SIGNIFICANCE OF DISTRIBUTION PATTERNS OF PLANKTONIC COPEPODS IN LOUISIANA COASTAL WATERS AND RELATIONSHIPS TO OIL DRILLING AND PRODUCTION

by James P. Marum

ABSTRACT

Zooplankton collections were made in the OEI area and in two additional Gulf of Mexico coastal areas to determine distribution patterns of holoplankton (single species copepod populations, diversity, biomass) and their relationship to long-term oil drilling and production. The plankton community in Timbalier Bay was found to consist of coastal-neritic and estuarine species, and a community in the inner shelf consisted of oceanic, slope-oceanic, shelf, and coastal-neritic species. Only limited faunal exchange appears to take place (except during severe spring floods) between Timbalier Bay and the adjoining shelf, because of a shallow sill, low tidal amplitude, and barrier islands.

In comparing the collections at the two oil producing platforms with their respective controls, no significant differences (F-test) were found between means of copepod single species populations (abundant species), diversity index values, or total biomass. When the data were subjected to two-way analysis of variance (stations $\times$ sampling dates), differences in counts (log-transformed) of abundant species between platforms and controls were never significant, while seasonal differences were always greater and usually significant. Seasonal variability, which simultaneously was affecting both platforms and controls, is a

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major controlling factor in zooplankton populations in this area. Copepod species composition of the OEI area is typical of coastal waters of the northern Gulf of Mexico, and apparently has not changed since limited records were made in 1952 and 1956. Offshore biomass values were high for neritic waters of the Gulf of Mexico (>0.3 g/m^3); studies in 1937 showed that this phenomenon is due to high primary productivity associated with Mississippi River runoff. These results and observations were interpreted as indicating that there have been no major changes in the quantity or composition of zooplankton in the OEI study areas as a result of long-term oil drilling and production. The hydrographic complexity of the area, however, could effectively mask localized short-term pollution damage, such as from an oil spill, to a portion of a zooplankton population.

INTRODUCTION

A zooplankton study was undertaken as part of the Offshore Ecology Investigation (OEI) in order to determine major distribution patterns of planktonic copepods and possible relationships to long-term oil drilling and production. Quantitative information is lacking on the extent and seasonality of faunal exchange between Gulf of Mexico coastal and estuarine waters, although it has long been known qualitatively that plankton zonation occurs in the Gulf of Mexico (Grice 1957) and other temperate and subtropical waters (Bowman 1971). Because coastal waters are characterized by rapid and large-scale physical and chemical variations, it is necessary to understand the normal distribution patterns for these parameters before one can fully evaluate pollution-caused stresses.

Low levels of pollution occurring over a number of years may adversely affect plankton populations in one or more of the following ways: increased numbers of the more resistant species, increased or decreased biomass, absence or decrease in numbers of the less resistant species, a shift in equitability toward uneven distribution, decrease in diversity index, and increase in patchiness of distribution. Long-term effects of pollutants on plankton (Odum et al. 1963) and fish (Bechtel and Copeland 1970) communities have been reported as occurring in some partially enclosed water bodies, such as in Galveston Bay near the Houston ship channel. Field evidence regarding the effects on plankton communities of chronic oil pollution in coastal waters is lacking. The study reported on herein was undertaken to provide a better understanding of this relationship.

METHODS AND MATERIALS

Locations of stations

A series of 20 stations was established (figure 1), spaced in such a way that a transect was formed connecting upper Timbalier Bay with the neritic waters 29 km from shore. Collections were made during eight sampling trips over an 18-month period in 1972-1974. One of the offshore stations (54A) and one of the bay stations (7) were within 100 m and 30 m, respectively, of oil production stations. An offshore control station (15A) and a bay control station (12) were established for faunal comparisons with the platform stations.

In Timbalier Bay, the oil platform was a tank battery located near the Philo Brice Islands. This platform was chosen because it was the only permanent platform in upper Timbalier Bay. Choosing a control station for Timbalier Bay was difficult, because of the great amount of oil industry activity throughout the bay. Capped oil and gas wells, and signs of previous drilling and production, were present at many places throughout the bay, and drilling rigs were frequently seen operating in the bay. Because it was virtually impossible to select a control station in the bay that had not been exposed to oil industry operations at some time during the previous twenty years, a control station was selected 9 km southeast of the platform, a location that appeared to have undergone little oil industry activity over the course of this study.

The offshore control station was 22 km northeast of the offshore platform. The platform was located approximately in the center of a group of six platforms occupying a 32 km^2 area. No platform was within 7 km of the control station.

To compare the zooplankton of the OEI study area with that of other Northern Gulf of Mexico areas having little or no oil exploration, six additional stations were established, three off the Texas coast sampled in July 1973, and three off the Mississippi coast sampled in October 1973. The Texas stations were 475, 350, and 250 km west of the OEI area, and the Mississippi stations were east of the Mississippi River along a transect extending toward the Chandeleur Islands, designed to be as close as possible to the OEI shelf transect in length, depth range, and salinity range.

Sample collection

Quantitative zooplankton collections were taken with 202 micron (#8) mesh nets with 0.6-meter mouth opening, and having a 5 to 1 net length-to-mouth diameter ratio. Flow meters (TSK) were centered in each net mouth. When opening-closing tows were taken for sampling discrete depths, General Oceanics opening-closing mechanisms (Niskin and Jones

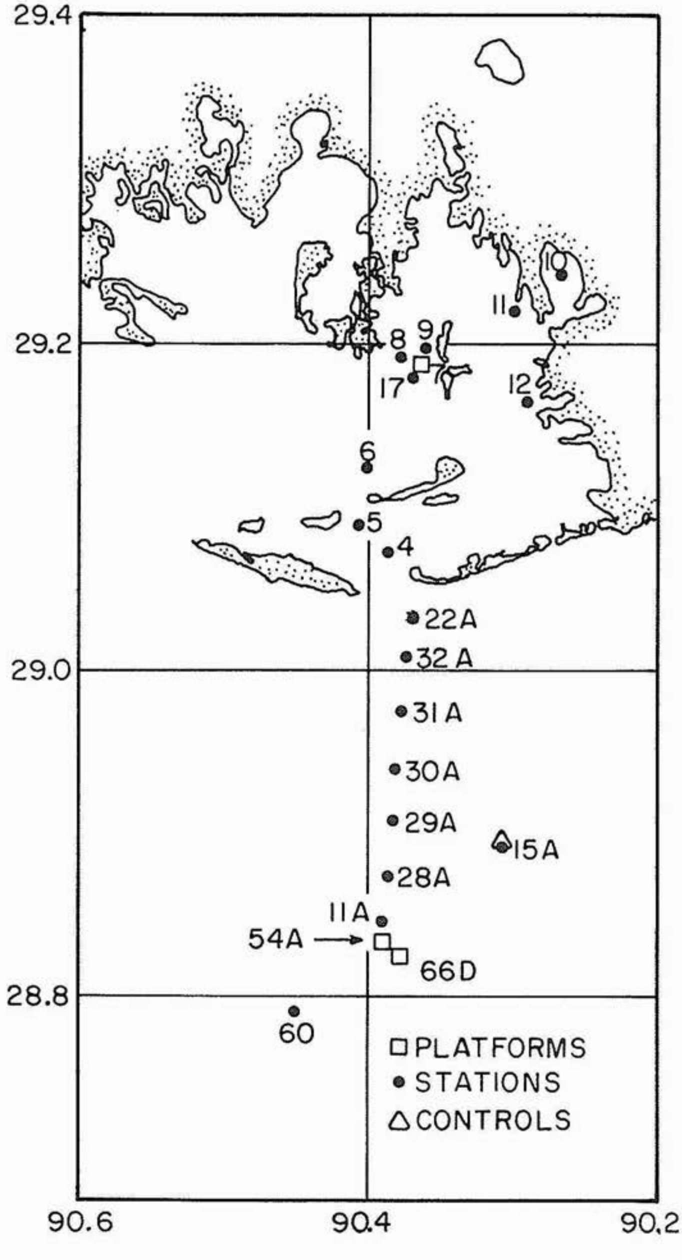

FIG. 1. LOCATIONS OF OEI ZOOPLANKTON STATIONS.

1963) were used with the nets. Some additional collections were taken with 116 micron (#12) mesh nets for determining net loss through the #8 mesh nets.

Attempts were made to take at least one sample over the entire water column at each station during each sampling trip. Because of inclement weather, however, particularly during winter months, sometimes the entire complement of samples was not obtained. Nearly complete complements of samples were collected on eight sampling trips, while the Timbalier Bay stations were sampled on a ninth trip.

Because Timbalier Bay is shallow (average depth, 1.8 m) and well-mixed, only horizontal surface tows were taken at the 10 bay stations. Because of large concentrations of ctenophores and detritus, tow times in the bay were limited to four minutes to avoid clogging. Approximately 50 m^3 of water were filtered in a four-minute tow.

Vertical tows over the entire water column were taken at offshore stations. Vertical tows consisted of a series of 7 to 10 round trip samplings of the water column while the ship was at anchor. With this procedure, sampling took place on the downward tow (with the net inverted) as well as on the upward tow. Seven to ten round trip tows were required to filter 50 m^3 of water. When sea states were high, vertical tows became unmanageable and oblique tows were used. With oblique tows, three depths were sampled, each for two minutes.

Opening-closing tows were taken at selected offshore stations to determine vertical distribution patterns. Three depths were sampled: surface, mid-depth, and bottom. All samples were preserved in 5% formalin buffered in sea water.

Laboratory methods

In the laboratory, samples were placed on #12 netting (116 μ), rinsed for five minutes with fresh water, and voided of interstitial water by allowing samples to drain on several pieces of absorbent paper toweling until more than 50% of the towel surface area beneath the plankton was dry after approximately three minutes. Samples were then weighed on a triple-beam balance. Because Timbalier Bay collections contained large amounts of detritus and ctenophore parts, biomass determinations on bay samples were limited to those few samples in which detritus and ctenophore parts were of minimal importance (determined by microscopic inspection).

Aliquots of the samples were taken with a modified Hopkins subsampler (Hopkins 1962) in preparation for counting. Each aliquot was 1/20 of the original volume. From 1/20 to 1/400 of a sample was counted, depending upon the size of the sample. Three identical aliquots were counted for each sample and the average count was used for determining numbers per cubic meter of water filtered. Depending upon the evenness of the distribution, 400 to 1500 (av. 750) copepods were counted. Approximately 10,000 additional individuals were examined in each sample in searching for rare species. Samples were counted and stored in 70% isopropyl alcohol.

Copepods were identified and counted at species level. Ninety-three copepod species were identified: 44 calanoids, 28 cyclopoids, 17 harpacticoids, and 4 caligoids (Marum 1974).

Name changes from previous reports were required in some cases because species once thought to be found worldwide are now considered to consist of distinct Atlantic and Pacific species (T. E. Bowman, personal communication). Thus, *Centropages fucatus* has become *C. velificatus* (Oliveira).

Bowman (1971) recognized three distinct species in the *Paracalanus parvus* group L: *P. parvus* (Claus), *P. indicus* (Wolfenden), and *P. quasimodo* (Bowman). He indicated that many of the specimens previously reported from tropical and subtropical waters labeled as *P. parvus* are either *P. indicus* or *P. quasimodo*. Both of these species were identified from the OEI collections, but both were counted together as *P. indicus,* the dominant species.

Some of the harpacticoid species were probably benthic harpacticoids. However, because each of these species occurred in more than one sample, I decided to include them as part of the plankton. In addition, several caligoid species (fish parasites) were counted as plankton. This is because they were found in more than one sample, and as Wilson (1932) indicates, are frequently freely swimming in the water column in search of new hosts.

Statistics and community indices

In preparation of statistical analyses, all counts were standardized to numbers of individuals per cubic meter. The numbers/m^3 were then logarithmically transformed prior to analysis of variance. Two-way analysis of variance was used to examine spatial and temporal variations along the transect and between oil platforms and controls. Linear and quadratic regression equations were developed and tested for significant inshore-offshore trends.

A method of grouping together species with similar inshore-offshore distribution patterns was developed (Marum 1974). I evaluated the data by applying the following criteria: (1) frequency of occurrence in Timbalier Bay and offshore, (2) stations at which maximum numbers occurred, and (3) presence of significant linear and quadratic trends.

Species diversity was determined by the Shannon-Weaver (1963) information content index. Despite some criticisms of this method

(Hurlbert 1971), the Shannon-Weaver index is useful because it is dimensionless, is nearly independent of sample size, expresses the relative importance of each species, and is widely used by marine ecologists. To correct for sample size, the Basharin (1959) correction was subtracted from the Shannon-Weaver value. Faunal affinity between samples was determined by the Morisita (1959) index.

Sources of error

Three types of potential error were investigated as part of this study: (1) laboratory subsampling (aliquoting) error, (2) error due to variability of replicate tows, and (3) organism loss through the 202-micron mesh net. Results of tests on reproducibility of the aliquoting procedure revealed low coefficients of variation (±10%) when 17 or more individuals were present in the counting tray, but dramatically increased variation (>40%) when there were fewer than 10 individuals counted per tray (Marum 1974). Although large errors from the aliquoting procedure may occur with the rarer species, these results are not thought to alter significantly the community structure analysis, because I found that species having low counting errors accounted for 98% of the total individuals.

Variability of replicate tows was determined for numbers of individuals of abundant species, diversity index, biomass, and faunal affinity index (table 1). Coefficients of variation (c.v.) for counts of abundant species ranged from 6% to 32% with an average of 16.5%. The average c.v. for diversity was 10% and the c.v. for biomass was also 10%. Furthermore, there was some evidence that replicate tow variability in the bay (stations 12, 4) was greater than variability offshore (station 54A), although data were limited. For example, c.v.'s of species counts in the bay ranged from 17% to 32%, while c.v.'s for offshore species counts ranged from 6% to 14%.

There have been reports of zooplankton loss through all mesh sizes except the very smallest (Hopkins 1966; Deevey 1971). The loss of organisms in estuarine and coastal waters can be large, because estuarine and coastal organisms are generally smaller than oceanic zooplankton. In order to estimate the loss of zooplankton through the 202 micron (#8) mesh, seventeen paired tows were taken with #8 mesh (202 μ) and #12 mesh (116 μ) during January 1974. The results are presented in table 2. It is evident that loss is greatest for those copepods having body volumes less than that of *Acartia tonsa*. *Acartia tonsa* is approximately 1 mm in length, and therefore those copepods less than 1 mm in length are probably not efficiently sampled by a #8 mesh net. Of those organisms not efficiently sampled, *Sapphirella* sp., *Oithona brevicornis*, and *Paracalanus crassirostris* are coastal species (i.e., they are present both in

TABLE 1. Variability of replicate tows. These data were obtained from 6 tows near offshore station 54A in July, 1973, 5 tows at bay station 12 in February, 1973, 4 tows at bay station 4 in July, 1973, and 3 tows at bay station 7 in June, 1973.

Parameter	$\bar{x}$	$\pm$	S.D.		c.v.	n
SPECIES						
Acartia tonsa	6095.	$\pm$	442.		7.	6
	2440.	$\pm$	783.		32.	5
	21700.	$\pm$	4958.		23.	4
Paracalanus indicus	380.	$\pm$	54.		14.	6
Centropages velificatus	164.	$\pm$	10.		6.	6
Paracalanus crassirostris	145.	$\pm$	25.		17.	4
Average			$\bar{x}$	=	16.5	
DIVERSITY INDEX (H')						
for n = 6	0.494	$\pm$	0.057		12.	6
for n = 5	0.259	$\pm$	0.043		17.	5
for n = 4	0.153	$\pm$	0.011		7.	4
for n = 3	0.453	$\pm$	0.022		5.	3
Average			$\bar{x}$	=	10.2	
BIOMASS						
for n = 6	0.329	$\pm$	0.024		7.	6
for n = 4	0.440	$\pm$	0.064		14.	4
Average			$\bar{x}$	=	10.5	
FAUNAL AFFINITY INDEX ($C\lambda$)						
for n = 6[1]	0.9996	$\pm$	0.0004		0.04	15

[1] $C\lambda$ values were determined for all possible pairs of samples. Hence, the mean and standard deviation are computed from 15 values.

TABLE 2. Comparison of average catch of copepods from 116 μ (#12) and 202 μ (#6) mesh nets.

Species	#12	#8	Loss (°/o)	Relative volume[1]
Sapphirella sp.	3810	20	99.	7
Oithona brevicornis	1769	0	100.	10
Paracalanus crassirostris	6063	401	95.	15
Oithona nana	218	0	100.	20
Acartia tonsa	4890	3555	27.	100
Paracalanus indicus	511	405	21.	135
Temora turbinata	468	378	19.	214
Centropages velificatus	25.6	26.7	0.	349
Eucalanus pileatus	242	227	6.	688
Labidocera aestiva	79	59	25.	766
Undinula vulgaris	6.7	9.3	0.	2039

[1] Relative to *A. tonsa*, which equals 100. Volume values taken from Grice 1957, p. 60.

the bay and offshore). *Oithona nana,* a shelf species, does not regularly occur in Timbalier Bay and so it was lost only in offshore collections.

Samples with the #12 net showed that 33% of the total numbers were small (< 1 mm) species offshore, while 40% were small species in the bay. It is possible that losses of small species were even greater than indicated if loss occurred through the #12 mesh. Although loss of numbers influences diversity and faunal affinity measurements, this type of error affects accuracy only, and therefore comparisons between stations in this study remain valid. Furthermore, sampling with the smaller mesh sizes greatly increases the chances for errors of precision, because of the potential for clogging (Yentsch and Duxbury 1956).

RESULTS

Distribution of single species populations

Eighty-four copepod species were identified from the offshore collections, while 43 species were identified from Timbalier Bay collections. Of the 93 total species, 36 were present offshore but not in Timbalier Bay, nine were present in Timbalier Bay but not offshore, and 48 were present both offshore and in Timbalier Bay.

Offshore, the numerically abundant species were (in order of decreasing abundance): *Acartia tonsa*, *Temora turbinata*, *Paracalanus indicus*, *Paracalanus crassirostris*, *Eucalanus pileatus*, *Centropages velificatus*, *Oncaea venusta*, and *Paracalanus aculeatus*. In Timbalier Bay, the numerically abundant species were *Acartia tonsa*, *Paracalanus crassirostris*, *Pseudodiaptomus coronatus*, *Labidocera aestiva*, and *Tortanus setacaudatus*. Distribution by station and season is given in Marum (1974).

On the average, offshore samples contained three times the number of individuals as Timbalier Bay samples (7700/m^3 vs. 2600/m^3). Total numbers of copepods of single samples ranged from 32,000 to 52,000/m^3 offshore and from 11,000 to 69,000 in Timbalier Bay. Maximum abundances were observed in the warmer months. The average number of specimens occurring from April to September was five times greater than from October to March (12,500/m^3 vs. 2,500/m^3).

A persistent trend of copepod zonation was evident along the length of the transect. Species that were present in the upper part of Timbalier Bay were replaced at offshore stations with marine species. Zonation of zooplankton, particularly zonation along a salinity gradient, has been reported extensively in many previous investigations. In this study, using the method described in Marum (1974), the distribution of species along the inshore-offshore transect was found to occur in four general types of patterns: (1) species restricted to Timbalier Bay waters (estuarine species), (2) species present along the entire transect, with maximum numbers at the estuarine-marine transition zone (coastal species), (3) species present in lower Timbalier Bay and offshore, with maximum numbers offshore (shelf species), and (4) species restricted to the offshore region (oceanic species). The inshore-offshore trends (seasonal averages) of abundant species are shown in figure 2.

Thus, the copepod fauna of Timbalier Bay and the adjacent offshore region is composed of four more or less distinct groups of species, each group exhibiting distribution patterns similar to other members of the group but unlike distribution patterns of other groups (figure 2). Because these patterns agree with those of previous studies (Fleminger 1956; Bowman 1971), it is probably correct to say that these patterns will be consistently found in tropical and sub-tropical waters.

Each net collection was composed of copepod fauna of two or more of the groups, i.e., the upper part of Timbalier Bay contained estuarine and coastal faunas, the lower part of Timbalier Bay had estuarine, coastal, and shelf faunas, and the offshore region had coastal, shelf, and oceanic faunas. There is evidence in the literature (Bowman 1971; McGowan 1971) that such mixtures of species groups are unique to hydrographically unstable areas, particularly estuarine and neritic waters, and result from mixtures of waters of different origins. In the OEI area, mixtures of species groups were observed both on the horizontal axis and on the vertical axis.

Variations due to seasonal fluctuations changed the basic patterns. Table 3 summarizes variation over the inshore-offshore transect from October 1972 to October 1973. In April 1973 the influence of the spring floods was already apparent, but the greatest impact of the floods was observed in July 1973. Coastal species were present in such great numbers that they dominated even the offshore collections. By October 1973, however, the waters had again become well-mixed, and the horizontal zonation pattern was similar to that of the previous October.

It became apparent during the course of this study that vertical zonation was frequently more marked than horizontal zonation. Over a vertical distance of a few meters, large variations occurred in total number of copepods, single species populations, diversity, and relative percentages of the species groups. The degree of difference was directly related to the heterogeneity of the water column (table 4). For example, in October 1972 the offshore waters were vertically mixed, although surface waters contained twice as many copepods (10,000/m^3) as mid-depth waters (5,200/m^3), and five times as many as bottom waters (1,800/m^3). Diversities increased with depth, and thus numbers of in-

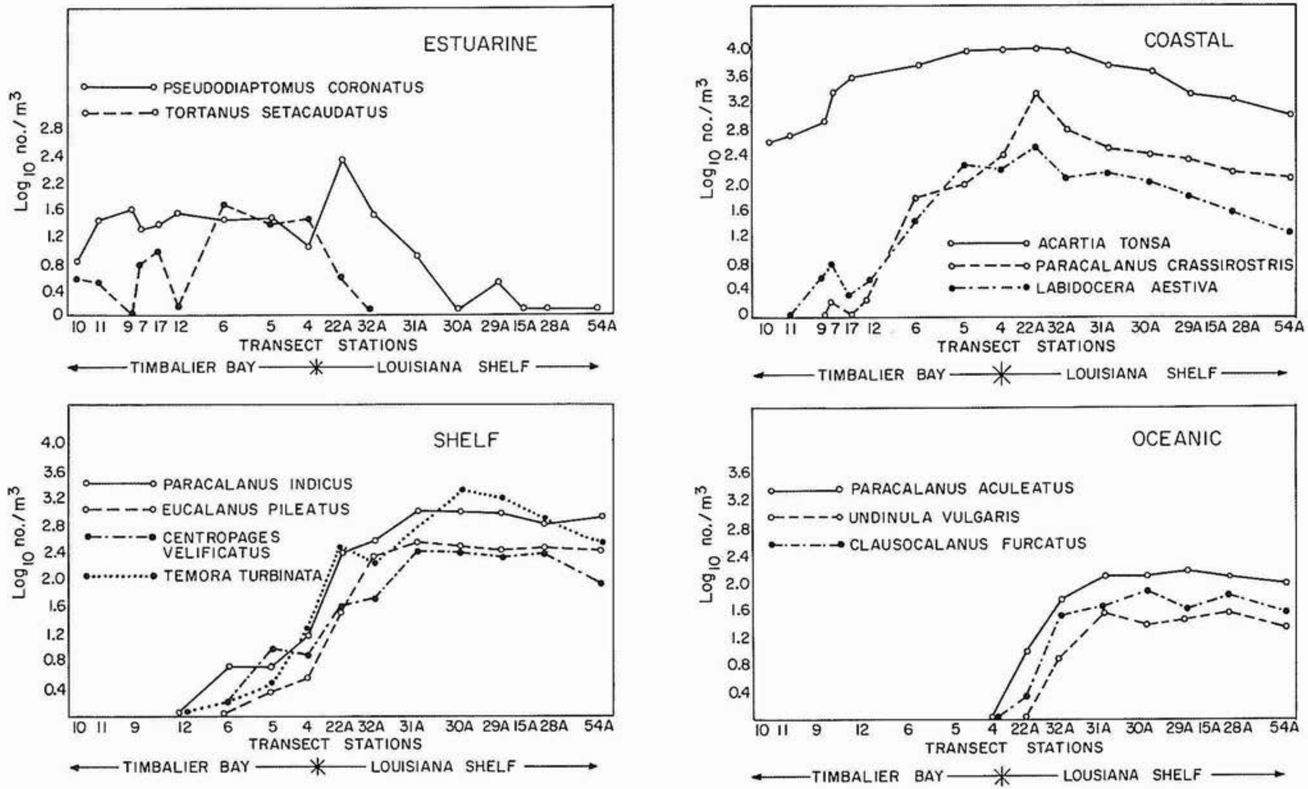

FIG. 2. DISTRIBUTION PATTERNS OF ABUNDANT SPECIES OF THE FOUR SPECIES GROUPS. Data averaged over all seasons.

TABLE 3. Seasonal variation of species groups at points along the transect.

		Percent Composition			
Date	Species Group	Inner Bay	Outer Bay	6 km Offshore	21 km Offshore
Oct. 1972	Estuarine	11	-	-	-
	Coastal	80	83	53	1
	Shelf	9	17	42	76
	Oceanic	-	-	5	23
April 1973	Estuarine	1	1	-	-
	Coastal	99	92	71	49
	Shelf	-	6	24	45
	Oceanic	-	1	5	6
July 1973	Estuarine	-	1	-	-
	Coastal	100	98	98	96
	Shelf	-	-	1	3
	Oceanic	-	1	1	1
Oct. 1973	Estuarine	6	1	0	0
	Coastal	90	89	35	12
	Shelf	4	10	59	69
	Oceanic	-	-	6	19

TABLE 4. Variation of species groups with depth.

		Present Composition		
Date	Species Group	Surface	Mid-Depth (7 m)	Bottom (14 m)
Oct. 1972	Coastal	3%	12%	2%
	Shelf	84%	76%	77%
	Oceanic	13%	12%	21%
July 1973	Coastal	98%	92%	1%
	Shelf	2%	7%	43%
	Oceanic	-	1%	56%

dividuals were inversely related to diversity values. The surface community was similar to the mid-depth community (similarity calculated by Morisita index), which was transitional with the bottom community. Exchange, therefore, was able to take place between surface and mid-depth communities. The mid-depth community was able to exchange only partially with the community at 14 meters.

A very different pattern of vertical zonation was observed in July 1973. Waters were highly stratified, a phenomenon that was reflected in the copepod communities. The surface and mid-depth communities were similar to each other, although dissimilar to the October patterns. The mid-depth community was unlike the bottom community. Therefore, exchange was able to take place between surface and mid-depth communities, but not between mid-depth and bottom communities. Surface and mid-depth waters contained large numbers of zooplankton, most of which were coastal species. In contrast, bottom waters had a much smaller population, composed primarily of oceanic and shelf species.

While a change from one community to another extended usually over a 16 to 25 km distance on the horizontal axis, the same change required only a few meters on the vertical axis. This reflects the hydrographic characteristics of the waters.

Species diversity

Copepod species diversity increased with distance from shore and decreased with distance into the bay. The average diversity of Timbalier Bay collections was 0.45 as compared with 1.62 for offshore collections. Lowest average diversities (both bay and offshore) were in July 1973 and highest in October 1972.

Offshore, diversity increased with depth and the difference between surface waters and bottom waters increased when spring floods carried large numbers of coastal species offshore. In October 1972, when offshore waters were well-mixed, diversities of offshore station 15A were 1.36 at the surface, 1.77 at mid-depth, and 1.83 at bottom. In July 1973, the equivalent values were 0.01, 0.32, and 1.91. The effect of the spring floods on copepod species diversity (H′), including subsequent "recovery" to a more homogeneous community, is shown graphically in figure 3.

Total zooplankton biomass (wet weight) values ranged from 0.66 g/m^3 in January 1974 to 2.57 g/m^3 in July 1973. Average values were lowest in December 1973 (0.179 g/m^3) and highest in July 1973 (0.775 g/m^3).

Biomass was infrequently determined for bay collections because of large concentrations of Ctenophora and detritus. Some Timbalier Bay values were determined, however, but only for those few samples in which the relative amount of detritus and ctenophore parts was insignificant as compared with the amount of non-ctenophore zooplankton. Values were in general lower than offshore biomass values. In addition, values in the upper bay were generally lower than values in the lower bay (stations 4, 5, and 6), and this related inversely to ctenophore biomass. Ctenophores are predators of other smaller zooplankton. A

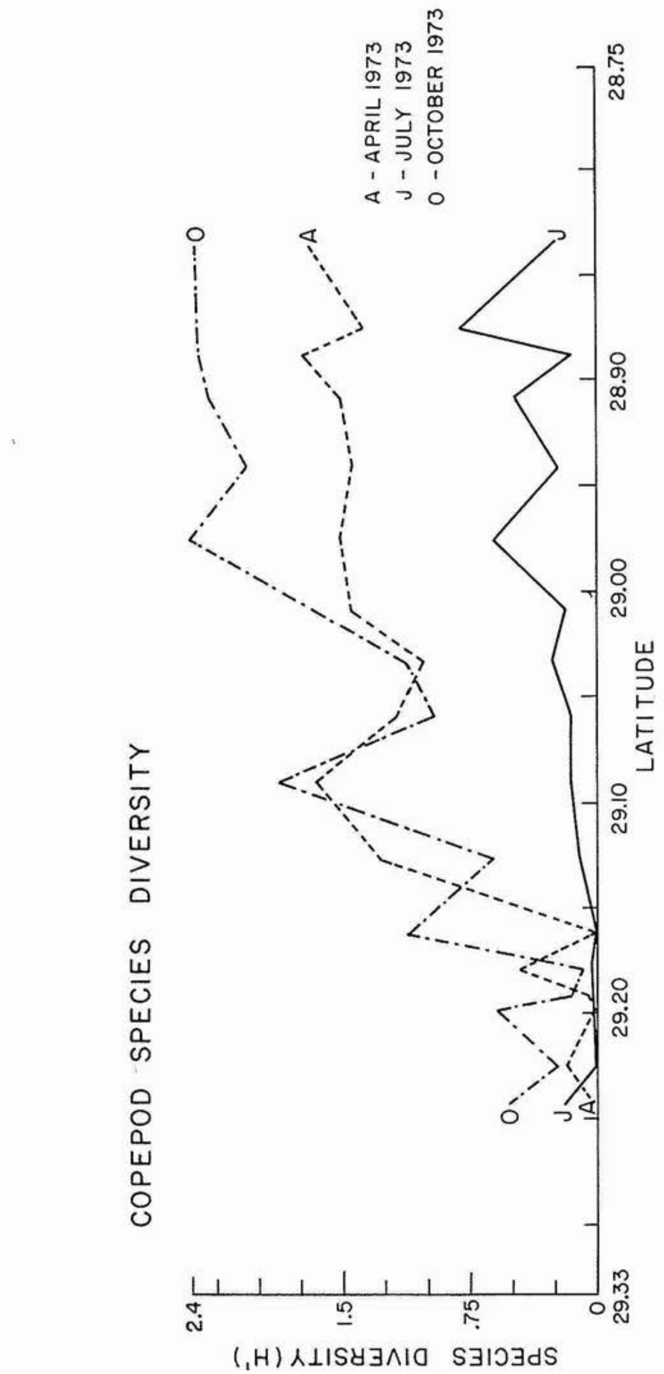

FIG. 3. SEASONAL VARIATION OF COPEPOD SPECIES DIVERSITY OVER THE LENGTH OF THE INSHORE-OFFSHORE TRANSECT.

summary of average biomass and diversity at platforms, reference stations, and other stations is shown in table 5.

Oil platform versus controls

The zooplankton community near the offshore platform (station 54A) was compared with that of the offshore control (station 15A) 10 km from the platform by analysis of variance of copepod single species populations, copepod diversity, and total zooplankton biomass. Species by species comparisons are in Marum (1974) for both bay and offshore comparisons. The eight most abundant species at the control station were the eight most abundant at the offshore platform. This closeness in ranking did not remain constant for species of lesser abundances. However, these differences in rankings are not thought to be due to the presence of the platform because (1) the variations were not consistent, and (2) errors in ranking often occur when one enumerates rare species, as I explained earlier (see also McGowan 1971). A total of 47 species was found at the control, 52 species were found at the platform; 43 of these were found at both locations.

The seasonal variations of abundant species are shown graphically in figure 4. Analyses of variance on log-transformed counts showed no significant differences between platform and control mean values. Seasonal variations were most pronounced and were significant for six of the abundant species. At least two of the species (*A. tonsa*, *T. turbinata*) showed large interaction terms, indicating clumped distribution patterns. But because the patches were not consistently present at either the plat-

TABLE 5. Average biomass and diversity at platforms, controls, and other stations.

Station	Biomass (g/m^3)	Diversity (H')
Offshore		
Platform (54A)	0.350 ± 0.133, n=9	1.60 ± 0.79, n=7
Control (15A)	0.344 ± 0.162, n=9	1.71 ± 0.78, n=7
Other OEI Stations[1]	0.436 ± 0.257, n=40	1.74 ± 0.59, n=37
Timbalier Bay[2]		
Platform (7)	0.090, n=2	0.331 ± 0.355, n=10
Control (12)	0.124, n=2	0.305 ± 0.358, n=10
Other Upper Bay (8,9,10,11,17)	0.065 ± 0.024, n=6	0.392 ± 0.322, n=39
Other Lower Bay (4,5,6)	0.233 ± 0.223, n=10	0.655 ± 0.567, n=25

[1]Stations 31A, 30A, 29A, 28A, 11A, and 60.

[2]Timbalier Bay biomass values are non-ctenophore biomass.

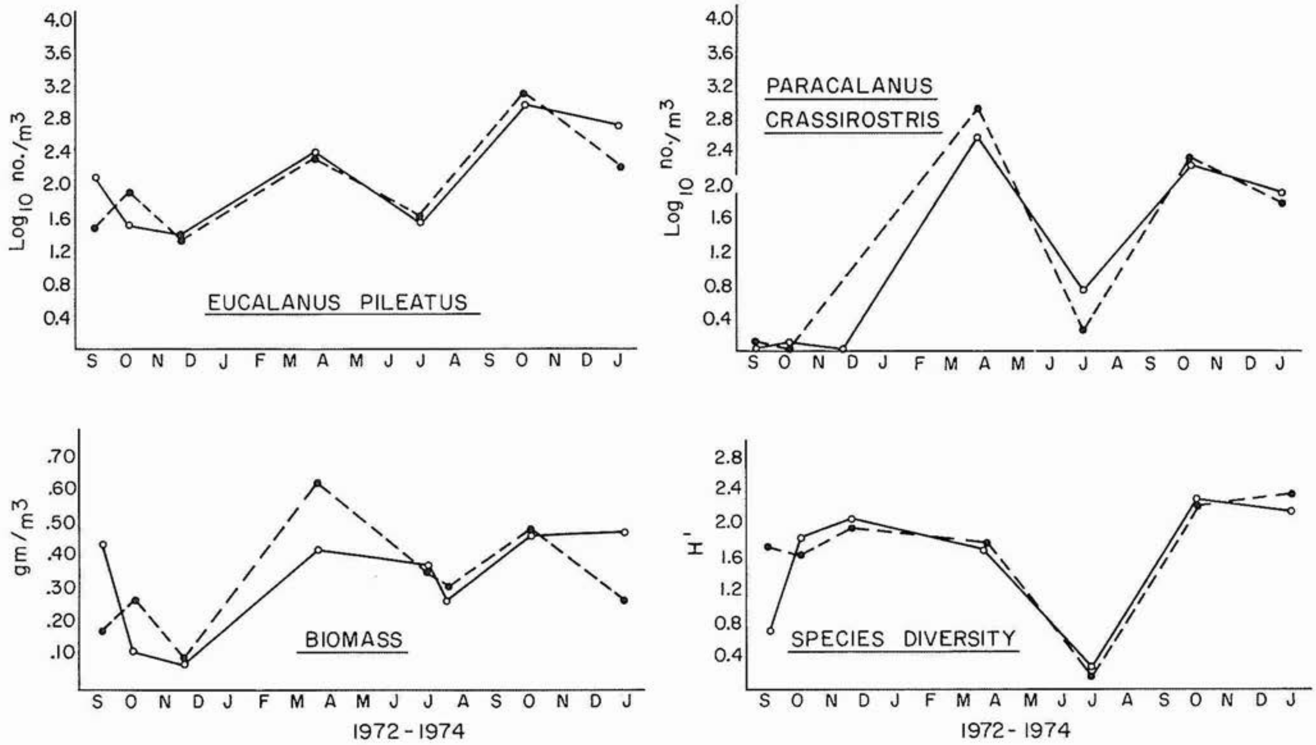

FIG. 4. SEASONAL VARIATIONS OF ABUNDANT COPEPODS, SPECIES DIVERSITY INDEX, AND TOTAL ZOOPLANKTON BIOMASS at offshore platform station 54A (solid line) and offshore control station 15A (dashed line).

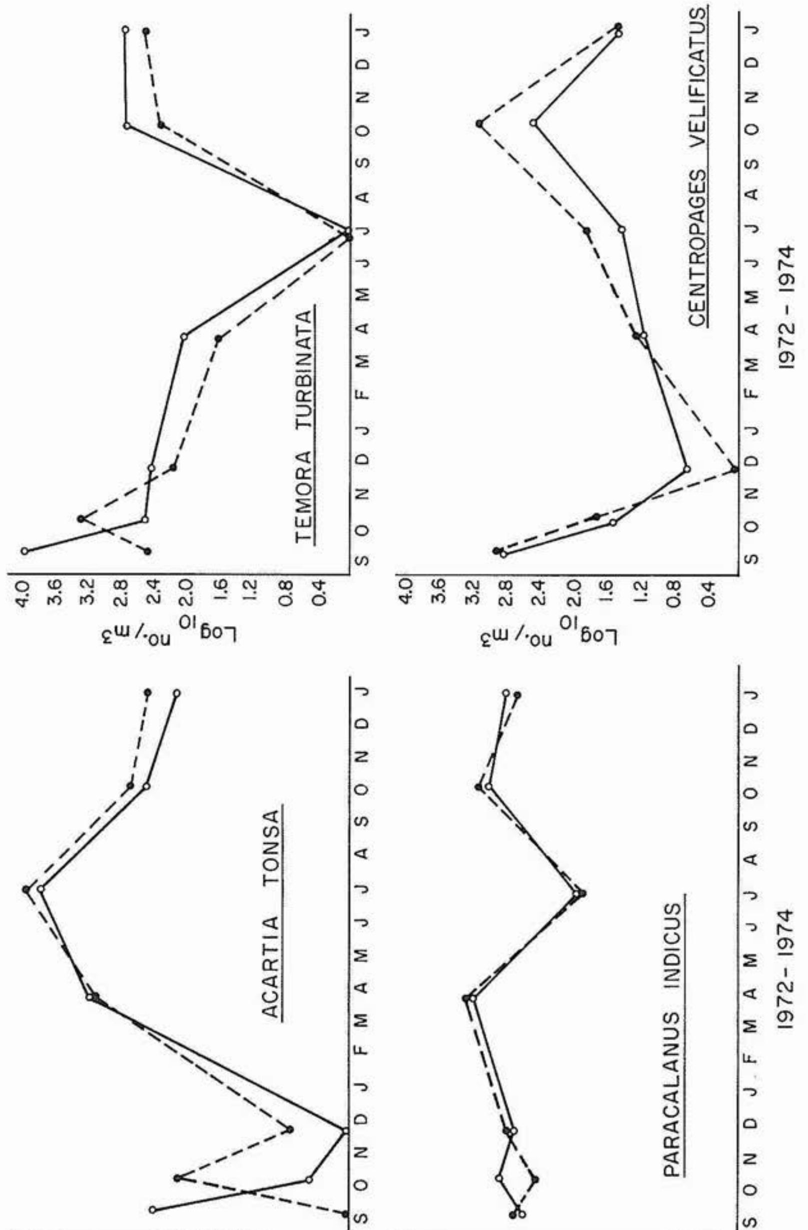

FIG. 4 continued.

form or the control, the mean values between the two stations were similar. Patchiness in single species populations has been observed in several previous studies (e.g., Wiebe et al. 1973) and are normal for estuarine and neritic waters where hydrographic and nutrient fluctuations are large.

Biomass values (wet weight) at Platform 54A and the control were also compared by analysis of variance; mean differences were not significant (figure 4). In addition, there were no significant seasonal differences over the months sampled. Biomass values of the OEI area were typically high for neritic waters in the direct influence of the Mississippi River (Bogdanov et al. 1968). The average biomass value is twice the Gulf shelf average of 1.17 g/m^3 (Arnold 1958) and is reported to be among the most productive in the Gulf (Riley 1937).

Seasonal changes in Shannon-Weaver diversity index are also shown in figure 4. An analysis of variance showed no difference between platform and control values. However, a significant seasonal trend was shown.

In Timbalier Bay, *Acartia tonsa* was by far the most numerically abundant, at both platform (Station 7) and control (Station 12). Of the five most abundant species at the control, four were among the most abundant at the platform. A total of 20 species was found at the control, 21 at the platform, with 15 of these at both locations.

The seasonal variations of *Acartia tonsa* and diversity are shown graphically in figure 5. Although the graphs from the three stations are somewhat similar to each other, there was considerable variability in results, although no significant differences between stations were shown by analysis of variance.

Faunal comparisons with non-drilling areas of the northern Gulf of Mexico

In evaluating the results of faunal comparisons between the OEI area and non-drilling areas off Texas, it is important to note that samples were taken during July 1973, when the impact of the Mississippi and Atchafalaya River plumes was greatest. This fact makes comparisons of the OEI area with outside areas more difficult because another variable, the effect of the plume on zooplankton populations, has been introduced.

The Texas station closest to the OEI area (250 km west) showed high faunal similarity (Morisita index) with OEI stations, indicating that the plume effect extended as far west as 360 km from the Mississippi River. For the other two stations (350 and 475 km west of OEI) there was low faunal similarity with OEI stations. However, these differences are thought to be due to the plume effect and not to oil industry effects

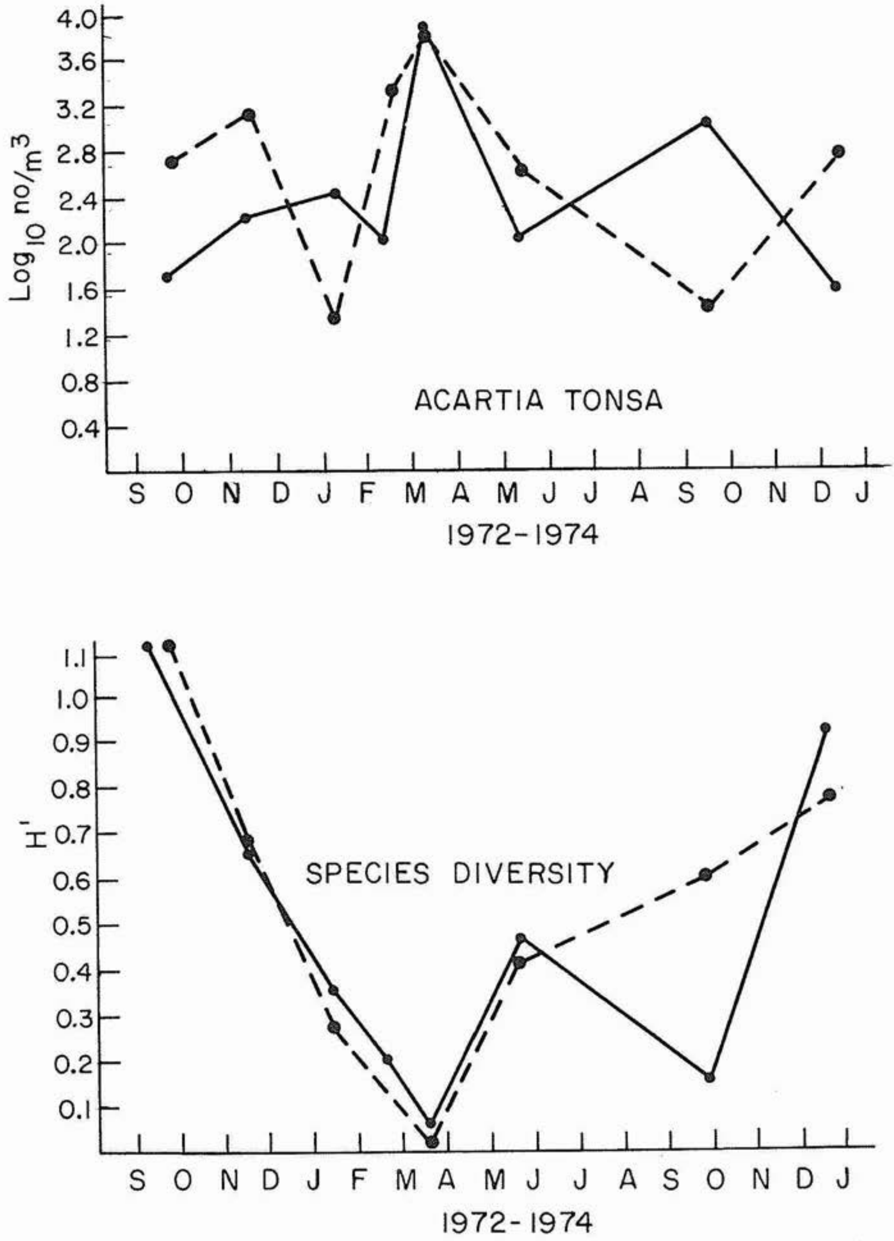

FIG. 5. SEASONAL VARIATIONS OF *A. TONSA* AND SPECIES DIVERSITY INDEX at Timbalier Bay platform station 7 (solid line) and Timbalier Bay control station 7 (dashed line).

because (1) the faunas of stations off the Texas coast were similar to the fauna found in the OEI area under non-stratified conditions, (2) the percentage of *Acartia tonsa* decreased with distance from the Mississippi River, *A. tonsa* being an indicator of low salinity water, (3) all three OEI stations showed similar values regardless of the proximity of an oil platform, and (4) all species found at Texas stations were also found in the OEI area.

DISCUSSION

Based on the faunal analyses, it appears that two separate copepod communities exist in the study area: a bay community composed of estuarine and coastal species, and an offshore community composed of coastal, shelf, and oceanic species. Between the two communities along the transect is a transition population composed of estuarine, coastal, shelf, and oceanic groups. The transition population is composed of species found either in upper Timbalier Bay or at the stations farthest offshore.

Shelf species exchange into lower Timbalier Bay throughout the year, but are prevented from exchanging into upper Timbalier Bay by Casse-tete and Calumet Islands. It is unlikely, however, that shelf species are able to propagate in the lower bay, but must depend upon tidal currents to carry them over the shallow sill. Oceanic species do not exchange into the bay. Estuarine species are generally restricted to Timbalier Bay, but are able to exchange with offshore surface waters during spring flood conditions. The movement of estuarine and coastal species offshore probably occurs every year. However, it is unlikely that the exchange in 1973 would have been so extensive were it not for the magnitude of the 1973 floods. The spring floods resulted in coastal species being moved offshore in such great numbers that they dominated the samples throughout the transect in July 1973. By October 1973, however, the waters had again become well-mixed, the communities had become more equitable, and the horizontal zonation pattern was similar to that of the previous October.

Communities of organisms that are in environmentally unstable areas are sometimes called *physically controlled communities*, where physical conditions fluctuate widely and the organisms are primarily adapted to stresses from the physical environment.

Community changes were much more pronounced through the water column offshore than over the inshore-offshore transect. While a change from one community to another extended usually over a 16 to 25 km distance on the horizontal axis, the same change required only a few meters on the vertical axis. This reflects the hydrographic characteristics of the waters. For example, a salinity change of 12 ppt over the horizontal axis covered 45 km, while a similar salinity change on the vertical axis occurred over a distance of a few meters.

Evidence presented shows that a wedge of shallow bottom water (underlying the surface layers) contains residual populations of oceanic species, which are probably present year-round regardless of surface phenomena. Therefore, it is not necessary to assume that oceanic incursions take place (e.g., from the Loop Current) in order for repopulation of surface waters to occur. A simple mechanism, involving only vertical mixing of the water column following breakdown of stratified conditions, is sufficient to explain the recovery of oceanic zooplankton fauna in surface waters. Thus, although this offshore ecosystem undergoes severe natural stresses, it is stable in the sense that the "resident" populations persist, if only in small numbers, in undisturbed wedges of water below the surface.

With regard to comparisons of fauna between oil platforms and reference areas, the evidence indicates that seasonal variations are substantially greater than variations that can be related to the presence of an oil platform or its associated activities. Seasonal fluctuations in the OEI area appear to be typical of coastal regions. Both the timing and the magnitude of the seasonal cycle in the OEI area are similar to other observations in the northern Gulf of Mexico, e.g., Cuzon du Rest (1963), Hopkins (1966), and Bogdanov et al. (1968).

A review of the species list from a sample collected in February 1952 in the OEI study area (28°54′N, 90°11′W) revealed that 20 of 23 calanoid copepods reported by Fleminger (1956) were found in spring collections from the OEI study area, and 22 of 23 were found in all OEI collections. Moreover, there were several species found in OEI collections that are not found in the 1952 collections, although this fact does not necessarily mean that they were not present in the area in 1952.

An attempt was made to compare the data of Cuzon du Rest (1963), collected east of the Mississippi River in 1959-1961, with the data from Timbalier Bay. Sub-area 3 in that study is similar in hydrography to Timbalier Bay, and there had been little or no oil drilling in sub-area 3 prior to the collections. Because of differences in collection sites, collection techniques, and presentation of the data, it was difficult to make rigid comparisons. Nevertheless, it is instructive to note that *Acartia tonsa* was the dominant copepod and was far more abundant than any other species. The list of other important copepod species from Cuzon du Rest was in reasonable agreement with that of Timbalier Bay collections. It should be pointed out that comparisons of OEI data with historical data are useful only as an indication that no gross effects have occurred in the copepod community as a result of the Louisiana oil drilling and production.

CONCLUSIONS

The totality of evidence from this study and the literature indicates that the zooplankton communities of the OEI study area (1) are similar to those of other northern Gulf of Mexico areas; and (2) have not changed over the past twenty years. In addition, there is no evidence of differences in zooplankton biomass or community structure between the waters of oil platforms and control waters. However, the OEI area is subject to extreme environmental fluctuations, primarily due to the runoff of the Mississippi River, which is carried in and out of the area by the complex patterns of tides and currents. If there were temporary changes in the zooplankton community structure caused by localized oil pollution, they could be effectively masked by the variability caused by the river.

ACKNOWLEDGMENTS

This work represents part of the fulfillment of the Ph.D. degree requirements at Florida State University. I thank the following persons for assistance during this investigation: Robert J. Menzies, for guidance and direction; James I. Jones, for loan of the equipment to make the collections; Thomas E. Bowman, for confirmation and identification of calanoid copepods; Frank Ferrari, for confirmation and identification of cyclopoid copepods; and Allen Z. Paul, for review of the manuscript. This work was supported by Gulf Universities Research Consortium grant number OB55HJM to Robert J. Menzies and James P. Marum.

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