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The Cumulative Ecological Effects of Normal Offshore Petroleum Operations Contrasted With Those Resulting From Continental Shelf Oil Spills [and Discussion]

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The cumulative ecological effects of normal offshore petroleum operations contrasted with those resulting from continental shelf oil spills

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Assessments of the cumulative ecological effects of chronic sublethal discharges from normal (non-spill) offshore petroleum operations have been based on (1) model studies, (2) controlled laboratory and microcosm experiments, (3) studies of spills of crude oil and its refined products and of severe organic pollution, and (4) ecological field studies in areas of intensive petroleum operations. Methods (2) and (3) involve (*a*) the extrapolation of results obtained from concentrations and rates of exposure that are not representative of chronic low-level exposure, (*b*) usually a different suite of chemical contaminants, and (*c*) usually a different ecosystem. The fourth method is faced with determining the ecological effects of very low levels of contamination in the presence of larger natural environmental and biological variations and of other sources or types of contamination.

This paper compares predictions based on method (3) with results obtained by using method (4) in the Gulf of Mexico. Primary data are from three studies on cumulative effects and from studies of spills in the Gulf. The response of benthic macroinfaunal communities and populations to sediment hydrocarbon concentrations are the primary basis for comparisons. Some principal environmental variables are 'normalized' to facilitate quantitative comparisons.

1. Rationale

The principal concern pertaining to ecological effects of normal offshore petroleum operations is that ecological damage might result from 'cumulative effects' of chronic low-level discharge of hydrocarbons in produced brine. This concern is enhanced by projections based on studies of spills of crude oil or its refined products, and by the hypothesis that three critical processes will take place:

(i) that hydrocarbons will be adsorbed on suspended particulates or incorporated into the faecal pellets of the biota and thus transported to, and retained in, bottom sediments,

(ii) that the accumulation of hydrocarbons by these means over long times will result in concentration in the bottom sediments to toxic or stressful levels, and, if so,

(iii) that damage to the macroinfauna will occur and will be evident from changes in their diversity, abundance and community structure and in the occurrence of dominant populations of 'indicator species'.

Numerous uncertainties regarding long-term cumulative effects have been documented by the Royal Society (1980) and the U.S. Interagency Committee on Ocean Pollution Research, Development and Monitoring (1981), including whether or not the processes and biotic responses actually take place as hypothesized on the basis of short-term spill studies.

In the following investigations, these hypotheses are tested by using synthesized extant data from (*a*) field studies on cumulative effects conducted in areas of intensive and prolonged petroleum development, and (*b*) major crude oil spills in the same general area.

2. Data sources

Three comprehensive field studies on cumulative effects have been conducted in the intensively developed continental shelf petroleum province offshore southern Louisiana and southeast Texas:

(1) the Offshore Ecology Investigation (O.E.I.), conducted in southern Louisiana coastal and offshore areas in 1972–4 (Morgan *et al.* 1974; Ward *et al.* 1979),

(2) the Central Gulf Platform Study (C.G.S.), conducted in this same offshore area in 1978–9 but covering a larger experimental area and 20 drilling and production sites (Southwest Research Institute 1980), and

(3) the Buccaneer Field Study (B.F.S.), conducted in the southeast Texas offshore area in 1976–9 (Middleditch 1981).

Each included detailed investigations at drilling or production platforms, or both, in areas where petroleum activities had been intensive for 25 years or more. In combination, they offer data relating to (*a*) point source effects with emphasis on short-term phenomena in the water column and related effects primarily on short-lived planktonic and mobile species, (*b*) point and distributed source phenomena with emphasis on statistical evaluations of contaminant accumulations and the response of immobile species to them, and (*c*) processes of vertical transport of hydrocarbons to, and retention by, bottom sediments, and the response of immobile species.

Data from two major spills are appropriate for comparison with the studies on cumulative effects for hypothesis testing in that (*a*) they occurred in offshore areas of the Gulf, (*b*) they were spills of crude oil, and (*c*) data for all studies include the concentrations of hydrocarbons in the sediments and, excepting one spill, data on the benthic macroinfauna:

(1) the Main Pass Spill (M.P.S.), which occurred on the continental shelf just east of the Main Pass of the Mississippi River in 1970 (McAuliffe *et al.* 1975), and

(2) the Ixtoc 1 Platform Spill, which occurred on the Campeche Sound continental shelf in 1979–80 (Instituto Mexicano del Petroleo 1980).

In addition to these primary data sources, numerous comprehensive data sets for the northwestern Gulf of Mexico resulted from 'baseline', impact and monitoring programmes. These provide similar data for comparable ecosystems with varying levels of petroleum development, at various distances from the cumulative effects studies, and progressive remoteness from the high municipal, industrial and natural biogenic input from the Mississippi River and the vast Louisiana marshlands.

3. Investigative procedures

The procedures for carrying out the investigations involved, first, the access of the required extant data that relate to the transport and accumulation of hydrocarbons in the sediments and to the response of the macroinfauna to hydrocarbon concentrations. All pertinent data were then organized into a totally addressable data base in which all data were consistent in

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nomenclature, coordinates and units. The investigations then involved both standard and arbitrary statistical testing, ordination and similarity clustering, and the interpretation of compressed visual display and various hierarchial sortings and tabulations of data that facilitate rapid assessment, correlation and interpretation.

4. Major factors affecting the comparison of field studies on spills and cumulative effects

The results of any field study on a spill or on cumulative effects are dependent on (*a*) the properties and variabilities of the ecosystem and (*b*) the contamination process being studied. Comparisons among and between studies on spills and cumulative effects must be made with the full realization that the range of validity and application of the results of each is dependent on these factors. Aside from the obvious uncertainties associated with comparisons or extrapolations between dissimilar ecosystems, some of the more important considerations are the following.

(*a*) For a given spill, the fate of the hydrocarbons is dependent on the amount, rate, areal density and duration of the spill as well as the properties and behaviour of the ecosystem. Therefore, biological effects are dependent on these factors, on the structure, composition and maturity mix of the resident biota, and on the toxicity of the suite of hydrocarbons composing the contaminant.

(*b*) In major spills, the high levels and rates of contamination and the relatively short time of contaminant exposure to the environment combine to facilitate both identification (McAuliffe *et al.* 1975) and measurement despite ecosystem variations.

(*c*) In a study on cumulative effects, the situation is quite different; the petroleum contaminant is generally similar over a given petroleum province, the rate of contamination is exceedingly small and relatively constant, the ecosystem is the same albeit a variable one, and contamination proceeds over long periods. As a consequence, the ultimate fate of the contaminants is dominated by natural processes (Bender *et al.* 1979; Middleditch 1981). The low concentrations and the prolonged exposure of the contaminant combine to make both identification and measurement exceedingly difficult. The discrimination of biogenic, petrogenic and other hydrocarbons in the sediments is therefore usually based on empirical criteria such as carbon preference indices (Farrington 1980). However, such indices are neither unambiguous nor accurately quantitative, particularly where weathering is extensive and multiple sources are involved (Southwest Research Institute 1980)

5. Hydrocarbon contamination of bottom sediments

(*a*) *Major spill studies*

Only broad generalizations can be supported by comparisons of spill study data. Where spills either occur in, or are driven into, shallow coastal waters, hydrocarbon concentrations in the sediments can be very high and, depending on ecosystem and contaminant properties and behaviour, can persist for long periods. Except for infrequent local cases, however, concentrations from spills in offshore areas are much lower and less persistent.

The Ixtoc 1 spill was the largest spill of crude oil related to drilling and production operations in terms of amount, rate and duration of spilled crude oil and application of dispersants. A total of 0.5×10^6 m^3 of unrecovered, unburned and unvaporized crude oil and more than 5560 m^3 of dispersant entered the waters in Campeche Sound between June 1979 and March 1980 at rates up to 4770 m^3/day. The spill occurred on the continental shelf in water depths of 50 m about 75 km from shore and affected an area of more than 50000 km^2. Concentrations of aliphatics and aromatics in bottom sediments before, during and after the spill as reported by the Instituto Mexicano del Petroleo (1980) and by Botello & Soto (1981) are shown in table 1.

TABLE 1. SEDIMENT HYDROCARBONS (MICROGRAMS PER GRAM DRY MASS)

	Instituto Mexicano del Petroleo (1980)			Botello & Soto (1981)		
date	mean	max.	no. of samples	mean	max.	no. of samples
June 1978	—	—	—	31.5	56.0	21
June 1979 (spill begins)	—	—	—	—	—	—
Oct.–Dec. 1979	49.7†	153.4†	40†	—	—	—
	73.5‡	1060.4‡	53‡	—	—	—
March 1980 (spill ends)	—	—	—	80.2	715.0	25
Sept. 1980	—	—	—	59.2	516.0	26
Dec. 1980	—	—	—	36.6	84.0	7

† Continental shelf areas. ‡ Four estuaries 130–185 km from spill site.

The maximum concentrations reported were all within 35 km of the spill site except for a single very high measurement in one estuary. Average concentrations over most of the continental shelf and in the four estuaries did not reach the 100 $\mu g\ g^{-1}$ level reported as being damaging in other spill studies. The data of Botello & Soto show a return to near pre-spill concentrations 9 months after spill termination; however, none of these measurements were within 35 km of the spill site.

The Main Pass Spill occurred during 1970 at a depth of 15 m on the continental shelf some 22 km from the Main Pass of the Mississippi River and outside Breton and Chandeleur Sounds. Up to 10300 m^3 of crude oil and 320 m^3 of dispersant entered the water over a period of three weeks and affected an area of more than 1000 km^2. In the 97 samples analysed for aliphatic and aromatic concentrations in the sediments, the maximum was 357 $\mu g\ g^{-1}$ and the mean was 23.5 $\mu g\ g^{-1}$, showing that sites of high concentration were a rare occurrence. All high concentrations were located within 20 km of the spill site. Stations of 100 $\mu g\ g^{-1}$ or greater that were resampled a year later showed a return to the levels observed throughout the area. Sediment concentrations, persistence and distributions are described further in §6.

The conclusions to be drawn from these and other spill studies are that (1) sediment contamination is, indeed, strongly dependent on spill and ecosystem variables, and (2) comparisons among and between data on spills and cumulative effects are best made within the same or similar ecosystems in which ecosystem properties and variance are known. This investigation therefore concentrates on evaluations and interpretations of the M.P.S., O.E.I., C.G.S. and B.F.S. data, with emphasis on the last two because of (1) the density and distribution of pertinent data for hypothesis testing and (2) the complementary nature of these two studies.

(*b*) *Studies on cumulative effects*

In the C.G.S., four 'primary' platforms (of 20 platforms and four control sites investigated) were sampled at 16 stations (100, 500, 1000 and 2000 m along north, east, south and west transects) in one season, and at eight of these same stations (500 and 2000 m along these azimuths) in two successive seasons. For these 200 samples, the maximum and mean values were 371 and 37 μg g^{-1} respectively, and 13 samples exceeded 100 μg g^{-1}. Figure 1 shows the

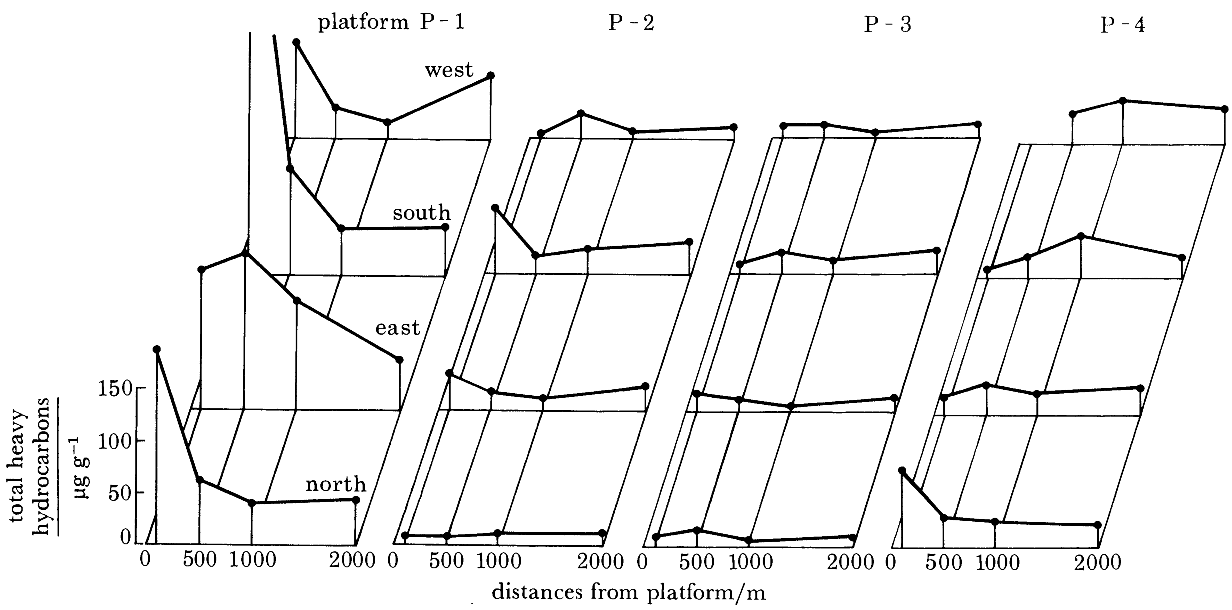

FIGURE 1. Concentrations of heavy hydrocarbons in the bottom sediments at the four primary C.G.S. platforms.

three-season average of concentrations of heavy molecular mass hydrocarbons (heavy hydrocarbons) at the four primary platforms. Except for primary platform no. 1, neither these averages nor single-season values show consistently high values nor radial gradients. Platform no. 1 is discussed more fully in §6.

Figure 2 shows heavy hydrocarbon concentrations for the B.F.S. platform and for the four C.G.S. primary platforms. Here the values have been 'normalized' against total organic carbon (Boehm & Fiest 1980) to reduce the influence of sediment type variance on the comparisons. The B.F.S. data record concentration gradients from the platform outward to approximately 30 m. However, (1) within this area, three types of tracer studies and the vertical sediment traps installed for the experiments indicated rapid dispersion and resultant minute concentrations in the water column (Middleditch 1981), and (2) where measurements were made on successive days, concentrations in the sediments at the platform changed from 12 to 1.0 μg g^{-1}, confirming that there was rapid horizontal sediment transport in this area.

These and similar data show that vertical transport processes are dominated by other natural processes, so that stressful levels of heavy hydrocarbons either do not occur or do not persist in these areas. In the Louisiana and Texas shelf areas, such processes include stratification, mud slides, turbidity currents, high rates of horizontal sediment transport, and a persistent nepheloid layer at or near bottom that attests to persistent sediment resuspension and lateral redistribution.

Comparisons of C.G.S. heavy hydrocarbon concentrations with those reported for other western Gulf offshore areas show them to be comparable with those in Louisiana and lower than those for south Texas. The latter might be considered a 'control area' since it is remote from significant petroleum development and from major rivers. It shows maximum and mean concentrations of 1700 and 206 μg g^{-1} respectively, compared with the 371 and 37 μg g^{-1} for

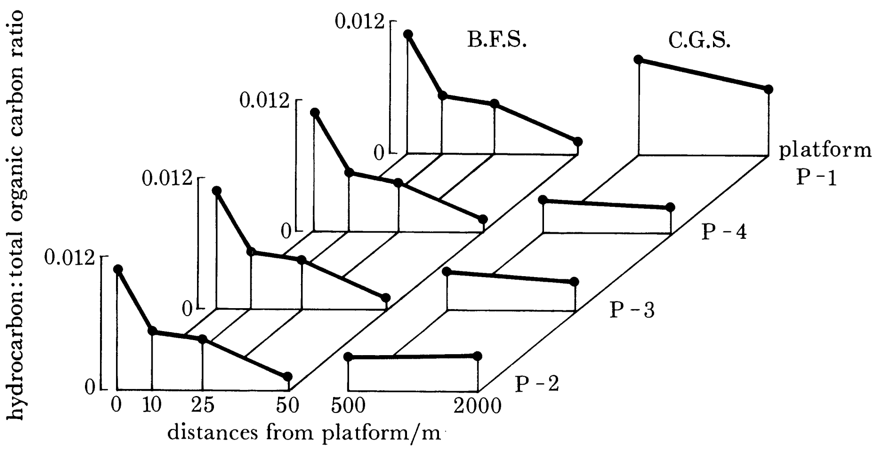

FIGURE 2. Radial gradients of normalized heavy hydrocarbon concentrations at the B.F.S. platform and the four primary C.G.S. platforms.

the C.G.S. The carbon preference index for south Texas averages 4.2 for *n*-C ranges from 25 to 35, while that for the C.G.S. ranges from 1.11 to 3.12 to 6.37 for *n*-C ranges of 14–20, 20–28 and 24–32 respectively, indicating high biogenic content for both areas, with the C.G.S. also showing significant levels of petrogenic and anthropogenic content. All northwestern Gulf areas show high levels of 'unresolved complex mixtures' whose origin is indeterminate.

6. Effects on the benthic macroinfauna

Predictions of changes in the macrobenthos as being indicative of spill-induced ecological damage are often expressed in terms of the diversity, density and structure of communities, and the abundance and behaviour of populations of dominant species. Definitions of these descriptors and in the criteria and procedures used to investigate their response to environmental variables can vary considerably. In using the data on spills and cumulative effects, consistent definitions and criteria were used.

(*a*) *The Main Pass spill*

Extant data include identification and abundance of more than 550 benthic taxa in 233 benthic sediment samples. Investigations emphasized correlations of diversity, composition, abundance, community structure and structural similarities, and of species dominance with hydrocarbon concentration, water depth, sediment type, and distances from the spill site, shoreline, Main Pass, and the Gulf outlet channel. Figure 3 is one compressed display of the many correlations made with data from the M.P.S.

Figure 3 shows the similarity clusters of the macroinfaunal communities and the corresponding (1) sediment type, (2) sediment concentrations of hydrocarbons, (3) dominant species and (4)

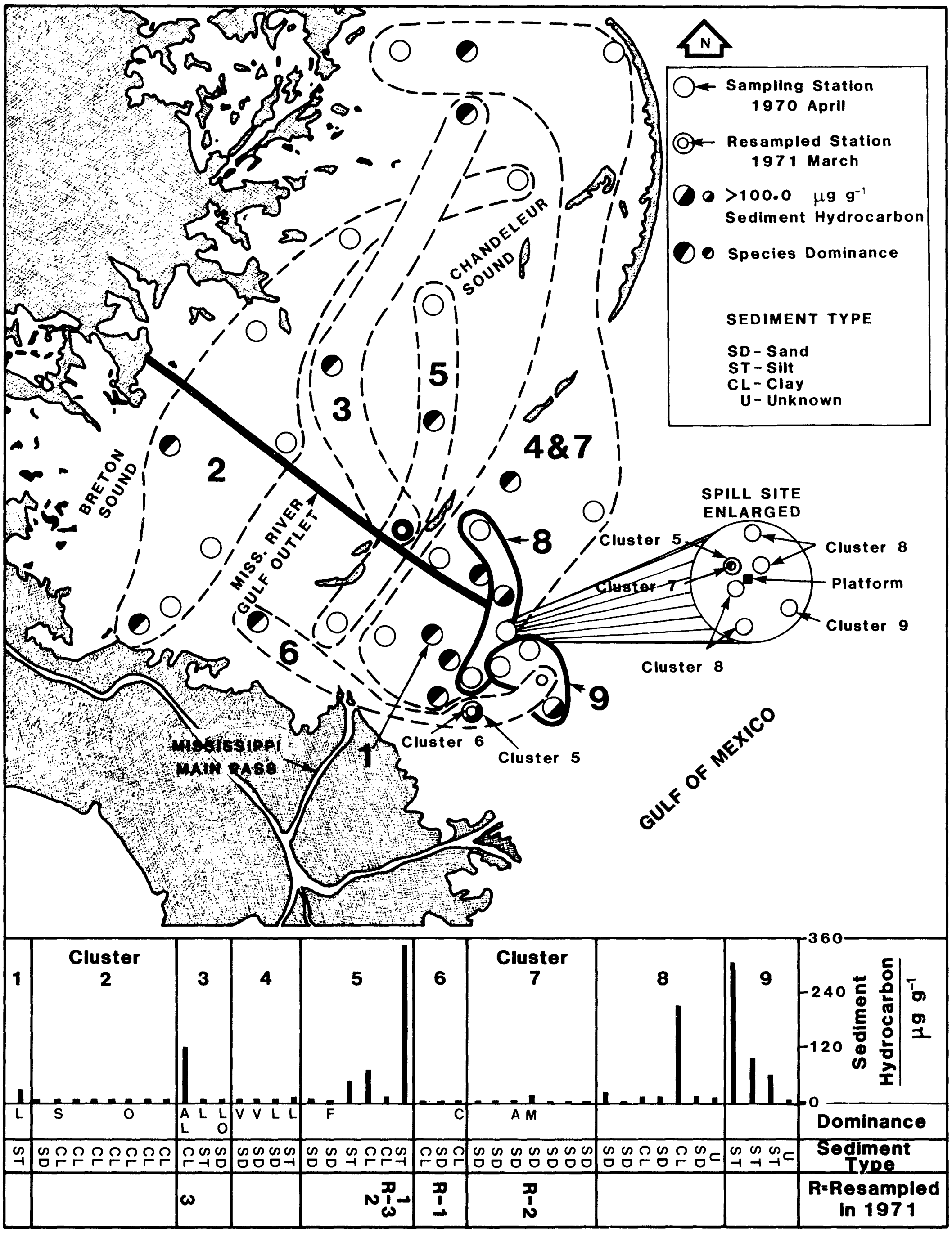

FIGURE 3. Spatial distributions of similar macroinfauna communities, heavy hydrocarbon concentrations in sediments, sediment type, and occurrence of species dominance not less than 30% in the Main Pass spill area during spring 1970 and 1971.

locations with respect to the spill, shoreline, etc. For this figure, input data were those for one season (March–April) including 43 stations for which complete hydrocarbon and macrobenthos data were available. Three sites are shown in which stations were reoccupied 1 year after the spill. Similarity clusters in this figure are based on the 20 most abundant taxa by using Bray–Curtis criteria; similarities ranged from 5 to 67% within the clusters identified by these criteria.

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Examination of this representative display identifies the following possible correlations.

(i) *Hydrocarbon concentrations* are more closely related to sediment type than to proximity to the spill site. Clusters 1, 5, 8 and 9, being close to the spill site, indicate a possible spill influence on community structure. Clusters 4 and 7, which were well within the area covered by the spill, show low concentrations consistent with the sandy substrate. Locations of the various clusters are associated with natural faunistic zones as defined by Walton (1964) rather than with hydrocarbon concentration or distance from spill.

(ii) *Species dominance* does not correlate with hydrocarbon concentration nor with distance from the spill. In only one of 14 cases where dominance exceeds 30% of a total of at least 500 individuals is the concentration of hydrocarbons greater than 100 μg g^{-1}. *Mulinia lateralis* (L in figure 3), frequently cited as a reliable indicator of organic pollution, is dominant in five single and one paired case including the single station showing high concentration; however, this occurrence shows no consistent correlation with hydrocarbon concentration, distance from the spill, or sediment type.

(iii) *Persistence* of the concentrations and species dominance occurring with the spill is not demonstrated. The three stations resampled a year after the spill show a marked decrease in hydrocarbon concentration accompanied by a shift to a different similarity cluster; however, two of these also show a concurrent change in sediment from clay or silt to sand such that a correlation is not demonstrated.

In other investigations of these data, distribution of relative abundance of all species at these 14 stations where dominance occurred did not show a departure from normalcy. No evidence of stress is indicated even where hydrocarbon concentration is high. Absence of significant stress is indicated further by the correlation of both community structure similarities and of dominant species with faunistic zones rather than with hydrocarbon concentration or with distance from spill. Regarding dominant species data, however, this observation is based on synoptic observations and therefore does not take into account the rapid growth and decline of 'indicator species' such as *Capitella capitata* observed in some spill and severe pollution studies (Sanders *et al.* 1980). Also, there was no correlation between the species diversity index, H', and hydrocarbon concentration, distance from spill, or sediment type. In view of the tight clustering of both the numbers of taxa and of individuals on a ternary diagram of sediment type, H' is not a sensitive indicator of structural change within this study area.

(*b*) *Studies on cumulative effects*

In exhaustive studies of the O.E.I. data, Morgan *et al.* (1974) and Bender *et al.* (1979) concluded that there were no significant cumulative effects in the O.E.I. area of southern Louisiana coastal or offshore areas that could be attributed to petroleum operations.

In the B.F.S. studies, benthic response studies were limited to platform leg communities located near the discharge point for produced brine containing the allowable average concentration of entrained hydrocarbons of less than 50 μg g^{-1}. Middleditch (1981) reported that no response of these communities of attached flora and fauna was detected beyond a few metres from the discharge point.

Because the content, density and distribution of the C.G.S. data support a comprehensive study of the response of the macroinfauna to hydrocarbon concentrations in the sediments, these data are used for discussion here. Hundreds of specific studies of the C.G.S. data were made to correlate macroinfaunal communities, populations and species with (1) sediment

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concentrations of hydrocarbons and (2) natural environmental variables. Typical findings are as follows.

(i) *Species diversity*. Figure 4 shows the values of species diversity, H', for the stations at 500 and 2000 m along the four transects at C.G.S. primary platforms. These correspond to the heavy hydrocarbon concentrations shown in figure 1. Comparison of the H' values with heavy hydrocarbon concentrations show (*a*) no significant change nor gradient in H' corresponding

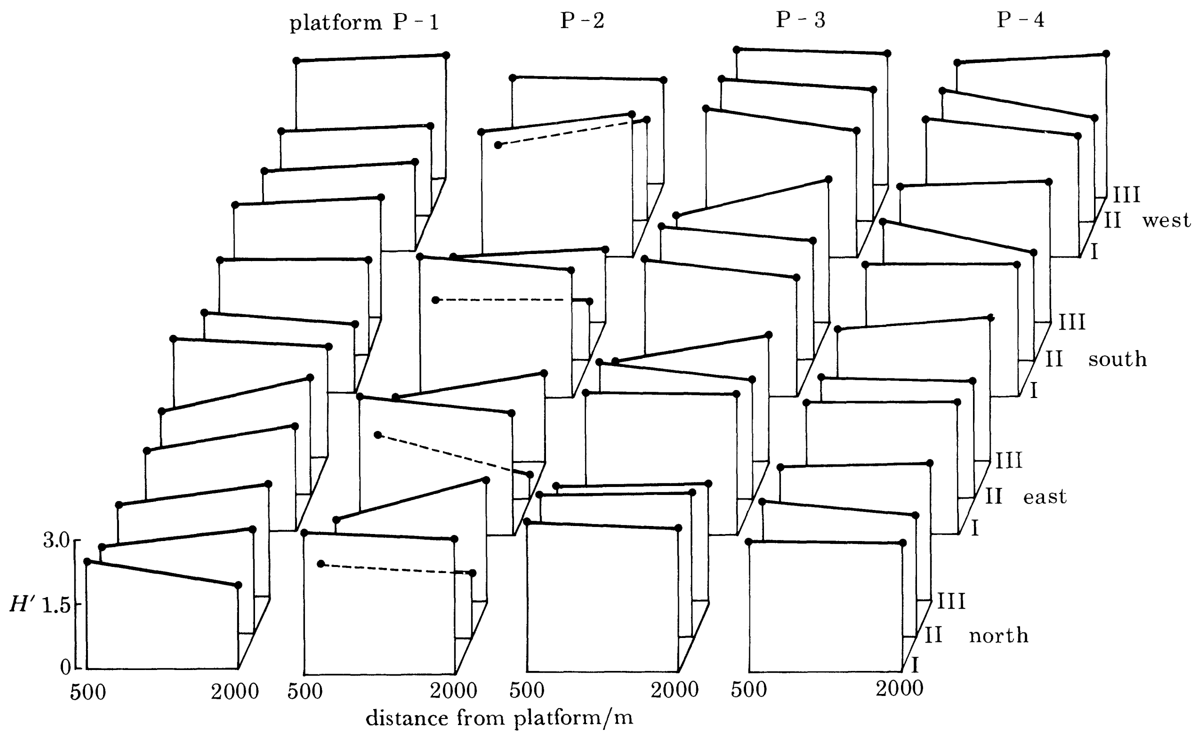

Figure 4. Radial gradients of Shannon–Weaver species diversity index, H', at four primary C.G.S. platforms for three seasons: I, May 1978; II, August 1978; III, January 1979.

to heavy hydrocarbon gradients, (*b*) no significant differences among the four widely separated platforms despite significant differences in heavy hydrocarbon concentrations, and (*c*) values of H' in the range 1.7–3.3 with a mean value of 2.60 for 140 samples taken over three seasons.

(ii) *Community structure*. Figure 5 shows discrete clustering of (*a*) the number of taxa and of individuals of macroinfauna during May 1978 at the primary platforms, and (*b*) the high degree of dependence of these structural descriptors on sediment type. In combination with figure 4, these data demonstrate that (*a*) dependence on a single index or descriptor can fail to distinguish the effects of contaminants because of masking by the influence of natural environmental variables, and (*b*) H' is neither a sensitive nor a reliable independent indicator of community health, normalcy, or change in this case. Other structural indices were also shown to be inadequate in varying degrees.

(iii) *Community response to high concentrations of heavy hydrocarbons*. Since highest concentrations of heavy hydrocarbons were found in the vicinity of primary platform no. 1, these occurrences were investigated in detail at the 500 and 2000 m stations where hydrocarbon and macroinfaunal data were available for the consecutive seasons. Concentrations of heavy hydrocarbons exceeding 100 μg g^{-1} occurred four times during three seasons, with high values occurring at the 500 m south station for two successive seasons. For this display, the influence of sediment type was normalized against total organic carbon (Boehm & Fiest 1980), and these values, numbers of individuals, numbers of taxa and H' were plotted for the 500 and 2000 m stations along four azimuths. The results displayed in figure 6 show (*a*) significant correlation between

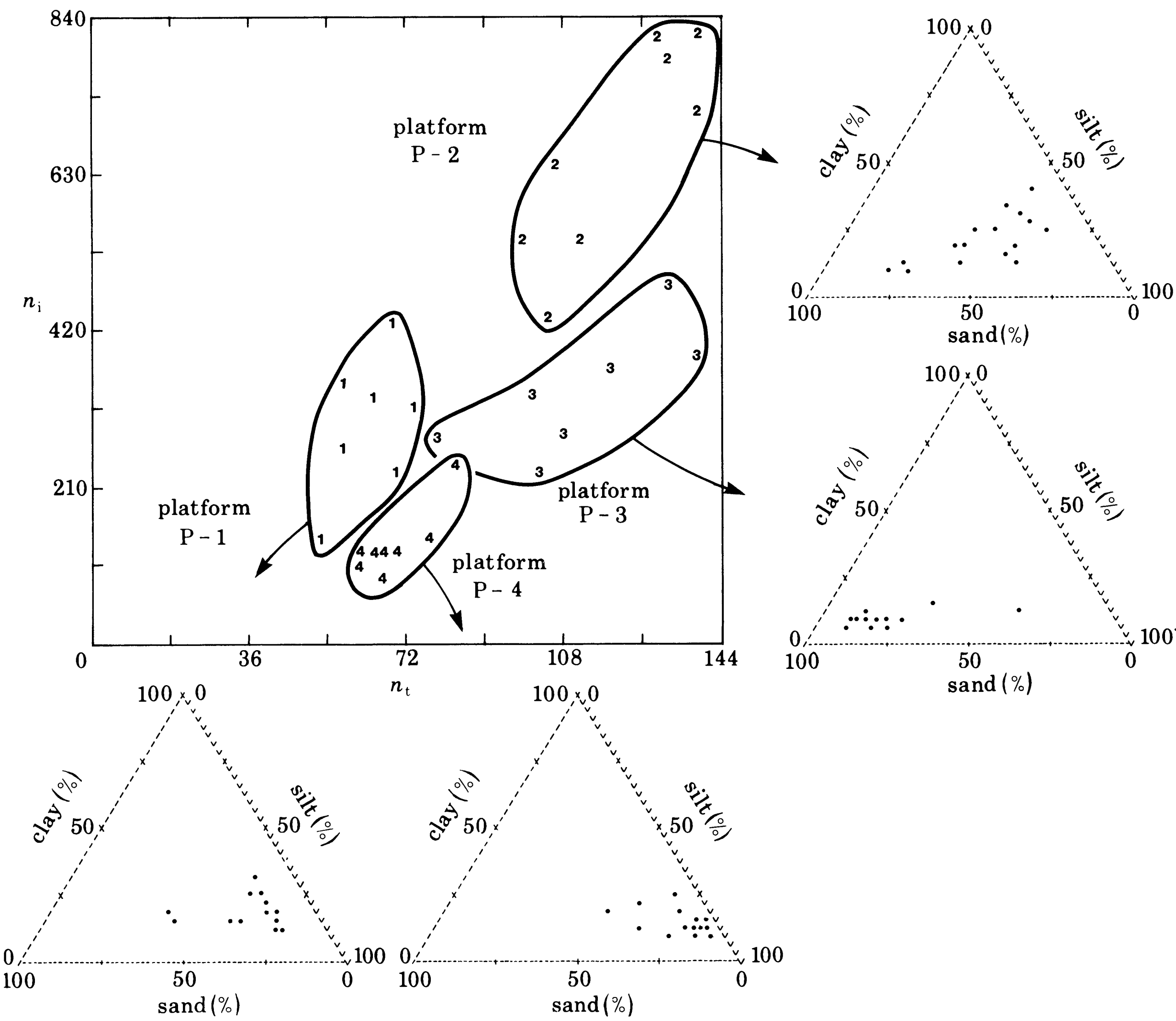

FIGURE 5. Variations in numbers of macroinfaunal taxa, n_t, and of individuals, n_i, per 0.09 m^2 at four C.G.S. primary platforms in May 1978 as a function of sediment type.

these selected extreme concentration values or gradients and these measures of biotic response only along the north transect, and (*b*) that no consistent response is evident from the various comparisons displayed.

(iv) *Species response to high concentrations of heavy hydrocarbons.* Changes in community structure are seen in more detail by comparisons of the relative abundance of species. Figure 7 shows spectra of species abundance for each of the 500 and 2000 m stations at platform no. 1 during August 1978. In each spectrum, the order of the species corresponds to its position in the all-station

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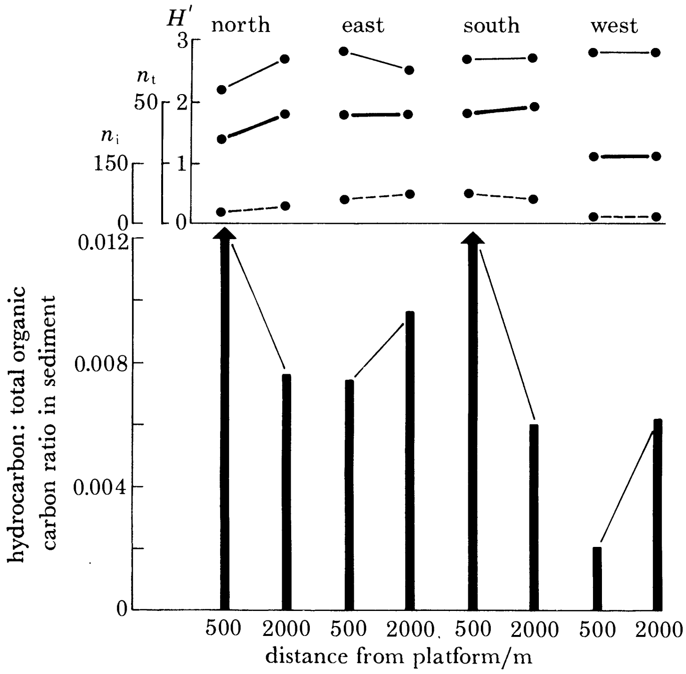

FIGURE 6. Response of macroinfaunal community to high heavy hydrocarbon concentrations at C.G.S. platform no. 1 during January 1979.

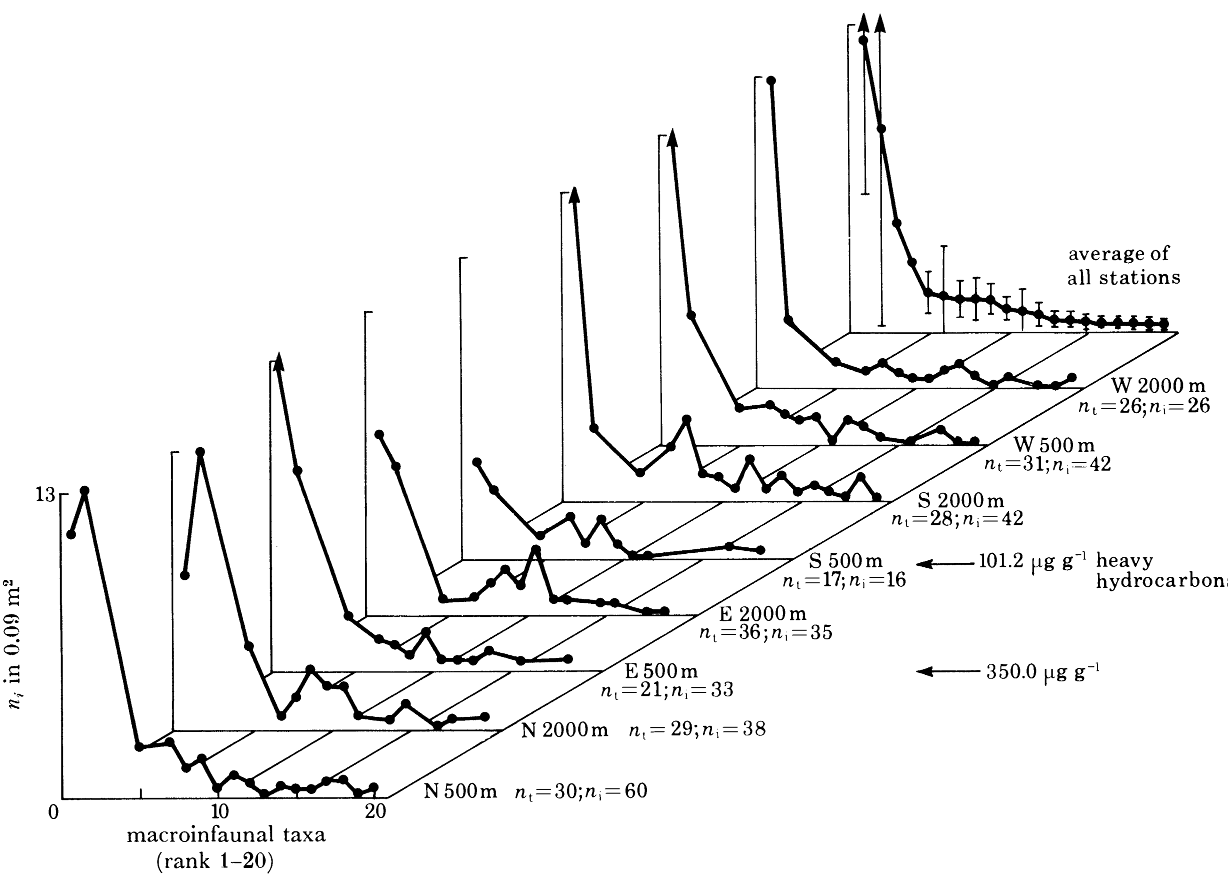

FIGURE 7. Species abundance distributions at C.G.S. platform no. 1 during August 1978. Results for average of all stations are shown as means ± s.d.

average shown at the top of the figure. Some distortion of the spectrum is noted for the 500 m south station where the heavy hydrocarbon concentration was 101.2 μg g^{-1}; however, no significant distortion is noted at the 500 m east station where the concentration was 350 μg g^{-1}. However, both stations show reduced levels of total individuals and taxa. Similar spectra for the ensuing season show total individuals and taxa for these stations comparable with the all-station average.

	occurrence		occurrence in > 10 % of sample density		occurrence in > 35 % of sample density	
	replicates	stations	replicates	stations	replicates	stations
Spiochaetopterus oculatus	18/840 (2.1 %)	13/140 (9.2 %)	0	0	0	0
Capitella capitata†	2/840 (0.2 %)	2/140 (1.4 %)	0	0	0	0
Mediomastus californiensis	91/840 (10.8 %)	33/140 (23.5 %)	18/840 (2.1 %)	4/140 (2.8 %)	0	0
Mulina lateralis	38/840 (4.5 %)	11/140 (3.2 %)	6/840 (0.7 %)	1/140 (0.7 %)	0	0

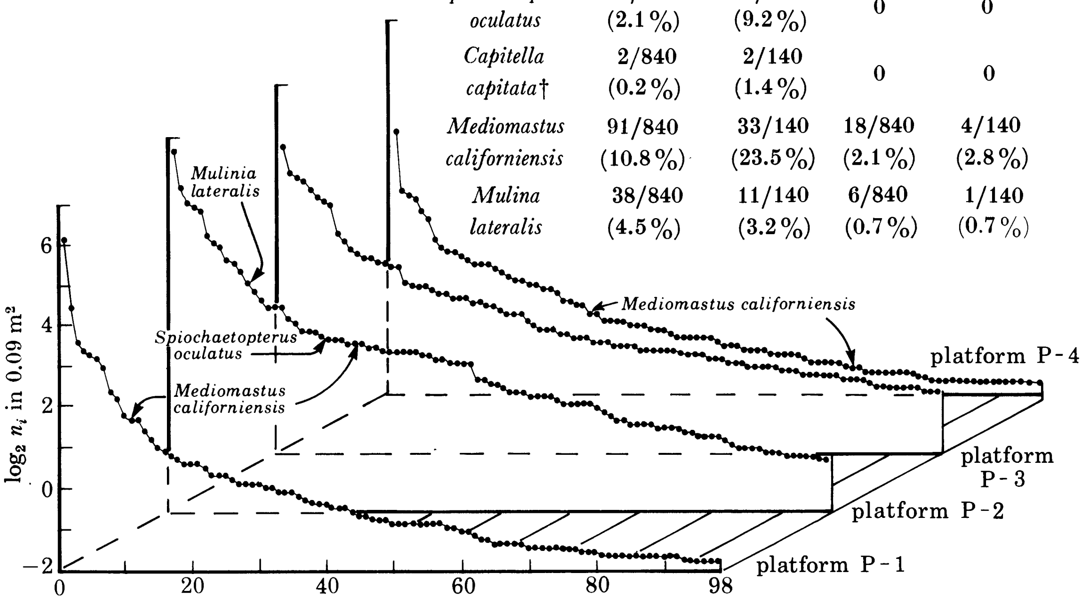

FIGURE 8. Species abundance distributions and dominant species occurrence and abundance at four C.G.S. primary platforms. † *Capitella capitata* occurred only as rare species at platform P-2. Numbers of individuals, n_i, plotted on a binary logarithmic scale.

(v) *Occurrence of dominant species*. Figure 8 shows the spectra of species abundance for the four C.G.S. primary platforms averaged over all stations and seasons with the number of individuals plotted against a binary logarithmic. Taxa are plotted in descending order of abundance for each platform. No significant distortion of the spectra, and hence no deviation from normal community structure, is indicated for any platform. Similar spectra are obtained when the seasonal spectra are plotted individually. No dominance is shown by *Spiochaetopterus oculatus*, *Capitella capitata*, *Mediomastus californiensis* or *Mulinia lateralis*, which have been cited as possible indicators of pollution in the northern Gulf. For the 840 replicates taken at 140 stations, none of these species shows a high frequence of occurrence, and no dominance in any replicate exceeding 35 % of the total individuals.

These and numerous other investigations of C.G.S. data fail to reveal significant correlations of concentration of petroleum hydrocarbons in the sediments with measures of macroinfaunal structure, abundance or diversity. Nor do they reveal evidence of general degradation, change, or unnatural distribution in this community that can be attributed to either point source or distributed source contamination from petroleum activities. The effects of the Mississippi River, with its large hydrocarbon load and natural variables such as depth and sediment type, are those variables correlating with macroinfaunal communities with greatest statistical confidence. The most evident correlations are with the faunistic zones that are defined by ecosystem properties and processes.

7. Conclusions

Chronic low-level discharges associated with normal petroleum operations in offshore areas do not result in persistent accumulations of hydrocarbons to stressful levels in the northern Gulf of Mexico.

The benthic macroinfauna do not exhibit a significant response to the concentrations of heavy molecular mass hydrocarbons occurring in the northern Gulf of Mexico offshore areas. Rather, community structure, abundance, composition and dominant species correlate most closely with natural faunistic zones.

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Discussion

A. J. Southward (*Marine Biological Association, Plymouth, U.K.*). Geyer has said that the fauna of the Gulf of Mexico is virtually unaffected by the chronic natural oil seeps that have continued for thousands of years. Has Dr Sharp any comments on this?

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J. M. Sharp. Dr Geyer's comprehensive Gulf-wide studies have identified numerous seep locations in the Gulf of Mexico. Gulf-wide studies of phytoplankton (e.g. by Dr El Sayed, Texas A&M University), fisheries catch statistics, and other data indicate that the biological productivity of the Gulf of Mexico equals or exceeds those of ecosystems devoid of petroleum activity. Intensive localized studies at the Coal Oil Point seep location, off California Coast, reported here by Dr Dale Straughan, also support Dr Geyer's conclusions. I therefore agree with Dr Geyer's conclusions.

J. S. Gray (*University of Oslo*, *Department of Marine Biology and Limnology*, *Oslo*, *Norway*). A number of speakers have referred to 'the sampling problem' with benthic surveys. In particular it has been shown that the influence of grain size was more important than the effects of oil. This, I should have thought, was well known and therefore it is incumbent that surveys are adequately designed. A pilot survey should be done to ascertain the major environmental gradients and stratified random sampling done. It is to me a fallacy that on practical grounds it is not possible to do a pilot survey. Such a survey improves efficiency immensely, helping to reduce the 'noise' in the system and makes it much more likely that effects of oil can be demonstrated since background variability is reduced.

J. M. Baker (*Field Studies Council*, *Orielton Field Centre*, *Pembroke*, *U.K.*). In response to Professor Gray's comment that it would be best to plan offshore benthic sampling strategies using information on distribution of sediment types, notwithstanding the benefits of this approach, it would in most cases require more ship time and would therefore be much more expensive. Given the inevitable financial constraints, it is difficult to see how current survey practice could be radically improved.

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