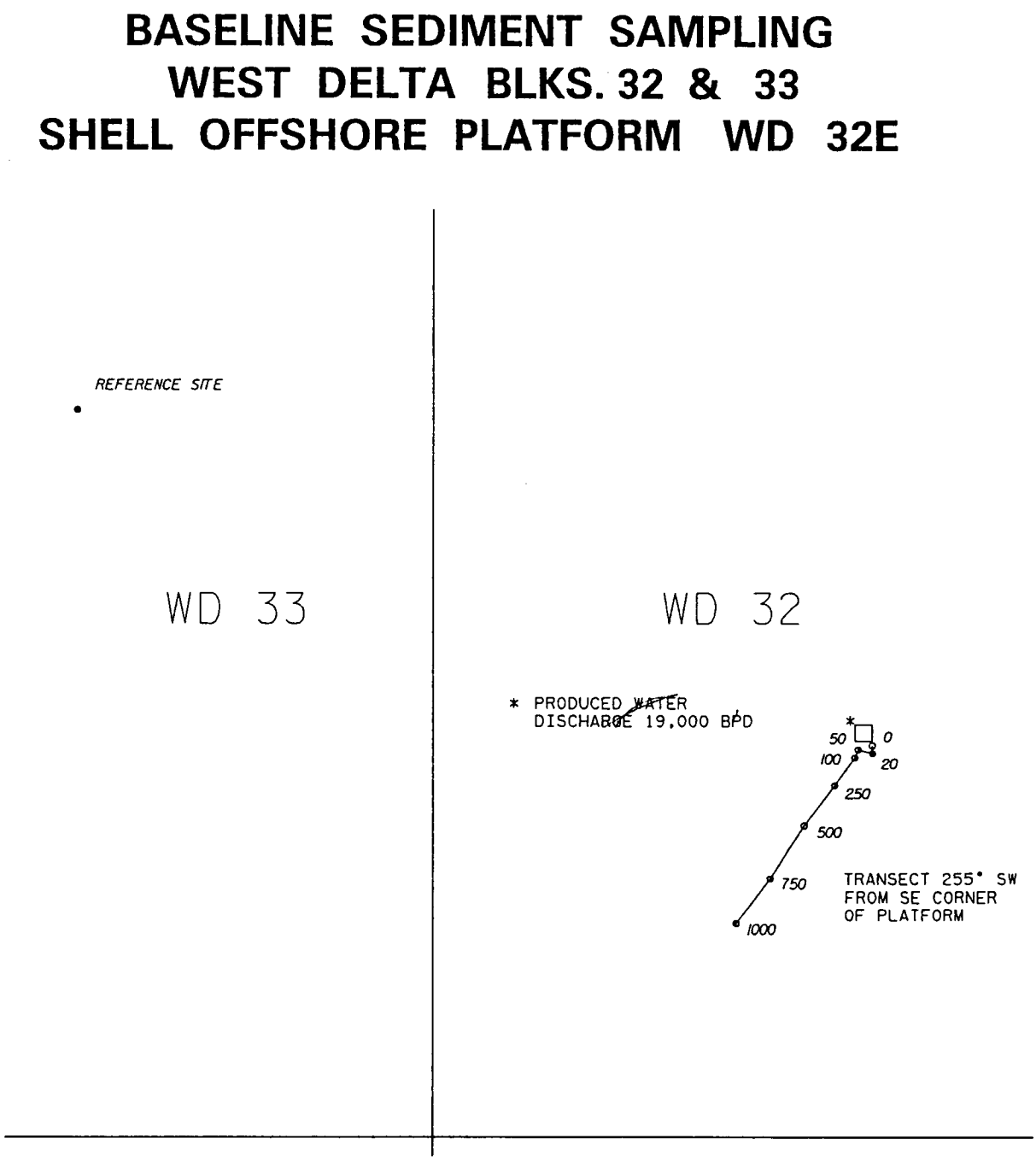

Figure 6. Location of Shell Offshore Inc. West Delta 32E platform with transect and stations and reference station in West Delta block 33.

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.

4.2 Laboratory Analyses and Quality Control

4.2.1 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 60-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.

4.2.2 Hydrocarbons

Hydrocarbons are ubiquitous in marine sediments and originate from sources that are 1) biogenic, including marine and terrestrial inputs, 2) petrogenic, anthropogenic inputs of petroleum from a variety of sources and also natural petroleum inputs, 3) pyrogenic, from incomplete combustion of fossil fuels and contemporary organic matter as well as from natural combustion processes, and 4) diagenetic, the production of hydrocarbons from other organic molecules through mediation of time, temperature or microbial activity (Boehm and Requejo 1986). The hydrocarbon assemblage of any marine sediment usually consists of a mixture of these source materials. The distribution of organic constituents in general, and hydrocarbons in particular, in continental shelf sediments are usually related directly to total organic carbon content and inversely related to grain size (Boehm and Requejo 1986). Particular attention in this study was devoted to the total saturated hydrocarbon concentration (resolved and unresolved), semivolatile analyses, the relative proportion of alkylated polynuclear hydrocarbons and parent polynuclear hydrocarbons, and a fossil fuel pollution index.

Sediment samples for hydrocarbon analyses were extracted and analyzed by the LSU Institute for Environmental Studies under the direction of E. B. Overton. The sediments were extracted using a sediment tumbled extraction method (MacLeod et al. 1985) and analyzed using a Hewlett Packard Model 5890 gas chromatograph equipped with a J&W, 30 m, DB-5 capillary column and interfaced directly to a Hewlett Packard 5970B mass spectrometer (GC/MS). The

mass spectrometer was used in selected ion monitoring mode to produce extracted ion chromatograms (EIC) in order to detect trace quantities of analytes in complex matrices. Concentrations are recorded per gram dry weight of sediment. Results of analyses of analyte-spiked sediments verified that the analysis produced compound recoveries which were generally within EPA (U.S. Environmental Protection Agency) acceptance criteria. In the few cases of spike recovery data which were outside the acceptance criteria, the deviation was at the upper end (> 100% recovery) in a sample for which the lack of duplicate analyses made the non-spike analyte concentrations less precise than in all other cases.

Semivolatile hydrocarbon analysis targeted a combination of compounds (see lists in Appendix D) that were chosen because of 1) relative abundance in petroleum sources such as crude oil and produced water, 2) potential to partition into the sediments and accumulate due to low water solubilities, and 3) persistence in the environment (Rabalais et al. 1991a). In addition to petrogenic compounds, common pyrogenic compounds (i.e., fluoranthene, pyrene and higher molecular weight polynuclear aromatic compounds (PAH)) were identified to aid in differentiating the contaminant source. Sums of analytes are often used to distinguish 1) pyrogenic PAH, which are the parent or non-alkylated PAH sources from the combustion of fossil fuels, although some parent compounds, such as naphthalene and phenanthrene are also in crude oil, and 2) alkylated PAH, which are various levels of alkylation of the parent PAH and are important constituents of the petroleum hydrocarbons.

The fossil fuel pollution index (FFPI) (Boehm and Farrington 1984) indicates the relative percentage of petroleum-derived hydrocarbons of the measured total PAH. The index is based on the distribution of PAH in petroleum, which contains a relative abundance of alkylated homologs of naphthalene, phenanthrene and dibenzothiophene compared to their unalkylated parent compounds. Crude oil would have an FFPI of about one. As the petroleum-derived hydrocarbons decrease and/or the pyrogenic hydrocarbons increase, the index is reduced. A value of 0.5 along the continuum from 0 to 1 is considered the boundary between petrogenic and pyrogenic characterization. The FFPI used for this study is derived from that of Boehm and Farrington (1984):

$$FFPI = [\Sigma\text{naphthalenes } (C_0\text{-}C_3) + \Sigma\text{dibenzothiophenes } (C_0\text{-}C_3) + 1/2\ \Sigma\text{phenanthrenes } (C_0\text{-}C_1) + \Sigma\text{phenanthrenes } (C_2\text{-}C_3)]/\Sigma PAH$$

C_n = number of alkyl carbons substituted

ΣPAH = sum parent PAH and alkylated naphthalenes, dibenzothiophenes, and phenanthrenes

Saturated hydrocarbons were determined by an extracted ion/internal standard method using mass 85. Total saturated hydrocarbons (aliphatics), total resolved saturated hydrocarbons and total unresolved saturated hydrocarbons were determined using a response factor based upon a standard containing nC-15 to nC-30 alkanes, pristane, phytane and squalane and hexamethylbenzene as a surrogate standard. Total resolved hydrocarbons were determined by a valley-to-valley integration technique, total saturated hydrocarbons by integrating the entire chromatogram, including the unresolved complex mixture, as a single peak. The total unresolved saturated hydrocarbons were determined by subtracting the resolved saturated hydrocarbons from the total.

4.2.3 Trace Metals

Sediment trace metal analyses were performed under the direction of R. P. Gambrell at LSU's Wetland Biogeochemistry Institute. The wet sediment was well mixed, and a 0.75- to 1-g

sample was dried, ground and then extracted for 6 hr with 10 ml of concentrated nitric acid, gradually increasing the temperature over an additional 2-hr period to a maximum of 130°C to complete the digestion. Heating was continued until 0.5 to 0.75 ml of acid remained. The acid was cooled, then brought to 35 ml with deionized water. The samples were sealed, the contents mixed thoroughly, and allowed to settle for a couple days to favor flocculation of clay particles and reduce the need for filtration The samples were analyzed on a Jarrell-Ash Model 855 inductively coupled argon plasma emission spectrometer (ICP). Reagent blanks and quality control samples were analyzed to check on possible reagent contamination and instrument performance. Elements analyzed included copper, zinc, cadmium, lead, chromium, nickel, iron, manganese, calcium, magnesium, arsenic, phosphorus, aluminum, potassium, sodium, barium and vanadium. [Mercury which requires a separate process was not analyzed.] Not all elements were analyzed for each sediment sample, but the major elements expected to be present in produced waters (Rabalais et al. 1991a) were. All elements, with the exception of barium and vanadium, were analyzed on a fixed detector. For barium and vanadium, a variable emission wavelength spectrometer and detector, supplemental to the main instrument, was used. For the April and June Ba and V samples, two different ICP instruments on the LSU campus were used to confirm the performance of the primary instrument located in the Wetland Biogeochemistry Institute. Most samples were analyzed in duplicate, and the average values are reported (Appendix C).

4.2.4 Radionuclides

Because previous studies have indicated that Pb-210 inventories in surficial sediments may not be a useful environmental variable to characterize the dispersion of a production platform's effluent (Rabalais et al. 1991a), a selected number of surficial sediment samples were sent to International Technology Corp., Oak Ridge, Tennessee, for analysis. In addition, because of regulatory concerns over produced sand discharges, Shell Offshore Inc. processed a series of sediment samples from this MMS/LUMCON University Initiative as well as other LUMCON hypoxia studies sediment samples for Ra-226 and Ra-228. Radium analyses were conducted by Shell Development Company, Bellaire Research Center, Houston, Texas and Core Laboratories, Casper, Wyoming (Randolph 1991, Randolph et al. 1992).

4.2.5 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. Quality control measures included resorting all samples. 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. Benthic macroinfaunal analyses were conducted under the direction of N. N. Rabalais.

4.3 Statistical Methods

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:

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

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).

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

The results of the field assessments were consolidated into a multi-component data base for characterizing the effects of production discharges and hypoxia on the sediments and benthic biota. The data base was developed so that information on each station/sample date was consolidated. General hydrocarbon and trace metal data were combined with hydrographic data, sedimentological data and benthic community data. Standard benthic community parameters, including number of species, number of individuals and measures of species diversity were entered into the data base.

The data provided the information needed to define the spatial and temporal scale of impacts. Differences in parameters (where replicated) were tested by analysis of variance and general linear model analyses (SAS Institute, Inc. 1982). Simple correlations and multiple regression analyses were used to relate species assemblage properties to location and environmental parameters. Where appropriate, multiple regression models were generated to determine the level of variability in the benthic community that could be attributed to the various environmental factors.

CHAPTER 5. CHARACTERIZATION OF ENVIRONMENTS

5.1 Conditions of Hypoxia

The 1990 season of hypoxia, as monitored off Terrebonne/Timbalier Bays and at ST53B (=C6A) in the hypoxia studies of Rabalais et al. (1991b, 1992b, unpubl. data) (Figure 1), was unusual from the previous five years in that hypoxia occurred earlier and more persistently in the spring, hypoxia was more severe through the summer months, hypoxic bottom waters occurred farther offshore and in deeper waters, long periods of anoxia were documented, and the generation of hydrogen sulfide in the bottom waters was recorded more often. For the only previous year in which bi-weekly or monthly samples were taken along the C transect for the entire year (1986), hypoxia occurred in mid-April to mid-June but in small patches and intermittently. For the few monthly samples available for 1989, hypoxia was not recorded until early August (Figure 7). The 1989 hypoxia season, however, was characterized by a tropical depression which entered the area in June and anomalous current patterns during spring 1989 when winds blew water consistently towards the east along the Louisiana inner shelf, opposite to the direction of normal flow (Wiseman et al. 1992).

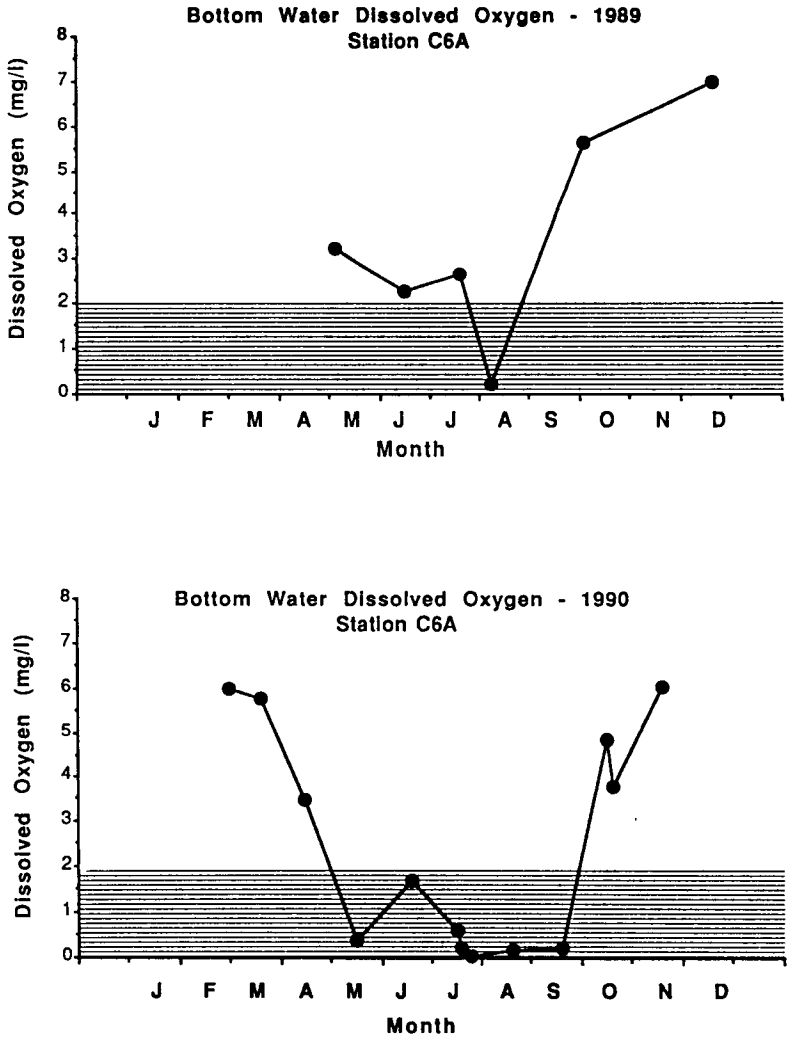

Figure 7. Comparison of temporal variation in near-bottom water oxygen concentrations for stations C6A in 1989 and 1990 (Rabalais et al., unpubl. data).

In 1990, monthly cruises along the C transect documented widespread, severe and persistent areas of hypoxia/anoxia (Figure 8). The oxygen meter also recorded persistent hypoxia, and often anoxia, at station C6A (=Unocal B, ST53B) for much of the record between 24 May and 15 October 1990 (Figure 9) (Rabalais et al. 1992b). The importance of stratification in the maintenance of hypoxia is evident from the differences in near-surface and near-bottom temperature, as a surrogate for density measures, in the time series for station C6A in 1990 (Figure 9). We observed the breakdown in stratification at the end of the hypoxic season and the associated reestablishment of oxygenated bottom water (Wiseman et al. 1992). Weaker mixing events, which did not fully destroy the stratification, were also reflected in increased bottom oxygen concentrations.

For those stations located in the vicinity of South Timbalier Blocks 52 and 53 (Chevron ST52C, Unocal ST53A = C6, and Unocal ST53B = C6A), dissolved oxygen concentrations in near-bottom waters among these platforms were very similar for any sampling period (Table 2). Hydrographic profiles were also similar for stations closest in time and location (Appendix A), as well as water column chlorophyll *a* and phaeopigment biomass and nutrients (Rabalais et al. unpubl. data reports). Continuous oxygen recordings were not available for Chevron ST52C and Unocal ST53A, but were assumed to be similar to that obtained for Unocal ST53B.

Table 2. Comparison of near-bottom oxygen concentrations at study sites during 1990. Values closest in time and location bracketed.

Platform	Date	Time	Oxygen Concentration (mg/l)
Unocal ST53A	4/16/90	1046	2.78]
Unocal ST53B	4/16/90	1410	3.50]
Chevron ST52C	4/18/90	0220	2.77
Shell WD32E	4/18/90	0825	4.73
Unocal ST53A	5/17/90	2341	0.26]
Unocal ST53B	5/17/90	1653	0.40]
Unocal ST53A	6/16/90	0630	0.80]
Unocal ST53A	6/17/90	1445	0.92]
Unocal ST53B	6/17/90	1020	1.69]
Shell WD32E	6/15/90	1531	0.26
Shell WD32E	7/11/90	1813	0.82
Unocal ST53B	7/16/90	1437	0.19
Unocal ST53B	7/18/90	2305	0.42
Unocal ST53B	7/24/90	1640	0.33
Shell WD 32E	7/17/90	2045	3.06
Unocal ST53A	8/15/90	1231	0.28
Unocal ST53A	8/16/90	1410	0.24]
Unocal ST53B	8/16/90	1020	0.18]
Shell WD32E	8/14/90	1422	2.06
Unocal ST53A	9/17/90	1240	0.25]
Unocal ST53B	9/17/90	1330	0.22]
Unocal ST53A	9/20/90	0715	0.20]
Unocal ST53B	9/20/90	0835	0.17]
Shell WD32E	9/19/90	1140	2.15
Unocal ST53B	10/15/90	1120	4.86
Unocal ST53A	10/16/90	1250	3.85]
Unocal ST53B	10/16/90	1340	3.80]
Unocal ST53A	10/18/90	0530	2.34
Shell WD32E	10/17/90	1545	1.96

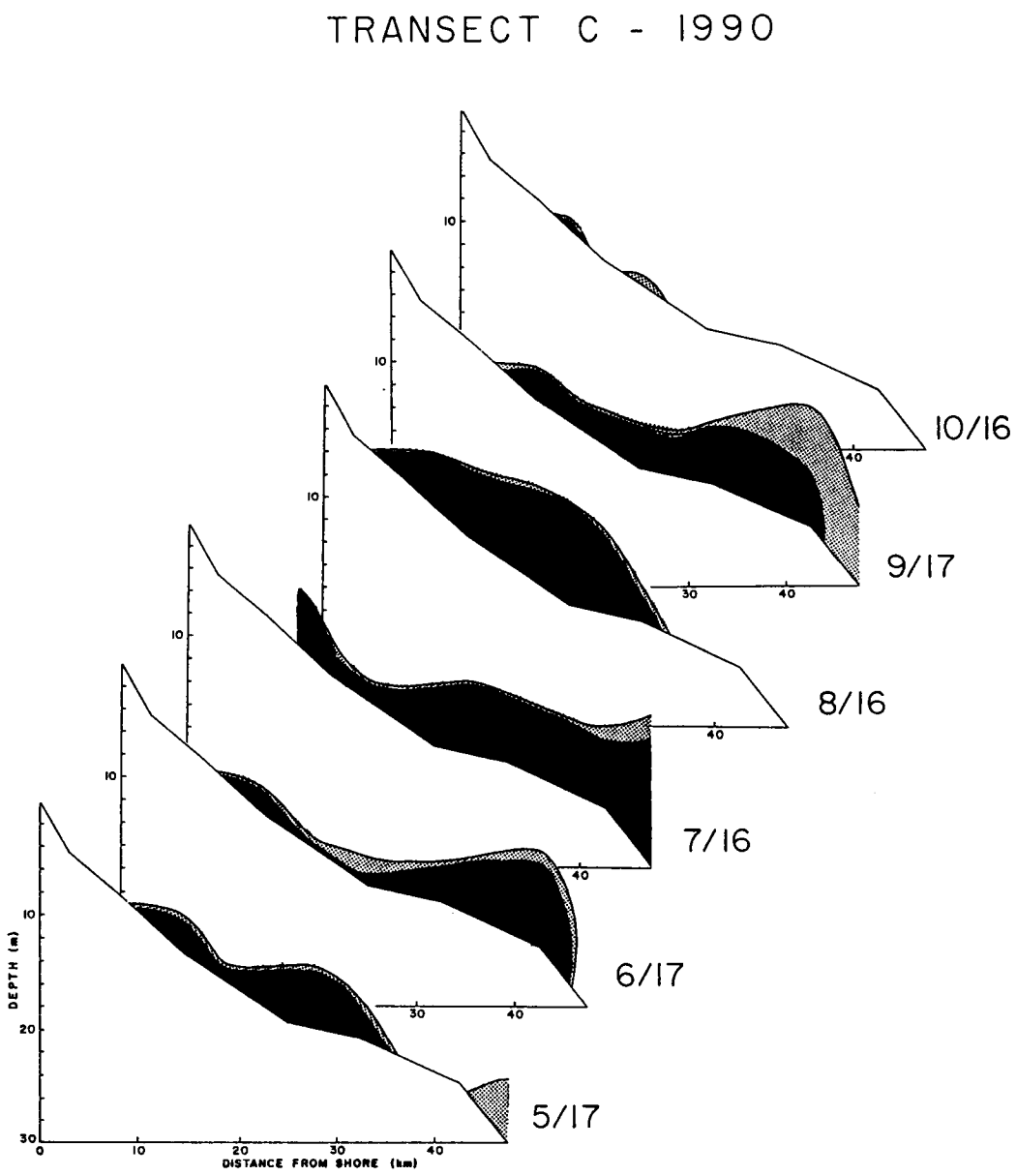

Figure 8. Time sequence of cross-shelf profiles for transect C in 1990 with stippled area indicating values of oxygen < 2 mg/l and dark areas, values of oxygen < 1 mg/l (modified from Rabalais et al. 1992b).

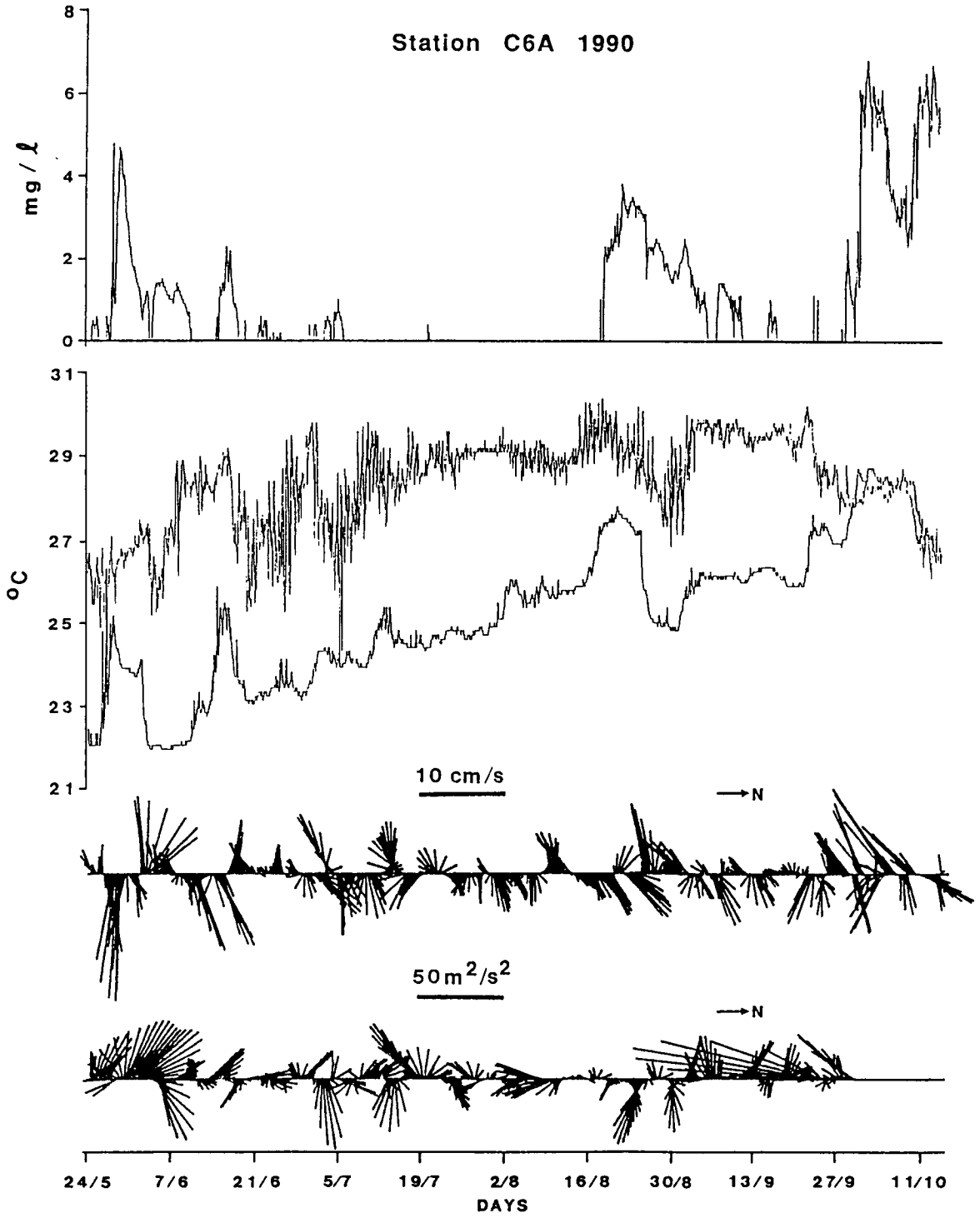

Figure 9. Time series (from top to bottom) of near-bottom dissolved oxygen, near-surface and near-bottom temperature, low-passed near-bottom currents and wind pseudo-stress. Stick diagrams have been rotated 90° clockwise. Period of record is May 24, 1990 through October 15, 1990. (From Rabalais et al. 1992b, Wiseman et al. 1992).

The flow of the Mississippi River was high for 1990, with a crest in March and another in June (Figure 10). The long-term average period of high flow is in April. Surface salinities at the mooring site in 1990 were considerably lower than normal (Figure 2) in March, April and June. The unusually high volume of freshwater present on the shelf late into spring and early summer contributed to greater intensity of density stratification.

On a shelfwide scale for mid-summer 1990, hypoxia was widespread along the southeastern Louisiana shelf between Barataria and Atchafalaya Bays, but not so much on the southwestern Louisiana shelf (Figure 1). The size or areal coverage was similar to previous and subsequent years, but the configuration of the areas was different. The area of hypoxia in the Mississippi River Delta bight near Shell's West Delta 32E platform (also near stations A3 and A4 of Rabalais et al., Figure 1) was constricted to a narrow depth range between the birdsfoot delta and Caminada Pass. Also the interface of normoxic/hypoxic waters is often near stations A3 and A4 (Figure 1 for 1991, and similar distributions for 1987, 1989 and 1991). Based on the mid-summer synoptic surveys, it appears that there is more variability in the configuration of the hypoxic area within the Mississippi River Delta bight than in the area off Terrebonne/Timbalier Bays. It may not be surprising, therefore, that the continuous oxygen record for West Delta 32E shows incursions in and out of hypoxic conditions, with no extremely low levels for prolonged periods (Figure 11).

Tidal currents on the northern Gulf of Mexico continental shelf are generally weak and diurnal. Tidal ellipses are generally oriented in the cross-shelf direction. Inertial currents and internal tides are also important in this region (Daddio et al. 1978). Time series analysis of the near-bottom oxygen record (Figure 11) for C6A indicates no consistent signal, because of the prolonged periods of anoxia in 1990. Where there was variation, however, the oxygen record contained brief bursts of diurnal energy; these were not of sufficient duration to determine if they were coherent with lunar or solar forcing (Wiseman et al. 1992). Coherence analysis of the longest available records (C6A, 1990, Figure 11) suggests a statistically significant association in the diurnal frequency band with the cross-shelf currents being coherent with the oxygen (Wiseman et al. 1992). A similar spectrum analysis of 3000 hours of the oxygen record for the same period at Shell WD32E produced clear peaks at the K1 and O1 tidal periods. This is not definitive evidence of tidal advection, because it would require more than one year of continuous record to allow separation of the K1 and 24-h peaks. The fact that the K1 and O1 peaks in the record are of similar magnitude strongly suggests an advective source for the peaks, since tidal analyses from this region also produce nearly equal amplitude K1 and O1 peaks. The incursions in and out of hypoxia indicate the WD32E platform was near the edge of a hypoxic water mass that moved across the area in response to tidal currents. The narrowness of the areal extent of hypoxia recorded in the mid-summer cruise in the vicinity of WD32E supports this observation.

5.2 Sedimentary Characteristics

As anticipated from the initial reconnaissance survey in April 1990, the sedimentary characteristics of the four 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 Figures 12-15 and detailed in Appendix B. Sediment TOC values (Appendix B) were consistently low across the study area, typically less than 1.0, were higher in the siltier sediments of the West Delta Blocks 32 and 33, and were also elevated where there were elevated concentrations of petrogenic hydrocarbons (see below). Sediment chlorophyll *a* and phaeopigment concentrations were consistent with season and distance from the Mississippi River (as described by Rabalais et al. 1992c), and spatially similar, where there were adequate values for comparison (Appendix B).

Despite two different transects being occupied at Chevron ST52C (15°NNE in April and 270°W in June), the sediment grain size distribution was uniformly a sandy silt composition with

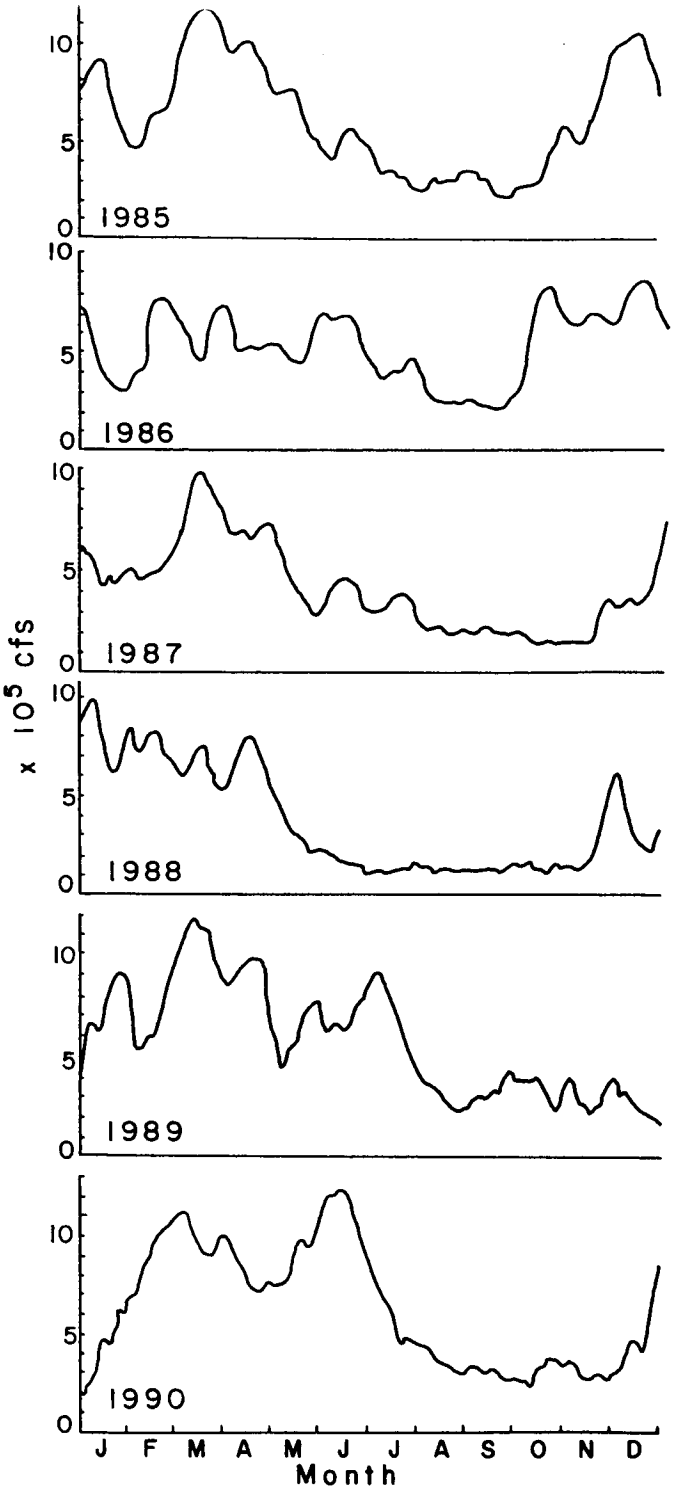

Figure 10. Average Mississippi River flow in 10^5 cubic feet per second (cfs) as recorded at Tarbert's Landing (Rabalais et al., unpubl. data).

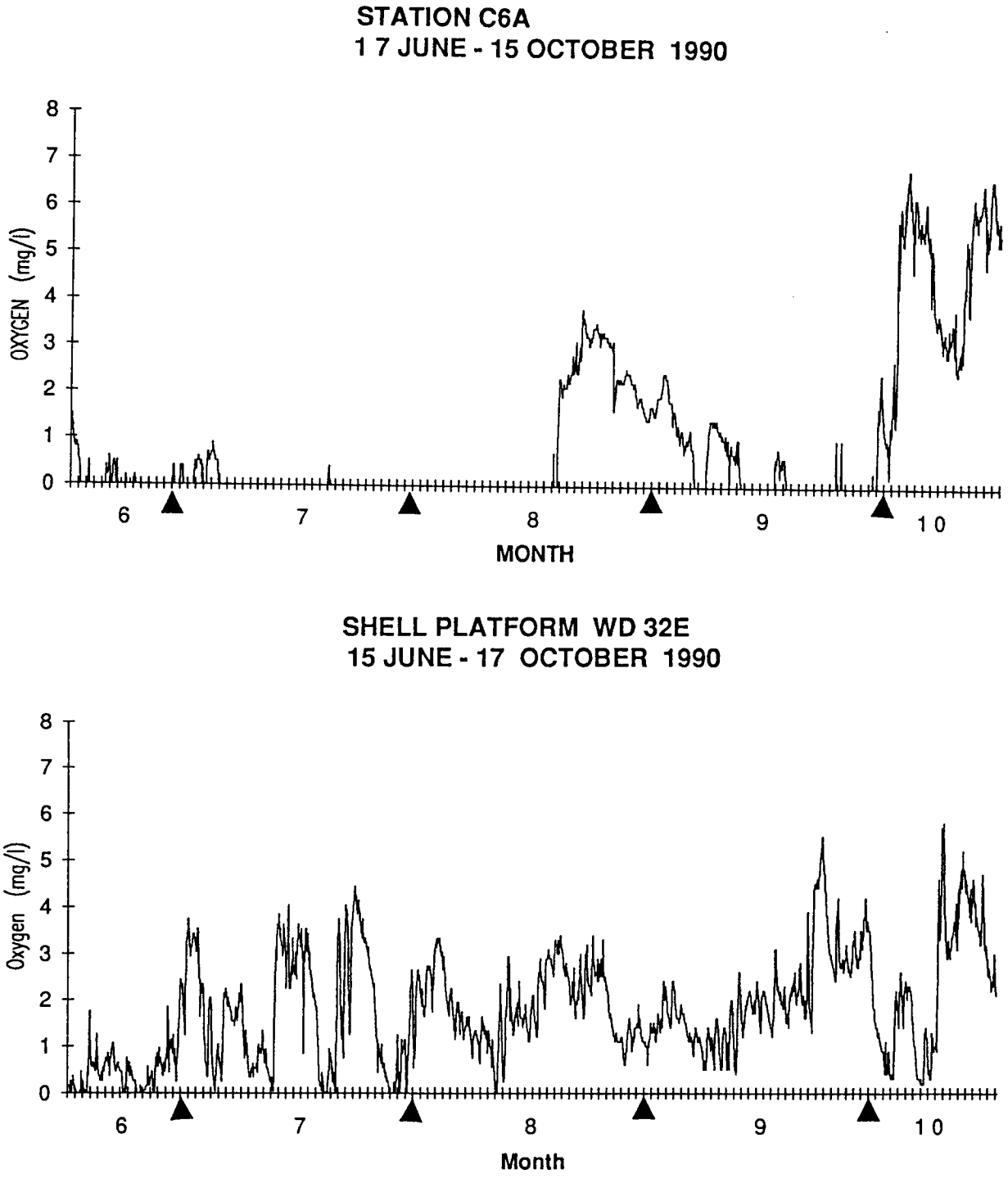

Figure 11. Time series of near-bottom dissolved oxygen for stations C6A (=UB) and WD32E (=SH) for the period indicated (Rabalais et al., unpubl. data).

little clay fraction (Figure 12). The distributions, however, do not illustrate the presence of large shell hash in the sediments at stations 20, 50 and 100 m that were removed prior to Coulter analysis. The percentage of sand increased with distance from the platform for both sample periods.

Sediments at Unocal ST53A (similar to ST52C) were predominantly sandy silts with little clay fraction, but the percentage of sand was greater than ST52C (Figure 13) for the two months of comparative data. There was also considerable variability spatially within a sample period and between sample periods with anomalously low sand percentage (1000 m in April and 100 m in June) or extremely high sand percentage (50 m in July). The percentage silt was greater in August-October at ST53A compared to April, June and July.

Unocal ST53B (the reference station for Chevron ST52C and Unocal ST53A) was the most variable in space and time with regard to sediment grain size distribution (Figure 14). Non-uniform and high percentages of sand or clay were not consistent with distance from the platform nor sample period. The percentage silt was greater in September and October at ST53B compared to April and June-August. 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 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 14, 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).

Sediments at Shell's WD32E platform were composed primarily of silts with some clay and sand, with the exception of stations closest to the platform (0, 20 and 50 m) where the sediment surface was impacted by sandblasting operations (Figure 15). At these times, anomalously high percentages of coarse-grained sands were present. These sediment differences so close to the platform complicated the interpretation of both chemical contaminant and benthic infaunal data.

5.3 Chemical Contaminants

5.3.1 Radionuclides

Limited surficial sediment samples were analyzed for a three radionuclides: Pb-210, Ra-226 and Ra-228, all three constituents of produced waters (Reid 1983, Rabalais et al. 1991a). Surface sediment Pb-210 activities in coastal environments are typically 1 pCi/g dry wt (Rabalais et al. 1991a), depending on many factors controlling the sorption reactions (e.g., grain size, percent organic carbon, turbidity in overlying waters). The values for the Shell WD32E, Unocal ST53A and Unocal ST53B samples were below this level (Appendix B). Little background information is available for Ra-226 and Ra-228 in continental shelf sediments (Randolph 1991, Randolph et al. 1992). The mean value for Ra-226 in sediments collected in the proximity of produced water discharges is 0.78 pCi/g dry wt (Randolph et al. 1992). Values for this study ranged from 0.0 to 4.0 pCi/g dry wt (Randolph 1991, Appendix B); higher values of 3.0 (Shell WD32E Reference, July 1990) and 4.0 (Chevron ST52C 20 m, June 1990) were not found in sediments associated with higher levels of petrogenic hydrocarbons. Values for Ra-228 ranged from 0.0 to 2.1 pCi/g dry wt (Randolph 1991, Appendix B).

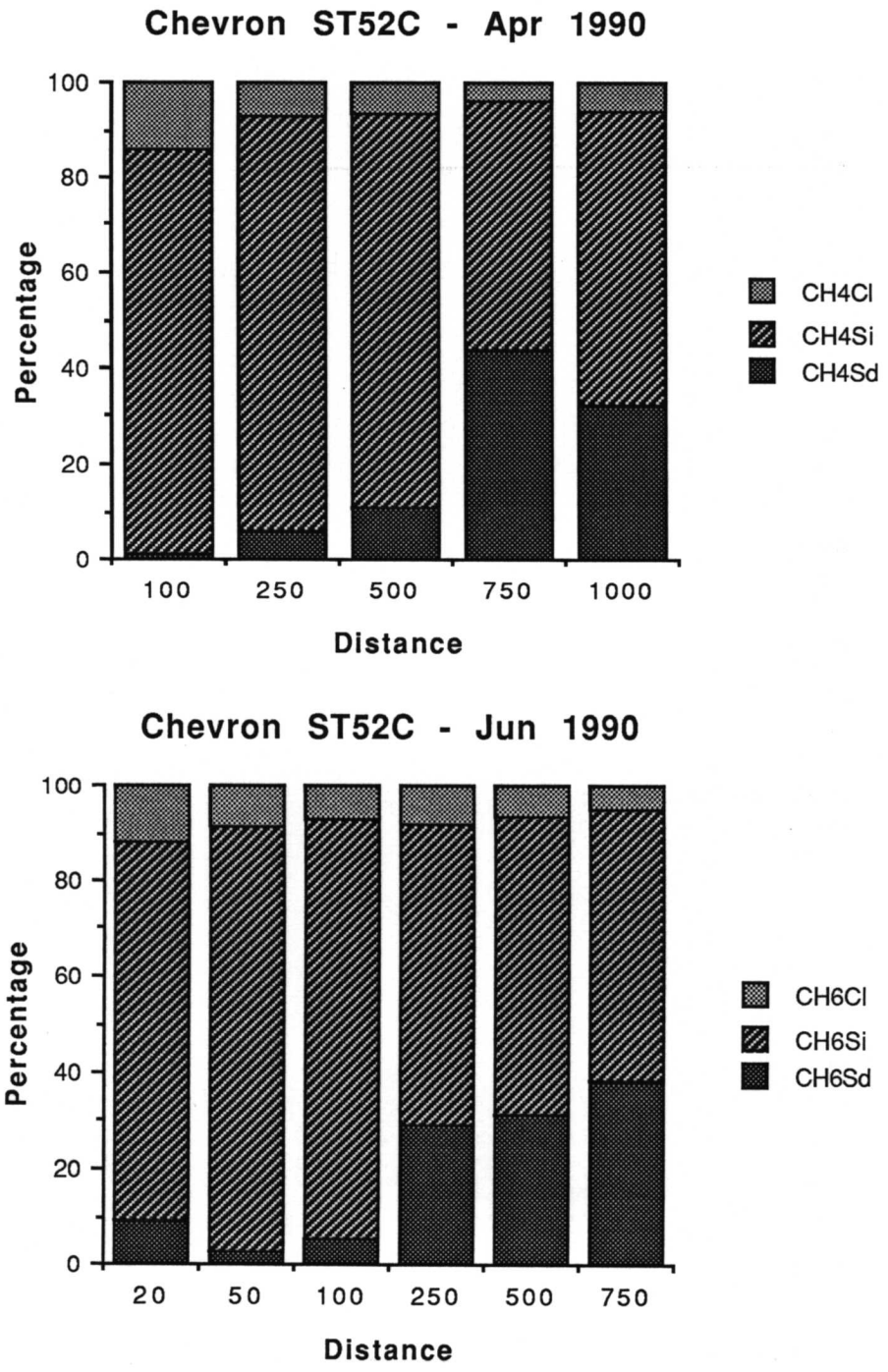

Figure 12. Percent composition of sand (Sd), silt (Si) and clay (Cl) for Chevron ST52C for periods indicated.

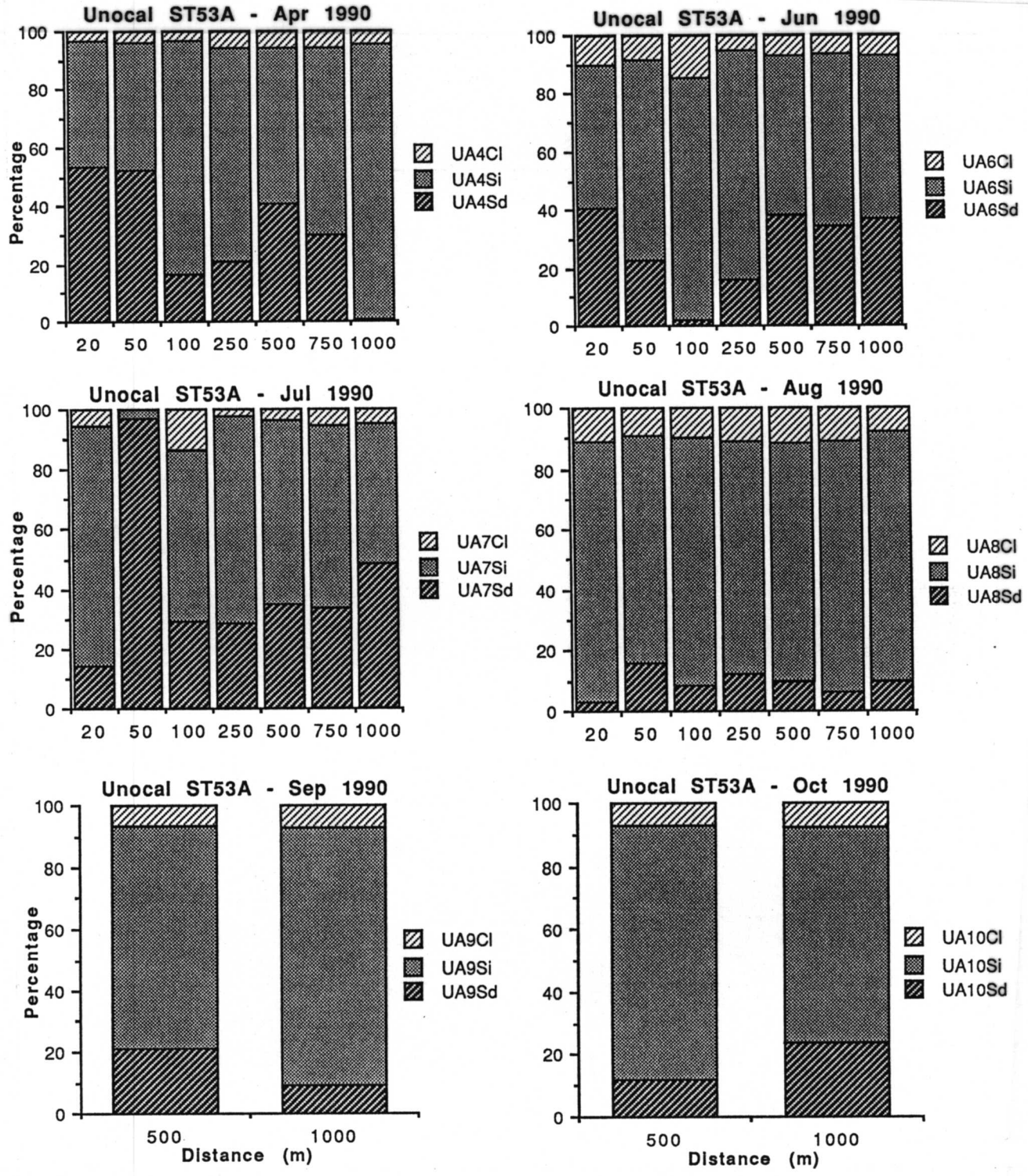

Figure 13. Percent composition of sand (Sd), silt (Si) and clay (Cl) for Unocal ST53A for periods indicated.

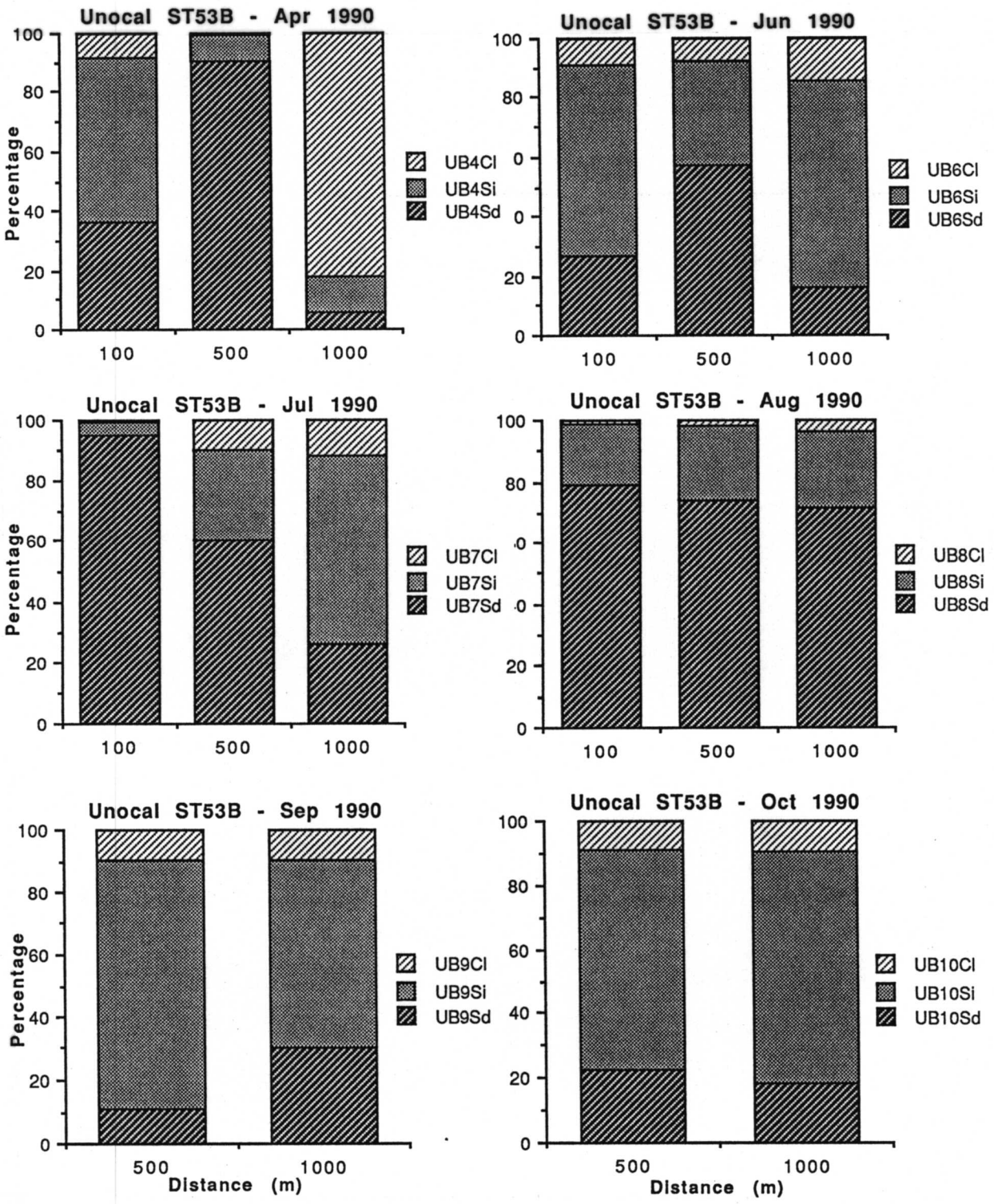

Figure 14. Percent composition of sand (Sd), silt (Si) and clay (Cl) for Unocal ST53B for periods indicated.

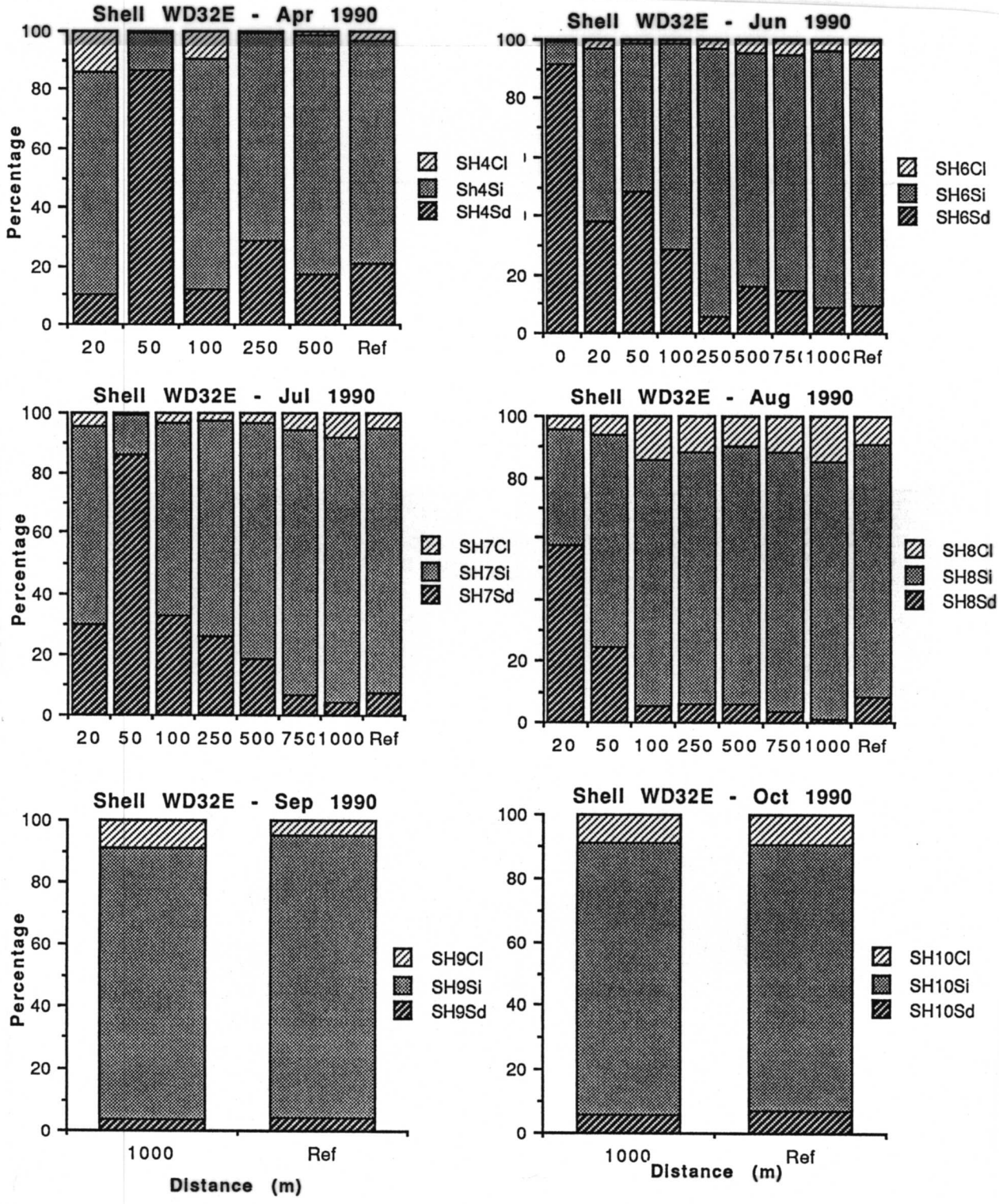

Figure 15. Percent composition of sand (Sd), silt (Si) and clay (Cl) for Shell WD32E for periods indicated.

5.3.2 Trace Metals

Metals which are reported to be elevated in produced water discharges are aluminum (Al), iron (Fe), barium (Ba), vanadium (V), nickel (Ni), chromium (Cr), copper (Cu), arsenic (As), lead (Pb), zinc (Zn), and mercury (Hg) (Rabalais et al. 1991a). Concentrations of selected metals in sediments were examined in greater detail because prior studies had indicated their presence in the vicinity of produced water discharges (Rabalais et al. 1991a). Barium, a constituent of drilling fluids (Neff et l. 1987), is commonly found in sediments adjacent to both drilling and production platforms.

For April and June, two transects 15°NNE and 270°W, respectively, were sampled at Chevron ST52C. In general, there was a decrease in the concentration of most metals with distance from the platform, for both months (Appendix C). As noted earlier, however, there was also a general increase in sand and decrease in fines along both transects with distance from the platform (Figure 12). Ba and Zn were elevated above background levels within 500 m of the platform in both months. The transect occupied in June (270°W) and in the expected direction of long-term current flow away from the platform had in general overall elevated values of Fe, Al, Ba, Cd, Cr and V over those detected along the 15°NNE transect in April. Grain size distributions along the two transects were similar between the two months, and these differences in metals concentrations could not be related to temporal differences in sediments.

There were no clear gradients in concentrations of metals away from the Unocal ST53A platform for the four months sampled (Appendix C). Where metals were elevated these differences could usually be attributed to differences in grain size distribution. For example, sediments at 100, 250 and 1000 m in April were elevated in most metals, but these stations also had the lowest percentage sand composition. Elevations in metals at the 1000-m station in June could not be attributed to any differences in grain size. Levels for all elements for Unocal ST53A 250 m, June 1990 were high compared to surrounding samples. A re-examination of sample weight and calibration samples around that sample showed the measurements to be authentic (R. Gambrell, pers. comm.). There is no apparent explanation for the elements in this sample all appearing high. For the 20 and 100 m stations in July, some metals were elevated above others; in this case the 20-m station contained little sand, and the 100-m station had a similar sand content but much greater clay content than most other stations in that and other months.

Values for most metals for all months at all stations at Unocal ST53B, the reference station for South Timbalier area, were not unlike the variability seen in the metals concentrations for sediments at Unocal ST53A (Appendix C). Values in general were lower for Unocal ST53B compared to Chevron ST52C, but sediments at ST52C contained a greater percentage of silts and less sands than ST53B.

For Shell WD32E there were elevated levels compared to background and those reported for a similar, but shallower continental shelf environment (Eugene Island Block 18, Rabalais et al. 1991a), for Zn and Pb within 50 to 100 m from the platform (Appendix C, Figure 16). For the Eugene Island study area, Zn concentrations of 100 to 150 µg/g within 200 m of the platform were the high concentrations; at WD32E values approached and exceeded 200 µg/g for three of the four months. With the exception of the 0-m and 50-m stations which had high sand content, sediments were primarily silts, with a decrease in the sand content with distance from the platform (Figure 15). Mn and V increased with distance from the platform in all months. With the exception of an elevated Cr concentration at 0 m in June, this metal also decreased with distance from the platform. There were no patterns in Fe, Al, Ba, Cu, Cd, and Ni with distance from the platform.

Metal content of sediments are related to sediment texture. Trace and toxic metals are more strongly associated with the fine, clay and silt particles, and the naturally occurring organic matter that tends to be found with this size fraction. Textural variability can contribute to considerable

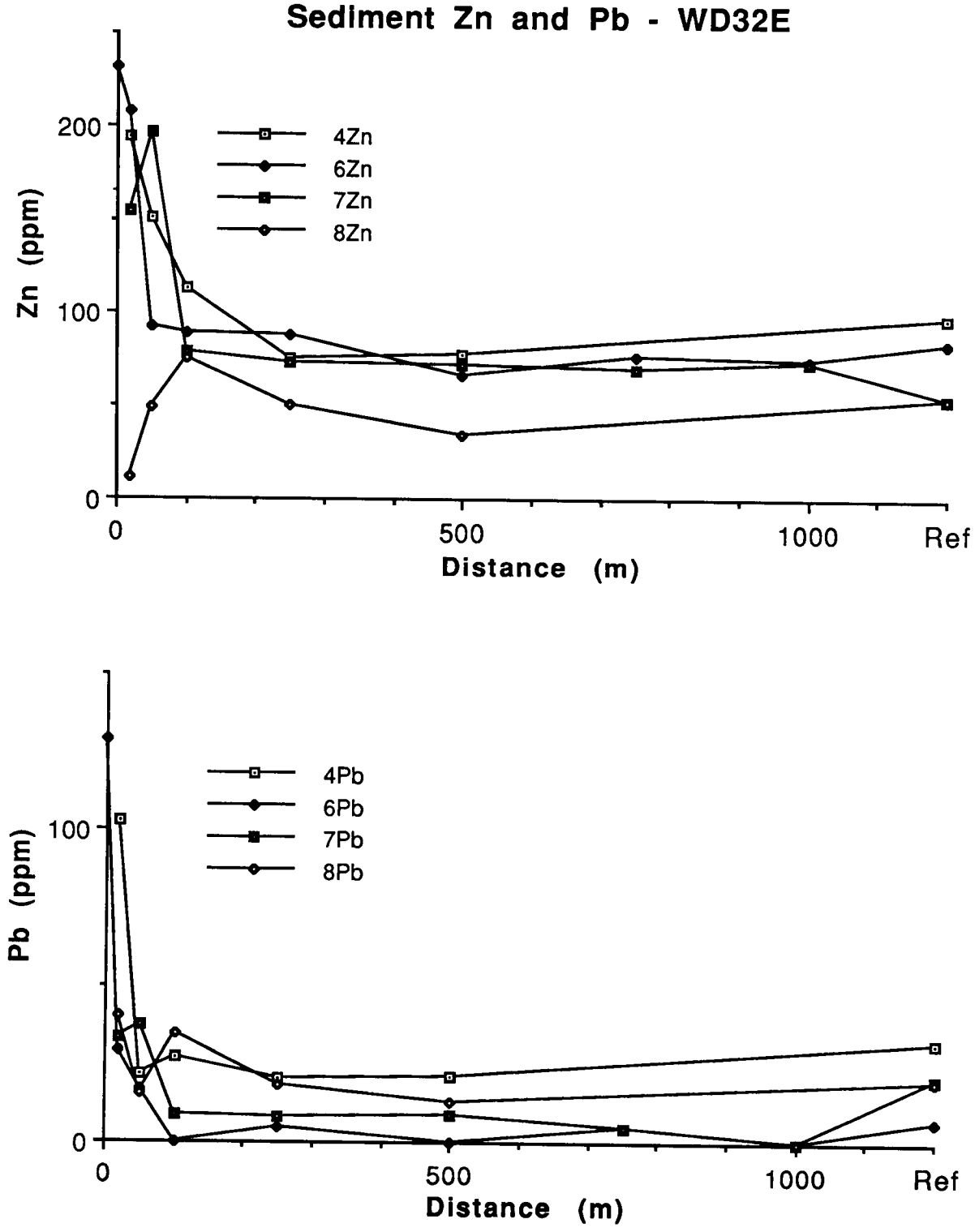

Figure 16. Distribution of Zn and Pb in sediments adjacent to Shell WD32E for months of April (4), June (6), July (7) and August (8).

variability in observed metals levels but can be normalized to non-pollutant elements typically found with weathered clays in high concentrations. Such metals, especially Fe and Al, will indicate something about texture differences. Consideration of the concentration of other metals in relationship to Al (Schropp et al. 1990) has become a standard method for identifying enrichment of metals above background levels. Two problems, however, are evident in conducting such an analysis: 1) a large number of samples must be collected from the site to ensure statistical reliability, and 2) most of the samples must come from non-contaminated areas. In our study, only Pb and Zn were of sufficient concentration (Shell WD32E) to apply this technique. The number of samples and range of Al concentrations in the sediments, however, were limited, and the range of Al concentrations in the WD32E environment were generally higher than those concentrations reported for other environments in Schropp et al. (1990). Our data could not be completely superimposed over the regression lines ± 95% confidence limits of Schropp et al. (1990), but metal concentrations clearly outside the limits were Pb > 100 ppm and Zn > 100 ppm.

Values for arsenic (As) were included for some samples but not others (Appendix C). Because the ICP works well in analyzing As for some samples (i.e., subsoil extracts and water samples) but very poorly for tissue digests and typical topsoils and sediments, data for As should be ignored (R. Gambrell, pers. comm.). Similarly, P data are not reported uniformly. Ca, Mg, K, and Na are naturally high constituents of sea water and not considered informative with regard to the fate of trace metals from production platforms. All of the above metals have been reported, however, in Appendix C.

5.3.3 Hydrocarbons

Hydrocarbons of all types were consistently more abundant in the June samples (270°W transect) than the April (15°NNE transect) at Chevron ST52C (Figure 17); the April hydrocarbon distributions were more characteristic of continental shelf sediments and were primarily biogenic. The westerly transect was in the direction of the expected current flow and dispersion of production platform effluents. Elevated levels along the westerly transect, and at two stations within the June 270°W transect could not be attributed to differences in grain size distribution (Figure 12). The April samples from ST52C showed no analyte concentration above 35 ppb (Table D.1); the June samples showed highest analyte concentrations at 50 m (5 to 300 ppb) and 250 m (10 to 100 ppb) (Table D.2). The FFPI ranged near 0.5 for most samples in both months. Alkylated PAHs exceeded parent PAHs in April, but were similar in makeup in June; summed PAH concentrations in June were 10 times greater than similar concentrations in April. Based on the results of a previous study of a continental shelf production platform (Eugene Island Block 18, Rabalais et al. 1991a), the summed PAH concentrations at 50 and 250 m in June (Figure 17) were at the threshold level ($\geq$ 450 ppb) where negative impacts could have affected the benthic infauna. The sediments at these two stations were considered "oiled" but not heavily. This study site was dropped from the overall sample design in July; however, because of the shell hash located within 100 m of the platform and thus dramatic differences in grain size along the transects, the change in transect direction between April and June, and the inability to reoccupy suitable stations during July.

The sediments adjacent to the Unocal ST53A platform contained hydrocarbons in low concentrations (Figure 18) of mostly a weathered petroleum or biogenic nature. For the April sample period, hydrocarbons in sediments at 20 m were a mixture, while farther out on the transect were primarily biogenic. The total saturated hydrocarbon concentrations were similar to those of the April (15°NNE) transect of the Chevron ST52C platform and did not approach the higher level of the June (270°W) transect for ST52C (Figure 17), although the transect from the ST53A platform (250°W) was in the direction of expected current flow and dispersion of platform effluents. The discharge of produced waters at ST53A was four times less than that of ST52C (5,500 bbl/d vs. 20,000 bbl/d). Although the FFPI often exceeded 0.5 for sediments at ST53A (Figure 18), no analyte concentration was above 50 ppb (Appendix D), and the summed alkylated

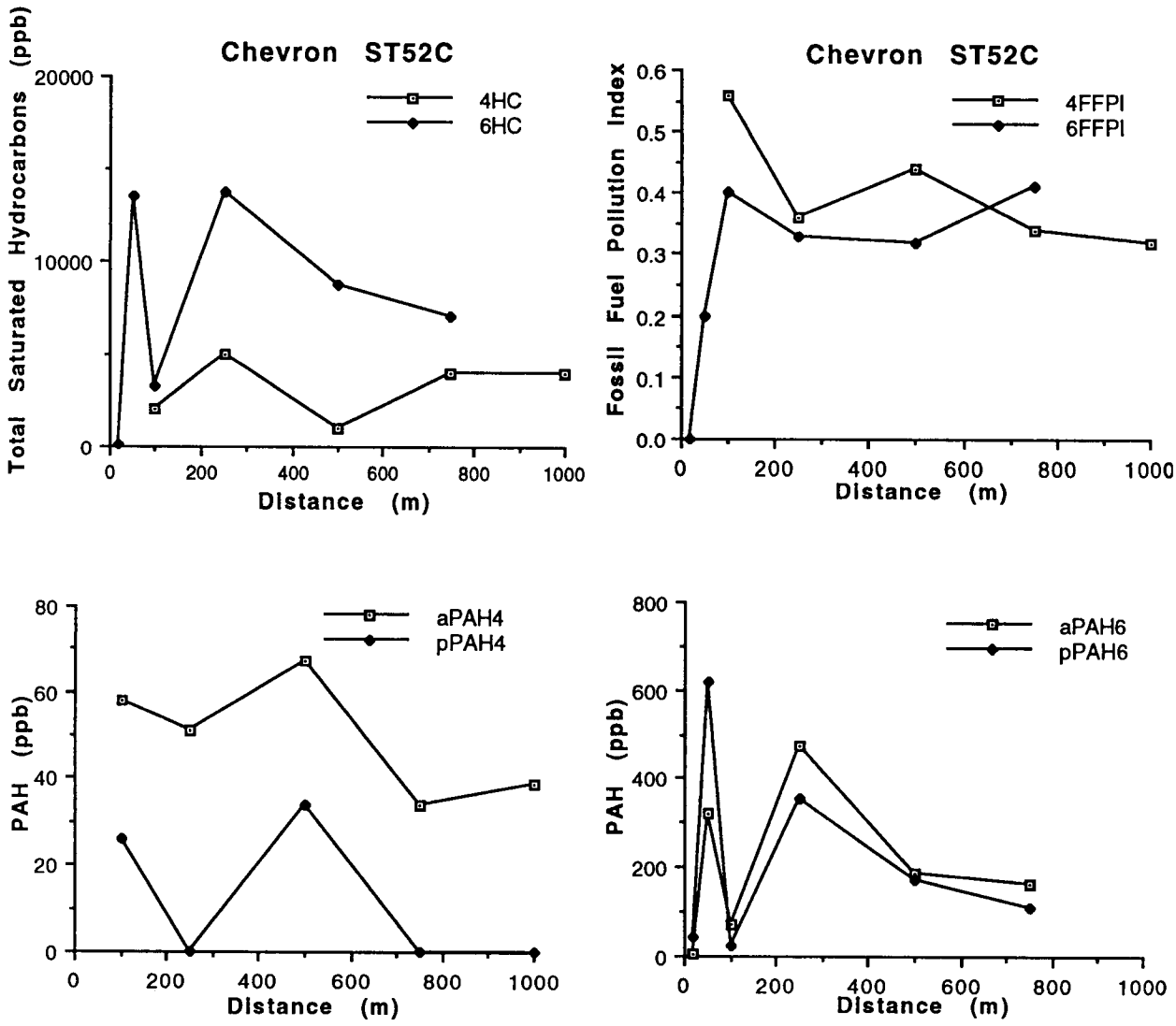

Figure 17. Distribution of total saturated hydrocarbons (HC), FFPI, summed parent PAH (pPAH) and alkylated PAH (aPAH) for months of April (4), June (6), July (7) and August (8) for Chevron ST52C.

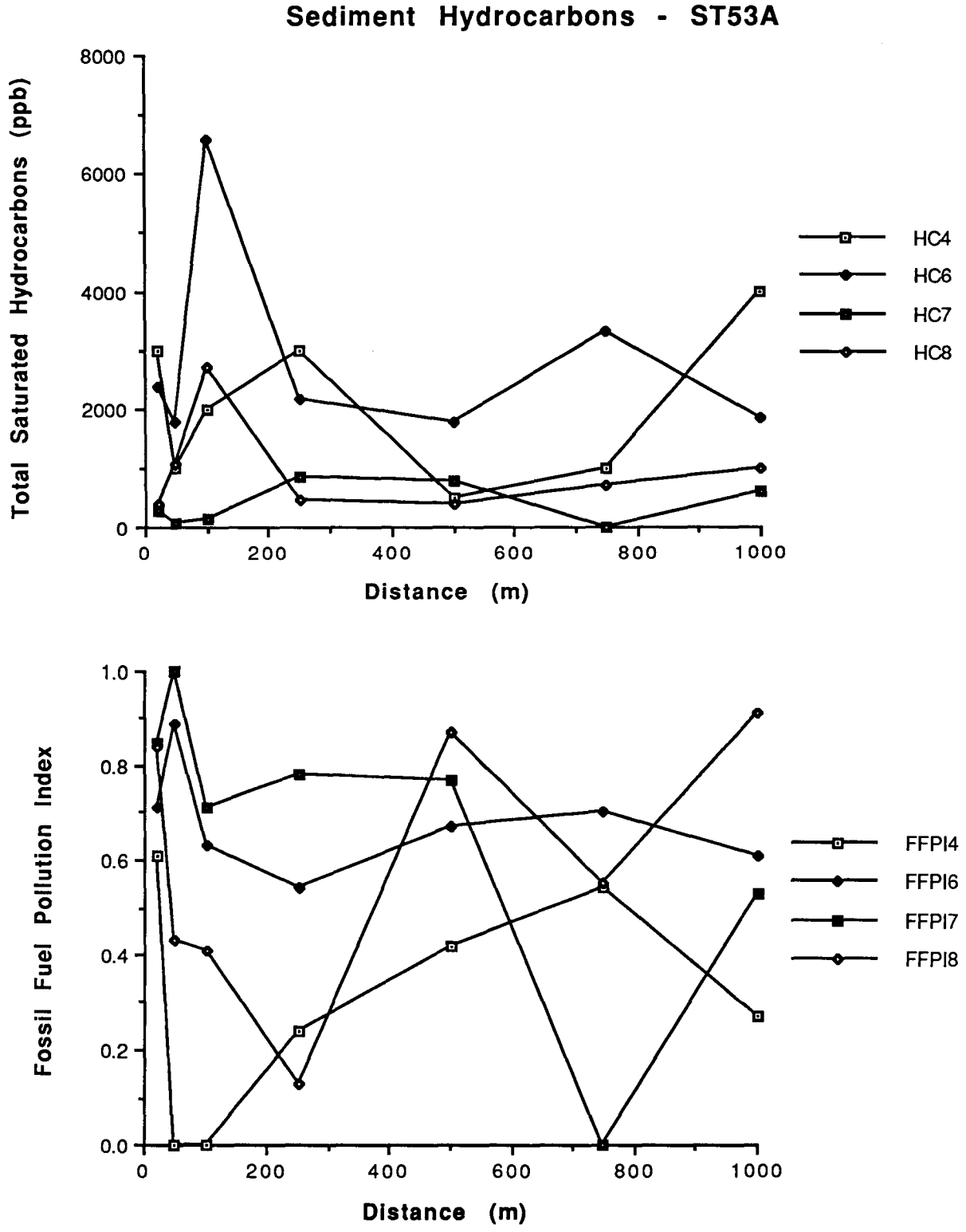

Figure 18. Distribution of total saturated hydrocarbons (top) and FFPI (bottom) for Unocal ST53A for months April (4), June (6), July (7) and August (8).

or parent PAH concentrations (Figure 19) 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. 1991a). 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 (Figures 20 and 21 cf. Figures 18 and 19). For the April sample period, hydrocarbons at the 1000 m station were primarily biogenic. Concentrations of single analytes and summed PAHs were much lower for ST53B than 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. For the April sample period, hydrocarbons at the 20-m and 250-stations were primarily petrogenic, those of the 750-m station primarily petrogenic with some biogenic (15-25%) components in June. With subsequent sample periods, the petrogenic hydrocarbons were more weathered and the biogenic hydrocarbons represented a larger fraction of the saturated hydrocarbons. 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. With the exception of the June sampling period, total saturated hydrocarbon concentrations for the Shell WD32E platform (Figure 22) were similar to the concentrations observed for South Timbalier Blocks 52 and 53, despite the higher percentage of fine sediments at WD32E. The higher concentrations of total saturated hydrocarbons in the June sampling period are unexplainable. There was a general decrease in the concentration of specific analytes and in summed PAHs from April through August (Figure 23). The relative proportion of alkylated PAHs to parent PAHs was similar with distance from the platform and through the length of the study. In the April samples, several analytes exceed 100 ppb and fluoranthene and pyrene approached 400 ppb (Table D.1). In June analyte concentrations often approached 100 ppb; values in July were generally lower than 70 ppb, and in August were lower than 30 ppb (Appendix D). High concentrations of alkylated PAHs at 100 m in April, 50 and 100 m in June, and 20 m in July indicated petrogenic origin hydrocarbons. The summed alkylated PAH concentrations at 50 and 100 m in June (Figure 23) exceeded the threshold level ($\geq$ 450 ppb) where negative impacts on benthic infauna have been shown previously.

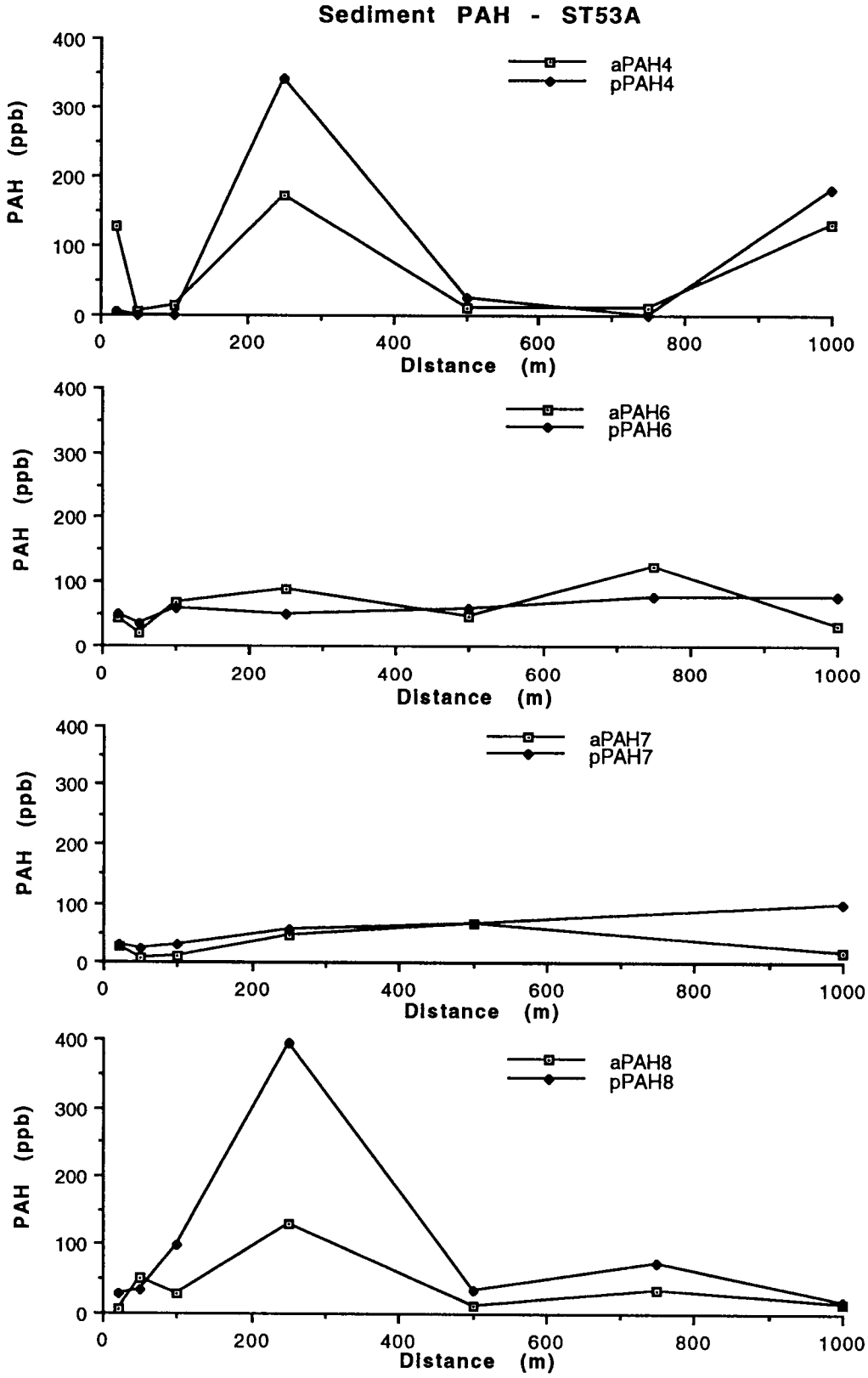

Figure 19. Distribution of summed parent PAH (pPAH) and alkylated PAH (aPAH) for Unocal ST53A for months of April (4), June (6), July (7) and August (8).

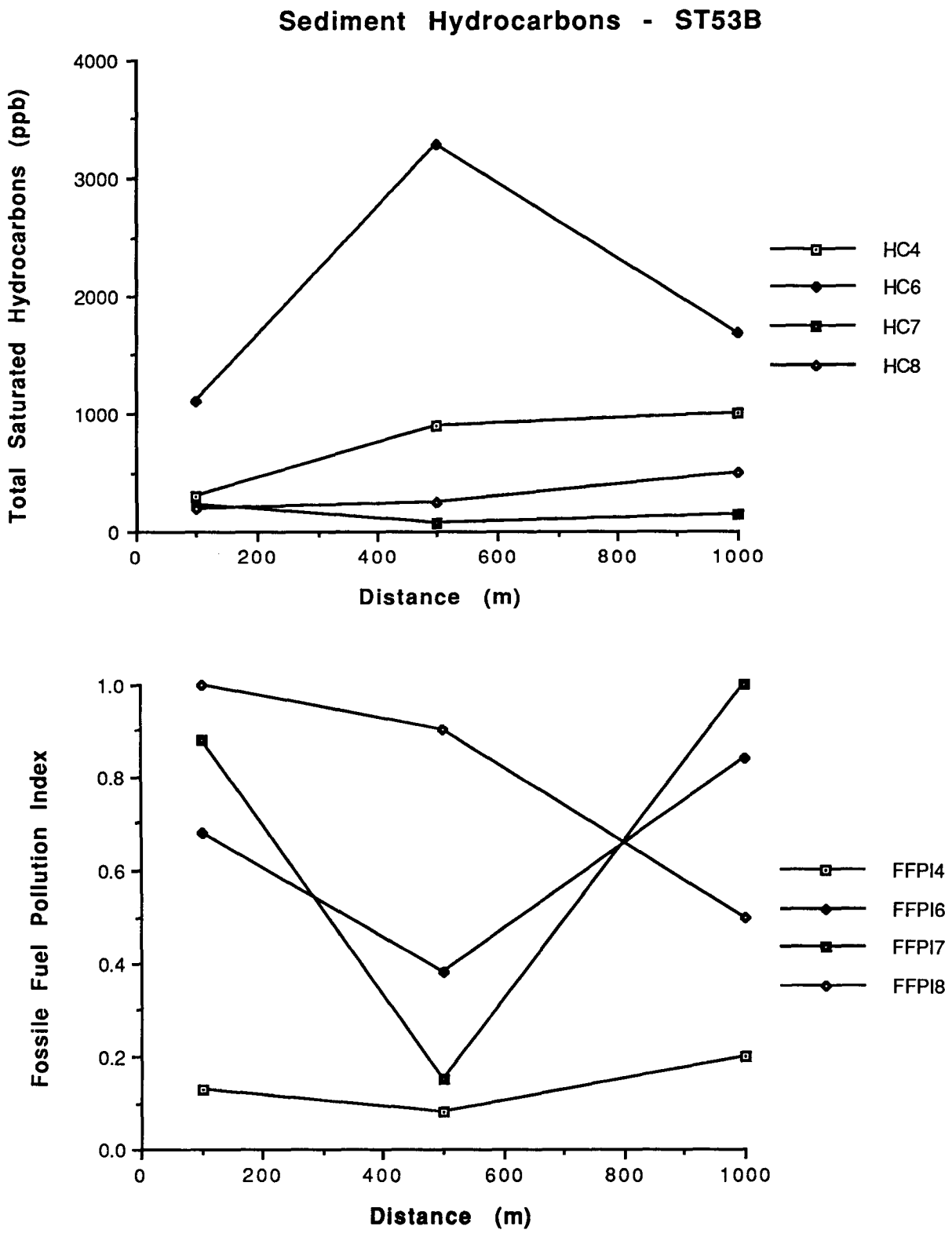

Figure 20. Distribution of total saturated hydrocarbons (top) and FFPI (bottom) for Unocal ST53B for months April (4), June (6), July (7) and August (8).

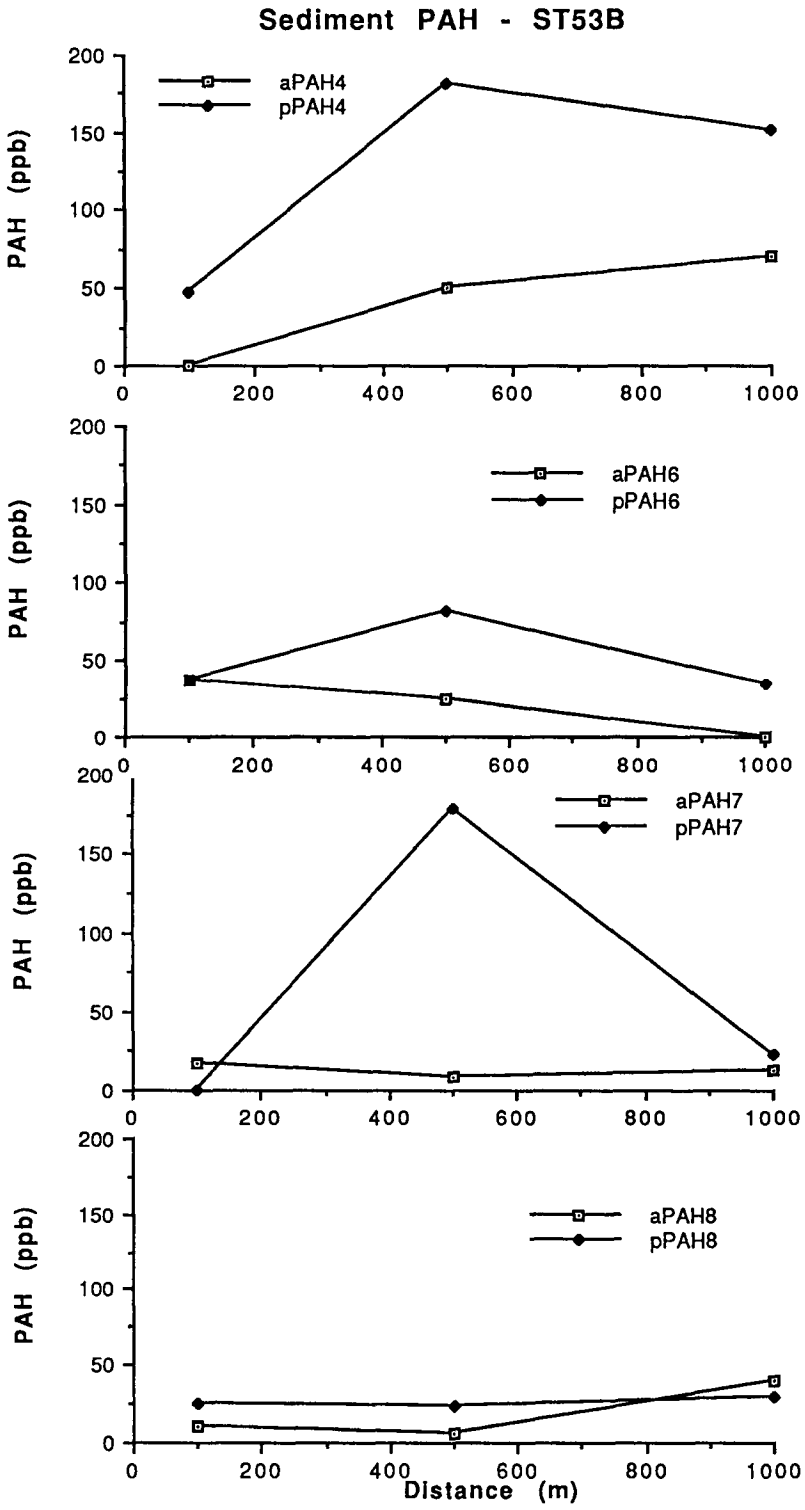

Figure 21. Distribution of summed parent PAH (pPAH) and alkylated PAH (aPAH) for Unocal ST53B for months of April (4), June (6), July (7) and August (8).

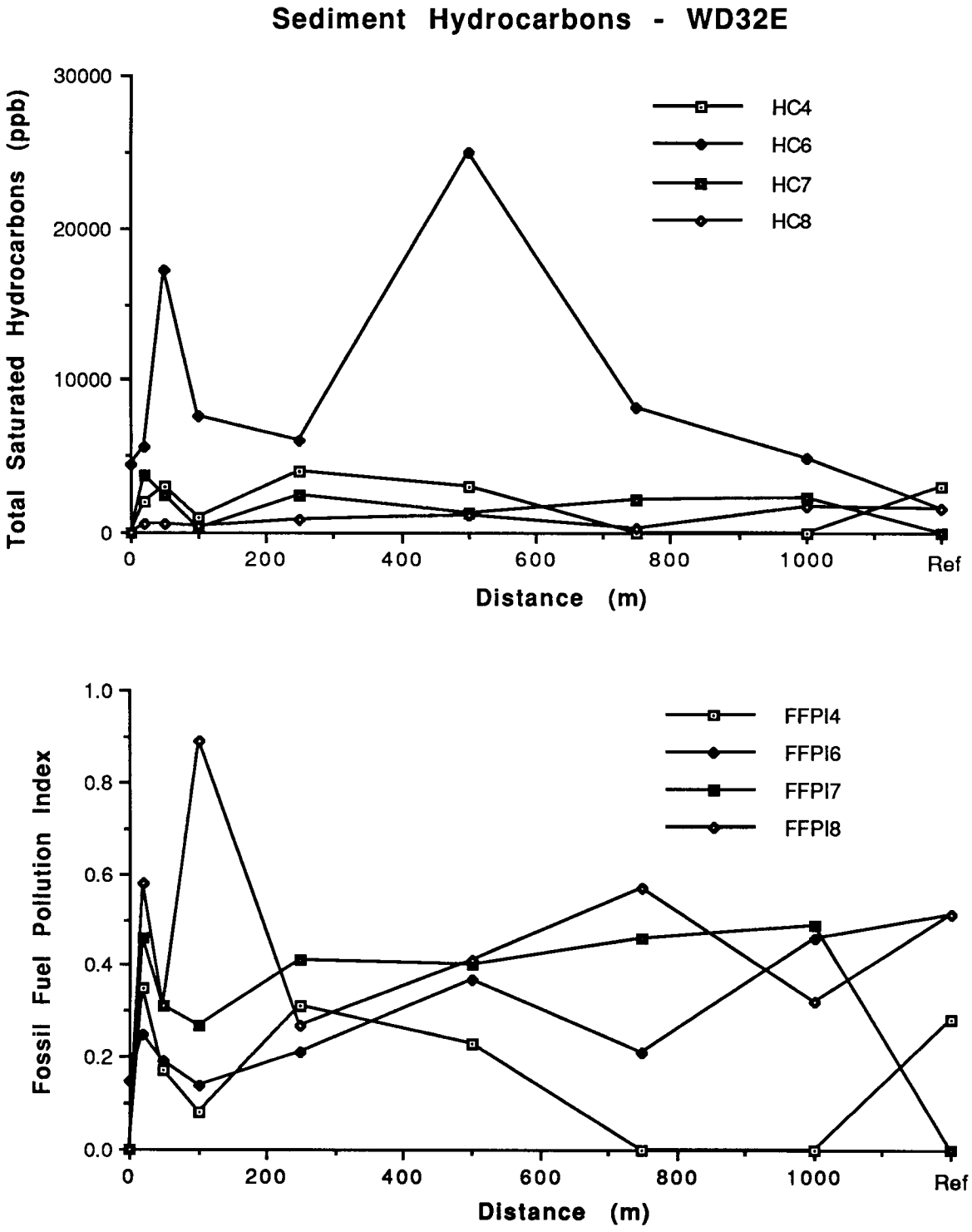

Figure 22. Distribution of total saturated hydrocarbons (top) and FFPI (bottom) for Shell WD32E for months April (4), June (6), July (7) and August (8).

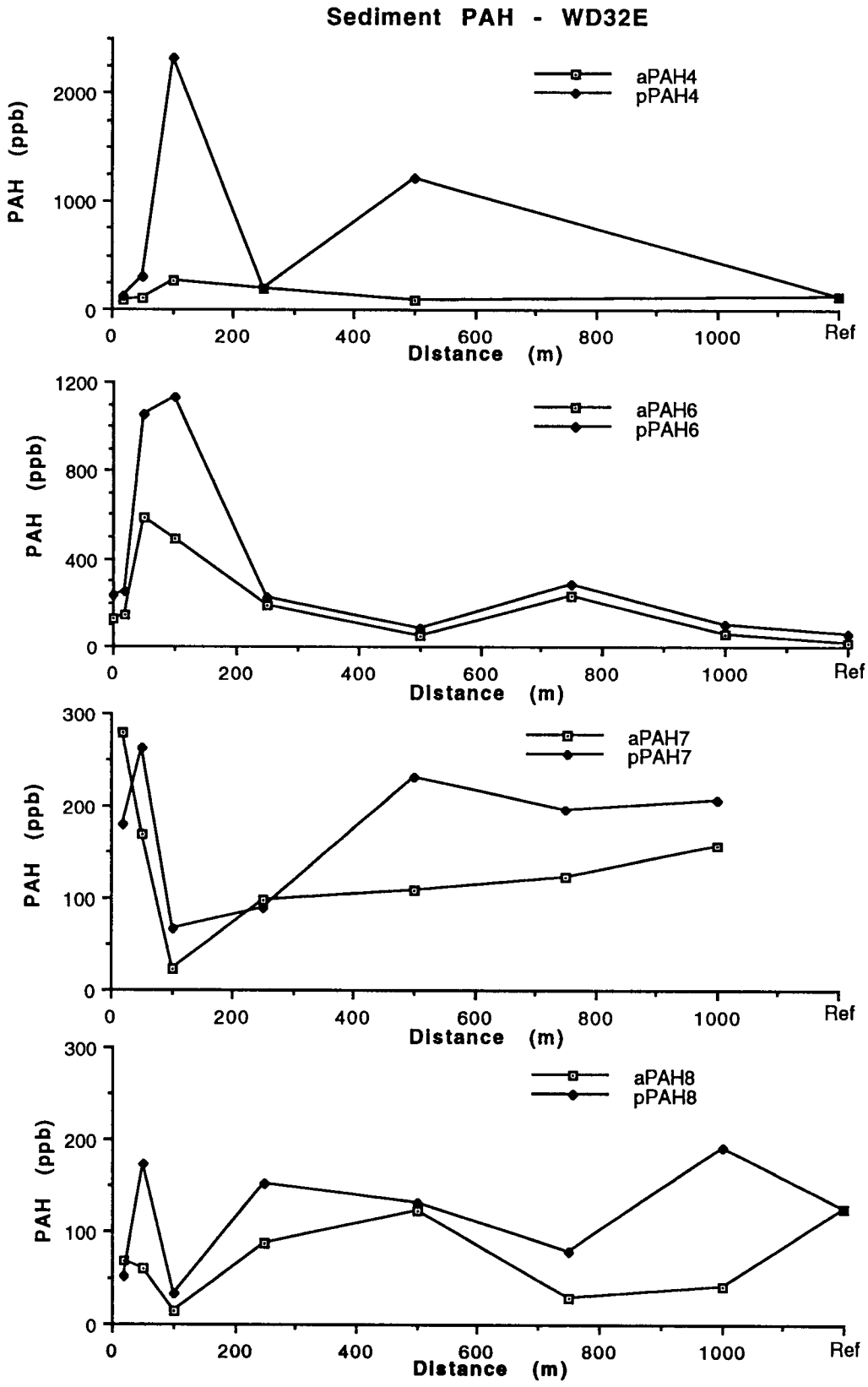

Figure 23. Distribution of summed parent PAH (pPAH) and alkylated PAH (aPAH) for Shell WD32E for months of April (4), June (6), July (7) and August (8).

CHAPTER 6. BENTHIC COMMUNITIES

6.1 Comparison of Study Sites

Results of benthic macroinfaunal analyses are summarized in Appendix E for the community parameters of number of species, number of individuals, diversity and evenness for each study site/date/station combination. Figures for three study sites are provided in Section 6.2 for number of species and number of individuals. Depending on the study site and month, there were often statistically significant differences among stations within each study site in the community parameters of number of individuals and number of species (see Section 6.2). The variability within each study site will be detailed in Section 6.2. We observed, however, that there were general trends in the benthic communities at each study site that could be described on a broad scale. To do this comparison, we minimized within study site variation by comparing community parameters for those stations that were 1) located more distally on the transect, 2) statistically similar to each other across time, 3) collected consistently across the study sites, and 4) collected most frequently. These were usually stations at 500 and 1000 m from the platform.

For this restricted set of samples, a comparison of species richness and mean number of individuals for selected stations at each of three study sites (Unocal ST53A, Unocal ST53B, and Shell WD32E) is shown in Figure 24. 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. There were statistically significant differences between months at each study site with regard to both number of species and number of individuals (Table 3).

Table 3. Results of general linear model (GLM) analysis of variance of natural log(x + 1) transformed data comparison of sample dates for number of species and number of individuals for each study site (stations 500 m and 1000 m only, WD32E Ref substituted for 500 m in Sep, Oct; alpha = 0.05 for significance *; ns = not significant) and Duncan's multiple range test results. [Underlined dates are not significantly different from each other. *n* = number of replicates. ^ indicates fewer replicates than others.]

Study Site	Parameter	GLM *p* value	*n*	Duncan's Multiple Range Test
Shell WD32E	Species	$p<0.0001$*	10,5	Oct Sep Jul Aug Apr^ Jun
	Individuals	$p<0.0001$*		Oct Sep Aug Jul Apr^ Jun
Unocal ST53A	Species	$p<0.0001$*	10,8	Aug^ Sep Jul Oct Apr Jun
	Individuals	$p<0.0001$*		Sep Aug^ Jul Oct Apr Jun
Unocal ST53B	Species	$p<0.0001$*	10,8	Aug^ Sep Oct Jul Jun Apr
	Individuals	$p<0.0001$*		Sep Aug^ Oct Jul Apr Jun
				——————increasing means——————→

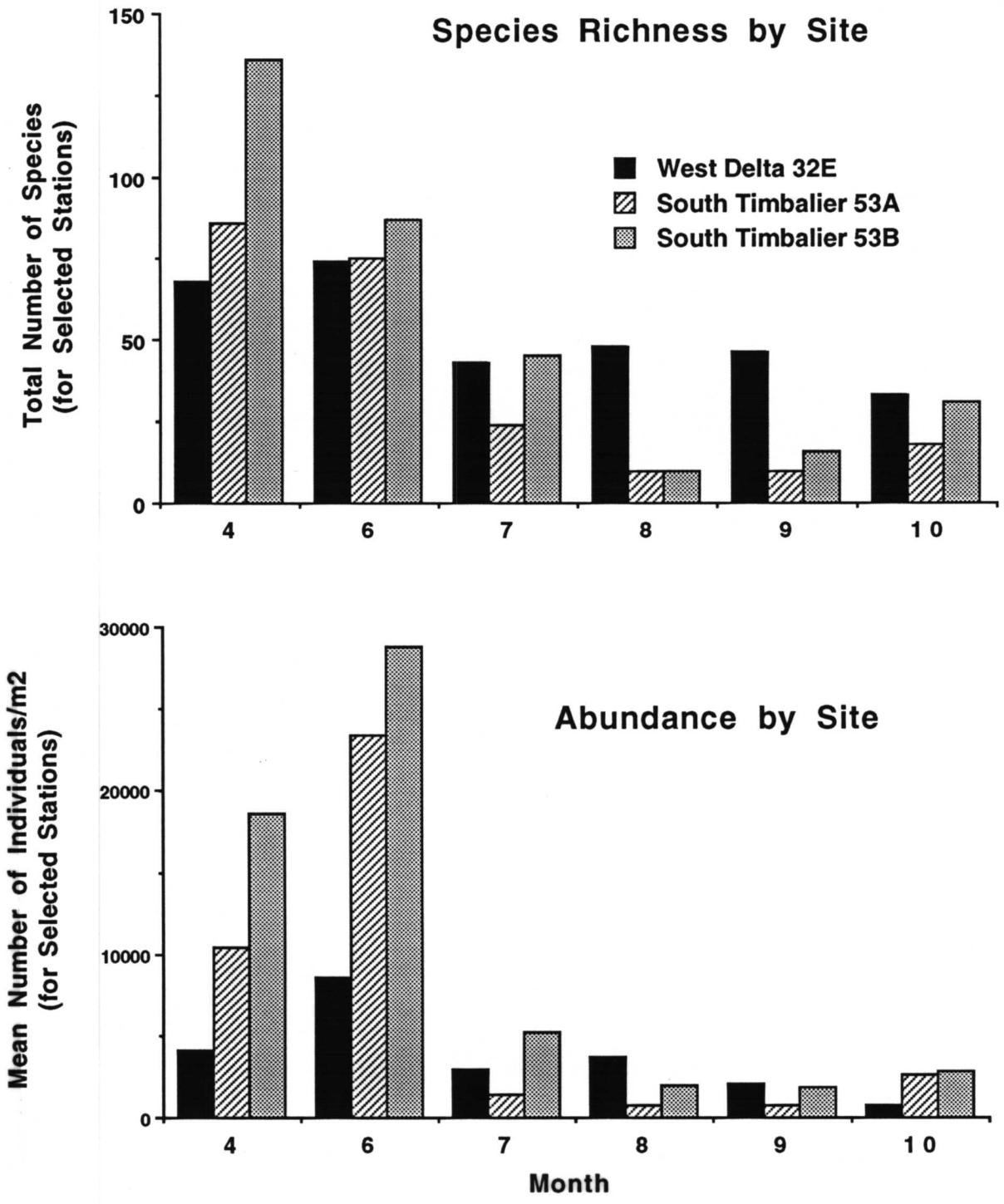

Figure 24. Comparison of species richness and mean number of individuals for each study site by month for selected stations (500 m and 1000 m only, WD32E Ref substituted for 500 m in Sep, Oct).

The most diverse benthic community, both in terms of species richness and diversity index, was at the West Delta 32E study site (Appendix E, Table 4). A comparison of the three study sites at selected stations (usually 500 and 1000 m) is shown in Table 4. Across all months combined, WD32E was the most diverse study site in terms of species richness. In April and June, during recruitment periods, ST53A and ST53B were more diverse than WD32E; for the remainder of the months, WD32E was the most diverse study site. 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 in August and September, when the benthic infauna was more abundant at WD32E. Community composition, both in terms of major taxonomic groups and

Table 4. Results of general linear model (GLM) analysis of variance of natural log(x + 1) transformed data comparison of study sites for number of species and number of individuals by sample period and all months combined (stations 500 m and 1000 m only, WD32E Ref substituted for 500 m in Sep, Oct; 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	$p < 0.0002$*	10,5	SH^	UA	UB
	Individuals	$p < 0.0033$*		SH^	UA	UB
Jun 1990	Species	$p < 0.0412$*	10	SH	UA	UB
	Individuals	$p < 0.0001$*		SH	UA	UB
Jul 1990	Species	$p < 0.0001$*	10	UA	UB	SH
	Individuals	$p < 0.0001$*		UA	SH	UB
Aug 1990	Species	$p < 0.0001$*	10,8	UA^	UB^	SH
	Individuals	$p < 0.0001$*		UA^	UB^	SH
Sep 1990	Species	$p < 0.0001$*	10	UA	UB	SH
	Individuals	$p < 0.0006$*		UA	UB	SH
Oct 1990	Species	$p < 0.0830$ns	10	UA	UB	SH
	Individuals	$p < 0.0001$*		SH	UA	UB
All Months Combined	Species	$p < 0.0005$*	58,55	UA	UB	SH^
	Individuals	$p < 0.0017$*		UA	SH^	UB
				——increasing means——→		

succession of species, differed among the study sites (see Section 6.2). In both comparisons of species richness and number of individuals across all months, ST53A and ST53B were statistically different from each other (Table 4), 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 statistically significant.

Because Chevron ST52C was dropped from the study design in July 1990, the benthic community analyses of all stations on the April and June transects were not completed. Representative stations from each period, however, were analyzed for general comparison with other study sites in the South Timbalier area. The community parameters for ST52C are detailed in Table E.1. A statistical analysis of species richness and number of individuals for similar distance stations, but including ST52C, is shown in Table 5. With respect to species richness, ST52C is statistically similar to ST53A and distinct from ST53B; for number of individuals, there were no differences for the sites for the sample periods and stations analyzed. Grouping of the Shell WD32E study site in this comparison showed similar results for the South Timbalier study area, with WD32E being distinct from them.

Table 5. Results of general linear model (GLM) analysis of variance of natural log(x + 1) transformed data comparison of study sites for number of species and number of individuals for selected stations and dates (Apr CV750 1000, UA750 1000, UB500 1000, SH250 500, Jun CV750, UA750, UB1000, SH750; 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. CV = Chevron South Timbalier 52C, UA = Unocal South Timbalier 53A, UB = Unocal South Timbalier 53B, SH = Shell West Delta 32E.]

Condition	Parameter	GLM p value	n	Duncan's Multiple Range Test			
Shell WD32E Excluded	Species	$p< 0.0086$*	15		CV	UA	UB
	Individuals	$p<0.2293$ns			CV	UA	UB
Shell WD32E Included	Species	$p<0.0001$*	15	SH	CV	UA	UB
	Individuals	$p<0.0001$*		SH	CV	UA	UB
				—— increasing means ——→			

6.2 Variability within Study Sites

Results of general linear model analysis of variance and Duncan's multiple range test (Tables 6, 8 and 10) indicated that within each study site there were often significant differences between stations within a sample period and sometimes 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 always statistically significant. Each study site, however, was distinct from the others in the characteristics of these differences, and in taxonomic composition. Details of each study site are given below.

6.2.1 Unocal ST53A

A general increase in species richness and number of individuals was evident with distance from the platform at Unocal ST53A (Figures 25 and 26). This trend was significant for number of individuals for all four months combined, and in June, July and August, but not April (Table 6). The trend for an increase in species richness with distance from the platform was significant only in June and August. The station at 20 m ranked low in species and individuals than any of the other stations with one exception (Table 6). The remainder of the stations usually grouped with 250 m, 500 m, 750 m and 1000 m having the most species and individuals, and with stations at 50 m and 100 m being intermediate.

Species richness was severely depressed in August and September, and was also extremely low in July and October (Figure 24, Table 3). Species richness in June and April was similar and approximately six times greater than in July through October. Abundance of individuals was high in April, higher in June with additional recruitment of several species; then the number of individuals was very low from July through September (Table 3). There was a slight recovery of species richness and number of individuals in October (Figure 24).

Table 6. Results of general linear model (GLM) analysis of variance of natural log(x + 1) transformed data comparison of stations at Unocal ST53A for number of species and number of individuals for each sample period and all months combined (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.]

Month	Parameter	GLM *p* value	*n*	Duncan's Multiple Range Test						
Apr 1990	Species	$p < 0.4273$ ns	5	500	250	20	100	750	50	1000
	Individuals	$p < 0.2552$ ns		20	500	250	100	750	50	1000
Jun 1990	Species	$p < 0.0001$*	5	20	100	50	1000	750	500	250
	Individuals	$p < 0.0008$*		20	50	100	1000	250	500	750
Jul 1990	Species	$p < 0.1526$ ns	5	20	250	100	50	500	1000	750
	Individuals	$p < 0.0002$*		20	250	100	500	50	750	1000
Aug 1990	Species	$p < 0.0039$*	5	20	50	100	750	1000	250	500
	Individuals	$p < 0.0001$*		20	100	50	250	500	1000	750
All Months Combined	Species	$p < 0.5154$ ns	20,18	20	100	50	250	750	500^	1000
	Individuals	$p < 0.0115$*		20	100	250	50	500^	750	1000
				——————increasing means——————→						

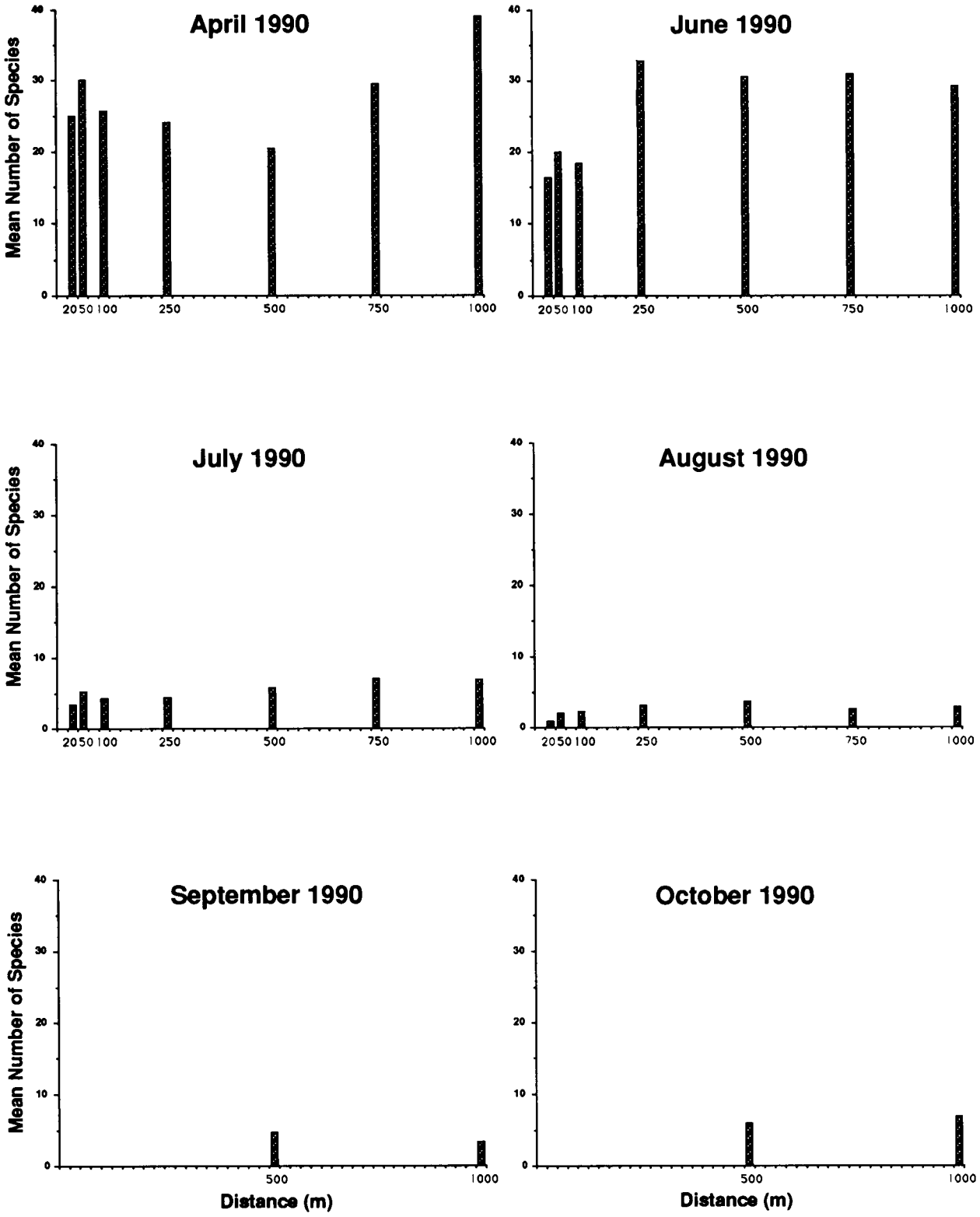

Figure 25. Mean number of species per grab for stations at Unocal ST53A (=UA) for months indicated.

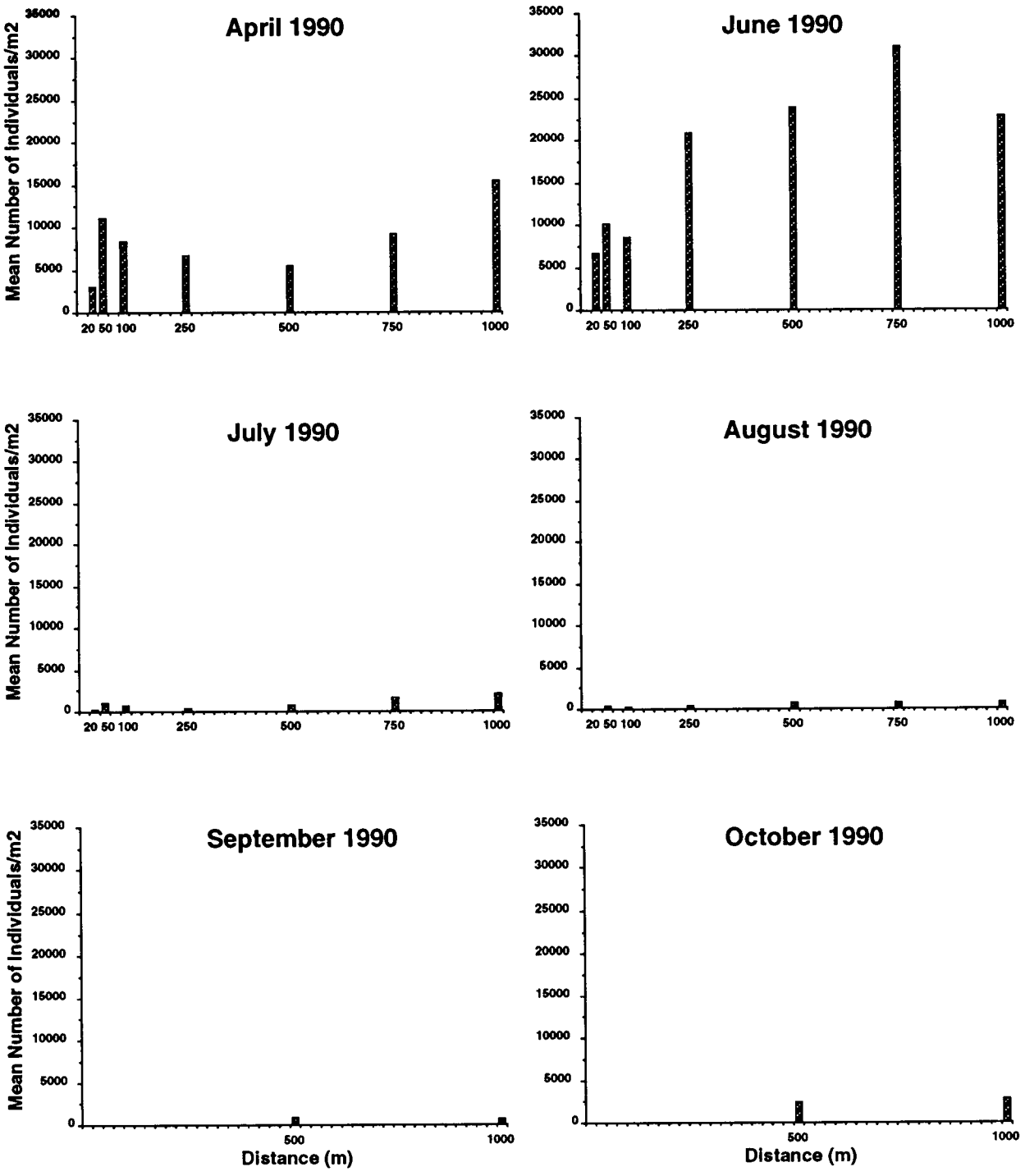

Figure 26. Mean number of individuals per square meter for stations at Unocal ST53A (=UA) for months indicated.

Environmental variables significant in explaining the variation in species richness and abundance for Unocal ST53A are listed in Table 7. Oxygen concentration was important only in the model for species richness, and was positively, but weakly correlated. Decreases in bottom water oxygen are related to the increase in bottom water salinity and an increase in the surface-to-bottom density differences which become greatest in mid-summer (see Figure 2). A decrease in fauna with an increase in water temperature is related to a general seasonal decline in the benthic community which is exaggerated during severe hypoxia. None of the variables related to grain size variability or hydrocarbon contamination (total saturated hydrocarbons, summed alkylated PAH, summed parent PAH, FFPI) were included in the models. It is not clear what environmental variables might be important in explaining the reduced infaunal community within 100 m of the platform. The potential for sublethal, chronic low-level pollutants or platform-related activities that were not measured remain a possibility.

Table 7. Results of multiple regression analysis for Unocal South Timbalier 53A (alpha = 0.05 for significance). [Months of September and October excluded; lacking chemistry data.]

Species Richness (number/grab)			Abundance (number/grab)		
Model $r^2 = 0.849$			Model $r^2 = 0.619$		
F-test, $p < 0.0001$			F-test, $p < 0.0001$		
Variable:	Probability	Correlation	Variable:	Probability	Correlation
Salinity	$p < 0.0001$	-	Salinity	$p < 0.0001$	-
Oxygen	$p < 0.0017$	+	Temperature	$p < 0.0002$	-
Temperature	$p < 0.0153$	-	Oxygen	$p < 0.0003$	+

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), then reduced to 4 to 6 major taxa in July through October (Figure 27). Dominant species (by number of individuals) for each sample period are listed in Table E.6, and the successive change in the abundances of several dominants is shown in Figure 27. 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. During September and October, 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.

6.2.2 Unocal ST53B

A general increase in species richness and number of individuals was evident with distance from the platform at the Unocal ST53B platform (Figures 28 and 29), but these differences were not usually statistically significant (Table 8). Number of individuals was statistically less at the 100 m station in July and August (Table 8).

Species richness was severely depressed in August (Figure 28, Table 3). Decreases in species richness were significantly different with values in July through October approximately one-half of those in the spring and early summer. Decreases in species richness were significant (Table 3). Abundance of individuals was high in April and June, but dropped significantly in July

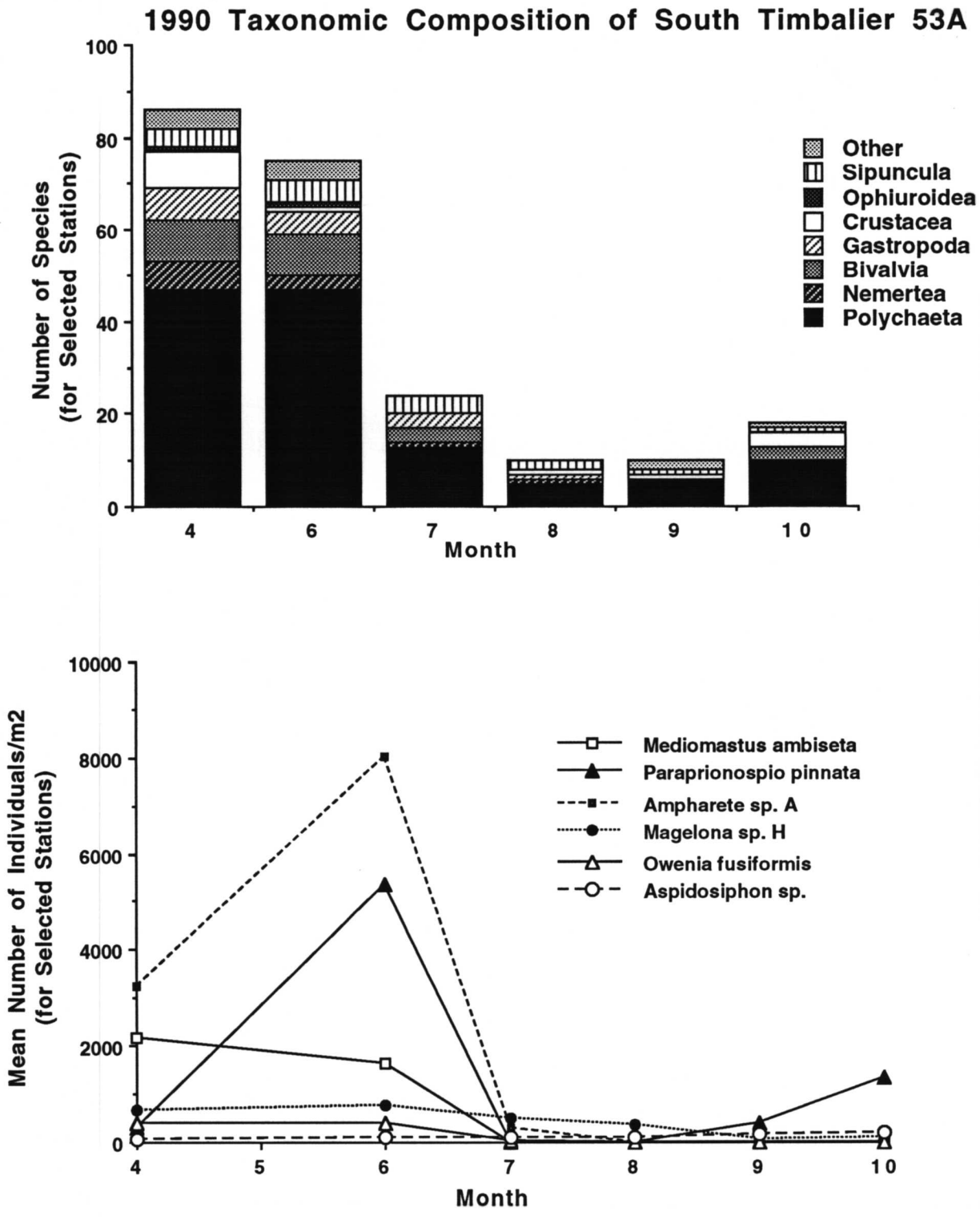

Figure 27. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Unocal ST53A (=UA) for months indicated.

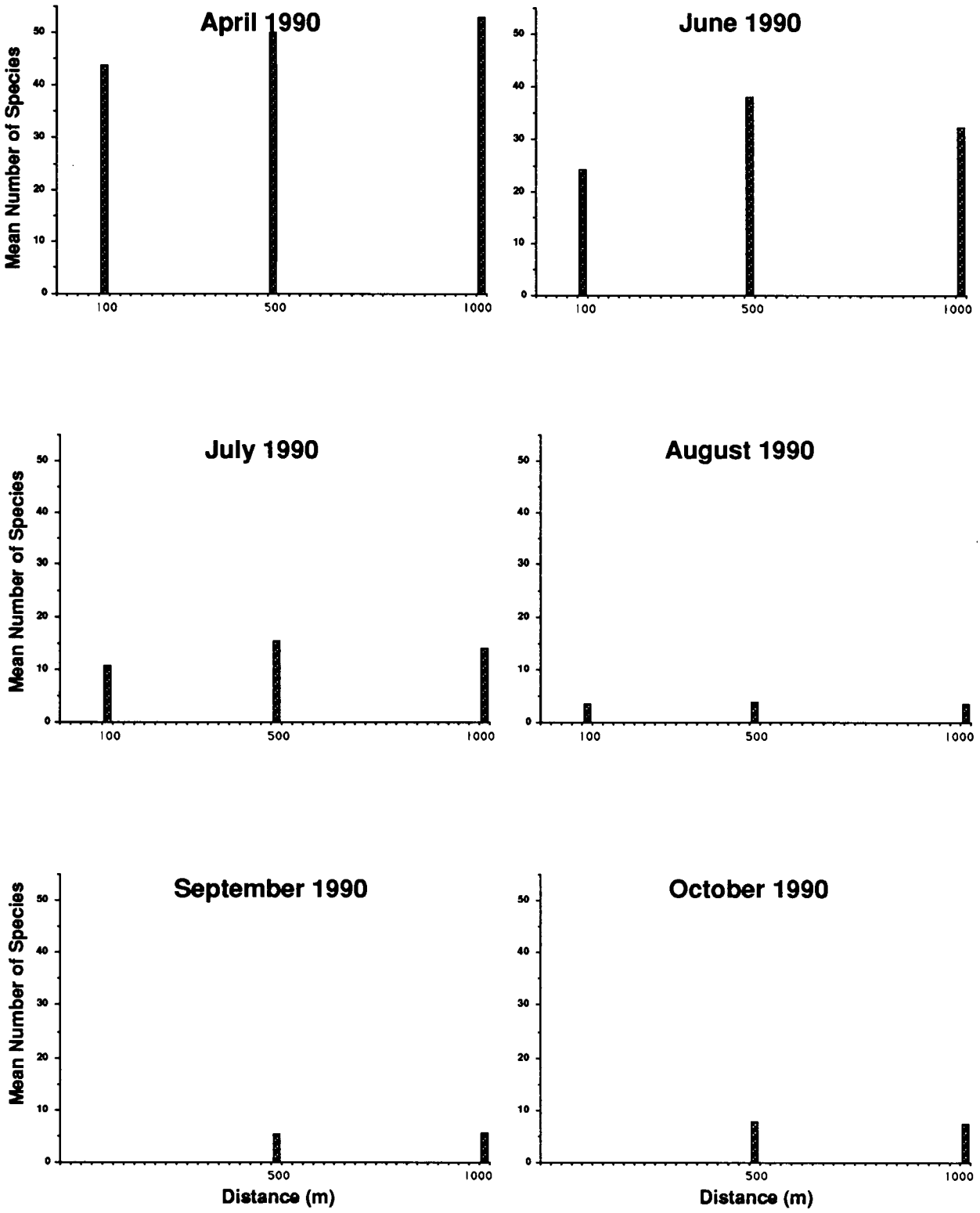

Figure 28. Mean number of species per grab for stations at Unocal ST53B (=UB) for months indicated.

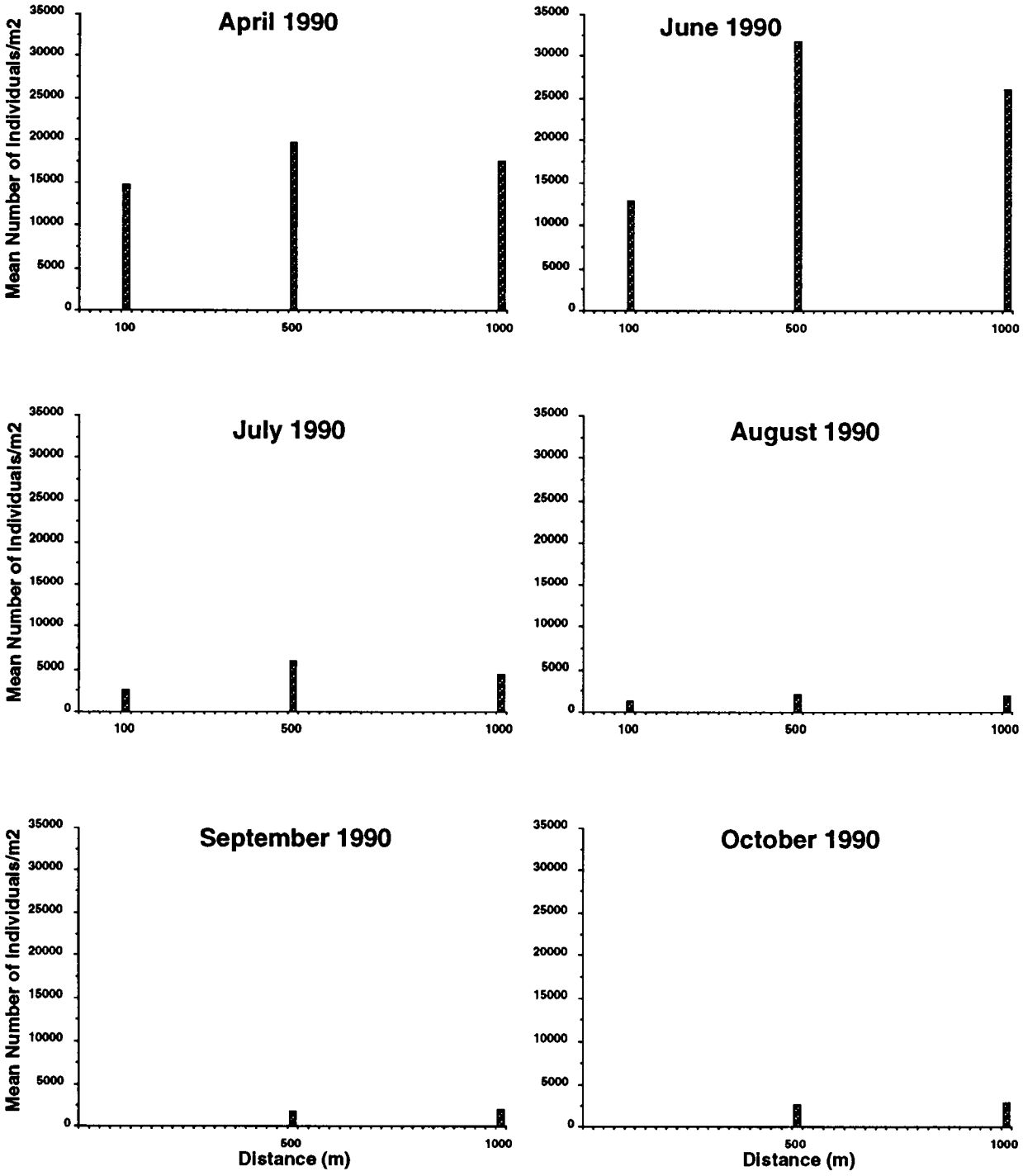

Figure 29. Mean number of individuals per square meter for stations at Unocal ST53B (=UB) for months indicated.

through August (Table 3). There was a slight recovery of species richness in the fall as shown by the statistically significant increase in number of species in September and October (Figure 28, Table 3). Number of individuals also increased in October but not significantly (Figure 29, Table 3).

Table 8. Results of general linear model (GLM) analysis of variance of natural log(x + 1) transformed data comparison of stations at Unocal ST53B for number of species and number of individuals for each sample period and all months combined (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.]

Month	Parameter	GLM *p* value	*n*	Duncan's Multiple Range Test		
Apr 1990	Species	$p< 0.2754$ns	5	100	500	1000
	Individuals	$p<0.6140$ns		100	1000	500
Jun 1990	Species	$p<0.0270$*	5	100	1000	500
	Individuals	$p<0.0645$ns		100	1000	500
Jul 1990	Species	$p<0.2033$ns	5	100	1000	500
	Individuals	$p<0.0274$*		100	1000	500
Aug 1990	Species	$p<0.8554$ns	5	100	1000	500
	Individuals	$p<0.0273$*		100	1000	500
All Months Combined	Species	$p<0.4979$ns	20,18	100	500	1000^
	Individuals	$p<0.1023$ns		100	500	1000^
				——increasing means—→		

Environmental variables significant in explaining the variation in species richness and abundance for Unocal ST53B are listed in Table 9. Oxygen concentration was important in the model for abundance, but not species richness. In the model for species richness, where oxygen was excluded, salinity was a strong and negatively correlated environmental variable. Decreases in bottom water oxygen are correlated with the increase in bottom water salinity and a seasonal increase in the surface-to-bottom density differences that become greatest in mid-summer (see Figure 2). Percent sand was important in both models. The relationship, however, was negative; this is counter-intuitive to most results where benthic community diversity is greater in sandy versus less sandy environments. None of the variables related to hydrocarbon contamination (summed alkylated PAH, summed parent PAH, FFPI) were included in the models. Total saturated hydrocarbon concentration was a significant variable in both models, suggesting an organic enhancement. The concentration of saturated hydrocarbons, however, at the ST53B study site (non-production platform), was much less than the other two study sites (both production

platforms). It is not clear what environmental variables might be important in explaining the reduced infaunal community within 100 m of the platform. The potential for sublethal, chronic low-level pollutants or platform-related activities that were not measured remain a possibility.

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 30A). Dominant species by number of individuals for each sample period are listed in Table E.7, and the successive change in the abundances of some dominants are shown in Figure 30B. The polychaetes *Mediomastus ambiseta*, *Paraprionospio pinnata*, and *Ampharete* sp. A were common in spring and early summer. 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, 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.

Table 9. Results of multiple regression analysis for Unocal South Timbalier 53B(alpha = 0.05 for significance). [Months of September and October excluded; lacking chemistry data.]

Species Richness (number/grab)			Abundance (number/grab)		
Model $r^2 = 0.981$			Model $r^2 = 0.968$		
F-test, $p < 0.0001$			F-test, $p < 0.0001$		
Variable:	Probability	Correlation	Variable:	Probability	Correlation
Salinity	$p < 0.0001$	-	Oxygen	$p < 0.0001$	+
Saturated HC	$p < 0.0003$	+	Saturated HC	$p < 0.0001$	+
% Sand	$p < 0.0335$	-	% Sand	$p < 0.0376$	-

6.2.3 Shell WD32E

Although there were statistically significant differences in species richness and number of individuals among the stations at WD32E, these differences were not always consistent with distance from the platform (Table 10, Figures 31 and 32). The stations grouped with the Reference and 100 m stations being the least diverse and having the least individuals, stations at 20 m and 50 m being the most diverse and having the most individuals, and the remainder being intermediate (Table 10). In April higher values for number of individuals at 20 m, 50 m and 100 were related to abundances of *Mediomastus ambiseta* and Tubificidae A, both indicators of organic enrichment. *Mediomastus ambiseta* occurred at stations greater than 100 m from the platform but in reduced numbers.

The species richness at the 20 m and 50 m stations may be related to platform effects, in particular, the greater percent sand at these stations and the potential for sloughing of epifaunal organisms from the platform to the sediments. Bivalves made up a greater proportion of the benthic community at these stations (20 and 50 m), especially in April and June. In this case (as

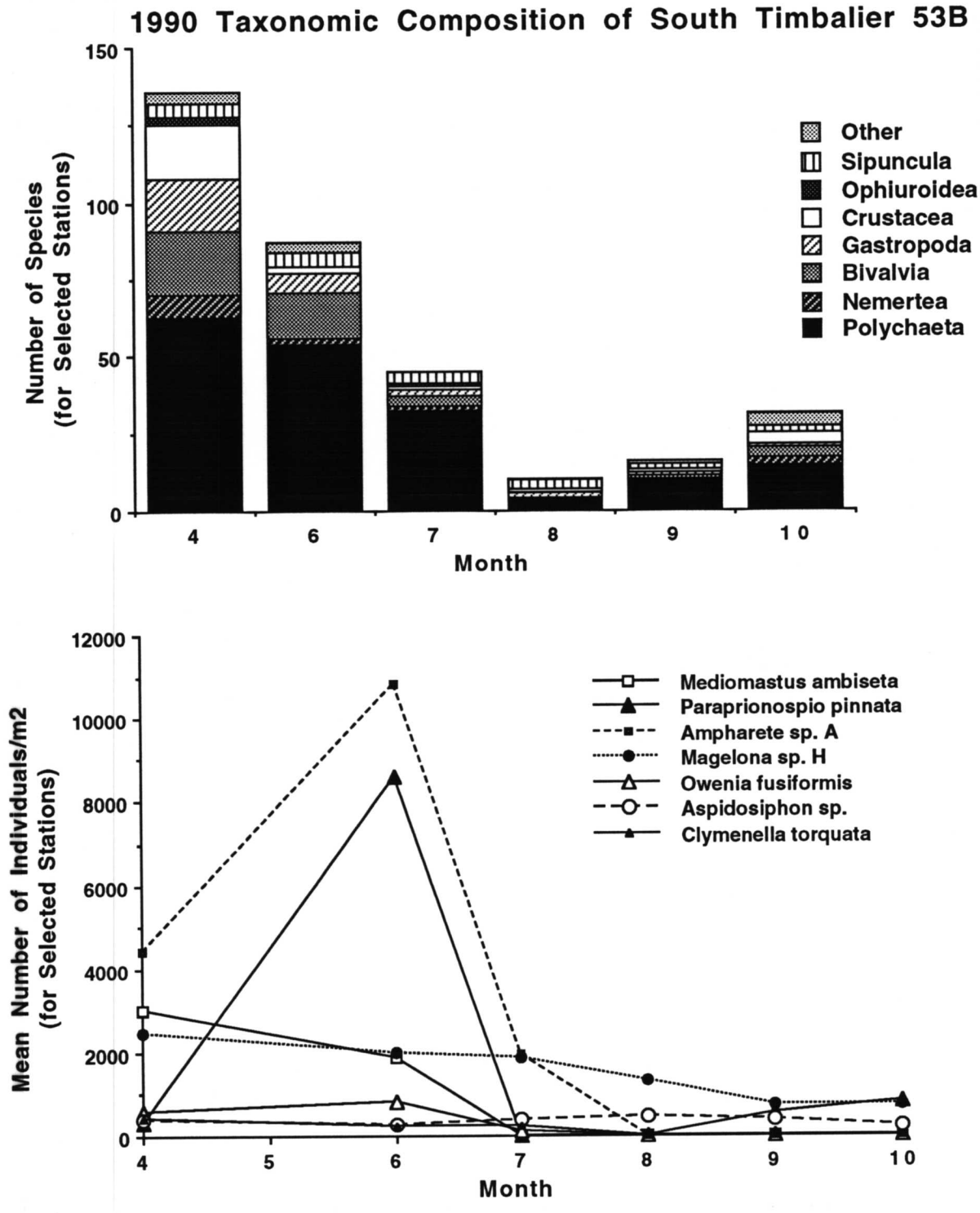

Figure 30. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Unocal ST53B (=UB) for months indicated.

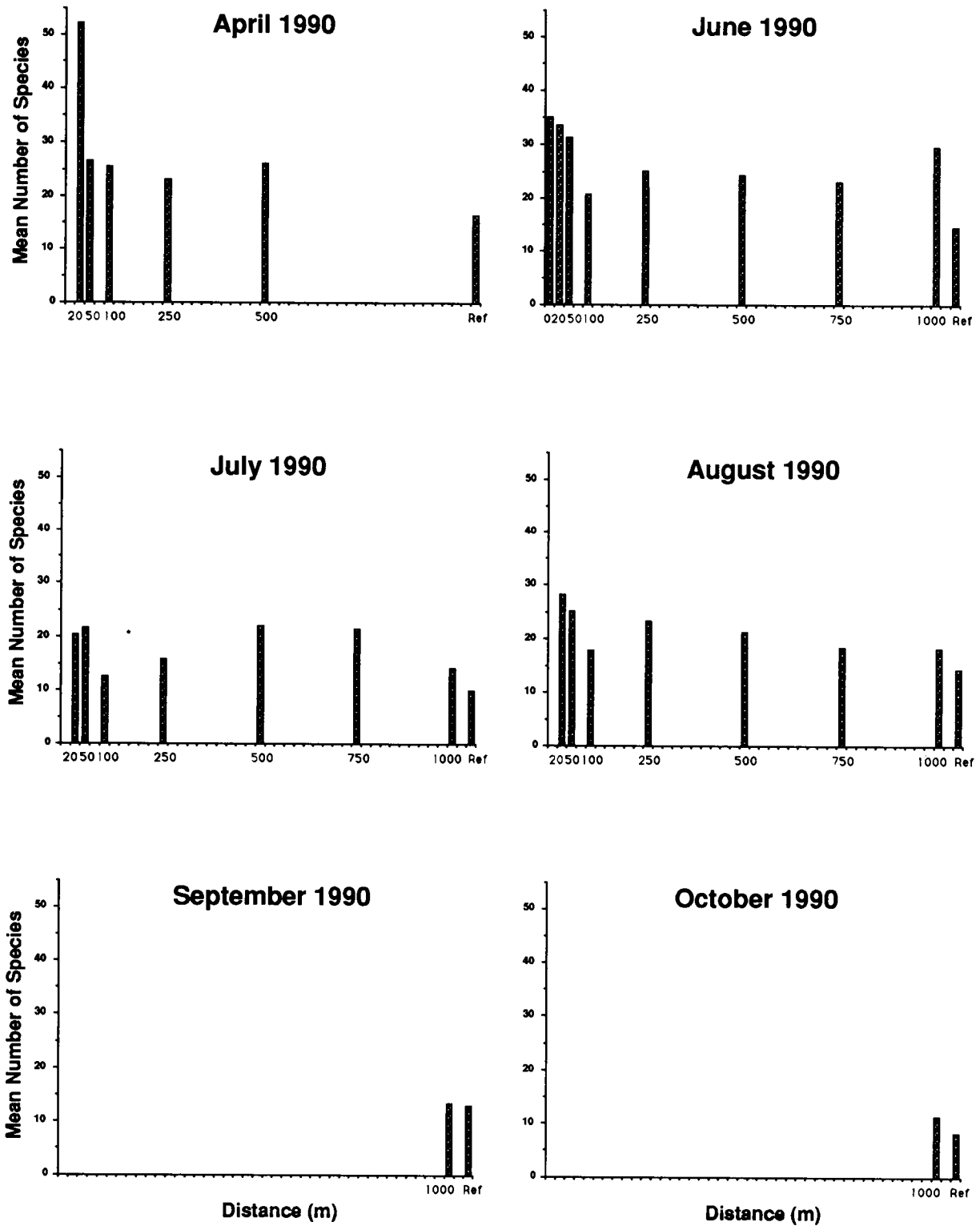

Figure 31. Mean number of species per grab for stations at Shell WD32E (=SH) for months indicated.

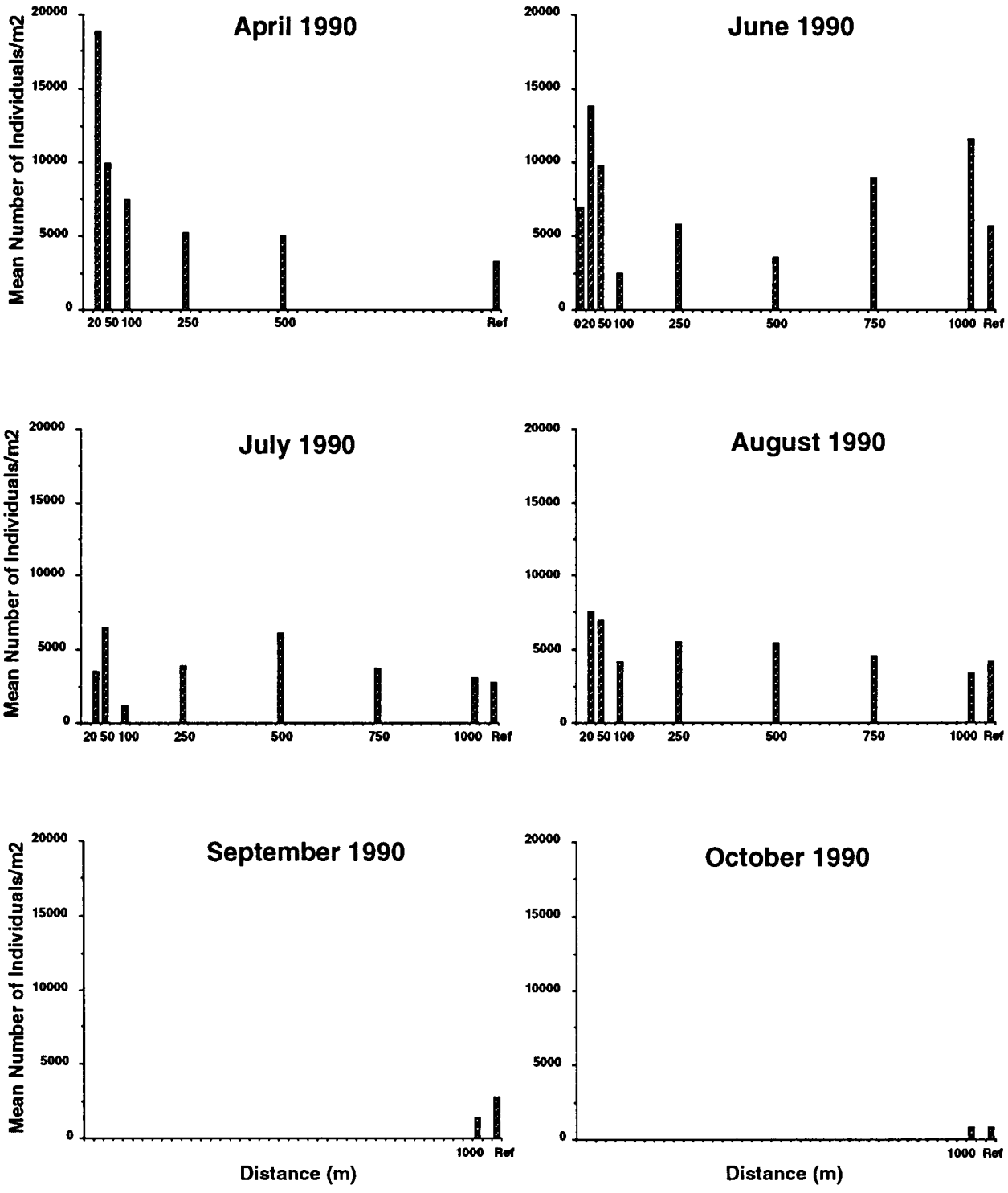

Figure 32. Mean number of individuals per square meter for stations at Shell WD32E (=SH) for months indicated.

opposed to ST53B; see Section 6.2.2), there was a strong and positive relationship of species richness with percent sand (or sand:mud ratio) (Table 10).

Abundances were lower than expected at the 100 m station, compared to those of the 20 m and 50 m stations, given the sometimes elevated percent sand in sediments at the 100 m station. There were perhaps some platform related discharge effects which were not evident beyond 100 m, and were not evident at 20 and 50 m because of the different sediment composition and related community. None of the environmental variables measured that could be attributed to platform discharges, however, were important in multiple regression models explaining species richness and abundance.

Species richness was similar in April and June, decreased in July and August, then decreased further in September and October (Table 3). There were no statistically significant differences in number of individuals in April through August, but values for September and October were lower (Table 3). A seasonal decline in the benthic community is an expected occurrence in mid-summer, with further reductions in the fall and winter. The benthic community followed this trend at WD32E (Figures 31 and 32). 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.

Table 10. Results of general linear model (GLM) analysis of variance of natural log(x + 1) transformed data comparison of stations at Shell WD32E for number of species and number of individuals for each sample period and all months combined (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.]

Month	Parameter	GLM *p* value	*n*	Duncan's Multiple Range Test
Apr 1990	Species	$p < 0.0001$*	5	Ref 250 100 500 50 20
	Individuals	$p < 0.0261$*		Ref 250 500 100 50 20
Jun 1990	Species	$p < 0.0027$*	5	Ref 100 750 500 250 1000 50 20
	Individuals	$p < 0.0154$*		100 500 Ref 250 750 50 1000 20
Jul 1990	Species	$p < 0.0001$*	5	Ref 100 1000 250 20 50 750 500
	Individuals	$p < 0.0001$*		100 Ref 250 1000 20 750 50 500
Aug 1990	Species	$p < 0.0054$*	5	Ref 100 1000 750 500 250 50 20
	Individuals	$p < 0.2118$ns		100 1000 Ref 750 250 500 50 20
All Months Combined	Species	$p < 0.0001$*	20,15	Ref 100 1000^ 250 750^ 500 50 20
	Individuals	$p < 0.0001$*		100 Ref 250 1000^ 500 750^ 50 20
				——— increasing means ———→

Environmental variables significant in explaining the variation in species richness and abundance for Shell WD32E are listed in Table 11. Oxygen concentration was important in both models, but in a different manner from the models for ST53A and ST53B. Salinity, or a surrogate for density stratification, was important in the abundance model, but weakly correlated. The negative correlation with temperature in both models is representative of the seasonal decline in benthic communities, paralleled by a steady warming of the bottom water temperature from 20.5°C in April to 28°C in October. Sediment characteristics were important in both models. The sand:mud ratio was strongly and positively related to species richness. Percent clay was negatively related to abundance. Both point to platform-related activity (i.e., sandblasting) and changes in the sedimentary environment within 50 to 100 m of the platform. The inclusion of TOC and Al in the models was related to grain size differences as described above.

None of the variables related to hydrocarbon contamination (total saturated hydrocarbons, summed alkylated PAH, summed parent PAH, FFPI) were included in the models. Because the sediments were siltier, in general, at WD32E than the South Timbalier study area and the volume discharged was high (20,000 bbl/d), it was expected that a clearer signal of hydrocarbon contamination would be evident in the sediments. Although there were stations where petrogenic hydrocarbons dominated, the chemical contaminant signal was less than expected and declined with time during the study. It is not clear what environmental variables might be important in explaining the reduced infaunal community at the 100 m station The potential for sublethal, chronic low-level pollutants or platform-related activities that were not measured remain a possibility. The elevated levels of Pb and Zn were most likely related to some platform activity or effluent, but the variables were not important in the multiple regression models with regard to affecting species richness and abundance of organisms.

Table 11. Results of multiple regression analysis for Shell West Delta 32E (alpha = 0.05 for significance). [Months of September and October excluded; lacking chemistry data.]

Species Richness (number/grab)			Abundance (number/grab)		
Model $r^2 = 0.77$			Model $r^2 = 0.463$		
F-test, $p < 0.0001$			F-test, $p < 0.0021$		
Variable:	Probability	Correlation	Variable:	Probability	Correlation
Temperature	$p < 0.0001$	-	Al	$p < 0.0033$	-
Sand:Mud	$p < 0.0005$	+	Temperature	$p < 0.0037$	-
Distance	$p < 0.0017$	-	Salinity	$p < 0.0094$	-
Oxygen	$p < 0.0073$	+	% Clay	$p < 0.0252$	-
TOC	$p < 0.0332$	-			
Al	$p < 0.0436$	-			

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 and August and 50:50 in June (Figure 33). Polychaete taxa dominated only in July, September and October. The number of taxonomic groups was fairly consistent with time (April, 13 taxa; June, 10 taxa; July, 8 taxa; August, 10 taxa; September, 9 taxa; October, 7 taxa), further indicating the lack of influence of 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. Dominant species (by number of individuals for each

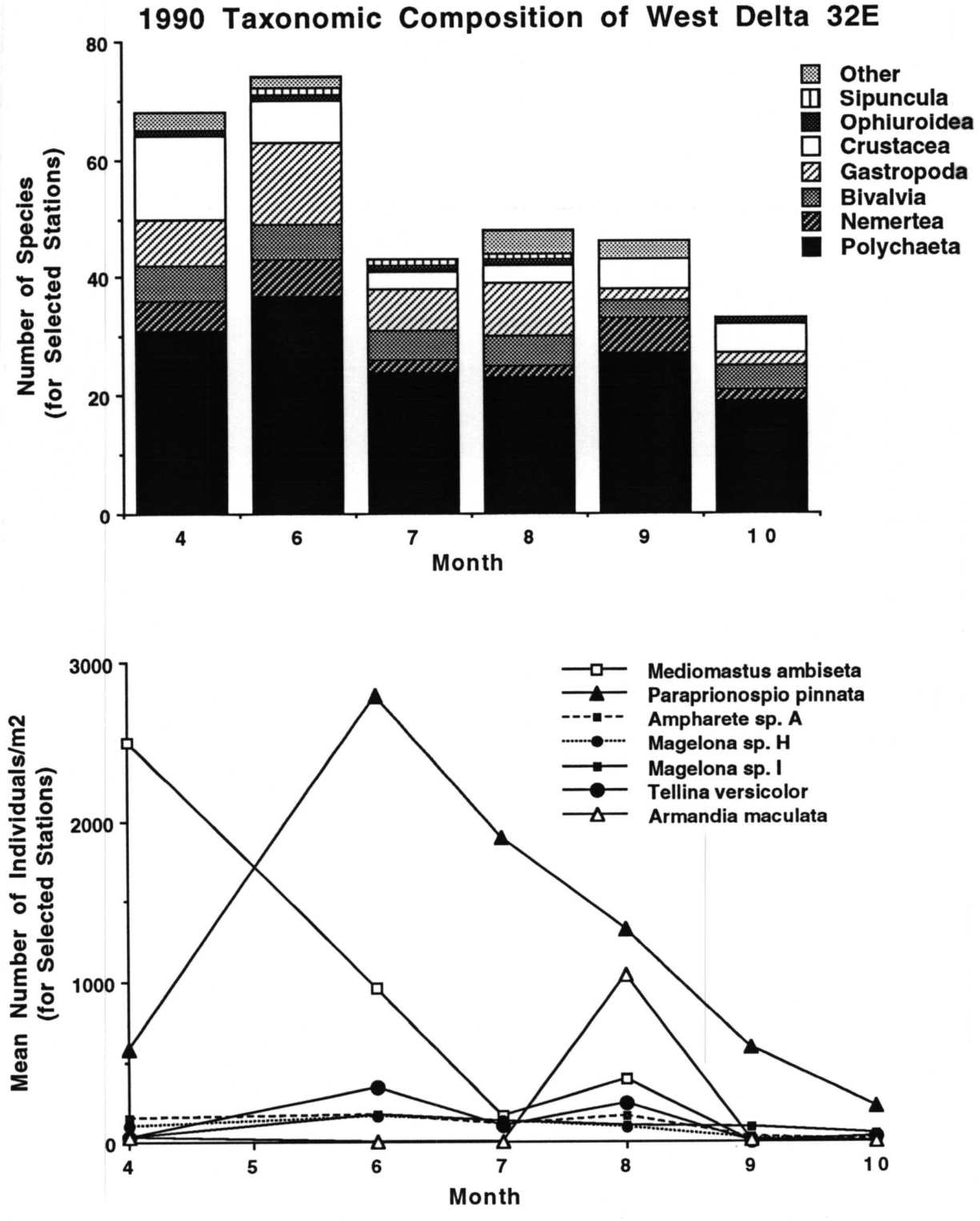

Figure 33. Taxonomic composition (upper) and change in number of individuals per square meter of dominant taxa (lower) at Shell WD32E (=SH) for months indicated.

sample period are listed in Table E.8, and the successive change in the abundances of several dominants are shown in Figure 33. 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 time were evident with *Prionospio cristata*, *Nephtys incisa*, *Magelona* sp. I, *Magelona* sp. H, *Ampharete* sp. A, and *Owenia fusiformis*.

CHAPTER 7. EFFECTS OF HYPOXIA AND CHEMICAL CONTAMINANTS

7.1 Assumptions and Hypotheses

We originally hypothesized that the effects of offshore oil and gas development in the form of a production platform discharge could be identified on the Louisiana inner continental shelf and placed in the context of natural, temporal variability as caused by hypoxic bottom waters. We formed this hypothesis based upon the results of several studies:

1) Differences in hydrocarbon contamination of sediments have been observed, particularly where there were large amounts of operational discharges, i.e., produced waters (e.g., Middleditch 1981, Bedinger 1981, Neff et al. 1989, Rabalais et al. 1991a, 1992a),

2) Studies of benthic communities in areas of hypoxia on the Louisiana and Texas continental shelf (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, 1992) have shown that we can identify the effects of hypoxia.

3) Even where large-scale natural processes, i.e., shallow, erosive water column and high flushing potential of the Atchafalaya River flow, were expected to obscure patterns, produced water hydrocarbon contamination was detected out to 200 m from a platform, and statistically significant differences in benthic communities extended to 300 m from the platform and were consistent across time (Rabalais et al. 1991a).

Several assumptions guided our research. First, it is highly probable that an area of the southeastern Louisiana inner continental shelf, where there are extensive oil and gas production activities, will experience hypoxic bottom waters during the summer season. Second, the dissolved oxygen levels at two or more sites will be similar throughout the season of hypoxia in concentration and duration. Third, benthic communities can be identified as being impacted by hypoxia. Fourth, concentrations of contaminants can be identified in the sediments adjacent to a production platform, and should be correlated with distance from the discharge.

As a result of these assumptions, we hypothesized that differences in the benthic fauna can be identified as a gradient in distance from the production platform, that these differences will be consistent across time, and that the relative importance of environmental variables that affect benthic community variability can be identified.

7.2 Suitability of Study Sites

A substantial problem evolved early in the determination of adequate study sites that would provide the suitable experimental setting to answer the original research questions. Four platforms were identified initially as potential study sites. Three were in the South Timbalier block area in 20 m water depth, the other was in the West Delta block area at the same depth (Table 1). Sediments are generally sandier in the South Timbalier area (less likely to adsorb hydrocarbon contaminants) and siltier in the West Delta area (more likely to adsorb hydrocarbon contaminants). In the South Timbalier area, one platform was dictated as the reference site, because it had no active discharge and was the site of a permanent instrument mooring with a continuously recording oxygen meter. The other platforms in South Timbalier (within 7 km of each other) were known to be similar in sediment characteristics and oxygen conditions, but had differing produced water discharges (5,550 vs. 20,000 bbl/d). The West Delta platform had a discharge of 19,000 bbl/d; and, given the siltier sediments, was expected to demonstrate some level of hydrocarbon contamination related to the discharge. The distance between the West Delta platform and the South Timbalier area (74 km) and the fact that limited historical data concerning hypoxia were available from the West Delta

area, dictated that the second continuously recording oxygen meter be placed in the West Delta area.

An April reconnaissance cruise was conducted to determine patterns of hydrocarbon and trace metal concentrations and sedimentary characteristics at each of the study sites. The results from the April transect (15°NNE) at ST52C indicated no signal of hydrocarbons in the sediments. There were detectable petrogenic hydrocarbon concentrations at ST53A and WD32E, but not in a clear gradient away from the platform. A second transect located in a more likely direction of dispersion from the ST52C platform was occupied in June (270°W) and indicated a gradient of chemical contamination, but shell hash used as stabilizing material at the base of the platform created artificial substrates at the 20-, 50- and 100-m stations which confounded interpretation of the effects of sediment characteristics on the distribution of the benthos. This gradient of sediment types and difficulty in reoccupying the same stations during July at ST52C caused us to drop the site from the sample design. Sediment grain size distribution was also complicated at the WD32E platform as a result of sandblasting activities on the platform.

At this point, however, we were compelled to continue focusing on the remaining three platforms that were originally selected, because of limitations of time to complete the study and be underway for the 1990 summer hypoxia season and limitations of resources to conduct further reconnaissance cruises. With data from these three sites, we assumed it would be possible (in the event of minimal chemical signals and confounding effects of sediment variability) to at least characterize the benthic communities from a variety of sedimentary regimes where hypoxia is persistent and severe during the summer months.

7.3 Environmental Variability

The 1990 season of hypoxia, as monitored off Terrebonne/Timbalier Bays and at ST53B was severe, in that hypoxia occurred early and persistently in the spring, hypoxia was severe in the summer (Figure 11), hypoxic bottom waters occurred far offshore, anoxic conditions were documented for long periods of the record, and the generation of hydrogen sulfide in bottom waters was recorded often. Dissolved oxygen concentrations in bottom waters at the two platforms without an oxygen meter (ST52C and ST53A) were similar to those at ST53B, where the instrument mooring was located. The oxygen record for WD32E located 74 km away, on the other hand, showed incursions in and out of hypoxic conditions, with no extremely low levels for prolonged periods (Figure 11). Oxygen conditions, therefore, were substantially different between the South Timbalier and West Delta areas. Conditions in the South Timbalier area could be characterized as severe and persistent, with effects expected on the benthic community. On the other hand, conditions at West Delta could be characterized as ephemerally hypoxic and not severe, with little impact expected on the benthic community.

The grain size distributions, as expected, were considerably different between the South Timbalier area (primarily sandy silts) and the West Delta area (primarily silts). The degree of variability among stations within a single study site was high, and not always consistent with time. For example, sediments at ST53A were predominantly sandy silts with little clay fraction, but substantially different sediments were often observed (e.g., anomalously low sand percentage at 1000 m in April and 100 m in June, or extremely high sand percentage at 50 m in July (Figure 13). There were no consistent gradients in sand/silt/clay percentages with time at ST53A. ST53B was the most variable in space and time with non-uniform and high percentages of sand or clay that were not consistent with distance from the platform nor sample period (Figure 14). Variability in sediments at ST53A and ST53B complicated the interpretation of benthic community data. Sediments at WD32E were composed primarily of silts, with the exception of stations closest to the platform (0, 20 and 50 m) where the sediment surface was impacted by sandblasting operations. At these times, anomalously high percentages of coarse-grained sands were present. These

sediment differences so close to the platform complicated the interpretation of both chemical contaminant and benthic infaunal data.

7.4 Chemical Contaminants

Limited surficial sediments analyzed for the radionuclides Pb-210, Ra-226 and Ra-228, indicated concentrations at or below typical coastal sediments. Elevated concentrations of Ra-226 at WD32E Ref and ST52C 20 m were not found in sediments associated with higher levels of petrogenic hydrocarbons.

Elevated levels of Ba and Zn were documented within 500 m of the ST52C platform in both months sampled (Appendix C). As noted earlier, however, there was also a general increase in sand and a decrease in fines along both transects with distance from the platform. Metal concentrations in June (along the transect in the expected direction of long-term current flow away from the platform) had in general overall elevated values of Fe, Al, Ba, Cd, Cr and V over those detected along the 15°NNE transect in April. Sediments were consistent along the two transects between the two months, and the differences in metals concentrations could not be related to temporal differences in sediments. The ST52C platform, however, was dropped from the study design in July. There were no clear gradients in concentrations of metals away from the ST53A or ST53B platform for the four months sampled. Values, in general, were lower for sediments at ST53B than at ST53A and ST52C. Metal concentrations clearly outside the limits of normalized Al concentrations (Schropp et al. 1990) (Pb > 100 ppm and Zn > 100 ppm) were evident within 100 m of the WD32E platform (Figure 16).

Petrogenic hydrocarbons were more elevated along the 270°W transect at ST52C than the 15°NNE transect (Figure 17); this was in the direction of the expected current flow and dispersion of production platform effluents. Sediments at 50 and 250 m along the 270°W transect contained petrogenic hydrocarbons, and the summed PAH concentrations were at the threshold level where negative impacts have been demonstrated to affect the benthic infauna (Rabalais et al. 1991a). This study site, however,was dropped from the study design in July. Sediments at ST53A contained hydrocarbons in low concentrations (Figure 18) of mostly a weathered petroleum or biogenic nature. The concentrations were similar to those along the 15°NNE transect at ST52C and did not approach the higher levels of the 270°W transect. The discharge volume at ST53A, however, was four times less than that at ST52C (5,550 vs. 20,000 bbl/d). There were no clear spatial nor temporal patterns evident in the distribution of hydrocarbons adjacent to the ST53A platform. Sediment hydrocarbons adjacent to ST53B were similar in composition to those of ST53A, but generally lower in concentration.

Hydrocarbon concentrations had a greater range at WD32E than the study sites in the South Timbalier area. The sediments at WD32E contained hydrocarbons mostly of a mixed weathered petroleum and biogenic nature; there were certain stations, however, where the hydrocarbon composition was distinctly petrogenic. There was also a trend for a greater predominance of biogenic hydrocarbons with distance from the platform. With the exception of the June sampling period, total saturated hydrocarbon concentrations for WD32E (Figure 22) were similar to concentrations in South Timbalier, despite the higher percentage of fine sediments at WD32E and the larger volume discharge. There was a general decrease in the concentration of specific analytes and in summed PAHs from April through August (Figure 23). The summed alkylated PAH concentrations at 50 and 100 m in June (Figure 23) exceeded the threshold level where negative impacts on benthic infauna have been shown previously (Rabalais et al. 1991a).

In summary, hydrocarbon concentrations ranged over the greatest values at WD32E, and there were obvious indicators of petrogenic origin hydrocarbons at selected stations during some months. In a few instances among the four study sites, analyte concentrations and summed PAH concentrations approached or exceeded the threshold level where negative impacts on benthic

infauna have been shown previously. Hydrocarbon concentrations, in general, however, were low for most study sites (even where sediments were silty) and were characterized as weathered petrogenic or biogenic in nature. In general, there were no consistent spatial nor temporal trends in hydrocarbon chemistry at the three study sites that remained part of the final experimental design.

7.5 Benthic Communities

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.

Although ST53A was consistently lower in number of species and individuals than ST53B, these differences were not always significant. It is tempting to attribute these differences to the consistently higher concentrations of produced water hydrocarbons at ST53A; however, a multiple regression model with both study sites combined indicates that only the environmental variables of oxygen concentration, temperature and salinity were significant in explaining the variation in species richness and abundance in the South Timbalier study area.

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. During September and October the overall increase in number of individuals was due primarily to the recruitment of *Paraprionosopio pinnata* and *Armandia maculata* and sustained population levels of *Magelona* sp. H and *Aspidosiphon* sp.

A large component of the benthic community at WD32E, on the other hand, was composed of polychaetes, but there was a much greater diversity of other major taxa than at the 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, and *Owenia fusiformis*.

The community composition of WD32E differed from that of the South Timbalier area as a result of sedimentary differences (silts vs. sandy silts) and the oxygen environments (ephemeral vs. persistent and severe hypoxia/anoxia). The benthic community at WD32E was more diverse, in general, and had a more diverse complement of major taxa. The presence of a variety of pericaridean crustaceans at WD32E indicated that hypoxia was not a major environmental variable affecting the benthic community composition. Where hypoxia/anoxia has been severe, at least temporarily (e.g. the New York Bight, Boesch and Rabalais 1991; the upper Texas coast, Harper

et al. 1981; the southwestern Louisiana shelf, Gaston 1985), amphipods were dramatically reduced and recovery was slow over a period of years. In the South Timbalier study area (this study), the low abundance of any pericaridean crustaceans in the initial sampling of spring 1990 indicated a consistent, yearly exposure to severe hypoxia/anoxia vs. the more ephemeral hypoxia of the WD32E area and the areas studied by Harper et al. (1981) and Gaston (1985). The presence of gastropods and bivalves at the South Timbalier area in the spring but not during hypoxia vs. sustained levels of these taxa at WD32E indicated the recruitment success in all three sites of the planktonic stages of these organisms, but not the continued survival of the populations at ST53A and ST53B under hypoxic/anoxic conditions. Dramatic increases in opportunistic species, particularly *Paraprionospio pinnata*, in the upper Texas coast and southwestern Louisiana shelf sites were not paralleled during fall in the South Timbalier study area. Abundances remained low through October 1990. In a previous study (Rabalais et al. 1989, Boesch and Rabalais 1991), dramatic increases in populations did not begin until the following spring following a severely hypoxic summer season. The reason for the differences between the community recoveries may be related to the fact that the southeastern Louisiana site lies within a large area which experiences persistent hypoxia virtually every year, while the other two sites are more at the periphery of hypoxic zones (Boesch and Rabalais 1991).

7.6 Interaction of Environmental Variables

Variability in the benthic community parameters of species richness and abundance was explained by differing combinations of the environmental variables of oxygen and related water temperature and salinity, sediments, and total saturated hydrocarbons (Table 12). The environmental variable of bottom water oxygen concentration was important in both models for ST53A and one each for ST53B and WD32E. In the case of ST53A and ST53B, there was more of a threshold effect, whereby numbers of species and individuals were dramatically reduced when the oxygen concentration fell below 0.5 mg/l. Sediment characteristics were incorporated in the models for ST53B but were inconsistent with benthic community paradigms (i.e., percent sand was negatively correlated to diversity and abundance). Contrary to many benthic studies, grain size distributions were not always paramount in explaining the variation observed in the benthos (e.g., Unocal ST53A); however, the relationship with oxygen was strong for that study site and sediment variability was minimal at ST53A. At only one study site, ST53B, were any hydrocarbon variables significant in the models that explained variability in species richness and abundance. The variable of total saturated hydrocarbons was positively related to species richness and abundance, perhaps indicating an enhancement effect of the biogenic-type hydrocarbons

Table 12. Summary of multiple regression models for variability in species richness and abundance. Xs indicate those environmental variables that were significant (alpha = 0.05) in the models in Tables 7, 9 and 11.

Study Site	Benthic Parameter	Oxygen	Salinity/ Temperature	Sediments	Hydrocarbons	Distance
Unocal ST53A	Species Richness	X	X			
	Abundance	X	X			
Unocal ST53B	Species Richness		X	X	X	
	Abundance	X		X	X	
Shell WD32E	Species Richness	X	X	X		X
	Abundance		X	X		

present in the sediments at the distal ends of the ST53B transect. As noted earlier, however, the concentration of saturated hydrocarbons at the ST53B study site (non-production platform), was much less than the other two study sites (both production platforms). Neither of the variables that would indicate the presence of produced water origin hydrocarbons (summed alkylated PAH and FFPI) were significant in any of the models. The potential for effects within 100 m of the WD32E platform were masked by the platform-related grain size distribution differences and other potential platform effects that would increase diversity and abundance.

7.7 Revisit with Assumptions and Hypotheses

Before we can draw conclusions regarding the relative importance of petroleum production activities versus hypoxic bottom waters on the benthic communities of the southeastern Louisiana shelf, we must first revisit the guiding assumptions for the study. First, hypoxia did occur as predicted on the southeastern inner shelf in both of the study areas, South Timbalier and West Delta. The second assumption, however, that dissolved oxygen levels would be similar at the numerous sites was not met. Oxygen conditions were dramatically different between the South Timbalier area (severe and persistent) and the West Delta area (ephemeral and not severe).

The obvious information in the benthic community data is the difference in communities in severely impacted hypoxic/anoxic environments versus those habitats that experience ephemeral hypoxia. The dramatic decrease in macroinfauna during severe hypoxia is recognizable even after the area becomes re-oxygenated, and into the following fall period, by the absence of certain taxa from the community. Without at least monthly data, patterns in the benthic community are difficult to discern. The initial assumption in the study design that benthic community parameters related to hypoxia could be discerned was met.

The final assumption was that concentrations of contaminants could be identified in the sediments adjacent to a production platform, and should be correlated with distance from the discharge. This assumption was not met at any of the study sites. Hydrocarbon concentrations were uniformly low at the South Timbalier study sites of ST53A and ST53B. While concentrations were greater at ST52C and indicated the presence of petrogenic hydrocarbons, this study site was dropped from the experimental design in July because of complications of the shell hash pad at the base of the platform. No clear evidence of produced water contaminants was seen at ST53A, and patterns of hydrocarbon distributions were not consistent with distance from the discharge. Concentrations of hydrocarbons were greater at ST53A than the non-production platform ST53B, but these variables did not enter into a multiple regression model for both sites combined that explained the variability of species richness and abundance. At the WD32E study site, petrogenic hydrocarbons were usually present in sediments at some of the stations, but these patterns were not in decreasing concentration with distance from the platform. Also, concentrations of the various categories of hydrocarbons were not consistent through time at WD32E, and, in fact, decreased generally through the study period. Thus, a major assumption concerning hydrocarbon contaminant signals was not met in the study design.

There were some gradients in benthic community parameters that were consistent through time. For example, species richness and abundance were generally lower at the 20 m station at ST53A. The remainder of the stations grouped with 250 m, 500 m, 750 m and 1000 m having the most species and individuals, and with stations at 50 m and 100 m being intermediate. These trends were not always significant, nor consistent through time. Also, no environmental variable analyzed showed the same consistent pattern with distance from the platform. Gradients with distance from the platform were seldom evident in the benthic community at the non-production platform, ST53B. When there were significant differences with distance from the platform, the fauna at 100 m was less diverse. Hydrocarbon concentrations were lower at this study site. Still, the primary environmental factors that explained the variability in species richness and abundance at the South Timbalier sites were oxygen and related salinity and temperature of the bottom water.

Benthic community parameters were significantly different (in most cases) by station at the WD32E platform, but these differences were not related to distance from the platform and were not consistent across time. Stations at 20 m and 50 m, in general, has more species and individuals than the other stations, but these differences can probably be related to platform effects based on the type of fauna in the samples. In April, higher values for number of individuals at 20 m, 50 m and 100 m were related to abundances of *Mediomastus ambiseta* and Tubificidae A, both indicators of organic enrichment. Tubificids were uncommon in the remainder of the study and at the other study sites.

Thus, there were some indications for gradients in benthic community parameters at the two production platforms, but these gradients were not always consistent in time, nor consistent with distance from the platform, nor significant. However, there were no clear environmental signals at any of the platforms with distance from the platform. Multiple regression analysis identified oxygen concentration, water temperature and salinity, and sediments as important environmental factors that explain the variation in benthic community parameters of species richness and abundance. Production discharge hydrocarbon concentrations were not significant in any of the models, but there were no clear environmental signals related to these contaminants at any of the study sites. As a result, our initial hypothesis concerning the interaction of hypoxia and production platform discharges could not be tested.

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Appendix A. Hydrography and Water Quality

Table A.1. Hydrography, April 1990.

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

Station: 06 Latitude: 28:51.44 N Hydrolab cast time: 10:46
Date: 04/16/90 Longitude: 90:27.68 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
0.1	20.30	15.34	8.35	9.82	11.59	140.1
1.0	20.26	15.80	8.36	10.18	11.45	138.6
1.8	20.16	17.26	8.34	11.31	11.20	136.5
2.9	20.07	21.88	8.31	14.82	10.40	130.0
4.0	20.02	25.14	8.66	17.30	9.70	123.5
5.1	20.02	26.83	8.22	18.58	8.94	114.9
6.0	20.07	27.47	8.21	19.05	8.75	113.0
7.9	20.30	30.27	8.17	21.11	7.93	104.6
9.9	20.34	30.71	8.17	21.43	7.91	104.7
12.0	20.55	31.30	8.18	21.83	7.67	102.3
14.0	20.58	31.74	8.17	22.15	7.44	99.5
16.0	20.53	32.60	8.01	22.82	5.22	70.1
18.0	20.55	32.75	7.97	22.93	4.63	62.3
19.0	20.56	32.97	7.95	23.09	4.47	60.2
20.0	20.58	33.34	7.85	23.36	3.01	40.6
21.1	20.60	33.56	7.82	23.53	2.70	36.5
22.0	20.60	33.49	7.81	23.47	2.78	37.6

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

Station: 6A Latitude: 28:51.44 N Hydrolab cast time: 14:10
Date: 04/16/90 Longitude: 90:27.68 W Secchi disk depth (m): 2.1

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.2	21.02	15.22	8.34	9.56	11.80	144.6
1.0	20.52	19.03	8.38	12.56	11.75	145.7
2.0	20.26	22.30	8.37	15.09	11.50	144.7
2.9	20.18	23.55	8.34	16.05	11.00	139.2
4.0	20.02	25.14	8.28	17.30	9.89	125.9
5.0	20.06	26.55	8.24	18.36	9.05	116.3
5.9	20.25	28.91	8.20	20.09	8.44	110.3
7.0	20.39	30.13	8.18	20.98	8.22	108.5
8.0	20.47	30.36	8.18	21.13	7.98	105.7
8.9	20.47	30.64	8.17	21.35	7.92	105.0
11.0	20.59	31.09	8.17	21.65	7.61	101.4
13.0	20.65	31.38	8.17	21.86	7.50	100.2
15.0	20.65	31.74	8.11	22.13	6.36	85.2
17.0	20.66	32.54	8.00	22.74	5.07	68.2
18.0	20.70	33.05	7.96	23.12	4.45	60.1
19.0	20.76	33.50	7.89	23.44	3.51	47.6
20.0	20.78	33.50	7.88	23.43	3.50	47.5

Table A.1. Continued.

CRUISE DATA - TRANSECT C

Station: CH 100m Latitude: 28:52.12 N Hydrolab cast time:2:20
Date: 04/18/90 Longitude: 90:29.42 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	21.67	14.44	8.68	8.82	17.14	211.7
1.0	21.66	14.71	8.68	9.02	17.11	211.6
1.9	21.65	16.84	8.67	10.63	16.92	211.8
3.0	21.16	19.25	8.55	12.57	14.64	184.1
3.9	20.87	21.64	8.48	14.44	12.65	160.4
5.0	20.56	23.49	8.39	15.92	11.21	142.8
6.0	20.03	25.42	8.24	17.51	8.57	109.3
6.9	20.14	27.33	8.21	18.93	8.75	113.1
8.0	20.18	29.05	8.20	20.21	8.45	110.4
10.0	20.33	29.99	8.18	20.89	7.81	102.9
10.9	20.40	30.28	8.17	21.09	7.64	101.0
13.0	20.34	30.78	8.08	21.49	6.41	84.9
15.0	20.52	32.17	8.00	22.49	4.94	66.2
15.9	20.58	32.83	7.95	22.98	4.30	57.9
17.1	20.63	33.41	7.82	23.41	2.70	36.5
18.0	20.64	33.42	7.82	23.41	2.71	36.7
18.8	20.64	33.42	7.82	23.41	2.77	37.5

Station: SH 100m Latitude: 29:07.63 N Hydrolab cast time:8:25
Date: 04/18/90 Longitude: 89:41.46 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	20.68	14.23	8.55	8.89	12.46	150.7
1.0	20.68	14.49	8.55	9.09	12.37	149.9
1.8	20.69	16.34	8.55	10.49	12.27	150.3
2.7	20.68	19.71	8.55	13.03	12.05	150.5
4.0	20.68	21.42	8.55	14.33	11.99	151.3
5.0	20.68	21.49	8.55	14.38	11.99	151.4
6.1	20.70	21.91	8.55	14.68	12.04	152.4
6.9	21.09	23.45	8.48	15.75	11.82	152.1
8.1	21.19	23.87	8.44	16.04	11.42	147.6
9.2	20.62	26.23	8.22	17.97	7.57	98.1
10.0	20.08	28.33	8.08	19.69	6.49	84.3
10.8	20.05	29.61	7.97	20.67	4.83	63.2
11.7	20.19	31.78	7.94	22.29	4.94	65.6
12.9	20.35	33.25	7.96	23.36	5.00	67.2
14.5	20.40	33.98	7.95	23.90	4.80	64.8
15.8	20.47	34.72	7.94	24.44	4.65	63.2
16.9	20.47	34.35	7.94	24.17	4.68	63.4
17.9	20.46	34.35	7.94	24.17	4.70	63.7
18.8	20.46	34.57	7.93	24.33	4.73	64.2

Table A.2. Hydrography, May 1990.

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

Station: 06 Latitude: 28:51.44 N Hydrolab cast time: 23:41
Date: 05/17/90 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	26.55	20.12	8.18	11.73	7.07	98.9
1.0	26.53	21.15	8.10	12.52	6.98	98.2
2.0	26.43	27.01	8.06	16.92	6.87	99.8
3.0	26.50	29.25	8.06	18.58	6.76	99.6
4.1	26.51	29.97	8.06	19.12	6.75	99.9
4.9	26.48	30.41	8.06	19.46	6.74	99.9
6.0	26.34	30.55	8.06	19.61	6.74	99.7
7.0	26.26	30.63	8.06	19.68	6.74	99.6
8.0	26.26	30.70	8.06	19.74	6.74	99.7
9.0	26.15	30.84	8.06	19.88	6.76	99.8
10.0	26.00	30.69	8.06	19.81	6.76	99.5
10.9	25.83	30.69	8.06	19.86	6.76	99.2
12.0	25.75	30.68	8.06	19.89	6.73	98.6
13.0	25.66	30.83	8.04	20.02	6.45	94.4
14.1	24.03	32.37	7.79	21.67	2.65	38.0
15.0	23.24	33.88	7.55	23.04	0.20	2.8
16.0	23.18	33.80	7.54	23.00	0.18	2.6
17.0	23.20	34.03	7.53	23.16	0.18	2.6
18.0	23.21	33.88	7.53	23.04	0.23	3.3
19.0	23.23	33.81	7.53	22.98	0.26	3.7

Table A.2. Continued.

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

Station: 6A Latitude: 28:50.41 N Hydrolab cast time: 16:53
Date: 05/17/90 Longitude: 90:26.03 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	26.20	29.17	8.07	18.61	7.01	102.6
1.0	26.20	29.09	8.07	18.56	7.00	102.5
2.0	26.19	29.02	8.07	18.50	6.99	102.2
3.0	26.14	29.09	8.07	18.57	7.03	102.8
4.0	26.15	29.09	8.07	18.57	7.04	102.9
5.0	26.12	29.09	8.07	18.58	7.05	103.0
6.0	26.11	29.16	8.07	18.64	7.01	102.5
7.0	26.05	29.16	8.06	18.65	7.00	102.2
8.0	26.03	29.16	8.06	18.66	6.99	102.0
9.0	26.00	29.16	8.06	18.67	6.99	102.0
10.0	25.91	29.16	8.06	18.69	6.91	100.6
11.0	25.82	29.16	8.05	18.72	6.77	98.4
12.0	25.38	29.58	7.96	19.17	5.31	76.8
13.0	23.45	31.03	7.75	20.83	2.80	39.4
14.0	23.19	32.04	7.77	21.66	3.47	48.9
15.0	22.86	33.20	7.57	22.63	1.07	15.1
16.0	22.95	33.86	7.52	23.11	0.52	7.4
16.9	23.05	34.02	7.51	23.20	0.43	6.1
18.0	23.08	34.17	7.48	23.30	0.25	3.6
19.0	23.00	34.16	7.48	23.32	0.25	3.6
19.5	23.08	34.24	7.48	23.36	0.30	4.3
19.9	23.09	34.24	7.48	23.35	0.40	5.7

Table A.3. Hydrography, June 1990.

Station: C6 1000m Latitude: 28:51.11 N Hydrolab cast time:6:30
Date: 06/16/90 Longitude: 90:28.06 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.2	28.90	11.04	8.43	4.26	7.63	105.8
0.9	28.90	16.11	8.43	8.03	7.54	107.6
2.0	28.90	16.99	8.43	8.68	7.52	107.9
3.1	29.20	17.73	8.35	9.14	7.16	103.7
3.8	29.43	21.17	8.26	11.63	6.85	101.6
4.8	29.65	23.56	8.16	13.33	6.48	97.8
6.0	29.24	24.90	8.12	14.46	6.38	96.3
6.7	29.04	25.47	8.12	14.95	6.40	96.6
7.9	28.92	25.68	8.11	15.15	6.21	93.6
8.9	28.76	25.83	8.10	15.31	5.96	89.7
9.9	28.76	26.61	8.07	15.89	5.73	86.6
10.8	28.65	27.19	8.03	16.36	5.50	83.2
12.1	28.60	27.26	8.02	16.43	5.34	80.8
13.0	28.37	27.98	7.96	17.04	4.76	72.0
14.0	27.80	29.78	7.87	18.57	4.04	61.1
14.8	28.36	30.89	7.90	19.22	5.39	82.9
15.8	28.59	31.41	7.89	19.53	5.36	83.0
17.0	26.50	33.95	7.70	22.11	1.70	25.7
17.8	24.65	34.55	7.54	23.13	0.85	12.5
19.0	24.15	34.52	7.51	23.26	0.67	9.7
19.3	24.16	34.60	7.51	23.31	0.80	11.6

Station: SH 50m Latitude: 29:07.65 N Hydrolab cast time:15:31
Date: 06/15/90 Longitude: 89:41.45 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.4	29.78	12.40	8.35	5.00	7.12	101.1
1.0	29.74	13.58	8.35	5.89	7.05	100.7
1.8	29.64	16.85	8.36	8.35	6.95	100.9
2.9	29.08	17.80	8.28	9.23	5.98	86.5
4.0	28.73	18.96	8.24	10.20	5.73	82.9
5.0	28.65	19.58	8.22	10.69	5.73	83.0
6.0	28.24	21.24	8.09	12.05	2.50	36.3
6.7	27.79	22.77	7.84	13.34	0.68	9.9
8.2	26.61	27.23	7.66	17.03	2.00	29.2
9.0	26.60	31.22	7.72	20.03	3.30	49.2
10.0	26.55	32.40	7.76	20.92	3.82	57.3
11.0	25.88	33.26	7.70	21.78	3.30	49.2
12.0	24.66	33.88	7.66	22.62	2.08	30.4
13.0	23.87	34.58	7.64	23.38	2.46	35.6
14.1	24.14	35.11	7.74	23.71	4.13	60.3
15.1	23.93	35.33	7.70	23.93	3.43	49.9
15.8	23.55	35.23	7.62	23.97	2.44	35.2
17.3	23.16	35.28	7.47	24.12	0.36	5.2
18.1	23.11	35.20	7.46	24.08	0.23	3.3
19.4	23.13	35.50	7.46	24.30	0.26	3.7

Table A.3. Continued.

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

Station: 06 Latitude: 28:51.44 N Hydrolab cast time: 14:45
Date: 06/17/90 Longitude: 90:27.68 W Secchi disk depth (m): 1.3

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	30.06	10.20	8.48	3.28	9.16	129.1
1.0	29.44	10.97	8.48	4.04	9.18	128.5
2.2	29.54	12.07	8.48	4.83	9.09	128.3
2.4	29.17	12.99	8.48	5.63	9.22	129.9
3.7	29.07	16.92	8.31	8.58	6.13	88.2
4.8	29.27	21.66	8.20	12.04	5.87	87.0
5.9	29.41	24.34	8.14	13.98	5.87	88.6
6.9	29.42	25.33	8.11	14.72	5.77	87.6
7.8	29.23	25.90	8.09	15.21	5.70	86.5
9.1	28.67	27.69	8.02	16.73	5.26	79.9
10.0	27.89	30.01	7.92	18.71	4.61	69.9
11.0	27.24	31.31	7.84	19.89	4.13	62.4
12.0	26.85	32.11	7.81	20.62	4.03	60.7
12.5	26.44	32.47	7.77	21.01	3.59	53.8
13.8	26.16	34.01	7.71	22.26	2.89	43.5
14.9	26.11	34.76	7.70	22.84	2.78	42.0
16.2	25.66	34.89	7.64	23.08	2.03	30.4
17.0	25.39	34.95	7.61	23.21	1.67	24.9
17.9	25.20	35.17	7.58	23.43	1.41	21.0
19.2	25.01	35.01	7.56	23.37	1.08	16.0
19.9	25.00	35.08	7.55	23.42	0.92	13.6

Table A.3. Continued.

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

Station: 6A Latitude: 28:50.49 N Hydrolab cast time: 10:30
Date: 06/17/90 Longitude: 90:26.02 W Secchi disk depth (m): 1.2

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.7	29.41	12.07	8.50	4.87	8.55	120.4
1.9	29.32	14.31	8.49	6.56	8.35	118.9
2.9	29.13	15.51	8.40	7.51	7.70	110.0
3.9	28.83	18.96	8.23	10.17	4.91	71.1
4.8	29.51	23.28	8.19	13.16	5.82	87.5
6.0	29.26	24.90	8.15	14.46	5.82	87.9
6.9	29.10	25.76	8.12	15.14	5.86	88.7
7.8	28.84	26.40	8.10	15.71	5.59	84.5
8.7	28.56	27.55	8.05	16.65	5.11	77.4
10.0	28.18	28.70	7.99	17.64	4.82	73.0
11.0	27.99	29.64	7.94	18.40	4.64	70.4
12.8	26.59	32.99	7.79	21.36	3.54	53.4
13.9	26.08	33.64	7.74	22.01	2.98	44.7
14.7	25.86	34.08	7.72	22.40	2.69	40.3
15.9	25.66	34.52	7.69	22.79	2.23	33.3
16.9	25.65	34.59	7.68	22.85	2.18	32.6
17.9	25.53	34.96	7.67	23.17	2.05	30.7
18.9	25.44	34.80	7.66	23.08	1.96	29.2
19.7	25.37	34.95	7.65	23.21	1.89	28.2
20.8	25.28	35.02	7.64	23.29	1.69	25.2

Table A.4. Hydrography, July 1990.

CRUISE DATA - TRANSECT C

Station: SH 750m Latitude: 29:07.33 N Hydrolab cast time:18:13
Date: 07/11/90 Longitude: 89:41.71 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.4	30.96	11.56	8.47	3.99	11.75	169.5
1.0	30.96	13.65	8.47	5.55	11.65	170.1
2.0	30.98	14.51	8.47	6.18	11.50	168.8
3.0	30.60	16.32	8.33	7.64	9.75	143.6
4.0	30.60	18.42	8.29	9.20	7.54	112.4
5.0	31.00	18.98	8.28	9.48	6.80	102.4
6.0	30.54	20.77	8.20	10.96	6.15	92.8
7.0	29.65	25.27	7.91	14.60	3.70	56.4
8.0	29.15	29.01	7.72	17.55	2.12	32.7
9.0	28.94	30.10	7.68	18.43	2.18	33.7
10.0	28.80	31.20	7.72	19.30	2.98	46.3
11.0	28.07	32.36	7.60	20.41	1.74	26.8
12.0	26.10	34.83	7.46	22.90	1.04	15.7
13.0	25.43	35.10	7.46	23.31	1.08	16.1
14.0	24.95	35.38	7.50	23.66	1.35	20.0
15.0	24.80	35.37	7.50	23.70	1.33	19.7
16.0	24.54	35.43	7.46	23.83	0.82	12.1
17.0	24.31	35.65	7.44	24.06	0.69	10.1
18.0	24.28	35.64	7.44	24.07	0.78	11.4
19.0	24.30	35.79	7.44	24.17	0.82	12.0

Table A.4. Continued.

NURC 1990 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6A Latitude: 28:50.37 N CTD time: 14:38
Date: 07/16/90 Longitude: 90:26.02 W Secchi disk depth (m): 3.5
Estimated total depth (m):19.5

HYDROGRAPHIC DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
1.521		19.37	1.17	28.72	3.35	87.8	10.47	
1.900		19.54	1.17	28.71	3.38	87.8	10.60	
2.100		19.61	1.17	28.73	3.39	87.8	10.64	
3.000	5.59	19.92	1.22	28.86	3.44	88.0	10.83	81.5
3.800	5.45	20.28	1.26	28.92	3.51	88.1	11.08	79.6
4.100	5.55	20.05	1.23	28.93	3.47	88.0	10.91	81.0
4.900	5.23	22.67	1.23	30.06	3.96	88.0	12.50	79.0
5.200	5.19	24.68	1.22	30.21	4.29	88.3	13.94	79.6
5.900	5.38	28.36	1.18	29.82	4.82	92.1	16.82	83.6
6.100	5.31	29.39	1.11	29.77	4.97	92.4	17.61	83.0
7.000	3.80	31.67	0.86	29.34	5.27	92.7	19.46	59.7
7.900	2.84	33.81	0.77	28.63	5.52	92.9	21.29	44.7
8.200	2.59	34.23	0.79	28.45	5.56	92.9	21.67	40.6
8.842	3.92	34.77	0.63	28.41	5.63	93.0	22.09	61.7
9.100	3.94	34.93	0.62	28.35	5.65	93.0	22.23	61.9
10.000	4.20	35.22	0.64	28.12	5.67	93.2	22.52	65.9
10.900	4.22	35.49	0.69	27.53	5.64	93.2	22.92	65.6
11.300	4.19	35.64	0.68	26.96	5.60	93.2	23.22	64.5
11.900	3.40	35.69	0.68	26.63	5.57	93.0	23.36	52.1
12.100	2.90	35.62	0.67	26.62	5.56	93.0	23.31	44.4
12.900	2.06	35.76	0.66	26.02	5.52	92.2	23.61	31.2
13.100	1.88	35.73	0.66	25.99	5.51	91.8	23.59	28.4
13.861	1.53	35.78	0.60	25.88	5.51	91.3	23.66	23.1
14.100	1.49	35.73	0.61	25.85	5.50	91.3	23.63	22.5
14.972	0.96	35.83	0.61	25.27	5.45	90.4	23.89	14.4
15.900	0.39	35.86	0.64	25.03	5.43	90.9	23.98	5.7
16.100	0.37	35.76	0.69	24.92	5.40	91.1	23.94	5.5
17.000	0.24	35.64	0.73	24.44	5.33	91.0	24.00	3.5
18.000	0.19	35.62	0.84	24.39	5.33	90.5	24.00	2.8
18.500	0.19	35.62	0.85	24.39	5.33	90.7	24.00	2.9
18.800	0.19	35.62	0.82	24.39	5.33	90.6	24.00	2.9
19.100	0.19	35.62	0.81	24.39	5.33	90.6	24.00	2.9

Table A.4. Continued.

NURC 1990 - TRANSECT SH

Station: 100 Latitude: 29:07.63 N CTD time: 20:45
Date: 07/17/90 Longitude: 89:41.50 W Secchi disk depth (m):##.#
Estimated total depth (m):19.0

HYDROGRAPHIC DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
1.897	8.22	16.94	3.87	28.28	2.94	74.7	8.79	116.6
2.100	8.29	16.95	3.95	28.29	2.94	74.8	8.79	117.6
3.100	8.26	16.99	4.01	28.28	2.95	74.8	8.83	117.2
4.100	8.26	17.01	3.99	28.29	2.95	74.8	8.84	117.2
5.000	7.92	17.48	4.19	29.50	3.10	74.5	8.82	115.1
6.000	5.46	27.52	1.56	29.65	4.68	92.1	16.25	84.3
7.000	4.66	28.93	1.29	29.85	4.91	92.2	17.24	72.7
8.000	4.13	31.55	1.13	29.87	5.31	93.2	19.19	65.5
9.000	4.44	32.16	0.84	29.74	5.39	93.4	19.69	70.4
10.000	4.35	32.91	0.63	29.61	5.49	93.5	20.29	69.2
11.000	4.18	33.08	0.61	29.52	5.50	93.5	20.45	66.4
12.000	3.91	33.93	0.61	28.20	5.49	93.4	21.53	61.0
13.000	1.87	34.69	0.54	26.37	5.41	92.5	22.69	28.4
14.000	1.48	35.14	0.43	26.17	5.45	90.3	23.09	22.3
15.000	2.86	35.60	0.37	25.82	5.47	91.3	23.54	43.1
16.000	3.39	35.68	0.36	25.50	5.45	87.2	23.71	50.8
17.000	2.91	35.78	0.40	25.31	5.44	83.6	23.84	43.5
18.000	3.00	35.93	0.54	25.02	5.43	64.7	24.04	44.7
18.100	3.03	35.92	0.56	25.01	5.43	60.9	24.04	45.2
18.200	3.06	35.93	0.58	25.00	5.43	57.9	24.05	45.5

Table A.4. Continued.

NURC 1990 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6A Latitude: 28:50.33 N CTD time: 23:05
Date: 07/18/90 Longitude: 90:26.19 W Secchi disk depth (m):##.#
Estimated total depth (m):19.0

HYDROGRAPHIC DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
1.600		23.59	1.07	28.47	3.98	92.7	13.69	
2.100		23.59	1.08	28.47	3.98	92.6	13.70	
3.100		23.58	1.06	28.45	3.98	92.6	13.69	
4.000		23.57	1.16	28.45	3.98	92.6	13.69	
5.000		23.60	1.09	28.48	3.99	92.6	13.70	
6.100	6.93	24.11	0.99	28.62	4.07	92.7	14.03	103.0
7.000	6.80	24.28	0.97	28.64	4.10	92.8	14.15	101.1
8.000	6.61	25.35	0.99	28.80	4.28	92.8	14.90	99.2
8.900	4.49	31.01	1.04	29.18	5.16	92.6	19.02	70.0
9.100	4.49	31.95	1.03	29.20	5.30	92.7	19.71	70.5
10.000	2.63	33.13	0.70	28.94	5.45	94.1	20.69	41.4
11.000	2.58	33.60	0.56	28.23	5.45	94.4	21.27	40.1
12.000	2.33	33.99	0.47	27.88	5.47	94.4	21.68	36.1
13.000	2.25	34.55	0.50	26.77	5.43	94.4	22.46	34.3
14.000	1.58	34.84	0.49	26.23	5.41	94.5	22.84	23.9
14.917	1.77	35.27	0.42	25.81	5.43	94.4	23.30	26.6
15.100	1.85	35.39	0.40	25.62	5.42	94.4	23.45	27.8
16.000	1.17	35.46	0.40	24.74	5.34	93.0	23.77	17.3
17.000	0.44	35.48	0.55	24.32	5.30	92.0	23.91	6.5
18.000	0.44	35.48	0.69	24.31	5.30	90.0	23.92	6.5
18.500	0.46	35.51	0.76	24.31	5.30	89.3	23.94	6.7
19.000	0.42	35.51	1.50	24.31	5.30	86.8	23.94	6.1

Table A.4. Continued.

SHELFWIDE 1990 - TRANSECT C
(off Cat Island Pass, Cocodrie)

Station: 6A Latitude: 28:50.18 N CTD time: 16:40
Date: 07/24/90 Longitude: 90:26.14 W Secchi disk depth (m): 4.0
Estimated total depth (m):19.0

HYDROGRAPHIC DATA

Depth (m)	D.O. (mg/l)	Sal. (ppt)	Fluor.	Temp. (C)	Conduct. (S/m)	% Light Trans.	Sigma-t	Percent Oxygen Saturation
0.863		21.81	1.10	30.59	3.86	89.6	11.68	
0.950		21.97	1.12	30.22	3.86	89.4	11.92	
1.046		21.95	1.11	30.12	3.85	89.4	11.94	
1.831		21.92	1.22	29.79	3.82	89.5	12.03	
2.101		21.93	1.28	29.66	3.81	89.5	12.07	
2.844		21.74	1.33	29.59	3.78	89.4	11.95	
3.031		21.68	1.37	29.60	3.77	89.4	11.91	
3.968		21.54	1.60	29.63	3.75	89.3	11.80	
4.193		21.52	1.57	29.67	3.75	89.3	11.76	
4.940		21.39	1.69	29.87	3.74	89.7	11.60	
5.153		21.45	1.75	29.75	3.74	90.1	11.69	
5.843		21.71	2.06	29.30	3.75	90.8	12.03	
6.258		21.74	2.04	29.25	3.76	91.8	12.06	
6.864		21.94	1.36	29.20	3.78	93.5	12.23	
7.115		21.94	1.18	29.21	3.79	93.9	12.23	
7.824		22.73	0.81	29.13	3.90	94.2	12.84	
8.000		22.88	0.77	29.08	3.92	94.2	12.97	
8.141		23.18	0.73	29.04	3.96	94.2	13.21	
8.990		25.42	0.79	28.76	4.29	93.0	14.97	
9.242		25.68	0.90	28.65	4.32	92.0	15.20	
9.935		27.66	1.16	29.05	4.65	90.5	16.55	
9.996		26.73	1.09	29.12	4.51	90.3	15.83	
10.008		26.54	1.12	29.11	4.48	90.9	15.69	
10.134		28.47	1.10	29.03	4.77	91.0	17.16	
10.903		28.93	0.51	28.74	4.81	93.8	17.60	
11.178		29.56	0.48	28.16	4.85	93.6	18.26	
11.810		31.17	0.49	27.69	5.04	93.5	19.62	
12.039		33.35	0.48	27.47	5.33	93.5	21.33	
12.988	6.02	34.92	0.46	26.76	5.48	93.6	22.74	92.0
13.095	4.14	34.78	0.46	26.97	5.48	93.5	22.56	63.5
13.964	1.21	35.40	0.45	26.10	5.48	93.8	23.31	18.4
14.158	1.10	35.48	0.47	25.92	5.47	93.8	23.42	16.6
14.966	0.83	35.73	0.47	25.27	5.43	93.1	23.81	12.4
15.191	0.85	35.84	0.49	25.05	5.43	92.5	23.96	12.6
15.904	0.80	35.68	0.97	24.89	5.39	89.9	23.89	11.8
16.156	0.77	35.65	1.02	24.85	5.38	88.5	23.88	11.4
16.906	0.47	35.56	1.08	24.79	5.36	88.4	23.83	6.9
17.242	0.44	35.54	1.08	24.77	5.36	88.1	23.82	6.5
17.970	0.36	35.51	1.14	24.75	5.35	87.8	23.81	5.3
18.264	0.36	35.51	1.14	24.74	5.35	87.2	23.81	5.3
18.790	0.33	35.50	1.18	24.74	5.35	86.9	23.80	4.9
18.915	0.33	35.48	1.39	24.75	5.34	85.1	23.78	4.9
18.984	0.32	35.49	1.34	24.74	5.35	84.8	23.80	4.7
19.003	0.33	35.50	1.26	24.73	5.35	85.2	23.80	4.9

Table A.5. Hydrography, August 1990.

Station: SH Latitude: 29:07.66 N Hydrolab cast time:14:22
Date: 08/14/90 Longitude: 89:41.41 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	32.28	9.25	8.61	1.85	14.56	212.2
1.0	31.87	12.08	8.48	4.08	10.58	155.6
2.0	30.71	20.01	8.31	10.34	7.87	118.6
3.0	30.43	21.25	8.30	11.36	7.73	116.7
4.0	30.37	22.02	8.27	11.95	7.44	112.7
5.0	30.37	23.99	8.09	13.41	6.39	97.9
6.0	30.24	25.06	8.00	14.25	5.55	85.3
7.0	30.04	29.46	7.76	17.59	3.86	60.6
8.0	29.66	31.44	7.66	19.20	3.40	53.7
9.0	29.44	31.95	7.62	19.65	3.01	47.5
10.0	29.12	32.61	7.55	20.25	1.51	23.8
11.0	28.83	34.09	7.52	21.46	1.67	26.4
12.0	28.65	34.76	7.46	22.02	1.16	18.3
13.0	27.91	35.34	7.41	22.70	0.70	10.9
14.0	27.40	35.70	7.46	23.14	1.54	23.9
15.0	27.05	36.06	7.45	23.52	1.43	22.1
16.0	26.55	36.12	7.46	23.73	1.66	25.5
17.0	26.14	36.33	7.47	24.01	1.97	30.0
18.0	26.16	36.56	7.46	24.18	2.06	31.4

Station: C6 500m Latitude: 28:51.26 N Hydrolab cast time:12:31
Date: 08/15/90 Longitude: 90:27.80 W Secchi disk depth (m):##.#

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	30.87	25.07	8.06	14.04	6.47	100.6
1.0	30.87	25.07	8.06	14.04	6.49	100.9
2.0	30.67	25.07	8.07	14.11	6.50	100.7
3.0	30.47	25.13	8.07	14.23	6.54	101.0
4.0	30.34	25.06	8.07	14.21	6.54	100.7
5.0	30.35	25.13	8.06	14.26	6.53	100.7
6.0	30.35	25.13	8.06	14.26	6.43	99.1
7.0	30.39	25.35	8.04	14.41	6.26	96.7
8.0	30.21	27.36	7.71	15.97	4.31	67.1
9.0	29.54	30.40	7.60	18.46	2.63	41.2
10.0	28.83	33.42	7.51	20.96	2.34	36.8
11.0	28.36	34.75	7.53	22.11	2.71	42.6
12.0	27.73	35.56	7.50	22.92	2.51	39.2
13.0	27.57	35.93	7.47	23.26	2.15	33.5
14.0	27.02	35.84	7.34	23.36	0.35	5.4
15.0	26.59	35.90	7.31	23.54	0.11	1.7
16.0	26.22	35.81	7.31	23.59	0.12	1.8
17.0	25.93	35.95	7.27	23.79	0.16	2.4
18.0	25.66	35.86	7.18	23.81	0.19	2.9
18.5	25.64	35.86	7.17	23.81	0.22	3.3
19.2	25.67	35.93	7.17	23.86	0.28	4.2

Table A.5. Continued.

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

Station: 06 Latitude: 28:51.44 N Hydrolab cast time: 14:10
Date: 08/16/90 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
0.3	31.52	15.65	8.15	6.84	6.96	103.8
1.0	31.60	16.19	8.15	7.22	6.76	101.3
2.0	31.17	17.41	8.15	8.26	6.91	103.4
3.0	30.92	21.75	8.15	11.56	6.69	102.2
4.0	30.91	24.22	8.12	13.40	6.39	99.0
5.0	30.93	25.29	8.07	14.18	6.38	99.4
6.0	30.80	27.66	7.87	15.99	5.50	86.7
7.0	30.40	28.45	7.79	16.72	4.47	70.3
7.0	30.40	28.45	7.79	16.72	4.47	70.3
8.0	29.85	29.68	7.70	17.82	3.32	52.0
9.0	29.38	31.73	7.66	19.51	2.71	42.6
10.0	28.77	33.57	7.57	21.09	1.71	26.9
11.0	28.08	35.12	7.57	22.48	2.21	34.6
12.0	27.72	35.56	7.51	22.93	1.30	20.3
13.0	27.32	35.62	7.42	23.10	0.16	2.5
14.0	27.11	35.76	7.40	23.28	0.23	3.6
15.0	27.02	35.84	7.40	23.36	0.15	2.3
16.0	26.93	35.91	7.37	23.45	0.29	4.5
17.0	26.49	35.82	7.41	23.52	0.12	1.8
18.0	25.83	35.87	7.35	23.76	0.16	2.4
19.0	25.73	35.79	7.29	23.73	0.17	2.6
19.5	25.76	36.24	7.30	24.06	0.24	3.6

Table A.5. Continued.

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

Station: 6A Latitude: 28:50.49 N Hydrolab cast time: 10:20
Date: 08/16/90 Longitude: 90:26.02 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
0.2	31.08	18.63	8.11	9.20	6.58	99.0
1.0	30.60	22.23	8.12	12.03	6.58	100.2
2.0	30.54	23.64	8.12	13.09	6.46	99.1
3.0	30.50	24.49	8.12	13.74	6.45	99.3
4.0	30.49	24.78	8.11	13.95	6.42	99.0
5.0	30.48	24.99	8.11	14.12	6.40	98.8
6.0	30.43	25.28	8.10	14.34	6.28	97.0
7.0	30.42	27.87	7.85	16.28	5.14	80.6
8.0	30.17	29.10	7.78	17.28	4.35	68.4
9.0	29.38	31.50	7.66	19.34	2.75	43.2
10.0	29.08	32.83	7.63	20.43	2.58	40.6
11.0	29.65	34.94	7.63	21.82	3.11	50.1
12.0	28.17	35.20	7.61	22.51	2.85	44.7
13.0	27.69	35.48	7.56	22.88	2.10	32.7
14.0	27.24	35.92	7.54	23.35	1.60	24.8
15.0	26.98	35.69	7.47	23.26	0.99	15.3
16.0	26.87	35.68	7.43	23.29	0.74	11.4
17.0	26.62	36.05	7.41	23.65	0.32	4.9
18.0	26.40	36.04	7.39	23.71	0.22	3.4
19.0	26.02	35.95	7.36	23.76	0.13	2.0
20.3	26.02	35.80	7.36	23.65	0.18	2.7

Table A.6. Hydrography, September 1990.

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

Station: 06 Latitude: 28:51.44 N Hydrolab cast time: 12:40
Date: 09/17/90 Longitude: 90:27.68 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
0.4	29.65	19.93	8.01	10.63	6.55	96.8
1.0	29.64	23.07	8.01	12.96	6.47	97.3
2.0	29.68	19.24	7.98	10.11	6.52	96.1
3.0	29.80	22.09	7.95	12.18	6.19	92.9
4.0	29.75	27.57	7.94	16.28	6.01	92.9
5.0	29.75	23.49	7.93	13.24	6.13	92.6
6.0	29.64	26.77	7.91	15.72	5.89	90.5
7.0	29.50	28.14	7.90	16.79	5.86	90.5
8.0	29.54	28.79	7.89	17.26	5.81	90.1
9.0	29.58	29.23	7.88	17.58	5.62	87.5
10.0	29.51	29.82	7.87	18.04	5.55	86.6
11.0	29.44	30.33	7.85	18.44	5.30	82.8
12.0	29.38	30.91	7.83	18.90	5.10	79.8
13.0	29.28	31.58	7.79	19.43	4.80	75.3
14.0	28.59	33.79	7.63	21.31	3.03	47.5
15.0	27.58	34.88	7.59	22.46	2.46	38.2
16.0	26.38	35.81	7.56	23.55	0.52	7.9
17.0	26.33	36.04	7.56	23.73	0.22	3.4
18.0	26.33	35.96	7.56	23.68	0.22	3.4
19.0	26.33	35.81	7.56	23.56	0.22	3.4
20.0	26.33	35.96	7.56	23.68	0.22	3.4
21.0	26.35	35.89	7.55	23.61	0.24	3.7
21.7	26.35	35.96	7.55	23.67	0.25	3.8

Table A.6. Continued.

CRUISE DATA - TRANSECT C

Station: SH 1000m Latitude: 29:07.22 N Hydrolab cast time:11:40
Date: 09/19/90 Longitude: 89:41.81 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
0.4	29.94	17.06	8.19	8.40	7.41	108.3
1.0	29.95	18.01	8.19	9.11	7.26	106.7
2.0	29.84	22.86	8.20	12.74	7.21	108.7
3.0	29.95	21.46	8.16	11.67	7.30	109.4
4.0	30.05	19.93	8.14	10.50	7.32	109.0
5.0	30.01	23.42	8.08	13.11	6.83	103.6
6.0	29.91	24.70	8.01	14.09	6.34	96.7
7.0	29.79	26.34	7.93	15.35	5.65	86.8
8.0	29.74	28.14	7.91	16.71	5.53	85.8
9.0	29.70	28.73	7.89	17.16	5.32	82.7
10.0	29.62	29.16	7.87	17.51	4.90	76.3
11.0	29.28	31.43	7.68	19.32	2.70	42.3
12.0	29.17	32.83	7.62	20.40	2.23	35.2
13.0	29.04	33.57	7.62	21.00	2.41	38.1
14.0	28.76	34.46	7.63	21.76	2.68	42.3
15.0	28.28	35.28	7.64	22.53	2.95	46.4
16.0	28.38	35.43	7.67	22.61	3.48	54.9
17.0	28.43	35.58	7.67	22.71	3.70	58.5
18.0	28.43	35.66	7.66	22.77	3.53	55.8
19.0	27.80	35.71	7.57	23.02	2.21	34.6
19.7	27.72	35.71	7.56	23.04	2.15	33.6

Table A.6. Continued.

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

Station: 6A Latitude: 28:50.49 N Hydrolab cast time: 13:30
Date: 09/17/90 Longitude: 90:26.02 W Secchi disk depth (m): 7.9

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.4	29.67	17.87	8.01	9.10	6.71	98.1
1.0	29.69	26.77	8.01	15.70	6.38	98.1
2.0	29.67	27.20	8.01	16.03	6.30	97.1
3.0	29.74	28.58	7.96	17.04	6.06	94.2
4.0	29.76	28.87	7.94	17.25	6.01	93.6
5.0	29.85	29.02	7.94	17.33	6.01	93.9
6.0	29.92	29.24	7.94	17.47	5.98	93.6
7.0	29.94	29.61	7.92	17.73	5.97	93.7
8.0	29.90	29.75	7.92	17.86	5.93	93.1
9.0	29.82	29.90	7.91	17.99	5.91	92.7
10.0	29.71	29.89	7.91	18.03	5.88	92.1
11.0	29.60	30.18	7.90	18.28	5.72	89.5
12.0	29.51	30.48	7.87	18.53	5.48	85.8
13.0	29.36	31.06	7.83	19.02	5.05	79.1
14.0	29.02	32.24	7.78	20.01	4.39	68.8
15.0	28.16	34.45	7.64	21.95	3.02	47.2
16.0	27.43	34.95	7.58	22.56	1.98	30.6
17.0	26.41	36.12	7.57	23.77	0.45	6.9
18.0	26.38	36.04	7.58	23.72	0.35	5.3
19.0	26.36	35.81	7.57	23.55	0.24	3.7
20.1	26.36	36.11	7.56	23.78	0.22	3.4

Table A.6. Continued.

Station: C6 1000m Latitude: 28:51.11 N Hydrolab cast time:7:15
Date: 09/20/90 Longitude: 90:28.06 W Secchi disk depth (m):5.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	29.82	20.55	8.05	11.04	6.60	98.2
1.0	29.83	25.41	8.05	14.65	6.39	97.7
2.0	29.83	25.48	8.06	14.70	6.40	97.9
3.0	29.83	25.48	8.05	14.70	6.40	97.9
4.0	29.84	25.34	8.06	14.59	6.40	97.9
5.0	29.88	25.48	8.05	14.68	6.38	97.7
6.0	30.11	26.42	8.02	15.30	6.18	95.5
7.0	29.83	28.36	7.92	16.84	5.60	87.1
8.0	29.64	29.23	7.87	17.56	5.20	81.0
9.0	29.55	29.96	7.88	18.13	5.47	85.4
10.0	29.39	31.95	7.80	19.67	3.86	60.8
11.0	28.55	34.01	7.61	21.49	2.15	33.8
12.0	27.77	35.04	7.49	22.52	0.68	10.6
13.0	27.54	35.40	7.44	22.87	0.17	2.6
14.0	27.02	35.69	7.41	23.25	0.06	0.9
15.0	26.44	35.97	7.42	23.64	0.07	1.1
16.0	26.20	36.03	7.43	23.77	0.08	1.2
17.0	26.17	35.96	7.42	23.72	0.11	1.7
18.0	26.17	35.96	7.42	23.72	0.12	1.8
19.0	26.17	36.03	7.42	23.78	0.14	2.1
19.3	26.18	35.81	7.42	23.61	0.20	3.0

Station: C6A 500m Latitude: 28:50.23 N Hydrolab cast time:8:35
Date: 09/20/90 Longitude: 90:26.26 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	29.82	25.55	8.05	14.75	6.40	98.0
1.0	29.82	25.55	8.05	14.75	6.37	97.5
2.0	29.82	25.55	8.05	14.75	6.39	97.8
3.0	29.82	25.48	8.05	14.70	6.39	97.8
4.0	29.82	25.55	8.05	14.75	6.39	97.8
5.0	29.82	25.48	8.05	14.70	6.36	97.3
6.0	29.84	25.62	8.05	14.80	6.25	95.7
7.0	29.72	28.36	7.91	16.88	5.50	85.4
8.0	29.42	29.45	7.90	17.79	5.62	87.3
9.0	29.12	31.72	7.73	19.59	3.51	55.0
10.0	28.75	33.49	7.67	21.04	2.80	44.0
11.0	28.61	33.64	7.60	21.19	2.15	33.7
12.0	28.32	34.83	7.50	22.18	0.60	9.4
13.0	27.68	35.33	7.46	22.77	0.55	8.6
14.0	27.20	35.62	7.43	23.14	0.09	1.4
15.0	26.69	35.53	7.43	23.23	0.05	0.8
16.0	26.15	35.80	7.42	23.61	0.07	1.1
17.0	26.01	35.87	7.41	23.71	0.07	1.1
18.0	26.01	35.80	7.41	23.65	0.10	1.5
19.0	26.01	35.87	7.41	23.71	0.13	2.0
19.5	26.03	35.95	7.41	23.76	0.17	2.6

Table A.7. Hydrography, October 1990.

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

Station: 6A Latitude: 28:50.49 N Hydrolab cast time: 11:20
Date: 10/15/90 Longitude: 90:26.02 W Secchi disk depth (m): 4.8

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.3	25.39	18.66	7.93	10.99	6.97	94.7
1.1	25.35	19.62	7.93	11.72	7.01	95.7
1.9	25.32	22.60	7.94	13.95	6.86	95.2
3.0	25.72	28.07	7.92	17.93	6.56	94.6
4.0	26.21	30.04	7.86	19.26	6.26	92.1
4.9	26.20	30.77	7.85	19.81	6.19	91.5
6.1	26.39	31.36	7.85	20.20	6.16	91.7
7.0	26.48	31.44	7.84	20.23	6.01	89.6
7.9	26.52	31.73	7.84	20.44	6.06	90.6
9.0	26.60	32.25	7.84	20.80	6.30	94.6
10.0	26.57	32.54	7.83	21.03	6.46	97.1
10.8	26.54	32.84	7.82	21.26	6.45	97.0
12.0	26.65	33.36	7.80	21.62	6.32	95.6
13.0	26.90	33.67	7.77	21.77	6.06	92.2
14.1	27.10	34.34	7.71	22.21	5.32	81.5
14.1	27.10	34.34	7.71	22.21	5.32	81.5
15.0	27.06	34.56	7.69	22.39	5.24	80.4
16.1	27.02	34.56	7.69	22.40	5.29	81.1
17.1	26.99	34.56	7.68	22.41	5.34	81.8
18.0	26.96	34.79	7.67	22.59	5.19	79.6
18.8	26.95	34.64	7.65	22.48	5.06	77.5
20.0	26.94	34.49	7.63	22.37	4.86	74.3

Table A.7. Continued.

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

Station: 06 Latitude: 28:51.44 N Hydrolab cast time: 12:50
Date: 10/16/90 Longitude: 90:27.68 W Secchi disk depth (m): 5.0

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	25.56	19.69	7.95	11.71	6.79	93.1
1.0	25.54	28.64	7.95	18.42	6.63	95.6
2.0	25.54	28.71	7.95	18.47	6.63	95.7
3.0	25.55	28.64	7.95	18.41	6.62	95.5
4.0	25.48	28.71	7.96	18.49	6.63	95.6
5.0	25.50	28.71	7.95	18.48	6.61	95.3
6.0	25.65	29.44	7.93	18.98	6.40	92.9
7.0	24.96	30.22	7.90	19.78	6.90	99.4
8.0	24.82	30.72	7.89	20.20	7.58	109.2
9.0	25.02	30.95	7.88	20.31	7.40	107.1
10.0	25.76	31.93	7.83	20.82	6.60	97.4
11.0	26.44	32.84	7.79	21.29	5.60	84.1
12.0	27.25	33.53	7.76	21.55	4.85	74.2
13.0	27.40	34.13	7.73	21.95	4.65	71.6
14.0	27.64	34.66	7.69	22.28	3.65	56.6
15.0	27.56	34.80	7.66	22.41	3.55	55.0
16.0	27.27	35.09	7.67	22.72	4.07	62.8
17.0	27.26	35.24	7.67	22.84	4.21	65.1
18.0	27.30	35.10	7.65	22.72	3.82	59.0
19.0	27.28	35.25	7.64	22.83	3.85	59.5

Table A.7. Continued.

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

Station: 6A Latitude: 28:50.49 N Hydrolab cast time: 13:40
Date: 10/16/90 Longitude: 90:26.02 W Secchi disk depth (m): 5.2

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.4	25.04	19.34	7.92	11.60	8.26	111.9
1.0	25.07	20.23	7.92	12.26	8.28	112.8
2.0	25.08	22.24	7.92	13.76	8.19	112.9
3.0	25.07	24.98	7.92	15.81	8.06	112.9
4.0	25.03	28.12	7.92	18.18	7.94	113.1
5.0	24.94	29.06	7.93	18.91	7.95	113.7
6.0	24.86	29.64	7.92	19.37	8.00	114.6
7.0	24.74	29.99	7.92	19.67	8.10	116.0
8.0	24.88	30.87	7.89	20.29	7.64	110.3
9.0	25.67	31.56	7.85	20.57	7.19	105.7
10.0	26.27	32.83	7.81	21.34	6.55	98.1
10.9	26.66	33.14	7.77	21.45	5.62	84.9
12.0	27.81	34.06	7.70	21.78	4.02	62.3
13.0	27.62	34.88	7.72	22.45	5.00	77.6
14.0	27.18	34.87	7.73	22.58	5.48	84.4
15.0	27.18	35.17	7.72	22.81	5.04	77.7
16.0	27.20	35.24	7.67	22.86	4.45	68.7
17.0	27.27	35.39	7.66	22.95	4.20	65.0
18.0	27.28	35.62	7.64	23.12	3.75	58.1
19.0	27.28	35.32	7.63	22.89	3.80	58.8

Table A.7. Continued.

Station: SH Latitude: 29:07.66 N Hydrolab cast time:15:45
Date: 10/17/90 Longitude: 89:41.41 W Secchi disk depth (m):4.5

HYDROGRAPHIC DATA

Depth (m)	Temperature (degrees C)	Salinity (ppt)	pH	Sigma-t	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation
0.5	25.90	19.35	7.90	11.36	8.60	118.4
1.0	25.84	30.10	7.93	19.42	8.07	118.0
2.0	25.76	30.25	7.92	19.55	8.00	116.9
3.0	25.67	30.32	7.91	19.63	7.87	114.9
4.0	25.66	30.46	7.90	19.75	7.74	113.1
5.0	25.71	30.46	7.90	19.73	7.67	112.1
6.0	25.75	30.54	7.89	19.78	7.54	110.4
7.0	25.77	30.61	7.89	19.82	7.51	110.0
8.0	25.90	30.61	7.88	19.79	7.29	107.0
9.0	26.00	30.62	7.87	19.76	7.07	104.0
10.0	26.16	31.13	7.86	20.10	6.88	101.8
11.0	26.35	31.58	7.85	20.37	6.72	100.0
12.0	26.52	31.73	7.83	20.44	6.57	98.2
13.0	27.07	33.00	7.78	21.22	5.83	88.6
14.0	27.25	33.60	7.76	21.61	5.45	83.4
15.0	27.90	34.89	7.65	22.37	3.67	57.2
16.0	28.03	35.12	7.56	22.49	2.36	36.9
17.0	28.05	35.49	7.54	22.77	2.11	33.1
18.0	28.05	35.42	7.53	22.71	2.02	31.7
18.8	28.02	34.97	7.53	22.38	1.96	30.7

Station: C6 1000m Latitude: 28:51.11 N Hydrolab cast time:5:30
Date: 10/18/90 Longitude: 90:28.06 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	25.63	13.51	7.95	7.07	6.83	90.5
1.0	25.63	20.04	7.95	11.95	6.85	94.2
2.0	25.63	21.63	7.95	13.14	6.82	94.7
3.0	25.63	25.49	7.94	16.03	6.71	95.2
4.0	25.27	29.00	7.91	18.76	7.40	106.4
5.0	25.17	29.86	7.91	19.44	7.56	109.1
6.0	25.22	30.30	7.90	19.76	7.40	107.1
7.0	25.16	30.45	7.91	19.88	7.39	106.9
8.0	25.19	30.52	7.90	19.93	7.23	104.7
9.0	25.30	30.81	7.90	20.12	7.13	103.7
10.0	25.54	31.33	7.87	20.44	6.83	100.0
11.0	25.96	32.01	7.84	20.82	6.02	89.2
12.0	27.25	33.68	7.68	21.66	3.05	46.7
13.0	27.78	34.36	7.57	22.01	0.67	10.4
14.0	28.08	35.04	7.55	22.42	1.27	19.9
15.0	28.08	34.89	7.55	22.31	1.37	21.4
16.0	28.10	35.19	7.55	22.53	1.64	25.7
17.0	27.96	35.27	7.58	22.63	2.05	32.1
18.0	27.68	35.03	7.61	22.54	2.69	41.8
19.0	27.43	35.10	7.60	22.68	2.28	35.3
19.5	27.43	34.95	7.58	22.56	2.34	36.2

Appendix B. Sedimentary Characteristics

Table B.l. Surficial sediment characteristics.

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)
4	CHN100	1.10	84.68	14.22	0.01	0.30	2.59	16.73	19.32
4	CHN250	6.13	86.75	7.12	0.07	0.84			
4	CHN500	11.02	82.30	6.68	0.12	0.32			
4	CHN750	43.71	52.33	3.96	0.78	0.30			
4	CHN1000	32.58	61.73	5.69	0.48	0.33			
4	SH20	10.42	75.76	13.82	11.63	0.05			
4	SH50	86.46	12.83	0.71	6.39	0.08	4.06	32.39	36.45
4	SH100	12.10	78.13	9.77	0.14	0.13			
4	SH250	28.46	70.72	0.82	0.40	0.33			
4	SH500	17.05	81.74	1.21	0.21	0.46			
4	SHRef	20.76	76.35	2.89	0.26	0.49			
4	UA20	53.51	43.09	3.40	1.15	0.17			
4	UA50	52.46	43.95	3.59	1.10	0.07			
4	UA100	16.69	80.25	3.06	0.20	0.22			
4	UA250	21.32	73.12	5.56	0.27	0.35	4.21	28.35	32.56
4	UA500	40.49	53.86	5.65	0.68	0.26			
4	UA750	29.76	64.75	5.49	0.42	0.05			
4	UA1000	0.95	94.41	4.64	0.01	1.05			
4	UB100	36.56	55.33	8.11	0.58	0.35			
4	UB500	90.18	9.29	0.53	9.18	0.47	3.27	26.29	29.56
4	UB1000	5.59	11.96	82.45	0.06	0.20			
5	UB500	38.31	53.95	7.74	0.62	0.09	2.33	19.83	22.16
6	CHW20	9.45	78.59	11.96	0.10	0.39			
6	CHW50	2.87	88.65	8.48	0.03	1.70			
6	CHW100	5.61	87.23	7.16	0.06	0.44			
6	CHW250	29.20	62.49	8.31	0.41	0.41	2.97	19.26	22.23
6	CHW500	31.30	61.99	6.73	0.46	0.42			
6	CHW750	38.26	56.85	4.89	0.62	0.39			
6	SH0	92.03	7.51	0.45	11.56	0.01			
6	SH20	38.23	58.40	3.37	0.62	0.23			
6	SH50	48.41	50.33	1.26	0.94	0.39	2.48	23.03	25.51
6	SH100	28.49	70.47	1.04	0.40	0.92			
6	SH250	5.75	91.22	3.03	0.06	0.56			
6	SH500	16.07	79.68	4.25	0.19	0.69			
6	SH750	14.66	80.06	5.28	0.17	1.01			
6	SH1000	8.64	87.32	4.04	0.09	1.16			
6	SHRef	9.46	83.87	6.67	0.10	0.77			
6	UA20	41.01	48.91	10.05	0.70	0.25			
6	UA50	23.09	68.62	8.29	0.30	0.41			
6	UA100	1.65	83.74	14.61	0.02	0.53			
6	UA250	16.10	78.70	5.20	0.19	0.36			
6	UA500	38.26	54.41	7.33	0.62	0.23			
6	UA750	34.59	59.08	6.33	0.53	0.49			
6	UA1000	36.83	56.38	6.79	0.58	0.51	6.14	25.51	31.65

Table B.1. Continued.

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)
6	UB100	27.05	64.25	8.70	0.37	0.34			
6	UB500	57.08	34.99	7.93	1.33	0.22	2.73	18.08	20.80
6	UB1000	16.14	68.96	14.90	0.19	0.18			
7	SH20	29.72	66.05	4.20	0.42	0.42			
7	SH50	86.40	13.22	0.39	6.35	0.22			
7	SH100	32.68	63.99	3.33	0.49	0.50			
7	SH250	25.93	71.28	2.79	0.35	0.61			
7	SH500	18.57	78.24	3.19	0.23	0.64			
7	SH750	6.72	87.98	5.30	0.07	1.15			
7	SH1000	4.04	87.64	8.32	0.04	1.24			
7	SHRef	7.51	87.77	4.72	0.08	0.72			
7	UA20	14.36	79.80	5.84	0.17	0.42			
7	UA50	96.83	3.00	0.17	30.55	0.07			
7	UA100	29.24	57.29	13.47	0.41	0.90			
7	UA250	28.70	68.78	2.52	0.40	0.42			
7	UA500	34.85	61.66	3.49	0.53	0.64			
7	UA750	33.61	61.08	5.31	0.51	0.62			
7	UA1000	48.27	46.73	5.00	0.93	0.43			
7	UB100	95.29	4.38	0.34	8.54	0.16			
7	UB500Ne	60.19	30.16	9.65	1.51	0.22	1.86	8.43	10.29
7	UB500	26.01	62.24	11.75	0.35	0.22			
7	UB1000	17.91	72.22	9.87	0.22	0.34			
8	SH20	57.46	38.18	4.37	1.35	1.49			
8	SH50	24.81	69.28	5.92	0.33	0.59			
8	SH100	5.37	80.28	14.35	0.06	0.62			
8	SH250	6.06	82.29	11.64	0.06	0.65			
8	SH500	6.27	83.93	9.80	0.07	0.79			
8	SH750	3.72	84.70	11.58	0.04	0.97			
8	SH1000	1.22	84.15	14.63	0.01	0.87	3.72	35.44	39.15
8	SHRef	8.61	81.89	9.50	0.09	1.07			
8	UA20	3.26	85.79	10.95	0.03	0.37			
8	UA50	16.05	74.72	9.24	0.19	0.49			
8	UA100	8.61	81.76	9.63	0.09	0.12			
8	UA250	12.28	76.61	11.11	0.14	0.76			
8	UA500	9.87	78.56	11.57	0.11	0.87			
8	UA750	6.26	82.50	11.24	0.07	0.67	5.43	40.28	45.71
8	UA1000	9.91	82.24	7.85	0.11	0.91			
8	UB100	79.33	19.25	1.42	3.84	0.48			
8	UB500	74.32	23.96	1.72	2.89	0.89	2.92	18.03	20.95
8	UB1000	72.08	24.13	3.80	2.58	1.09			
9	SH1000	3.55	87.60	8.85	0.04	0.96	2.17	32.18	34.35
9	SHRef	4.46	90.57	4.97	0.05	1.07			
9	UA500	21.26	71.78	6.97	0.27	0.57			
9	UA1000	8.80	84.19	7.00	0.10	0.58	1.44	18.61	20.06

Table B.1. Continued.

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)
9	UB500	10.67	79.90	9.43	0.12	0.60			
9	UB1000	30.36	60.15	9.49	0.44	1.11	0.91	22.22	23.13
10	SH1000	5.87	85.27	8.86	0.06	0.90	7.08	43.17	50.26
10	SHRef	7.14	83.10	9.76	0.08	0.79			
10	UA500	12.15	80.57	7.28	0.14	0.71			
10	UA1000	23.77	68.78	7.45	0.31	0.64	3.78	111.80	115.50
10	UB500	22.29	68.62	9.09	0.29	0.63	0.34	24.97	25.31
10	UB1000	18.57	72.14	9.29	0.23	0.71			

Table B.1. Continued.

Month	Station & Distance	Pb-210 (pCi/g dry wt)	Ra-226 (pCi/g dry wt)	Ra-228 (pCi/g dry wt)
4	CHN100		2.0	1.0
4	CHN250			
4	CHN500			
4	CHN750			
4	CHN1000		2.0	1.0
4	SH20			
4	SH50			
4	SH100			
4	SH250			
4	SH500			
4	SHRef		2.0	1.0
4	UA20		2.0	0.0
4	UA50			
4	UA100			
4	UA250			
4	UA500			
4	UA750			
4	UA1000		2.0	2.1
4	UB100			
4	UB500			
4	UB1000			
5	UB500			
6	CHW20		4.0	2.0
6	CHW50			
6	CHW100			
6	CHW250			
6	CHW500			
6	CHW750		1.0	1.0
6	SH0			
6	SH20	0.391		
6	SH50	0.564		
6	SH100	0.606		
6	SH250	0.902		
6	SH500			
6	SH750	0.839		
6	SH1000			
6	SHRef	0.851		
6	UA20	0.604		
6	UA50	0.655		
6	UA100	0.399		
6	UA250	0.250		
6	UA500	0.639		
6	UA750			
6	UA1000			

Table B.1. Continued.

Month	Station & Distance	Pb-210 (pCi/g dry wt)	Ra-226 (pCi/g dry wt)	Ra-228 (pCi/g dry wt)
6	UB100			
6	UB500	0.459		
6	UB1000			
7	SH20		1.0	1.0
7	SH50			
7	SH100			
7	SH250			
7	SH500			
7	SH750			
7	SH1000		3.0	1.0
7	SHRef		0.0	1.0
7	UA20			
7	UA50			
7	UA100			
7	UA250			
7	UA500			
7	UA750			
7	UA1000			
7	UB100			
7	UB500Ne			
7	UB500			
7	UB1000			
8	SH20			
8	SH50			
8	SH100			
8	SH250			
8	SH500			
8	SH750			
8	SH1000			
8	SHRef			
8	UA20			
8	UA50			
8	UA100			
8	UA250			
8	UA500			
8	UA750			
8	UA1000			
8	UB100			
8	UB500			
8	UB1000			
9	SH1000			
9	SHRef			
9	UA500			
9	UA1000			

Appendix C. Trace Metals

Table C.1. Surficial sediment trace metal concentrations, April 1990.

Station & Distance	Fe (μg/g)	Mn (μg/g)	Al (μg/g)	Ba (μg/g)	Cu (μg/g)	Zn (μg/g)	Cd (μg/g)	Pb (μg/g)	Cr (μg/g)	Ni (μg/g)	V (μg/g)
Chevron 20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 100	18648	525	16735	133	17.5	84.2	1.5	24.9	26.3	22.3	80
Chevron 250	18661	377	16840	273	15.1	73.3	1.5	28.6	25.3	20.2	72
Chevron 500	20863	388	18484	211	17.0	100.0	1.5	25.3	25.6	21.2	63
Chevron 750	10039	185	8658	185	7.2	47.3	0.0	11.7	15.2	12.6	36
Chevron 1000	13624	224	11369	272	10.8	63.9	0.5	15.5	18.2	14.4	38
Shell 0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell 20	7404	118	4543	211	17.1	193.6	0.6	102.9	15.9	6.8	31
Shell 50	12254	199	7494	180	8.5	150.3	0.5	21.6	17.7	12.1	41
Shell 100	13079	283	8841	221	9.3	113.1	1.4	27.2	20.2	14.8	33
Shell 250	22067	325	13656	207	12.0	75.6	1.2	20.4	23.6	16.2	61
Shell 500	26675	348	14625	268	14.2	77.5	1.2	21.4	24.5	16.5	54
Shell 750	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell 1000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell Ref	21047	595	18980	216	15.8	96.8	1.7	32.0	31.0	21.4	80
Unocal A 20	6372	129	3622	160	6.9	62.7	0.0	7.5	8.4	8.8	19
Unocal A 50	9072	137	5619	221	7.3	44.9	0.0	8.1	9.9	10.0	16
Unocal A 100	12337	207	8761	239	13.6	53.0	0.5	13.5	14.5	13.5	30
Unocal A 250	13005	213	9732	280	10.4	49.3	0.5	12.4	14.6	12.7	29
Unocal A 500	10864	142	7274	222	7.9	43.5	0.0	10.5	11.7	10.8	25
Unocal A 750	10969	150	7623	333	8.7	43.5	0.0	10.2	11.9	11.2	30
Unocal A 1000	11814	171	8419	225	12.2	45.2	1.1	11.5	13.5	12.1	29
Unocal B 100	7895	121	4721	269	6.6	31.3	0.0	7.2	7.9	8.8	15
Unocal B 500	8872	141	5944	186	9.4	37.8	0.0	8.7	10.7	11.0	23
Unocal B 1000	8992	121	5422	202	8.3	34.6	0.0	5.9	7.4	9.8	19

Table C.1. Continued.

Station & Distance	As (μg/g)	P (μg/g)	Ca (μg/g)	Mg (μg/g)	K (μg/g)	Na (μg/g)
Chevron 20	ND	ND	ND	ND	ND	ND
Chevron 50	ND	ND	ND	ND	ND	ND
Chevron 100	ND	ND	7746	7502	4298	8893
Chevron 250	ND	ND	10468	8447	3432	9740
Chevron 500	ND	ND	9562	9205	4072	10065
Chevron 750	ND	ND	4789	4918	2404	7230
Chevron 1000	ND	ND	6577	6502	2692	8221
Shell 0	ND	ND	ND	ND	ND	ND
Shell 20	ND	ND	14471	2978	1005	4669
Shell 50	ND	ND	7935	5589	1957	8111
Shell 100	ND	ND	7839	5742	2283	5970
Shell 250	ND	ND	10174	9989	3627	10491
Shell 500	ND	ND	14166	12041	3477	10762
Shell 750	ND	ND	ND	ND	ND	ND
Shell 1000	ND	ND	ND	ND	ND	ND
Shell Ref	ND	ND	9067	9236	4247	10289
Unocal A 20	ND	ND	27537	4382	1039	3797
Unocal A 50	ND	ND	5687	3717	1266	3926
Unocal A 100	ND	ND	10281	5422	2034	7420
Unocal A 250	ND	ND	8030	6027	2069	6808
Unocal A 500	ND	ND	12800	4931	1578	5148
Unocal A 750	ND	ND	7065	5271	1659	6554
Unocal A 1000	ND	ND	9213	5435	1962	7229
Unocal B 100	ND	ND	27145	3545	985	3703
Unocal B 500	ND	ND	5589	4325	1464	6743
Unocal B 1000	ND	ND	7229	4205	1270	4981

Table C.2. Surficial sediment trace metal concentrations, June 1990.

Station & Distance	Fe (µg/g)	Mn (µg/g)	Al (µg/g)	Ba (µg/g)	Cu (µg/g)	Zn (µg/g)	Cd (µg/g)	Pb (µg/g)	Cr (µg/g)	Ni (µg/g)	V (µg/g)
Chevron 20	25657	377	35839	337	19.8	106.0	2.4	3.6	34.3	24.9	118
Chevron 50	26774	517	36336	664	18.1	80.0	2.3	0.0	29.8	19.9	126
Chevron 100	25512	370	32750	330	19.4	88.3	2.2	0.0	29.2	21.6	110
Chevron 250	22516	329	29833	266	14.4	133.4	2.0	1.8	29.1	21.0	108
Chevron 500	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 750	19674	220	24975	220	10.3	53.7	1.6	0.0	20.4	15.2	75
Chevron 1000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell 0	10220	134	10981	420	8.1	231.7	1.3	128.9	45.8	8.9	44
Shell 20	13322	180	11627	198	12.9	207.3	1.4	29.3	21.5	12.7	43
Shell 50	16599	217	14983	179	9.0	92.1	1.6	17.2	22.3	14.7	0
Shell 100	32789	440	43559	282	17.9	89.4	2.3	0.0	29.1	20.9	108
Shell 250	25276	376	31747	149	16.6	88.1	2.3	4.7	34.3	22.0	104
Shell 500	22200	292	27175	168	11.5	66.4	1.7	0.0	23.1	16.5	69
Shell 750	20539	308	25309	285	13.7	76.8	2.1	5.0	27.2	19.6	102
Shell 1000	26977	366	36270	239	14.3	73.7	1.9	0.0	26.2	18.6	122
Shell Ref	25943	480	32479	211	16.6	83.8	2.4	6.8	34.3	21.4	118
Unocal A 20	10849	109	8698	126	5.2	30.5	1.0	4.4	11.9	9.9	38
Unocal A 50	14869	182	14279	125	8.0	50.9	1.4	5.4	18.6	15.5	55
Unocal A 100	12881	161	13119	177	7.7	48.2	1.2	6.0	17.9	14.9	54
Unocal A 250	30506	387	37815	236	21.0	98.6	3.1	11.8	43.5	27.3	103
Unocal A 500	15179	190	16572	178	9.5	55.0	1.6	7.3	21.4	16.7	67
Unocal A 750	13482	166	14463	151	7.8	47.9	1.3	3.6	18.8	14.5	63
Unocal A 1000	18111	237	22392	211	12.6	60.1	1.7	4.8	25.2	18.8	81
Unocal B 100	8766	110	7699	106	4.0	30.2	0.0	2.8	11.7	9.3	0
Unocal B 500	11114	143	11567	142	6.7	39.6	1.2	4.9	17.3	13.1	46
Unocal B 1000	3399	52	2754	106	1.8	15.9	0.0	1.5	4.4	4.7	0

Table C.2. Continued.

Station & Distance	As (µg/g)	P (µg/g)	Ca (µg/g)	Mg (µg/g)	K (µg/g)	Na (µg/g)
Chevron 20	58.9	427	23112	10741	8231	10434
Chevron 50	0.0	431	64418	11562	8860	19860
Chevron 100	14.2	346	11932	10607	8053	11087
Chevron 250	29.0	367	8606	10084	7320	12326
Chevron 500	ND	ND	ND	ND	ND	ND
Chevron 750	0.0	285	10065	8181	5740	9870
Chevron 1000	ND	ND	ND	ND	ND	ND
Shell 0	28.1	248	28358	4635	2777	6623
Shell 20	32.2	353	10592	5932	3195	5137
Shell 50	30.3	420	10589	6622	3765	6914
Shell 100	0.0	342	12434	13768	10001	11540
Shell 250	46.4	555	20168	10490	7477	11238
Shell 500	0.0	351	9588	9394	6280	8120
Shell 750	39.6	401	8354	9073	8795	12464
Shell 1000	0.0	357	10681	12098	8625	13863
Shell Ref	63.6	497	10095	10337	7879	17188
Unocal A 20	23.8	202	18367	3296	2442	4202
Unocal A 50	33.9	353	8998	5501	3664	8125
Unocal A 100	33.2	316	9360	5388	3433	7829
Unocal A 250	100.2	587	15905	12679	10841	16158
Unocal A 500	40.5	361	8123	7044	4118	7909
Unocal A 750	24.2	339	6489	6135	3936	9903
Unocal A 1000	43.3	320	7743	7942	5681	8801
Unocal B 100	18.8	213	5130	3955	2461	3980
Unocal B 500	34.8	248	5532	4640	3030	5194
Unocal B 1000	7.5	117	2606	1329	676	1695

Table C.3. Surficial sediment trace metal concentrations, July 1990.

Station & Distance	Fe (µg/g)	Mn (µg/g)	Al (µg/g)	Ba (µg/g)	Cu (µg/g)	Zn (µg/g)	Cd (µg/g)	Pb (µg/g)	Cr (µg/g)	Ni (µg/g)	V (µg/g)
Chevron 20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 250	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 500	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 750	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 1000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell 0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell 20	12260	191	11465	127	9.6	153.7	1.4	33.4	23.9	12.7	45
Shell 50	12944	192	11101	122	7.4	196.9	1.5	37.5	22.1	13.2	45
Shell 100	21630	354	23918	202	12.2	79.2	1.8	8.9	26.1	17.0	79
Shell 250	19872	329	22944	103	12.4	72.5	1.9	8.2	28.9	18.2	0
Shell 500	17926	293	22694	204	12.3	72.0	1.8	9.1	29.5	16.7	73
Shell 750	20503	309	26937	229	13.5	69.9	2.0	4.9	28.3	18.1	81
Shell 1000	25257	369	33890	203	14.5	72.8	2.1	0.0	25.7	18.5	100
Shell Ref	16380	354	18547	237	12.7	53.1	1.4	20.3	21.7	16.1	62
Unocal A 20	11984	182	14420	78	10.3	35.7	1.0	11.8	15.7	12.9	42
Unocal A 50	8642	71	7690	105	3.8	24.5	0.4	4.4	6.4	7.9	16
Unocal A 100	9671	138	10717	122	7.3	31.0	0.7	10.3	13.1	10.8	46
Unocal A 250	3167	122	3532	122	6.2	26.2	0.6	8.4	9.4	8.8	25
Unocal A 500	4603	67	4823	65	4.6	16.1	0.3	4.6	7.2	5.4	14
Unocal A 750	8421	102	9587	99	5.0	24.9	0.5	7.7	11.7	8.7	27
Unocal A 1000	7641	124	7476	129	6.4	29.8	0.7	9.3	11.3	10.4	31
Unocal B 100	7301	105	6367	122	5.1	26.2	0.8	7.7	9.2	9.1	23
Unocal B 500	9037	124	7910	125	6.6	30.1	0.7	9.2	11.4	10.9	30
Unocal B 1000	4620	72	5338	70	3.7	17.7	0.4	4.8	7.2	6.2	19

Table C.3. Continued.

Station & Distance	As (µg/g)	P (µg/g)	Ca (µg/g)	Mg (µg/g)	K (µg/g)	Na (µg/g)
Chevron 20	ND	ND	ND	ND	ND	ND
Chevron 50	ND	ND	ND	ND	ND	ND
Chevron 100	ND	ND	ND	ND	ND	ND
Chevron 250	ND	ND	ND	ND	ND	ND
Chevron 500	ND	ND	ND	ND	ND	ND
Chevron 750	ND	ND	ND	ND	ND	ND
Chevron 1000	ND	ND	ND	ND	ND	ND
Shell 0	ND	ND	ND	ND	ND	ND
Shell 20	34.1	305	8051	5012	2935	4657
Shell 50	33.9	394	8871	5434	3039	5448
Shell 100	14.2	461	9516	9216	5644	9963
Shell 250	45.7	461	9890	8738	5391	9704
Shell 500	55.0	390	6983	8094	6141	10623
Shell 750	40.5	394	7980	8294	6903	8988
Shell 1000	0.0	364	10224	10661	9132	14660
Shell Ref	ND	ND	8442	7795	5590	12632
Unocal A 20	ND	ND	7875	5716	3491	4984
Unocal A 50	ND	ND	4743	4109	1013	3294
Unocal A 100	ND	ND	6874	4785	3047	6790
Unocal A 250	ND	ND	2389	1836	2924	7574
Unocal A 500	ND	ND	2669	1996	1749	3763
Unocal A 750	ND	ND	4438	4025	2484	7011
Unocal A 1000	ND	ND	7070	3889	2604	6493
Unocal B 100	ND	ND	14420	3630	1844	4942
Unocal B 500	ND	ND	18134	4309	2241	5124
Unocal B 1000	ND	ND	3263	2627	1384	2658

Table C.4. Surficial sediment trace metal concentrations, August 1990.

Station & Distance	Fe (μg/g)	Mn (μg/g)	Al (μg/g)	Ba (μg/g)	Cu (μg/g)	Zn (μg/g)	Cd (μg/g)	Pb (μg/g)	Cr (μg/g)	Ni (μg/g)	V (μg/g)
Chevron 20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 250	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 500	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 750	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chevron 1000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell 0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Shell 20	13678	230	14637	78	11.1	11.1	1.1	40.7	19.0	12.9	41
Shell 50	9314	212	10395	112	8.6	49.2	0.9	16.0	14.4	11.9	40
Shell 100	14294	498	14749	393	20.9	74.9	2.0	34.6	31.8	24.3	51
Shell 250	11403	270	12996	108	11.5	49.8	1.3	18.3	20.9	15.9	49
Shell 500	7655	189	9412	136	8.2	34.2	0.7	12.8	14.7	10.2	38
Shell 750	15117	281	14763	255	14.5	ND	ND	ND	ND	ND	56
Shell 1000	17591	314	22750	223	12.8	ND	ND	ND	ND	ND	67
Shell Ref	15848	393	17168	203	13.7	54.0	1.3	20.0	21.0	17.5	51
Unocal A 20	8372	135	10269	55	7.7	26.5	0.7	9.8	12.1	10.2	42
Unocal A 50	7676	120	6773	113	6.9	26.8	0.6	7.4	9.2	9.3	ND
Unocal A 100	10343	162	8092	128	8.0	38.0	0.8	14.0	13.9	13.5	27
Unocal A 250	12828	206	13059	131	9.3	39.8	1.0	13.3	15.9	14.1	40
Unocal A 500	9345	141	9233	111	7.6	34.8	1.0	10.5	13.2	12.0	30
Unocal A 750	9884	139	10014	160	7.3	33.5	0.8	10.4	12.6	11.5	35
Unocal A 1000	3752	37	4176	83	3.7	13.4	0.2	4.4	5.9	4.5	19
Unocal B 100	8264	139	7116	122	7.3	28.7	0.8	8.5	10.1	11.2	27
Unocal B 500	4361	139	3945	137	8.5	31.0	0.7	9.1	11.6	11.3	15
Unocal B 1000	4802	66	4715	69	3.3	16.6	0.3	4.4	7.1	5.6	16

Table C.4. Continued.

Station & Distance	As (µg/g)	P (µg/g)	Ca (µg/g)	Mg (µg/g)	K (µg/g)	Na (µg/g)
Chevron 20	ND	ND	ND	ND	ND	ND
Chevron 50	ND	ND	ND	ND	ND	ND
Chevron 100	ND	ND	ND	ND	ND	ND
Chevron 250	ND	ND	ND	ND	ND	ND
Chevron 500	ND	ND	ND	ND	ND	ND
Chevron 750	ND	ND	ND	ND	ND	ND
Chevron 1000	ND	ND	ND	ND	ND	ND
Shell 0	ND	ND	ND	ND	ND	ND
Shell 20	ND	ND	6384	5940	3700	7025
Shell 50	ND	ND	5450	4918	3202	6577
Shell 100	ND	ND	5968	6552	6706	12299
Shell 250	ND	ND	5187	5761	4732	9671
Shell 500	ND	ND	3854	3714	4855	8218
Shell 750	ND	ND	7266	6958	4414	9419
Shell 1000	ND	ND	8180	8253	6293	11893
Shell Ref	ND	ND	7637	7480	4697	9657
Unocal A 20	ND	ND	5457	4477	3068	3665
Unocal A 50	ND	ND	5971	3791	2134	5929
Unocal A 100	ND	ND	6815	4771	2691	5999
Unocal A 250	ND	ND	8449	6297	3157	7441
Unocal A 500	ND	ND	9412	4298	3213	6122
Unocal A 750	ND	ND	5488	5163	2694	6773
Unocal A 1000	ND	ND	3108	1654	1815	3770
Unocal B 100	ND	ND	10955	4050	1993	4767
Unocal B 500	ND	ND	6339	2240	2048	5334
Unocal B 1000	ND	ND	4179	2372	1204	2252

Appendix D. Hydrocarbons

Table D.1. Surficial sediment hydrocarbon concentrations, April 1990.

	CHEVRON 100 M	CHEVRON 250 M	CHEVRON 500 M	CHEVRON 750 M	CHEVRON 1000 M
DRY WT. (g)	9.9	8.5	13.23	16.8	16.4
TOTAL SATURATED HYDROCARBONS	2000	5000	1000	4000	4000
TOTAL RESOLVED SATURATED HC	600	2000	500	2000	2000
TOTAL UNRESOLVED SATURATED HC	1000	3000	900	2000	2000
ANALYTES (Detection Limit 5ppb)					
NAPHTHALENE	TR	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR	TR	TR
C-2 NAPHTHALENES	TR	TR	24	TR	6
C-3 NAPHTHALENES	5	TR	6	TR	TR
C-4 NAPHTHALENES	TR	TR	TR	TR	TR
FLUORENE	TR	ND	TR	TR	TR
C-1 FLUORENES	TR	24	32	8	17
C-2 FLUORENES	TR	7	12	6	5
C-3 FLUORENES	9	8	12	8	11
DIBENZOTHIOPHENE	ND	TR	12	ND	TR
C-1 DIBENZOTHIOPHENE	TR	5	TR	TR	6
C-2 DIBENZOTHIOPHENE	7	5	TR	5	5
C-3 DIBENZOTHIOPHENE	9	TR	6	TR	TR
PHENANTHRENE	TR	TR	TR	TR	TR
C-1 PHENANTHRENE	8	TR	TR	TR	TR
C-2 PHENANTHRENE	13	7	6	6	TR
C-3 PHENANTHRENE	7	5	7	TR	TR
ANTHRACENE	TR	ND	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND
C-1 NAPHTHOBENZOTHIOPHENE	ND	TR	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	ND	ND	ND	TR
FLUORANTHENE	6	TR	8	TR	TR
PYRENE	6	TR	8	TR	TR
C-1 PYRENES	10	TR	6	TR	TR
C-2 PYRENES	TR	TR	TR	TR	ND
BENZ(a)ANTHRACENE	ND	TR	ND	TR	ND
CHRYSENE	ND	TR	ND	TR	ND
C-1 CHRYSENES	ND	TR	ND	TR	ND
BENZO(b,k)FLUORANTHENE	ND	ND	TR	ND	TR
BENZO(a)PYRENE	ND	TR	TR	TR	TR
INDENO(1,2,3-cd)PYRENE	ND	TR	TR	ND	ND
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND	ND
BENZO(g,h,i)PERYLENE	ND	TR	TR	ND	ND
FFPI	0.56	0.36	0.44	0.34	0.32

Table D.1. Continued.

	SHELL 20 M	SHELL 50 M	SHELL 100 M	SHELL 250 M	SHELL 500 M	SHELL REF
DRY WT. (g)	20	16.08	16.28	15.11	13.1	14.23
TOTAL SATURATED HYDROCARBONS	2000	3000	1000	4000	3000	3000
TOTAL RESOLVED SATURATED HC	700	800	400	1000	1000	900
TOTAL UNRESOLVED SATURATED HC	1000	2000	1000	3000	2000	2000
ANALYTES (Detection Limit 5ppb)						
NAPHTHALENE	TR	TR	25	TR	TR	6
C-1 NAPHTHALENES	TR	TR	14	5	TR	6
C-2 NAPHTHALENES	10	9	TR	18	5	9
C-3 NAPHTHALENES	TR	7	12	10	7	6
C-4 NAPHTHALENES	ND	5	10	TR	TR	TR
FLUORENE	ND	TR	19	TR	TR	TR
C-1 FLUORENES	16	19	59	27	9	19
C-2 FLUORENES	6	10	14	14	5	10
C-3 FLUORENES	TR	11	6	15	8	8
DIBENZOTHIOPHENE	10	TR	21	9	TR	TR
C-1 DIBENZOTHIOPHENE	11	9	14	14	5	10
C-2 DIBENZOTHIOPHENE	9	7	10	11	6	6
C-3 DIBENZOTHIOPHENE	6	7	14	10	7	7
PHENANTHRENE	TR	9	157	10	7	10
C-1 PHENANTHRENE	8	14	64	14	9	11
C-2 PHENANTHRENE	13	11	31	17	9	TR
C-3 PHENANTHRENE	7	9	13	10	8	10
ANTHRACENE	TR	7	53	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	TR	TR	TR	ND	ND	ND
C-1 NAPHTHOBENZOTHIOPHENE	TR	ND	TR	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	TR	TR	TR	ND
C-3 NAPHTHOBENZOTHIOPHENE	ND	ND	TR	TR	TR	ND
FLUORANTHENE	20	34	404	22	14	19
PYRENE	16	36	369	23	15	28
C-1 PYRENES	8	19	176	14	10	17
C-2 PYRENES	TR	7	55	11	6	9
BENZ(a)ANTHRACENE	TR	35	322	22	13	TR
CHRYSENE	14	38	272	20	8	TR
C-1 CHRYSENES	TR	23	85	15	7	TR
BENZO(b,k)FLUORANTHENE	19	34	219	22	ND	15
BENZO(a)PYRENE	13	28	332	21	23	15
INDENO(1,2,3-cd)PYRENE	10	16	206	11	29	9
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND	ND	ND
BENZO(g,h,i)PERYLENE	5	19	207	17	20	14
FFPI	0.35	0.17	0.08	0.31	0.23	0.28

Table D.1. Continued.

	UNOCAL A 20 M - D	UNOCAL A 20 M - 150H	UNOCAL A 20 M - dup150H	UNOCAL A 50 M	UNOCAL A 100 M
DRY WT. (g)	20.03	18.59	18.59	12.7	8.3
TOTAL SATURATED HYDROCARBONS	3000	2000	1000	1000	2000
TOTAL RESOLVED SATURATED HC	800	600	300	400	800
TOTAL UNRESOLVED SATURATED HC	3000	2000	1000	600	1000
ANALYTES (Detection Limit 5ppb)					
NAPHTHALENE	TR	TR	TR	TR	TR
C-1 NAPHTHALENES	7	TR	TR	TR	TR
C-2 NAPHTHALENES	14	16	12	TR	TR
C-3 NAPHTHALENES	12	9	10	TR	TR
C-4 NAPHTHALENES	16	12	9	TR	TR
FLUORENE	TR	TR	TR	TR	TR
C-1 FLUORENES	31	11	9	6	9
C-2 FLUORENES	9	TR	TR	TR	TR
C-3 FLUORENES	9	5	TR	TR	5
DIBENZOTHIOPHENE	TR	6	20	TR	TR
C-1 DIBENZOTHIOPHENE	TR	TR	TR	TR	TR
C-2 DIBENZOTHIOPHENE	7	7	8	TR	TR
C-3 DIBENZOTHIOPHENE	7	TR	9	TR	TR
PHENANTHRENE	5	TR	TR	TR	TR
C-1 PHENANTHRENE	5	0	TR	TR	TR
C-2 PHENANTHRENE	12	14	8	TR	TR
C-3 PHENANTHRENE	TR	6	TR	TR	TR
ANTHRACENE	TR	TR	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND
C-1 NAPHTHOBENZOTHIOPHENE	ND	TR	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	TR
C-3 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND
FLUORANTHENE	TR	TR	TR	TR	TR
PYRENE	TR	TR	TR	TR	TR
C-1 PYRENES	TR	TR	ND	TR	TR
C-2 PYRENES	ND	TR	ND	TR	ND
BENZ(a)ANTHRACENE	ND	ND	ND	ND	TR
CHRYSENE	ND	ND	ND	ND	TR
C-1 CHRYSENES	ND	TR	ND	ND	TR
BENZO(b,k)FLUORANTHENE	TR	TR	TR	TR	TR
BENZO(a)PYRENE	ND	TR	ND	TR	TR
INDENO(1,2,3-cd)PYRENE	ND	TR	TR	TR	TR
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND	ND
BENZO(g,h,i)PERYLENE	ND	6	6	TR	TR
FFPI	0.47	0.63	0.74	0.00	0.00

Table D.1. Continued.

	UNOCAL A 250 M	UNOCAL A 500 M	UNOCAL A 750 M	UNOCAL A 1000 M
DRY WT. (g)	15.19	16.8	17.1	14.17
TOTAL SATURATED HYDROCARBONS	3000	500	1000	4000
TOTAL RESOLVED SATURATED HC	1000	200	700	1000
TOTAL UNRESOLVED SATURATED HC	2000	300	500	2000
ANALYTES (Detection Limit 5ppb)				
NAPHTHALENE	TR	TR	TR	TR
C-1 NAPHTHALENES	6	TR	ND	TR
C-2 NAPHTHALENES	18	5	TR	10
C-3 NAPHTHALENES	18	TR	ND	8
C-4 NAPHTHALENES	19	TR	ND	8
FLUORENE	TR	TR	ND	TR
C-1 FLUORENES	15	5	5	6
C-2 FLUORENES	15	TR	ND	12
C-3 FLUORENES	19	TR	ND	18
DIBENZOTHIOPHENE	18	5	ND	10
C-1 DIBENZOTHIOPHENE	18	TR	TR	10
C-2 DIBENZOTHIOPHENE	11	TR	TR	12
C-3 DIBENZOTHIOPHENE	10	5	ND	11
PHENANTHRENE	8	TR	TR	6
C-1 PHENANTHRENE	9	TR	TR	10
C-2 PHENANTHRENE	15	TR	5	16
C-3 PHENANTHRENE	TR	TR	ND	9
ANTHRACENE	TR	TR	ND	TR
NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-1 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
FLUORANTHENE	20	TR	TR	23
PYRENE	22	5	TR	25
C-1 PYRENES	19	TR	TR	20
C-2 PYRENES	11	ND	ND	12
BENZ(a)ANTHRACENE	31	ND	ND	20
CHRYSENE	30	ND	ND	20
C-1 CHRYSENES	25	ND	ND	18
BENZO(b,k)FLUORANTHENE	30	TR	ND	15
BENZO(a)PYRENE	49	TR	TR	22
INDENO(1,2,3-cd)PYRENE	31	6	ND	6
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND
BENZO(g,h,i)PERYLENE	48	5	ND	16
FFPI	0.24	0.42	0.54	0.27

Table D.2. Continued.

	SHELL 0 M	SHELL 20 M	SHELL 50 M	SHELL 100 M	SHELL 250 M	SHELL 500 M	SHELL 750 M	SHELL 1000 M	SHELL REF
DRY WT. (g)	16.72	16.56	15.14	16.54	11.62	11.01	11.51	10.35	11.28
TOTAL SATURATED HYDROCARBONS	4448	5601	17255	7659	6052	25021	8193	4872	1630
TOTAL RESOLVED SATURATED HC	1139	1032	3804	2041	1535	987	2315	1705	1406
TOTAL UNRESOLVED SATURATED HC	3309	4569	13452	5617	4517	24034	5877	3167	223
ANALYTES (Detection Limit 5ppb)									
NAPHTHALENE	TR	TR	7	TR	TR	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	7	TR	TR	TR	TR	TR	TR
C-2 NAPHTHALENES	6	16	38	17	TR	TR	10	TR	TR
C-3 NAPHTHALENES	TR	6	30	16	9	TR	9	TR	TR
C-4 NAPHTHALENES	TR	TR	20	11	8	TR	TR	TR	TR
FLUORENE	TR	5	10	12	TR	TR	TR	TR	TR
C-1 FLUORENES	31	TR	16	14	TR	TR	25	TR	TR
C-2 FLUORENES	8	TR	18	13	10	TR	TR	TR	TR
C-3 FLUORENES	11	TR	15	9	TR	5	8	9	TR
DIBENZOTHIOPHENE	TR	TR	TR	7	TR	39	TR	42	38
C-1 DIBENZOTHIOPHENE	TR	TR	11	TR	TR	TR	9	TR	ND
C-2 DIBENZOTHIOPHENE	10	9	30	21	5	TR	14	TR	TR
C-3 DIBENZOTHIOPHENE	ND	6	TR	24	12	TR	8	TR	TR
PHENANTHRENE	9	22	50	24	27	13	14	12	6
C-1 PHENANTHRENE	TR	18	93	67	18	9	18	10	TR
C-2 PHENANTHRENE	12	24	62	52	19	10	19	12	TR
C-3 PHENANTHRENE	13	18	55	39	20	6	24	13	6
ANTHRACENE	10	10	104	116	11	7	42	6	TR
NAPHTHOBENZOTHIOPHENE	TR	TR	TR	TR	TR	TR	TR	TR	ND
C-1 NAPHTHOBENZOTHIOPHENE	TR	TR	TR	TR	TR	TR	TR	TR	ND
C-2 NAPHTHOBENZOTHIOPHENE	TR	TR	TR	TR	TR	ND	TR	TR	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	TR	TR	TR	TR	TR	TR	TR	ND
FLUORANTHENE	66	39	191	261	31	21	44	12	5
PYRENE	55	45	165	217	44	19	57	13	8
C-1 PYRENES	26	38	92	129	45	13	46	11	5
C-2 PYRENES	9	16	33	29	21	6	21	7	6
BENZ(a)ANTHRACENE	16	28	103	100	25	8	36	TR	TR
CHRYSENE	26	19	93	79	25	7	30	TR	TR
C-1 CHRYSENES	ND	TR	68	50	24	ND	17	TR	ND
BENZO(b,k)FLUORANTHENE	22	27	122	103	19	7	TR	8	ND
BENZO(a)PYRENE	7	21	107	109	14	6	18	8	TR
INDENO(1,2,3-cd)PYRENE	25	6	50	52	17	ND	34	TR	6
DIBENZO(a,h)ANTHRACENE	ND	TR	ND	ND	TR	ND	TR	TR	ND
BENZO(g,h,i)PERYLENE	TR	15	50	53	8	ND	8	6	TR
FFPI	0.15	0.25	0.19	0.14	0.21	0.37	0.21	0.46	0.51

Table D.2. Continued.

	UNOCAL A 20 M	UNOCAL A 50 M	UNOCAL A 100 M	UNOCAL A 100 M - D
DRY WT. (g)	14.80	15.23	14.50	14.50
TOTAL SATURATED HYDROCARBONS	2398	1792	3197	6573
TOTAL RESOLVED SATURATED HC	1422	912	1517	2669
TOTAL UNRESOLVED SATURATED HC	976	881	1680	3904
ANALYTES (Detection Limit 5ppb)				
NAPHTHALENE	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR	TR
C-2 NAPHTHALENES	6	6	TR	6
C-3 NAPHTHALENES	TR	TR	TR	6
C-4 NAPHTHALENES	TR	TR	TR	TR
FLUORENE	TR	TR	TR	TR
C-1 FLUORENES	TR	TR	TR	18
C-2 FLUORENES	TR	TR	TR	7
C-3 FLUORENES	7	TR	8	5
DIBENZOTHIOPHENE	27	25	27	30
C-1 DIBENZOTHIOPHENE	TR	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	ND	TR	TR
PHENANTHRENE	11	10	16	19
C-1 PHENANTHRENE	TR	TR	9	10
C-2 PHENANTHRENE	9	6	7	7
C-3 PHENANTHRENE	12	9	10	10
ANTHRACENE	TR	TR	TR	5
NAPHTHOBENZOTHIOPHENE	TR	TR	TR	TR
C-1 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	TR	TR	TR
FLUORANTHENE	TR	TR	TR	TR
PYRENE	TR	TR	TR	6
C-1 PYRENES	TR	TR	TR	5
C-2 PYRENES	TR	TR	TR	TR
BENZ(a)ANTHRACENE	TR	TR	TR	TR
CHRYSENE	TR	TR	TR	TR
C-1 CHRYSENES	ND	ND	ND	ND
BENZO(b,k)FLUORANTHENE	TR	TR	TR	TR
BENZO(a)PYRENE	ND	TR	ND	TR
INDENO(1,2,3-cd)PYRENE	11	TR	TR	TR
DIBENZO(a,h)ANTHRACENE	ND	TR	ND	TR
BENZO(g,h,i)PERYLENE	TR	1	TR	TR
FFPI	0.71	0.89	0.73	0.54

Table D.2. Continued.

	UNOCAL A 250 M	UNOCAL A 500 M	UNOCAL A 750 M	UNOCAL A 1000 M
DRY WT. (g)	15.34	14.29	12.66	14.65
TOTAL SATURATED HYDROCARBONS	2183	1765	3289	1844
TOTAL RESOLVED SATURATED HC	996	914	1663	904
TOTAL UNRESOLVED SATURATED HC	1187	852	1625	940
ANALYTES (Detection Limit 5ppb)				
NAPHTHALENE	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR	TR
C-2 NAPHTHALENES	TR	9	16	7
C-3 NAPHTHALENES	TR	TR	10	TR
C-4 NAPHTHALENES	TR	TR	TR	TR
FLUORENE	TR	TR	TR	TR
C-1 FLUORENES	24	7	7	TR
C-2 FLUORENES	8	6	TR	6
C-3 FLUORENES	11	7	17	TR
DIBENZOTHIOPHENE	32	39	46	39
C-1 DIBENZOTHIOPHENE	TR	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	7	TR
C-3 DIBENZOTHIOPHENE	TR	ND	ND	ND
PHENANTHRENE	12	19	27	22
C-1 PHENANTHRENE	8	TR	14	8
C-2 PHENANTHRENE	14	8	17	TR
C-3 PHENANTHRENE	20	10	19	11
ANTHRACENE	TR	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	TR	TR	TR	TR
C-1 NAPHTHOBENZOTHIOPHENE	TR	TR	ND	TR
C-2 NAPHTHOBENZOTHIOPHENE	TR	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	ND	ND	ND
FLUORANTHENE	TR	ND	TR	5
PYRENE	TR	6	5	6
C-1 PYRENES	5	TR	6	6
C-2 PYRENES	TR	TR	TR	TR
BENZ(a)ANTHRACENE	TR	TR	TR	TR
CHRYSENE	TR	TR	TR	TR
C-1 CHRYSENES	TR	ND	ND	ND
BENZO(b,k)FLUORANTHENE	TR	TR	TR	TR
BENZO(a)PYRENE	TR	TR	TR	TR
INDENO(1,2,3-cd)PYRENE	6	TR	TR	5
DIBENZO(a,h)ANTHRACENE	TR	TR	ND	ND
BENZO(g,h,i)PERYLENE	TR	TR	TR	TR
FFPI	0.54	0.67	0.70	0.61

Table D.2. Continued.

	UNOCAL B 100 M	UNOCAL B 500 M	UNOCAL B 1000 M
DRY WT. (g)	15.89	17.41	17.42
TOTAL SATURATED HYDROCARBONS	1114	3281	1876
TOTAL RESOLVED SATURATED HC	562	1493	1098
TOTAL UNRESOLVED SATURATED HC	552	1788	778
ANALYTES (Detection Limit 5ppb)			
NAPHTHALENE	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR
C-2 NAPHTHALENES	TR	TR	TR
C-3 NAPHTHALENES	TR	TR	TR
C-4 NAPHTHALENES	TR	TR	TR
FLUORENE	TR	TR	TR
C-1 FLUORENES	TR	6	TR
C-2 FLUORENES	6	TR	TR
C-3 FLUORENES	8	TR	TR
DIBENZOTHIOPHENE	37	25	25
C-1 DIBENZOTHIOPHENE	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	TR	TR
PHENANTHRENE	11	10	9
C-1 PHENANTHRENE	TR	TR	TR
C-2 PHENANTHRENE	9	7	TR
C-3 PHENANTHRENE	10	5	TR
ANTHRACENE	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	TR	TR	TR
C-1 NAPHTHOBENZOTHIOPHENE	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	TR	TR
FLUORANTHENE	TR	14	TR
PYRENE	TR	12	TR
C-1 PYRENES	5	7	TR
C-2 PYRENES	TR	TR	TR
BENZ(a)ANTHRACENE	TR	5	TR
CHRYSENE	TR	5	TR
C-1 CHRYSENES	TR	ND	ND
BENZO(b,k)FLUORANTHENE	TR	5	TR
BENZO(a)PYRENE	TR	TR	ND
INDENO(1,2,3-cd)PYRENE	TR	6	TR
DIBENZO(a,h)ANTHRACENE	TR	TR	TR
BENZO(g,h,i)PERYLENE	TR	TR	TR
FFPI	0.68	0.38	0.84

Table D.3. Surficial sediment hydrocarbon concentrations, July 1990.

	SHELL 20 M	SHELL 50M	SHELL 100 M	SHELL 250 M	SHELL 500 M	SHELL 750 M-C	SHELL 750 M-U	SHELL 1000 M
DRY WT. (g)	19.07	20.96	15.96	16.26	14.57	14.56	13.62	13.51
TOTAL SATURATED HYDROCARBONS	3779	2413	320	2492	1303	2118	226	2312
TOTAL RESOLVED SATURATED HC	793	445	154	979	517	686	49	818
TOTAL UNRESOLVED SATURATED HC	2985	1968	166	1512	786	1432	177	1494
ANALYTES (Detection Limit 5ppb)								
NAPHTHALENE	TR	TR	TR	TR	TR	TR	TR	TR
C-1 NAPHTHALENES	8	TR	TR	TR	TR	TR	ND	TR
C-2 NAPHTHALENES	53	9	7	ND	36	17	12	61
C-3 NAPHTHALENES	33	12	TR	9	6	8	TR	13
C-4 NAPHTHALENES	24	14	TR	12	TR	TR	TR	12
FLUORENE	TR	TR	TR	TR	TR	TR	TR	TR
C-1 FLUORENES	28	15	11	13	TR	26	9	11
C-2 FLUORENES	16	7	TR	11	ND	ND	7	9
C-3 FLUORENES	15	12	TR	12	8	5	15	TR
DIBENZOTHIOPHENE	60	54	18	51	59	60	34	65
C-1 DIBENZOTHIOPHENE	10	TR	TR	TR	TR	5	TR	6
C-2 DIBENZOTHIOPHENE	16	11	TR	TR	6	8	TR	TR
C-3 DIBENZOTHIOPHENE	ND	ND	ND	TR	ND	ND	TR	TR
PHENANTHRENE	15	10	TR	TR	28	33	19	23
C-1 PHENANTHRENE	TR	17	TR	11	TR	TR	TR	7
C-2 PHENANTHRENE	TR	19	TR	5	6	11	5	9
C-3 PHENANTHRENE	21	16	TR	9	TR	16	10	9
ANTHRACENE	18	TR	TR	TR	15	14	TR	11
NAPHTHOBENZOTHIOPHENE	TR	TR	TR	ND	TR	TR	ND	TR
C-1 NAPHTHOBENZOTHIOPHENE	TR	ND	TR	ND	TR	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	ND	ND	ND	TR	TR	ND	TR
FLUORANTHENE	22	41	8	20	23	18	19	13
PYRENE	23	40	8	19	23	20	19	16
C-1 PYRENES	26	26	5	16	13	13	8	14
C-2 PYRENES	10	11	TR	5	6	TR	TR	5
BENZ(a)ANTHRACENE	14	31	7	ND	17	9	27	14
CHRYSENE	15	33	6	ND	17	10	ND	12
C-1 CHRYSENES	19	TR	ND	TR	ND	ND	TR	ND
BENZO(b,k)FLUORANTHENE	TR	TR	TR	TR	11	TR	6	6
BENZO(a)PYRENE	12	31	7	TR	26	16	19	19
INDENO(1,2,3-cd)PYRENE	TR	11	6	TR	10	TR	27	8
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND	ND	ND	ND	ND
BENZO(g,h,i)PERYLENE	ND	11	6	TR	11	15	30	20
FFPI	0.46	0.31	0.27	0.41	0.40	0.46	0.26	0.49

Table D.3. Continued.

	UNOCAL A 20 M	UNOCAL A 50 M	UNOCAL A 100 M	UNOCAL A 250 M	UNOCAL A 500 M	UNOCAL A 1000 M
DRY WT. (g)	16.03	19.58	18.58	15.55	12.53	15.26
TOTAL SATURATED HYDROCARBONS	287	84	142	870	784	589
TOTAL RESOLVED SATURATED HC	125	22	83	520	608	438
TOTAL UNRESOLVED SATURATED HC	162	62	58	350	176	151
ANALYTES (Detection Limit 5ppb)						
NAPHTHALENE	TR	TR	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	ND	TR	TR	TR
C-2 NAPHTHALENES	12	7	15	13	33	12
C-3 NAPHTHALENES	6	TR	5	8	ND	TR
C-4 NAPHTHALENES	9	TR	TR	9	10	ND
FLUORENE	TR	TR	TR	TR	TR	TR
C-1 FLUORENES	TR	TR	5	TR	TR	TR
C-2 FLUORENES	TR	TR	ND	ND	TR	TR
C-3 FLUORENES	TR	TR	TR	7	10	TR
DIBENZOTHIOPHENE	29	23	24	41	52	42
C-1 DIBENZOTHIOPHENE	TR	TR	TR	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	ND	ND	TR	ND	TR
PHENANTHRENE	TR	TR	5	14	9	7
C-1 PHENANTHRENE	TR	TR	TR	TR	TR	TR
C-2 PHENANTHRENE	TR	ND	TR	TR	TR	TR
C-3 PHENANTHRENE	TR	TR	TR	8	12	5
ANTHRACENE	TR	TR	ND	TR	6	TR
NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND	TR
C-1 NAPHTHOBENZOTHIOPHENE	TR	ND	ND	ND	ND	TR
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND	ND
FLUORANTHENE	TR	TR	TR	TR	TR	7
PYRENE	TR	TR	TR	TR	TR	7
C-1 PYRENES	TR	TR	TR	TR	TR	6
C-2 PYRENES	TR	TR	TR	TR	TR	TR
BENZ(a)ANTHRACENE	ND	ND	ND	ND	ND	9
CHRYSENE	ND	ND	ND	ND	ND	8
C-1 CHRYSENES	TR	ND	TR	ND	ND	TR
BENZO(b,k)FLUORANTHENE	ND	ND	ND	TR	TR	9
BENZO(a)PYRENE	ND	ND	TR	TR	TR	10
INDENO(1,2,3-cd)PYRENE	ND	ND	ND	ND	ND	TR
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND	ND	TR
BENZO(g,h,i)PERYLENE	ND	ND	ND	ND	ND	TR
FFPI	0.85	1.00	0.71	0.78	0.77	0.53

Table D.3. Continued.

	UNOCAL B 100 M	UNOCAL B 500 M	UNOCAL B 1000 M
DRY WT. (g)	20.76	18.97	20.23
TOTAL SATURATED HYDROCARBONS	222	68	149
TOTAL RESOLVED SATURATED HC	113	23	93
TOTAL UNRESOLVED SATURATED HC	110	46	55
ANALYTES (Detection Limit 5ppb)			
NAPHTHALENE	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR
C-2 NAPHTHALENES	11	8	7
C-3 NAPHTHALENES	TR	TR	TR
C-4 NAPHTHALENES	TR	TR	TR
FLUORENE	TR	TR	TR
C-1 FLUORENES	TR	TR	TR
C-2 FLUORENES	TR	TR	TR
C-3 FLUORENES	TR	TR	TR
DIBENZOTHIOPHENE	TR	20	23
C-1 DIBENZOTHIOPHENE	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	TR	ND
PHENANTHRENE	TR	TR	TR
C-1 PHENANTHRENE	TR	TR	TR
C-2 PHENANTHRENE	ND	TR	ND
C-3 PHENANTHRENE	6	TR	6
ANTHRACENE	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	ND	ND	ND
C-1 NAPHTHOBENZOTHIOPHENE	TR	TR	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	TR	ND
FLUORANTHENE	TR	TR	TR
PYRENE	TR	5	TR
C-1 PYRENES	TR	TR	TR
C-2 PYRENES	TR	TR	TR
BENZ(a)ANTHRACENE	ND	13	ND
CHRYSENE	ND	ND	ND
C-1 CHRYSENES	TR	ND	TR
BENZO(b,k)FLUORANTHENE	ND	16	ND
BENZO(a)PYRENE	TR	19	TR
INDENO(1,2,3-cd)PYRENE	TR	27	ND
DIBENZO(a,h)ANTHRACENE	ND	28	ND
BENZO(g,h,i)PERYLENE	ND	51	ND
FFPI	0.88	0.15	1.00

Table D.4. Surficial sediment hydrocarbon concentrations, August 1990.

	SHELL 20 M	SHELL 50 M	SHELL 100 M	SHELL 250 M	SHELL 250 M-D
DRY WT. (g)	18.48	13.79	15.83	16.82	14.93
TOTAL SATURATED HYDROCARBONS	606	637	416	898	605
TOTAL RESOLVED SATURATED HC	212	186	158	207	148
TOTAL UNRESOLVED SATURATED HC	395	451	258	691	457
ANALYTES (Detection Limit 5ppb)					
NAPHTHALENE	TR	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR	TR	TR
C-2 NAPHTHALENES	21	18	14	14	17
C-3 NAPHTHALENES	7	7	TR	TR	9
C-4 NAPHTHALENES	TR	ND	TR	TR	TR
FLUORENE	TR	TR	TR	TR	TR
C-1 FLUORENES	12	9	TR	32	18
C-2 FLUORENES	6	ND	TR	TR	TR
C-3 FLUORENES	TR	TR	TR	TR	TR
DIBENZOTHIOPHENE	26	33	29	27	32
C-1 DIBENZOTHIOPHENE	TR	TR	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	ND	ND	TR	ND
PHENANTHRENE	6	5	6	16	11
C-1 PHENANTHRENE	TR	TR	TR	7	TR
C-2 PHENANTHRENE	16	6	TR	7	TR
C-3 PHENANTHRENE	TR	8	TR	6	TR
ANTHRACENE	TR	6	TR	11	5
NAPHTHOBENZOTHIOPHENE	ND	ND	ND	TR	ND
C-1 NAPHTHOBENZOTHIOPHENE	TR	ND	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	ND	TR	TR	TR	TR
FLUORANTHENE	11	28	TR	22	6
PYRENE	9	27	TR	18	6
C-1 PYRENES	7	13	TR	11	7
C-2 PYRENES	TR	TR	TR	5	TR
BENZ(a)ANTHRACENE	ND	19	ND	14	ND
CHRYSENE	ND	17	ND	14	ND
C-1 CHRYSENES	TR	ND	TR	11	6
BENZO(b,k)FLUORANTHENE	TR	TR	TR	13	5
BENZO(a)PYRENE	TR	18	TR	11	5
INDENO(1,2,3-cd)PYRENE	TR	11	ND	ND	TR
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND	ND
BENZO(g,h,i)PERYLENE	TR	9	ND	6	8
FFPI	0.58	0.31	0.89	0.27	0.47

Table D.4. Continued.

	SHELL 500 M	SHELL 750 M	SHELL 1000 M	SHELL REF
DRY WT. (g)	12.92	14.07	11.92	13.44
TOTAL SATURATED HYDROCARBONS	1183	314	1780	1566
TOTAL RESOLVED SATURATED HC	473	215	610	761
TOTAL UNRESOLVED SATURATED HC	710	98	1171	805
ANALYTES (Detection Limit 5ppb)				
NAPHTHALENE	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR	TR
C-2 NAPHTHALENES	41	14	21	52
C-3 NAPHTHALENES	11	8	9	14
C-4 NAPHTHALENES	6	ND	TR	TR
FLUORENE	TR	TR	TR	TR
C-1 FLUORENES	23	9	5	10
C-2 FLUORENES	9	TR	TR	TR
C-3 FLUORENES	6	TR	TR	TR
DIBENZOTHIOPHENE	36	33	39	35
C-1 DIBENZOTHIOPHENE	TR	TR	TR	8
C-2 DIBENZOTHIOPHENE	TR	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	TR	ND	ND
PHENANTHRENE	20	16	11	22
C-1 PHENANTHRENE	TR	5	TR	TR
C-2 PHENANTHRENE	7	TR	TR	7
C-3 PHENANTHRENE	TR	TR	TR	TR
ANTHRACENE	8	5	9	8
NAPHTHOBENZOTHIOPHENE	TR	ND	TR	ND
C-1 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	TR	ND	ND	ND
C-3 NAPHTHOBENZOTHIOPHENE	TR	TR	ND	TR
FLUORANTHENE	7	6	13	10
PYRENE	6	6	14	10
C-1 PYRENES	TR	TR	7	6
C-2 PYRENES	TR	TR	TR	5
BENZ(a)ANTHRACENE	9	ND	12	9
CHRYSENE	10	ND	11	9
C-1 CHRYSENES	19	TR	ND	24
BENZO(b,k)FLUORANTHENE	11	6	13	9
BENZO(a)PYRENE	10	7	14	8
INDENO(1,2,3-cd)PYRENE	6	ND	18	5
DIBENZO(a,h)ANTHRACENE	TR	ND	10	ND
BENZO(g,h,i)PERYLENE	9	TR	28	TR
FFPI	0.41	0.57	0.32	0.51

Table D.4. Continued.

	UNOCAL A 20 M	UNOCAL A 50 M	UNOCAL A 100 M	UNOCAL A 250 M
DRY WT. (g)	16.04	18.22	15.11	14.01
TOTAL SATURATED HYDROCARBONS	402	1080	2703	477
TOTAL RESOLVED SATURATED HC	252	279	999	163
TOTAL UNRESOLVED SATURATED HC	150	802	1704	314
ANALYTES (Detection Limit 5ppb)				
NAPHTHALENE	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR	TR
C-2 NAPHTHALENES	TR	8	11	16
C-3 NAPHTHALENES	TR	TR	7	TR
C-4 NAPHTHALENES	5	TR	TR	TR
FLUORENE	TR	TR	TR	TR
C-1 FLUORENES	TR	44	9	TR
C-2 FLUORENES	TR	TR	TR	TR
C-3 FLUORENES	TR	TR	TR	9
DIBENZOTHIOPHENE	28	25	30	34
C-1 DIBENZOTHIOPHENE	ND	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR	TR
C-3 DIBENZOTHIOPHENE	TR	ND	ND	ND
PHENANTHRENE	TR	9	8	7
C-1 PHENANTHRENE	TR	TR	TR	TR
C-2 PHENANTHRENE	TR	TR	TR	15
C-3 PHENANTHRENE	TR	TR	TR	TR
ANTHRACENE	TR	TR	7	9
NAPHTHOBENZOTHIOPHENE	ND	ND	ND	TR
C-1 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	TR
C-2 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	TR
C-3 NAPHTHOBENZOTHIOPHENE	TR	ND	TR	ND
FLUORANTHENE	TR	TR	13	81
PYRENE	TR	TR	10	73
C-1 PYRENES	TR	TR	TR	42
C-2 PYRENES	TR	TR	TR	13
BENZ(a)ANTHRACENE	ND	ND	9	52
CHRYSENE	ND	ND	9	55
C-1 CHRYSENES	ND	TR	TR	34
BENZO(b,k)FLUORANTHENE	ND	ND	TR	34
BENZO(a)PYRENE	TR	TR	7	37
INDENO(1,2,3-cd)PYRENE	ND	ND	TR	ND
DIBENZO(a,h)ANTHRACENE	ND	ND	TR	ND
BENZO(g,h,i)PERYLENE	ND	TR	6	12
FFPI	0.84	0.43	0.41	0.13

Table D.4. Continued.

	UNOCAL A 500 M	UNOCAL A 750 M	UNOCAL A 1000 M
DRY WT. (g)	18.00	16.95	15.38
TOTAL SATURATED HYDROCARBONS	390	703	271
TOTAL RESOLVED SATURATED HC	114	230	102
TOTAL UNRESOLVED SATURATED HC	276	472	169
ANALYTES (Detection Limit 5ppb)			
NAPHTHALENE	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR
C-2 NAPHTHALENES	12	18	14
C-3 NAPHTHALENES	TR	TR	TR
C-4 NAPHTHALENES	TR	ND	TR
FLUORENE	TR	TR	TR
C-1 FLUORENES	TR	TR	TR
C-2 FLUORENES	ND	TR	ND
C-3 FLUORENES	TR	TR	TR
DIBENZOTHIOPHENE	26	28	17
C-1 DIBENZOTHIOPHENE	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	ND	ND
PHENANTHRENE	8	13	TR
C-1 PHENANTHRENE	TR	TR	TR
C-2 PHENANTHRENE	TR	TR	TR
C-3 PHENANTHRENE	TR	5	TR
ANTHRACENE	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	ND	ND	ND
C-1 NAPHTHOBENZOTHIOPHENE	ND	TR	ND
C-2 NAPHTHOBENZOTHIOPHENE	TR	TR	ND
C-3 NAPHTHOBENZOTHIOPHENE	ND	ND	ND
FLUORANTHENE	TR	9	TR
PYRENE	TR	9	TR
C-1 PYRENES	TR	TR	TR
C-2 PYRENES	TR	TR	TR
BENZ(a)ANTHRACENE	ND	ND	ND
CHRYSENE	ND	ND	ND
C-1 CHRYSENES	TR	10	TR
BENZO(b,k)FLUORANTHENE	TR	6	ND
BENZO(a)PYRENE	TR	7	TR
INDENO(1,2,3-cd)PYRENE	ND	ND	ND
DIBENZO(a,h)ANTHRACENE	ND	ND	ND
BENZO(g,h,i)PERYLENE	ND	TR	ND
FFPI	0.87	0.55	0.91

Table D.4. Continued.

	UNOCAL B 100 M	UNOCAL B 500 M	UNOCAL B 500 M-D	UNOCAL B 1000 M
DRY WT. (g)	18.82	21.26	20.40	20.86
TOTAL SATURATED HYDROCARBONS	193	169	319	498
TOTAL RESOLVED SATURATED HC	95	85	81	162
TOTAL UNRESOLVED SATURATED HC	98	84	237	336
ANALYTES (Detection Limit 5ppb)				
NAPHTHALENE	TR	TR	TR	TR
C-1 NAPHTHALENES	TR	TR	TR	TR
C-2 NAPHTHALENES	11	8	6	13
C-3 NAPHTHALENES	TR	TR	TR	TR
C-4 NAPHTHALENES	TR	TR	TR	27
FLUORENE	TR	TR	TR	TR
C-1 FLUORENES	TR	TR	TR	TR
C-2 FLUORENES	TR	TR	ND	TR
C-3 FLUORENES	TR	TR	TR	TR
DIBENZOTHIOPHENE	25	22	23	23
C-1 DIBENZOTHIOPHENE	TR	TR	TR	TR
C-2 DIBENZOTHIOPHENE	TR	TR	TR	TR
C-3 DIBENZOTHIOPHENE	ND	ND	ND	ND
PHENANTHRENE	TR	5	TR	TR
C-1 PHENANTHRENE	TR	TR	TR	TR
C-2 PHENANTHRENE	TR	TR	ND	TR
C-3 PHENANTHRENE	TR	TR	TR	TR
ANTHRACENE	TR	TR	TR	TR
NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-1 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	ND
C-2 NAPHTHOBENZOTHIOPHENE	TR	ND	TR	TR
C-3 NAPHTHOBENZOTHIOPHENE	ND	ND	ND	TR
FLUORANTHENE	TR	TR	TR	TR
PYRENE	TR	TR	TR	TR
C-1 PYRENES	TR	TR	TR	TR
C-2 PYRENES	ND	TR	ND	TR
BENZ(a)ANTHRACENE	ND	ND	ND	6
CHRYSENE	ND	ND	ND	TR
C-1 CHRYSENES	ND	TR	ND	ND
BENZO(b,k)FLUORANTHENE	ND	TR	ND	ND
BENZO(a)PYRENE	ND	TR	TR	TR
INDENO(1,2,3-cd)PYRENE	ND	ND	ND	TR
DIBENZO(a,h)ANTHRACENE	ND	ND	ND	ND
BENZO(g,h,i)PERYLENE	ND	ND	TR	ND
FFPI	1.00	0.85	0.95	0.50

Appendix E. Benthic Community Parameters

Table E.1. Benthic community parameters, Chevron ST52C.

Month/ Station	No. Repl.	No. Species X±SD	No. Individuals X±SD	No. Calc.	Diversity X±SD	Evenness X±SD
April						
CV750	5	31.0±7.4	246.8±144.9	5	0.970±0.06	0.20±.01
CV1000	5	28.4±4.5	199.2±98.8	5	0.98±0.08	0.20±.02
June						
CV750	5	33.0±9.3	616.4±234.7	5	0.81±0.06	0.16±0.01

Table E.2. Benthic community parameters, Unocal ST53A.

Month/ Station	No. Repl.	No. Species X±SD	No. Individuals X±SD	No. Calc.	Diversity X±SD	Evenness X±SD
April						
UA20	5	25.0±9.3	70.6±47.7	5	1.22±0.12	0.27±0.02
UA50	5	30.0±11.9	258.6±168.3	5	1.01±0.11	0.22±0.05
UA100	5	25.6±9.1	195.6±173.7	5	1.02±0.10	.027±0.04
UA250	5	24.0±9.8	155.2±158.2	5	0.98±0.08	0.22±0.03
UA500	5	20.4±6.4	127.8±115.3	5	0.95±0.10	0.22±0.04
UA750	5	29.4±15.9	211.0±185.4	5	0.98±0.21	0.22±0.04
UA1000	5	39.0±6.0	359.8±113.2	5	0.97±0.09	0.18±0.02
June						
UA20	5	16.4±6.5	155.0±153.0	5	0.74±0.12	0.19±0.06
UA50	5	20.0±5.7	236.4±144.2	5	0.77±0.12	0.18±0.04
UA100	5	18.4±3.0	196.4±45.7	5	0.74±0.12	0.19±0.06
UA250	5	32.8±2.9	486.2±213.6	5	0.77±0.12	0.18±0.04
UA500	5	30.4±1.7	554.0±54.7	5	0.74±0.06	0.18±0.01
UA750	5	30.8±7.7	722.6±328.0	5	0.84±0.05	0.17±0.01
UA1000	5	29.2±9.12	531.2±455.2	5	0.80±0.06	0.16±0.01
July						
UA20	5	3.4±1.5	5.4±4.0	5	0.48±.018	0.29±0.02
UA50	5	5.2±1.8	22.8±16.5	5	0.51±0.17	0.22±0.05
UA100	5	4.2±1.3	16.4±9.8	5	0.49±0.11	0.25±0.03
UA250	5	4.4±2.9	8.6±6.9	4*	0.63±0.11	0.27±0.03
UA500	5	5.6±1.8	17.2±5.4	5	0.57±0.11	0.24±0.03
UA750	5	7.0±2.3	38.0±12.3	5	0.49±0.14	0.18±0.03
UA1000	5	6.8±1.9	48.2±17.2	5	0.49±0.11	0.18±0.03
August						
UA20	5	0.8±0.8	1.2±1.3	3*	0.10±0.17	0.29±0.02
UA50	5	2.0±1.0	7.4±3.0	5	0.23±0.22	0.22±0.05
UA100	5	2.2±0.8	7.2±3.8	5	0.24±0.16	0.25±0.03
UA250	5	3.0±1.4	9.0±7.6	5	0.34±.017	0.27±0.03
UA500	5	3.7±2.1	16.7±13.6	3^	0.33±0.18	0.24±0.03
UA750	5	2.4±0.5	17.8±4.6	5	0.26±0.02	0.22±0.05
UA1000	5	2.8±0.8	17.8±10.6	5	0.30±0.15	0.20±0.06
September						
UA500	5	4.6±1.5	20.4±8.3	5	0.51±0.07	0.24±0.02
UA1000	5	3.4±1.7	13.4±15.7	5	0.32±0.21	0.21±0.08
October						
UA500	5	6.0±1.9	56.4±39.6	5	0.50±0.08	0.21±0.04
UA1000	5	6.8±2.2	64.0±25.2	5	0.54±0.10	0.20±0.01

*replicates with zero individuals.
^replicates mistakenly combined in laboratory; deleted from analysis.

Table E.3. Benthic community parameters, Unocal ST53B.

Month/ Station	No. Repl.	No. Species X±SD	No. Individuals X±SD	No. Calc.	Diversity X±SD	Evenness X±SD
April						
UB100	5	43.6±9.7	340.8±119.0	5	1.13±0.19	0.21±0.03
UB500	5	50.0±12.2	456.8±225.6	5	1.18±0.08	0.21±0.01
UB1000	5	52.8±3.7	406.4±89.4	5	1.26±0.04	0.22±0.01
June						
UB100	5	24.4±5.6	300.8±202.0	5	0.79±0.07	0.17±0.02
UB500	5	38.0±8.9	736.6±299.6	5	0.90±0.08	0.17±0.01
UB1000	5	32.2±6.8	603.6±316.3	5	0.80±0.09	0.16±0.02
July						
UB100	5	10.6±4.3	58.6±34.1	5	0.75±0.15	0.23±0.02
UB500	5	15.4±1.5	139.8±66.7	5	0.70±0.05	0.18±0.01
UB1000	5	14.0±5.9	103.8±24.1	5	0.72±0.11	0.19±0.01
August						
UB100	5	3.4±1.5	29.2±7.0	5	0.30±0.08	0.19±0.05
UB500	5	3.8±1.3	48.4±14.4	5	0.33±0.15	0.17±0.03
UB1000	5	3.3±0.6	44.0±6.6	3^	0.39±0.07	0.23±0.02
September						
UB500	5	5.4±2.5	40.4±26.2	5	0.47±0.20	0.20±0.05
UB1000	5	5.6±2.1	47.0±16.7	5	0.56±0.10	0.23±0.02
October						
UB500	5	7.8±2.9	62.8±19.2	5	0.54±0.10	0.23±0.02
UB1000	5	7.4±2.6	69.0±42.5	5	0.65±0.08	0.23±0.02

^replicates mistakenly combined in laboratory; deleted from analysis.

Table E.4. Benthic community parameters, Shell WD32E.

Month/ Station	No. Repl.	No. Species X±SD	No. Individuals X±SD	No. Calc.	Diversity X±SD	Evenness X±SD
April						
SH20	5	52.2±12.0	438.0±285.5	5	1.21±0.14	0.21±0.03
SH50	5	26.6±4.3	230.2±222.6	5	0.90±0.26	0.19±0.06
SH100	5	25.6±6.5	174.0±107.2	5	0.92±0.28	0.20±0.06
SH250	5	23.2±7.9	121.8±162.4	5	1.01±0.14	0.25±0.04
SH500	5	26.2±5.8	117.0±65.4	5	1.09±0.15	0.23±0.04
SHRef	5	16.4±4.0	75.8±60.7	5	0.82±0.11	0.21±0.03
June						
SH0	5	35.0±5.3	162.6±84.8	5	1.24±0.06	0.24±0.02
SH20	5	33.4±9.1	321.6±209.6	5	0.93±0.21	0.19±0.05
SH50	5	31.2±11.1	227.2±167.8	5	0.96±0.05	0.20±0.03
SH100	5	20.8±5.2	57.4±25.1	5	1.11±0.07	0.26±0.02
SH250	5	25.2±6.5	135.6±113.9	5	1.10±0.16	0.25±0.04
SH500	5	24.4±5.3	81.8±38.0	5	1.11±0.14	0.24±0.03
SH750	5	23.2±7.1	209.6±134.4	5	0.83±0.16	0.19±0.05
SH1000	5	29.6±4.2	269.8±126.5	5	0.89±0.14	0.18±0.03
SHRef	5	14.6±6.0	131.4±110.9	5	0.64±0.09	0.17±0.03
July						
SH20	5	20.4±3.1	80.2±20.1	5	1.05±0.06	0.24±0.01
SH50	5	21.8±4.9	149.8±97.7	5	0.96±0.11	0.22±0.03
SH100	5	12.6±3.8	26.2±15.3	5	0.97±0.07	0.27±0.02
SH250	5	15.8±6.4	89.8±74.5	5	0.76±0.19	0.20±0.05
SH500	5	22.2±3.9	141.6±28.7	5	0.79±0.18	0.17±0.03
SH750	5	21.6±2.9	85.2±26.0	5	0.89±0.14	0.20±0.03
SH1000	5	14.2±2.3	70.4±17.6	5	0.75±0.12	0.20±0.03
SHRef	5	10.0±1.6	64.0±25.1	5	0.52±0.20	0.16±0.05
August						
SH20	5	28.2±6.8	174.6±92.7	5	1.16±0.13	0.24±0.03
SH50	5	25.2±5.1	162.0±129.3	5	1.03±0.11	0.22±0.03
SH100	5	17.8±6.8	96.2±115.3	5	0.99±0.10	0.25±0.02
SH250	5	23.4±7.9	127.8±73.3	5	1.02±0.09	0.23±0.01
SH500	5	21.4±2.7	126.6±36.1	5	0.94±0.07	0.21±0.01
SH750	5	18.4±2.9	105.4±36.3	5	0.84±0.09	0.20±0.02
SH1000	5	18.2±4.8	78.2±31.9	5	0.96±0.09	0.23±0.02
SHRef	5	14.4±3.4	96.0±30.1	5	0.72±0.04	0.19±0.02
September						
SH1000	5	13.4±1.9	32.8±11.3	5	0.91±0.12	0.24±0.03
SHRef	5	13.0±1.2	63.6±15.1	5	0.63±0.02	0.17±0.01
October						
SH1000	5	11.4±4.3	17.8±6.8	5	0.94±0.20	0.27±0.03
SHRef	5	8.2±3.3	19.0±10.6	5	0.75±0.15	0.26±0.02

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

Code	Species	Code	Species
Abr aeq	Abra aequalis (B)	Mag I	Magelona sp. I (P)
Albun A	Albuneidae sp. A (D)	Med amb	Mediomastus ambiseta (P)
Amph A	Ampharete sp. A. (P)	Med cal	Mediomastus californiensis (P)
Anc jon	Ancistrosyllis jonesi (P)	Micr atr	Microphiopholis atra (O)
Aric frag	Aricidea fragilis (P)	Mont A	Monticellina sp. A (P)
Aric A	Aricidea sp. A (P)	Nat pus	Natica pusilla (G)
Arm mac	Armandia maculata (P)	Nean micr	Neanthes micromma (P)
Aspido	Aspidosiphon sp. (S)	Nemer A	Nemertea sp. A (N)
Asy elon	Asychis elongatus (P)	Nep inc	Nephtys incisa (P)
Autom	Automate sp. (D)	Nuc acut	Nuculana acuta (B)
Biv L	Bivalvia L (B)	Nuc conc	Nuculana concentrica (B)
Cer lact	Cerebratulus lacteus (N)	Owe fus	Owenia fusiformis (P)
Cerian	Ceriantharia (A)	Palaeo	Palaeonemertea (N)
Chaet D	Chaetozone sp. D (P)	Para B	Paramphinome sp. B (P)
Cirr	Cirratulidae (P)	Para pin	Paraprionospio pinnata (P)
Cirr A	Cirrophorus sp. A (P)	Pod lev	Podarkeopsis levifuscina (P)
Cirr B	Cirrophorus sp. B (P)	Prio cris	Prionospio cristata (P)
Clym torq	Clymenella torquata (P)	Prio del	Prionospio delta (P)
Cos del	Cossura delta (P)	Prio perk	Prionospio perkinsi (P)
Cos soy	Cossura soyeri (P)	Sig tent	Sigambra tentaculata (P)
Golfin	Golfingia sp. (S)	Sip X	Sipuncula X (S)
Hesion	Hesionidae (P)	Sthen	Sthenelais sp. (P)
Lepid A	Lepidasthenia sp. A (P)	Tell vers	Tellina versicolor (B)
Linei	Lineidae (N)	Then	Thenaria (A)
Mag H	Magelona sp. H (P)	Vitr flor	Vitrinella floridana (G)
Mag I	Magelona sp. I (P)	Vol tex	Volvulella texasiana (G)

A- Anthozoa
B - Bivalvia
D- Decapoda
G - Gastropoda
N - Nemertea
O - Ophiuroidea
P - Polychaeta
S - Sipuncula

Table E.6. Dominant taxa by month (number/grab) for Unocal ST53A (=UA).

Rank	Apr	Jun	Jul	Aug	Sep	Oct
1	Amph A 75.4	Amph A 186.6	Mag H 11.8	Mag H 8.6	Para pin 9.6	Para pin 31.2
2	Med amb 50.5	Para pin 124.4	Amph A 6.6	Aspido 2.7	Aspido 4.2	Arm mac 17.6
3	Mag H 15.7	Med amb 37.9	Aspido 2.1	Anc jon 0.3	Mag H 1.7	Aspido 4.4
4	Owe fus 9.5	Mag H 18	Owe fus 1	Golfin 0.2	Then 0.5	Mag H 2.3
5	Para pin 7	Chaet D 14	Clym torq 0.6	Linei 0.1	Nean micr 0.3	Sig tent 2
6	Nean micr 4.6	Owe fusi 9.4	Vitr flor 0.5	Aric A 0.1	Albun A 0.2	Abr aeq 0.6
7	Aric A 3.7	Biv L 6.5	Para pin 0.4	Vit flor 0.1	Sig tent 0.2	Biv L 0.5
8	Clym torq 3.4	Med cal 5.4	Albun A 0.3	Sig tent 0.1	Pod lev 0.1	Sthen 0.2
9	Sig tent 3.2	Tell vers 5.4	Sig tent 0.2	Para pin 0.1	Cerian 0.1	Autom 0.2
10	Prio cris 2.5	Sig tent 4.6	Asy elon 0.2	Albun A 0.1	Aric frag 0.1	Then 0.1

Codes located in Table E.5.

Table E.7. Dominant taxa by month (number/grab) for Unocal ST53B (=UB).

Rank	Apr	Jun	Jul	Aug	Sep	Oct
1	Amph A 103	Amph A 251.3	Amph A 45.2	Mag H 31.1	Mag H 17.3	Para pin 19.6
2	Med amb 70.1	Para pin 199.7	Mag H 43.9	Aspido 10.5	Para pin 12.4	Mag H 17.6
3	Mag H 57.9	Mag H 46.6	Aspido 9.1	Vitr flor 3.5	Aspido 9.4	Arm mac 17.6
4	Owe fus 13.5	Med amb 44.2	Clym torq 5.6	Sip X 0.5	Sig tent 1.3	Aspido 5.9
5	Aric A 13.3	Owe fus 18.9	Owe fus 2.6	Golfin 0.4	Anc jon 1.1	Sig tent 0.7
6	Prio crist 12.7	Biv L 9.3	Vit flor 2.4	Cirr B 0.3	Nean micr 0.6	Golfin 0.6
7	Clym torq 9.7	Chaet D 8	Mont A 1.4	Anc jon 0.3	Golfin 0.6	Prio perk 0.3
8	Aspido 9	Tell vers 6.7	Cirr B 1.1	Cos del 0.1	Nat pus 0.2	Nean micr 0.3
9	Para pin 7.3	Cirr 6.4	Asy elon 1	Albun A 0.1	Hesion 0.1	Lipid A 0.3
10	Nean micr 7.1	Aspido 6	Cirr A 0.9		Cos del 0.1	Anc jon 0.3

Codes are located in Table E.5.

Table E.8. Dominant taxa by month (number/grab) for Shell WD32E (=SH).

Rank	Apr	Jun	Jul	Aug	Sep	Oct
1	Med amb 58.1	Para pin 65	Para pin 44	Para pin 30.8	Para pin 13.8	Para pin 5.2
2	Para pin 13.6	Med amb 22.3	Med amb 3.8	Arm mac 24.3	Mag I 2	Nean micr 1.6
3	Prio crist 5.6	Tell vers 7.9	Mag I 3.1	Med amb 9.1	Sig tent 1.6	Mag I 1.2
4	Owe fus 4.5	Mag I 4.1	Sig tent 3	Tell vers 5.6	Prio del 1.4	Nep inc 1
5	Amph A 3.4	Amph A 3.9	Mag H 3	Amph A 3.7	Nuc conc 1.4	Vol tex 0.6
6	Nean micr 3.2	Mag H 3.9	Amph A 2.7	Linei 3.2	Nean micr 1.4	Tell vers 0.6
7	Palaeo 2.9	Linei 3.1	Linei 2.5	Vol tex 2.7	Vol tex 1	Nuc acut 0.6
8	Mag H 2.4	Nemer A 2.2	Tell vers 2.3	Sig tent 2.4	Mont A 1	Micr atr 0.6
9	Linei 2.4	Cos soy 2.2	Vol tex 2.1	Mag I 2.4	Para B 0.8	Cer lact 0.6
10	Aric A 2.1	Sig tent 2	Nean micr 1.2	Mag H 2.1	Nemer A 0.6	Sig tent 0.4

Codes are located in Table E.5.

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.