III

INDEPENDENT APPRAISAL

RE-EXAMINATION OF THE OFFSHORE ECOLOGY INVESTIGATION

by M. E. Bender, D. J. Reish, and C. H. Ward

CRITIQUE OF THE OEI EXPERIMENTAL RATIONALE AND DESIGN

The objective of the OEI, according to Sharp and Appan (1978), was "to determine whether long-term and intensive petroleum drilling and production has resulted in harmful environmental or ecological effects in offshore and adjacent estuarine ecosystems." They also state that "because the objective emphasized *cumulative* effects, it [the OEI] was concerned principally with the effects of chronic low-level discharges of petroleum hydrocarbons, heavy metals, and the like, which might be attributed to drilling and production operations."

The experimental logic and design used to accomplish this objective included: (1) point source discharge (local impact) evaluations based on data sets taken synoptically at active platform "experimental" sites and at "control" sites, both in Timbalier Bay and offshore Louisiana; (2) dispersed source discharge (general ecosystem health) evaluations based on comparisons of OEI data with that from similar ecosystems and historical data considered applicable to the OEI study sites; and (3) system dynamics evaluations by (a) relating habitat parameters to principal driving forces such as tides, Mississippi River influences, etc., (b) sampling four roughly parallel synoptic transects generally perpendicular and "upstream" from the platform and control sites offshore and remote from intensive petroleum production activities, and (c) determination of exchange processes between bay and offshore areas by sampling a connecting 25-mile transect.

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Since they lacked comprehensive pre-drilling ecological baselines and had only general descriptive information regarding current systems, biomes, variabilities, etc., the 1972 logic and rationale employed for the OEI appeared, at the time, to be the soundest approach possible. In this re-examination of the OEI, however, it became apparent that either the point source studies based on platform-control site comparisons were an unproductive approach (for the objectives as specified), or the control sites, particularly offshore, were not appropriate to implement the approach effectively.

The experimental logic and design failed to include the concept of "qualification" of control sites based on specific parameters to be measured. In other words, the experimental design failed to validate the "criteria" used in selecting control sites. The logic was to compare platform sites (point sources) with control sites unaffected by oil drilling and production operations as a basis for judging impacts of "chronic low-level discharges of petroleum hydrocarbons" (Sharp and Appan 1978). However, the data collected by Oppenheimer et al. (1974) and by Laseter and Ledet (1974) strongly suggest that petroleum hydrocarbon levels were not significantly different at platform and control sites. Oppenheimer's group chose not to speculate on the origin of the petroleum-derived hydrocarbons found in the Gulf of Mexico, but stressed that "the OEI study areas do not differ appreciably in hydrocarbon concentrations or types relative to non-production 'Gulf' control areas several hundred miles from the study sites." They also state, "Based on all evidence it would appear that the nearshore Gulf of Mexico is uniformly exposed to hydrocarbons which probably are derived from petroleum and partially degraded remnants of the parent mixture can be found in seawater and associated with marine plankton and other organisms." The data of Laseter and Ledet do not contradict these conclusions. However, Brent et al. (1974) felt that their "offshore investigations revealed [total] organic carbon loading of the marine system from operating platforms and wells ranging from 2-4 mg/l above background levels. The effects usually extend some 800 to 1600 m from the platform." They also felt that the "offshore area near Grand Isle, Louisiana is one of the most organic rich ecosystems in the world of its type, quite atypical of an 'open' continental shelf region." Because of the naturally high organic load and its effects on oxygen resources, they warned that "vigilance should be maintained in minimizing effects from oil platform effluents and operational spills because of the instability of this ecosystem during spring and summer months." Brent's methods did not allow him to differentiate among petroleum hydrocarbons, other hydrocarbons, and total organic carbon.

The OEI data do not support a conclusion of "no effect" where the validity of the comparisons between platform and control sites is dependent on there being a difference in hydrocarbons present. Rather, it appears that most of the OEI data were collected from the same "population" and should be expected to be the same within statistical errors of sampling. In addition, great temporal and spatial variability of data on specific species, coupled with the probability of the Gulf being "completely mixed" with reference to hydrocarbon content, probably prohibits utilization of classical experimental versus control design concepts.

Several investigators firmly state that no evidence was found to indicate oil drilling and production effects. However, many directly or indirectly agree with Marum (1974) (who worked on zooplankton) that "variability of the results was high. Since the area is one of extreme environmental fluctuations, temporary pollution damage, if it occurred, would be difficult to detect." We believe that a conclusion of no effect must be followed by the question "Was the experimental design, quantity of data, and quality of data adequate to detect an effect if present?" The answer for much of the OEI is, we believe, no. However, we believe also that it is probably unreasonable to expect that the limited data-gathering effort of the OEI could generate the information required definitively to detect low-level effects of oil, which, by definition, must be minimal.

Other investigators appear to have found effects of oil drilling or production, regardless of whether they chose to discount them or felt that their findings did not indicate adverse effects on the general health of the Gulf. Perry (1974) found with reference to fish that "the offshore production site had the lowest biomass value and the lowest species diversity." He felt that this finding was "symptomatic of an adverse effect caused by the discharge of drilling mud solutions which form a hard crust on the bottom to the detriment of the infauna. . . . This lack of numbers of bottom fishes [near production platforms] is strongly believed to be influenced by the lack of bottom-dwelling, burrowing type invertebrates which these fishes feed on. . . . The invertebrate section of this study has indeed found this to be the case. This apparently is the result of the overboard discharge of large amounts of drilling mud solutions. . . . In lease tracts with heavy drilling pressure such a situation could become detrimental to the welfare of a considerable amount of viable offshore bottomland for a considerable time."

Montalvo and Brady (1974) found that "zinc, lead, and cadmium [in water samples] are higher near the rig sites than at areas remote from the rig sites." They considered the limited density of samples at platform and control sites and the lack of trace metal and sediment analyses serious deficiencies in experimental design. Their studies did not establish cause-effect relationships, but they felt that they had "obtained some data that indicates that there is at least a possibility of danger [from Zn, Pb, and Cd concentrations at the rigs]."

Fish et al. (1974), with reference to the meiofauna of Timbalier Bay, felt that "those stations located near active oil production sites consistently yielded a lower calculated species diversity index than did their corresponding control sites. As the only observable difference in each pair of stations was their proximity to active oil wells, the above data indicates that the environmental stress that was recorded for these environments may have been caused by the nearby active oil production sites." Without complete hydrocarbon analysis to aid in the interpretation of their data, they concluded that "active oil wells located within Timbalier Bay have had only a minimal effect on the distribution and abundance of Foraminifera inhabiting the area."

The findings or opinions of the OEI investigators noted above do not clearly indicate effect or no effect of oil drilling and production in the Gulf. Hence, we feel that the OEI Council conclusions (Morgan et al. 1974) should be reviewed and restated to indicate clearly the limitations of the experimental design and the data base for definitively answering questions on chronic effects of oil.

This re-examination of the OEI has shown that the natural variability inherent in the biological, physical, and chemical processes in the Gulf of Mexico precludes acquisition of adequate, representative, or valid baseline data in a period limited to two years. The quality of the OEI data is in some cases excellent, however, even though many of the investigators appear to have worked largely independently. Because their research was often conducted independently, the usefulness of the total OEI data base is limited for some scientific purposes. For instance, if total organic carbon, soluble organic carbon, particulate organic carbon, phytoplankton (or chlorophyll), primary productivity, zooplankton, hydrocarbons, and microbial flora had all been determined in the same rather than in different samples, the OEI data base would represent a unique resource for answering questions vital to our current understanding of carbon partitioning and flow in ocean ecosystems (Pomeroy 1974).

Regardless of the shortcomings in experimental design and density of data on specific parameters, the data amassed by the OEI investigators is invaluable to U.S. science, government, and industry, and at the time it was collected, it represented the best and most cost-effective data base in existence on any part of the Gulf of Mexico. The OEI data, in combination with more recent studies such as those sponsored by the Bureau of Land Management, represent the most comprehensive data base available on a salt water system. We believe that it is fortuitous that much of the OEI data appears to have come from the same "population."

Every effort should be made to find avenues to expand the Gulf environmental data base and to establish quantitative indicators of "acceptable limits of performance." But such indicators can only be identified with adequate knowledge of spatial and temporal variability of parameters important to the functioning of marine ecosystems. New avenues to, and philosophies for, experimental design for environmental assessment should be explored in order to develop approaches fully

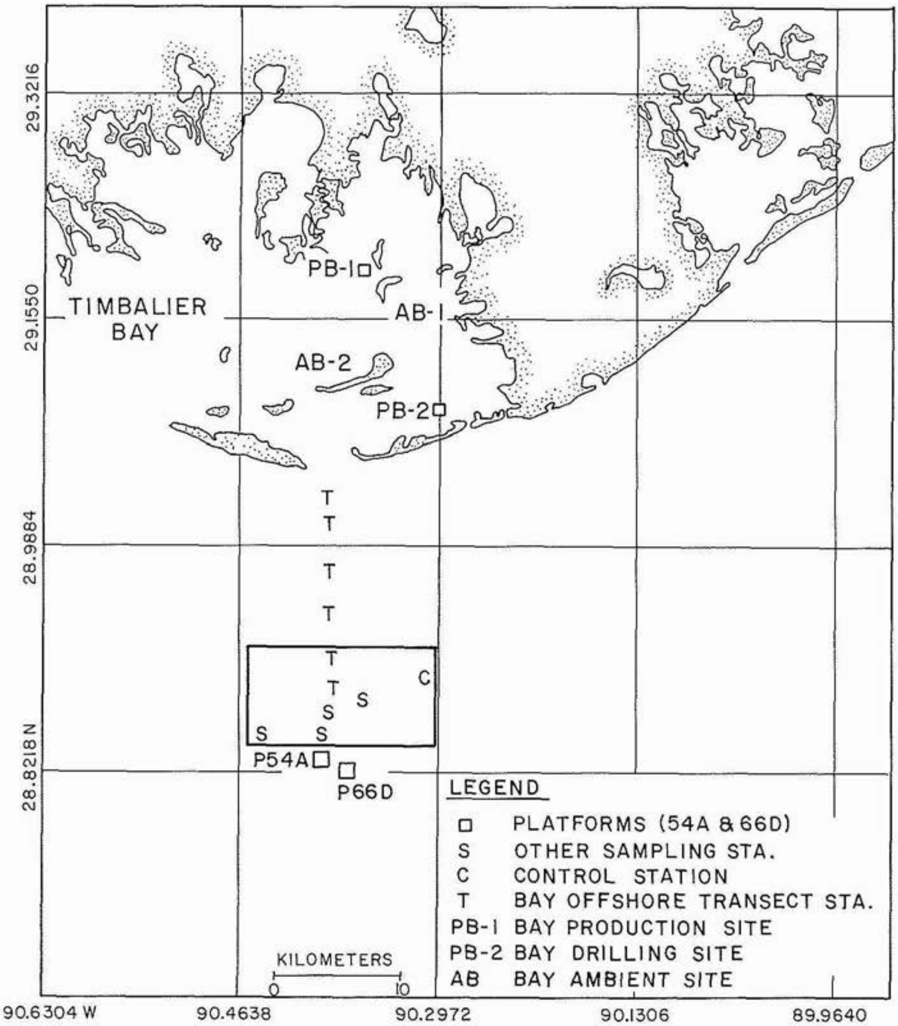


FIG. 1. LOCATIONS OF BAY AND OFFSHORE SAMPLING STATIONS used in the re-examination of the Offshore Ecology Investigation.

consistent with the scientific method or to provide acceptable alternatives. Consensus qualification of selected indicators as criteria for judging "good ecological health" might serve as a first approach.

RE-EXAMINATION AND ANALYSIS OF OEI DATA

Water column and sediment characteristics

Platform Versus Control

Minimum statistical treatment of data was evident in most of the OEI investigators' final reports, and conclusions reached were often limited to opinions based on qualitative review of the data. The density of the OEI data appeared to be the primary factor limiting quantitative comparisons.

Figure 1 illustrates the location of bay sampling sites, transect stations, platforms, other sampling stations, and the control, which was about 11 km east of the platforms.

To explore the degree to which the offshore control site was environmentally comparable to the platform site—except, of course, for the physical presence of the platform—we selected the four (of the eight) seasonal exercises that offered the most complete sets of data. Computer-generated displays were obtained of selected data taken at both the platform site (54A, also referred to as HOR-54A and Exxon 54A in other papers in this volume) and the control. Several sampling stations near the platform were chosen to illustrate the natural variability in the immediate platform area. Environmental parameters used in the comparisons were salinity, dissolved oxygen, temperature, optical transparency (transmittance), depth, and bottom type. Figures 2 through 5 are representative of the data that collectively indicate that the sites were comparable in these regards. Depths and bottom types were also similar.

Water quality parameters used to compare the platform and control sites were trace metals, nutrients, and carbon chemistry (organic carbon, inorganic carbon, and total carbon). Tables 1, 2, and 3 (p. 45) present representative data, most of which is insufficiently dense to permit statistical treatment. Site-related differences are not readily apparent; some seasonal and depth variations can be distinguished, however.

Taken as a whole, these data roughly show that the primary environmental difference between the two offshore sites was the physical presence of the platform in one and not the other, that the habitats varied essentially simultaneously in response to meteorological or seasonal events, and that prevailing current direction and speed (figure 6, p. 46) were such that materials originating at the platform would not normally reach the control site during most of the year.

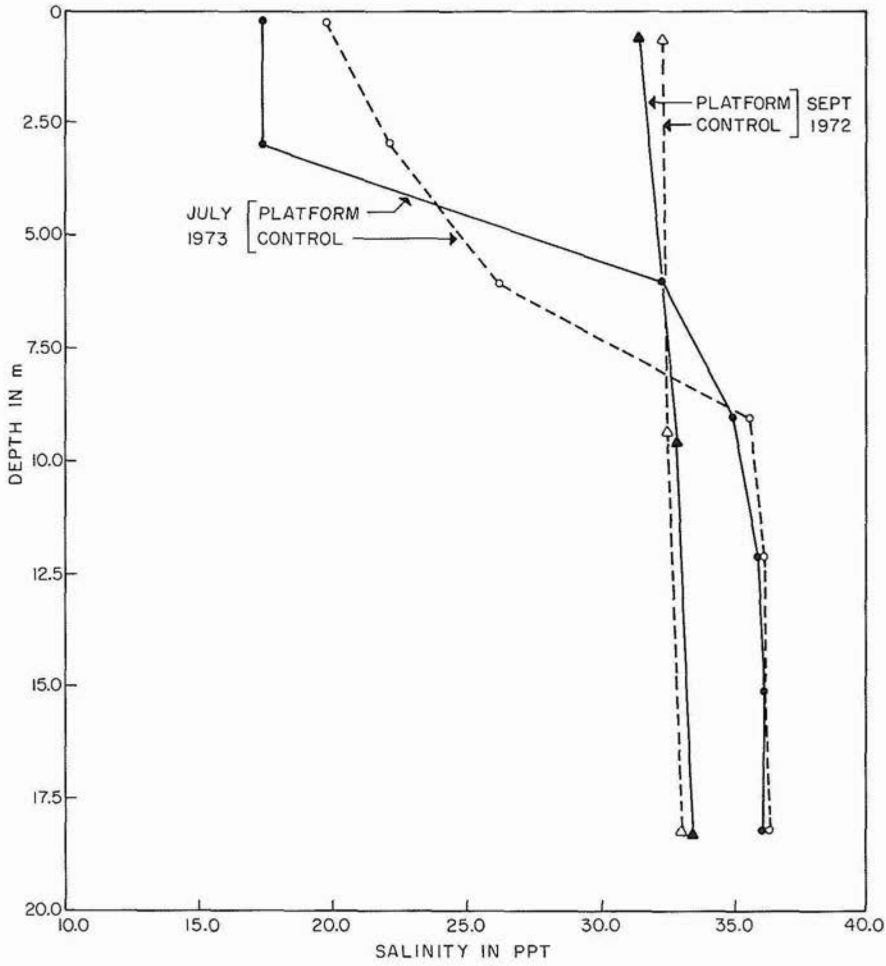


FIG 2. SALINITY WITH DEPTH DURING TWO SEASONAL SAMPLING EXERCISES.

Entrained material in the Mississippi River outflow, runoff from adjacent land, and platforms are probable sources of nutrients, trace metals, and organic carbon in the OEI study area. Water column measurements for arsenic, mercury, lead, cadmium, and zinc showed that arsenic was always below detectable levels. Trace metals, probably bound to suspended materials, were generally higher in water samples taken from the nepheloid layer. Figure 7 (p. 47) shows a non-statistical, but informative, treatment of the similarity between platform zinc concentrations and concentrations at stations 1,500 m or more away from the platform.

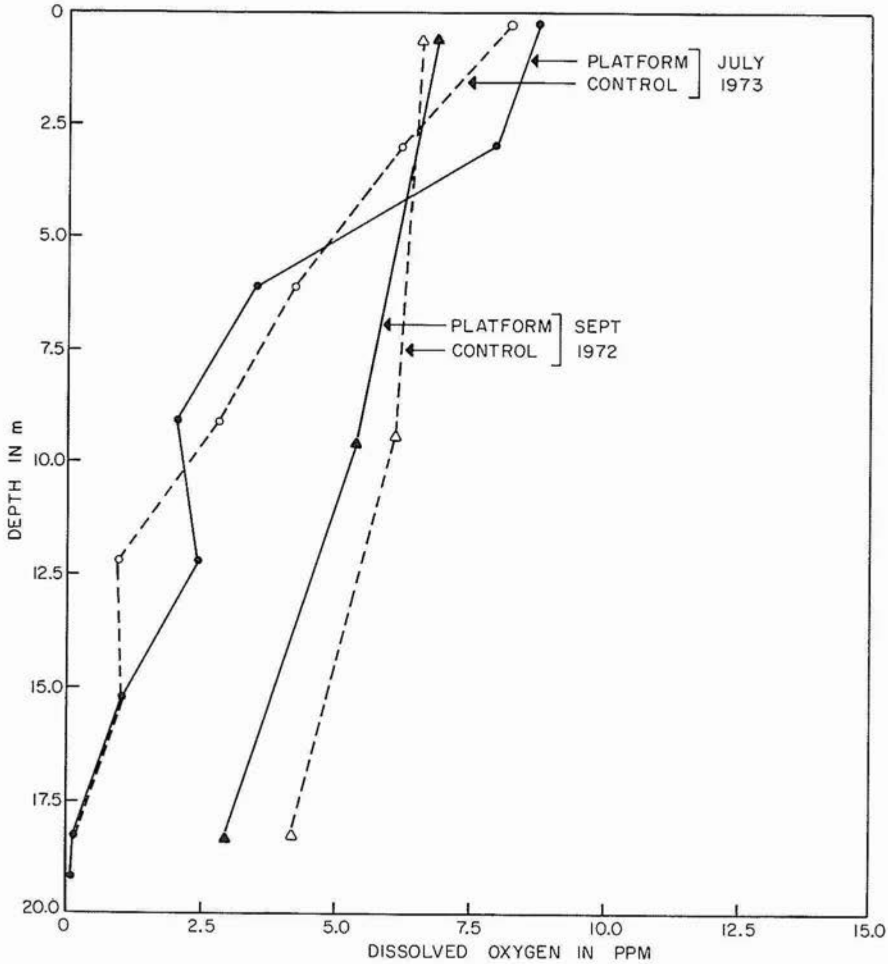


FIG. 3. DISSOLVED OXYGEN WITH DEPTH DURING TWO SEASONAL SAMPLING EXERCISES.

Dissolved oxygen concentrations varied more significantly with depth than with location. As would be expected, surface values were uniformly higher than those from deeper waters, and dissolved oxygen concentrations varied directly in relation to water temperature. During the summer of 1973, near-bottom values approached zero over the entire offshore region.

Except during the post-flood period, Biochemical Oxygen Demand (BOD) was usually slightly higher at the production platform offshore than at the drilling platform, and both were usually higher than at the

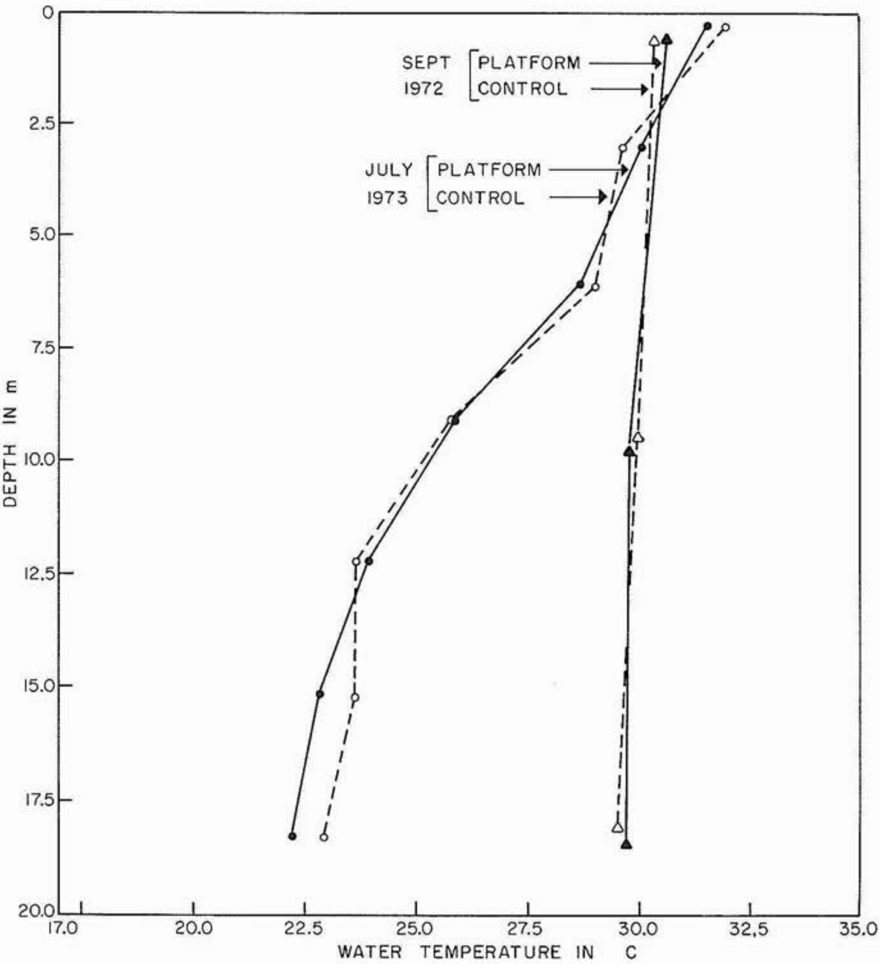


FIG. 4. WATER TEMPERATURE WITH DEPTH DURING TWO SEASONAL SAMPLING EXERCISES.

control site. The large fouling community that colonized the legs of the platforms may have contributed to the higher BOD values around the platforms. Differences between the production and drilling platforms, similarly, may have resulted from the smaller submerged surface area at the drill site. Surface values of BOD ranged from 0 to 2.7 mg/l at the platform and from 0 to 2.6 mg/l at the control over a period of four seasons. Near-bottom values during the same time ranged from 0.1 to 2.2 mg/l at the platform and from 0.7 to 0.9 at the control. Inadequate

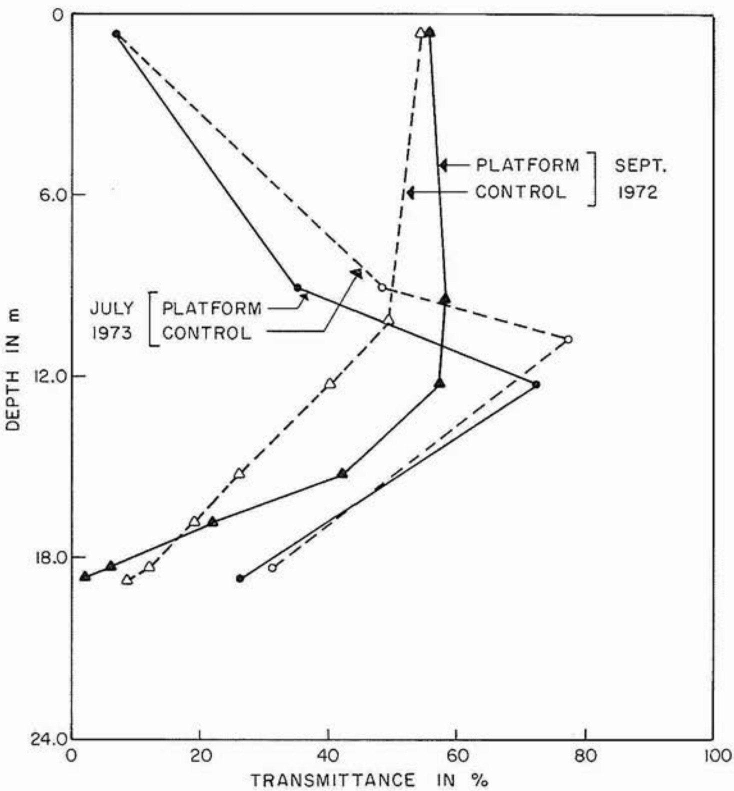


FIG. 5. TRANSMITTANCE WITH DEPTH DURING TWO SEASONAL SAMPLING EXERCISES.

BOD data were available to permit statistical treatment of possible differences between platform and control sites.

Slightly higher concentrations of total organic carbon (TOC) were often found around platforms (see table 3). Possible sources of organic carbon at platforms include kitchen and human wastes, oil, and contributions from the fouling communities. Data collected in the OEI do not permit differentiation of these sources and there was no obvious relationship between various hydrocarbon fractions and TOC.

Although only qualitative comparisons can be made between possible contaminants present at the OEI platform and control sites, it would appear that the effluents from drilling and production (1) are so small as to cause no significant concentrations of contaminants, (2) are rapidly diffused, and/or (3) are masked by distributed source effects in the intensely oil-active OEI area. In any event, such effects as may be

TABLE 1. Mercury concentrations (ppb) in the water column with depth at platform and control sites during four of eight OEI sampling exercises.

Date	Depth	Hg Range		Mean		No. of Observations	
		Platform	Control	Platform	Control	Platform	Control
Exercise 1	Top	0.4-3.0	0.4-0.8	0.9	0.6	6	2
1972 Sept.	Middle	0.3-0.6	0.4-0.5	0.4	0.4	6	2
	Bottom	0.3-2.9	0.3-0.4	0.8	0.3	6	2
Exercise 3	Top	0.3-0.3	0.3	0.3	0.3	2	1
1972 Nov.-Dec.	Middle	0.3-0.7	0.3	0.5	0.3	2	1
	Bottom	0.3-0.3	0.3	0.3	0.3	2	1
Exercise 5	Top	0.3	-	0.3	-	1	0
1973 Apr.	Middle	-	-	-	-	0	0
	Bottom	-	-	-	-	0	0
Exercise 6	Top	0.3-0.3	0.3-0.3	0.3	0.3	4	2
1973 July	Middle	0.3-0.3	0.3	0.3	0.3	2	1
	Bottom	0.3-0.5	0.3	0.3	0.3	7	1

Top, 0-5 m; Middle, 8-13 m; Bottom, 14 m - bottom.

TABLE 2. Nitrate plus nitrite nitrogen (ppm) in the water column with depth at platform and control sites during four of eight OEI sampling exercises.

Date	Depth	$NO_3 + NO_2$ Range		Mean		No. of Observations	
		Platform	Control	Platform	Control	Platform	Control
Exercise 1	Top	0 -0.45	0-0.45	0.06	0.22	7	2
1972 Sept.	Middle	0 -0.55	0-4.00	0.09	2.00	7	2
	Bottom	0 -0.70	0-0	0.13	0	7	2
Exercise 3	Top	4.34	2.34	4.34	2.34	1	1
1972 Nov.-Dec.	Middle	1.70	5.38	1.70	5.38	1	1
	Bottom	0	52.98	0	52.98	1	1
Exercise 5	Top	0.17	0.58	0.17	0.58	1	1
1973 Apr.	Middle	-	0.70	-	0.70	0	1
	Bottom	0.47-0.59	-	0.52	-	3	0
Exercise 6	Top	0.09-0.33	0.19-0.35	0.18	0.28	6	6
1973 July	Middle	0.14-0.04	0.04-0.32	0.19	0.22	2	3
	Bottom	0.05-0.29	0.05-0.30	0.15	0.19	6	3

Top, 0-5 m; Middle, 8-13 m; Bottom, 14 m - bottom.

TABLE 3. Total Organic Carbon (ppm) in the water column with depth at platform and control sites during four of eight sampling exercises.

Date	Depth	TOC Range		Mean		No. of Observations	
		Platform	Control	Platform	Control	Platform	Control
Exercise 1	Top	5.3-6.6	5.1-6.2	5.9	5.6	2	2
1972 Sept.	Middle	6.9-7.9	6.0-6.6	7.4	6.3	2	2
	Bottom	5.3-7.6	5.6-6.0	6.4	5.8	2	2
Exercise 3	Top	2.7	-	2.7	-	1	0
1972 Nov.-Dec.	Middle	-	-	-	-	0	0
	Bottom	-	-	-	-	0	0
Exercise 5	Top	8.2	7.2	8.2	7.2	1	1
1973 Apr.	Middle	-	2.8	-	2.8	0	1
	Bottom	-	3.3	-	3.3	0	1
Exercise 6	Top	4.4-11.7	6.8	7.3	6.8	5	1
1973 July	Middle	2.6-2.8	-	2.7	-	2	0
	Bottom	1.6-7.1	-	4.4	-	4	0

Top, 0-5 m; Middle, 8-13 m; Bottom, 14 m- bottom.

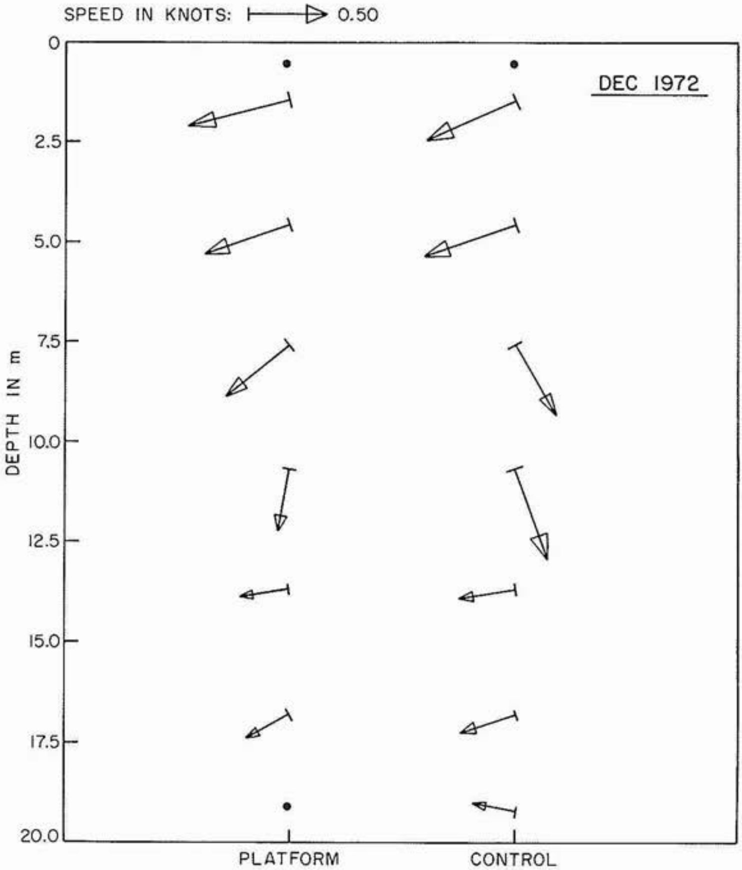


FIG. 6. CURRENT DIRECTION AND SPEED WITH DEPTH FOR PLATFORM AND CONTROL DURING ONE SEASONAL SAMPLING EXERCISE.

present appear to be small in comparison with seasonal variabilities. It should be noted that the observed variabilities were experienced at both platform and control sites at about the same time and magnitude, however, indicating that relative effects originating from oil drilling and production might be observed, if they occur, in the presence of large seasonal variations, provided that monitoring data are adequate to permit rigorous statistical treatment.

Since the density of the OEI data would not permit, for the most part, meaningful statistical comparisons between platform and control sites, the OEI as originally designed provided little evidence for or against cumulative point source effects.

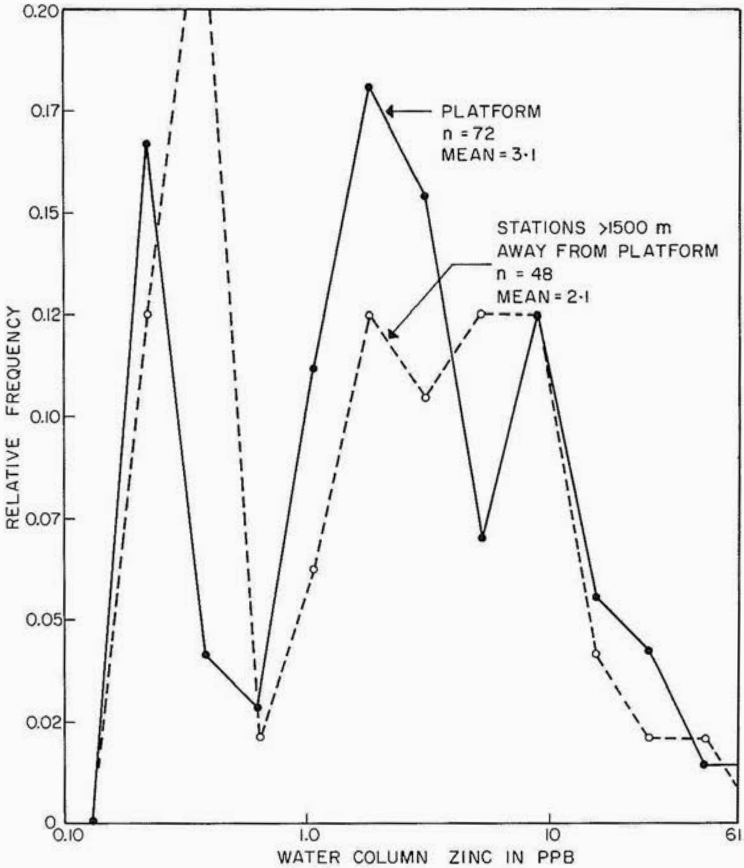


FIG. 7. FREQUENCY DISTRIBUTION OF WATER COLUMN ZINC CONCENTRATIONS for Platform 54A and stations greater than 1500 m from the platform.

Platform Versus Ambient

Since the OEI sampling design, primarily because of lack of replication, precluded statistical treatment of the data, it was decided to explore the possibility of expanding the data base to provide additional stations against which the platform stations might be compared. It was necessary, therefore, to explore the degree to which additional "control" sites might be environmentally comparable to the platform sites, except, of course, for the physical presence of the platform itself.

To accomplish these comparisons, the computerized data files were queried to provide plots displaying selected data taken at the platforms

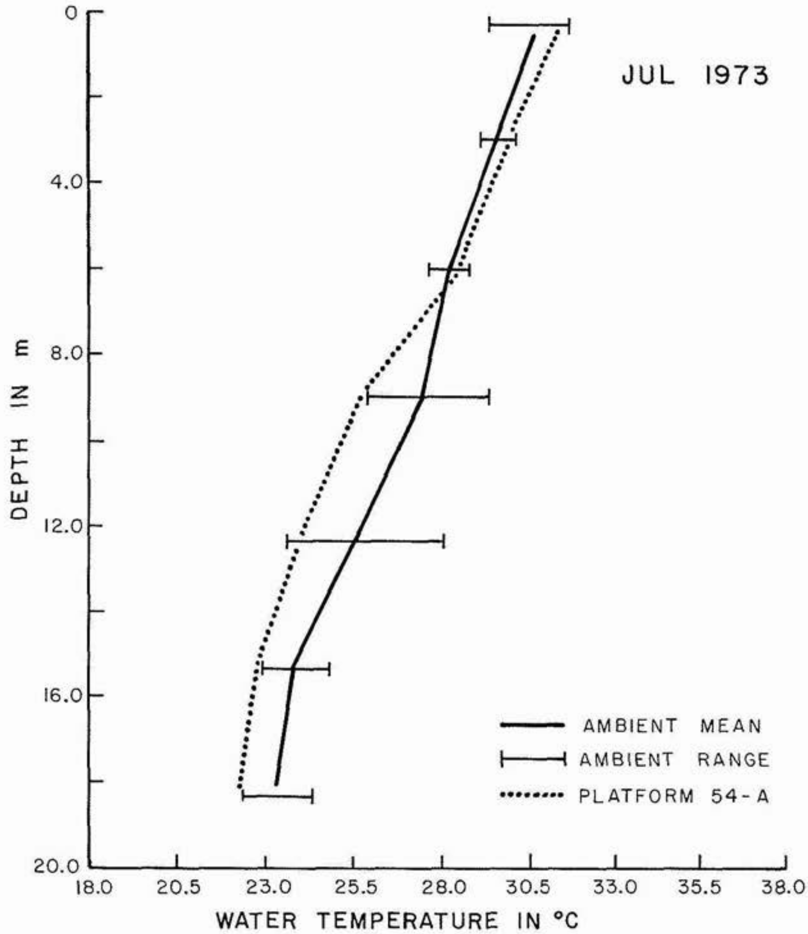


FIG. 8. WATER TEMPERATURE WITH DEPTH FOR AMBIENT AND PLATFORM STATIONS.

and potential additional controls. Environmental parameters used in the comparisons were salinity, dissolved oxygen, temperature, optical transparency, current, depth, and bottom type. For a station to qualify as an additional control in the near-shore region, the criteria were that it must: (1) be located at least 1,000 meters from the platform, (2) be sampled the same day as the platform site, (3) have similar salinities and temperatures, (4) have similar bottom substrates, (5) have depths within 5 meters of those at the platform with which comparisons were made, and (6) not receive transported materials originating at the platform during the sampling period.

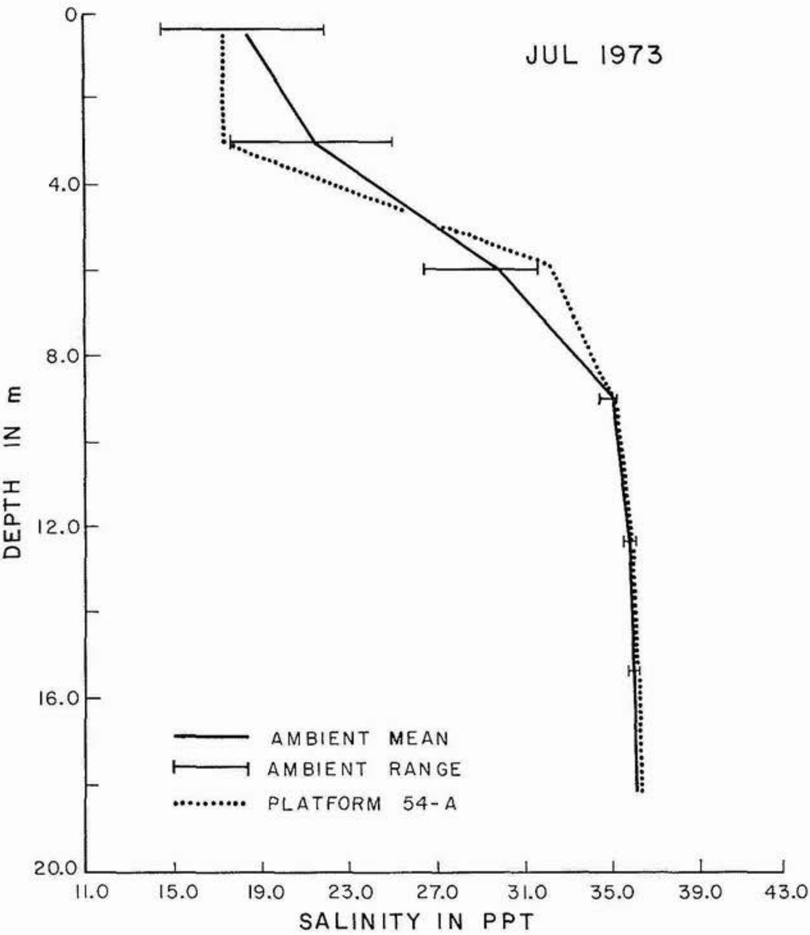


FIG. 9. SALINITY WITH DEPTH FOR AMBIENT AND PLATFORM STATIONS.

Figures 8, 9, and 10 are representative of the data that supported the inclusion of additional stations for statistical comparisons. A review of the OEI data showed that six stations, in addition to the original control, qualified as ambient stations (figure 1, stations included in rectangle).

Each seasonal field exercise was screened to determine whether a sufficient number of comparable ambient stations had been sampled to yield at least three samples for comparison with the platform. If so, the normality of the data was tested by comparing means and standard deviations with "corner tests" as described by Olmstead and Tukey (1947).

In the offshore region, the data indicated that normal statistics could

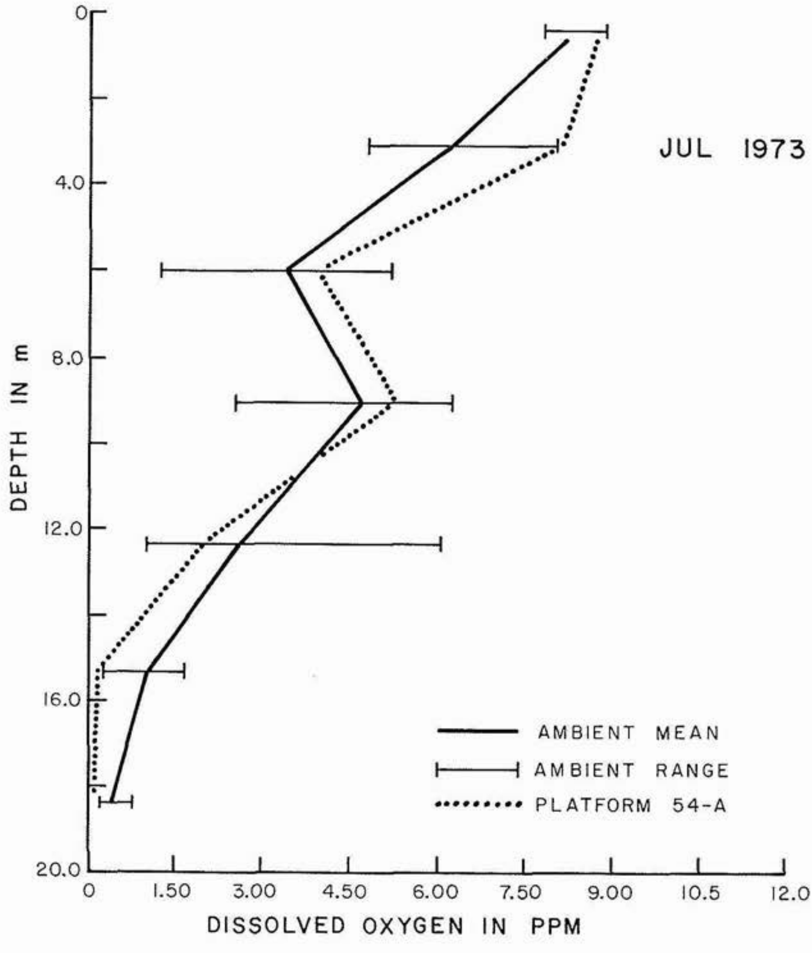


FIG. 10. DISSOLVED OXYGEN WITH DEPTH FOR AMBIENT AND PLATFORM STATIONS.

be used to test differences between platform and ambient stations for the parameters of lead, ammonia, and nitrate-nitrite nitrogen. Logarithmic transformations of the data not indicated as normal were performed before the data were used for "t" tests. In Timbalier Bay, square root transformations of nutrient and trace metal data were necessary before normal statistics could be applied.

Offshore—Table 4 shows the results of "t" test comparisons of eight parameters between platform 54A and the newly defined offshore ambient stations. Measurements were paired by depth at each station for

TABLE 4. Paired 't' test comparisons of water quality parameters between platform 54-A and offshore ambient stations.

Date	TOC[1)]	Zn[2)]	Pb	Cd[2)]	Dissolved[2)] Silica	NH_3-N	NO_3+NO_2	O-PO_4[2)]
Exercise 1 1972 Sept.	(6)	(12)	(12)	(12)	(12)	(12)	(12)	(12)
Exercise 2 1972 Oct.	IS (1)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
Exercise 3 1972 Nov.-Dec.	IS (0)	(6)	(6)	(6)	(3)	(3)	(3)	(3)
Exercise 4 1973 Jan.-Feb.	IS (1)	IS (0)	IS (0)	IS (0)	IS (1)	IS (0)	IS (0)	IS (1)
Exercise 5 1973 Apr.	IS (1)	IS (0)	IS (0)	IS (0)	IS (1)	IS (1)	IS (1)	IS (1)
Exercise 6 1973 July	IS (0)	(7)	(7)	(7)	(18)	(18)	(18)	(16)
Exercise 7 1973 Oct.	IS (2)	(8)	(8)	(8)	(12)* Amb.High	(12)* 54A High	(12)	(12)* Amb.High
Exercise 8 1974 Jan.	(9)	(8)	(8)	(8)	(12)	(12)	(12)* 54A High	(12)

1) data not normally distributed even when log transformed. Chi-square used to test significance;
2) log transformed; ( ) number of paired observations; * significant difference at 0.05 level;
IS inadequate sample size, n = <3 pairs.

The water column was divided into 3 depth zones: Top, 0.00 to 5.00 m; Mid, 5.01 to 13.00 m; Bottom, 13.01 to bottom. For each cruise a Top value of 54-A was paired with a Top value of Ambient. The pairing was done using random numbers. When a matching value was not available for pairing that measurement was not included in this 't' test.

AMB	n=	6	2		1	2		4	9
66D	n= 16					2	15	1	27
54A	n=	6	2	2	6	2	14	2	23
ALL	n=22	42	28	9	16	19	53	12	99

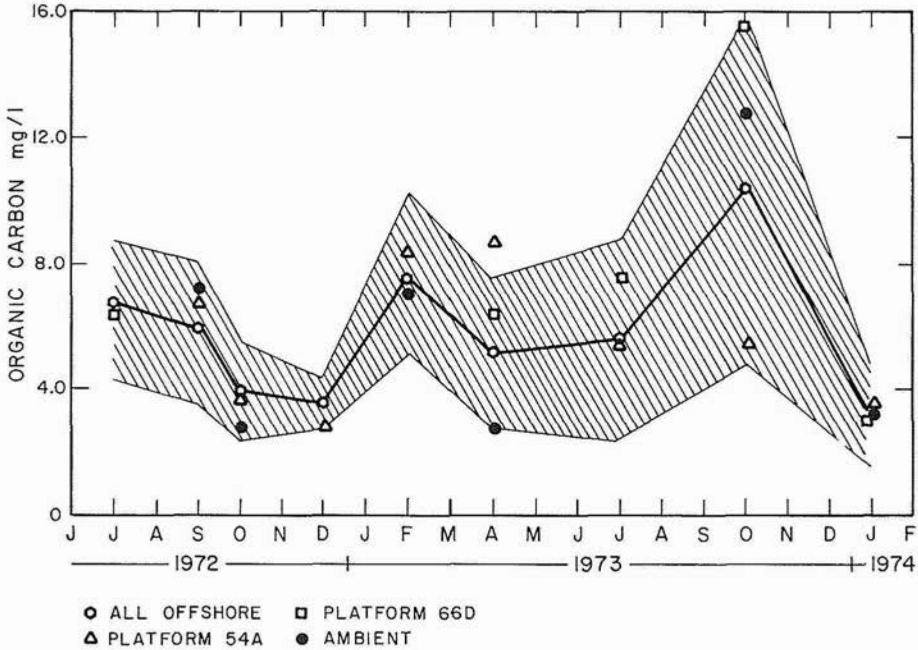


FIG. 11. SEASONAL VARIABILITY OF ORGANIC CARBON IN THE WATER COLUMN OFFSHORE.

each of the eight sampling exercises. Comparisons were not made when there were fewer than three pairable observations between the platform and one of the ambient stations. Single instances occurred where dissolved silica, ammonia nitrogen, nitrate-nitrite nitrogen, and orthophosphate were significantly higher or lower at platform 54A. Since these were single instances there is little basis for interpretation. It is important to note, however, that the analysis gave no indication of differences between platform and ambient in organic carbon or metals in the water column.

Further analysis of the TOC and BOD data of Brent et al. (1974) with season (figures 11 and 12) does not clearly demonstrate the presence of platforms 54A and 66D based on these parameters. The dashed area in each figure is one standard deviation above and below the mean of all

AMB	n=	6	2		1	2		4	9
66D	n= 16					2	15	1	27
54A	n=	6	2	2	6	2	14	2	23
ALL	n=22	42	28	9	16	19	53	12	99

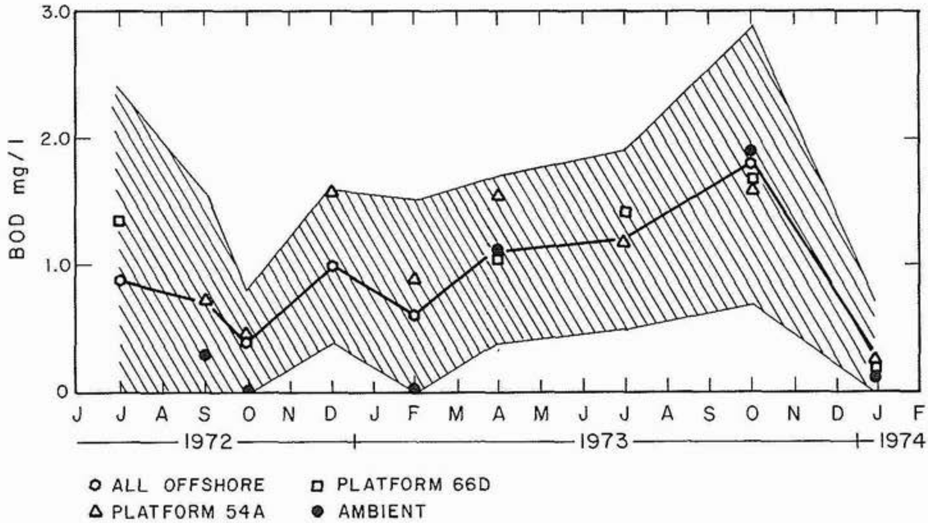


FIG. 12. SEASONAL VARIABILITY OF BIOCHEMICAL OXYGEN DEMAND IN THE WATER COLUMN OFFSHORE.

offshore data. Platforms 54A and 66D are the means of all data within a 750 m × 750 m area around each platform. "Ambient" is the mean of all data from all stations falling in the rectangular area shown in figure 1. Poor correlation exists between BOD and TOC concentrations at platform and ambient stations (figure 13).

Figures 14 and 15 present the BOD and TOC data with distance from platform 54A. The horizontal line connects the mean of all the data within each 1,000 m segment of the range from platform 54A, spanning an azimuth of 360 degrees. The number of observations in each mean is indicated at the top of each figure. The thick vertical line represents the 95% confidence interval of the mean and the thin vertical line is one standard deviation. Platform 54A is located at 0 on the ordinate; platform 66D at about 2,000 m. Both the BOD and TOC decrease initially with distance from 54A, but the number of observations also decreases with distance and variability of the data increases. The presence of the platforms could not be demonstrated from the collection of data, nor are the platforms significant point sources of TOC or biodegradable carbon.

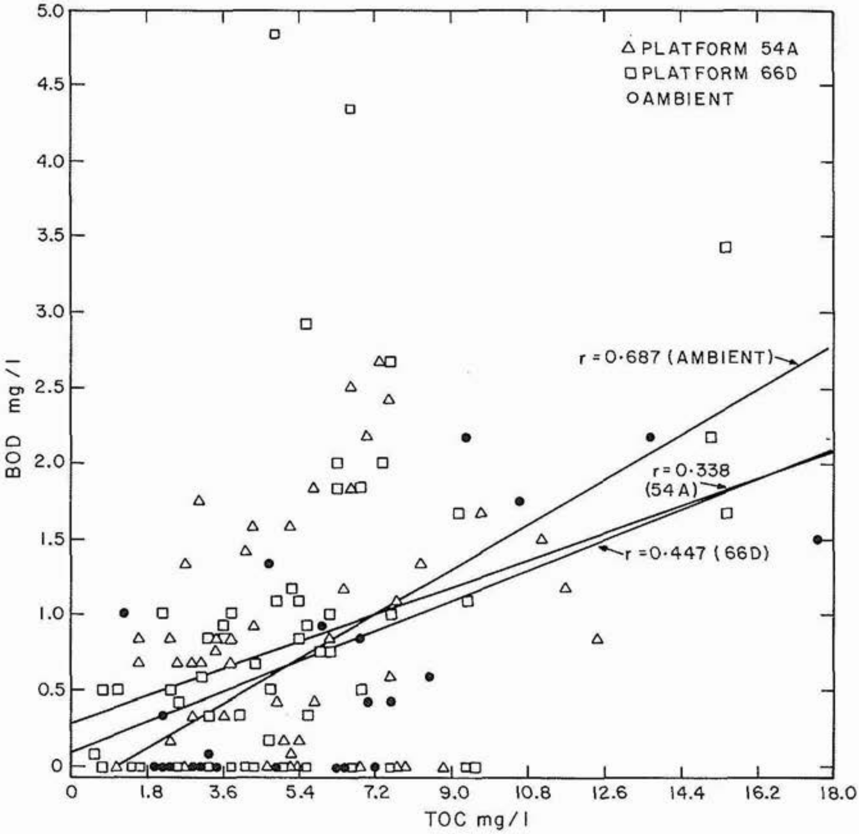


FIG. 13. RELATIONSHIP BETWEEN BOD AND TOC AT PLATFORM AND AMBIENT SAMPLING STATIONS OFFSHORE.

Laseter and Ledet (1974) analyzed sediment, beach, and air/sea interface samples for hydrocarbons and free fatty acids using gas chromatography and mass spectrometry. The air/sea and beach data were not sufficiently replicated to permit statistical comparisons; however, "t" test comparisons of the hexane, benzene, and methanol eluates of sediment samples from platform 54A and ambient stations showed no differences at the 5% confidence level (table 5, p. 56).

Figures 16, 17, 18, and 19 (pp. 57-58) present hydrocarbon data with distance from platform 54A. The horizontal line connects the mean of all data of all cruises within each 2000-meter segment of the range from 54A, spanning an azimuth of 360 degrees. The vertical line is one standard deviation. The data points are coded by cruise number. The hexane eluate contains the paraffins; the benzene eluate the aromatics, high mo-

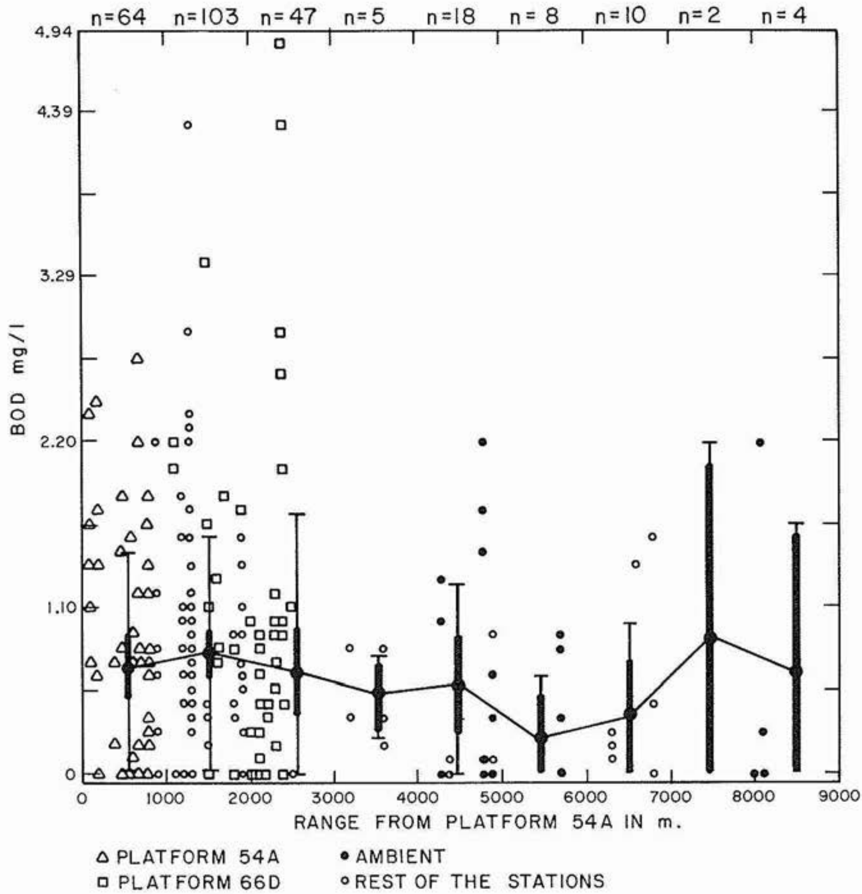


FIG. 14. VARIABILITY OF BOD IN THE WATER COLUMN WITH DISTANCE FROM PLATFORM 54A.

lecular weight ketones, and esters; the methanol eluate the free fatty acids and polar compounds. Since the data for each eluate represent mass per unit area and not percentage of the total hydrocarbons recovered, higher values would be expected at the platform if it were a significant source of petroleum hydrocarbons. This is clearly not the case but the low density of the data prevents rigorous statistical treatment.

Figures 20, 21, and 22 (pp. 59-61) present data for three hydrocarbon eluates with season. Inadequate benzene data were available for this type of analysis. The dashed area is one standard deviation above and below the mean of all offshore data. The points labeled "platform" are the mean of all data within a range of 0 to 2,500 m from 54A, spanning an azimuth of 360 degrees, which includes platform 66D. "Ambient" in

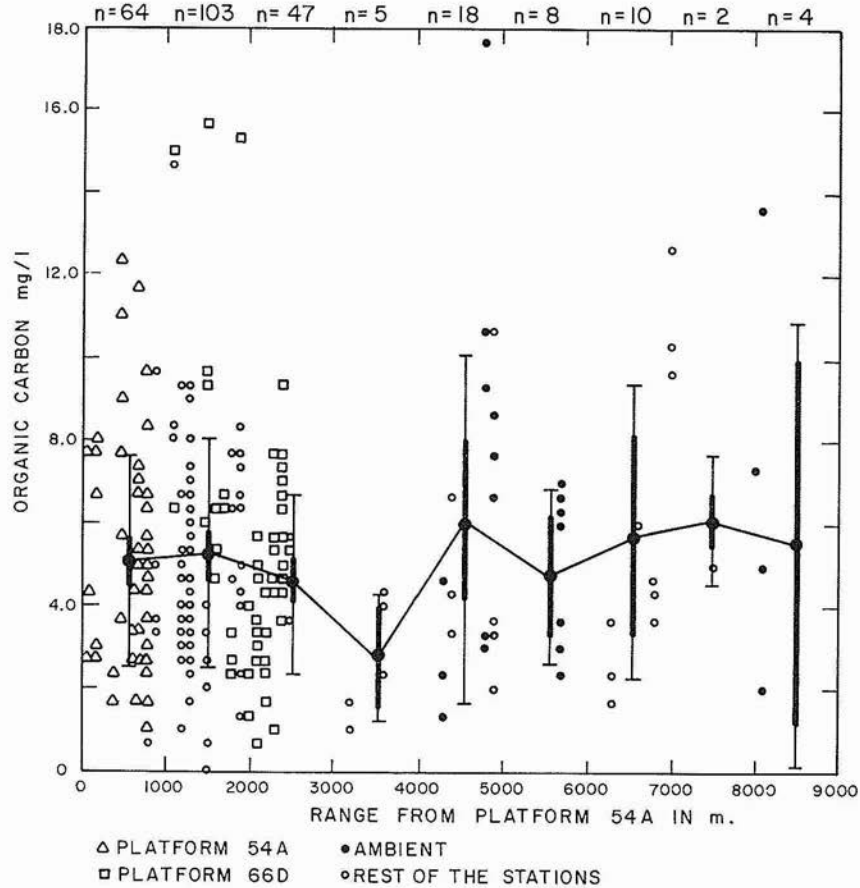
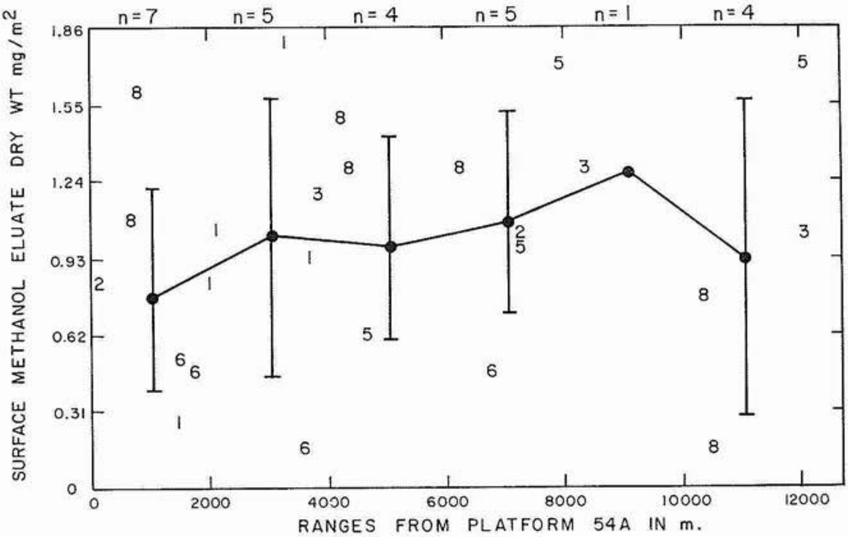


FIG. 15. VARIABILITY OF ORGANIC CARBON IN THE WATER COLUMN WITH DISTANCE FROM PLATORM 54A.

TABLE 5. Comparison between hydrocarbon fractions in offshore sediment samples collected during August, September, October, and December 1972.

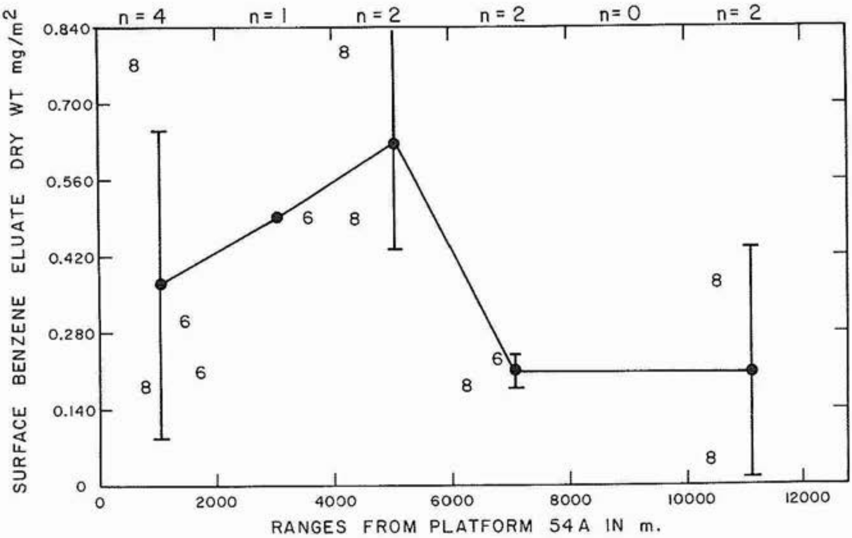
Eluate	Range[1)]	n	Min	Max	$\bar{x}$	Std. error	s	Student's t	t.05
Hexane eluate mg/100 g	Platform	6	1.90	14.00	4.97	1.89	4.63	0.63	2.11
	Ambient	13	1.80	14.50	6.17	0.99	3.57		
Benzene eluate mg/100 g	Platform	6	0.30	18.20	5.73	2.72	6.65	0.44	2.11
	Ambient	13	1.00	23.30	7.21	1.96	7.06		
Methanol eluate mg/100 g	Platform	6	6.80	48.80	19.90	6.86	16.80	1.92	2.11
	Ambient	13	10.00	80.00	39.17	6.06	21.84		

1) Platform = 0 to 1,600 m range from platform 54A. This includes Platform 66D samples.
Ambient = 1,601 to 12,500 m range from platform 54A.



1 = SEP 72 2 = OCT 72 3 = NOV-DEC 72 4 = JAN-FEB 73 5 = APR 73 6 = JUL 73 7 = OCT 73 8 = JAN 74

FIG. 16. METHANOL ELUATE OF SURFACE WATER SAMPLES WITH DISTANCE FROM PLATFORM 54A.



1 = SEP 72 2 = OCT 72 3 = NOV-DEC 72 4 = JAN-FEB 73 5 = APR 73 6 = JUL 73 7 = OCT 73 8 = JAN 74

FIG. 17. BENZENE ELUATE OF SURFACE WATER SAMPLES WITH DISTANCE FROM PLATFORM 54A.

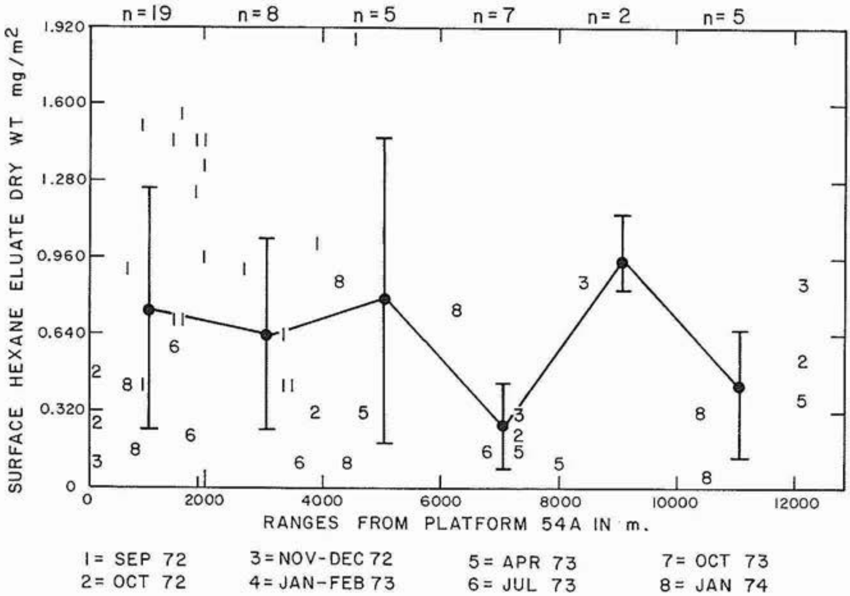


FIG. 18. HEXANE ELUATE OF SURFACE WATER SAMPLES WITH DISTANCE FROM PLATFORM 54A.

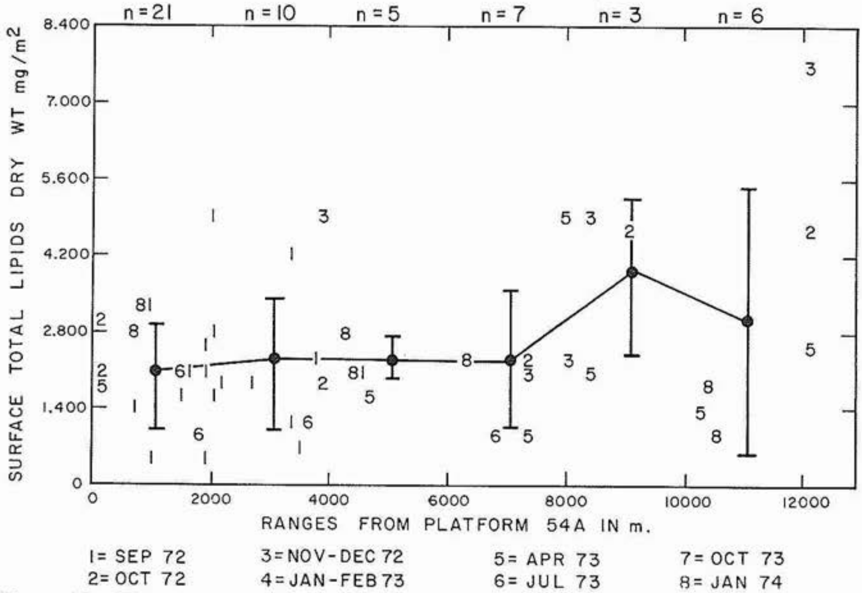


FIG. 19. TOTAL LIPIDS OF SURFACE WATER SAMPLES WITH DISTANCE FROM PLATFORM 54A.

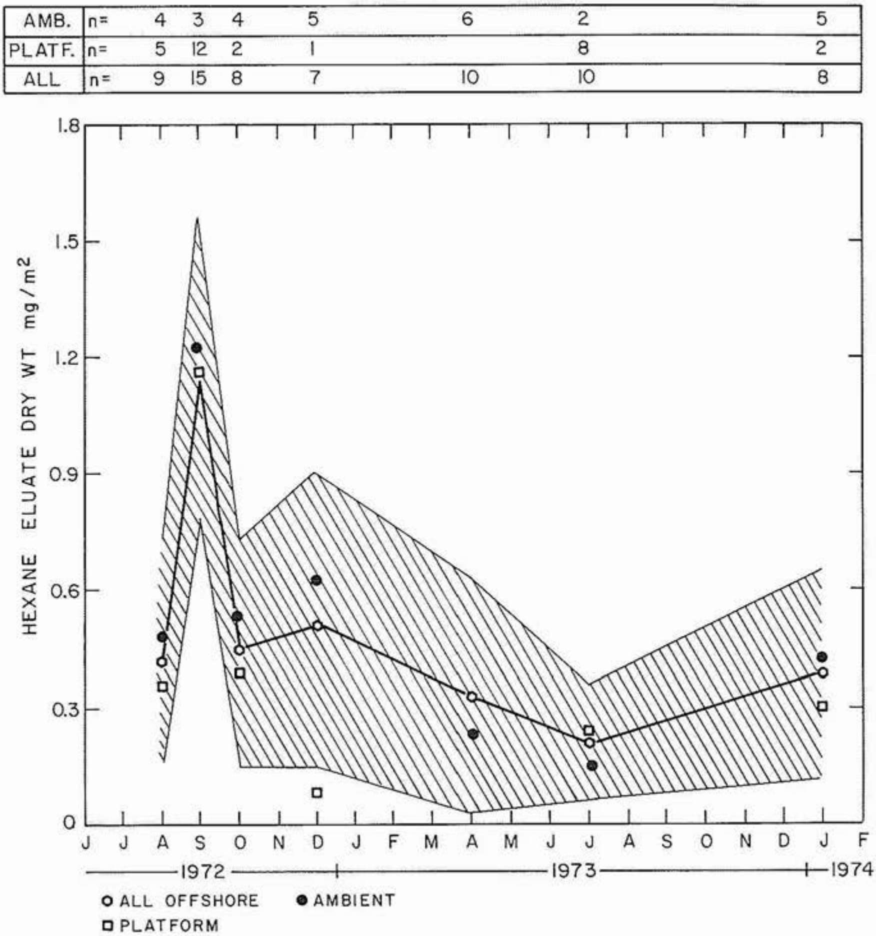


FIG. 20. SEASONAL VARIABILITY OF HEXANE ELUATE FROM SURFACE WATER SAMPLES OFFSHORE.

these figures is the mean of all data within a range of 2,501 to 12,500 m from 54A, spanning an azimuth of 360 degrees. The number of observations in each mean is given at the top of each figure. Again, the platform would be expected to have higher concentrations of the various hydrocarbon eluates if it were a significant point source of hydrocarbon-containing effluents. This does not seem to be the case, since the ambient means are frequently higher than the means for the platform.

Although the concentrations of TOC, BOD, and hydrocarbons do not appear to differ between platform and ambient sites, the ternary diagrams in figures 23 and 24 suggest that relative amounts of types of

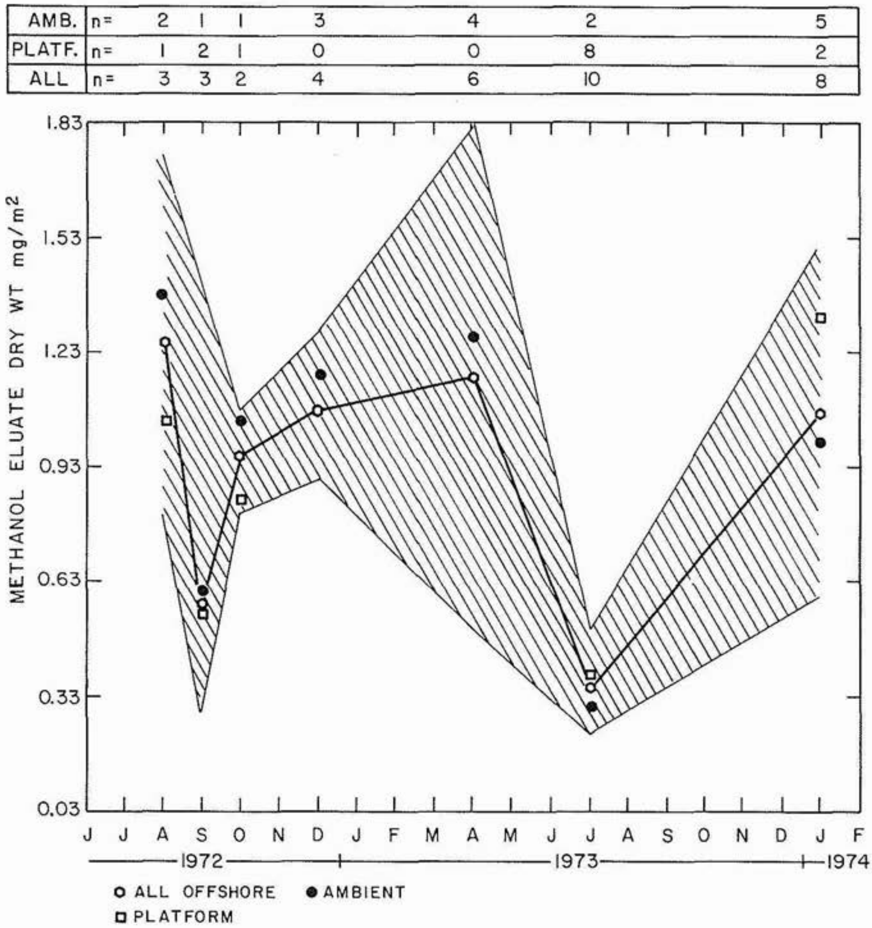


FIG. 21. SEASONAL VARIABILITY OF METHANOL ELUATE FROM SURFACE WATER SAMPLES OFFSHORE.

hydrocarbons in the air/sea interface and in sediments may differ between platform and ambient sites. The arrows in figure 23 (p. 62) indicate how to read a ternary diagram. "Platform" represents all data of all samples collected within a range of 0 to 2,500 m from 54A, spanning an azimuth of 360 degrees, which includes platform 66D. "Ambient" represents all data within a range of 2,501 to 12,500 m from 54A, spanning an azimuth of 360 degrees. The platform data tend to cluster and, with two notable exceptions, have the highest levels of benzene eluates (aromatics). Since aromatics usually disappear most rapidly with weathering of oil,

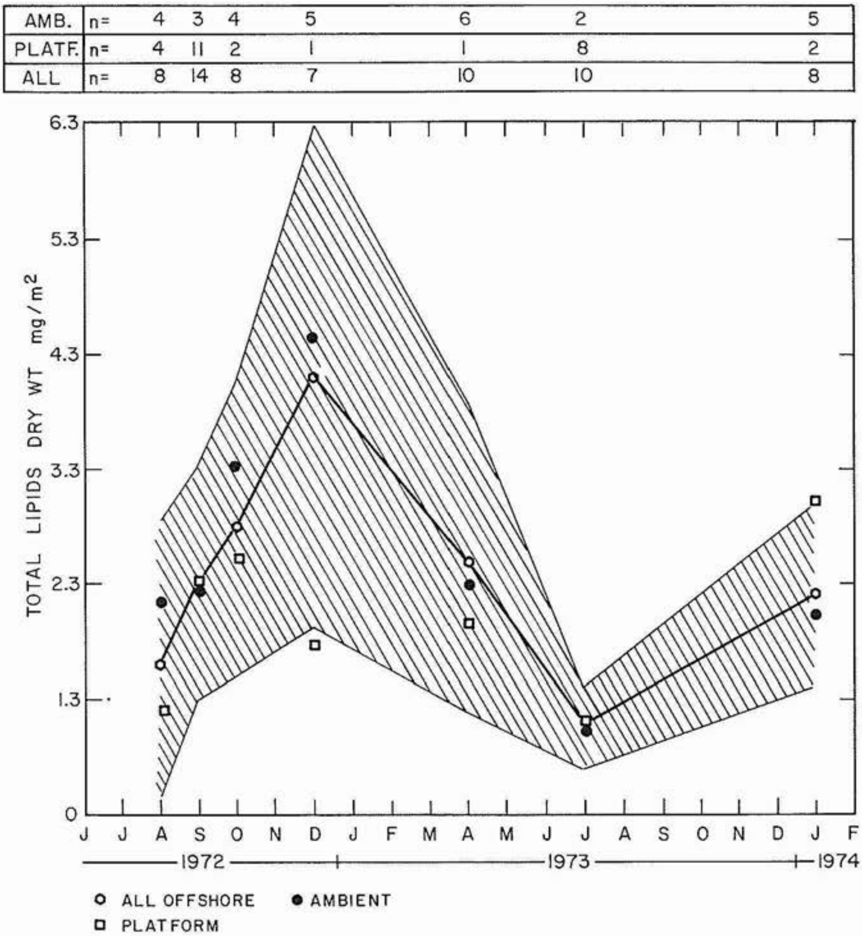


FIG. 22. SEASONAL VARIABILITY OF TOTAL LIPIDS FROM SURFACE WATER SAMPLES OFFSHORE.

this analysis suggests that the platform may be the source of fresh petroleum.

Figure 24 (p. 63) indicates that aromatic hydrocarbons do not tend to accumulate in sediments offshore, perhaps because they rapidly disappear during weathering of oil. The two samples within 750 m of 54A had the highest aromatic content. There were no samples taken within 750 m of platform 66D. All platform samples were taken within 2,500 m of 54A and ambient samples within the range of 2,501 to 12,500 m.

Data in figure 25 (p. 64) indicate that petroleum hydrocarbons present

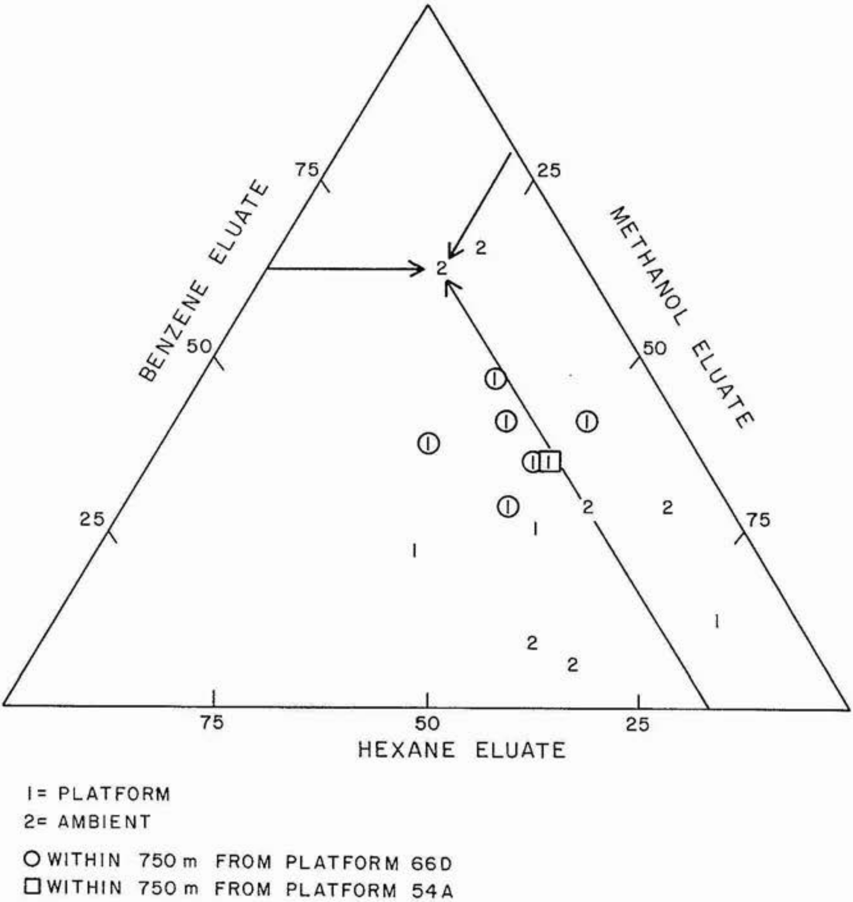


FIG. 23. TERNARY DIAGRAM OF HEXANE, BENZENE, AND METHANOL ELUATES OF SURFACE WATER SAMPLES AT PLATFORM AND AMBIENT STATIONS OFFSHORE.

in sediments are more weathered (have lower aromatic content) than those present in air/sea interface and beach samples. This diagram presents all the hydrocarbon data for all of the cruises.

In summary, we do not feel that the OEI data quantitatively demonstrate that platforms are significant sources of TOC, BOD, or hydrocarbons; on the other hand, display of the data in ternary diagrams suggests that platforms are sources of unweathered oil. The OEI data are inadequately replicated to support rigorous statistical treatment of platform versus ambient comparisons even with the redefinition of control sites.

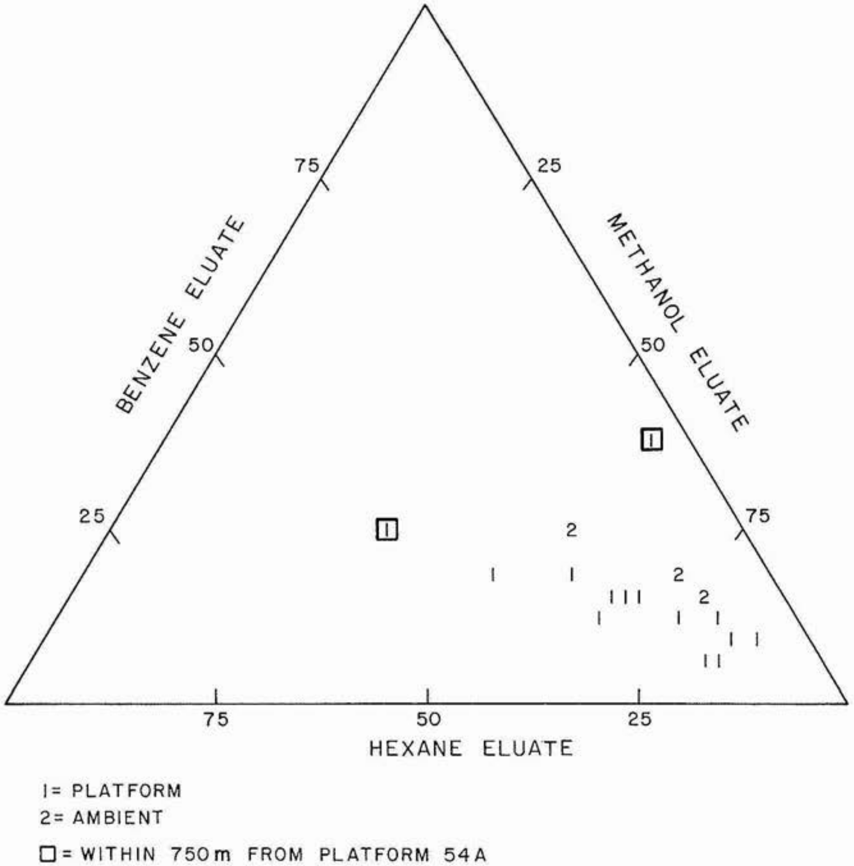


FIG. 24. TERNARY DIAGRAM OF HEXANE, BENZENE, AND METHANOL ELUATES OF SEDIMENT SAMPLES AT PLATFORM AND AMBIENT STATIONS OFFSHORE.

Timbalier Bay—Tables 6 and 7 present data for eight water quality parameters for production, workover, and ambient sites in Timbalier Bay. Data for zinc, lead, and cadmium were taken only during the first two sampling exercises. Significant differences between production or workover sites and ambient sites were determined by "t" tests.

The significant differences observed between PB1 and ambient sites and between PB2 and ambient sites are difficult to interpret without detailed analyses of flow patterns from inner to outer bay and influences from Mississippi River flow. This is illustrated for dissolved silica, orthophosphate, ammonia nitrogen, and nitrate-nitrite nitrogen during the

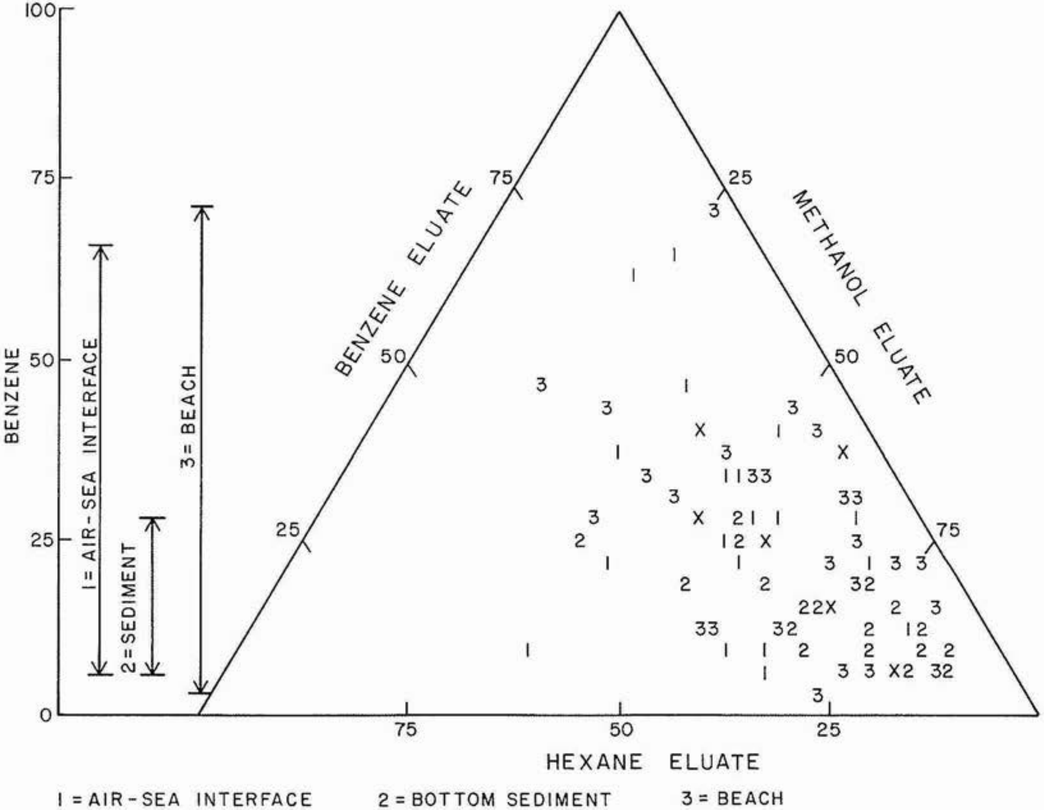


FIG. 25. TERNARY DIAGRAM OF HEXANE, BENZENE, AND METHANOL ELUATES OF ALL SAMPLES TAKEN FOR HYDROCARBON ANALYSIS.

TABLE 6. "t" test comparisons of metals concentrations in water samples taken at production, workover, and ambient sites in Timbalier Bay. (Values reported are before square root transformation.)

		Zn (ppb)			Pb (ppb)			Cd (ppb)		
Date	Station	x	s	n	x	s	n	x	s	n
Exercise 1	PB-1	8.8	14.1	15	2.1	1.9	15	0.2	0.0	15
1972 Sept.	PB-2	-	-	0	-	-	0	-	-	0
	Amb.	7.8	5.1	5	1.2	0.2	5	0.2	0.0	5
Exercise 2	PB-1	10.8	6.3	11	4.5	3.9	11	0.2	0.1	11
1972 Oct.	PB-2	10.3	6.2	17	6.9	9.8	17	0.5	0.5	17
	Amb.	11.1	7.3	30	6.6	18.5	30	0.8	1.8	30

Data were square root transformed before "t" test.
PB-1 = Production platform site: 750m x 750m area; PB-2 = Workover site: 750m x 750m area; Amb. = Ambient: rest of the Bay.

July sampling exercise, which coincided with the 100-year flood of the Mississippi River. When different, these variables were significantly lower in the inner bay from the generally distributed ambient stations. This pattern could indicate transport of nutrients from the Mississippi or enhanced flow of fresh water into the inner bay. Significant differences in organic carbon at PB1 or PB2 from the ambient stations generally reflect the gradient of organic carbon from inner to outer bay (see figure 30, p. 71). The significant difference indicated for nitrate-nitrite nitrogen during the January 1974 exercise appears impossible but resulted from the use of square root-transformed data.

Bay-Offshore Transect

The OEI included samples collected along a transect ranging from the inner part of Timbalier Bay to the offshore production and drilling platforms. Figure 26 illustrates the 13 sectors sampled during eight sampling exercises.

Figures 27 through 32 (pp. 68-73) present data for 14 water column and two sediment parameters. Water column data are means of all measurements made during all of the exercises averaged over depth. Sediment data for total phosphate and total nitrogen are averaged over all exercises. Shaded areas are one standard deviation from the means.

Salinity increases steadily from inner bay to offshore, transmissivity decreases markedly immediately outside the bay, perhaps because of littoral currents, and temperature appears to fluctuate more in the bay than offshore (figure 27). Sediment phosphate appears to be higher in the vicinity of the offshore platforms and total nitrogen decreases steadily from inner to outer bay (figure 28). Water column orthophosphate, ammonia nitrogen, and nitrate-nitrite nitrogen appear to have no definite pattern from inner bay to offshore (figure 29). Organic carbon and BOD decrease rapidly from inner bay to outer bay, but COD does not appear

TABLE 7. "t" test comparisons of water quality parameters at production, workover, and ambient sites in Timbalier Bay. (Values reported are before square root transformation.)

Date	Station	TOC[1] (mg/l)			Diss. Silica (mg/l)			$O\text{-}PO_4$ (μg/l)			NH_3-N (mg/l)			NO_3+NO_2 (mg/l)		
		$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
Exercise 1	PB-1	15.0	0.5	2	1.3	0.2	18	52.8	62.1	18	0.1	0.3	18	0.3	0.4	18
1972 Sept.	PB-2	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0
	Amb.	12.5	2.5	10	1.2	0.2	8	36.0	36.8	8	0.0	0.0	8	0.6	1.4	8
Exercise 2	PB-1	-	-	0	2.0	0.5	18	169.7*	119.8	18	0.1	0.2	18	0.0	0.1	18
1972 Oct.	PB-2	7.0	4.3	12	1.4*	0.5	18	476.3	390.8	18	0.0**	0.0	18	0.0	0.1	18
	Amb.	7.3	4.0	2	2.0	0.8	14	400.3	305.8	14	0.1	0.1	14	0.1	0.1	14
Exercise 3	PB-1	14.0	1.4	2	0.1	0.0	18	133.3	137.4	18	1.2	2.3	18	5.8	8.0	18
1972 Nov.-Dec.	PB-2	7.4*	0.3	4	0.6	0.5	6	112.5	28.0	6	1.9	2.9	5	25.9	25.9	5
	Amb.	13.8	1.5	11	0.3	0.3	10	125.0	60.2	10	0.3	0.4	10	17.6	26.2	10
Exercise 4	PB-1	13.9*	4.4	13	0.2	0.2	24	111.2	28.4	24	5.9	11.1	24	10.1	19.9	24
1973 Jan.-Feb.	PB-2	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0
	Amb.	9.0	5.9	13	0.1	0.1	22	109.5	43.7	22	6.6	11.8	22	7.7	14.9	22
Exercise 5	PB-1	21.5	0.0	1	0.7	0.3	18	102.8*	53.1	18	0.1*	0.0	18	0.1	0.1	18
1973 Apr.	PB-2	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0
	Amb.	6.7	2.8	7	0.9	0.4	24	145.5	81.6	24	0.2	0.2	24	0.1	0.2	24
Exercise 6	PB-1	-	-	0	1.0**	0.3	28	24.4**	40.5	28	0.4**	0.1	28	0.3**	0.1	28
1973 July	PB-2	-	-	0	1.6**	0.1	8	92.9	23.3	8	0.7**	0.1	8	0.4	0.1	8
	Amb.	-	-	0	1.3	0.5	62	82.7	44.3	62	0.6	0.1	62	0.8	1.0	62
Exercise 7	PB-1	14.2	3.3	4	2.2*	0.4	30	89.4	52.0	30	0.3	0.1	30	0.1	0.0	30
1973 Oct.	PB-2	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0
	Amb.	12.4	2.2	3	2.0	0.6	51	77.1	24.8	50	0.4	0.1	50	0.1	0.1	50
Exercise 8	PB-1	9.2	5.0	12	0.6	0.1	26	88.8	49.2	26	0.6**	0.2	26	0.1**	0.1	26
1974 Jan.	PB-2	5.5*	1.5	9	0.9**	0.2	18	98.9	37.9	18	0.5**	0.1	18	0.1	0.1	18
	Amb.	9.9	3.6	24	0.7	0.3	50	90.8	33.8	50	0.7	0.2	50	0.1	0.1	50

Data were square root transformed before "t" test.
* significant at 0.05 level.
** significant at 0.01 level.
1) data not normally distributed even when square root transformed. Chi-square used to test significance.
PB-1 = Production platform site: 750m x 750m area; PB-2 = Workover site: 750m x 750m area;
Amb. = Ambient: rest of the Bay.

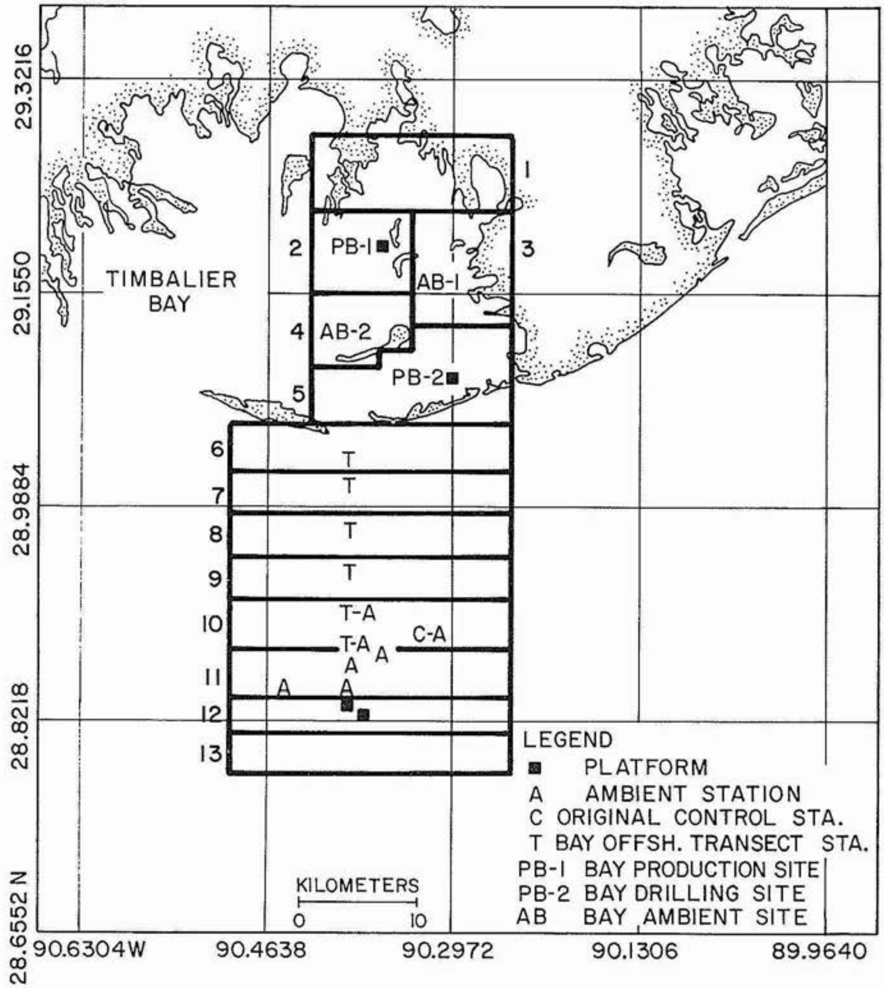


FIG. 26. SECTORS SAMPLED IN BAY-OFFSHORE TRANSECT (see figs. 27 through 32).

to be strongly related to position on the transect. Mercury appears to increase somewhat offshore, while zinc, cadmium, and lead decrease (figures 31 and 32). Lead concentrations are surprisingly high and variable at the mouth of the bay (figure 32).

With the possible exception of sediment phosphate near the offshore platform, the transect data do not demonstrate the platforms under study in the OEI to be possible sources of chronic low level discharges of pollutants.

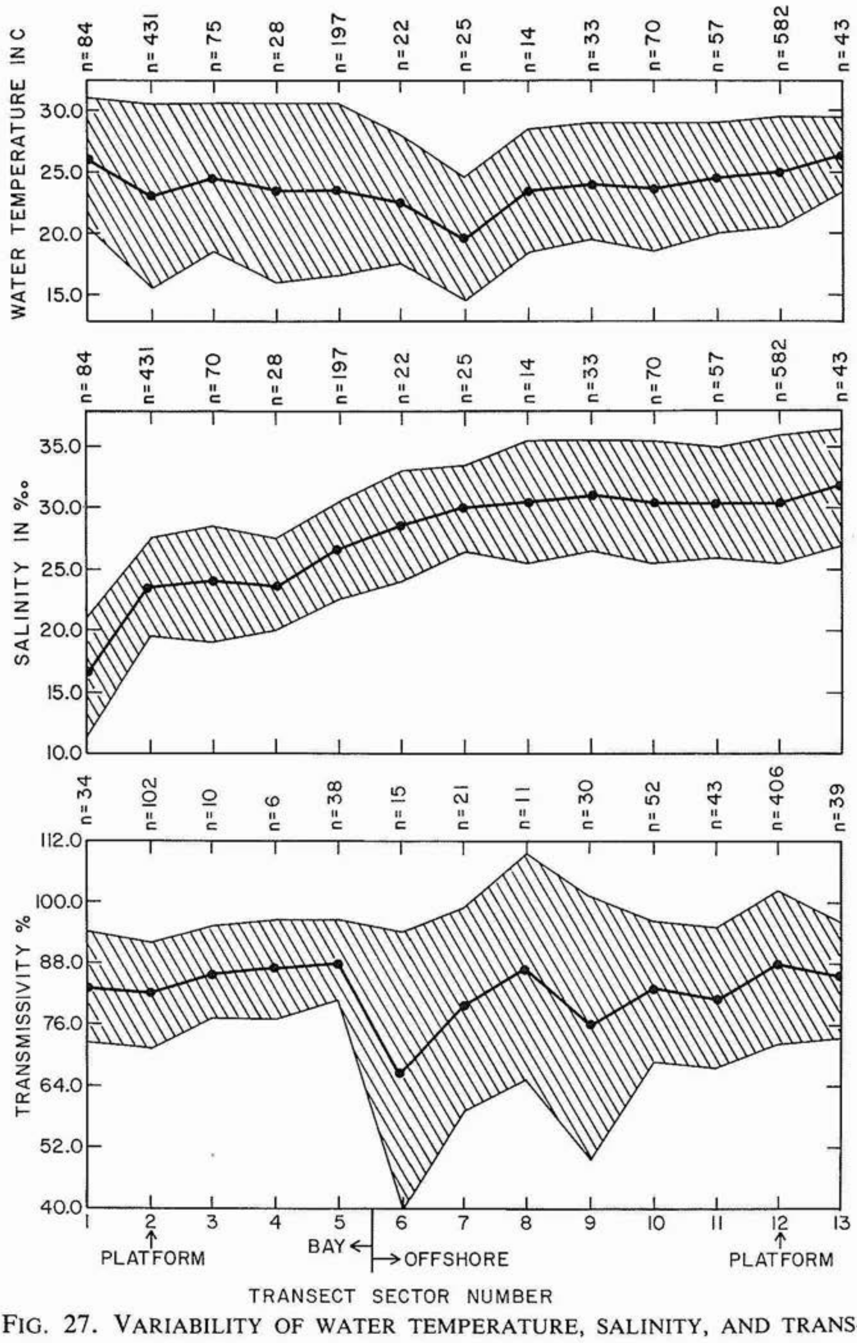


FIG. 27. VARIABILITY OF WATER TEMPERATURE, SALINITY, AND TRANSMISSIVITY FROM INNER BAY TO OFFSHORE.

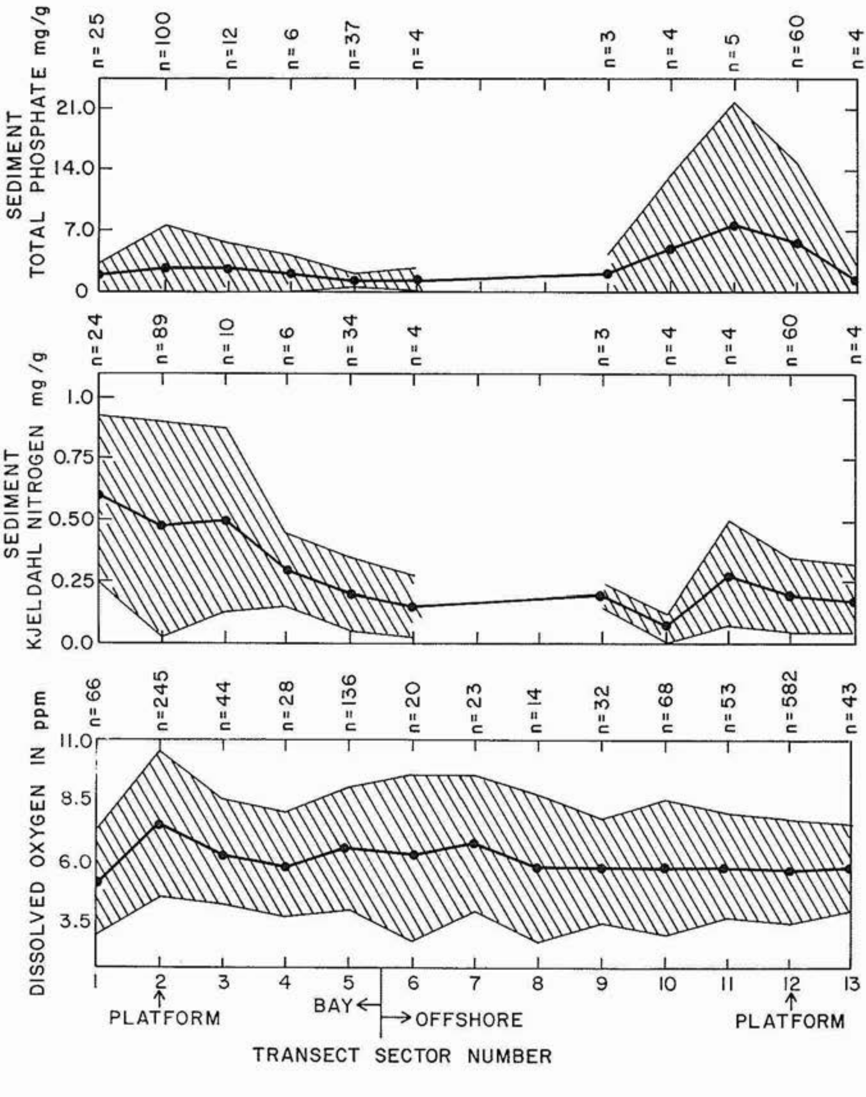


FIG. 28. VARIABILITY OF SEDIMENT PHOSPHATE AND NITROGEN AND DISSOLVED OXYGEN IN THE WATER COLUMN FROM INNER BAY TO OFFSHORE.

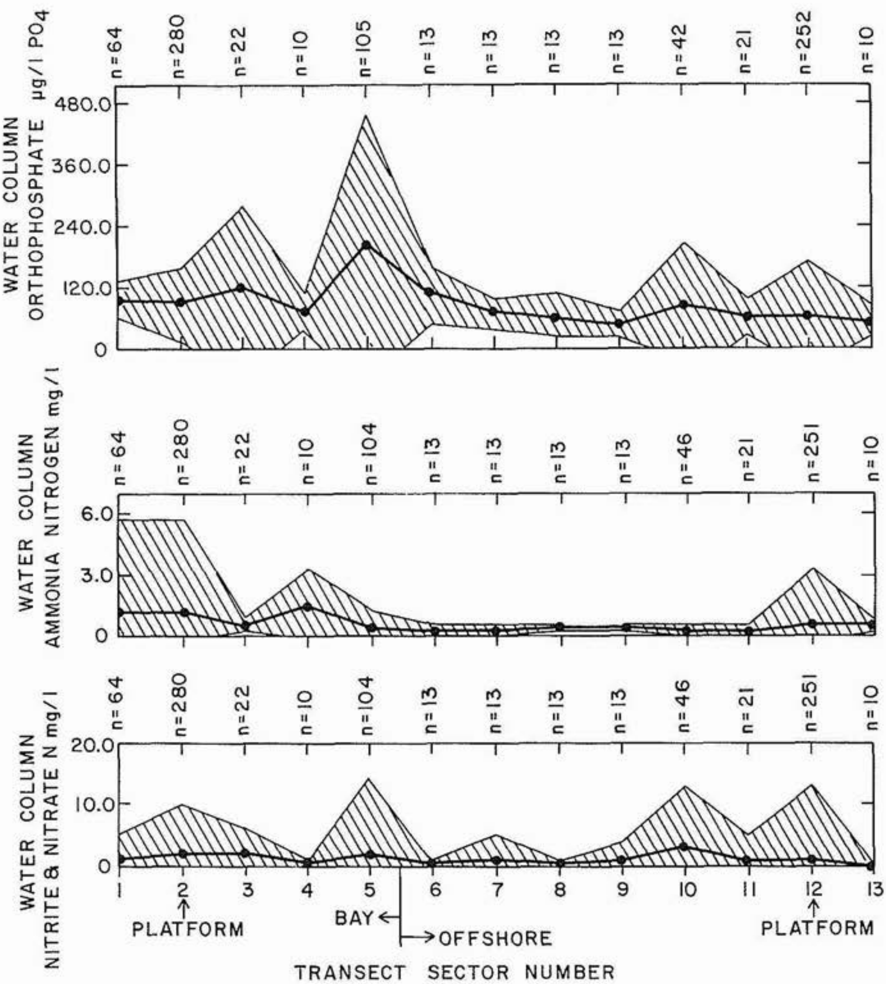


FIG. 29. VARIABILITY OF PHOSPHATE, AMMONIA NITROGEN, AND NITRITE-NITRATE NITROGEN IN THE WATER COLUMN FROM INNER BAY TO OFFSHORE.

Benthic biology

The benthic biology program of the OEI in 1972-1974 consisted of separate investigations in the following disciplines: Timbalier Bay —polychaetous annelids (Kritzler 1974; Fish et al. 1974), molluscs and crustaceans (Perry 1974; George 1974; Farrell 1974a), fish (Perry 1974), foraminifera (Ostrom 1974; Fish et al. 1974), and algae (Humm 1974).

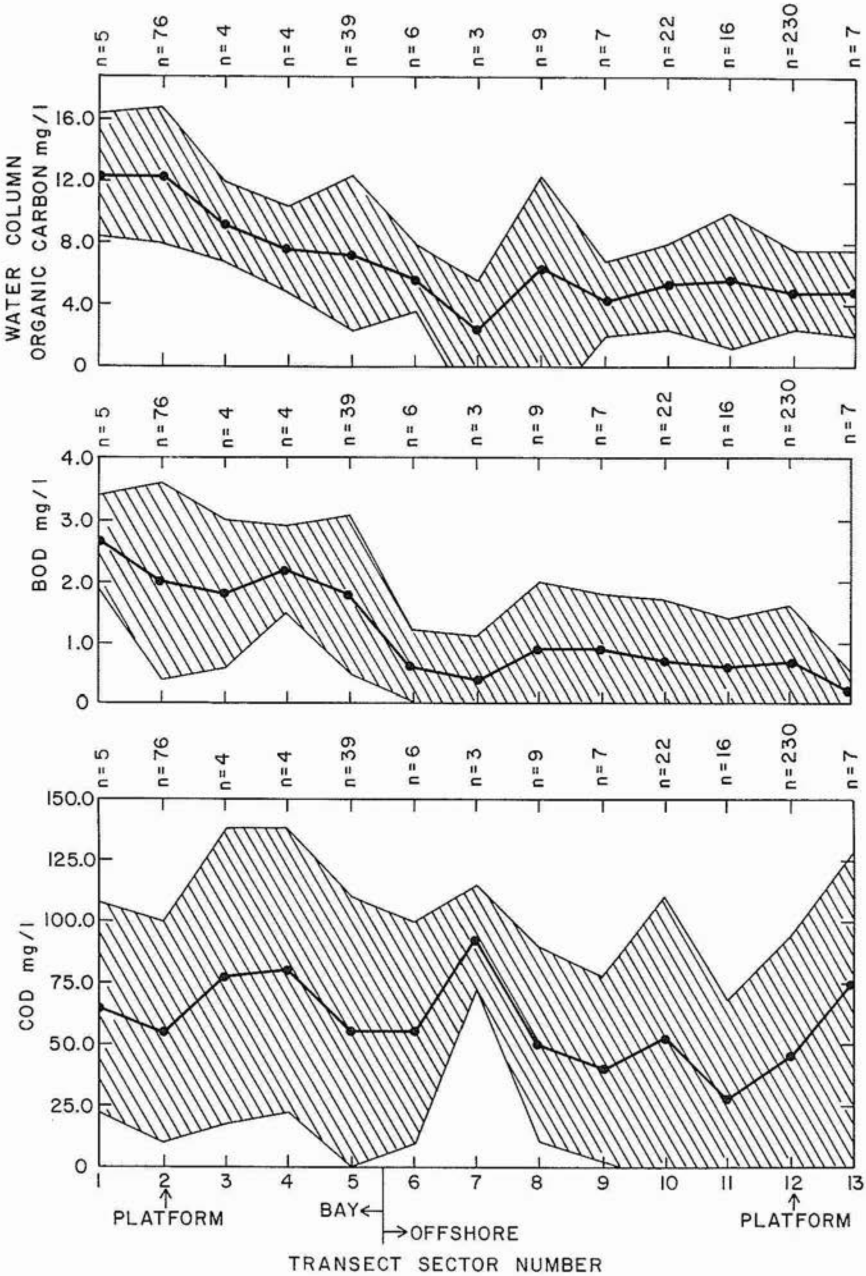


FIG. 30. VARIABILITY OF ORGANIC CARBON, BOD, AND COD IN THE WATER COLUMN FROM INNER BAY TO OFFSHORE.

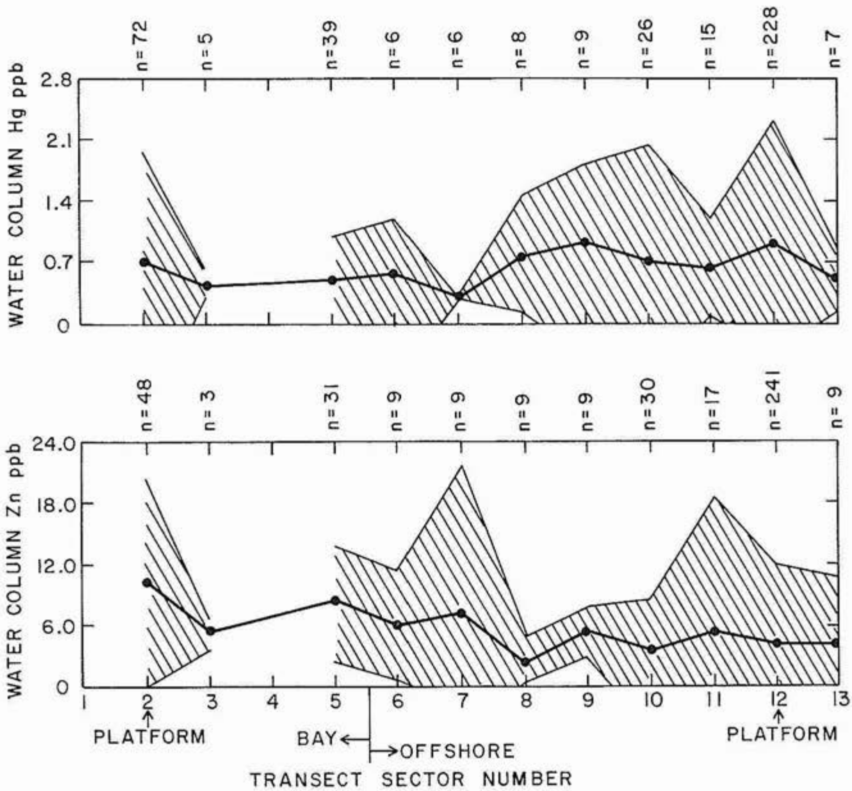


FIG. 31. VARIABILITY OF MERCURY AND ZINC IN THE WATER COLUMN FROM INNER BAY TO OFFSHORE.

Offshore biological data consisted of molluscs and crustaceans (Waller 1974; Farrell 1974b), fish (Perry 1974), algae (Humm 1974), and fouling organisms (George and Thomas 1974). Because of the varied methods of data collection used in these studies, it was not possible to analyze quantitatively all the data generated by these investigations. It was only possible to analyze the polychaete, mollusc, and crustacean data with computer-assisted programs. Because of the importance of certain other organisms to the understanding of environmental changes, however, some salient points dealing with the benthic foraminifera, algae, and fouling organisms will be discussed here.

Benthic organisms, especially infaunal species, have been considered useful in assessing environmental conditions because they have been

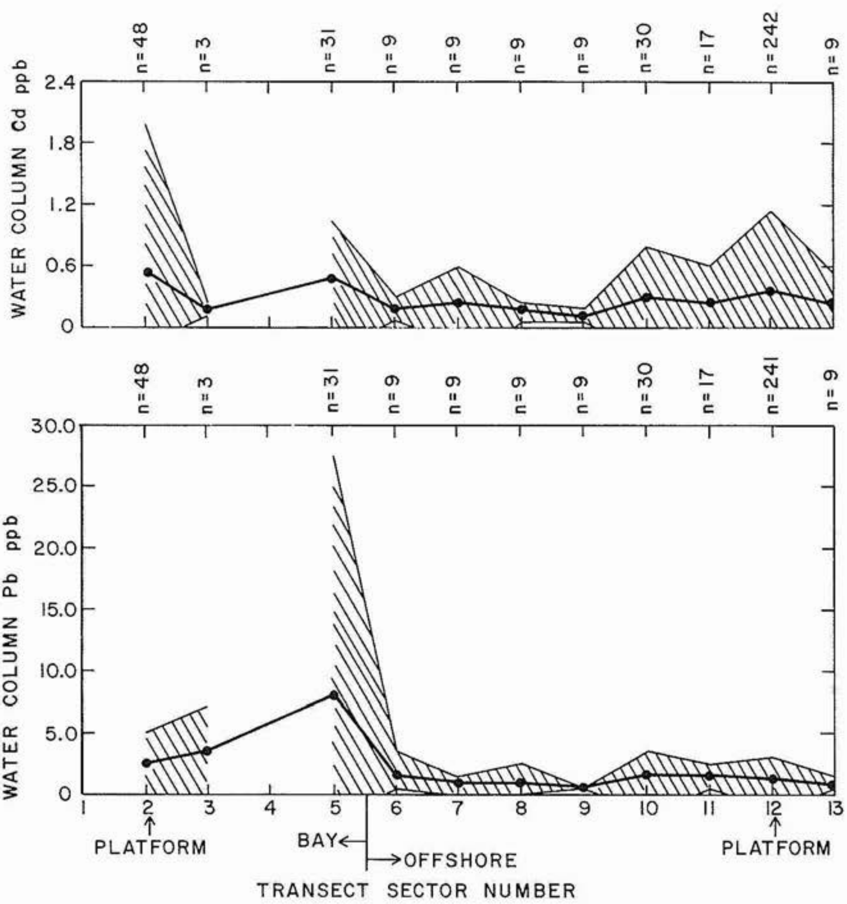


FIG. 32. VARIABILITY OF CADMIUM AND LEAD IN THE WATER COLUMN FROM INNER BAY TO OFFSHORE.

subjected to a possible contaminant not only at the time of sampling but for some time previously (Reish 1973). In contrast, pelagic organisms may have entered the particular area just prior to capture and may not have been previously exposed to the contaminant. Polychaetes, molluscs, and crustaceans are the most abundant groups of macroinvertebrates in the marine benthos; they constitute approximately 90% of the species and specimens present within a benthic sample (Jones 1969). It is therefore imperative to include the identification of these groups of species in the assessment of the environmental condition of any marine area. Since a large amount of data on these benthic groups in Timbalier Bay was generated but not synthesized, it was apparent that this appraisal should include a synthesis of the polychaete, mollusc, and crustacean occurrences and distributions. No previous studies dealing with the benthic polychaetes, molluscs, and crustaceans within the OEI study area had been undertaken.

Timbalier Bay Macroinvertebrates

Data Base—Polychaetes were collected five times at four stations during 1973. Samples were taken with a plastic tube, which sampled an area of 625 cm^2 to a depth of 10 m. The sampler was connected to an air hose, which lifted the material into the boat, where it was washed through a 0.5 mm mesh sieve; the material retained on the sieve was preserved (Kritzler et al. 1974). Sixteen replicates were taken at each station, giving a total surface area of 1 m^2. Two stations were located near oil operations (production PB1 and drilling PB2), and two were located as far as possible from such activity to represent natural environmental conditions (AB1 and AB2) (table 8, figure 33). The data from the winter, spring, and summer collections were coincident in time and space with mollusc and crustacean data.

Molluscs and crustaceans were taken with a Van Veen grab, which sampled an area of 2000 cm^2 to a depth of 10 cm at seven stations within Timbalier Bay. Collections were taken during winter, spring, and summer in 1973. Since one of the stations was located in the Little Lake area, which was far from any polychaete sampling station, the data generated at that locality were not included in these analyses (table 8, figure 33). Samples were washed through a 0.5 mm mesh sieve and preserved. Since the Van Veen sampled an area of 0.2 m^2, the data, for a number of specimens collected, was multiplied by five in order to coincide with the total surface area sampled for polychaetes.

Methods of Analysis—The combined data for polychaetes, molluscs, and crustaceans were grouped according to the two platforms and two ambient stations (table 8, figure 33) for the winter, spring, and summer collections. The data were analyzed for species diversity (Shannon and Weaver 1963) and faunal affinities (Morisita 1959; Ono 1961), and the stations were grouped by cluster analysis.

The cluster analysis program in this study was the Bray-Curtis similarity coefficient and group average sorting (Boesch 1977). The similarity (or dissimilarity) coefficient can be expressed as:

$$D_{jk} = \frac{i\ (x_{ij} - x_{ik})}{I\ (s_{ij} + x_{ik})}$$

TABLE 8. Corresponding station locations for analyses of polychaete, mollusc, and crustacean data, Timbalier Bay, 1973.

Sampling Site	Combined Station Number	Polychaete Stations			Mollusc-Crustacean Stations		
		Number	Latitude	Longitude	Number	Latitude	Longitude
Production Platform	PB-1	PBO3	29°11.90'	90°21.50'	7	29°11.47'	90°21.62'
					9	29°11.88'	90°21.43'
Ambient	AB-1	BCO2	29°09.50'	90°18.30'	12	29°09.70'	90°17.50'
Ambient	AB-2	BPO1	29°07.79'	90°24.16'	6	29°07.59'	90°23.96'
Drilling Platform	PB-2	GF13	29°04.93'	90°19.13'	3	29°03.72'	90°21.26'
					4	29°04.16'	90°23.35'

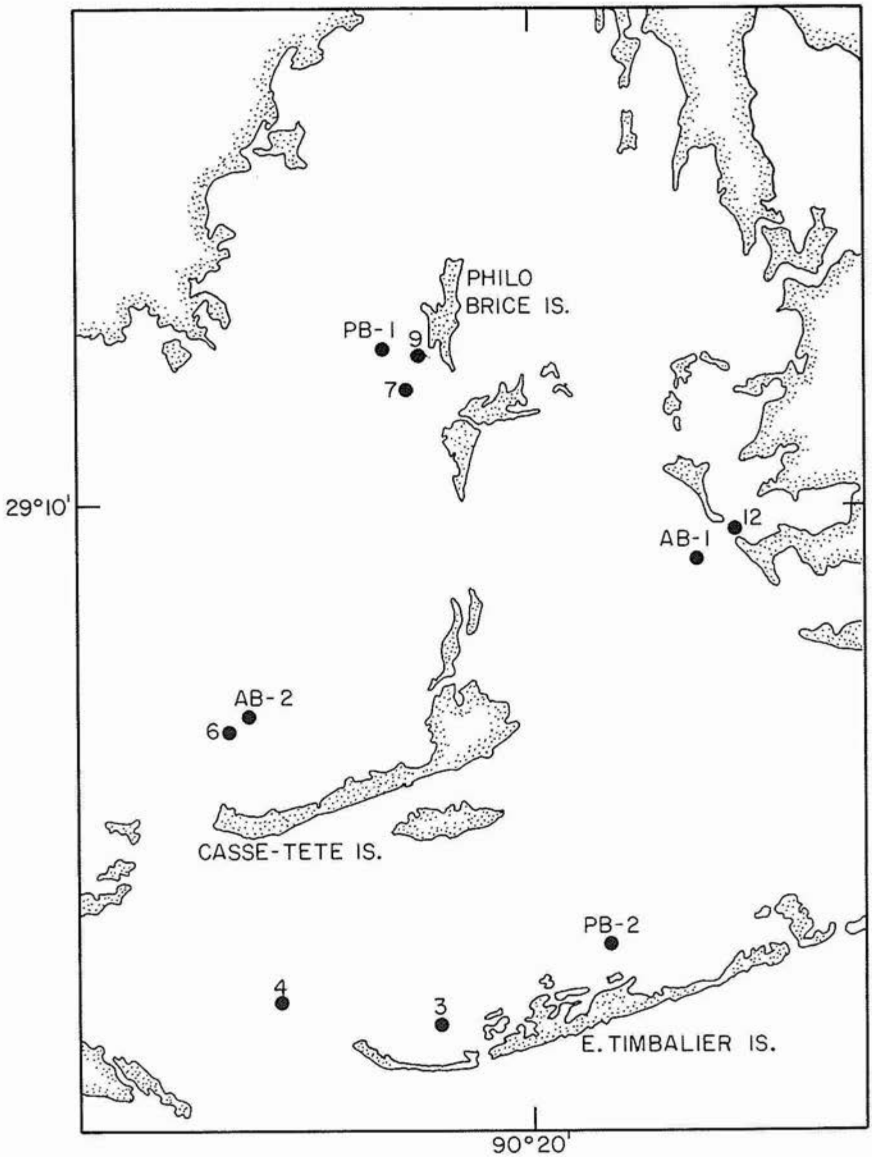


FIG. 33. BENTHIC SAMPLING STATIONS IN TIMBALIER BAY.

where D_{jk} is the distance between entities j and k; x_{ij} and x_{ik} are the values of attribute i in entities j and k, respectively. The group averaging sorting strategy was used to form the dendrogram for each of the four stations for the three collecting periods. In the clustering used herein, the numbered value ranges from 0 to 1 with the 0 indicating complete similarity and 1 indicating complete dissimilarity. The calculations are made with the aid of a computer-assisted program and are then summarized graphically in a dendrogram. Species that were encountered only five or fewer times in the entire study were excluded from this analysis.

Results—The data on benthic fauna were classified according to the Shannon-Weaver index of species deversity (H ′) and are summarized in table 9. Because of the dominance of the polychaete *Spiochaetopterus oculatus*, the indices are given with and without the data for this species. The H ′ is also given with the mollusc and crustacean data multiplied by five, with and without the *Spiochaetopterus* data. H ′ ranged from 0.79 to 3.94 when the data for *Spiochaetopterus* were included. Two groups of H ′ values were noted; one varied from 3.40 to 3.94 at the production station PB1 and ambient station PB2, and the other varied from 0.79 to 1.40 at the ambient station AB1 and the drilling station PB2. When the number of specimens of molluscs and crustaceans was multiplied by five, the H ′ index ranged from 0.80 to 4.12; the separation of the two groups of stations was evident but not as marked. Exclusion of the *Spiochaetopterus* data altered the H ′ index. It ranged from 3.17 to 4.42 when the mollusc-crustacean data were not multiplied by a factor of five and from 2.50 to 4.31 when they were. The dominance of *Spiochaetopterus* at these stations within Timbalier Bay is apparent from table 9. The H ′ values of ambient station AB1 and drilling site PB2 are influenced by the large quantity of this species at these two sites in comparison to the other two. No relationship between the H ′ value and the season of collection is apparent from these data.

The Morisita-Ono index of faunal similarity (λ) among the four groups of stations is summarized according to the period of collection and the composition of the data in figures 34 and 35. Indices of similarity were calculated utilizing four different data sets, as was done for the Shannon-Weaver index. The occurrence of the dominant species by station, by data, by total number of specimens, and by percentage of occurrence is included in table 10 (p. 82).

The index of similarity varies from 0.28 to 0.99 when the *Spiochaetopterus* data are included in the analyses, and from 0.13 to 0.87 when the data for this polychaete are excluded. The greatest similarity is noted for all three collecting periods between the ambient station AB1 and the drilling station PB2 when the *Spiochaetopterus* data

TABLE 9. Species Diversity of Polychaetes, Crustaceans, and Molluscs in Timbalier Bay, 1973.

(Shannon-Weaver H')

Winter 1973							
Station Number	Number of Species	Number of Specimens	No. of Specimens excluding Spiochaetopterus	H'	H' excluding Spiochaetopterus	H' X 5 Mollusc and Crustacea	H' excluding Spiochaetopterus and X 5 Mollusc and Crustacea
Production Platform PB-1	30	361	248	3.45	3.72	2.99	2.83
Drilling Platform PB-2	40	21.1	259	1.04	4.20	1.46	3.28
Ambient AB-1	42	4670	460	0.79	3.39	0.80	3.42
AB-2	39	486	416	3.40	3.28	3.33	3.18

Spring 1973							
Station Number	Number of Species	Number of Specimens	No. of Specimens excluding Spiochetopterus	H'	H' excluding Spiochaetopterus	H' X 5 Mollusc and Crustacea	H' excluding Spiochaetopterus and X 5 Mollusc and Crustacea
Production Platform							
PB-1	34	709	501	3.58	3.83	3.65	3.85
Drilling Platform							
PB-2	56	3954	671	1.40	4.42	2.60	3.93
Ambient							
AB-1	35	4961	645	0.96	3.17	1.06	3.26
AB-2	39	344	288	3.74	3.71	2.68	2.50

Summer 1973							
Station Number	Number of Species	Number of Specimens	No. of Specimens excluding Spiochaetopterus	H'	H' excluding Spiochaetopterus	H' X 5 Mollusc and Crustacea	H' excluding Spiochaetopterus and X 5 Mollusc and Crustacea
Production Platform							
PB-1	25	515	401	3.47	3.47	3.53	3.54
Drilling Platform							
PB-2	28	1993	285	1.07	3.41	1.50	2.59
Ambient							
AB-1	36	3133	580	1.30	3.30	1.31	3.33
AB-2	41	333	254	3.94	4.13	4.12	4.31

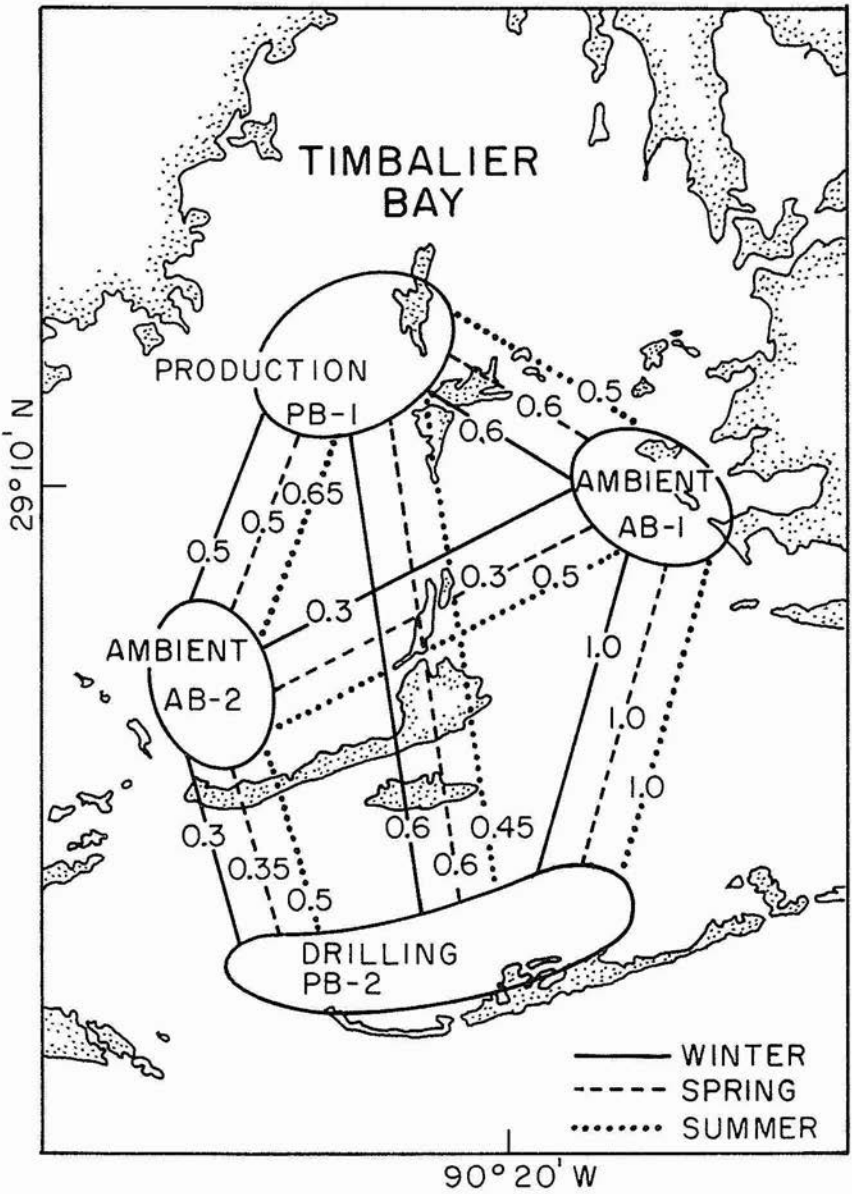


FIG. 34. DIAGRAMMATIC REPRESENTATION OF THE MORISITA-ONO INDEX OF FAUNAL SIMILARITY IN TIMBALIER BAY (from Bender et al. 1979; Copyright, Offshore Technology Conference, 1979; reproduced by permission).

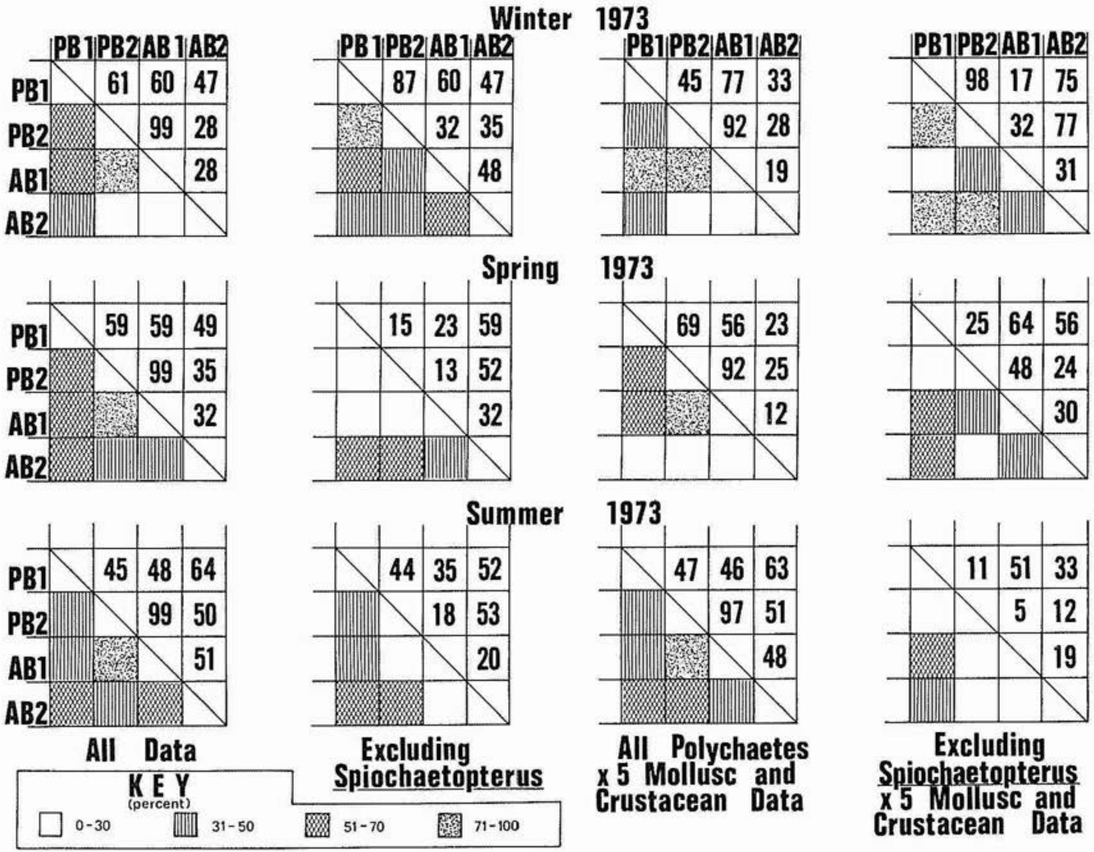


FIG. 35. TRELLIS REPRESENTATION OF THE MORISITA-ONO INDEX OF FAUNAL SIMILARITY (× 100) IN TIMBALIER BAY.

TABLE 10. Dominant species of benthic invertebrates as measured by percent occurrence, Timbalier Bay, 1973.

Species[1]	PB-1 W	PB-1 Sp	PB-1 Sum	AB-1 W	AB-1 Sp	AB-1 Sum	AB-2 W	AB-2 Sp	AB-2 Sum	PB-2 W	PB-2 Sp	PB-2 Sum	Total Number of Specimens	Percent Occurrence
Spiochaetopterus oculatus	X	X	X	X	X	X	X	X	X	X	X	X	19,502	100
Paraeurythoe americana	X	X	X	X	X	X	X	X	X	X	X	X	604	100
Lumbrineris parvapedata	X	X	X	X	X	X	X	X	X	X	X	X	447	100
L. bassi	X	X	X	X	X	X	X	X	X	X	X	X	259	100
Glycinde polygnatha	X	X	X	X	X	X	X	X	X	X	X	X	153	100
Harmothoe trimaculata	X	X	X	X	X	X	X	X	X	X	X		670	92
Heteromastus filiformis	X	X	X	X	X	X		X	X	X	X	X	181	92
Notomastus latericeus	X	X		X	X	X	X	X	X	X	X	X	145	92
Magelona cincta		X	X	X	X	X	X	X	X	X	X	X	61	92
Sigambra tentaculata	X	X	X	X	X	X	X	X	X		X	X	43	92
Gyptis capensis	X	X	X	X	X		X	X	X	X	X	X	34	92
Prionospio sexoculata	X	X	X		X	X		X	X	X	X	X	243	83
Euclymene sp.	X	X	X	X	X	X	X		X	X	X		84	83
Polydora socialis	X	X		X	X	X	X	X	X		X	X	42	83
Myriochele bioculata	X	X	X	X	X		X	X	X	X			367	75
Mulinia lateralis	X[2]	X[2]			X		X	X	X	X[2]	X[2]	X[2]	299	75
Cossura hoodi	X	X	X	X	X	X	X	X	X				77	75
Aediciera pallida			X	X		X	X	X	X	X	X	X	44	75
Neanthes succinea			X	X		X	X	X	X	X	X	X	30	75
Paraprionospio pinnata	X	X	X	X	X	X			X			X	81	67
Ancistrosyllis hamata	X		X		X	X	X	X	X	X			15	67

1) All species are polychaetous annelids except for the pelecypod *Mulinia lateralis*.
2) Data included for two stations in the vicinity.

TABLE 11. Principal living foraminifera species of Timbalier Bay, 1973.

Species	Intertidal Mud	Intertidal Sand	Intertidal All Substrates	Subtidal
Ammoastuta inepta	X			
Ammonia b. var. *parkinsoniana*			X	X
A. b. var. *tepida*			X	X
Ammotium dilatatum	X			
A. salsum	X			X
Arenoparella mexicana	X			
Bolivina striatula				X
Elphidium gunteri			X	X
E. matagordanum		X		X
E. poeyanum		X		X
E. vadescens				X
Haplophragmoides manilaensis	X			
H. wilberti	X			
Nonionella atlantica		X		
N. opima		X		
Palmerinella gardenislandensis				X
Quinqueloculina compta		X		
Q. funafutiensis		X		
Q. lamarckiana		X		
Q. rhodiensis		X		
Q. tenagos				X
Trochammina inflata	X			

are included. Regardless of which data are used in the analyses of index of similarity, the figure is less than 0.7 at least 75% of the time. While there were 11 species of polychaetes that were present in at least 90% of the collections (table 11), the dominance of *Spiochaetopterus* at all stations in all collections reduces the index values when data for this polychaete are excluded. For example, the high index of similarity between ambient station AB1 and drilling station PB2, which was essentially 1.0 at all three dates, dropped to between 0.18 and 0.32 when the data for *Spiochaetopterus* were excluded.

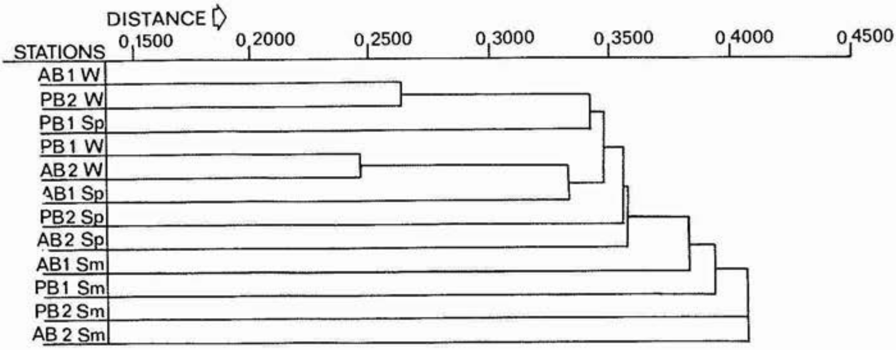


FIG. 36. DENDROGRAM FROM THE CLUSTER ANALYSIS OF BENTHIC BIOLOGICAL DATA FROM TIMBALIER BAY.

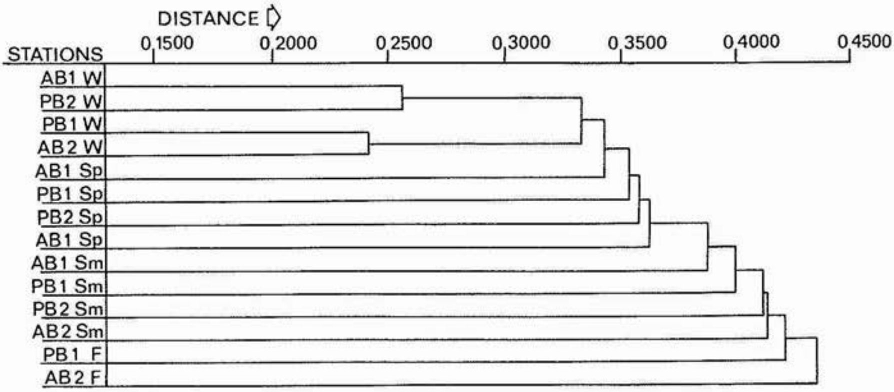


FIG. 37. DENDROGRAM FROM THE CLUSTER ANALYSIS OF THE POLYCHAETE BENTHIC DATA FROM TIMBALIER BAY.

The index of similarity does not seem to indicate any marked seasonal difference in the benthic populations. There is a slight indication of greater similarity between stations in summer than in winter. This can be noted particularly in the comparisons of ambient station AB1 with the other stations.

The benthic biological results in Timbalier Bay were subjected to cluster analysis using all polychaete, crustacean, and mollusc data (figure 36), and using all polychaete data (figure 37). The combined data included collections made in winter, spring, and summer 1973, and the polychaete data included collections made during the same seasons plus two samplings taken in fall 1973. With the combined data for the three animal groups, three distinct assemblages are noted, which coincided, in part, with the seasons (figure 36). The four summer stations fell out as a group. The four winter stations were grouped with two spring stations. The two remaining spring stations were together in one group. No benthic biological differences existed between the platform stations and the ambient stations when this method of analysis was used.

The dendrogram drawn from the polychaete data showed a separation of the stations according to the season (figure 37). The four winter collections were separated as a group with two subdivisions. The remaining 10 collections were grouped according to season but were added one-by-one in a step-wise cluster.

Sample Replication—In conducting his study of the polychaetes of Timbalier Bay, Kritzler (1974) made 16 replicates at each station during each collection period. Each replicate was processed separately, and the data were presented separately in individual reports. Although not all replicates and stations were analyzed, the data presented afford a unique opportunity to determine how many replicates one should take at a site to characterize that particular locality adequately. These data based on 14-16 replicates at 14 stations were plotted in figure 38 according to range, mean, and standard deviation for those polychaete species represented six or more times when the data from all replicates were combined. This latter exclusion of some data was based on the elimination of species with five or fewer specimens from cluster analysis (Boesch 1977).

It is apparent from both graphs in figure 38 that with each additional replicate, the ranges and standard deviations become less. It was necessary to take 10 replicates in order to gather 90% of the polychaete species present within an area, but when those species present fewer than six times were excluded, the 90% recovery was reached by the third replicate. Apart from the mathematical interpretation of these data, one must also consider the effort and money involved in sorting and identifying the organisms from the additional replicates. Each replicate requires essentially the same amount of time for identification and enumeration. Do we achieve, in this instance, over three times the amount of information for analyzing 10 samples rather than three? We think not. Since pelagic larvae are common in polychaetes, larval settlement can occur over wide areas, including those not necessarily within their optimum environment. Undoubtedly, we are encountering many such species within Timbalier Bay. Of the 82 species of polychaetes reported by Kritzler from Timbalier Bay, 39, or 48%, of the species encountered were represented by fewer than 6 specimens. Many of these species are more common offshore; but because of the absence of knowl-

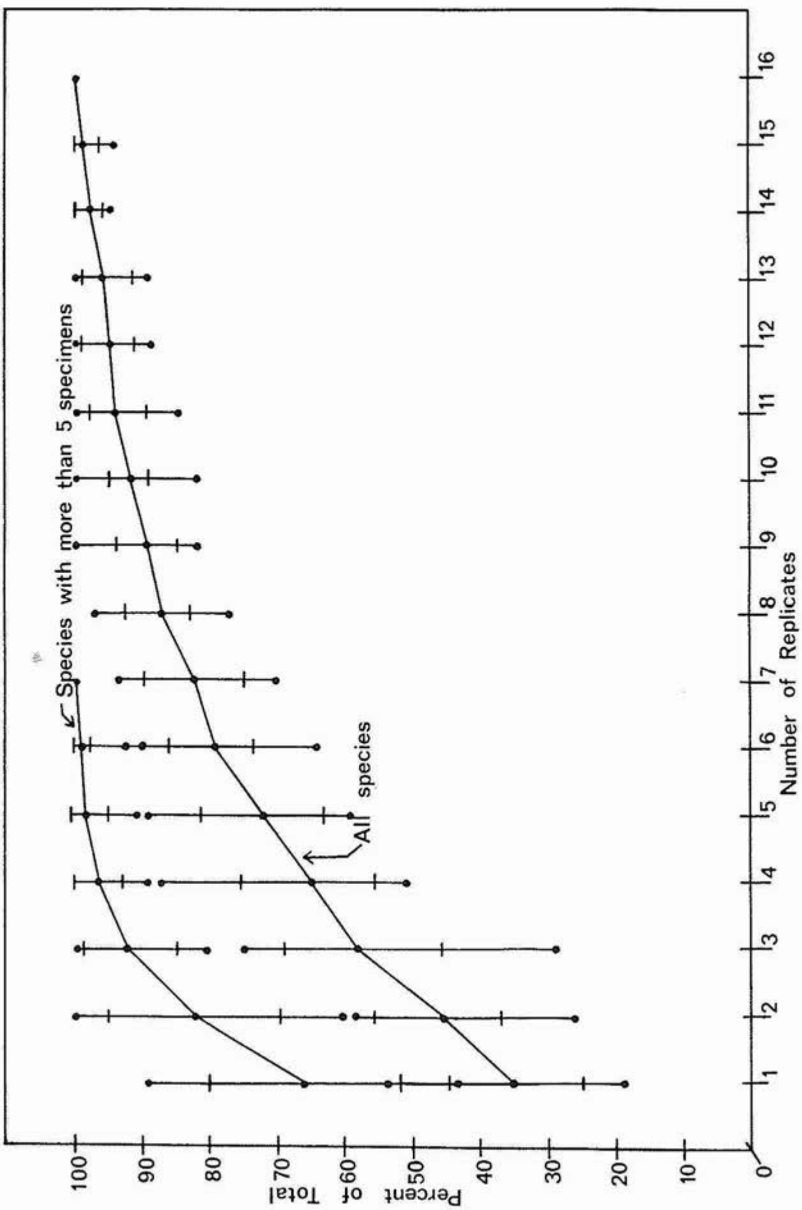


FIG. 38. NUMBER OF POLYCHAETE SPECIES PER REPLICATE EXPRESSED AS A PERCENTAGE OF THE TOTAL.

edge of the quantitative distribution of most of these species, the number of typically offshore inhabitants settled in Timbalier Bay is unknown.

Timbalier Bay Foraminifera

The intertidal benthic Foraminifera population in Timbalier Bay was determined by Fish et al., and the subtidal by Ostrom. A total of 59 living species was collected from the bay in these two studies (Appendix 1, p. 103). No additional analyses of these data have been carried out in connection with this re-examination; because Foraminifera are so important in oil exploration, however, and because these organisms have been utilized as indicators of stressed conditions in the environment (Shafer 1973), a generalized synthesis of these reports is presented here. In addition, Foraminifera are the only group of benthic organisms for which prior data for Timbalier Bay were available (Waldron 1957). Only the living species are discussed here.

The presence or absence of a particular species of Foraminifera in Timbalier Bay was found to be dependent upon the type of substrate, the salinity, and the tidal level. In general, the sediments became coarser in texture as one moved from the inner bay to the entrance. The salinity also increased towards the entrance of the bay.

The subtidal benthos in Timbalier Bay was dominated by 10 living species of Foraminifera, all of which were distributed throughout the bay. Generalized peaks in distribution were noted in some of these species. Among those species that reached population maxima in the inner reaches of the bay were *Ammonia beccarii* var. *parkinsoniana*; *Ammonia beccarii* var. *tepida*, which peaked near ambient station AB1; and *Elphidium vadescens*, which peaked near production station PB1. Middle bay primary inhabitants included *Elphidium matagordanum*, *E. poeyanum*, and *Quinqueloculina tenagos*. Principal inhabitants of lower bay areas included *Ammotium salsum, Elphidium gunteri,* and *Palmerinella gardenislandensis*. *Bolivina striatula* is an offshore inhabitant, but some living specimens were found throughout the bay.

Many of the principal intertidal species were also dominant members of the subtidal benthos (table 11). While these species were widely distributed throughout the intertidal reaches of the bay, the majority of the species were more commonly present in association with a particular substrate type. The intertidal mud association was dominated by seven species of Foraminifera, one of which, *Ammotium salsum,* was also an important species in the subtidal zone. Eight species were the principal components of the sand association, of which *Elphidium matagordanum* and *E. poeyanum* were important in the subtidal environment. Three species, *Ammonia beccarii* var. *parkinsoniana*, *A. b.* var. *tepida*, and

Elphidium gunteri, were present in all intertidal collections, as well as being important components of the subtidal foraminiferan fauna.

In summary, a knowledge of the living foraminiferan populations can be useful in indicating environmental conditions. It has been shown by others (e.g., Shafer 1973) that living species composition is a useful indicator of varying degrees of environmental stress near domestic sewage outfall discharges. While the relationship of foraminiferan species to oil spills or oil refinery discharges has not been established, it is reasonable to assume that some type of correlation can be expected. Comparisons of the Foraminifera data reported by Ostrom (1979) and Inabinet and Fish (1979) to the earlier work by Waldron indicate that there has been no appreciable change in the foraminiferan fauna in Timbalier Bay in the past two decades.

Marine Algae

Qualitative comparisons of the benthic algae of Timbalier Bay and offshore waters are indicated in Appendix 1. Numerically, there were 28 and 40 species of Chlorophyta, 26 and 22 species of Cyanophyta, 12 and 20 Phaeophyta, and 18 and 38 Rhodophyta in the bay and offshore area respectively. The reduction in the number of species of Chlorophyta, Phaeophyta, and Rhodophyta in Timbalier Bay is probably related to the lower salinities and higher turbidities (Humm and Bert 1979). The environmental difference noted in the offshore area is similar to one that shows the influence of the Mississippi River plume.

Twenty-three species of algae were present within the bay but not offshore, whereas 55 species were restricted to offshore habitats. Fewer species of algae, especially blue-greens and reds, were collected from those offshore platforms within or near the Mississippi River plume than in Timbalier Bay. The four distant offshore platforms studied were rich in greens, browns, and reds.

The use of benthic algae in assessing potential damage as a result of oil drilling and production activities is of limited value unless it is known what species were present before operations began. The use of algae as a means of assessing environmental damage as a result of an oil spill would be valuable in determining the latitudinal, longitudinal, and bathymetrical extent of any destruction. Because of the influence of such environmental parameters as salinity and turbidity, particular care should be exercised in making such comparisons; platforms must be within similar conditions in order to draw valid conclusions.

On the basis of data collected during the OEI program and algal studies previously conducted in Louisiana (Humm and Bert 1979), we have identified no significant adverse effect upon the algae of Timbalier Bay or offshore waters during the past 35 years of operations.

Offshore Oil Platform Fouling Organisms

The occurrence and bathymetric distribution of fouling organisms on offshore oil platforms were studied by the examination of existing populations on platform legs and by the suspension of test panels at various depths for a 60-day period. Knowledge of the existing population on the platform legs is particularly valuable in assessing the damage to marine organisms if there is an oil spill or other environmental stress. Because such organisms exist from the intertidal zone to the sediment line, it is also possible to measure the extent of damage due to such a stress. Since the larger and more conspicuous fouling organisms are attached species, they serve as indicators not only of present environmental conditions, but also of previous ones, much the same as benthic species serve as indicators of bottom environmental conditions.

Because the data collected from platform 54A are largely qualitative, it is not possible to analyze them with a computer-assisted program. The purpose of this supplemental analysis is to discuss the importance of this biological community as a means of monitoring the environmental conditions of the water mass surrounding an oil platform.

The dominant species present on platform 54A's legs are diagrammatically represented in figure 39. Beginning at the mean low tide level, the green alga *Enteromorpha* sp. dominates the upper 1 m of the leg, with the amount rapidly diminishing below the upper 5-10 cm of growth. The barnacles *Balanus reticulatus* and *B. improvisus* and the hydroid *Syncoryne* sp. are interspersed throughout the *Enteromorpha* zone. Below 2 m, *Enteromorpha* is replaced by the sea anemone *Aiptasia* sp., and there are larger and more frequent occurrences of the two species of barnacles. Between the depths of 7.5 and 12 m, the barnacles diminish in numbers and the hydroid *Bouganvillia tennella* dominates the association. *Balanus reticulatus* is the principal barnacle species, while *B. tintinnabulum* and *B. improvisus* are only infrequently present. Below 12 m, hydroids such as the *Bouganvillia* dominate the fouling material; a few serpulid polychaete worm tubes are also present.

Many additional species of marine invertebrates are present within the masses of dominating fouling organisms. Such organisms may either be free-living or attached forms, such as sponges, nematodes, polychaetes, crustaceans, and molluscs. Many may occur seasonally, so a knowledge of the seasonal occurrence of these smaller species is essential before such data can be utilized in environmental assessment.

Suspension of test panels for a sufficient length of time has been useful in assessing environmental conditions (Reish 1971). Because succession may occur, however, the species composition may not necessarily correspond with that present on a platform leg at a given depth. The chief value of the test panels is that they ease collection and

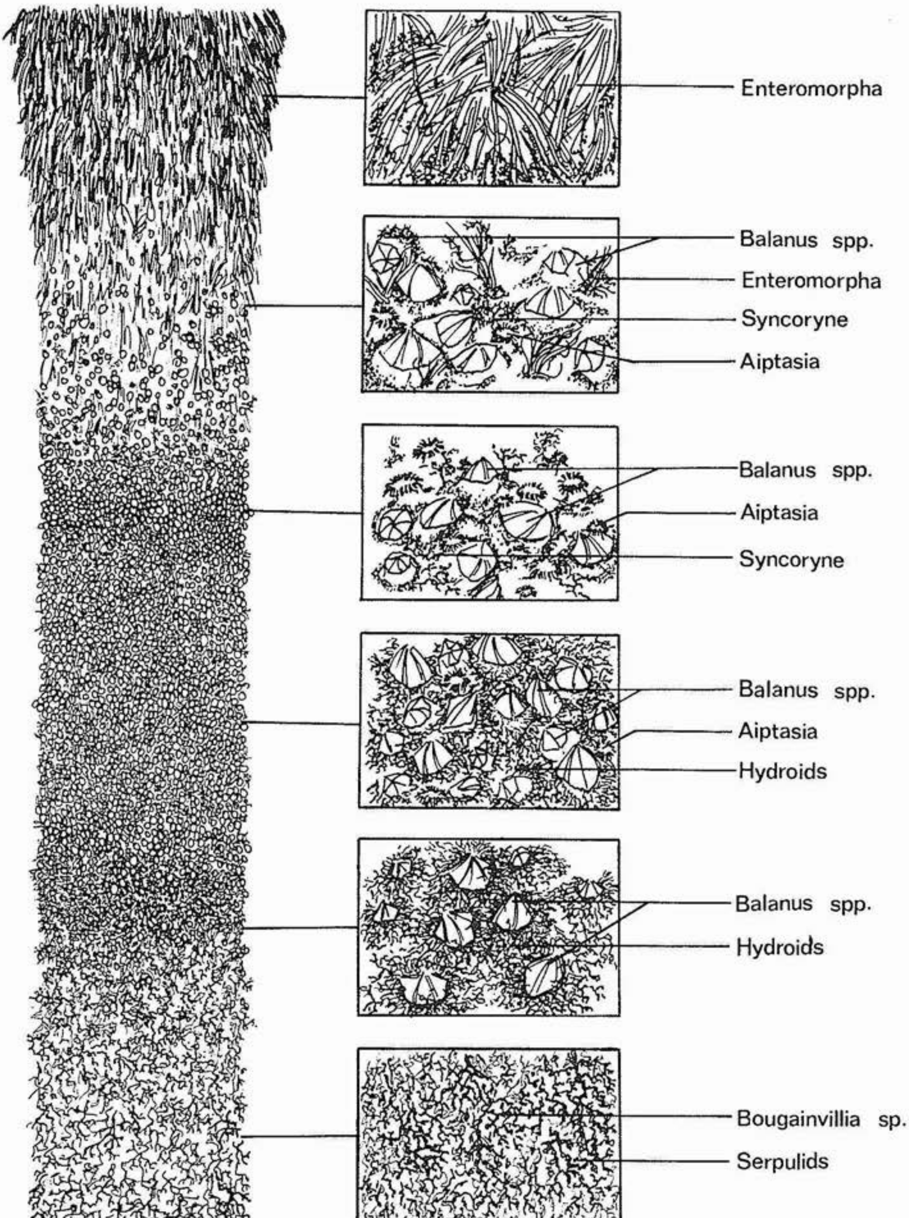


FIG. 39. DIAGRAMMATIC REPRESENTATION OF THE PRINCIPAL MARINE FOULING ORGANISMS ATTACHED TO PILINGS AT PLATFORM 54A.

biological analysis. As in the case of studying the fouling growth on platform legs, the larger the number of oil platforms used for suspension of test panels, the more useful the data.

In summary, an in-depth knowledge of the fouling organisms present on either platform legs or on test panels can be useful in measuring the effects of an oil spill or other environmental stress, if it should occur. Particular care must be exercised in identification of the organisms, and in noting the tidal level, the season, and the locality of the collection, in order to obtain meaningful data. There are limitations to the use of fouling organisms in evaluating the possible effects of oil platform activity in the OEI studies since there are no other offshore structures (not associated with oil activities) with which to make comparisons. As we stated above, fouling organisms are particularly useful as a monitoring device. In the event of an environmental stress or disaster at a given point, the biological communities on platform legs should be examined for destruction of marine life. Nearby platforms should be examined, in addition, in order to assess the extent of these effects. Test panels, if they have been utilized previously, can also be examined for possible bathymetric damage as well as latitudinal and longitudinal damage. The more thorough the background data on fouling organisms, the more useful these data become in assessing damage.

Offshore Macroinvertebrates

Benthic samples used for analyses of marine macroinvertebrates from the shallow offshore Louisiana waters are limited in both the number taken and in biological analyses made. It is possible to compare only the mollusc and crustacean data for the January and April 1973 periods from the production platform station 54A, and ambient stations 17A and 22A (located 2 and 12 miles, respectively, from station 54A). The sediments at all three stations were predominately sandy. An evaluation of the molluscan and crustacean data presented by Farrell (1979) does not give any indication of a clearly defined benthic community. All samples contained pelecypods, gastropods, amphipods, and cumaceans, but of the species in these groups, none was characteristic of all stations. The dwarf surf clam, *Mulinia lateralis*, was very abundant at the station 12 miles from the platform, but only one specimen was taken elsewhere. Other species were also found in abundance at one or two stations but not at other stations.

On the basis of the offshore benthic biological data, we found no indications that the benthic macroinvertebrate community structure has been altered as a result of the offshore oil production in Louisiana. It is unfortunate that the other groups of invertebrates, including coelenterates, nemerteans, sipunculoids, polychaetes, ophiuroids, and cephalochordates were not identified, because with such additional data it may have been possible to draw a more positive conclusion.

Discussion

The OEI benthic biological data from Timbalier Bay and the shallow offshore waters of Louisiana were re-examined with and without the assistance of computer analysis. Data consisted of the quantitative distribution of polychaetes, molluscs, crustaceans, and foraminiferans, as well as the qualitative occurrence of benthic algae in Timbalier Bay and offshore platforms, and also of fouling organisms attached to offshore platform legs.

With the exception of a previous study of the foraminiferans in Timbalier Bay, no data from previous quantitative studies of these organisms in the OEI study area were found. Ostrom occupied some of the same stations as Waldron. The data from these two studies were compared using the Morisita-Ono index of faunal similarity, which indicated no significant change during the past two decades.

In the absence of previous data on the occurrence and distribution of benthic fauna, data collected near platforms were compared to those collected some distance from any oil production or drilling activity. By and large, regardless of the type of analysis, the conclusions were similar—ambient station AB1 had greater affinity to drilling station PB2 than to the other stations. The close affinity of these two stations was largely the result of a large population of *Spiochaetopterus*, since the index of affinity was low when the *Spiochaetopterus* data were excluded (see figure 35). In one type of cluster analysis with the polychaete data (figure 37), the separation of stations was by season rather than by station.

Analyses of the species composition of bay and offshore benthic algae indicate that salinity and turbidity play an important role in the distribution of these species. Salinity reduction and increased water turbidity from outer to inner Timbalier Bay or offshore towards the Mississippi plume caused a reduction in the number of species of greens, browns, and reds.

If drilling and production operations had added appreciable amounts of hydrocarbons to Timbalier Bay during the past 25 years, then one would expect to find measurable effects in the benthic community. The faunal index would be reduced at the stressed stations, and the populations in the affected areas would separate from the ambient stations in a cluster analysis. Furthermore, if there had been a buildup of hydrocarbons or other pollutants, then one would expect a reduced benthic fauna and the appearance of pollution-tolerant species, such as *Capitella capitata*, in large numbers at the affected localities. No separate pollution-tolerant population of benthic organisms was found at any of the localities studied.

It is undetermined how the benthic fauna in the shallow Timbalier Bay area is affected by trawling for shrimp or by boating, but it is known that the wake of such boat activity is etched into the surface sediments. If such activity is of significance, then some macroinvertebrates, especially free-living epibenthic species, would be susceptible to exclusion, but others, such as *Spiochaetopterus*, would retreat downward in their tubes and later reconstruct the upper end, if it had been cut off. *Spiochaetopterus* constructs a cylindrical, annulated, translucent, flexible, horny tube, one end of which is extended into the substrate. This species is apparently able to tolerate sediment removal and deposition that may be the result of any natural or man-made cause. None of the dominant species listed in table 10 is truly epibenthic; *Paraeurythoe americana* and *Gyptis capensis* live in the upper 1 to 2 cm of sediment. As they would presumably be affected by boat activity, they may be stirred up with the sediment and transferred to another locality. The constant reworking of the sediment would, in the long run, lead to a similarity in sediment characteristics throughout the bay, which in turn would lead to a similar benthic community in the bay. This is essentially what the benthic biological conditions were in Timbalier Bay in 1973, when it was characterized by sandy silt or silty sand sediments and dominated by the polychaete *Spiochaetopterus*.

Conclusions

Analysis of the benthic biological data in Timbalier Bay and offshore waters does not indicate any environmental stress resulting from oil drilling and production activities. Variations in biota are the result of salinity or turbidity variability rather than of environmental changes resulting from petroleum-related operations. The presence of a rich and diversified polychaete, algae, and foraminiferan population at all areas sampled, together with the absence of any indication of a stressed biotic community at any locality, lead us to conclude that oil drilling and production activities have not adversely affected environments in the OEI study area of Louisiana.

CRITIQUE OF THE OEI "CONSENSUS CONCLUSIONS"

The 1974 consensus conclusions of the GURC OEI Program Council have been presented previously (Morgan et al. 1974). One objective of the re-examination was evaluation of the OEI data base using computerized and computer-assisted methods for synthesis and interpretation.

These evaluations have also been directed to determining the value of the experience and knowledge gained from the OEI as related to the original conclusions. We hoped to gain knowledge from retrospective evaluation of the program rationale and design to serve as the basis for formulation of recommendations for future studies. A restatement of the OEI conclusions and our critique of each conclusion follows:

> **Conclusion 1:** "Timbalier Bay has not undergone significant ecological change as a result of petroleum drilling and production since just prior to 1952 when other more limited baseline data were generated."

An intensive review of the data base and references to historical data that are pertinent to time-change comparison purposes leads us to the conclusion that, on the basis of historical comparison alone, this conclusion is not sufficiently supported by the evidence. Direct evidence acquired during the OEI, however, does support the conclusion.

In the logic and rationale of the OEI program, historical comparisons were only one of three elements that constituted the "substitute time trajectory." Comparisons of ecological health with comparable ecosystems and the exercise of individual judgment based on cumulative scientific experience were also used to arrive at the Council's consensus conclusions. In our judgment, the combination of these three criteria would suggest more scientifically supportable conclusions:

> **Existent historical ecological data, which mostly consist of knowledge of the Foraminifera, indicate no significant changes in the Timbalier Bay ecosystem as a result of petroleum drilling and production. Further, the ecological health (as judged against comparable ecosystems) and the low concentrations of both hydrocarbons and trace metals in the environment argue that the OEI study area probably has not suffered.**

While sufficient baseline data were not available to support Conclusion 1 fully, the existing data indicate that the conclusion is probably valid, but further confirmation is needed. The existence of the OEI data base, which is now a 5- to 7-year-old baseline, offers the opportunity for at least a partial, and important, confirmation or invalidation of this conclusion, by offering a means for determining whether changes subsequent to the OEI have occurred.

> **Conclusion 2:** "Every indication of good ecological health is present. The region of the sampling sites is a highly productive one

from the biological standpoint, more so than other regions thus far studied in the eastern and open Gulf of Mexico."

The OEI data support this conclusion. While our appraisals were confined to the OEI data *per se* and to the reports of the OEI Principal Investigators, those indices currently used by others to indicate ecological health support the conclusion, in our opinion. Furthermore, the in-depth examinations of the data—exercised primarily in seeking alternative rationales and experimental approaches—have developed statistical summaries that further support the conclusion, while generating no statistical evidence to the contrary.

More conclusive statistical evidence to validate or invalidate the conclusion might have been generated through a more effective basic rationale using different measurements, parameters, spatial and temporal density, and patterns.

Probably the evidence to support this conclusion is more convincing for the bay than for the offshore area, as a consequence of there being greater data density for important parameters (especially the benthos) for the bays.

Therefore, we concur with the conclusion, but with the reservation that it should be further confirmed by using the newly available baseline data for other Gulf areas as the means for conducting a more comprehensive comparison of habitats and communities to determine relative ecological health and productivity as a function of habitat parameters. The data of Fucik and El-Sayed (1979), Marum (1979), and Brent et al. (1979) adequately document the high biological productivity of the OEI study area.

Conclusion 3: "Concentration of all compounds which are in any way related to drilling or production are sufficiently low to present no known persistent biological hazard."

The OEI data on hydrocarbon and trace metal contamination that might be related to oil drilling and production generally support this statement, with the exception that the OEI did not address "all compounds" in a comprehensive sense. The OEI data show concentrations within the bay and the offshore area as being generally below those considered significant for biological uptake and cumulative effects. However, the data regarding hydrocarbon compounds are inadequate to eliminate the possibility of subtle cumulative effects that may be due to specific hydrocarbon compounds or specific chemical combinations of trace metals in the environment. Again, in the absence of data to support a completely sound statistical treatment, it is necessary to view the rather extensive evidence that is contained in the OEI data base in the light of more broadly applicable evidence—i.e., that of very low concentrations of trace metals and petroleum fractions, of concentrations of fractions less than or comparable to those reported for the Gulf and for the world's oceans, and concentrations quite low as compared with regulatory limits—to draw the more supportable conclusion:

> **Concentrations of petroleum-related hydrocarbons and trace metals found in the OEI area are below those generally considered to have biological significance.**

There were insufficient sediment samples analyzed for hydrocarbons in the OEI adequately to assess buildup or possible effects on benthic organisms.

> **Conclusion 4:** "Natural phenomena such as seasonality, floods, upwellings, and turbid layers have much greater impact upon the ecosystem than do petroleum drilling and production activities."

The OEI provided abundant evidence to support this conclusion. Fortunately, the record Mississippi River flood occurred near the midpoint of the seasonal exercises, so that its effects throughout the OEI area were dramatically recorded and, importantly, could be compared with more stable pre-flood and post-flood periods. The turbid layer, its ecological effects, and its origin were defined, conclusively providing baseline information about ecological impacts of natural phenomena. The seasonal variabilities were of the character and magnitude to be expected and were conclusively demonstrated. Such variabilities now permit the development of more definitive judgments of the effects of either natural or human activity-related variations within the study area described by the OEI data.

The study area chosen for the OEI is heavily influenced by the adjacent land mass and receives significant hydrocarbon inputs from the Mississippi, which drains two-thirds of the continental United States. Petroleum-related hydrocabrons flowing into the Gulf from the Mississippi probably exceed all estimates of inputs attributable to oil drilling and production activities.

CONCLUSIONS BASED ON RE-EXAMINATION OF THE OEI DATA BASE

1. The platform versus control site experimental design used in the OEI would be valid only if the sites selected proved to be different in one or more specific parameters believed to be related to oil drilling and production. Data collected in the OEI did not substantiate that the sites were different. However, analyses for hydrocarbons, metals, and nutrients were mostly limited to the water column.

2. Methods and procedures used in the OEI were carefully recorded (Menzies 1973) to permit subsequent duplication of individual sampling and analytical methods and procedures, but use of standard procedures was not enforced. Hence, for example, benthic fauna in Timbalier Bay and offshore were collected by seven different investigators using different techniques, making synthesis and interpretation of benthic data a formidable task. The synthesis accomplished in this re-examination allows for only limited interpretation, an unfortunate circumstance considering the time and expense incurred in collecting the data.

3. The detection and interpretation of low-level, chronic disturbances of ecosystems requires careful attention to experimental design, including such things as selection of appropriate parameters for judging effects and methods of collection and statistical treatment of data. Based on our review of the OEI program, it is our opinion that most of the investigators believed that oil operations associated with platforms would produce large, easily detectable sources of contamination, and hence would be easily monitored by water column measurements, with little need for replication and statistical treatment of data. This did not prove to be the case.

4. Analyses of water column characteristics (physical, chemical, and biological) did not lead to definitive conclusions because of the highly variable nature of the data collected.

5. Our analyses of the benthic biological data in both Timbalier Bay and offshore did not reveal any indication of a stressed environment near or around oil drilling and production platforms.

6. We wish to re-emphasize conclusion number 4 of the OEI Council on the importance of recognizing the effects of natural phenomena on results obtained from environmental monitoring and analysis. For example, the data of Humm (1974) clearly show a direct relationship between the number of algal species on platforms and distance from the flow of the Mississippi River.

7. Programs designed to detect the presence or effects of petroleum hydrocarbons should have as a primary component of the experimental design the most advanced analytical support for quantifying hydrocarbons in the most likely sinks, especially in sediments and organisms.

8. The ability to distinguish environmental change at any specific time, based on monitoring programs, is greatly enhanced by the availability of historic baseline data. Unfortunately, with the exception of the Foraminifera, little meaningful historic data was available to the OEI. Hence, the OEI data base represents an invaluable resource for detection of changes in the Gulf ecosystem that may occur in the future.

RECOMMENDATIONS FOR FUTURE STUDIES

Existing data bases

The OEI was conducted with the single purpose of determining the cumulative ecological effects of normal petroleum drilling and production operations. Although the results of the investigation did not yield evidence of cumulative effects, certain aspects of the study design preclude a definitive statement to that effect. Since the OEI was conducted, however, numerous comprehensive environmental data bases have been generated for the northern continental shelf and coastal ecosystems of the Gulf of Mexico. These data bases contain much of the necessary information to assess the cumulative impacts of offshore development, but they have not been put to that use. Using investigative methods similar to those employed in this re-examination of the OEI in combination with a regional data base, which merges the data produced as a result of government and industrial programs in this geographical area, we recommend that: (1) the data be synthesized for interpretation, (2) the data base be analyzed for adequacy and validity to determine process variabilities, patterns of accumulation, etc., (3) relationships between contaminants and community structure be determined, and (4) the information be synthesized for management decision.

The data base so generated should also systematically accumulate data submitted to federal and state agencies in compliance with drilling permits and other petroleum operations. Such a program would continuously expand the data base, fill in gaps in time and space, and provide valuable quantitative information about point sources concerning contaminants and their concentrations.

Participation in a Gulf study of the nature described above should be national in experimental design and in data synthesis and interpretation.

Future studies

If a program with the objectives of the OEI were undertaken today, we would recommend an experimental design that would concentrate much less effort on measuring biological and chemical characteristics of the water column. Plankton populations are generally so spotty and have such high population resiliency that they make detection of chronic effects from field studies almost impossible. This same reasoning applies to measurements of petroleum hydrocarbons and metals in the water column. Intermittent releases at the platforms would result in patchiness in distribution, which would be compounded by variable current patterns. These factors are often further compounded by analytical problems, suggesting that efforts in measuring chemical contamination would be better spent in monitoring sediments and/or sessile biota.

An adequate prior knowledge of the physical environment including currents, sediment composition, and stability must be obtained prior to the selection of sampling stations. Once knowledge of these factors is available, the sampling design can be determined. We would suggest that any study designed to detect chronic effects include determinations of the following: (1) benthic community composition and structure, (2) petroleum hydrocarbon and trace metal contamination of sediments and sessile biota, (3) petroleum hydrocarbon and trace metal contamination and tainting of commercially important biota, and (4) provision to allow for special studies to investigate the significance of any unusual contamination found in the field monitoring. In addition, many habitats may present special cases when the further stratification of sampling efforts must be considered, e.g., benthic substrates, when more than one type are important in the area.

Whenever any large-scale marine ecological program is contemplated, it is imperative that all phases of sample collection and data analysis and interpretation be thoroughly planned and discussed with all scientific disciplines. The nature and amount of data collected must be adequate, within the limits of monetary constraints, to accomplish the objectives of the study. Collection of data without analysis is meaningless and a waste of resources. Constant vigilance and re-analysis is essential to avoid merely collecting data for data's sake; all data must be meaningful and useful to the study. More specific recommendations are:

1. All sampling stations must be coordinated so that the data from one discipline can be used by another.
2. Natural, as well as anthropogenic, environmental changes must be considered in the selection of stations and sampling techniques.
3. The number of samples taken must be carefully considered in order to assure valid statistical analysis.
4. If the purpose of the monitoring program is to ascertain whether or not a particular man-caused activity has caused damage, natural areas of sufficient distance, but similar characteristics, must be studied in order to draw valid conclusions. Naturally-caused environmental events, such as seasonal run-off from rivers, must be taken into consideration in assessing the environmental condition of the area.
5. Since the knowledge of what species of organisms are present in a particular environment is essential for making an accurate assessment of the state of the environment, it is important that the species be identified by competent scientists to the lowest possible taxon,

preferably to the level of species. Identification of all species of macroflora and fauna may be impossible in some instances because of the lack of reasonably good reference works. Therefore, we recommend that identification of marine organisms be limited to macroalgae, polychaetes, molluscs, crustaceans, echinoderms, and fish, with the proviso that such requirements be expanded to include other groups of organisms that may be of importance to a particular area, e.g., corals in tropical seas. Because of the importance of Foraminifera in oil exploration, we recommend that this group also be included in benthic analyses. Only by making such limitations on identification of organisms can there be hope to accomplish this difficult and time-consuming task with sufficient replication to minimize errors and to compensate adequately and correctly for natural variability.

6. All procedures for the collection and analysis of data should be standardized.

Exceptional caution should be observed in drawing conclusions without either a comprehensive synoptic interdisciplinary data base or a pre-established minimum set of monitoring data. Misinterpretation of ecological phenomena could easily occur if conclusions are based on single elements of the ecosystem or on a limited number of parameters. While it appears likely that the number of parameters required for ecological monitoring can be reduced, reduction in number can be done only after accounting for seasonal variabilities and parameter interactions.

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NOTE: Individual papers of the OEI Principal Investigators for 1979 referred to in this section can be found in section IV of this book.

APPENDIX I

APPENDIX 1

Systematic List of the Marine Organisms Reported from the OEI Study Area

1972-1974

Compiled by Donald J. Reish and S.G. Appan

	Timbalier Bay	Offshore Waters
Phylum Chlorophyta		
Batophora oerstedii		X
Bryopsis hypoides		X
B. pennata		X
Chaetomorpha brachygona		X
C. gracilis		X
C. linum	X	X
C. minima	X	X
Cladophora albida	X	X
C. brachyclona		X
C. catenata		X
C. dalmatica	X	X
C. delicatula	X	
C. flexuosa		X
C. gracilis	X	X
C. repens		X
C. sericea		X
C. vagabunda		X
Cladophoropsis membranacea	X	X
Derbesia lamourouxii		X
D. vaucheriaeformis		X
Enteromorpha chaetomorphoides		X
Phylum Chlorophyta (continued)		
E. clathrata	X	X
E. compressa	X	X
E. erecta		X
Enteromorpha flexuosa	X	X
E. intestinalis	X	X
E. lingulata	X	X
E. plumosa	X	X
E. prolifera	X	X
E. salina		X
E. sp.		X
Entocladia viridis		X
Gomontia polyrhiza	X	X
Monostroma oxyspermum	X	
Ostreobium quekettii	X	X
Phaeophila dendroides		X
Protoderma marinum		X
Pseudoendoclonium marinum	X	
Pseudotetraspora antillarum	X	X
Rhizoclonium hookeri	X	X
R. kerneri	X	
R. kochianium	X	X

	Timbalier Bay	Offshore Waters
Phylum Chlorophyta (continued)		
R. riparium	X	X
R. tortuosum	X	
Stichococcus marinus	X	X
Ulothrix flacca	X	
Ulva curvata	X	
Ulvella lens	X	X
Phylum Pyrrhophyta		
Ceratium fusus		X
Exuviaella compressa		X
Gonyaulax diegensis		X
G. fragilis		X
G. monilata		X
G. polygramma		X
G. sp.		X
G. turbyne		X
Peridinium pellucidium		X
P. trochoideum		X
Prorocentrum gracile		X
Phylum Chryophyta		
Asterionella japonica		X
Bacteriastrum delicatum		X
Biddulphia mobiliensis		X
Cerataylina pelagica		X
Chaetoceros affinis		X
C. atlanticus		X
C. compressus		X
C. curvisetus		X
C. decipiens		X
C. didymus		X
C. laciniosus		X
C. lorenzianus		X
C. messanensis		X
C. pelagicus		X

	Timbalier Bay	Offshore Waters
Phylum Chryophyta (continued)		
C. pseudocurvisetus		X
C. sp.		X
Corethron criophilum		X
Coscinodiscus centralis		X
C. radiatus		X
Cyclotella striata		X
C. sp.		X
Denticula elegans		X
Dictyocha fibula		X
Eucampia cornuta		X
Guinardia flaccida		X
Hemiaulus sinensis		X
Leptocylindrus danicus		X
Melosira sp.		X
Nitzschia closterium		X
N. pungens		X
N. subfraudulenta		X
N. vitrea		X
N. sp.		X
Pleurosigma naviculaceum		X
Rhizosolenia alata		X
R. calcar-avis		X
R. delicatula		X
R. fragilissima		X
R. setigera		X
R. shrubsolii		X
R. stolterfothii		X
R. styliformis		X
Skeletonema costarum		X
Synedra acus?		X
Thalassionema nitzschioides		X
Thalassiosira aestivalis		X
T. decipiens		X
T. excentrica		X
T. oestrupii		X

APPENDIX 1 (continued)

	Timbalier Bay	Offshore Waters
Phylum Chryophyta (continued)		
T. rotula		X
T. sp.		X
Thallassiothrix mediterranea		X
Phylum Cyanophyta		
Agmenellum thermale	X	X
Anacystis aeruginosa	X	X
A. dimidiata	X	X
A. marina	X	
A. montana	X	X
Calothrix crustacea	X	X
Coccochloris elabens	X	X
C. stagnina	X	X
Entophysalis conferta	X	X
E. deusta	X	X
Gomphosphaeria aponina	X	X
Johnnesbaptista pellucida	X	
Mastigocoleus testarum	X	X
Microcoleus lyngbyaceus	X	X
M. vaginatus	X	X
Nostoc spumigena	X	
Oscillatoria erythraca	X	X
O. lutea	X	X
O. submembranacea	X	X
Porphyrosiphon kurzii	X	
P. notarisii	X	X
Schizothrix arenaria	X	X
S. calcicola	X	X
S. mexicana	X	X
S. tenerrima	X	X
Spirulina subsalsa	X	X

	Timbalier Bay	Offshore Waters
Phylum Phaeophyta		
Acinetospora crinita		X
Ascocyclus orbicularis		X
Bachelotia antillarum	X	X
Ectocarpus dasycarpus	X	
E. elachistaeformis		X
E. intermedius	X	X
E. variabilis	X	X
Giffordia conifera	X	X
G. indica	X	X
G. mitchellae	X	X
G. rallsiae	X	X
Herponema tortugense		X
Hummia onusta		X
Myriotrichia subcorymbosa	X	X
Phaeostroma pusillum		X
Pseudostictyosiphon onustus	X	
Sargassum fluitans	X	X
S. natans		X
S. sp.		X
Sphacelaria furcigera	X	X
S. tribuloides		X
Spongonema tomentosum		X
Phylum Rhodophyta		
Acrochaetium antillarum		X
A. crassipes	X	
A. dufourii		X
A. flexuosum		X
A. gracile	X	X
A. hoytii		X
A. sargaeanum	X	X
A. sancti-thomae		X

	Timbalier Bay	Offshore Waters
Phylum Rhodophyta (continued)		
A. seriatum		X
A. thureitii		X
A. trifilum		X
A. virgatulum	X	
Antithamion cruciatum		X
Asterocystis ramosa		X
Bangia fuscopurpurea	X	X
Bostrichia radicans	X	
B. r. forma *moniliforme*	X	
B. tenella	X	
Ceramium byssoideum		X
C. fastigiatum		X
C. f. forma *flaccida*		X
Erythrocladia recondita		X
E. subintegra		X
E. vagabunda		X
Erythrotrichia carnea	X	X
Fosliella atlantica		X
F. farinosa		X
F. f. var. *solmsiana*		X
Goniotrichum alsidii	X	X
Gracilaria foliifera	X	X
G. verrucosa	X	
Gracilariopsis sjoestedtii	X	
Herposiphonia secunda		X
Hypnea musciformis	X	
Jania adherens		X
Laurencia papillosa		X
L. poitei	X	
Lophosiphonia cristata		X
L. saccorhiza		X
L. subadunca	X	X
Polysiphonia echinata	X	
P. havanensis		X
P. hemisphaerica	X	X
Phylum Rhodophyta (continued)		
P. howei		X
P. subtilissima	X	X
P. sp.		X
Pterocladia americana		X
Spermothamium investiens		X
Phylum Protozoa (Foraminifera)		
Ammoastuta inepta	X	
Ammobaculites crassus	X	
A. dilatatus	X	
A. exiguus	X	
A. subcatenulatus	X	
Ammonia beccarii var. *parkinsoniana*	X	
A. beccarii var. *tepida*	X	
A. beccarii var. A	X	
A. beccarii var. B	X	
A. pauciloculata	X	
A. rolshauseni	X	
Ammotium dilatatum	X	
A. fragile	X	
A. salsum	X	
Ammoscalarin pseudospiralis	X	
Arenoparella mexicana	X	
Bolivina lowmani	X	
B. striatula	X	
Bucella hannai	X	
Bulimenella bassendorfensis	X	
B. elegantissima	X	
Clavulina gracilis	X	
Cornuspira sp.	X	
Elphidium advena	X	
E. delicatulum	X	
E. discoidale	X	
E. gunteri	X	
E. limosum	X	

APPENDIX 1 (continued)

	Timbalier Bay	Offshore Waters
Phylum Protozoa (continued)		
E. matagordanum	X	
E. mexicana	X	
E. poeyanum	X	
E. vadescens	X	
Epistominella vitrea	X	
Gaudryina exilis	X	
Hanzawaia strattoni	X	
Haplophragmoides manilaensis	X	
H. wilberti	X	
Jadammina polystoma	X	
Miliammina fusca	X	
Nonionella atlantica	X	
N. opima	X	
Palmerinella gardenislandensis	X	
Proteonina lagenaria	X	
Quinqueloculina compta	X	
Q. funafutiensis	X	
Q. lamarckiana	X	
Q. poeyana	X	
Q. rhodiensis	X	
Q. seminulum	X	
Q. tenagos	X	
Q. wiesneri	X	
Recurvoides sp.	X	
Sulcophax sp.	X	
Triloculina sidebottomi	X	
Trochammina comprimata	X	
T. inflata	X	
T. laevigata	X	
T. macrescens	X	
Typhotrocha comprimata	X	

	Timbalier Bay	Offshore Waters
Phylum Porifera		
Cliona sp.		X
Lissodeudoryx sp.		X
Unidentified		X
Phylum Coelenterata		
Aiptasia sp.		X
Astrangia astreiformis		X
Bougainvillia tennella		X
Bundosoma cavernata		X
Calliactis tricolor		X
Chrysaura quinquecirrha		X
Pelagia noctiluca		X
Renilla mulleri		X
Syncoryne sp.		X
Anthozoa, unidentified		X
Phylum Platyhelminthes		
Leptoplana sp.		X
Phylum Nematoda		
Nematodes, unidentified	X	
Phylum Nemertea		
Cerebratulus lacteus		X
Phylum Annelida		
Class Polychaeta		
Aedicira belgicae	X	
Aglaophamus verrilli	X	
Ammotrypane aulogaster	X	
Amphinomidae	X	
Anaitides maculata	X	

	Tambalier Bay	Offshore Waters
Class Polychaeta (continued)		
Ancistrosyllis hamata	X	
Arabella iricolor	X	
Aricidea fauveli	X	
Armandia polyophthalma	X	
Asychis urceolata	X	
Autolytus faciatus	X	
Axiothella mucosa	X	
Bhawania goodei	X	
Branchioasychis americana	X	
Cabira brevicirrus	X	
Capitella capitata	X	
Cirratulus cirratus	X	
Cirriformia tentaculata	X	
Clymenella torquata calida	X	
Cossura delta	X	
Dasybranchis lumbricoides	X	
Diopatra cuprea spirobranchus	X	
D. c. cuprea	X	
Dorvillea rudolphi	X	
Drilonereis magna	X	
D. sp.	X	
Eteone heterpoda	X	
Euclymene sp.	X	
Eumida sanguinea	X	
Eunice subra	X	
Exogone dispar	X	
E. sp.	X	
Glycera americana	X	
G. rouxi	X	
Glycinde polygnatha	X	
Gyptis capensis	X	
Haploscoloplos robustus	X	
Harmothoe lunulata	X	
H. trimaculata	X	
Hesionid	X	

	Tambalier Bay	Offshore Waters
Class Polychaeta (continued)		
Heteromastus filiformis	X	
Laonice cirrata	X	
Loandalia americana	X	
Loimia viridis	X	
Lumbrineris bassi	X	
L. erecta	X	
L. parvapedata	X	
L. sp.	X	
Magelona cincta	X	
M. longicornis	X	
Malacoceros vanderhorsti	X	
Maldane sarsi	X	
Maldanid	X	
Megalomma bioculatum	X	
Megalona sp.	X	
Melinna maculata	X	
Melinnexis sp.	X	
Myriochele oculata	X	
Myriowenia sp.	X	
Mystides borealis	X	
Naineris laevigata	X	
N. setosa	X	
Neanthes arenaceodentata	X	
N. succinea	X	X
Nephtys bucera	X	
N. picta	X	
Nereiphylla fragilis	X	
N. parreti	X	
Nereis sp.		X
Nerine agilis	X	
Ninoe nigripes gracilis	X	
Notomastus hemipodus	X	
N. latericeus	X	
Onuphis eremita oculata	X	
Ophiodromus sp.	X	

APPENDIX 1 (continued)

	Timbalier Bay	Offshore Waters
Class Polychaeta (continued)		
Owenia fusiformis	X	
Paraeurythoe americana	X	
Paraonid	X	
Paraprionospio pinnata	X	
Pectinaria gouldii	X	
Pilargis verrucosa	X	
Pista mirabilis	X	
Poecilochaetus sp.	X	
Polydora socialis	X	
Pomatoceros sp.		X
Prionospio caspersi	X	
P. cirrifera	X	
P. sexoculata	X	
Sabella microphthalma	X	
Scoloplos rubra	X	
Semiodera roberti	X	
Sigambra tentaculata	X	
Sphaerosyllis sp. a	X	
S. sp. b	X	
Spiochaetopterus costarum	X	
Spiophanes bombyx	X	
S. soederstromi	X	
Sthenelais articulata	X	
S. boa	X	
Streblospio benedicti	X	
Syllidia armata	X	
Tharyx monilaris	X	
Phylum Sipunculoidea		
Sipunculids		X
Phylum Mollusca		

	Timbalier Bay	Offshore Waters
Class Gastropoda		
Anachis avara	X	X
A. obesa	X	
Busycon contrarium		X
Cantharus cancellarius		X
Crepidula fornicata	X	X
Distorsio clathrata		X
Epitonium krebsi		X
E. rupicola	X	
Mitrella sp.		X
Murex fulvescens		X
Nassarius acutus	X	X
N. vibex	X	X
Nudibranchia		X
Oliva sayana		X
Polinices duplicatus	X	X
Sinum perspectivum		X
Terebra dislocata		X
Thais haemastoma	X	X
Thais sp.		X
Turbonilla sp.		X
Class Pelecypoda		
Aequipecten irradians		X
Anadara ovalis	X	
A. transversa	X	X
Chione cancellata	X	X
C. grus		X
C. latilirata		X
Corbula sp.		X
Crassostrea virginica	X	X
Diplodonta punctata	X	X
Docinus discus	X	

	Timbalier Bay	Offshore Waters
Class Pelecypoda (continued)		
Donax texasianus	X	
Ensis minor	X	
Lithophaga aristata		X
Macoma mitchilli	X	
M. sp.		X
Mercenaria campechiensis	X	X
Mulinia lateralis	X	
Noetia ponderosa		X
Nucula proxima		X
Nuculana concentrica	X	X
Ostrea equestris		X
Solen viridis		X
Tellidora cristata	X	
Tellina alternata	X	
T. iris	X	X
Class Cephalopoda		
Dorytheuthis plei		X
Loligo pealei		X
Lolliguncula brevis		X
Octopus vulgaris		X
Phylum Arthropoda		
Class Crustacea		
Subclass Copepoda		
Order Caligoida		
Caligus sp. a	X	
C. sp. b	X	X
C. sp. c	X	
C. sp. d	X	
Lernaeocera sp.	X	
Order Calanoida		
Acartia danae		X
A. tonsa	X	X

	Timbalier Bay	Offshore Waters
Order Calanoida (continued)		
Acrocalanus longicornis		X
Anomalocera ornata		X
Calanopia americana		X
Calocalanus pavo		X
C. styliremis		X
Candacia curta		X
C. pachydactyla		X
Centropages furcatus	X	X
C. hamatus	X	X
C. velificatus	X	X
Clausocalanus furcatus		X
C. jobei		X
Eucalanus crassus		X
E. hyalinus		X
E. pileatus	X	X
E. sewelli		X
Euchaeta marina		X
Euchirella rostrata		X
Eurytemora hirundoides	X	
Labidocera acutifrons		X
L. aestiva	X	X
Lucicutia gaussae		X
Nannocalanus minor		X
Neocalanus gracilis		X
N. robustior		X
Paracalanus aculeatus		X
P. crassirostris	X	X
P. indicus	X	X
Paracandacia simplex		X
Pleuromamma abdominalis		X
P. piseki		X
Pontella securifer		X
Pontellopsis villosa		X
Pseudodiaptomus coronatus	X	X
Rhincalanus cornutus		X

APPENDIX 1 (continued)

	Timbalier Bay	Offshore Waters
Order Calanoida (continued)		
Scolecithrix danae		X
Temora stylifera	X	X
T. turbinata		X
Tortanus setacaudatus	X	
Undinula vulgaris		X
Order Cyclopoida		
Copilia mirabilis		X
Corycaeus amazonicus	X	X
C. clausi		X
C. giesbrechti		X
C. latus		X
C. lautus		X
C. limbatus		X
C. ovalis		X
C. speciosus		X
C. subulatus		X
Cyclopoida sp.	X	
Farranula carinata	X	X
F. gracilis	X	X
F. rostrata		X
Lubbockia squillimana		X
Oithona brevicornis	X	X
O. nana		X
O. plumifera	X	X
O. similis		X
O. simplex		X
Oncaea curta		X
O. mediterranea		X
O. venusta	X	X
Sapphirella sp. a	X	
S. sp. b		X
Order Cyclopoida (continued)		
Sapphirina nigromaculata		X
Order Harpacticoida		
Clytemnestra rostrata		X
C. scutellata		X
Euterpina acutifrons	X	X
Macrosetella gracilis	X	X
Microsetella norvegica	X	X
M. rosea	X	X
Miracia efferata		X
Harpacticoid sp. a	X	
Harpacticoid sp. b	X	
Harpacticoid sp. c		X
Harpacticoid sp. d	X	
Harpacticoid sp. e		X
Harpacticoid sp. f	X	
Harpacticoid sp. g		X
Harpacticoid sp. h	X	
Harpacticoid sp. i		X
Harpacticoid sp. j	X	
Harpacticoid sp. k		X
Subclass Cirripedia		
Balanus amphitrite	X	X
B. eberneus		X
B. improvisus		X
B. reticulatus		X
B. tintinnabulum		X
Lepas sp.		X
Subclass Malacostraca		
Order Stomatopoda		

	Timbalier Bay	Offshore Waters
Order Stomatopoda (continued)		
Squilla empusa	X	X
Order Mysidacea		
Mysidacea		X
Order Cumacea		
Cyclaspis sp.		X
Eudorella monodon	X	
Leucon sp.	X	
Oxyurostylis smithi	X	X
Order Tanaidacea		
Leptochela serratorbita		X
Tanaids		X
Order Isopoda		
Aegathoa oculata	X	
Ancinus depressus	X	X
Cymothoa excisa	X	
Edotea montosa	X	X
Idotea sp.	X	
Limnoria tripunctata		X
Lironeca ovalis	X	
L. texana		X
Munna sp.		X
Neroclia lanceolata		X
Sphaeroma quadridentatum		X
Order Amphipoda		
Acanthohaustorius sp.	X	
Ampelisca holmesi	X	X
A. vadorum	X	X
Amphilochus sp.		X
Batea catharinensis	X	X
Caprella sp.	X	X
Order Amphipoda (continued)		
Cerapus tubularis		X
Corophium acherusicum	X	X
C. sp.		X
Elasmopus rapax	X	
Erichthonius brasiliensis		X
Haustorius sp.	X	
Hemigena minuta		X
Hyperiidae		X
Lembos sp.		X
Listrella clymenella	X	X
Microprotopus raneyi	X	
Monoculoides nyei	X	X
Orchestia platensis	X	
Protohaustorius sp.	X	X
Stenothoe minuta	X	X
S. sp.		X
Synchelidium sp.	X	X
Order Decapoda		
Acetes americanus		X
Albunea pareti		X
Alpheus sp. a		X
A. sp. b		X
Calappa sulcata		X
Callinectes sapidus	X	X
C. similis	X	X
C. sp.	X	
Clibanarius vittatus	X	
Emerita portoricensis	X	
Euceramus praelongus		X
Eurypanopeus abbreviatus		X
Hepatus epheliticus		X
H. sp.		X
Hexapanopeus angustifrons	X	X
H. paulensis		X

APPENDIX 1 (continued)

	Timbalier Bay	Offshore Waters
Order Decapoda (continued)		
Isocheles wurdmanni	X	X
Labina dubia	X	
Latreutes fucorum		X
L. parvulus	X	X
Leander tenuicornis		X
Libinia dubia		X
Metoporhaphis calcarata		X
Neopanope texana		X
Ogyrides alphaerostris		X
O. limicola	X	X
Ovalipes guadulpensis	X	X
Paguridae	X	
Paguristes hummi		X
Pagurus annulipes	X	
P. longicarpus	X	
P. pollicaris	X	X
P. sp.		X
Palaemonetes vulgaris	X	
Panopeus herbstii	X	
Penaeus aztecus	X	X
P. duorarum	X	
P. fluviatilis	X	X
P. setiferus	X	
Persephona crinita		X
P. punctata		X
P. sp.		X
Petrochirus diogenes		X
P. bahamensis		X
Pilumus pannosus		X
Pinnixa cristata		X
P. sp.		X
Porcellanidae		X

	Timbalier Bay	Offshore Waters
Order Decapoda (continued)		
Porcellana sayana		X
Portunidae		X
Portunus gibbesi	X	X
P. spinimanus		X
Processa hemphilli		X
Sicyonia brevirostris		X
S. dorsalis		X
Synalphaus townsendi		X
Trachypenaeus constrictus	X	X
T. similis	X	X
Upogebia sp.		X
Xanthidae	X	
Xiphopeneus kroyeri	X	
Phylum Ectoprocta		
Acanthodesia sp.		X
Bugula neritina	X	X
Membranipora sp.		X
Phylum Echinodermata		
Class Asteroidea		
Astropecten duplicatus		X
Luidia clathrata		X
Class Echinoidea		
Arbacia punctulata		X
Class Ophiuroidea		
Ophiuroidea		X
Phylum Chordata		
Class Tunicata		

	Timbalier Bay	Offshore Waters
Class Tunicata (continued)		
Ascidians		X
Class Pisces		
Anchoa hepsetus	X	X
A. lyolepis	X	X
A. mitchilli		X
A. nasuta		X
A. sp.		X
Anquilliformes	X	X
Antennarius radiosus		X
Archosargus probatocephalus		X
Arius felis	X	
Bagre marinus	X	
Bairdiella chrysura		X
Balistes capriscus		X
Bothidae		X
Brevoortia patronus	X	
Caranx crysos		X
C. hippos	X	X
Carcharhinus leucas		X
Canthidermis sufflamen		X
Centropristis ocyurus		X
C. philadelphicus		X
Chaetodipterus faber	X	X
Chloroscombrus chrysurus	X	X
Citharichthys spilopterus		X
Clupeidae	X	
Cynoscion arenarius	X	X
C. nebulosus	X	
C. nothus	X	X
Dasyatis sabina	X	
Diplectrum bivittatum		X
Dorosoma cepedianum	X	
Etropus crossotus	X	X
Eucinostomus argenteus		X
Class Pisces (continued)		
E. gula		X
Halieutichthys aculeatus		X
Harengula pensacolae	X	X
Hypleurochilus geminatus		X
Lagodon rhomboides	X	X
Larimus fasciatus	X	X
Leiostomus xanthrus	X	X
Lutjanus campechanus		X
L. griseus		X
L. synagris		X
Membras martinica	X	
Menticirrhus americanus	X	X
Micropogon undulatus	X	X
Mugil curema	X	
Myrophis punctatus	X	
Ogcocephalus parvus		X
Ophidion welshi	X	
Opisthonema oglinum	X	X
Orthopristis chrysopterus	X	X
Paralichthys lethostigma		X
Peprilus alepidotus	X	X
P. burti	X	X
Polydactylus octonemus	X	X
Pomatomus saltatrix	X	X
Pontinus longispinis		X
Porichthys porosissimus		X
Prionotus pectoralis		X
P. roseus		X
P. rubio	X	X
P. salmonicolor		X
P. scitulus	X	
P. sp.	X	X
P. tribulus	X	X
Rhizoprionodon terraenovae	X	
Saurida brasiliensis		X

APPENDIX 1 (continued)

	Timbalier Bay	Offshore Waters
Class Pisces (continued)		
Sciaenidae	X	
Scomberomorus maculatus	X	
Selene vomer	X	X
Serranidae		X
Sphoeroides parvus	X	X
Stellifer lanceolatus	X	
Stenotomus caprinus		X
Syacium gunteri		X
Symphurus civitatus	X	X
S. plagiusa		X
Syngnathus louisianae	X	
Synodus foetens	X	X
Trachurus lathami		X
Trichiurus lepturus		X
Urophycis floridanus		X
Vomer setapinnis	X	X