and winter and fall 1977. In 1979, the number of taxa had dropped to 22, and further declined to 15 in 1980. Overall, Animal Group D was second in terms of total number of individuals (12,837); from fall 1976 through fall 1977, 10,360 individuals of Animal Group D taxa were collected. In fall 1977, Animal Group D individuals constituted 31% of the total sample; in the remaining sampling periods, Animal Group D was roughly constant in percentage abundance (range = 19% - 23%), except for 1980, when Animal Group D dropped to 6% of the total number of individuals collected. The numbers of individuals per taxon in Animal Group D show a similar pattern. In fall 1977, Animal Group D was third in number of individuals per taxon (121) at its highest value; in fall 1976 and winter 1977, the number of individuals per taxon remained roughly the same (106 and 94, respectively); lower values were recorded in winter 1976 (55), 1979 (25), and 1980 (12).

Animal Group B included eleven taxa; all eleven were present in fall 1976, winter 1977, and fall 1977, but two were absent in winter 1976 and five were missing from 1979 and 1980 samples. Overall, Animal Group B was third in terms of numbers of individuals (6,645), largely as a result of high abundances in fall 1976 and winter 1977. In winter 1976 and fall 1977, Animal Group B was reduced by about half its maximum value (fall 1976, 2442 individuals), and in 1979 and 1980 the abundance of Animal Group B was about an order of magnitude less than its maximum value had been. However, Animal Group B taxa constituted a relatively stable proportion of the total numbers of individuals present from winter 1976 through winter 1977 (13% - 15%); after this period of constancy, Animal Group B declined in percentage of individuals to 8% (fall 1977) and then to 6% (1979 and 1980). In winter and fall 1976, Animal Group B was second in number of individuals per taxon (110 and 222, respectively). Animal Group B had its highest number of individuals in fall 1976. In subsequent sampling periods, Group B suffered a steady, monotonic decline in number of individuals per taxon, dropping to fifth place by 1980 with only twelve individuals per taxon. Animal Group B was composed of two suspension feeding bivalves (Diplodonta cf. soror and Lucina amiantus); two omnivorous polychaetes Aglaophamus verrilli and Litocorsa stremma; and eight detritovores and deposit feeders, including three congeneric tube-dwelling amphipods (Ampelisca agassizi, A. cf. cristata and Ampelisca sp.), the tanaid Apseudes taylori, and the polychaetes Aricidea taylori, Prionospio cristata, and Clymenella torquata (a tubicolous maldanid polychaete).

Animal Group F included ten taxa; all ten were present from winter 1976 through fall 1977; in 1979 and 1980, seven and eight taxa (respectively) were collected from Animal Group F. Animal Group F was fourth in terms of numbers of individuals (3,852); Animal Group F taxa were most abundant in fall 1976 (1373), less common in winter 1977 (887) and fall 1977 (715), and roughly equal in abundance in winter 1976 and in 1979 and 1980 (352, 225, and 300, respectively). On a percentage basis, though, Animal Group F was most important in 1979 and 1980 (10% and 8% of the individuals collected, respectively), and ranked third overall for both years. In other sampling periods, Animal Group F ranked fourth in overall abundance, ranging from 5% - 8% of the total number of individuals collected. Animal Group F fluctuated considerably in number of individuals per taxon, ranging from a high of 137 in fall 1976, when it ranked fourth overall in number of individuals per taxon, to a low of 32 in 1979, when it ranked third overall in number of individuals per taxon. In winter 1977, Animal Group F had 89 individuals per taxon (ranked sixth overall), 72 in fall 1977 (ranked fifth overall), and 35 and 38 per taxon in winter 1976 and 1980, respectively (ranked fourth overall in both sampling periods). Animal Group F included three taxa of omnivorous or carnivorous polychaetes: Ninoe nigripes, Sigambra tentaculata and Nephtys incisa. Animal Group F also included the gastropod Hyala sp. A. The remaining taxa in Animal Group F were deposit feeders, and included the tubicolous amphipod Ampelisca abdita; the polychaetes Magelona longicornis, Cossura delta, Notomastus cf. latericeus, and Armandia maculata; and the cumacean Eudorella monodon.

Animal Group C included only five taxa: the gastropod Vitrinella floridiana, the corophiid amphipod Photis macromanus, the cirratulid polychaete Tharyx annulosus, the spionid polychaete Prionospio steenstrupi, and the pelecypod Nuculana acuta. All were present from fall 1967 through fall 1977, while Tharyx was absent in winter 1976, 1979 and 1980 and Photis was absent in 1979 and 1980. All taxa in Animal Group C are deposit feeders, with the possible exception of Photis, which is a tubicolous suspension feeder as well as a surface detritovore (Biernbaum 1979).

Animal Group C was fifth in abundance overall (1,529 individuals). In fall 1976, when Animal Group C was at its peak, it constituted 4% of the total number of individuals of all taxa collected, thus ranking fifth among the groups. At that time, Animal Group C also had more individuals per taxon (130) than in any other sampling period. In winter 1977, the number of individuals and the number of individuals per taxon in Animal Group C dropped to 509 and 102, respectively, but Animal Group C still comprised 4% of the total number of individuals of all taxa collected. In fall 1977, the number of individuals decreased to 232, 2% of the total for all samples, and the number of individuals per taxon fell to 46. Animal Group C only made up 1% of the total number of individuals of all taxa for all samples in the other three sampling periods (73, 39, and 27 for winter 1976, 1979, and 1980, respectively). During these three periods, the numbers of individuals per taxon were the lowest recorded for any group: 18, 13, and 9, respectively. Animal Group C taxa were most common as an assemblage in Station Group 2 stations, a nearshore set of three sandy shallow sites (10-15 m deep) and one sandy deeper site (27 m) biologically most similar to one another in 1976 and 1977 (Figure 4-60).

Animal Group E included only three deposit-feeding polychaete taxa: the paraonid Paraonis sp. A, and the maldanids Asychis elongata and Asychis sp. They were collected in the first four sampling periods, but were not seen in 1979 or 1980. These taxa together included 1,650 individuals, thus ranking sixth overall. In winter 1976, they were relatively uncommon; only 31 individuals were collected, and the number per taxon was ten. In fall 1976, winter 1977, and fall 1977, Animal Group E was quite constant in numbers of individuals (512, 574, 533, respectively) and numbers of individuals per taxon (171, 191, 178, respectively), and amounted to 3%-4% of the total number of individuals of all taxa collected per sampling period. Animal Group E taxa were scattered through Station Groups 2, 3b, and 3c stations, which span the range from the shallowest, sandiest sites to the deepest, muddiest sites.

Animal Group H included only the predatory gastropod Natica pusilla. Natica was collected only in 1979, when it was quite rare (four individuals seen) and in 1980, when 686 individuals were collected, 24% of the total number of individuals of all taxa collected. Animal Group H ranked seventh overall in abundance among the groups, but in terms of numbers of individuals per taxon was ranked first in 1980. Natica was most common at Station Group 4a stations, three sandy and silty-clayey sand stations, and at two Station Group 4b stations, one muddy and the other sandy.

Animal Group G included only the deposit-feeding synaptid holothuroid Protankyra cf. benedeni. Protankyra was collected only at a single station (I-1, having silty-clayey sand, depth 18 m) and only in 1980, when 225 individuals were seen, 8% of the total number of individuals of all taxa collected. Animal Group G ranked eighth overall in abundance among the groups, but in terms of numbers of individuals per taxon, was ranked second in 1980.

Animal Group I included only the omnivorous or carnivorous lumbrinerid polychaete Lumbrineris cruzensis. Lumbrineris cruzensis was rare in fall 1977, when nine individuals were seen. It was more abundant in 1979; 125 individuals were found, 4% of the total number of individuals of all taxa collected. Lumbrineris cruzensis was not collected in any other sampling period. Animal Group I ranked last overall in abundance among the groups, but in terms of numbers of individuals per taxon, was ranked second in 1979. It was most common at Stations IV-1, IV-4, and III-4, three sandy sites.

There were major differences between sediment texture between stations (Figure 4-67). Within stations, however, sediment texture indices based on the standard definitions of sand, silt, and clay (cf. Folk 1980) showed no statistically significant differences from one time period to the next (Friedman two-way ANOVA, $p>0.05$). Nonetheless, in very few cases did sediment texture remain constant in different sampling periods. For example, Station I-4 shifted toward muddier sediment in 1980 compared to previous years; Station II-1 became more silty in 1980 and Stations II-4, III-1, and IV-5 became more clayey in 1980.

The distributions of a number of numerically dominant taxa were correlated with one or more of the sediment texture indices (Table 4-5). The most common pattern was a statistically significant ($p\leq0.05$) positive correlation of abundance with the relative proportion of larger particles, and a significant negative correlation with the relative proportion of fine particles. Forty-one taxa (57% of 72) were positively correlated with mean grain size. Forty-nine taxa (68% of 72 dominants) were positively correlated with the ratio sand:mud; i.e. the ratio of material made up of particles ≥0.0625 mm in size ("sand") to that of smaller fractions ("mud"). Forty-nine taxa were positively correlated with percentage sand. Fifty-five taxa (76%) were negatively correlated with either percentage silt or percentage clay, or both. Fifty-seven taxa (79%) were negatively correlated with percentage of particles less than 0.001 mm in size. In most cases, taxa falling in this group showed both negative correlations with indices of fine particles and positive correlations with indices of coarser particles; 15 of these taxa also were negatively correlated in abundance with TOC.

Several numerically dominant taxa showed an inverse of this pattern, their abundance being positively correlated with indices of fine particles and negatively correlated with indices of coarser particles. Four taxa

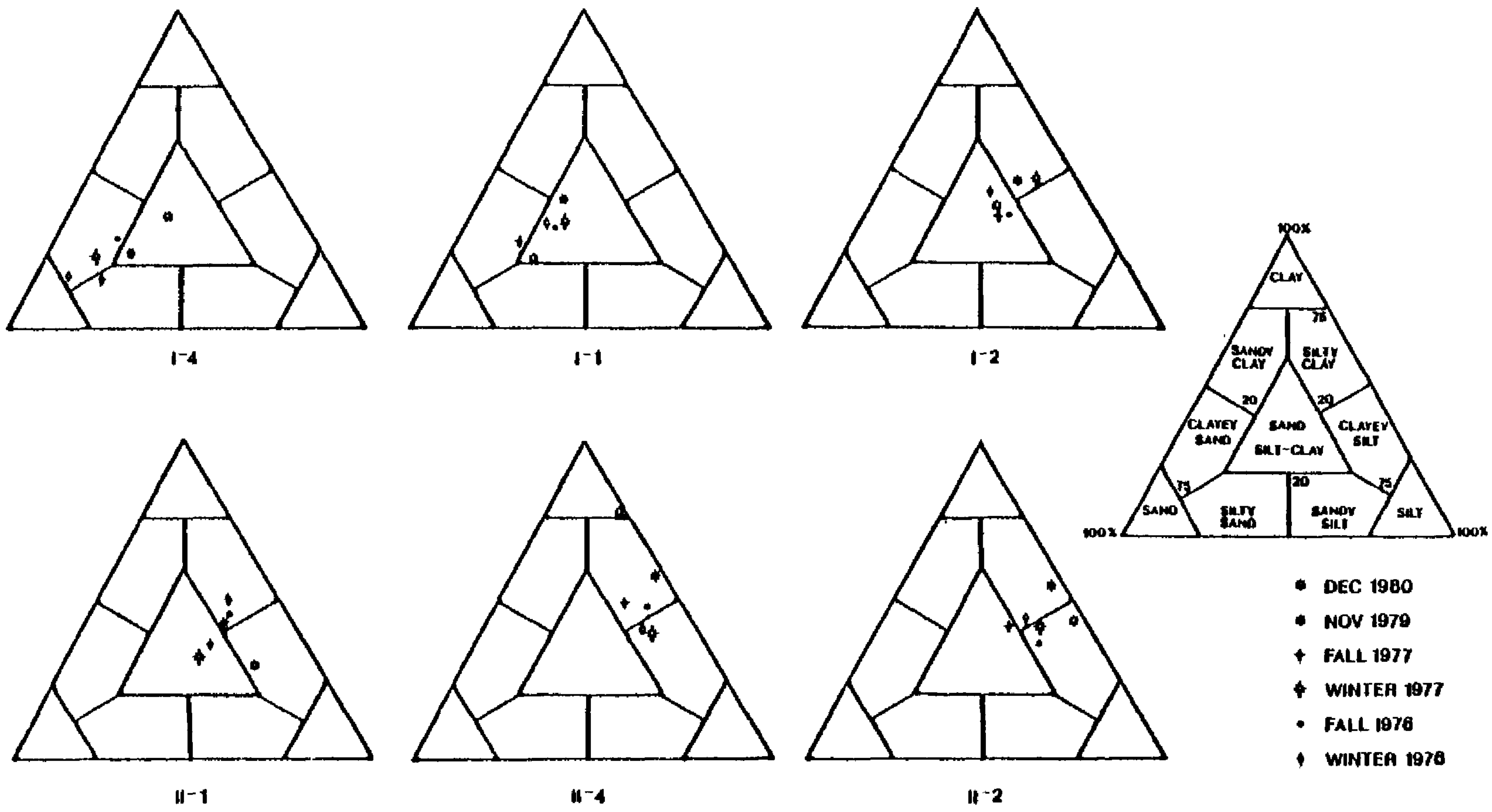

Figure 4-67. Sediment characterization by station for six sampling periods.

....continued

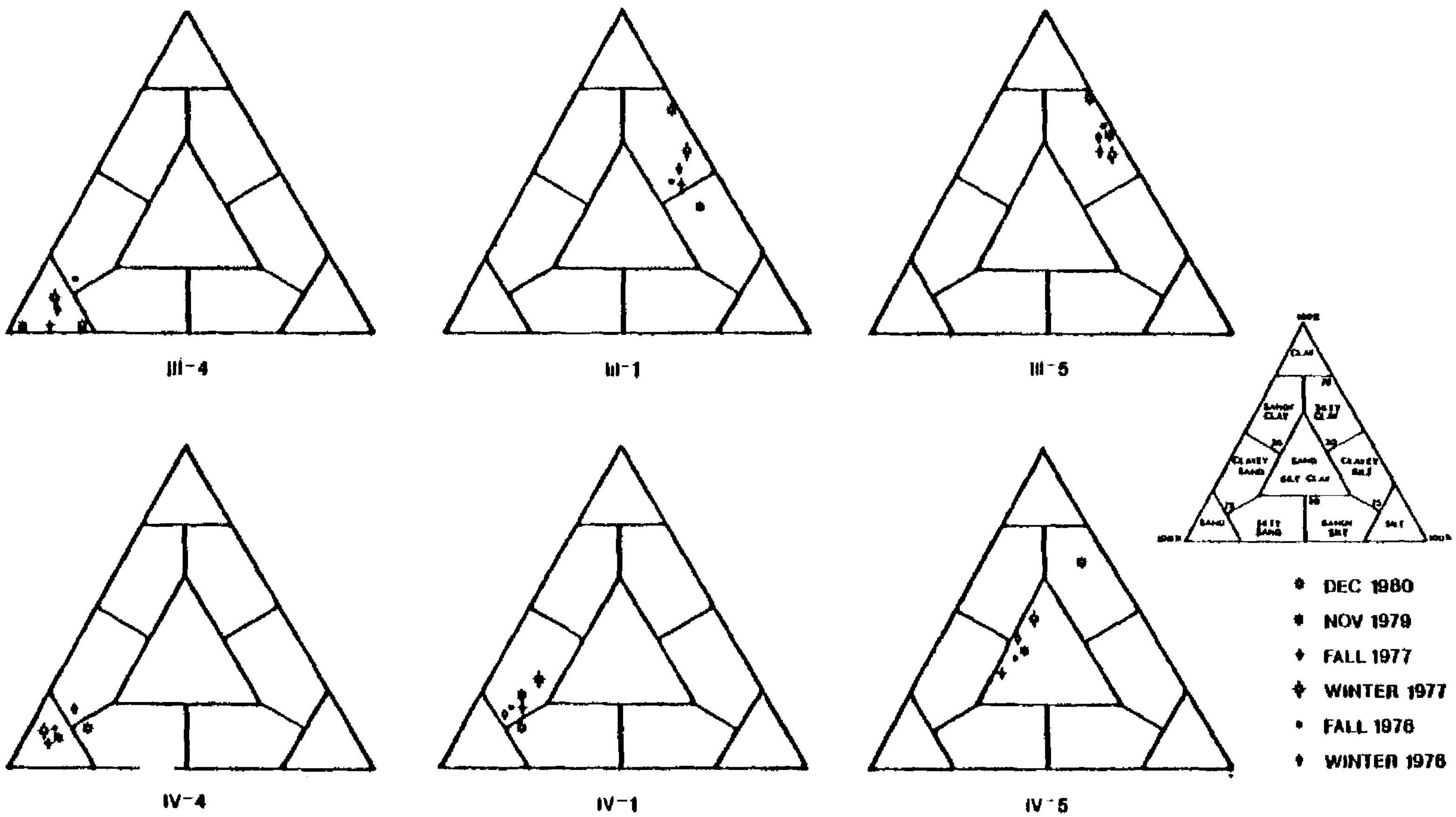

Figure 4-67 (cont'd)

Table 4-5. Results of correlation analysis of abundance of numerically dominant taxa (0.2% cutoff) with sediment parameters. S:M = ratio sand:mud (mud = silt+clay+fines); fines = particles < 0.001 mm; TOC = total organic carbon; + or − = statistically significant positive or negative correlation ($P \leq 0.05$); no symbol = no statistically significant correlation.

	CORRELATE						
Taxon	Mean Grain Size	% Sand	% Silt	% Clay	% Fines	S:M	TOC
Abra aequalis	+	+	−		−	+	−
Aedicira belgicae		+	+	+	−	+	
Aglaophamus circinata	+	+	−		−	+	
Aglaophamus verrilli	+	+	−	−	−	+	−
Ampelisca abdita				+			
Ampelisca agassizi							
Ampelisca cf. *cristata*	+	+	−		−	+	
Ampelisca sp.	+	+	−		−	+	
Ampelisca verrilli		+		+	−		
Anadara transversa	+	+	−		−	+	
Apoprionospio pygmaea	+	+	−	−	−	+	
Apseudes sp. A				+			
Aricidea jeffreysii	+	+	−		−	+	
Aricidea taylori	+	+	−	−	−	+	
Aricidea wassi	+	+	−		−	+	
Armandia maculata							
Asychis elongata		+	−		−	+	
Asychis sp.		+	−	+	−	+	
Caecum pulchellum			−	+	−	+	
Clymenella torquata	+	+	−		−	+	
Corbula swiftiana				+	−		
Cossura delta				+			
Diopatra cuprea	+	+	−	−	−	+	−
Diplodonta cf. *soror*	+	+	−		−	+	
Eudorella monodon	−	−	+	+	+	−	
Hyala sp. A	−	−		+	+		
Isolda pulchella	+	+	−		−	+	
Listriella barnardi	+	+	−		−	+	−
Litocorsa stremma	+	+	−		−	−	−
Lucina amiatus	+	+	−		−	+	−
Lumbrineris cruzensis			−		−	+	
Lumbrineris sp. nov.	+	+	−		−	+	−
Lumbrineris tenuis	+	+	−		−	+	
Magelona longicornis	−	−	+	+	+	−	
Magelona pettiboneae	+	+	−		−	+	
Magelona phyllisae	+	+	−	−	−	+	−
Magelona rosea	+	+		+	−		
Maldanidae (misc. unid.)	+	+	−		−	+	
Mediomastus californiensis	+	+	−		−	+	
Minuspio cirrifera		+			−		
Natica pusilla							

Table 4-5 (cont'd)

Taxon	Mean Grain Size	% Sand	% Silt	% Clay	% Fines	S:M	TOC
Nemertinea (misc. unid.)	+	+	-		-	+	-
Nephtys incisa	-	-	+	+	+	-	+
Nereis micromma	+	+	-		-	+	-
Ninoe nigripes	-	-	+	+	+	-	+
Notomastus cf. *latericeus*			+	+			
Nuculana acuta	+	+	-		-	+	
Onuphis sp.	+	+	-		-	+	
Ophiuroidea (misc. unid.)	+	+	-		-	+	
Ostracoda (misc. unid.)	+	+	-	-	-	+	
Paleanotus heteroseta	+	+	-		-	+	
Paraonidae (misc. unid.)		+	-	+	-	+	
Paraonides lyra	+	+	-		-	+	
Paraonis gracilis		+			-		
Paraonis sp. A				+			
Paraprionospio pinnata				+	-		-
Phoronida (misc. unid.)	+	+	-		-	+	
Photis macromanus				+	-		
Prionospio cristata	+	+	-	-	-	+	
Prionospio steenstrupi	+	+	-		-	+	
Protankyra cf. *benedeni*					+		
Sigambra tentaculata	+	+			-	+	-
Sipuncula (misc. unid.)	+	+	-	-	-	+	-
Spionidae (misc. unid.)		+		+	-		
Spiophanes bombyx	+	+	-		-	+	
Tellina versicolor	+	+	-		-	+	
Terebellides stroemii	+	+	-		-	+	
Tharyx annulosus			-	+	-	+	
Tharyx marioni	+	+	-		-	+	-
Vitrinella floridana							
Xenanthura brevitelson			-		-	+	-
Zoantharia (misc. unid.)			-		-	+	

(6%) were negatively correlated with mean grain size, with the ratio sand:mud, and with percentage sand; and also were positively correlated with percentage clay, with percentage silt, and with percentage of particles finer than 0.001 mm. These taxa were the cumacean Eudorella monodon, the mageloнid polychaete Magelona longicornis, the nephtyid polychaete Nephtys incisa, and the lumbrinerid polychaete Ninoe nigripes. The gastropod Hyala sp. A also showed negative correlations with mean grain size and percentage sand, and positive correlations with percentage clay, but no statistically significant relationship with either the ratio sand:mud or percentage silt. Nephtys incisa and Ninoe nigripes were the only taxa whose abundance was positively correlated with TOC.

4.4 Discussion

The main goals originally set for LGL's portion of the impact assessment program for the Ixtoc I oil spill were to:

1. Evaluate mid-spill (November 1979) biological conditions for the macroinfaunal community at 12 stations previously sampled in the STOCS program;

2. Evaluate post-spill (December 1980) biological conditions for the macroinfaunal community at 12 stations previously sampled in November 1979 and during the STOCS program;

3. Compare and contrast pre-spill biological conditions with mid-spill and post-spill conditions for the macroinfaunal community at the same 12 stations; and, should the data from the chemical portion of the impact assessment program permit,

4. Determine whether or not observed differences in macroinfauna at the 12 stations over time (pre-, mid-, and post-spill) were correlated with the presence of Ixtoc I residues.

In fact, Goals 1 through 3 have been accomplished quite successfully, largely as a result of the use of standardized sampling methodology and coordination between STOCS personnel and LGL staff to keep taxonomic problems to a minimum. While some large taxa were not identified to the species level (e.g. the nemerteans), their appearance in nearly all samples should not be a source of too much difficulty to biologists who will recognize these groups as "catch-alls" made up of many species. LGL has had every taxonomic identification at the family level or below independently verified, in most cases by the same persons who were responsible for STOCS identifications.

For LGL to complete Goal 4 would require quantitative information on the relative amounts of Ixtoc I residues at each station. Since the sediment samples collected on site did not contain any detectable traces of oil (see Section 2), it was not possible to associate any biological changes from one sampling period to the next with the Ixtoc I or Burmah Agate spills. Therefore, this report is perhaps best considered to be an source of follow-up baseline information for 1979 and 1980 on a selected group of 12 stations previously sampled through 1977 in the STOCS baseline program. The authors have purposely avoided use of the terms "pre-spill", "mid-spill", and "post-spill" in this report when discussing biological data, as the lack of evidence of the presence of oil in or on benthic sediments suggests that these terms might be misleading or used improperly if taken out of context. From the standpoint of the benthic organisms (based on the chemical information in this report) there was, in some senses, no spill. It is considered unlikely that hydrocarbons from Ixtoc I might have contacted benthic organisms and not left traces in the sediment (P. Boehm, pers. comm. 1982).

There is no question that major changes have occurred through time at the 12 study stations. Both numbers of taxa and numbers of individuals rose markedly between winter 1976 and fall 1976 samples, and then decreased during the next two sampling periods (winter 1977 and fall 1977). When the sites were again visited during the oil spill in November 1979, the numbers of taxa and numbers of individuals had dropped below even the winter 1976 values. One year later, in December 1980, the numbers of taxa and numbers of individuals had declined to their lowest values, about a third of the number of taxa seen during fall 1976 and about a fifth of the number of individuals.

The first sampling period (winter 1976) and the last two sampling periods (November 1979 and December 1980) shared many similarities compared to the other three sampling periods. They did not differ significantly from one another in numbers of taxa or numbers of individuals. In addition, the intervening sampling periods (fall 1976, winter 1977, and fall 1977) did not differ significantly from one another in numbers of taxa or numbers of individuals. It appears that three successive sampling periods characterized by high infaunal abundance and numbers of taxa followed one with lower abundance and numbers of taxa within a two-year time span, and were again followed by two sampling periods one year apart that resembled the first one.

The differences between the two basic groups of sampling periods (high abundance and low numbers of taxa vs. low abundance and low numbers of taxa) were not confined to a few stations; Figures 4-36 through 4-47 demonstrate that whatever factors were influencing these aspects of the biological community were acting without regard to depth or location.

Furthermore, most taxa showed the same pattern, indicating that the differences between sampling periods were not due simply to changing abundances of a few particularly common organisms. Figure 4-64 clearly shows increases in the abundance of most numerically dominant taxa in every group from winter 1976 to fall 1976, and in most cases a decline in subsequent sampling periods, with lowest values in November 1979 or 1980. The exceptions to this generalization represent highly localized increases in abundance of two taxa (one holothuroid and one gastropod) not previously collected. Both of these taxa Natica, Animal Group H, and Protankyra, Animal Group G, also proved common at other locations sampled in 1980 (see Appendices 9.3.1 and 9.3.2) indicating substantial temporal and spatial variability for these organisms. Additional corroboration for the non-specific nature of temporal differences is that the relative numerical importance (percentage of total individuals per sampling period) of each group of taxa delineated by the cluster analysis remained quite constant over time, with the apparent drops in several groups in December 1980 being primarily a result of the sudden appearance of the two aforementioned increases (Figure 4-65). The rather similar shape of the curves in Figure 4-66 demonstrates that most taxa were best represented (greater numbers per taxon) during the three sampling periods of high overall abundance and numbers of taxa, and were present in low absolute abundances during the three other sampling periods.

The largest groups of taxa separated on phylogenetic bases also more or less retained their relative positions with respect to one another from one sampling period to the next. Polychaetes were numerically dominant in every sampling period, with deposit feeders ranked first, followed in decreasing order of abundance by errant omnivores and carnivores, suspension feeders, and those whose feeding type was undetermined. Amphipods were the largest group of crustaceans, and pelecypods outnumbered gastropods in all periods except December 1980. These groups included over 90% of the total individuals found in the study. The other groups shown in Figure 4-10 shifted ranks, largely in response to drastic increases and decreases of single taxa from one time period to the next.

A final line of evidence for the contention that changes were not only area-wide but also pan-phyletic may be found in the data for occurrences of taxa at more than one station within any given sampling period (Figures 4-50 and 4-51). In winter 1976, November 1979, and December 1980 there were consistently fewer taxa at many stations than between fall 1976 through fall 1977, when many taxa were widely distributed. In other words, under some conditions many of the taxa in the study area were ubiquitous, but during three of the sampling periods these taxa suffered restrictions in the habitats available to them.

Unfortunately, it is impossible to assign any particular cause to the pronounced differences in community structure from one sampling period to the next. It is conceptually simplest, of course, to invoke some physical factor rather than complex biological interactions, which are poorly understood for the great majority of the taxa in the area. That the differences in abundance and numbers of taxa were area-wide implies strongly that some density-independent factor(s) rather than biological interactions were involved. The gaps in time between sampling periods after the conclusion of the STOCS program were lengthy, and intervening events left no clearly interpretable record to be inferred from the data. Consequently, any attempt to attribute an observed phenomenon to its proper cause(s) has a strong tautological element.

It is tempting to speculate on possible causes for the differences seen between the three sampling periods characterized by high infaunal abundance and numbers of taxa and three other sampling periods in which infaunal abundance and numbers of taxa were low. However, it is crucial for the reader to keep in mind that life history information is incomplete for nearly every taxon included in the study, and that the static data obtained from samples collected infrequently may present a deceptively simple picture bearing little relationship to any cause-and-effect situation. For example, the numerically dominant taxa in this study were the polychaetes, which typically have pelagic larvae. The residence time of their larvae in the plankton in the Gulf of Mexico is essentially unknown. As a result, the populations of polychaetes collected in this study may not have originated as larvae in the immediate area where they were collected. If they were present in the study area, ready to settle, and in excess of the numbers which the substrate could support, then biological conditions in the area of origin would have little or no effect upon their eventual density in the study area. If, on the other hand, the numbers of larvae in the study area were less than required to "saturate" the substrate, then densities would be directly dependent upon the abundance of larvae, which would in turn depend upon conditions between the site of origin and the study site, as well as upon the condition of the adult population which produced them. Neither the site of origin nor the conditions under which the larvae spent the earlier stages of their lives is known in this study.

Pronounced cycles in abundance are the rule, rather than the exception, for many of the taxa in this study, and it is entirely likely that the differences noted between sampling periods may be a product of natural variability rather than attributable to any single cause (human-induced or otherwise). Large fluctuations in abundance on monthly, seasonal, and annual bases are common for many infaunal taxa (Dexter 1969; Frankenberg and Leiper 1977; Moore and Lopez 1969, 1970a, 1970b, 1973; Penzias 1969; Tunnel et al. 1980; Wright and Moore 1970)

The types of physical factors which would be most likely to have significant effects on the benthic community would include major changes in bottom water characteristics (such as oxygen content, salinity, or temperature), or mechanical disturbance, especially if such disturbance altered the sediment composition (texture or organic content) to any great degree. Flint and Holland (1980) found that variability in bottom water parameters (salinity and temperature) was the most important factor in determining taxonomic abundance, diversity, and equitability. Without data from intervening periods at these sites, it is not possible to evaluate hydrographic variability with regard to the November 1979 and December 1980 collections (i.e., those of the greatest interest in this study).

Sediment texture is often the single most important determinant of macroinfaunal community components (Hargrave 1977). A detailed discussion of this subject may be found in Flint and Rabalais 1980 (Volume I, Chapter 5). Many taxa in this study can not, however, be described as sediment-limited. A large suite of taxa (mostly deposit-feeding polychaetes) dominated both nearshore, sandy sites and offshore muddy sites. These taxa included surface deposit-feeding polychaetes (Magelona phyllisae, M. longicornis, M. roseae, Tharyx marioni, and numerous spionids, especially Paraprionospio pinnata); subsurface deposit feeding polychaetes (Paraonis gracilis, Aricidea spp., Mediomastus californiensis); surface omnivorous or carnivorous polychaetes (Nephtys incisa, Lumbrineris spp.); tubicolous amphipods (Ampelisca spp.), and two phyla not identified to species level (sipunculids and nemerteans). These taxa have been described as ubiquitous in other regions as well as in south Texas (Eagle 1973, Flint and Holland 1980, Howard and Dorges 1972, Holland and Polgar 1976, Warwick and Davies 1977, Whitlach 1977).

Although both the sandy stations and the muddy stations were dominated by the ubiquitous taxa mentioned above (especially the magelonid polychaetes), some numerically abundant taxa were found exclusively at the sandy stations. These taxa included three deposit-feeding bivalves

(Tellina versicolor, Abra aequalis, and Nuculana acuta); two filter-feeding bivalves (Anadara transversa and Diplodonta cf. soror); the filter-feeding polychaete Terebellides stroemii; the predatory gastropod Natica pusilla; the deposit-feeding gastropod Caecum pulchellum; four deposit-feeding polychaetes (Magelona pettibonae, Spiophanes bombyx, Paleonotus heteroseta, and Isolda pulchella); four amphipods (Listriella barnardi, Photis macromanus, Ampelisca cristata, and Ampelisca sp. B); and the isopod Xenanthura brevitelson. That these taxa were present at three shallow stations (10 to 15 m) and one deeper station (27 m) confirms that they were not restricted by depth, but rather were confined to sandy substrates found at all four stations.

Only a few taxa appeared to be limited to deeper stations. The great preponderance of taxa found throughout the study region suggests that a more-or-less coherent community group was being sampled at all study stations, with the addition of a specialized set of shallow-water or sandy-station taxa at some locations. No clear faunal break was seen at the deeper stations, although the appearance of a few taxa not found at the sandy stations implies that perhaps the deepest stations lay near the edge of a transition zone between shallow shelf-fauna and deeper-water. The shallow-water stations therefore had greater numbers of taxa than did the deeper-water stations, in direct contrast to the results reported by Flint and Holland (1980) for three stations along one of the transects described in this study.

The study area was subjected to a major tropical storm in September 1979 (Tunnell et al. 1980), shortly before the November 1979 samples were collected. One of the most serious hurricanes ever to hit the south Texas coast (Hurricane Allen) also occurred several months prior to the collection of the 1980 samples. The evidence is mixed about the effects of heavy weather on soft-bottom benthic communities, although it can under some circumstances cause substantial changes (Rees et al. 1977), whereas under others it may have little effect (Barnett 1981).

Storms do produce water movement, reductions in salinity, and organic and sediment addition and resuspension, especially in shallow areas. The heavy rains and terrestrial erosion associated with Hurricane Allen undoubtedly caused a great deal of sediment to enter the nearshore zone of the study area. The finer fractions would remain in suspension for some time, especially nearshore where water movement is greatest, and to settle out some time later farther offshore. This transport may possibly be reflected in the data for five of the study sites (four in the 25 m to 40 m depth range, and one shallow site at 10 m depth) at which sediment texture was altered toward finer fractions (clay) in December 1980 as opposed to earlier sampling periods. The inverse of this effect (a nearshore coarsening of sediments due to removal of fine fractions) due to hurricane-generated waves was apparently observed in 1977 (Flint and Rabalais 1980, Chapter 4).

An increase in suspended sediment in the water might be expected to alter the abundance and distribution of a variety of organisms. The nearshore stations included a large number of taxa that were more or less confined to sandy habitats; a variety of these taxa are filter feeders whose feeding and respiratory apparatus may be easily clogged by the addition of fine sediments to the environment (McNulty et al. 1962a, 1962b, O'Gower and Wacasey 1973, Paine 1961). Even the relatively mild resuspending activities of surface deposit feeders have been found to have deleterious effects on filter feeders (Levinton 1972, Rhoads and Young 1970). A shift in sedimentary regime following a major storm could have drastic effects upon these taxa. Nearshore water movement would be expected to remove fine particles rapidly by resuspension at shallower sites, however, leaving little subsequent evidence of physical change.

The deeper stations would be expected to have taxa more tolerant to fine sediments, but many of the detritus-feeding taxa at these sites are dependent upon a surficial layer of detritus settling out in areas of reduced turbulence (McNulty et al. 1962b). An increase in water motion could (temporarily, at least) deplete available food resources.

Burial of organisms and/or abrasive scour due to turbulence during tropical storms have also been shown to have significant biological effects (Jackson 1972). For example, the muddy sediment and sand communities between Sabine Pass and Point Bolivar, Texas, were essentially destroyed by the passage of Hurricane Carla (Keith and Hulings 1965).

Analyses of variance did not detect any statistically significant differences between sampling periods for sediment texture, although sediment samples were quite variable between replicates within stations. The lack of significance in the ANOVA should not be interpreted to mean that no biologically important differences in sediment texture were present, however. The ANOVA was based upon admittedly arbitrary definitions of sand, silt, clay, and so forth, using traditional size partitions to separate the categories. It would be surprising, in fact, if organisms responded to the same size criteria. One of the more puzzling features of the correlation analysis (Table 4-4) is the preponderance of taxa positively correlated with sand and coarser fractions, and negatively correlated with silt and finer fractions, yet showing few significant correlations—or positive correlations—with percentage clay. A possible cause for this apparent anomaly may be the use of arbitrary sediment size categories which may bear no relationship to those criteria which determine animal distributions. The alternative explanation is that many of these organisms do best in sandy clay but not well if percentages of silt or fines are high. The data do not permit rejection of one hypothesis in favor of the other.

Another possible cause of differences in abundance and distributions of taxa over the entire study area could have been large-scale depressions in the oxygen content of water near the bottom, resulting in hypoxic conditions in surface sediments. Hypoxic bottom water ($\leq$2 mg per litre) is a common phenomenon in the Gulf of Mexico (Bedinger et al. 1980, Harper and McKinney 1980, Ragan et al 1978). Hypoxic bottom water is typically associated with elevated concentrations of organic matter produced by erosional runoff during times of thermal stratification, producing high biological oxygen demand below pycnoclines (Gallaway 1981). Mississippi River water is the main source of hypoxic water in the northwestern Gulf of Mexico (Presley et al. 1980), which sometimes may cover the entire south Texas outer continental shelf (Flint and Rabalais 1980). While the STOCS data indicate that little density statification occurs in the study area during fall, winter, and spring (Smith 1980) and that bottom oxygen levels were generally highest in the winter (Flint and Rabalais 1980), hypoxic benthic conditions have been documented immediately north of the study area (Gallaway and Reitsema 1981).

Whether or not hypoxic conditions could, in fact, be responsible for area-wide reductions in faunal abundance is unclear, however. Sometimes low salinities accompany low oxygen levels, and may result in widespread mortality and morbidity of polychaetes, crustaceans, molluscs, cnidarians, and other organisms (Harper and McKinney 1980). Some taxa seem to suffer when deprived of oxygen, while others seem unaffected for long periods of time. For example, nereid and sabellid polychaetes, holothurians, and hydroids have been damaged or destroyed by hypoxic, hyposaline water from tropical rains (Goodbody 1961). The abundance of spionid (Spiophanes bombyx), nephtyid, maldanid, paraonid (Aricidea and Paraonis spp.), and cirratulid (Tharyx) polychaetes has been shown to be positively correlated with benthic oxygen levels on Georges Bank, while the only taxon which increased in abundance with decreased oxygen levels was the capitellid polychaete Notomastus latericeus (Maurer and Leatham 1980, 1981). Tenore (1972) described complete die-off of all macrobenthos (capitellid polychaetes and bivalves included) at stations which became anoxic in the Pamlico River estuary.

On the other hand, burrowing infaunal organisms probably encounter hypoxic conditions rather frequently, and a number of other benthic invertebrates are capable of facultative anaerobic metabolism (Dales 1958, Eliassen 1955, Hochachka and Somero 1973).

During the warmer months, thermal stratification is typical of the nearshore waters of the outer continental shelf, with benthic temperatures commonly reaching 25° to 29° (Flint and Rabalais 1980). Dramatic reductions in temperature may occur in the study area during fall and winter. Smith (1980) reported that from late fall through early December, the thermally mixed layer extended to depths of about 75 m, beyond the outer limits of the study area, and reached low temperatures averaging 11° - 13° Celsius. However, extremely cold, dry Arctic air masses with temperatures often below freezing ("northers") frequently move through the study area, dropping water temperatures sharply. As these storms occur during a time when the water column is essentially unstratified, chilled surface water probably sinks due to increased densities, and mixes rapidly since high winds also are characteristic of northers.

The typical reproductive season for many of these taxa is during the winter (Moore and Lopez 1970a, 1970b, 1973; Penzias 1969; Wright and Moore 1970), when northers are most likely. Since most taxa increase their populations by recruitment of planktonic larvae to the benthos, and since the origin of those larvae is unknown, it is not possible to ascertain whether or not larval recruitment in the study area would be affected by any physical factor in the study area itself. For that matter, so little is known about critical temperature tolerances of nearly all of the taxa included in this study that it is not even possible to state definitively whether or not low bottom temperatures might be responsible for changes in abundances of macroinfaunal adults.

As a final caution, the authors wish to point out that in the absence of detectable residues of Ixtoc I oil in the sediments at the study sites, it is tempting to search for other catastrophic events which might have been responsible for the pronounced declines in most macroinfaunal taxa at the 12 study sites. While we have yielded somewhat to that temptation in this section, we feel the need to re-emphasize our contention that this study is probably best viewed as a description of natural variation. The similarities between the winter 1976 data and the mid- and post-spill data are obvious. It is just as plausible to consider fall 1976, winter 1977, and fall 1977 unusually favorable seasons from the standpoint of infaunal abundance, and winter 1976, November 1977, and December 1980 more average seasons, as it is to consider winter 1976, November 1979, and December 1980 to be unfavorable seasons for macroinfaunal abundance.

Many thoughts about the effectiveness of the damage assessment strategy utilized in this study have occurred to the authors while evaluating their own data and that of the STOCS baseline program which made this project possible. While hindsight is an easy virtue, the authors would like to share some of their concerns and recommendations with readers. Virtually all biological research programs have been forced to strike a balance between the ideal and the possible with respect to resources, time, expertise, and level of resolution of data, and these comments should be viewed in the light of practical realities rather than a plea for an ultimate study design.

The decision to re-sample the STOCS stations during and following the spill using the same sampling methodology and number of replicates collected at each station was entirely reasonable. Had there been an opportunity to alter the original program, the authors would have favored the collection of a greater number of replicates at each station, even if the size of each sample had been smaller, which would have yielded a more precise estimate of population densities, but given the pre-existing STOCS data base it would have been unnecessary to take more replicates in the 1979 and 1980 collections.

One of the major problems encountered in interpreting current results was that the time of year of sample collection varied from one year to the next. As a result, the winter collections from 1976 and 1977 may not have been comparable to those taken in November 1979 and December 1980. Without samples taken during intervening periods, it is not possible to determine whether or not faunal differences might have been due to seasonal effects, for example. An even more serious problem is the gap between the end of the STOCS program and the start of sampling in 1979, and that between the 1979 and 1980 samples. Since large differences between samples taken during the same time of year from one year to the next were seen during the STOCS program, it would have been very useful to have access to data from additional samples in winter and fall of 1978, and during winter and fall of 1979, along with those from November 1979. Certainly, collecting samples at the same time of year is no assurance that hydrographic or biological conditions will be comparable in different years, but it would at least simplify the analytical tasks conceptually, and eliminate one of the multitude of uncontrolled variables that plague damage assessments in general.

Significant taxonomic difficulties occurred due to the lack of access to a complete reference collection of STOCS specimens for verification purposes. Changes in the abundances of some taxa may be artificial, resulting from identification problems which may label the same animal with different names, for example, leading to artificial appearances and disappearances in the data set. We strongly recommend that a complete voucher collection be maintained in a central location for each such damage assessment program in the future, to avoid some of these difficulties. We were fortunate to be able to consult with many of the taxonomists involved in the STOCS program, but later groupings or splittings of taxa are quite possible, and without a reference collection it is not possible to compare new samples with older samples.

Although a recommendation for funds for additional sampling—e.g. follow-on years—is a standard ploy in ecological research programs, in this case a set of samples from 1981 would have been especially interesting biologically, since there were such marked changes in the macroinfaunal community in 1979 and 1980, compared to 1977 and 1976. Had there been petroleum residues detected in sediment, the apparent downward trend in macroinfaunal abundance could have been followed for signs of further decreases or of recovery from the spill. However, since no oil was found in sediment samples, a further measure of natural variability from one year to the next would have helped to understand the range of normal changes in the macroinfaunal shelf community, so that in the event of a spill it would be less likely that unwarranted conclusions about drastic declines might be reached.

One serious concern of the authors in evaluating the damage assessment approach used in this program is that all attention had to be focused upon the static or structural aspects of the macroinfaunal community, i.e. numbers of organisms, rather than upon the dynamics of the community. Many uncommon organisms—e.g. predators in particular—have an importance in forming and shaping a community which far outweighs their numerical abundance. This program was designed to assess large-scale changes in the most common taxa. While some might argue that any truly important modifications in community function would also, by definition, have to alter the abundances of the conspicuous forms to be recognized, the authors feel that there is not sufficient information on the biology of even the common forms to reach this conclusion. Unfortunately, we can propose no easy solution to this problem, but the gradual accumulation of life history information and toxicological response data for selected macroinfaunal taxa, for example, would go a long way toward improving the situation.

On a more practical note in the interests of economy, it would be less than honest not to mention that the authors had serious doubts about the value of analyzing the biological samples before any of the chemical results were available. As it turned out, there was no evidence of contamination of sediments with <u>Ixtoc I</u> oil. The most cost-effective approach the BLM could have taken in this program would have been to collect all of the necessary samples (which it did), and then simply archive the biological samples until the chemical samples had been analyzed. Upon finding oil in the chemical samples, it would have been reasonable to analyze the biological samples that were contaminated and to select a subset, perhaps, of uncontaminated biological samples for comparative purposes, rather than to analyze the entire set simultaneously. Taking this point to its logical conclusion, since there was no direct (chemical) evidence that the macroinfauna was exposed to oil, it was not necessary to analyze the biological samples at all, unless the program goal was to collect yet another two years of baseline data (the actual, final product)!

In summary, then, future damage assessment programs would be most likely to be successful and cost-effective if they (1) utilized comparable sampling techniques and collected equivalent numbers of replicate samples; (2) were designed for high replication of each set of samples, to cope with the expected natural variability; (3) were scheduled to include samples collected at the same time of year or comparable seasons; (4) continued for at least a year or two following the suspected impact, especially if pronounced faunal changes appear to have occurred; (5) produced complete, validated reference collections of specimens; (6) worked in step-wise fashion, with chemical results preceding the further analysis of archived biological samples.

4.5 Summary and conclusions

1. South Texas Outer Continental Shelf program (STOCS) samples from winter 1976, fall 1976, winter 1977, and fall 1977 were determined to be the most directly comparable to November 1979 and December 1980 collections, from the standpoint of equivalence of replication and time of year. Consequently, comparisons were restricted to a data set from 12 stations ranging in depth from 10 m to 49 m, and which were sampled in each of these 6 sampling periods.

2. The data set described in this report included 65,166 individuals composed of 576 taxa of macroinfaunal invertebrates. There were major differences in numbers of taxa and numbers of individuals collected from one sampling period to the next, with numbers of both rising sharply from fairly low values in winter 1976 (248 taxa, 8,569 individuals) to their highest values in fall 1976 (339 taxa, 18,844 individuals). Values then gradually declined in winter 1977 (317 taxa, 15,640 individuals) and fall 1977 (318 taxa, 14,701 individuals). They subsequently dropped precipitously in November 1979 (207 taxa, 4,066 individuals) and then fell further in December 1980 to the lowest values observed (127 taxa, 3,346 individuals).

3. The November 1979 and December 1980 samples differed significantly in terms of numbers of taxa from the fall 1976 and winter 1977 samples, while periods of intermediate values (winter 1976 and fall 1977) were not statistically distinguishable from the sampling periods with either low or high numbers of taxa. The greatest similarities were seen between the three sampling periods having the largest numbers of taxa: fall 1976, winter 1977, and fall 1977.

4. The November 1979 and December 1980 samples differed significantly in terms of numbers of individuals from the

fall 1976, winter 1977 and fall 1977 samples; the winter 1976 samples had intermediate values and were not statistically distinguishable from the sampling periods with either low or high numbers of taxa. The greatest similarities were seen between the three sampling periods having the largest numbers of individuals: fall 1976, winter 1977, and fall 1977.

5. Most of the taxa considered in this study were extremely rare; 105 taxa were represented by only one individual, and 249 taxa by five or fewer individuals.

6. Diversity (H') remained relatively constant for all stations together from fall 1976 through November 1979 (range from 3.86 to 4.13), but showed the lowest values in the first and last sampling periods (winter 1976, H'= 3.55; December 1980, H'= 3.12). Evenness (V') showed a similar pattern, with low values (0.62) in winter 1976 and December 1980 and a range from 0.66 to 0.72 between fall 1976 and November 1979.

7. Most of the numerically dominant taxa spanned the depth range from the shallowest to the deepest stations in fall 1976 (40 taxa), winter 1977 (33 taxa), and fall 1977 (38 taxa), when abundance and numbers of taxa were highest. During winter 1976 and November 1979 and December 1980, substantially fewer taxa were as broad in their distributions (25, 17, and 11 taxa, respectively). The proportions of multiple occurrences of taxa rose from winter 1976 (13% at seven or more stations) to its highest value in fall 1976 (16%), and declined to 12%, 11%, and 9% in subsequent sampling periods.

8. A distinct suite of taxa was restricted to a set of three shallow (10 to 15 m) one deeper (27 m) station, all fairly near shore and having rather coarse, sandy sediment. During fall 1977, November 1979, and fall 1976 this group included 19, 17, and 15 taxa, respectively, and was reduced to twelve, eleven and ten taxa in winter 1976, winter 1977, and December 1980.

9. There were only three taxa which were rarely found at the shallowest stations. These three taxa were most common during the earlier sampling periods, and were for the most part absent from November 1979 and December 1980 samples. Other than these three, no clearly defined set of taxa was restricted to the deeper stations; the great majority of taxa common at the deepest stations were also common at the shallowest stations.

10. The abundance of most numerically dominant taxa was positively correlated with mean grain size and the proportions of coarser fractions of sediment (percentage sand, ratio sand:mud), and negatively correlated with the proportions of finer sediment (percentages of silt, clay,

and "fines" smaller than 0.001 mm). Four taxa showed the inverse of this pattern, being positively correlated with percentages of clay, silt, and "fines," and negatively correlated with percentage sand, mean grain size, and the ratio sand:mud. These four taxa also were among the eight taxa having the deepest average depth of collection.

11. The abundance of many numerically dominant taxa was negatively correlated with sediment total organic carbon (TOC). Only 2 taxa were positively correlated with TOC; these two taxa were among the eight taxa having the deepest average depth of collection.

12. Cluster analysis based upon abundance of numerically dominant taxa typically grouped stations within any given sampling period into a nearshore cluster which included the sandy stations, an offshore cluster which included the stations characterized by muddy sediments, and several lying at an intermediate distance and depth. The nearshore cluster included those stations having many broadly-distributed taxa found at all stations as well as those taxa restricted just to sandy, nearshore sites. The offshore stations included the broadly distributed taxa, and several taxa not found within the nearshore cluster. The intermediate cluster of stations usually included the broadly distributed taxa, and a reduced number of the nearshore-associated taxa not found at the deeper stations.

13. A two-way table produced by merging a cluster analysis of numerically dominant taxa and an inverse dendrogram of stations for all sampling periods suggested that at least nine distinct groups of taxa and eight distinct groups of station/periods could be differentiated. Several large-scale patterns could be seen clearly, and are described below.

14. Several groups of taxa (e.g. A and F) were important at all stations regardless of sampling period, and may be legitimately described as ubiquitous within the study area.

15. Several groups of taxa (e.g. B and C) were most important at stations having coarse, sandy sediment, and rare or absent at stations with fine sediment. The converse was not true, though. There were no groups which were primarily restricted to stations with fine sediment, but stations with fine sediment did include many of the same taxa found at sandy stations.

16. Groups of taxa (e.g. D and E) which were predominant at both muddy and sandy stations were most important during 1976 and 1977, and were less well represented at the same stations during November 1979 and 1980.

17. Unusually high abundances of several groups (e.g. G and H) at a few stations during a few sampling periods were seen; however, ubiquitous taxa (such as those in A and F) were more often responsible for "blooms," achieving relative dominance during a given sampling period or at a few stations.

18. Deposit-feeding polychaetes dominated the study area during all sampling periods (49% to 57% of the total numbers of individuals seen in any given sampling period). Another very important assemblage included errant omnivorous and carnivorous polychaetes, which were second in relative importance (16% to 20%) in all sampling periods but one. Other dominant groups (in relative order of % abundance) were amphipods (3% to 9%), gastropods (1% to 3% except in 1980 when a single taxon raised the total to 22%), pelecypods (1% to 8%), sipunculids (2% to 7%), nemerteans (1% to 7%), non-decapod crustaceans (1% to 3%), decapods (1% to 4%), echinoderms (1% or less except in 1980 when a single taxon raised the total to 7%), and other polychaetes (2% or less).

19. Since residues of Ixtoc I oil were not identified in any of the sediment samples, the temporal variations in the benthic macroinfaunal community could not be related definitely to the spill, or, for that matter, to any particular human-induced or environmental factor(s) and may fall within the range of natural variability.