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Effects of Beach Replenishment on the Nearshore Sand Fauna at Imperial Beach, California

by

Terence Parr, Douglas Diener, and Stephen Lacy

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This study evaluates the changes in intertidal and shallow subtidal sand-bottom infaunal populations in response to the addition of approximately 765,000 cubic meters of dredged material added to an eroded beach at Imperial Beach, California. A sampling design utilizing small sampling units and extensive replication was effective in generating reliable numerical estimates of infaunal densities and diversity.

(Continued)

The dredged material had a high proportion of fine material with lesser amounts of shell fragments. Fine sediments were rapidly transported offshore while shells persisted on the beach. Measured beach effects were short term (5 weeks or less) involving increases in abundance mostly of motile crustacean species which brood their young. Planktonic recruitment of polychaetes was evident during this period.

As the fine sediments worked offshore, silt and fine sand fractions increased in the bottom sediments. At subtidal depths, there was a positive correlation between the silt-clay fraction and number of species and abundance. Overall abundance and diversity of the benthos were not adversely affected by beach replenishment. In response to an unpredictable, changing environment (erosion-deposition), most of the resident biota are short-lived, opportunistic species which are typically patchy in distribution both temporally and spatially. Possible longer term effects upon longer lived species, such as sand dollar populations, were not determined.

PREFACE

This report is published to provide information to coastal engineers on the potential impacts of beach replenishment programs upon intertidal and shallow sedimentary benthic biota. The work was carried out under the coastal ecology research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by Stephen Lacy of WESTEC Services, Inc., San Diego, California, and authored by Terence Parr and Dr. Douglas Diener, Marine Ecological Consultants, Solana Beach, California, under CERC Contract No. DACW72-76-0007.

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R.M. Yancey was the CERC contract monitor for the report, under the general supervision of E.J. Pullen, Chief, Ecology Branch, Research Division.

Comments on this publication are invited.

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JOHN H. COUSINS
Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

GLOSSARY OF BIOLOGICAL TERMS

AGGREGATION - The clumped distribution of individuals, in which distribution is not random and the variance is significantly greater than the mean value.

BENTHOS - A collective term describing: (1) Bottom organisms attached or resting on or in the bottom sediments. (2) Community of animals living in or on the bottom.

BIOCOENOSIS - Approximately equal to a biotic community of plants (phytocoenosis) and animals (zoocoenosis).

BIOMASS - The amount of living material in a unit area for a point in time. Also standing crop, standing stock, live weight.

DETRITUS - Any fine particular debris, usually of organic origin, but sometimes defined as organic and inorganic debris. In this report, the commonly used biological definition - dead organic matter.

DEMERSAL - Organisms that live on or slightly above the bottom.

FECUNDITY - The amount of egg or sperm production per individual or population per unit time.

INFAUNAL - The animal population living within the sediments.

INTERSTITIAL - A term referring to the spaces between particles (e.g., the spaces between sand grains).

PERACARID CRUSTACEA - Animals in the division Peracarida of the class Crustacea (including pillbugs, beach hoppers, and mysids).

EFFECTS OF BEACH REPLENISHMENT ON THE NEARSHORE SAND FAUNA AT IMPERIAL BEACH, CALIFORNIA

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I. INTRODUCTION

Unconsolidated sediments comprise the most prevalent nearshore benthic marine habitat. Biological communities associated with these sediments assimilate much of the energy flow through the nearshore ecosystem. Soft-bottom invertebrates play an integral role in the conversion of the organic deposits of the continental shelves into biomass available to higher trophic levels such as predatory demersal fishes whose population densities show positive correlation with benthic invertebrate standing crops (Stevens, 1930; Longhurst, 1958; Day, 1967).

This report presents results from a study of impacted and potentially impacted sedimentary communities in and near an area where approximately 765,000 cubic meters of dredged sediment was pumped onto a coastal, exposed beach to replenish part of the shoreline at Imperial Beach, California. This process may also be referred to as beach nourishment (Allen, 1972). The aim of the study was to establish relationships between beach replenishment and measurable biological variables in the shallow-water community (e.g., composition, species abundances, and diversity) and those measurable abiotic variables (e.g., sediment type) considered important for their influence on biological community structure. A review of general ecological effects associated with dredging and beach replenishment was presented by Thompson (1973).

The open-coast shoreline of southern California is about 84 percent sand beach. Of the beaches, only 30 percent are truly depositional regions of the coast (Emery, 1960). Terrestrial inputs of sediment to southern California beaches have been reduced as a result of man's activities and serious beach erosion has been a problem for some time at various places along the coastline. Beach replenishment with dredge material from depositional environments such as bays provides a feasible means of counteracting beach erosion in certain areas. This study discusses the biological effects associated with this process.

The program design subscribed to sampling at points (space, time) which could test various hypotheses related to effects of the added sediments. Although correlations between physical-chemical and biological events may be observed, the idea of causation is a complex one and correlated variables may not always be directly related. To fully understand mechanisms underlying observed distributions, the detailed relationships of species associations to environmental parameters may require subsequent experimental verification. Jumars and Fauchald (1977) emphasize the importance to sedimentary communities of factors such as individual species foraging patterns and local fluxes of food source--these being either impossible to measure or impractical within the scope of most studies. Until more dynamic approaches to studying infaunal communities can be developed, standard geological sediment parameters will continue to be overemphasized.

Macrofauna and meiofauna have been variously defined but are usually respectively regarded as those organisms retained by and passing through a 0.5-millimeter screen (Hulings and Gray, 1971; Cox, 1976). In sublittoral sediments meiofauna comprise only a small proportion of community biomass (usually less than 5 percent) and for this reason are usually ignored in sampling programs. However, their contribution to community metabolism and numbers of species and individuals is more significant (Weiser, 1959; McIntyre, 1969; Gerlach, 1971). Intertidal beach meiofaunal biomass may equal that of the macrofauna (Gerlach, 1971). The meiofauna may include early developmental stages of macrofaunal species. Most studies, including this one, have focused on macrofaunal relationships.

II. MARINE SEDIMENTARY COMMUNITIES

Nearshore exposed coast sedimentary environments are physically restrictive and outwardly appear to be biologically barren. Furthermore, practical difficulties exist in effectively sampling subtidal areas within the surge zone. Perhaps, it is for these reasons that few studies have comprehensively dealt with these nearshore biological communities. Fager's (1968) study of a subtidal sand bottom was the first to be based upon direct observation.

Early intertidal studies are cited by Hedgepeth (1957) in his review of sandy beaches. Dahl (1953) described general worldwide zonation patterns of sand beach macrofauna and their relation to tidal cycles. In North America the most complete marine beach studies are those of Pearse, Humm, and Wharton (1942) and Pamatmat (1968); the latter extensively detailed physical-chemical and metabolic relationships on a protected bay intertidal flat. Unfortunately, the information is not specifically relevant to exposed coastal environments. Recent investigations of sand beaches include those of McIntyre (1968), Brown (1971), Ansell, et al. (1972), Dexter (1972), and Cox (1976).

Subtidal sediment populations until recently have been studied primarily from a descriptive standpoint. Early studies by Petersen (1913, 1915, 1918) helped shape the traditional biocoenosis view of a relatively uniform physical habitat dominated by a small number of conspicuous species. This view persisted through studies by Thorson (1955, 1957) who documented the occurrence of similar species within restricted sediment types from different geographic regions, implying that species show fairly precise selection for particle type or correlated variables. Observed distributions fit this contention and there is some experimental evidence supporting this hypothesis (reviews by Meadows and Campbell, 1972; Gray, 1974). However, within a given set of environmental variables, biological interactions may determine much of the observed community structure via such control mechanisms (e.g., predation, competition for space) as have been demonstrated experimentally for other marine communities (Connell, 1972, 1974). Unfortunately, infaunal communities have not been amenable to similar types of manipulation or direct observation, so these interactions have received little attention.

The biocoenosis view of stable coadapted species assemblages in long-term equilibrium with the environment has been revised by more recent approaches of ordination and multifactorial analysis (see Mills, 1969; Lie and Kelley, 1970) which have shown how infaunal species distributions may be viewed as loose co-occurrences or aggregations along continua of the physical environment. Probably varying degrees of both situations exist within any observed pattern. Knowledge of infaunal distribution patterns has suffered from a lack of experimental verification of degrees of physical control, and from few attempts to define biological interactive and coactive determinants of structure. Hutchinson (1953) discusses these factors.

1. <u>Physical-Chemical Factors.</u>

The sediment-water interface is a biologically active boundary supporting a complex of interacting invertebrates and fishes which derive energy primarily from carbon and nitrogen sources in organic detritus, either directly or through trophic steps (Rowe, 1971; Hargrave, 1973). Although little information is available on actual nutritive values of detritus (Darnell 1967; Tenore, 1977), the qualitative composition and magnitude of detrital flux to the sediment strongly influence species composition, abundance and biomass, with greater faunal densities occurring along gradients of increasing detrital supply (Sanders, 1969; Sanders and Hessler, 1969). However, in very shallow water where sediments are regularly disturbed by wave activity, this relationship does not hold. Margalef (1968, 1975) has pointed out that in changing, unstable environments, ecosystems are energetically expensive to operate because excess fecundity is necessary to compensate for loss of individuals. On the positive side is their ability to function under a wider range of conditions. This serves to explain why shallow, nearshore communities in relatively productive waters generally have lower biomass and species abundance than offshore communities of the continental shelves where sediments are more stable (Barnard, 1963; Lie and Kisker, 1970).

The overriding importance of sediment grain size as a controlling community variable has been emphasized by Jannson (1967) and Thorson (1957), and reviewed by Gray (1974). This importance derives from its control over biologically meaningful variables such as porosity, oxygen tension, water content, and retention of organic material. For example, Weiser (1960) examined a bay environment and found few fauna in common where silt-clay fractions differed. Sanders (1958, 1960) found that grain size correlated with infaunal densities and was important in determining basic feeding modes (suspension versus deposit feeding) of the species. Closely related species may show distinct sediment-size preferences (Clark and Haderlie, 1963). Nichols (1970) found that polychaete species assemblages corresponded most clearly with clay content. Mineralogical composition may be important to certain species (Fager, 1964). In comparison with subtidal habitats, sand beaches experience unique conditions (exposure to air, desiccation, and evaporation) and greater vicissitudes of physical factors, and pose a more restrictive habitat for macrofaunal organisms.

Tidal height and exposure conditions are important factors. Their relationships to physical and chemical factors which affect infaunal distributions have been discussed by Bruce (1928), Newcombe (1935), Emery and Foster (1948), Hedgepeth (1957), Johnson (1965), and Cox (1976).

In southern California, exposed beaches typically undergo sand accretion in the summer (reduced wave energy) and erosion in the winter (high energy); thus, sandbars build offshore in the winter and migrate shoreward onto the beaches in the summer. Observations (unpublished) support those of Speidel (1975) who reported that seasonal shifting of sediment generally occurs in water less than 9.2 meters deep off southern California and is greatest in the surf zone. Seasonal differences in sand level may exceed 1 meter at a depth of 4.9 meters below mean lower low water (MLLW) (personal communication, D. Aubrey, Scripps Institution of Oceanography, 1977).

Sediment stability is an important factor in determining species associations. Ansell, et al. (1972) found that species composition, abundance, and zonation patterns were correlated significantly with monsoon conditions and stability of substrate. Yancey and Welch (1968) mentioned the heavy mortality of nearshore populations of Atlantic coast surf clams during storms, though the impact upon population dynamics was unknown. Enright (1962) documented the adverse effects of increased wave activity upon a beach amphipod population. What is *not* known is the extent of onshore-offshore migration of motile infaunal species in response to such perturbations. Certainly apropos is Longhurst's (1964) statement that the problem in studying these biological communities lies in the lack of a simple starting point such as a landscape.

Few studies have examined subtidal communities along exposed coasts in depths of less than 7.6 meters. The biological community at these shallow depths is continually affected by wave action. Day, Field, and Montgomery (1971) characterized this inshore "turbulent zone" as one with relatively fewer species and greater fluctuations in abundance and composition. Parr and Diener (1978) drew similar conclusions in comparing 7.6- and 18.3-meter depths on an exposed bottom. Barnard (1963) and Day, Field, and Montgomery (1971) have commented on the absence of gallery-forming faunas on inshore sands where the substrate is not sufficiently compact to permit much deep burrowing and tube building by infaunal organisms.

2. Biological Factors.

Sand-bottom communities are not amenable to direct observation and experimental manipulations are difficult. Only one sand beach study by Boaden (1962) is cited by Connell (1974) in his review of field experiments in marine ecology. This lack of information on biological interactions has naturally led to an overemphasis of more easily measured physical-sediment parameters. Correlations with these variables are often weak and questions of causality left unanswered.

In an analysis of sediment communities from shelf depths along the entire southern California coast, Jones (1969) found shallow-water fauna to be of heterogeneous taxonomic composition and only very loosely defined relationships to physical sediment parameters were evident. Thus, "patchiness" was an integral part of Hartman's (1966) interpretation of these same communities. Rhoads (1974) was the first to measure effects of biological activities on physical-sediment parameters (bioturbation). Fager (1964) and Mills (1969) showed how single species may influence substrate stability. Diener and Parr (1977) studied a nearshore community dominant tube-building polychaete and found localized effects of increased sediment coarseness and species diversity in its immediate vicinity. Recently, through experimental manipulation, studies have documented the significance of key species interactions, habitat modification, predation, and competition (Blake and Jeffries, 1971; Woodin, 1974; Hall, 1977; Virnstein, 1977). Biological activities may be dominant factors underlying observed patterns of infaunal distribution, with an increase in their influence proceeding from the unstable and more physically mediated beach and surf zones to more stable regions offshore.

3. The Importance of Life-History Information.

As an adaptation to an unstable habitat, organisms tend to be short-lived (e.g., most beach fauna are annuals; Hedgepeth, 1957), and either have high fecundity with wide powers of dispersal via planktonic larvae or have low fecundity with brood protection of young ensuring a higher rate of survival.

For those species with planktonic larvae (about 60 percent according to Thorson, 1946), an unmeasurable source of variation is induced by selective factors operating on planktonic larval stages. Observed fauna may largely reflect the timing and numbers of larvae available for settlement. Species occurrence at a particular locality usually reflects availability of larvae in the plankton and concomitant suitability of water, physical and biological substrate qualities as cues for settlement. Absence of a species may indicate lack of larvae, unsuitability of cues for settlement, or postsettlement mortality. Specific factors affecting larvae are not well known. Coe (1953) and Barnes and Wenner (1968) showed a high degree of spatial and temporal variation in larval settlement patterns of sand beach macrofauna. Diener and Parr (1977) found that abundances of certain dominant infaunal polychaete species varied up to a hundredfold between sampling periods at 7.6-meter depths off southern California.

It may be concluded from the unstable nature of the physical habitat and the ephemeral nature of infauna populations as a result of their life-history characteristics, that nearshore sediment populations show wide variations in their numbers both in space and time. Proceeding offshore to more physically stable conditions, populations become more diverse (Day, 1967; Day, Field, and Montgomery, 1971). This conforms with Sanders' (1969) thesis of higher diversity in less physically controlled (offshore) environments.

Implications of variations in basic life-history characteristics, such as lifespan, fecundity, and age of reproduction in relation to environmental stability have been discussed by Frank (1968), Margalef (1968, 1975), Pianka (1970), and MacArthur (1972). The importance of relating empirical data to considerations of ecological theory and translating this to such applied problems as environmental impacts of man-induced perturbations upon marine benthic communities lies in the fact that environmental impacts of these perturbations are most prevalent in nearshore and coastal regions. Superimposed upon seasonal recruitment patterns, nearshore populations, via the aforementioned life-history strategies, frequently experience periods of population expansion when the environment is not resource limiting or physically disruptive. Furthermore, most species show a high degree of spatial aggregation, even in apparently physically homogeneous areas (Buchanan, 1963; Gardefors and Orrhage, 1968; Gage and Geekie, 1973). It is upon this background of natural variability that detection of responses to perturbations must be discerned. From an engineering standpoint it becomes a problem of signal extraction; statistically based detection of low level responses may be difficult. High variability within these nearshore communities should be recognized as basic features of their existence. Sampling design, statistical treatment, and monitoring have to operate within this framework.

4. Diversity.

The classical (and largely theoretical) contention regarding biological diversity is that high diversity should promote resistance to change (MacArthur, 1955). However, diverse communities have shown high susceptibility to perturbations (Paine, 1969; May, 1975). In addition, experiments (e.g., Hairston, et al., 1968) and models (Strobeck, 1973; Maynard-Smith, 1974) have shown that stability is not a necessary consequence of increased complexity. Steele (1974) concluded that neither a system's diversity or efficiency is a definite reflection of its dynamic stability; thus, there is a lack of general predictive capacity for evaluating the consequences of large-scale man-induced disturbances. The likelihood that multiple stable points may exist within natural communities (Lewontin, 1969; MacArthur, 1972; Sutherland, 1974) further complicates this issue.

5. Southern California and Imperial Beach Sediments.

The Continental Shelf off southern California is more complex geographically and has more mixed substrate patterns than typical shelf sediments from other regions (Emery, 1960). The shelf off Imperial Beach is wider than off other southern California areas and is typified by 8.8-percent rock, 76.4-percent sand, and 14.6-percent silt (Stevenson, Uchipi, and Gorsline, 1959). As the subtidal delta of the Tijuana River is approached at the southern end of Imperial Beach, sediments become coarser and better sorted, ranging from very fine to medium sand with median grain sizes between 150 to 300 micrometers (Intersea Research Corporation, 1978). Muslin (1978) reported intertidal beach sediment median grain size to be about 200 micrometers (fine sand). Mineralogical composition of beach sediments is dominated by hornblende (Intersea Research Corporation, 1978) and characterizes a metamorphic source rock (Pettijohn, 1957). Imperial Beach lies within a zone of wave convergence and also experiences longshore currents flowing northward. These two sources of energy create a high rate of sediment transport to the north. The potential transport rate is 76,500 cubic meters per year. Erosion loss has been estimated at 22,900 cubic meters per year (Intersea Research Corporation, 1978; Muslin, 1978). These sediments must be constantly replenished if erosion of the beach is to be stabilized. Previously, Tijuana River basin runoff was the major source of sediment input, but this has been reduced by an estimated 70 percent during this century due to a reduction in precipitation, creation of upstream dams, and use of water for agricultural purposes (Intersea Research Corporation, 1978). Further details of the erosion problem at Imperial Beach are presented by Inman (1973).

6. Southern California and Imperial Beach Infauna.

Knowledge of distribution patterns of the southern California mainland shelf macrofauna is almost entirely derived from the extensive surveys between Point Conception and the Mexican border conducted by the Allan Hancock Foundation (AHF) in the late 1950's. Much of this work is summarized in Barnard, Hartman, and Jones (1959) and Jones (1969).

The AHF program was not specifically designed to test for effects of important environmental variables on community composition nor were replicate samples taken which would provide estimates of within-station variability and permit statistical comparisons between stations. Furthermore, depths seaward and shoreward of 10 meters were sampled with different devices now known to vary greatly in their efficiencies (Word, 1975). However, a valuable descriptive account of the fauna is provided and certain loosely defined relationships are evident. Species groupings were delimited by Jones (1969) and Baker (1975) who applied cluster-analysis techniques to the AHF data. From Jones' (1969) analysis it is evident that the fauna in shallow water is of heterogeneous taxonomic composition and spatial distribution; several species associations inhabit the bottom. Farther offshore the fauna is less patchy and more consistent.

A comprehensive study of the open-coast subtidal sand-bottom infaunal community residing within the strong surge zone (to 7.6-meter depth) has not been conducted in southern California. These fauna may have distinctive features as reported elsewhere (Day, Field, and Montgomery, 1971). Barnard (1963) and Jones (1969) provided valuable descriptions of some of the resident infaunal elements. Fager's (1968) comprehensive study off La Jolla, California, dealt primarily with a few epifaunal species. Oliver and Slattery (1976) reported on a nearshore (6.1 to 19.8 meters) infaunal community off central California and responses of species to dredge disposal. Their report includes good information on seasonality of abundance and reproductive conditions of the species. Patterson (1974) published the only study which enumerates and quantifies southern California beach biota; nine beaches were sampled seasonally. Other sand beach studies from this region have received little attention due to their minimal circulation as technical reports or dissertations. Particularly relevant are studies by Dexter (1977) at Imperial Beach and Clark (1969) from several beaches in the San Diego area. Dexter's study used different sampling methods than the present study, thus comparisons in sampling effectiveness can be made but comparisons of numerical data require caution.

7. Sampling Design Considerations.

In addition to problems posed by the inherent variability of nearshore populations, these populations are also subject to a high degree of sampling error (Longhurst, 1964). This is attested to by a fairly regular input of literature comparing effectiveness and efficiency of various sampling devices (e.g., Holme, 1964; Gallardo, 1965; Wigley, 1967; Word, 1975). In shallow water where scuba diving is possible, the use of hand-operated core samplers obviates most of the problems associated with large shipboard grab-sampling devices (e.g., inconsistent sampler volume, penetration depth, and disturbance of sediment). The compromise made is one of smaller sample volume of corers and the general physical limitations of working underwater. The advantages are that greater replication is possible and samples may be spaced according to design and taken with little disturbance of surface sediments. This is important since most small infaunal organisms reside within the upper 4 to 5 centimeters in benthic sediments.

The use of different sampling devices as well as a wide variety of screen sizes for sorting organisms has made it difficult to compare data between studies (Reish, 1959; Knox, 1977). In particular, data obtained for species diversity and abundance are highly contingent on screen size. Selection of screen size is based on sediment type and a balance between the specific type of information desired (e.g., diversity, biomass), as well as time limitations for sorting samples and making taxonomic identifications. Experience with nearshore samples from differing sediment types in southern California has indicated a twofold to threefold increase in sorting time between 1.0- and 0.5-millimeter screen sizes. Recently, monitoring programs have used smaller screens more frequently. A recommended strategy is to sieve samples through nested screens (e.g., 1.0 millimeter above a 0.5-millimeter screen). Material is preserved separately. Organisms from the larger screen can be analyzed, then if cost or time limitations permit, a greater level of description of the biota can be obtained by analyzing material from smaller screen sizes.

Since the time required to process samples and identify the organisms imposes a limitation on the number of samples which can be processed within the constraints of any sampling program, choices dealing with the timing, spacing, and number of replicates assume an added importance. Sampling design should maximize information return within these constraints. Optimization approaches have seldom been invoked in benthic sampling programs. Recently, Saila, Pikanowksi, and Vaughan (1976), Cox (1976), Scherba and Gallucci (1976), and Diener and Parr (1977) have dealt with maximization of information return and problems of precision in estimating sedimentary macrofaunal and meiofaunal populations.

Analyses of data from benthic programs have traditionally utilized parametric statistics to test for differences between populations. However, assumptions underlying these analyses require preconditions (equal sample variances, variance equal to the mean) which are not usually met with biological data. More frequently, animals are aggregated and their distribution quite often fits a negative binomial distribution (Bliss and Fisher, 1953; Debauche, 1962) in which case the variance exceeds the mean. Various approaches to analysis of benthic data and transformations to normality for different types of data distributions are detailed by Elliott (1971). When animals are aggregated (patchy) in samples, a small sample unit is more effective than a large one (Beall, 1939; Finney, 1946; Elliott, 1971; Gerard and Berthet, 1971); the major reasons are: (a) More samples can be taken from a given bottom area, thus for the same analytical effort statistical error is reduced by increased replication; (b) several small sampling units can assess a wider range of the habitat mosaic than a few large samples; and (c) greater ease of handling, screening, and sorting of smaller samples. However, the sampling unit (core sample, etc.) should be large enough to capture enough organisms of interest in each sample so that sets of data are not extremely skewed towards zero values (see Elliott, 1971). In our biological sampling we have emphasized extensive replication with small-size sampling units.

III. MATERIALS AND METHODS

Three permanent reference points (stations A, B, and C) were established along the beach at Imperial Beach, California (Fig. 1). Station A was located near the beginning of the dredge-disposal area. Proceeding downcoast, station B was located at the terminus of the dredge disposal, 1.188 kilometers downcoast, and station C was established as a control site, 954 meters downcoast of station B. At each reference point sampling was conducted intertidally as well as directly offshore in 3.7 and 6.1 meters of water below mean lower low water (MLLW). The station reference points are shown in Figure 1 and are described as follows:

(a) Station A (northern dredge-disposal site) - located directly off of Carnation Avenue; station origin on fence approximately 171 meters south from groin No. 1 (start of dredge-disposal zone); located 732 meters north of the municipal pier.

(b) Station B (dredge-disposal terminus) - located just south of Coronado Avenue near Black Avenue; station origin approximately 1.359 kilometers south of groin No. 1; located 412 meters south of the municipal fishing pier.

(c) Station C (southern control site) - located south of Encanto Avenue; station origin is sixth house north of the terminus of First Street; located approximately 2.313 kilometers south of groin No. 1 or 1.426 kilometers south of the municipal fishing pier. This station was 1.125 kilometers north from the mouth of the Tijuana River.

Nine sampling locations were established within the three stations, three per station--one intertidally, and one each at the 3.7- and 6.1-

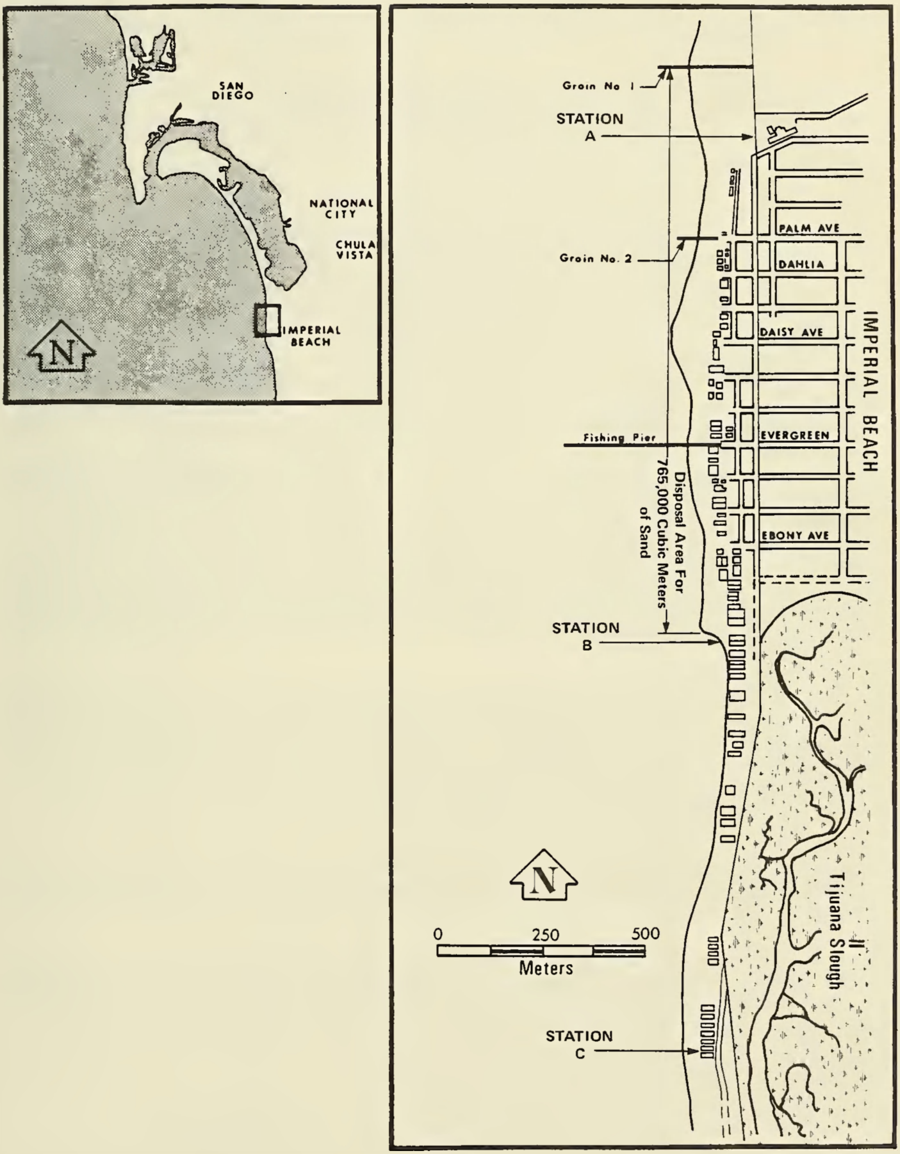

Figure 1. Location of sampling stations at Imperial Beach, California.

meter depths (e.g., station A-intertidal, station A-3.7 meters, station A-6.1 meters).

Stations A and C (all depths) were surveyed four times while station B (all depths) was surveyed five times over a 15-month span which included the beach replenishment period (22 March to 20 June 1977). Sampling dates are shown in Table 1.

For each intertidal survey the beach width (BW) was defined as the distance from the highest point of the previous high tide extending into the water to 61 centimeters below MLLW. In accordance with Dahl (1953), sampling strata were determined by dividing the beach width into thirds: the upper stratum representing the highest tide level (upper one-third of the beach), the middle stratum representing the middle one-third of the beach, etc. Three parallel transect lines 50 meters apart centered on the station reference point were alined perpendicular to the shoreline (Fig. 2). Infauna were sampled by taking 10 core samples (8 centimeters in diameter by 10 centimeters deep) per stratum along each of the three transects for a total of 90 cores per intertidal station. Cores were taken at regular intervals on the center transect (transect line 2) at each intertidal station by a line-point method. Along the upcoast and downcoast transect lines (transect line 1 and 3) infaunal cores were taken within 5 meters either side of the transect line; i.e., by a stratified random sampling method (Fig. 2). Within each stratum of these two outer transects, sampling distances along the transect and to sampling points on either side of the transect were determined from a random numbers table.

Directly offshore of station reference points at 3.7- and 6.1-meter depths below MLLW, samples were taken by scuba divers (Fig. 2). Fifteen cores were taken at each depth. Cores were randomly taken within a 15-meter-diameter circle about the boat anchor. Surge conditions did not permit application of a systematic spatial design for collection of samples at these nearshore depths.

Intertidal surveys were made during minus tides (27 to 58 centimeters MLLW) and the 3.7- and 6.1-meter depth stations were sampled during high tide.

Sediment samples were collected for grain-size analysis and organic and inorganic carbon content in 100-millimeter length by 45-millimeter-diameter jars. At each intertidal station, four sediment samples were taken (three for grain-size analysis, one for carbon analysis); two samples were taken at offshore sampling points (Fig. 3). Samples for carbon analysis were frozen until analyzed.

The total number of samples taken and processed is shown in Table 2. Biological cores were sieved through a 0.5-millimeter sieve, Tyler 32 mesh (U.S. Geological Series sieve equivalent No. 35). All organisms were counted and identified to the lowest possible taxon. At some

Table 1. Sampling dates for Imperial Beach study.

Station Designation	Depth	SURVEY				
		I	II	III	IV	V
A	intertidal	22 Sept. 76	14 Feb. 77	--[1]	27 July 77	10 Nov. 77
B	intertidal	23 Sept. 76	15 Feb. 77	2 June 77	28 July 77	11 Nov. 77
C	intertidal	24 Sept. 76	16 Feb. 77	--[1]	29 July 77	12 Nov. 77
A	3.7 meters	30 Aug. 76	6 Apr. 77	--[1]	12 Aug. 77	29 Nov. 77
B	3.7 meters	30 Aug. 76	6 Apr. 77	2 June 77	12 Aug. 77	29 Nov. 77
C	3.7 meters	30 Aug. 76	6 Apr. 77	--[1]	12 Aug. 77	29 Nov. 77
A	6.1 meters	31 Aug. 76	9 Mar. 77	--[1]	12 Aug. 77	29 Nov. 77
B	6.1 meters	31 Aug. 76	9 Mar. 77	2 June 77	12 Aug. 77	29 Nov. 77
C	6.1 meters	31 Aug. 76	9 Mar. 77	--[1]	12 Aug. 77	29 Nov. 77

[1]Not surveyed.

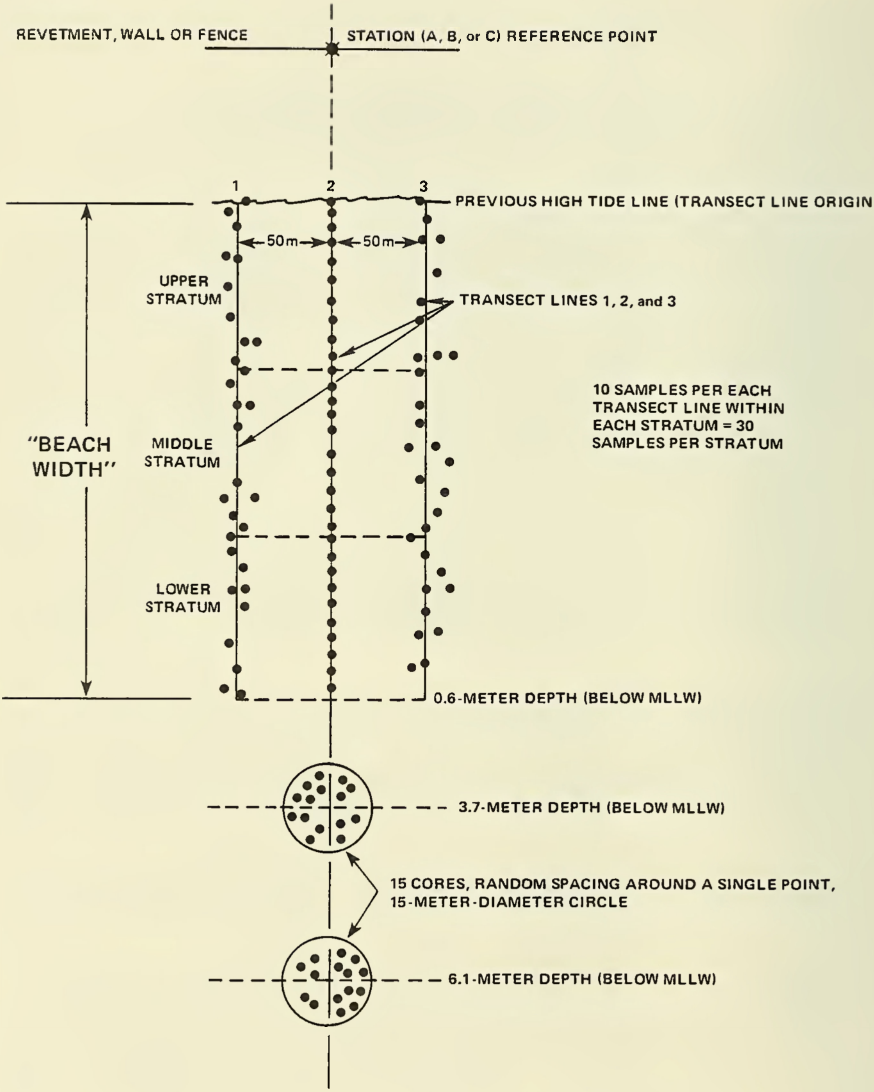

Figure 2. Single station sampling scheme (not to scale).

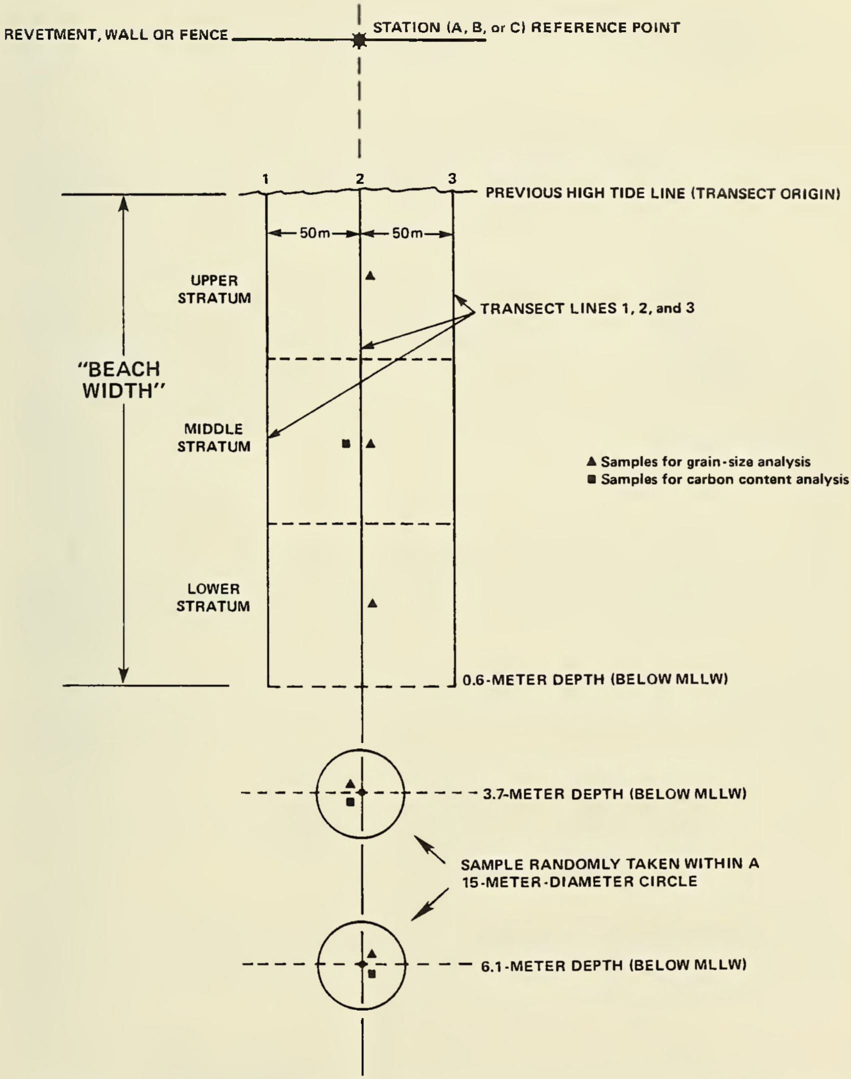

Figure 3. Sampling scheme for cores for analysis of grain size and carbon content (not to scale).

Table 2. Total number and type of core samples taken at all stations for Imperial Beach.

Station Designation	Depth	Cores		
		Biological[1]	Sand Grain[2]	Carbon[2]
A	intertidal	360	12	4
B	intertidal	450	15	5
C	intertidal	360	12	4
Subtotal:		1,170	39	13
A	3.7 meters	60	4	4
B	3.7 meters	75	5	5
C	3.7 meters	60	4	4
Subtotal:		195	13	13
A	6.1 meters	60	12	4
B	6.1 meters	75	5	5
C[3]	6.1 meters	30	2	2
Subtotal:		165	19	11
TOTAL SAMPLES:		1,530	71	37

[1]Core size = 8-centimeter diameter x 10-centimeter depth.
[2]Core size = 4.5-centimeter diameter x 10-centimeter depth.
[3]During surveys II and IV, station C (6.1 meters) had eroded to a cobble bottom, preventing core sampling.

stations the volume (milliliter) of sediment retained by the 0.5-millimeter screen was recorded during the sample screening process. This represents the volumetric proportion of coarse sand (larger than 0.5 millimeter) found within the core sample.

Grain-size composition was determined by sieving dried sediment samples through a standard set of Tyler screens (Morgans, 1956). Fractions retained on each screen were weighed and the results expressed in percent of total weight. Median diameter and sorting were computed on the basis of the cumulative distribution curve of the sieved fractions.

To determine carbon content of sediments, samples were dried and homogenized, and part of the homogenate analyzed for total carbon using a Leco Carbon Analyzer in which carbon is measured as carbon dioxide released upon combustion. A subsample of each homogenate was treated with 1:1 hydrochloric acid and redried. The carbon remaining following acidic carbonate removal is the organic fraction of total carbon. The difference between this organic fraction and total carbon is an index of calcium carbonate (shell fragments) in the sediments.

Water temperature was measured during the sampling period to the nearest 0.2° Celsius.

Photos of the intertidal stations were taken to depict beach topography using fixed reference points. Photos used in conjunction with transect lines and a bubble level bar and protractor provided data for estimating beach profiles.

Wave data were obtained from published reports from the Department of Navigation and Ocean Development (DNOD), Sacramento, California. A pressure sensor is located at the end of the Imperial Beach pier at a 9.3-meter MLLW depth (below MLLW).

The data are presented in terms of the total variance, $<n^2>$, which is related to the wave energy per unit surface area (E):

$$E = pg<n^2>$$

where p is the fluid density and g is the gravitational acceleration, $<n^2>$ is listed in units of square centimeters. The significant wave height $H_{1/3}$ is estimated from the wave variance $<n^2>$ through the equation:

$$H_{1/3} = 4 \quad <n>^2 \quad .$$

<u>Beach Replenishment.</u>

Approximately 765,000 cubic meters of material was pumped onto Imperial Beach between 22 March and 20 June 1977 (see Fig. 1; App. A).

The material used for beach replenishment was dredged from the San Diego Bay. The median grain size was 120 micrometers (Muslin, 1978). The average composition of the dredged material consisted of 70 to 85-percent sand, 5- to 15-percent silts and clays, and 5- to 15-percent shell material (App. A). The composition of Imperial Beach before the dredge disposal was 95- to 99-percent sand with only small amounts of shell and silt.

Beach replenishment started at rock groin No. 1 (Fig. 1) and proceeded slowly south at an average rate of 15 meters per day, and eventually terminated 1.36 kilometers south near station B. Consequently, the full impact of beach dredge disposal occurred at different times at the sampling stations. For example, during survey II (6 April 1977) the 3.7-meter offshore stations were sampled 15 days (137,700 cubic meters deposited) after the start of beach replenishment. Thus, the 3.7-cubic meter depth at station A had been affected by dredge disposal (Fig. 1) while there was no discernible dredging impact at the 3.7-meter depth at station B, 1.19 kilometers south of station A.

The material deposited on Imperial Beach averaged approximately 10-percent silts and clays. Most of this fraction was rapidly washed offshore either during the sediment deposition or on exposure to wave regimes. Therefore, it is estimated that approximately 76,500 cubic meters of the material applied to the beach was rapidly transported into the sublittoral zone. An estimate of the area impacted by these fine sediments (length of disposal area = 1.34 kilometers times distance offshore to the 9.2-meter isobath) is 1.25×10^6 square meters. This area, if covered evenly by 76,500 cubic meters of sediment, would be buried under 6.1 centimeters of silts and clays. This is consistent with observations made during the beach disposal period (survey III, 2 June 1977) which found 2 to 6 centimeters of silt in the upper part of the 10-centimeter-deep cores from 6.1 meters of water. This layer of silt appeared responsible for the burial not only of infauna but also larger macrofauna such as the sand dollar, *Dendraster excentricus*.

IV. PHYSICAL AND CHEMICAL RESULTS

1. Beach Topography.

Profiles of the beach are biologically important because from them estimates of sediment gain or loss (sediment stability) can be ascertained. Additionally, significant features (e.g., surge channels and sandbars), which partition the intertidal area into different habitats, can be quantified. Sandbars create low-energy zones while surge channels generally represent areas of rapid water and sediment movement.

The approximate beach profiles of the three intertidal stations are shown in Figure 4. These profiles show the extent of beach

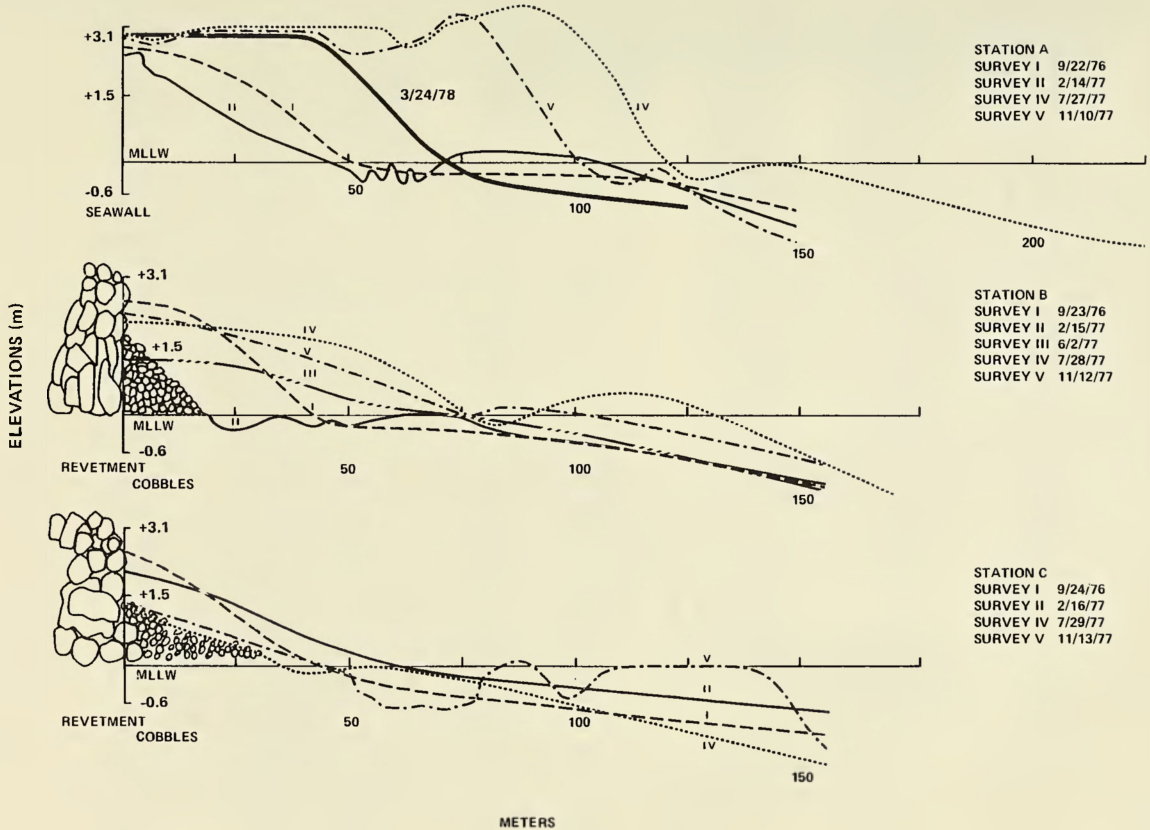

Figure 4. Approximate beach profiles for intertidal stations for all surveys. Vertical scale in meters exaggerated 10 times.

replenishment and the general features of the beach for each station surveyed. Significant beach features are summarized in Table 3. Changes in beach topography are shown by photos in Figures 5 and 6.

Intertidal survey I (22, 23, and 24 September 1976) was conducted toward the end of the southern California summer at a time of maximum seasonal beach accretion. All three intertidal stations were fine sandy beaches with small but well-developed berms and no surge channels or sandbars.

Survey II (14, 15, and 16 February 1977) stations all had some sand loss, probably due to winter waves. Station B was extensively eroded with the upper intertidal consisting exclusively of cobble with large surge channels. This correlated with the lowest abundances of intertidal organisms in any survey.

Survey III (2 June 1977) was conducted 2.5 weeks before the end of beach replenishment and the dredge pipe was located 290 meters north of station B. However, it was evident from the beach profile that sediment had accumulated at this station. Intertidal station B was covered with 2 to 3 centimeters of a fine silt layer over large shell fragments and some gravel.

Survey IV (postdisposal, 27, 28, and 29 July 1977) was conducted during a period of low wave energy (Fig. 7). Stations A and B had wide berms while station C continued to lose sand.

Survey V (10, 11, and 12 November 1977) found 20 percent of the beach width at station A eroded since Survey IV (107 days). Major sand loss occurred at both stations A and B while station C showed little sand loss but had more cobble in the upper intertidal.

On 24 March 1978, a return visit to all stations found a steep beach slope at station A with an estimated 60 percent of the added sediments having been eroded from this station since Survey IV (242 days) (Figs. 4 and 5). Station B appeared to have some sand loss but no measurements were taken; station C had eroded to almost exclusively cobble with no sand exposed at low tide (Fig. 6). The considerable erosion of these beaches was largely due to heavy winter storms which were of an intensity to be expected once in 10 years.

2. <u>Grain-Size Analysis.</u>

The median grain diameter for Imperial Beach has been reported as 200 micrometers (Dexter, 1977; Muslin, 1978); however, this study found

Table 3. Significant features of intertidal stations at Imperial Beach for all surveys.

Survey	Station A Northern dredge disposal	Station B Dredge-disposal terminus	Station C Downcoast "Control"
Survey 1 22 to 24 Sept. 1976	BW - 150 m[1] Berm - 15 m[2] Fine sandy beach; no sandbar or surge channels	BW - 120 m Berm - 15 m Fine sandy beach; no sandbar or surge channels	BW - 105 m Berm - 10 m Fine sandy beach; no sandbar or surge channels
Survey 2 14 to 16 Feb. 1977	BW - 135 m Berm - 8 m Fine sandy beach; sand loss, moderate; sandbar, 30 m wide; small surge channel	BW - 120 m Berm - 0 m Upper intertidal exclusively cobble; sand loss, large; sandbar, 20 m wide; large surge channels	BW - 150 m Berm - 0 m Fine sandy beach; sand loss, small; sandbar, 0 m wide; no surge channels
Survey 3 2 June 1977	Not sampled	BW - 120 m Berm - 35 m Fine sandy beach with a few cobbles in upper intertidal covered with silt and shell fragments; sand gain, moderate; no sandbar and no surge channel	Not sampled
Survey 4 27 to 29 July 1977	BW - 125 m Berm - 100 m Fine sand mixed with large patches of shell; sand gain, large; sandbar, 20 m wide; small backwash zone	BW - 150 m Berm - 55 m Fine sandy beach with scattered patches of shell; sand gain, large; sandbar, 40 m wide; small backwash zone	BW - 105 m Berm - 0 m Fine sandy beach; upper intertidal mixed cobble; sand loss, large; sandbar, 20 m wide; large surge channel
Survey 5 10 to 12 Nov. 1977	BW - 95 m Berm - 80 m Fine sand mixed with large patches of shell; sand loss, large; sandbar, 2 m wide; backwash zone	BW - 150 m Berm - 35 m Fine sandy beach; sand loss, moderate to large; sandbar, 2 m wide; small backwash zone	BW - 150 m Berm - 0 m Fine sandy beach; upper intertidal mixed cobble; sand loss, no appreciable sand loss or gain; sandbar, 40 m wide; large surge channel
24 March 1978	Berm - 40 m Fine sandy beach; patches of shell noticeably absent	Fine sandy beach	Cobble beach

[1]BW = Beach width, previous high tide line to -0.6 meters MLLW.

[2]Berm = Reference point to crest of beach slope (see Figure 2).

10 JUNE 1977

24 MARCH 1978

Figure 5. Station A (northern dredge-disposal site) changes in beach profile.

2 FEBRUARY 1977

24 MARCH 1978

Figure 6. Station C (control site), an unreplenished section of beach showing natural erosion.

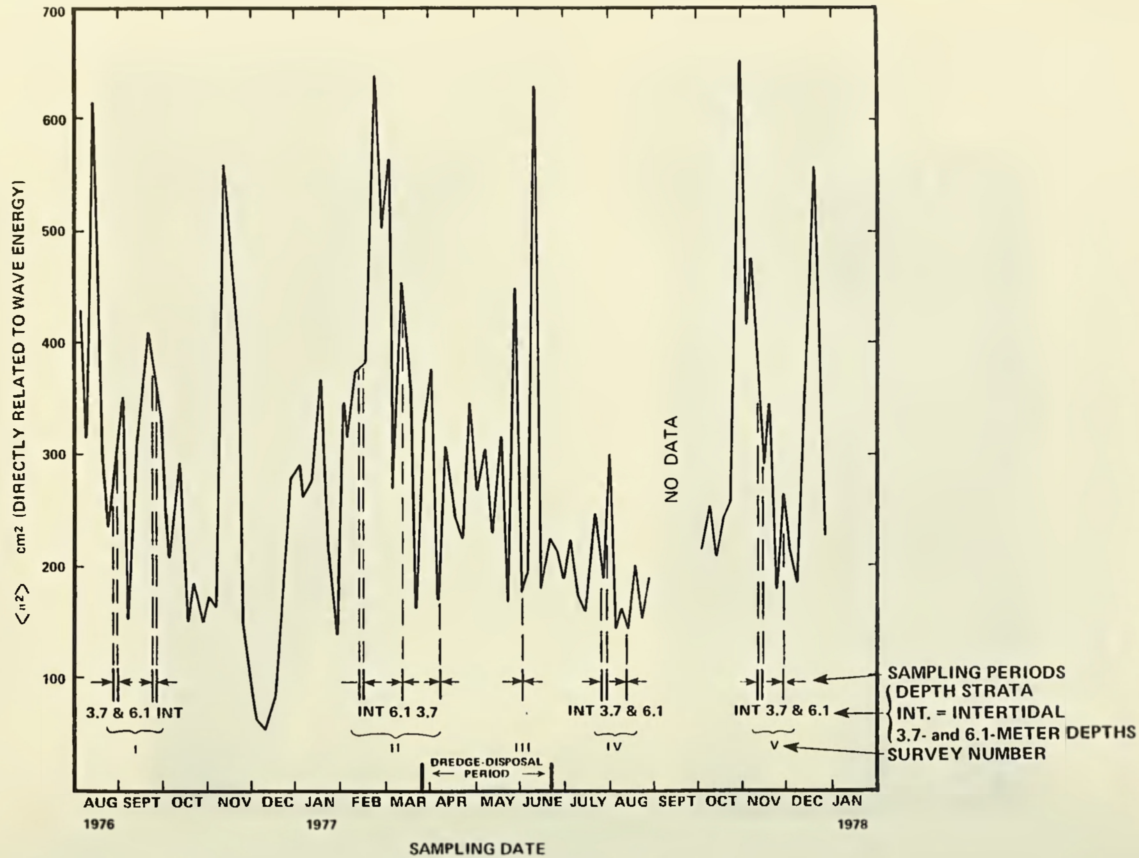

Figure 7. Wave energies for Imperial Beach expressed in terms of $\langle n^2 \rangle$ cm^2.

the sand to be slightly coarser at 210 to 250 micrometers. The mineral content of the sand averages about 50-percent hornblende (Intersea Research Corporation, 1978). Grain-size diameter is considered a parameter of major biological importance (Jannson, 1967). The most commonly used grain-size parameter is the median grain size (Md) (Fig. 8). Intertidal sediments (Md = 210 to 275 micrometers) were coarser than offshore sediments. The sediment at 6.1 meters (Md = 84 to 110 micrometers) was finer than at 3.7 meters (Md = 125 to 165 micrometers).

The intertidal sediments were finer (Md = 133 micrometers) during survey III (2 June 1977) than during any other intertidal survey. The large increase in fine sediments at the 3.7- and 6.1-meter impacted stations indicated that some of these fine sediments were quickly transported offshore (Figs. 8 and 9). The rapid recovery of intertidal station B sediments following the termination of beach replenishment and the lack of any measurable change in median grain size or percent of very fine sand at intertidal station A also indicate how rapidly these fine sediments are moved offshore. Five months after beach replenishment the median grain size and percent of very fine sand for all stations had returned to values comparable to those found at the initiation of the study.

That longer lasting changes occurred in sediment parameters is indicated by consideration of the coarse sediment fractions. The coarse sand fraction was measured in two different ways. First, the percentage of sand larger than 1 millimeter was calculated from sand-grain distribution data. Secondly, the volume (milliliters) of coarse sand retained on a 0.5-millimeter screen from a 0.5-liter core sample was measured. An indication of the extent and persistence of coarse sediments in the replenished area is shown in the coarse sediment volume for all core samples taken at the intertidal stations (90 cores per station) for survey V (Table 4).

Table 4. Total volume of coarse sand (diameter larger than 0.5 millimeter) retained from 90 cores (45 liters) per intertidal station, survey V, November 1977.

Station Designation	Volume (ml)	Volume sampled (pct)
A	12,600	28
B	10,150	23
C	2,745	6

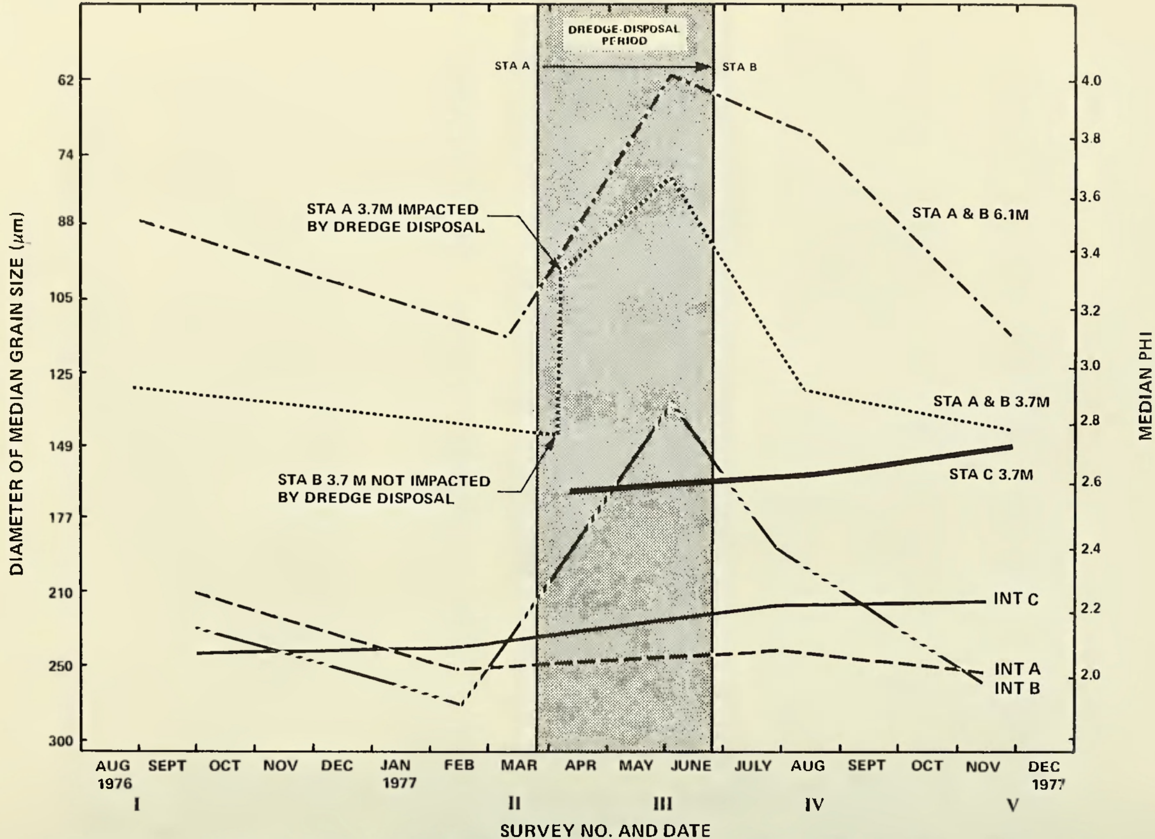

Figure 8. Median grain-size diameter and median phi units from sediment samples (STA = station designation, INT = intertidal station).

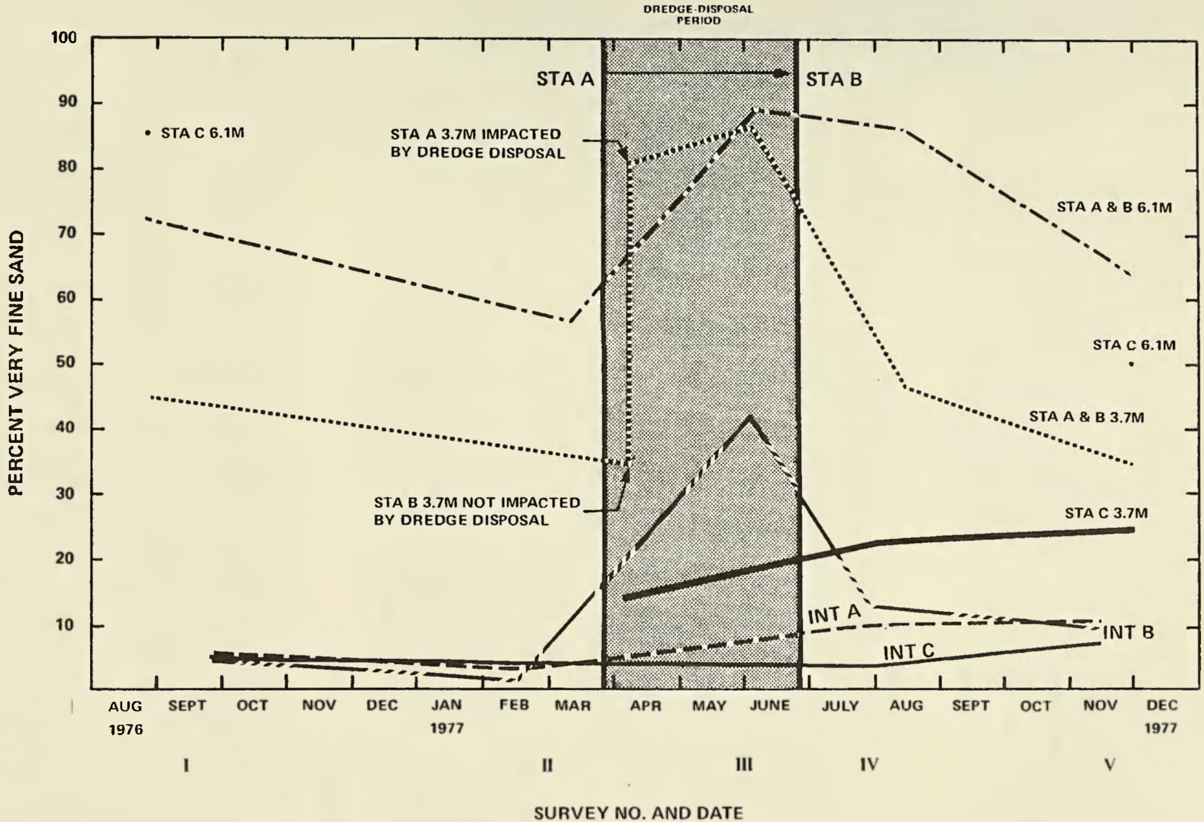

Figure 9. Percent very fine sand (diameter smaller than 125 micrometers) from sediment samples (STA = station designation, INT = intertidal station).

The impacted intertidal stations, 4.5 months after beach replenishment had approximately five times more coarse sand than the intertidal control station. The spatial distribution of coarse sand volume along the beach transect (high waterline to -0.6 meter MLLW) for stations A and C for survey V shows that the coarse sand persisted on the berm and beach slope (Fig. 10). Additionally, the proportion of coarse sand was maximum along the beach face indicating that as waves rework the deposited sediments a part of the coarse sand is carried up on the beach face. At the beach-water interface and proceeding offshore, the sediments are reworked and sorted to the extent that there is no difference between the northern dredge station and the southern control (Fig. 11).

The large increase in coarse sand found in the sediment samples is correlated with the large aggregations of shells formed by the resorting of deposited sediment which contained 5- to 20-percent shell material. After the winter storms of 1977-78 the beach was again photographed (March 1978) and there was a conspicuous absence of these shell deposits. It is suggested that storm surf has reworked these shell deposits either into smaller fragments or buried them offshore. In March 1978, patches of shells were found in the swash zone beneath an estimated 10- to 20-centimeter overburden of finer material.

A further measure of sediment modification induced by beach replenishment is revealed by the sediment-sorting coefficient, $\sigma\phi = (\phi_{84} - \phi_{16})/2$, determined from sediment samples via gravimetric sand-grain analysis. This is a measure of how uniform the sand-grain diameter is in a sediment sample. Coefficients of 0.4 to 0.6 indicate well-sorted sand or uniform grain size and constant pore space while values of 0.7 or larger indicate a greater range of sediment diameters and less porous sand with variable pore space. Sediment sorting coefficients for the 3.7- and 6.1-meter stations are shown in Figure 12. There was no change in sediment sorting for the offshore stations. Impacted intertidal stations (A and B) had an increase in both the sorting coefficient and in the range of coefficients measured (Fig. 13).

3. Organic Carbon.

Organic carbon in the sediments is an indication of food source for deposit-feeding infauna. Organic carbon values were generally highest at the 6.1-meter stations, less at the 3.7-meter stations and lowest intertidally (Fig. 14). Intertidally, there was no measurable influence of beach replenishment on the organic carbon content of sediments. However, offshore at the 3.7-meter stations (survey II, 6 April 1977), sediments at station A which were sampled during the dredge-disposal period had a 51-percent increase in organic carbon compared to station B and a nearly threefold increase compared to station C. Station B, survey III (2 June 1977) was impacted by beach replenishment and a 36- and 146-percent increase in organic carbon was found, compared to station B, survey II at 3.7- and 6.1-meter depths. Organic carbon values remained higher at the impacted stations than at

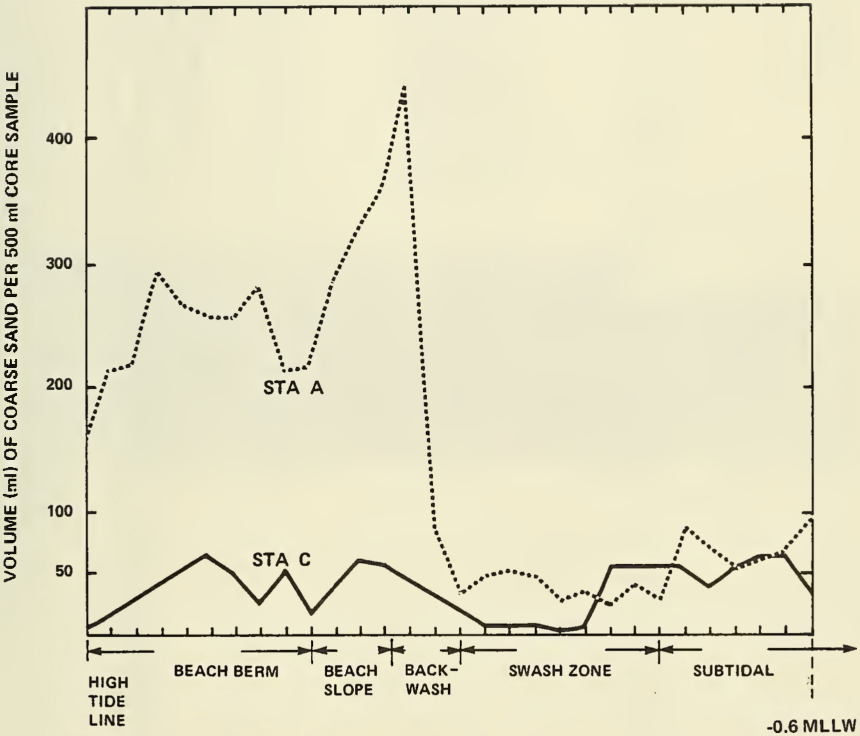

Figure 10. Volume (milliliters) of coarse sand (diameter larger than 0.5 millimeter) along intertidal transect lines for station A and station C for survey V, November 1977.

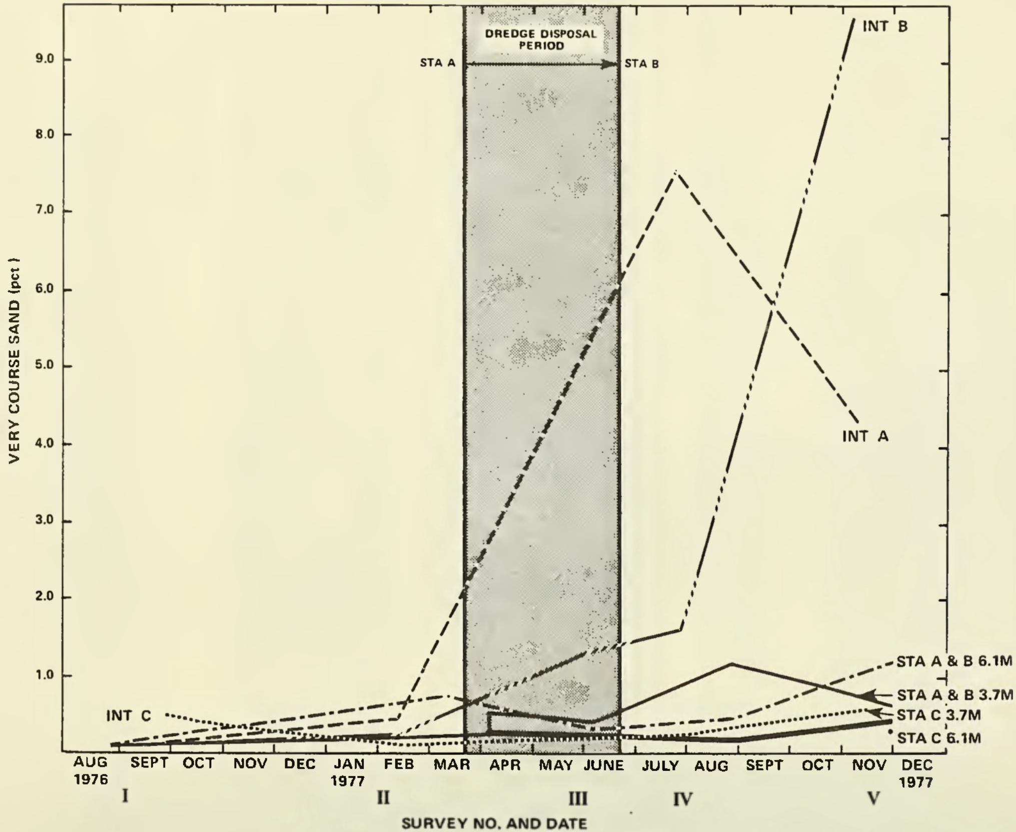

Figure 11. Percent very coarse sand (diameter larger than 1.0 millimeter) from sediment samples.

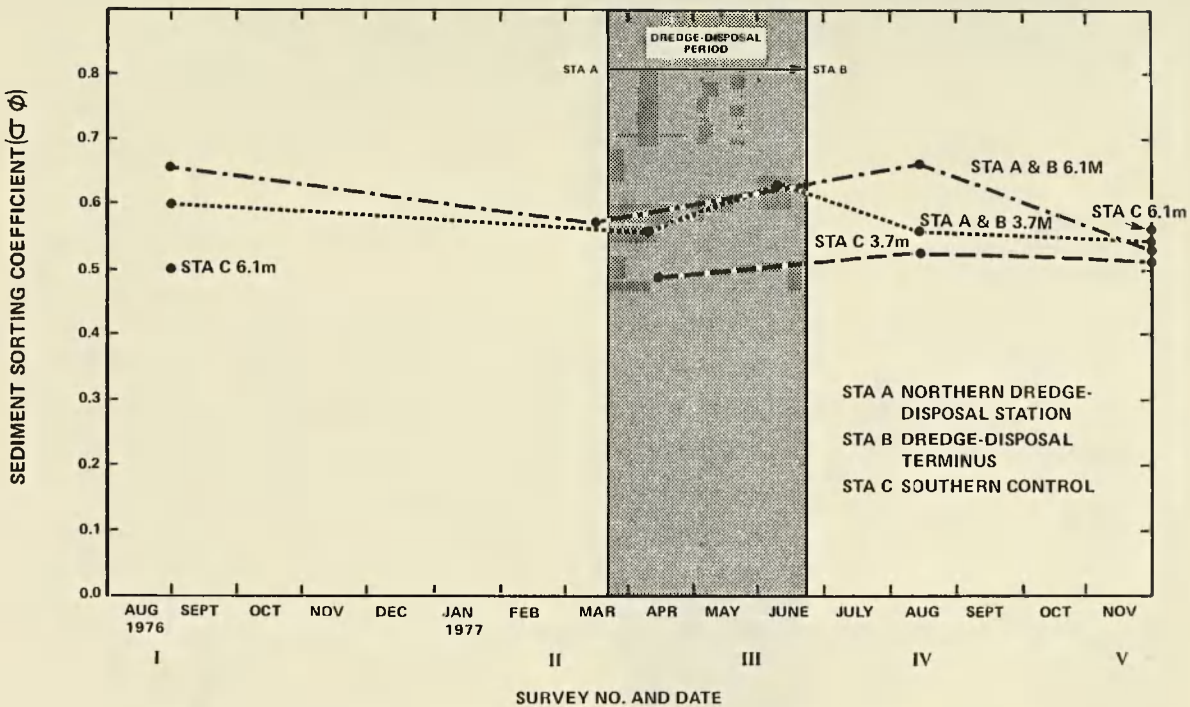

Figure 12. Sediment sorting coefficients for 3.7- and 6.1-meter stations.

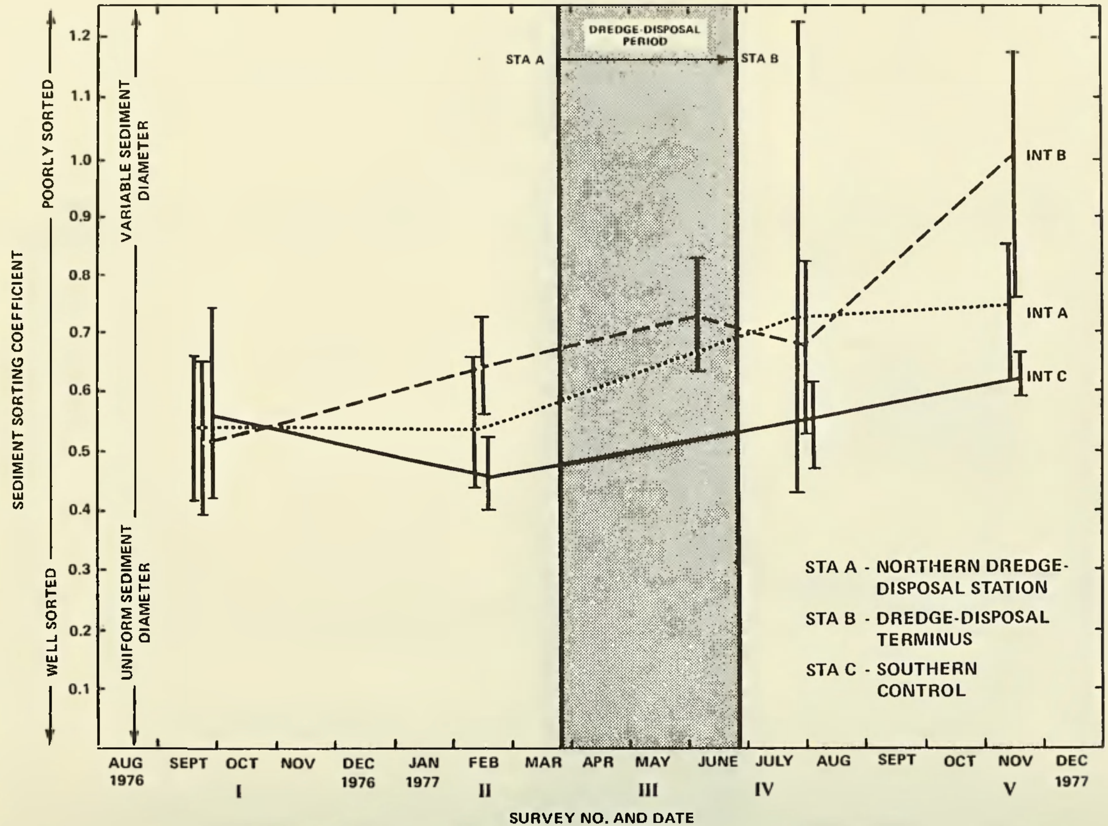

Figure 13. Sediment sorting coefficients for intertidal stations (INT). Bars indicate range of coefficients measured.

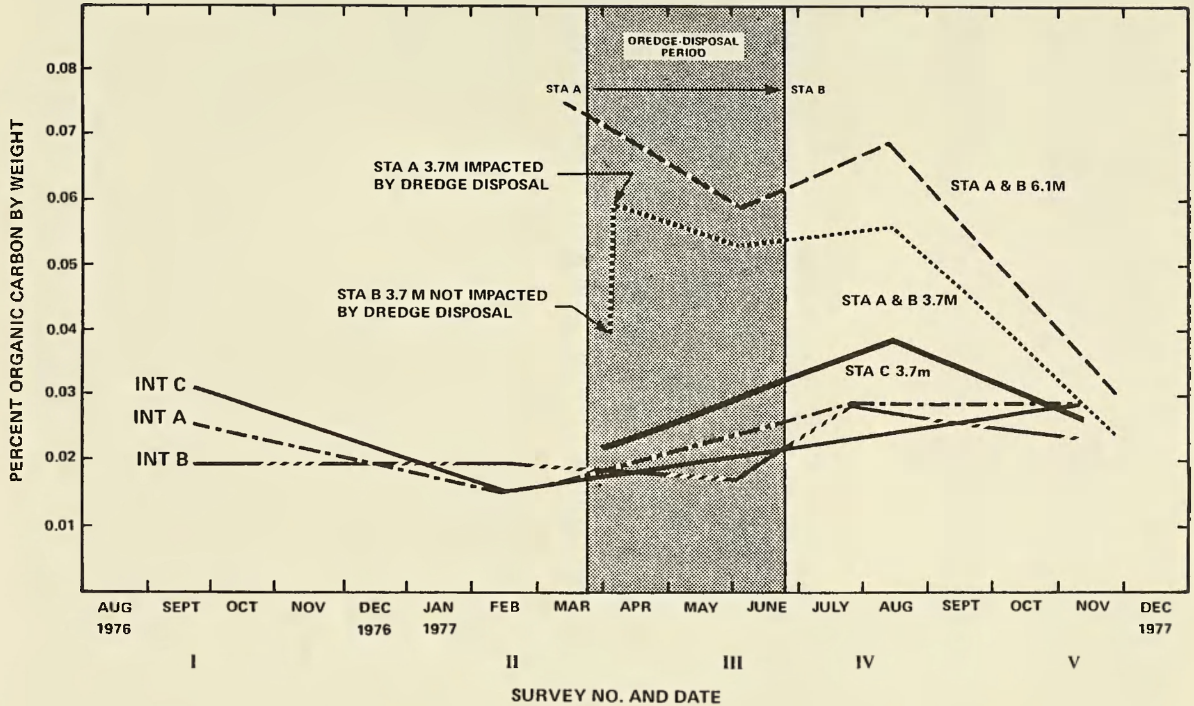

Figure 14. Percent organic carbon content by weight from organic carbon samples.

the control station through survey IV but were noticeably lowered at all stations by survey V (Fig. 14). This uniform decrease of organic carbon correlated with the onset of winter surf (Fig. 7) and the return of the offshore sediments (3.7 and 6.1 meters) to values comparable at the initiation of this study (Figs. 8 and 9). A regression analysis of combined stations and surveys showed a significant ($p < .05$) positive correlation between organic carbon and silt.

Organic carbon values at station C, about 1.1 kilometers north from the Tijuana River, appeared not to be influenced by its proximity to this potential source of organic detritus.

4. Temperature.

Temperature is considered a major factor in controlling the distribution of organisms. Temperatures recorded during sampling at Imperial Beach varied little between stations (Table 5). Offshore at the 3.7- and 6.1-meter depths, temperatures showed more seasonal variation but differed little between stations during each survey.

5. Wave Data and Seasonal Storms.

Wave patterns and storms are forces which determine the littoral zone profile and influence the diversity and abundance of organisms found near the shore. Local storms affecting Imperial Beach generally cause short-period waves of 10 seconds or less, and although they may occur at any time, they tend to occur more often during the winter. North Pacific storms generally occur during late fall, winter, and early spring and cause longer waves with periods between 12 and 20 seconds. Southern tropical storms produce waves from the south with periods between 12 and 20 seconds in late spring to early fall (Muslin, 1978).

The wave data for this study are shown in Figure 7. The data are presented in terms of the $\langle n^2 \rangle$ cm^2, which is directly related to the wave energy as described in Section III, 1.

Wave energies ranged from 50 to 650 square centimeters and the wave period ranged from 6 to 18 seconds. These wave energies and frequencies can be converted to horizontal velocities at a given depth (for more detail see U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1977). Comparison of these calculated bottom velocities with threshold of motion studies (Menard, 1950; Manohar 1955; Inman, 1957) indicates whether sand suspension or sand transport might occur. Bottom velocities of about 0.2 meter per second are needed to resuspend sand in the size range found at Imperial Beach and about 0.3 meter per second is necessary to initiate ripple formation (Fig. 15). If these values are compared with some typical wave frequencies and periods for Imperial Beach (Table 6), it is evident that at the 3.7-meter stations

Table 5. Water temperature at Imperial Beach for all stations for each survey date.

Station	Depth	Survey									
		I		II		III		IV		V	
		°C	Date	°C	Date	°C	Date	°C	Date	°C	Date
A	intertidal	19.5	22 Sept. 76	18.0	14 Feb. 77	--[1]		19.0	27 July 77	19.0	10 Nov. 77
B	intertidal	19.0	23 Sept. 76	17.5	15 Feb. 77	17.5	15 Feb. 77	17.0	2 June 77	18.1	28 July 77
C	intertidal	20.0	24 Sept. 76	18.5	16 Feb. 77	--		21.0	29 July 77	19.5	12 Nov. 77
A	3.7 meters	19.2	30 Aug. 76	18.5	6 Apr. 77	--		19.0	12 Aug. 77	16.2	29 Nov. 77
B	3.7 meters	19.1	30 Aug. 76	17.2	6 Apr. 77	16.8	2 June 77	18.9	12 Aug. 77	15.9	29 Nov. 77
C	3.7 meters	19.3	30 Aug. 76	17.8	6 Apr. 77	--		18.9	12 Aug. 77	16.0	29 Nov. 77
A	6.1 meters	19.9	31 Aug. 76	17.1	9 Mar. 77	--		18.7	12 Aug. 77	16.0	29 Nov. 77
B	6.1 meters	19.9	31 Aug. 76	16.9	9 Mar. 77	16.6	2 June 77	18.8	12 Aug. 77	15.7	29 Nov. 77
C	6.1 meters	20.0	31 Aug. 76	--	9 Mar. 77	--		--		15.8	29 Nov. 77

[1]Not surveyed.

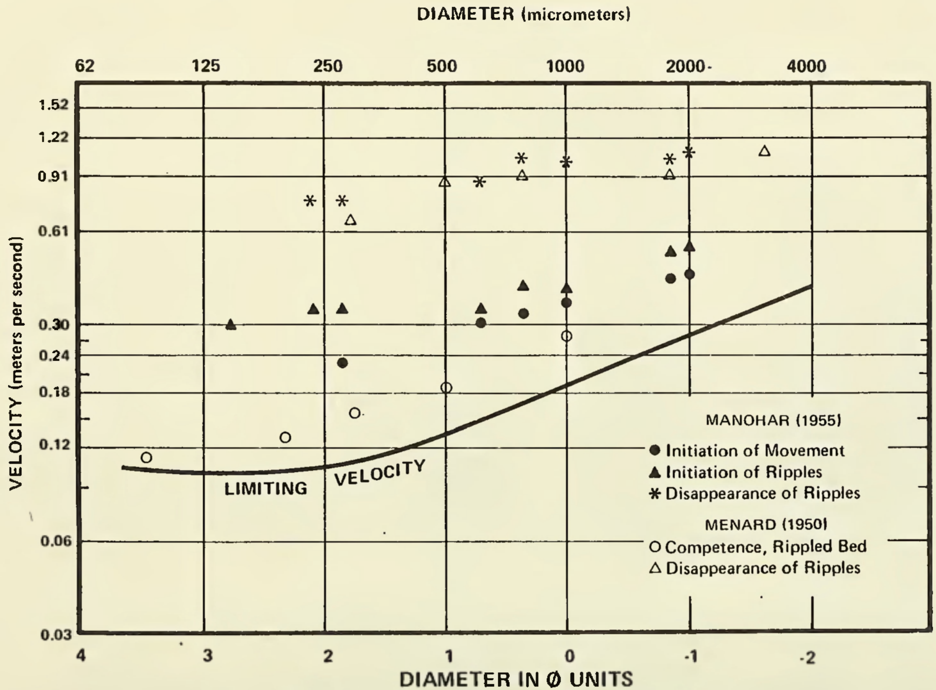

Figure 15. Minimum velocity for the initiation of sand motion for a given sediment diameter (from Inman, 1957).

the sand bottom is in flux except under the most calm conditions. Even at the 6.1-meter depth sand is being transported regularly because of wave energy (Fig. 7). This implies that the nearshore environment of Imperial Beach was an area where sediment fluxes existed continually for most of the year extending beyond the 3.7-meter depth.

Table 6. Calculated horizontal velocity of wave motion (meters per second) at the bottom for three wave energies, three depths, and for three wave periods.

Depth (m)	Wave Energy[1]	Wave period(s)		
		6	12	18
3.7	200	0.28	0.32	0.33
3.7	400	0.40	0.45	0.46
3.7	600	0.49	0.55	0.57
6.1	200	0.20	0.24	0.25
6.1	400	0.27	0.34	0.35
6.1	600	0.34	0.42	0.43
12.2	200	0.10	0.16	0.17
12.2	400	0.14	0.23	0.24
12.2	600	0.17	0.28	0.30

[1]Wave energy per unit surface area per square centimeter, $E = \rho g \langle \eta^2 \rangle$, where p = fluid density and g = gravitational acceleration (see Sec. III).

V. BIOLOGICAL RESULTS

1. Sampling Design Effectiveness.

If sampling data and conclusions derived from monitoring, research and survey programs are to be utilized in decisionmaking processes, it is necessary to know the levels of precision and confidence of statements made regarding such community attributes as abundance and diversity. These considerations are essentially a function of error in taking samples and inherent variability of sampled properties. Since most biological data are typified by high variance, this study hoped to minimize the variance and increase precision by extensive replication with small sampling units (Elliott, 1971) and reduce bias in sampling by using hand-operated core samplers which minimize sediment disturbance and take a consistent sample volume.

a. Precision of Estimates. The number of samples from intertidal, 3.7-meter, and 6.1-meter sampling stations needed to estimate population values for abundance and species richness at 50- and 30-percent levels of precision (P%) at a 95-percent level of confidence was calculated (Table 7). These are the average number of samples needed to know that 95 percent of the time the true population means will lie within ±P% of the measured mean. These estimates from the sample data are derived from properties of variance in the data and are corrected for nonnormal distribution properties. Most of the contagiously distributed data sets fit a negative binomial distribution. Types of distributions of sampled data are presented in Table 8.

In sampling design considerations, it was expected that a greater heterogeneity of factors would influence distribution on the beach more than offshore; therefore, 90 samples per survey were taken at each intertidal station and subtidal assessments were based on 15 samples at each of two depths. Subsequent analysis indicated the adequacy of this approach. Precision of estimates of species and abundance population parameters were approximately equal from the different depths using these discrepant sample numbers (Table 9). The number of samples taken at all depths was (on the average) sufficient to estimate these population parameters at a ±30-percent precision level. A 50-percent precision level may be reached by taking approximately half this number of samples within each depth habitat. This fact is a useful one in relating level of information return to the inherent cost factors on a given project. For example, in the present study a 20-percent loss of precision would accompany a 50-percent reduction in sample analysis time (Table 7).

b. Small-Scale (Within-Station) Variation on the Beach and Comparison of Intertidal Transect Methods. At each intertidal station no significant differences in variability or precision of estimate were found between transects sampled either randomly or at fixed intervals within strata (Fig. 2). An advantage of the line-point method is the possibility of constructing regressions of variables with fixed positions along the transect (see Fig. 10) and relating these to observed profile features along the beach.

Considering only a single transect along the beach, abundance and species richness are estimated at respective precision levels of about 27 and 45 percent. Grouping of the three transects at each intertidal station increased precision by decreasing these estimates to 17 and 27 percent, respectively. Here again, cost optimization factors may be considered in relation to precision criteria and sampling design.

Single transects had mean values that deviated an average of 20.6 percent (median value = 13 percent) from the average of three transects combined; i.e. assuming that three transects located 50 meters apart represent "true" population densities on the beach, then any

Table 7. Average number of samples needed to estimate abundance and species per sampling unit at precision levels of 50 and 30 percent at a 95-percent confidence level during Imperial Beach study.[1]

Depth	Abundance (pct) 50	Abundance (pct) 30	Species (pct) 50	Species (pct) 30
intertidal	49	85	17	44
3.7 meters	-	14	6	10
6.1 meters	6	11	5	8

[1] If P = precision and Y = confidence level, the true population mean will lie within ±P% of the measured mean Y% of the time. Sample number estimates are derived from an actual data series and do not assume a normal distribution of data points.

Table 8. Frequencies of different distribution types for abundance per sample and species per sample during Imperial Beach study.

	Contagious (aggregated) (pct)	Random (pct)	Even (pct)
INTERTIDAL			
Individuals per sample	92.3	7.7	0
Species per sample	30.8	69.2	0
3.7-METER DEPTH			
Individuals per sample	61.5	38.5	0
Species per sample	0	84.6	15.4
6.1-METER DEPTH			
Individuals per sample	72.7	27.3	0
Species per sample	9.1	63.6	27.3

Table 9. Precision of estimate (P) at 95-percent confidence level for species per sample and abundance per sample during Imperial Beach study.[1]

	Sample[2] (no.)	Species per sample (pct)	Individuals per sample (pct)
INTERTIDAL			
3 transects	90	17.2	26.9
1 transect	30	26.9	45.1
3.7-meter depth	15	13.9	18.6
6.1-meter depth	15	14.0	20.7

[1]True population mean lies with ±P% of the sampled mean 95 percent of the time, assuming random distribution. Most species per sample data fit a random description. When data are contagiously distributed skewness of precision estimates introduces an error term (see Table 8).

[2]Samples consisted of 500-milliliter cores; 8-centimeter diameter x 10-centimeter depth.

single transect will deviate from this "true" value by 13 percent half of the time and the average error is 20.6 percent. Considering the homogeneous appearance of the beach this finding was at first unexpected. Yet, most of the beach organisms are motile crustaceans which can form aggregations creating small-scale patchiness.

c. Species Acquisition. The number of species occuring at a given site is important to ecologists. How effectively can the true population be estimated? Species acquisition curves provide one approach to answering this question. An area is considered to be well sampled in terms of species composition if increased sampling only rarely adds additional species; i.e. the species acquisition curve approaches an asymptote in relation to sampling effort. Species acquisition relationships of Imperial Beach samples are presented in Figure 16. At intertidal stations when sample size was 90, approximately 70 percent of the total species were found in the first 30 samples. At subtidal stations, when sample size was 15, 70 percent of the species were found in the first six samples. Therefore, the sampling method used effectively depicts species composition at a given time and locality. Acquisition curves through time were also constructed (Fig. 17). These were not asymptotic indicating somewhat continuous seasonal introductions of new species with time. Introduction rates were higher subtidally in association with higher diversity at these depths. These data indicate that sites cannot be fully typified with respect to species composition by a single, or even a few, surveys. If knowledge of species composition is an important design criterion, such information as presented above is useful in optimizing the allocation of program time and cost resources.

2. Biological Impacts of Dredge Disposal.

It is assumed that most organisms residing within beach sediments which were deposited upon probably perished due to burial. Some liquefaction of indigenous sediments was evident during deposition and possibly motile species (amphiods, decapods, etc.) escaped burial. The assumption that introduced sediments from San Diego Bay were defaunated following pumping at high pressures through mechanical impeller booster pumps along variable lengths of pipe (up to 7,600 meters) was verified by inspecting core samples from the surface of newly deposited sediments. They were devoid of live organisms.

A list of all species collected at different times and depths is presented in Appendix B.

a. Intertidal Abundance. Total abundance of organisms from the intertidal stations ranged from 100 to 2,100 per square meter and averaged 882 per square meter during the study. This is high compared to densities of 200 per square meter reported for the area in February

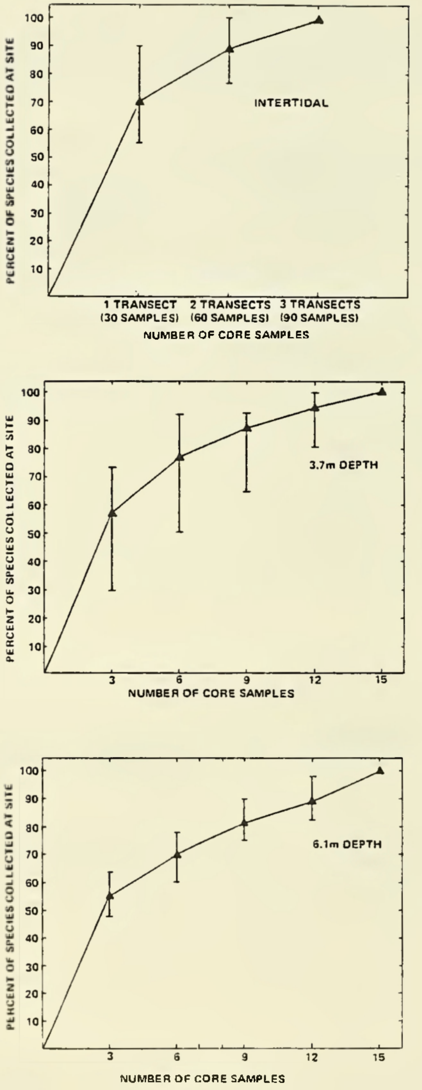

Figure 16. Species acquisition curves for each depth stratum as a function of sample numbers. Bars indicate ranges from individual stations and surveys.

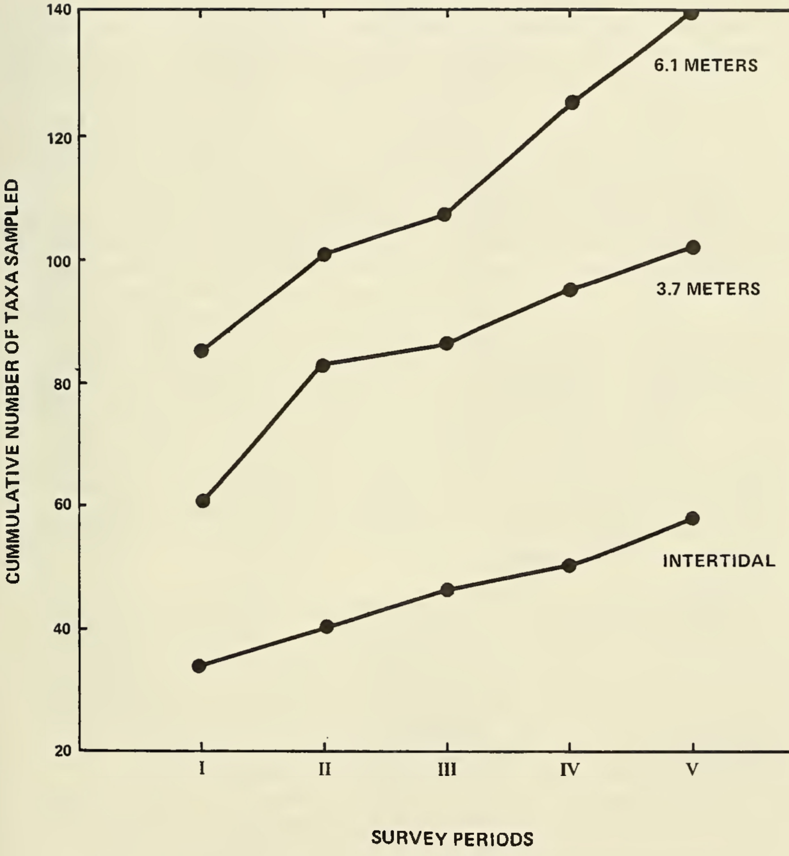

Figure 17. Species acquisition curves through time for each depth stratum.

by Dexter (1977). Estimated densities of the abundant species and the rank order of abundance in the intertidal area are presented in Tables 10 and 11. Summer periods (June, July, and September) had the highest densities of organisms, while winter periods (November and February) were lower. Seasonal total abundance patterns at all three intertidal stations (Fig. 18) showed drops in abundance from summer to winter preceding the beach replenishment operation. This correlates well with measurements of increased wave action offshore (Fig. 7) and with observations of beach erosion during this period (Fig. 4, Table 3). Surf temperatures averaged only 1.5° Celsius lower in winter (Table 5). Thus, twofold or more seasonal changes in total abundance occurred here in response to natural events. Before beach replenishment, intertidal abundance varied significantly between stations ($p<.05$) along the 2.1-kilometer stretch of nearly straight sand beach (Figs. 18 to 21). Localized erosion-deposition patterns may have been responsible. Based upon beach profiles, it was determined whether beach stations had built up or been eroded between surveys. This was compared with abundance data. A significant ($p<.05$) correlation was found between these variables, (sign test, Tate and Clelland, 1957); i.e., abundances generally increased during calm depositional periods and decreased with beach erosion. Upper intertidal sediments had been eroded at all beach stations before survey II (February), but this was most severe at station B. It is here that relatively few organisms were found (Fig. 20, see also Fig. 4). Localized wave and current patterns along beaches may significantly affect species composition and abundance; e.g., a rock groin is located 170 meters north of station A and wave and current patterns may be different here. Observations of physical events should accompany biological studies in order to help sort out natural versus induced effects on populations.

Beach replenishment occurred in the spring (22 March to 20 June 1977), followed by increases in abundance at all stations the following summer (Fig. 18). At station A (impacted station) and station C (control) abundances were not significantly different from each other and were similar to those in the previous late summer. Similarities between these impacted and control intertidal stations suggest that deposition effects are not long term. Note that fine sediments were not present in sediment samples from station A 4 months after sediment deposition while they were evident 1 month after deposition at station B (Figs. 8 and 9). This indicates that fine sediments were sorted out of beach material within 4 months after deposition. Concomitant offshore increases in fine sediments substantiate this (Figs. 8 and 9).

Sampling at station B indicated a possible short-term effect of beach replenishment. Summer populations were sampled just 290 meters

Table 10. Intertidal organisms occurring at densities greater than 50 per square meter during Imperial Beach study.

INTERTIDAL STATION	SURVEY NUMBER AND DATE				
	I (Sept. 1976)	II (Feb. 1977)	III (June 1977) Dredge Disposal	IV (July 1977)	V (Nov. 1977)
A - Northern Disposal Site	Amphipod *Synchelidium* sp. 520/m² *Eohaustorius* spp. 91/m² Polychaete *Euzonus mucronata* 244/m² Cumacean *Cyclaspis* sp. B 73/m²	Amphipod *Synchelidium* sp. 266/m²	NOT SURVEYED	Amphipod *Synchelidium* sp. 655/m² Decapod *Emerita analoga* 82/m²	Amphipod *Synchelidium* sp. 198/m²
B - Dredge-Disposal Terminal	Amphipod *Synchelidium* sp. 375/m²	None Exceeding 50/m²	Amphipod *Synchelidium* sp. 1277/m² *Eohaustorius* sp. 102/m² *Trichophoxus epistomus* 91/m² Polychaete *Scoloplos armiger* 60/m²	Amphipod *Synchelidium* sp. 1,418/m² *Eohaustorius* sp. 60/m² Cumacean *Cyclaspis* sp. B 293/m² Decapod *Emerita analoga* 142/m²	Amphipod *Synchelidium* sp. 691/m²
C - Control	Amphipod *Synchelidium* sp. 487/m² *Eohaustorius* sp. 64/m²	Amphipod *Synchelidium* sp. 438/m² *Eohaustorius* sp. 64/m²	NOT SURVEYED	Amphipod *Synchelidium* sp. 1,011/m²	Amphipod *Synchelidium* sp. 231/m²

Table 11. Rank order of abundance of species from combined surveys for each depth.

Intertidal			-3.7 meter MLLW			-6.1 meter MLLW		
Species	Taxon[1]	No./m²	Species	Taxon[1]	No./m²	Species	Taxon[1]	No./m²
Synchelidium spp.	A	583	*Euphilomedes* spp.	O	867	*Euphilomedes* spp.	O	1,175
Eohaustorius spp.	A	88	*Apoprionospio pygmaea*	P	809	*Apoprionospio pygmaea*	P	727
Cyclaspis sp.	C	41	Nematodes		567	Nematodes		534
Emerita analoga	D	25	*Scolelepis squamata*	P	385	*Eohaustorius* spp.	A	490
Euzonus mucronata	P	22	*Trichophoxus epistomus*	A	319	*Owenia fusiformis*	P	375
Trichophoxus epistomus	A	20	*Magelona pitelkai*	P	305	*Diastylopsis tenuis*	C	253
Scolelepis acuta	P	13	*Mandibulophoxus gilesi*	A	256	*Magelona pitelkai*	P	242
Nephtys californiensis	P	12	*Cyclaspis* sp.	C	211	*Tellina modesta*	Mo	187
Scoloplos armiger	P	10	*Spiophanes bombyx*	P	185	*Scoloplos armiger*	P	182
Scolelepis squamata	P	9	*Synchelidium* spp.	A	168	*Typosyllis hyalina*	P	177
Orchestoidia californiana	A	8	*Scoloplos armiger*	P	146	*Trichophoxus epistomus*	A	121
Paraonella platybranchia	P	7	*Leptocuma forsmani*	C	90	*Magelona sacculata*	P	97
Donax gouldii	Mo	6	Nemertean B		64	*Synchelidium* spp.	A	85
Hemipodus borealis	P	5	*Acanthomysis macropsis*	My	61	*Leptocuma forsmani*	C	81
Nemertean B		5	*Olivella baetica*	Mo	55	*Spiophanes bombyx*	P	80

[1] A = Amphipod; C = Cumacean; D = Decapod; P = Polychaeta; Mo = Mollusk; My = Mysid; O = Ostracod

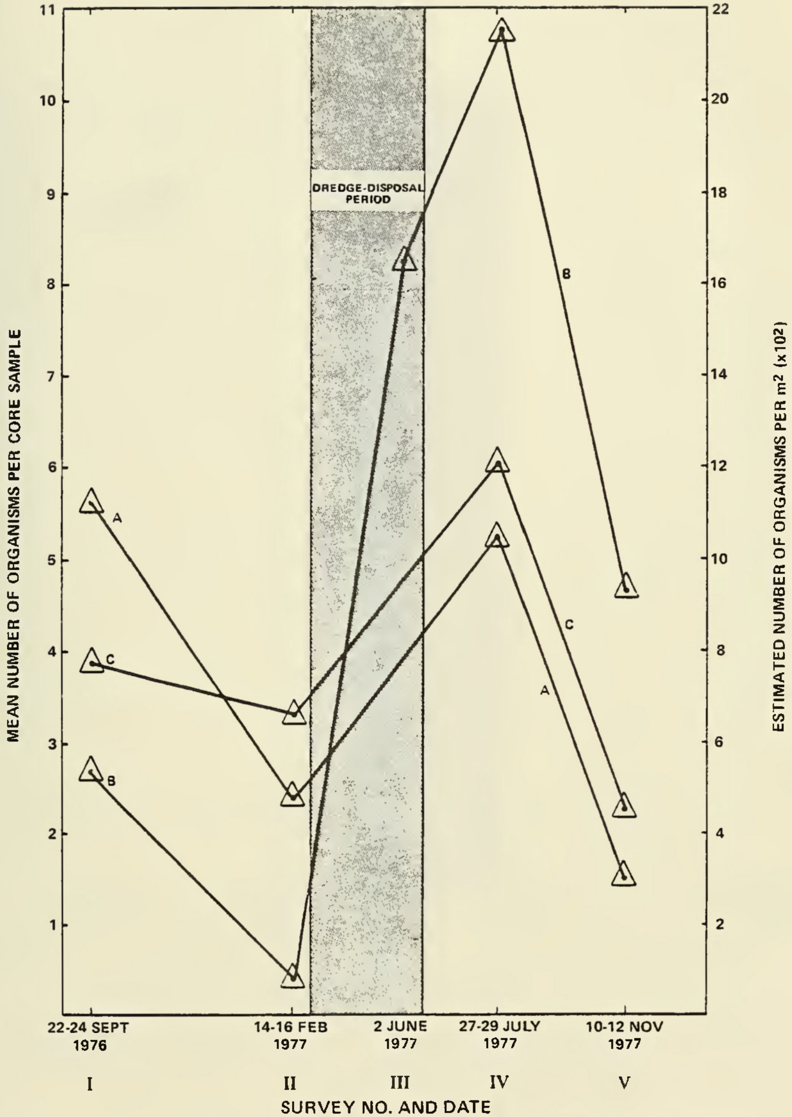

Figure 18. Mean number of organisms per core sample and estimated abundances per square meter for intertidal stations.

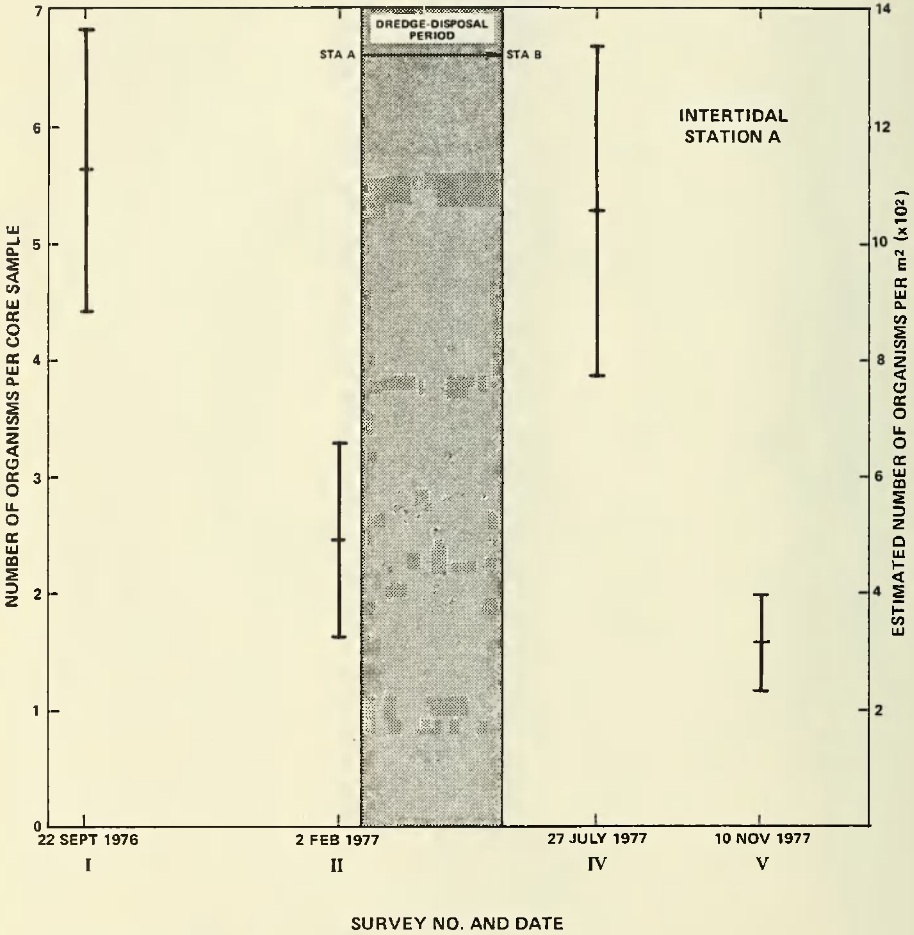

Figure 19. Mean number of organisms per core sample and estimated abundances per square meter for intertidal station A. Bars = $\bar{X} \pm t_{.95} S_{\bar{X}}$.

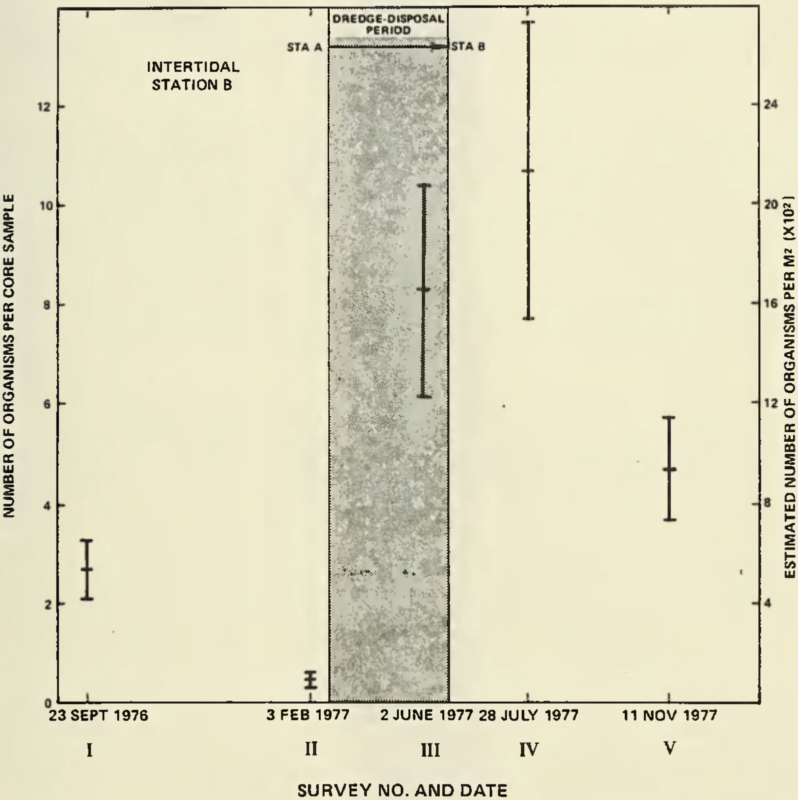

Figure 20. Mean number of organisms per core sample and estimated abundances per square meter for intertidal station B. Bars = $\overline{X} \pm t_{.95} S_{\overline{X}}$.

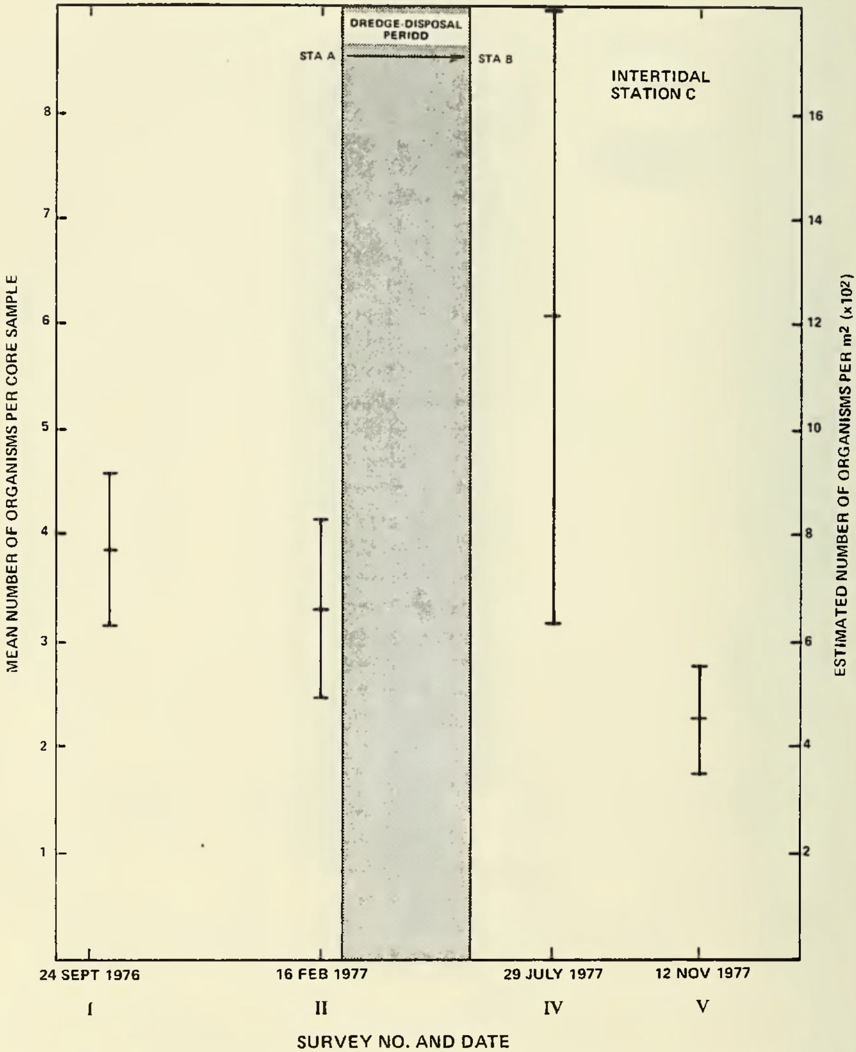

Figure 21. Mean number of organisms per core sample and estimated abundances per square meter for intertidal station C. Bars = $\bar{X} \pm t_{.95} S_{\bar{X}}$.

south of the advancing disposal path in June and 5 weeks after deposition in July. Significant increases in total abundance were noted (Fig. 20). Station B (survey IV) densities were significantly greater ($p<.05$) than those at the other intertidal stations in any season (Figs. 18 to 21). This strongly suggests an enhancement effect from the recent beach deposits. Elevated numbers at station B were primarily due to increases in motile crustacean species. Possibly, they behaviorally responded to factors associated with introduced bay sediments (e.g., dissolved and particulate organics, increased fine sediments, etc.).

Many of the prevalent crustacean species such as *Synchelidium* sp. (undescribed oedocerotid amphipod) carry their eggs and release miniature adults. Therefore, these increases at station B were primarily a result of the presence of adults, as beach population dynamics may largely reflect behavorial responses of adults and release of broods in selected areas. Less dramatic increases in polychaete numbers were observed at station B during survey IV. These primarily recruit from the plankton, and their settlement was not impaired. Individuals were generally aggregated in their distribution (Table 8). Considering the behavorial attributes of the species, this was not unexpected.

b. Intertidal Diversity. Statements concerning diversity refer to patterns of the density of species per sample and total species collected at a site. Diversity indices which combine abundance and species richness into a single index were not used as they can be misleading.

Species density (number per sample) generally followed a pattern similar to abundance (Figs. 22 to 25, Table 12). Significant differences ($p<.05$) existed between stations before dredge disposal. These were similar to abundance patterns in relation to season. Winter storm periods reduce species density on the beach.

As with abundance, an increased number of species and species density was observed at station B during deposition and 5 weeks later. Subsequent to this, density decreased between July and November (surveys IV and V) at stations A and B. However, at the southern control station C, species density increased (Fig. 25). This was probably a result of increased habitat complexity at station C due to the development of a complex beach flat area (Fig. 4). Total numbers of species collected per survey at beach stations do not indicate a significant impact by beach replenishment (Table 12).

Fifty-six species were collected intertidally during the study. The first survey at three stations collected about half of these. This diversity is considerably higher than the total (n = 33) from

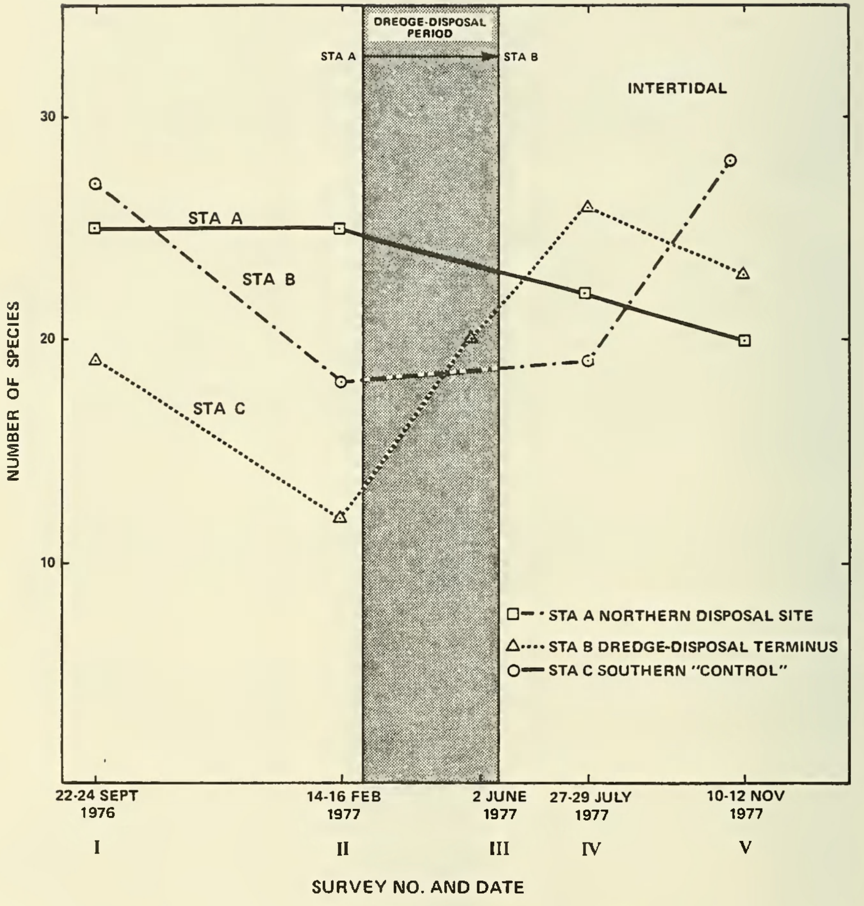

Figure 22. Total number of species sampled at each intertidal station (STA = station designation).

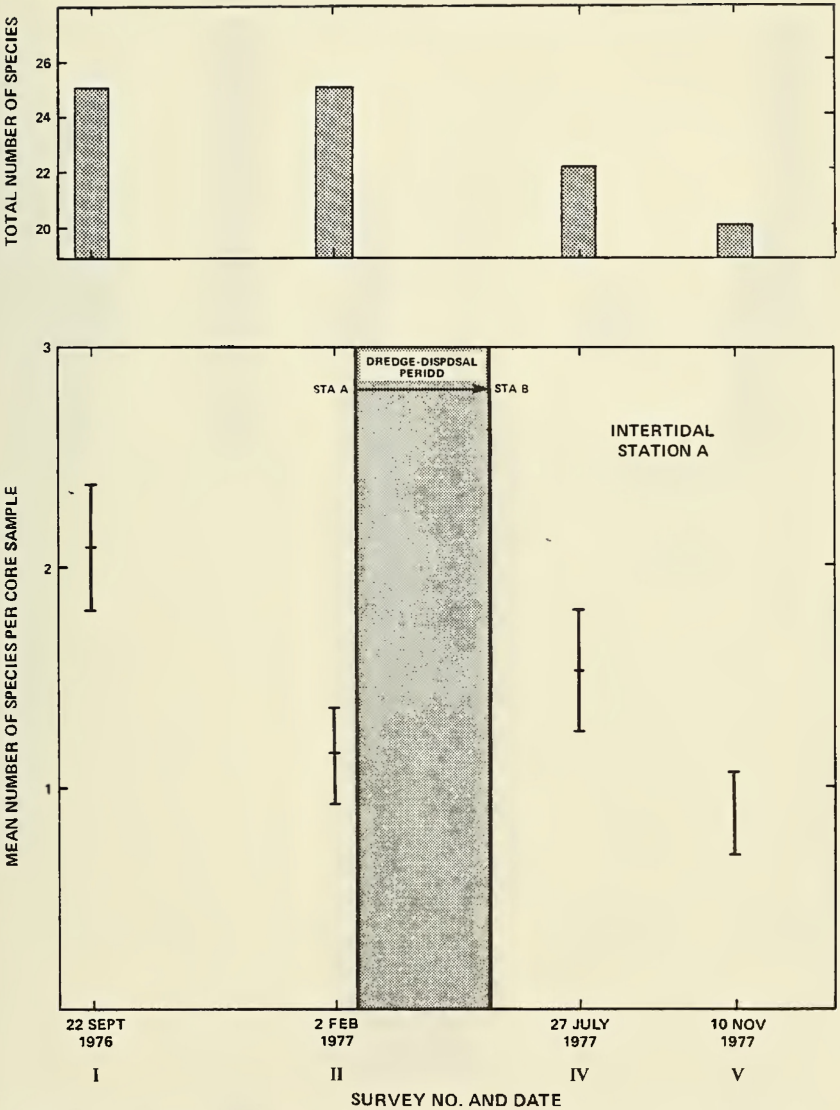

Figure 23. Mean number of species per core sample and total species sampled per survey for intertidal station A. Bars = $\bar{X} \pm t_{.95} S_{\bar{X}}$.

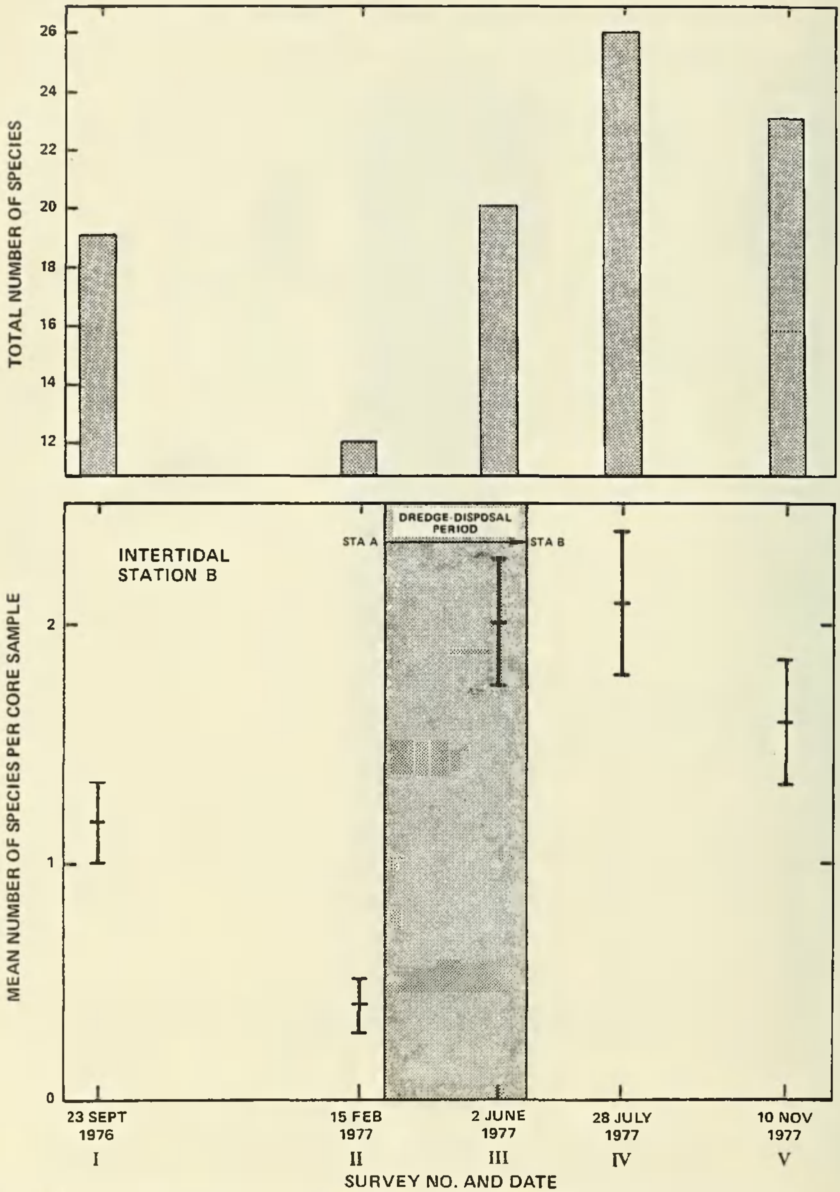

Figure 24. Mean number of species per core sample and total species sampled per survey for intertidal station B. Bars = $\bar{X} \pm t_{.95} S_{\bar{X}}$.

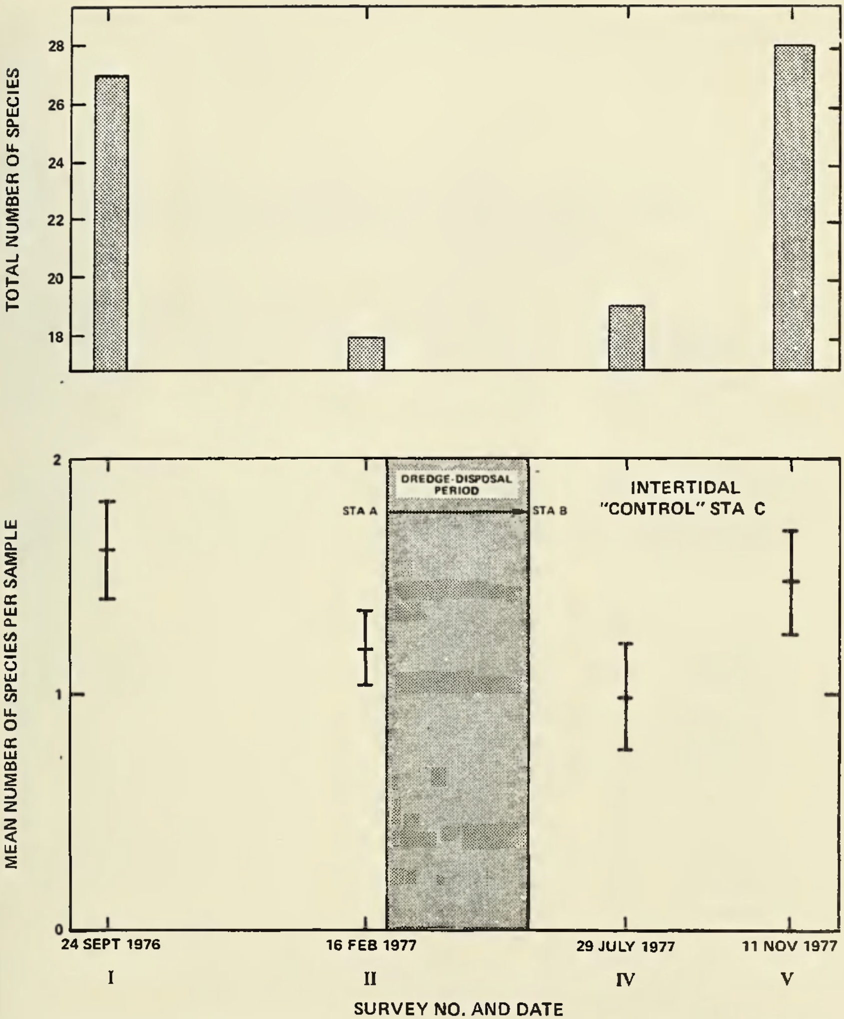

Figure 25. Mean number of species per core sample and total species sampled for intertidal station C. Bars = $\bar{X} \pm t_{.95} S_{\bar{X}}$.

Table 12. Numbers of species sampled at beach stations and directly offshore at dredge-disposal stations A and B and at control station C.

	Survey					STATION AVERAGE (ALL SURVEYS)
	I	II	III	IV	V	
Intertidal						
Sta. A	25	25		22[1]	20[2]	23.00
Sta. B	19	12	20[1]	26[1]	23[2]	20.00
Sta. C	27	18		19	28	23.00
SURVEY AVERAGE (All Stations)	23.67	18.33	20.00	22.33	23.67	Overall average 21.84
3.7-METER DEPTH						
Sta. A	46	41[1]		25[1]	19[2]	32.75
Sta. B	33	34	30[1]	32[1]	17[2]	29.20
Sta. C	30	17		32	15	23.50
SURVEY AVERAGE (All Stations)	36.33	30.67	30.00	29.67	17.00	Overall average 28.54
6.1-METER DEPTH						
Sta. A	53	38		47[1]	44[2]	45.50
Sta. B	50	38	36[1]	44[1]	29[2]	39.40
Sta. C	49	cobbles		cobbles	30	39.50
SURVEY AVERAGE (All Stations)	50.67	38.00	36.00	45.50	34.33	Overall average 41.64

[1]Disposal within previous 5-week period.

[2]Disposal within previous 3 months.

nine different southern California beaches reported by Patterson (1974), who used a larger mesh screen in sample processing. Dexter (1977) sampled a single intertidal locality at Imperial Beach in February and found 15 species.

In conclusion, the effects of the deposited sediments do not appear to have reduced the numbers of species or individuals of beach infauna. Sediment and biological data indicate a short-term enrichment effect (five surveys of station B). Evidence of an intermediate term effect (4 months) is lacking (four surveys of station A).

There was an accumulation of coarse shell material which accompanied finer sediments in the dredged material (Fig. 11). These shells represented typical bay species, and are probably large enough to remain on the beach for some time. As more of the finer particles are sorted out by wave activity, the shells may have an increasing influence on infaunal distribution patterns. Coarse sediments on the beach, if prevalent, would be inimical to the settlement of many species.

c. Intertidal Faunal Similarity. Similarity indices were calculated at station B for each of the five surveys (Table 13). The greatest changes occurred just after beach replenishment when abundance and diversity were increasing. This index, as calculated, appears overly sensitive to species which are extremely abundant.

Table 13. Station similarity indices[1] between surveys at dredge-disposal terminus station B.

	SURVEY			
	I-II	II-III	III-IV	IV-V
INTERTIDAL	0.194	0.066	0.761	0.588
3.7-Meter Depth	0.395	0.363	0.346	0.066
6.1-Meter Depth	0.253	0.347	0.402	0.181

[1]The similarity index used is C_z (Czekanowski's coefficient; Bray and Curtis, 1957). The coefficient compares species similarity between two sampling periods or two separate localities. $C_z = 2W/M + N$; W = sum of the lower measures of each species co-occurring during the two sampling periods or localities; M and N = total abundance of all species from each sampling period or separate locality (M and N).

d. Subtidal Abundance and Diversity. The average abundances at 3.7- and 6.1-meter depths for all surveys combined were, respectively, 5,470 and 6,118 organisms per square meter. Dexter (1977) reported subtidal densities at Imperial Beach which are an order of magnitude lower (190 to 510 per square meter). Barnard (1963) reported a density of 3,600 organisms per square meter from nearshore sands in southern California. Screen sizes used in were similar to those used in this study; however, collection methods differed. Estimated densities for abundant species and rank order of abundance for the 3.7- and 6.1-meter depths are presented in Tables 11, 14, and 15. The high numbers obtained in the present study by use of core samples may represent unusually high population densities, but more likely are typical of such habitats and were recorded due to greater effectiveness in sampling. Parr and Diener (1978) reported relatively elevated numbers elsewhere in southern California using replicate diver-operated core samplers.

Total population densities at Imperial Beach were highly variable at 3.7- and 6.1-meter depths. Certain species were capable of considerable population increases and decreases and spatial patchiness along this offshore zone. For example, significant ($p<.05$) sixfold differences in abundance existed between 3.7-meter stations in survey I before beach replenishment; these were primarily due to differences in density of the ostracod, *Euphilomedes* sp., which exceeded 8,000 per square meter at station B and was not present in samples from station C located only 950 meters south. Clearly, much patchiness is evident in this seemingly homogeneous environment. However, some patterns in relation to sediment deposition were evident. Sediment decreased in average grain size as the fine sediment fractions increased at the 3.7- and 6.1-meter depths offshore at disposal stations A and B, and these changes in fine sediments had diminished 7 weeks after termination of beach replenishment (Figs. 8 and 9). No such fluctuations were evident at the control station C. During this period, fine sediments washed from the dredge disposal were transported offshore, covering and mixing with the existing bottom sediments.

The 6-meter depths were sampled, just before beach replenishment, while 3.7-meter depths were sampled 2 weeks after the operation started (Table 1). Abundance and numbers of species per station are given in Figures 26 to 29, and in Table 12. The patterns are complex. Significant differences between stations existed before and during the disposal operation. High numbers at 6.1-meter stations A and B when fine sediments were prevalent and at the 3.7-meter station A following deposition were possibly due to the change in particle size and increased organic matter. For example, at 3.7-meter stations following deposition survey IV, three polychaete species comprised most of the abundance; at the 3.7-meter station B, an amphipod and a cumacean were also prevalent (Table 14). Large numbers of another polychaete species settled at the 6.1-meter station A several weeks after disposal, but not at stations B or C.

Populations were influenced significantly by physical factors. For example, subtidal abundances were relatively high during calmer

Table 14. Organisms from 3.7-meter depth occurring at densities greater than 500 per square meter during Imperial Beach study.

3.7-meter Station	SURVEY NUMBER AND DATE				
	I 30 Aug. 1976	II 6 Apr. 1977	III 2 June 1977	IV 12 Aug. 1977	V 29 Nov. 1977
A	Nematodes - 782/m^2 Amphipod *Mandibulophoxus gilesi* 623/m^2	Nematodes - 2,559/m^2 Polychaetes *Scolelepsis squamata* 1,986/m^2 *Magelona pitelkai* 1,445/m^2 *Apoprionospio pygmaea* 902/m^2 Mysid *Acanthomysis macropsis* 650/m^2	NOT SURVEYED	Nematodes - 1,074/m^2 Ostracod *Euphilomedes* spp. 1,034/m^2 Amphipod *Synchelidium* sp. 660/m^2	NONE EXCEEDING 500/m^2
B	Ostracod *Euphilomedes* spp. 8,314/m^2 Polychaete *Scoloplos armiger* 530/m^2	Cumacean *Cyclaspis* sp. B 1,233/m^2 Amphipod *Trichophoxus epistomus* 1,127/m^2 Polychaete *Scolelepis squamata* 1,353/m^2 *Magelona pitelkai* 862/m^2	Nematodes - 570/m^2 Ostracod *Euphilomedes* spp. 729/m^2 Polychaete *Apoprionospio pygmaea* 636/m^2	Polychaete *Apoprionospio pygmaea* 4,721/m^2 Nematodes - 530/m^2	NONE EXCEEDING 500/m^2
C	Amphipod *Mandibulophoxus gilesi* 650/m^2	Polychaete *Scolelepis squamata* 1,658/m^2 *Apoprionospio pygmaea* 557/m^2	NOT SURVEYED	Polychaete *Apoprionospio pygmaea* 2,122/m^2 *Spiophanes bombyx* 2,122/m^2	NONE EXCEEDING 500/m^2

Table 15. Organisms from 6.1-meter depth occurring at densities greater than 500 per square meter during Imperial Beach study.

6.1-meter Station	SURVEY NUMBER AND DATE				
	I 30 Aug. 1976	II 8 Apr. 1977	III 2 June 1977	IV 12 Aug. 1977	V 29 Nov. 1977
A	Polychaete *Typosyllis hyalina* 570/m^2	Polychaete *Scoloplos armiger* 910/m^2	NOT SURVEYED	Polychaete *Owenia fusiformis* 4,097/m^2 *Apoprionospio pygmaea* 1,618/m^2 Mollusk *Tellina modesta* 769/m^2 Ostracod *Euphilomedes* spp. 517/m^2 Cumacean *Diastylopsis tenuis* 663/m^2	Nematodes - 2,957/m^2
B	Ostracod *Euphilomedes* spp. 2,970/m^2 Amphipod *Eohaustorius* sp. 2,692/m^2	Nematodes - 1,590/m^2 Polychaete *Apoprionospio pygmaea* 3,210/m^2	Ostracod *Euphilomedes* spp. 1,472/m^2 Nematodes - 862/m^2 Polychaetes *Apoprionospio pygmaea* 517/m^2 *Magelona pitelkai* 1,326/m^2	Ostracod *Euphilomedes* spp. 6,935/m^2 Polychaete *Magelona pitelkai* 636/m^2	Polychaete *Apoprionospio pygmaea* 888/m^2
	Amphipod *Eohaustorius* sp. 1,671/m^2 *Diastylopsis tenuis* 835/m^2	COBBLE BOTTOM	COBBLE BOTTOM	COBBLE BOTTOM	NONE EXCEEDING 500/m^2

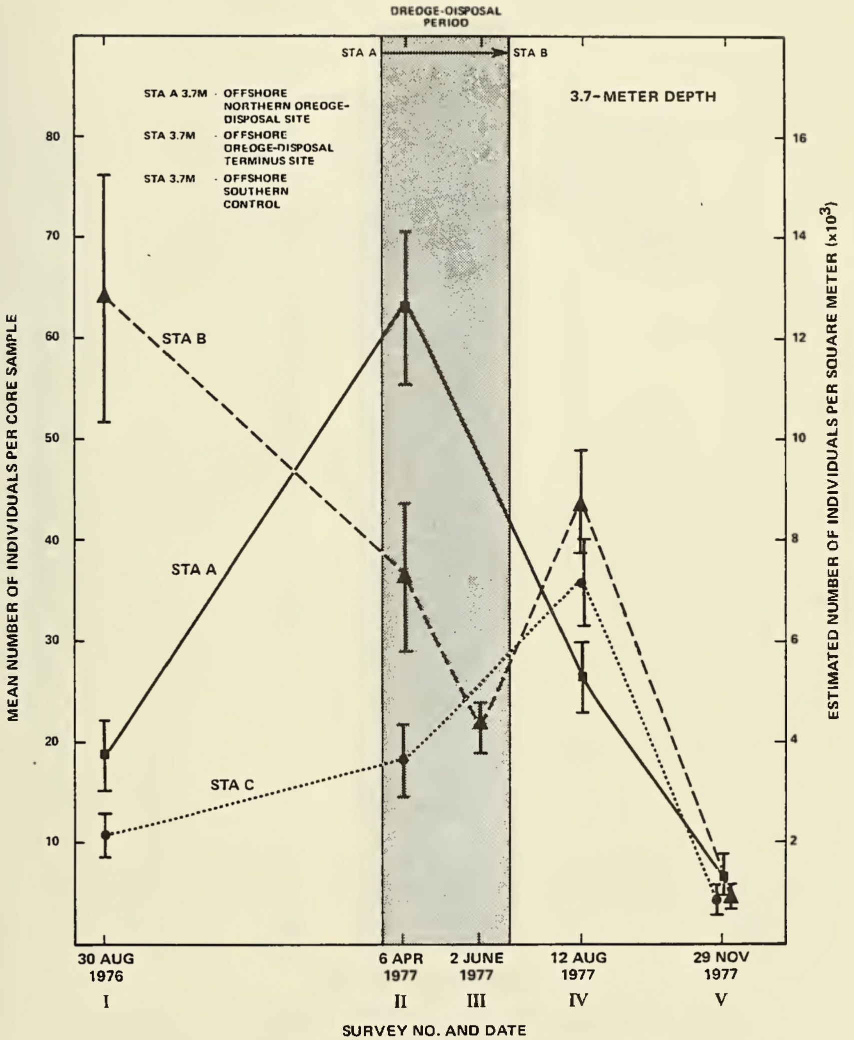

Figure 26. Mean number of organisms per core sample and estimated abundances per square meter for 3.7-meter stations. Bars = $\bar{X} \pm t_{.95} S_{\bar{X}}$.

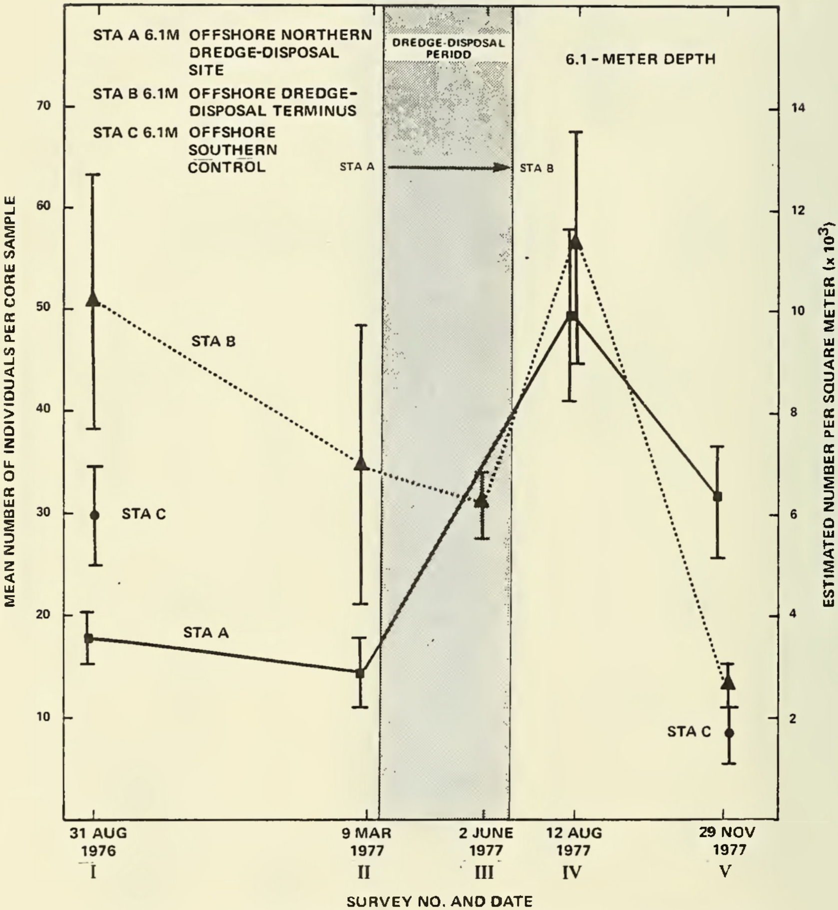

Figure 27. Mean number of organisms per core sample and estimated abundances per square meter for 6.1-meter stations. Bars = $\bar{X} \pm t_{.95} S_{\bar{X}}$.

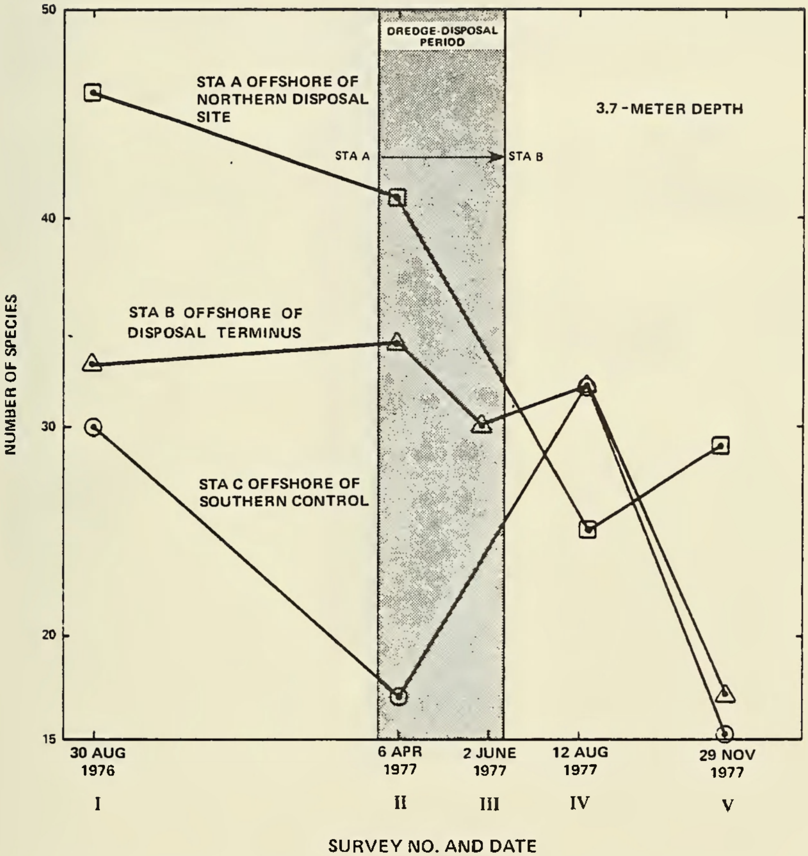

Figure 28. Total number of species sampled per survey for 3.7-meter stations.

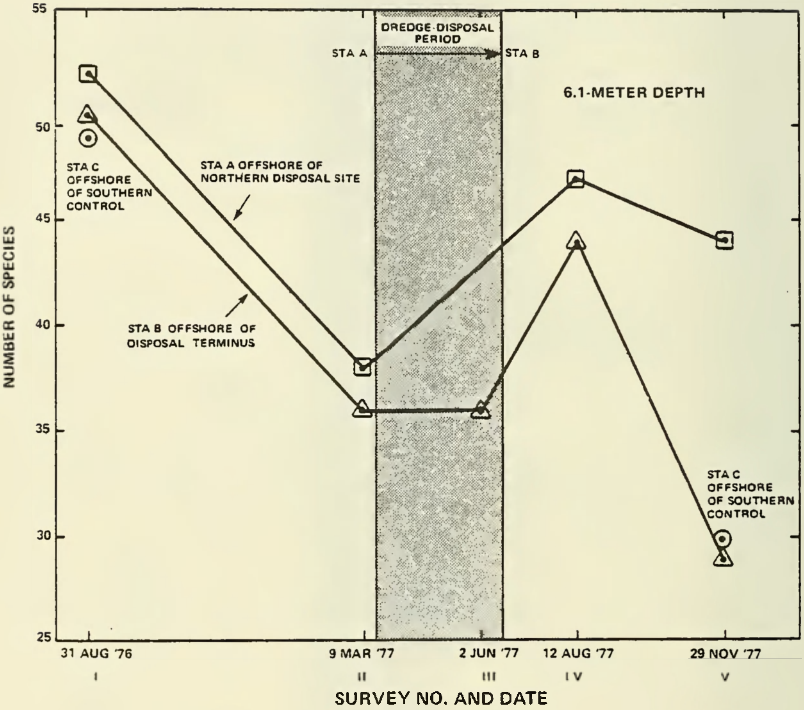

Figure 29. Total number of species sampled per survey for 6.1-meter stations.

periods and were decreased by a storm just before the fifth survey, 5 months after deposition of beach sediments (Fig. 7).

Biological activities of the sand dollar, *D. excentricus*, may have had an effect on infaunal communities within the subtidal zone. They comprised a large part of the biomass and migrated on and offshore. This movement possibly influenced other infaunal organisms; however, the sampling program did not provide a detailed picture of *D. excentricus* movements. A total of 140 taxa was collected from the subtidal zone (App. B). This compares with the 131 taxa reported from the subtidal (to 7.6-meter depth) at Imperial Beach by Dexter (1977).

e. Faunal Similarities. Similarity indices at the 3.7- and 6.1-meter stations were compared for the five surveys at station B. No changes related to beach nourishment were detected (Table 13). The greatest changes observed appeared to be related to a storm which preceded survey V, 5 months after deposition.

f. Biomass Relationships. Biomass data from all surveys are presented in Table 16. An increase in the biomass proceeding offshore is evident. The sand dollar, *D. excentricus*, accounted for 87 percent of the total biomass at 3.7- and 6.1-meter depths. Biomass data were too variable and sporadic in relation to *D. excentricus* distribution (Fig. 30) to be useful in assessing deposition effects.

g. Abundance and Diversity in Relation to Depth. Relationships are presented in Figure 31 and Tables 17 and 18. During the study period there was a significant ($p<.05$) increase in abundance and species density proceeding from the upper to middle strata of the intertidal zone. At the lowest stratum of the intertidal zone there was a drop in abundance (not significant at the $p<.05$ level) and species density was similar compared to the middle stratum. Differences between the intertidal zone and 3.7 meters were pronounced and significant ($p<.05$); however, total abundance and species density did not increase much between 3.7- and 6.1-meter depths. These relationships are in accord with other observations of increased diversity in less physically controlled (more stable) environments with increasing depths proceeding offshore (Day, 1967; Sanders, 1969; Day, Field, and Montgomery, 1971; Parr and Diener, 1978). Although they appear to be more stable and diverse, communities in deeper water may be more susceptible to changes in physical variables since they do not regularly experience them. The nearshore communities, although experiencing greater vicissitudes of environment and fluctuations in abundance, may be a more resilient system. Ecosystem resiliency is discussed in Holling (1973).

h. Community Composition in Relation to Depth. Relative numbers of species and abundances of major taxonomic groups change with depth (Table 19). The intertidal zone was dominated by crustaceans both in

Table 16. Biomass, converted to grams wet weight per square meter at Imperial Beach sampling stations.

Depth	Station	Survey I	II	III	IV	V	Average
Intertidal	A	10	7		18	4	(all stations and surveys)
	B	32[1]	18	27	51[1]	35	
	C	194[1,2]	4		172[2]	17	45.3
3.7 meters	A	236[3]	506[4]		868[4]	21	
	B	11	510[4]	119[4]	21	11	
	C	45	6		20	8	183.2
6.1 meters	A	17	5		48	1505[4]	
	B	15	22	2857[4]	40	12	
	C	68				19	418.9

[1] Presence of Pismo Clams (*Tivela stultorum*) in samples ranging from 43 to 78 percent of total sample weights.

[2] Presence of single large crab (*Blepharipoda occidentalis*) = 46 and 78 percent of total sample weight.

[3] Presence of single clam (*Tellina bodegensis*) = 95 percent of total sample weight.

[4] Presence of Sand Dollars (*Dendraster excentricus*) in samples ranging from 93.4 to 99.8 percent of total sample weight.

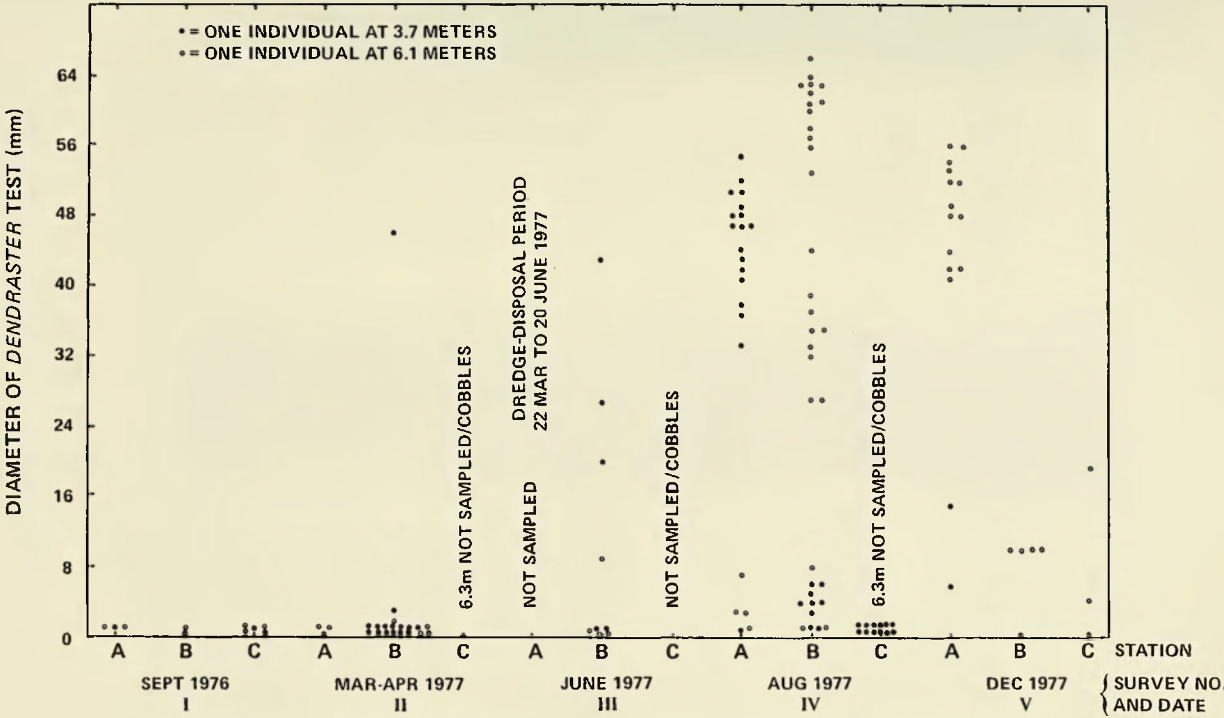

Figure 30. Size (millimeters) and numbers of *Dendraster excentricus* sampled with infauna core samples for 3.7- and 6.1-meter stations.

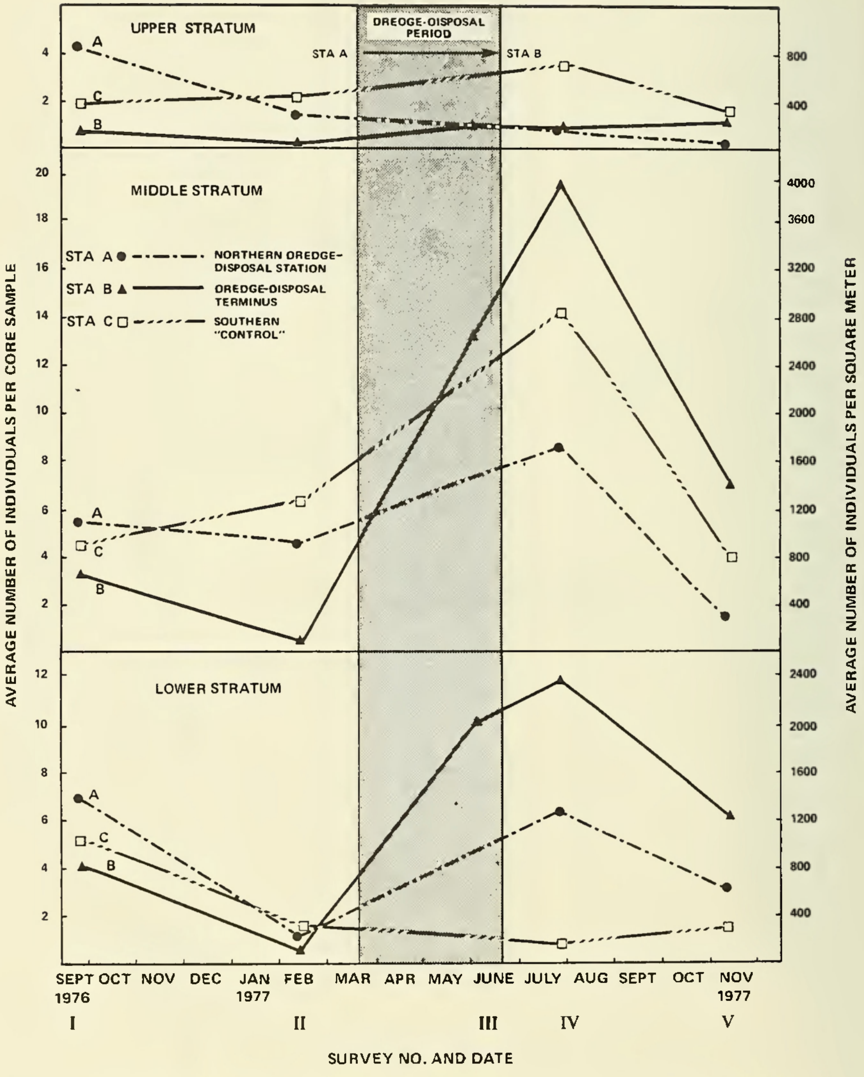

Figure 31. Mean number of organisms per core sample and estimated abundances per square memter for intertidal beach strata.

Table 17. Numbers of species collected within major taxa and depth strata.

Depth strata	Polychaeta	Crustacea	Mollusk	Other	Total (all taxa)
Intertidal	18	23	5	10	56
3-7-meter	34	44	14	13	105
6-1-meter	46	43	27	15	131
TOTAL (all depths; not additive)	56	64	29	21	170

Table 18. Average abundance and number of species per sample as a function of intertidal stratum and depth during the Imperial Beach study.[1]

	INTERTIDAL					SUBTIDAL	
Depth strata	Upper		Mid	Lower		3.7 meters	6.1 meters
Number of surveys	13		13	13		13	11
Number of animals per sample	1.54	sig. .05	7.15	4.55	sig. .05	27.35	30.59
Number of species per sample	0.76	sig. .05	1.70	1.79	sig. .05	8.70	10.35

[1]All within-depth stations from different sampling dates were combined; sample unit = 8-centimeter diameter by 10-centimeter depth. Differences between successive strata or depths significant at 5-percent level are indicated by sig. .05.

Table 19. Percent contribution of major taxonomic groups and their abundance and diversity at different depths during Imperial Beach study.

SPECIES GROUP	ABUNDANCE (pct)				SPECIES COMPOSITION (pct)			
	INTERTIDAL STATION				INTERTIDAL STATION			
	A	B	C	ABC[1]	A	B	C	ABC[1]
Crustaceans	77	91	85	84	46.5	48	53	49
Polychaetes	19	7	11	12	38	38	32	36
Mollusks	1	1	2	1	6.5	7	6.5	7
Other	3	1	1	2	9	7	7	8
	3.7-METER STATION				3.7-METER STATION			
	A	B	C	ABC[1]	A	B	C	ABC[1]
Crustaceans	40	52	30	41	51	46	36	48
Polychaetes	33	35	64	44	32.5	32	30	31.5
Mollusks	2	4	1	2	8	12.5	7	9
Others	25	9	4	13	9	9	17	11.5
	6.1-METER STATION				6.1-METER STATION			
	A	B	C	ABC[1]	A	B	C	ABC[1]
Crustaceans	21.5	55	60	45.5	38	38	34	35
Polychaetes	53	33	28	38	44	45	49	46
Mollusks	8	3	9	6.5	10	14	6	10
Others	17.5	9	3	10	8	9	10	9

[1]Combined values of stations A, B, and C.

numbers (84 percent) and species (49 percent). Motility appears to be an important adaptation to this zone. Statements on the overriding importance of polychaetes in infaunal communities (Dauer and Simon, 1976) do not apply to these exposed coastal shallow sediments within the surf zone. At the 3.7-meter depths, crustaceans comprised over 41 percent of the numbers and 48 percent of the species; at the 6.1-meter depths, crustaceans comprised 45.5 percent of the numbers and 35 percent of the species. These were mostly motile brood-carrying pericarid crustaceans (e.g., amphipods, cumaceans) similar to those in the intertidal zone. Polychaetes at 6.1-meter depths comprise 38 percent of the abundance and 46 percent of the species. Since most polychaetes recruit from the plankton, increased sediment stability with depth may be important to larval settlement and probably underlies this observed relationship. Polychaetes are reported to predominate in offshore environments (Knox, 1977) where sediments are more stable.

i. Relationship of Abundance and Diversity for Specific Sediment Parameters. An increase was expected in fine sediment fractions and possibly of organic matter from the San Diego Bay sediments used to replenish Imperial Beach.

Within each depth stratum all surveys were combined and significance of the correlations of numbers of species and average abundance with organic carbon content, silt-clay fraction, and very fine sand fraction was determined. Correlation of silt with carbon was also determined (Table 20).

Correlations were determined using regression analyses (Sokal and Rohlf, 1969). Tests for significance of correlation between factors were set at a 95-percent confidence level. Results were as follows:

(a) Intertidal (n = 13 comparisons)

No significant correlation between variables.

(b) 3.7-meter depth (n = 13 comparisons)

(1) Significant increase in total species present with increased silt.

(2) Significant increase of average abundance per sample with increased silt.

(3) Significant increase in organic carbon with increased silt.

(c) 6.1-meter depth (n = 11 comparisons)

(1) Significant increase in average abundance per sample with increased silt.

Table 20. Regression analysis file of associated biological and physical-chemical variables from Imperial Beach surveys.

	Species (total)	Abundance per sample (avg.)	Silt-Clay (pct-wt.)	Fine sand or smaller (pct-wt.)	Organic carbon (pct-wt.)
INTERTIDAL	25	5.5	0.18	17.85	0.024
	19	3.2	0.05	7.07	0.020
	27	4.5	0.06	7.41	0.029
	25	4.7	0.02	2.58	0.015
	12	.5	0.03	1.89	0.020
	18	6.2	0.01	2.74	0.015
	20	13.7	3.44	35.00	0.018
	22	8.6	0.04	5.91	0.029
	26	19.5	0.16	22.51	0.029
	28	14.1	0.05	5.16	0.024
	20	1.4	0.13	13.16	0.029
	23	6.9	0.09	7.00	0.024
	19	4.0	0.19	15.00	0.029
3.7-meter depth	46	18.6	--[1]	--	--
	33	64.2	7.09	44.6	--
	30	10.8	--	--	--
	41	63.1	15.90	81.72	0.059
	34	36.5	1.50	34.17	0.039
	17	18.1	0.31	13.90	0.020
	30	21.3	7.88	86.13	0.053
	25	26.3	4.61	51.33	0.069
	32	44.0	2.59	39.44	0.043
	32	36.1	0.97	21.18	0.038
	29	6.8	0.33	20.59	0.024
	17	4.9	1.92	48.74	0.024
	15	4.8	0.39	24.74	0.024
6.1-meter depth	53	17.9	12.52	69.55	--
	50	51.1	20.66	73.87	--
	49	29.7	20.86	86.70	--
	38	14.4	8.85	75.52	0.127
	36	34.9	1.44	35.71	0.024
	36	31.1	10.20	89.92	0.059
	47	49.7	36.83	88.47	0.059
	44	57.3	45.94	82.46	0.078
	44	31.3	8.19	85.99	0.029
	29	13.3	2.35	41.50	0.029
	30	8.5	2.42	47.58	0.029

[1] Not surveyed.

(2) Significant increase in total species present with increased fine fraction (particles less than 0.125 millimeter median grain diameter).

(3) Significant increase in organic carbon with silt.

These results indicate a possible effect of silt and fine sediment fractions on the diversity and abundance of benthic infauna in the subtidal zone; this positive correlation suggests that silty sediments which are being washed offshore may temporarily enrich the nearshore biota on the way to equilibrium conditions at greater depths. Fine sediments did not remain long on the beach (e.g., station A, Figs. 8 and 9) after deposition. The increased carbon with added silt may have an adjunctive effect. Although carbon did not directly show significant correlation with abundance and diversity, it showed a positive correlation ($p<.05$) with silt.

Particle size generally decreased with depth. This is a function of the wave energy impinging on the bottom affecting sorting and transport processes. Certainly, typical increases in diversity with depth (Sanders, 1968; Gray, 1974; Parr and Diener, 1978) correlated with increases of fine sediments offshore may reflect the covariance of these factors with important energy-related factors (e.g., orbital velocity on the bottom). Water motion on the bottom may be very important to infaunal organisms. The disposal of appreciable amounts of silts in the nearshore environment by the beach replenishment provided an opportunity to assess the importance of silts as a single factor within different wave energy zones and its significance was noted.

3. Major Species.

This section discusses the biology and effects of beach nourishment upon major or "key" species. In this report "key" species refer to species that were numerically abundant or contributed greatly to the biomass or are believed to be important in structuring the composition of the nearshore community.

a. *Dendraster excentricus* (Sand Dollar). *Dendraster* has a major role in determining dynamics of shallow-sand communities along the coast. *Dendraster* is capable of forming extensive beds and is probably the most significant biomass component in shallow water just beyond the surf along its geographic range from British Columbia to central Baja California. At Imperial Beach, there was a greater number of infaunal species in areas with *Dendraster* compared to similar areas and depths without *Dendraster*. This may be due to creation of greater habitat complexity by *Dendraster* (Table 21).

Table 21. Number of infaunal species collected at Imperial Beach during predisposal surveys I and II at the 3.7-meter depth.

	STATION					
	A		B		C	
	Surveys					
	I	II	I	II	I	II
No. of species	49	46	37	37	38	23

Note: Station A is adjacent to a *Dendraster* bed; stations B and C are not near a *Dendraster* bed.

Although the sand dollar, *D. excentricus*, was not always numerically abundant within the core samples (Fig. 30), underwater observation showed this species was gregarious and formed extensive beds at times. This aggregating behavior has been attributed to their reproductive habits, as fertilization is external (Weihe and Gray, 1968), but the problem is probably more complex and further study is needed. In Dexter's (1977) study of Imperial Beach, *D. excentricus* had maximum densities of more than 1,200 per square meter. Diving observations found extensive beds with hundreds of individuals per square meter. Densities calculated from core samples varied from 0 to 350 per square meter. Large variations in abundance patterns are expected considering the biological and physical factors controlling distribution.

Shoreward, *D. excentricus* occurrence is limited by wave action and a strong bottom surge. On the open coast, they are typically not found within the surf zone (Ricketts and Calvin, 1952), but occur in numbers just seaward of the breaker line. According to Merrill and Hobson (1970), a size gradation of *D. excentricus* is found from the surf to the outer limit of approximately 4- to 12-meter depths. They reported that juvenile *D. excentricus* (<10 millimeter) were more abundant near the shore, and the adults more abundant offshore. The ability of *D. excentricus* to migrate on and offshore is an important aspect in understanding its distribution. At Imperial Beach, *D. exentricus* populations moved more than 100 meters offshore and then back during the study. Dexter (1977) found a seasonal pattern to these migrations. In late spring and summer, *D. excentricus* moved shoreward and there was a general offshore movement into deeper, calmer water during winter months and storm activity.

Strong wave action and bottom surge directly affect deposition and erosion of nearshore sediments. Movements of nearshore sand can strongly influence the size of sand dollar populations. Merrill and Hobson (1970) reported that *D. excentricus* is occasionally carried by sliding sediments to depths of 37 meters. Shifting substrates and sediment composition affect sand dollar populations. Weihe and Gray (1968) found that the sand dollar, *Mellita quinquiesperforata*, a genus related to *Dendraster*, was adversely affected by a high percentage of silt and mud. In the laboratory, *Mellita* had a definite preference for sandy substrate. Dredging, which deposited heavy amounts of silt and mud near their study area, totally eliminated sand dollar populations, which had been abundant in previous years. Turbidity and silt deposition affected settling of *Mellita* larvae or smothered juveniles which had settled. Along the California coast large populations of *D. excentricus* existed in areas preceding dredging operations (MacGinitie, 1935, 1939; Ricketts and Calvin, 1952), but have not been found since (Merrill and Hobson, 1970). Burial of *D. excentricus* is not the crucial problem since they may undergo natural burial when conditions become unfavorable. However, under buried conditions water circulation and food supply must be maintained. Fine sediment loads may prevent this. Merrill and Hobson (1970) and Weihe and Gray (1968) found the optimum habitat for sand dollars to be clean, well-sorted sand with moderate water currents.

Core sampling at 3.7- and 6.1-meter depths included a large part of the typical *D. excentricus* depth range, and the individuals collected varied widely in size (Fig. 30). Newly metamorphosized juveniles (<2 millimeter) were found at the 3.7-meter depth in all surveys except survey V which occurred 5 months after the end of the beach deposition program, and after the first winter storm. Survey IV (post-dredge disposal) found juveniles at all 3.7-meter depth stations but more abundant at station C than at the 3.7-meter impacted stations A and B.

Divers found extensive beds of sand dollars at the 3.7-meter depth only for stations A and B in surveys I and II (predisposal surveys). At these stations during surveys III and IV, the sand dollars were buried under 3 to 9 centimeters of fine sediment, but they appeared to be alive and healthy. In survey V, none were observed at any of the 3.7-meter stations. Divers found no adult *D. excentricus* beds at 6.1-meter depths in surveys I and II. During survey III (station B, 6.1 meters), scattered small individuals were found covered by 3 to 9 centimeters of fine sediment. This survey was concurrent with beach replenishment; the highest percentage of the fine silt for the entire study period was found on this survey. At station A, 6.1 meters, survey IV, there were no adult specimens of *D. excentricus* observed, but at station B, 6.1 meters, survey IV, they appeared common and were buried by 3 to 9 centimeters of silt. At the latter station in survey V, the individuals that were previously common, had moved out of the area, and only a few scattered specimens remained. However, in survey V, abundant beds were present at station A, 6.1 meters, survey V. Since number and size of these individuals were similar with individuals present at station A, 3.7 meters, survey IV, the same population is assumed to have moved offshore to station A, 6.1 meters, survey V. The timing of this migration indicates a seasonal response rather than an avoidance of perturbations induced by beach nourishment. This is most evident since by survey V the physical conditions had returned to levels comparable to those at the onset of this study.

Since the sampling program was not specifically designed to follow *D. excentricus* movement, it is impossible to quantify the direct effects of the beach deposition program on the beds. Beach replenishment buried some large beds of sand dollars with very fine sediment, but no direct mortality was seen. Onshore-offshore migrations may have been affected by deposition of fines but offshore migration was evident 5 months after beach replenishment and correlated well with the onset of the first winter storms.

b. Crustaceans. Crustaceans in nearshore sediments are dominated by species which do not disperse by planktonic larvae (amphipods, isopods, cumaceans). Many are capable of leaving the sediments to form reproductive swarms or seek food or another habitat. Densities are more variable since patchiness may result from response preferences, reproductive aggregations, localized brood release, and response to food source. The following is a discussion of the response of selected crustaceans or species groups to beach replenishment.

(1) *Synchelidium* spp. (Amphipod). This species group, composed of an undescribed intertidal species (personal communication, J.L. Barnard, 1977) and offshore species including *S. shoemakeri*, ranked 1, 10, and 13 in abundance for intertidal, 3.7- and 6.1-meter depth stations, respectively (Table 11). The abundance of *Synchelidium* in the intertidal varied from 13 to over 1,400 per square meter (Fig. 32, Table 10). Egg-carrying individuals were found at all stations in all five surveys.

Abundance of *Synchelidium* did not differ between stations in the intertidal zone during survey 1. There was a significant drop in abundances at intertidal station B, survey II, which correlated with extensive erosion that exposed cobbles at this station (Figs. 4 and 31, Table 3). Survey III (station B only) was concurrent with beach replenishment. Estimates of over 1,250 individuals per square meter indicated that beach replenishment did not preclude *Synchelidium*. In survey IV (postdisposal) intertidal abundances were high at all stations. Station B had significantly higher abundances than station A but neither differed significantly from station C. Five months after disposal (survey V), abundances at all stations were lower, and station B was significantly higher than stations A and C.

The general abundance pattern observed for this species group of amphipods suggests a seasonal pattern with low abundances in winter and high in summer only to decrease again with the onset of

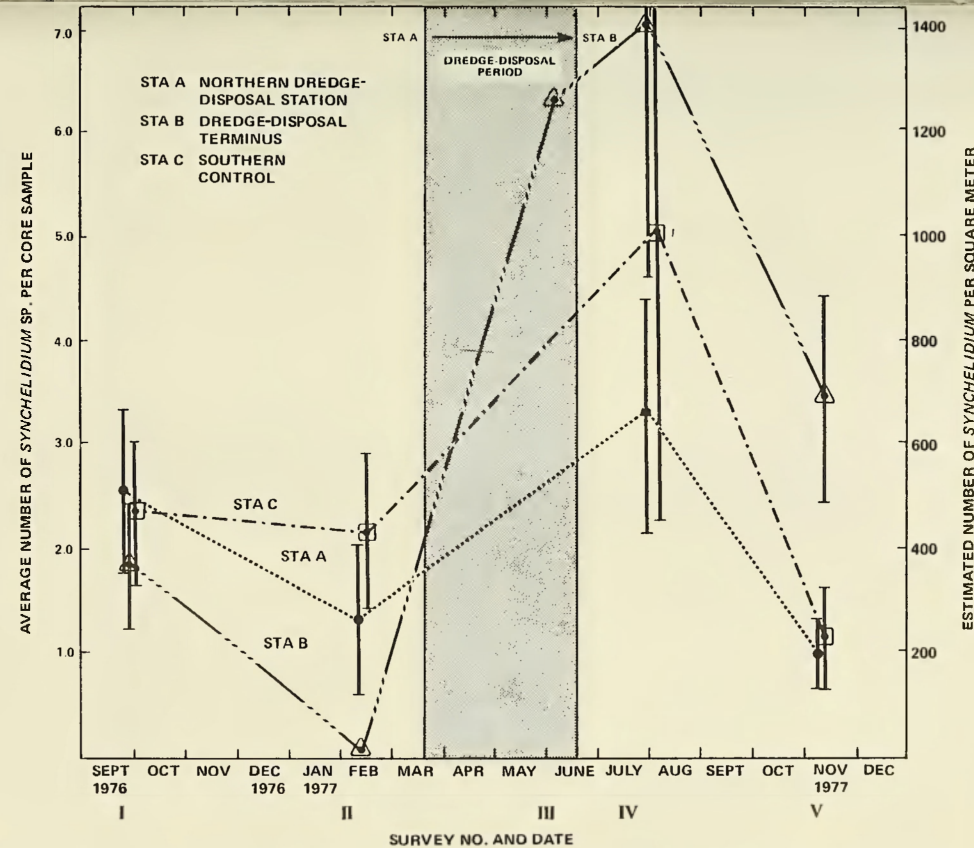

Figure 32. Mean number per core sample and estimated abundances per square meter for *Synchelidium* sp. (amphipod) at intertidal stations. Bars = $\overline{X} \pm t_{.95} S_{\overline{X}}$.

winter storms. This agrees with Enright (1962) who studied the intertidal *Synchelidium* in southern California and found their numbers to be adversely affected by storms.

The greatest abundance of *Synchelidium* was during periods of low wave energy and the lowest numbers coincided with higher wave energies (compare Figs. 7 and 32). There appeared to be no adverse impact of beach replenishment upon intertidal populations of this species group.

(2) *Euphilomedes* spp. (Ostracod). This ostracod group consisted of two species, *E. carcharodonta* (distributed from British Columbia to southern California) and *E. longiseta* (California). These crustaceans occurred sporadically in large numbers. Ostracods are mobile crustaceans and *E. carcharodonta* is believed to be a detritus feeder (Baker, 1975). This group ranked number one in abundance in the 3.7- and 6.1-meter depths but was only sampled once intertidally (Fig. 33, Table 11).

This group was abundant only at Station B where densities of over 8,000 individuals per square meter were estimated. Abundances appear to be highest between June and October, but because of their obvious patchy occurrence, relationships are difficult to discern. However, during survey IV (postdisposal) when abundances at station B, 6.1 meters, increased to 6,900 per square meter; this group was scarce at the 3.7-meter depth (133 per square meter). Strong aggregation is evident in this species as indicated by large differences ($p<.05$) in abundance between stations before beach deposition.

(3) *Eohaustorius* spp. The taxonomy of this genus of amphipods is poorly known for the eastern Pacific. More than one species occurs in the nearshore California sediments (Smith and Carlton, 1975), and at least two species were sampled at Imperial Beach, including *Eohaustorius washingtonianus*. The abundance of this group ranked second intertidally and fourth at the 6.1-meter depth (Table 11).

Intertidal densities of *Eohaustorius* reached a maximum of 102 per square meter during survey III (June 1977, station B, concurrent with beach replenishment) and remained high at this station through survey IV, July 1977 (Table 10). At the 3.7-meter depth the group was sampled regularly with densities estimated from 0 to 200 per square meter. At the 6.1-meter depth densities also fluctuated greatly and ranged from 0 to 2,700 per square meter (Table 15).

Intertidal abundances immediately after replenishment appear to be positively correlated. Since this reponse was not observed at station A approximately 2.5 months after the beach replenishment operation had moved south of rock groin No. 2 or at station B less than 3.5 months after replenishment, this potential enhancement of abundances was of short duration. No relationship of abundance or persistence to replenishment was observed at the 3.7- and 6.1-meter depths.

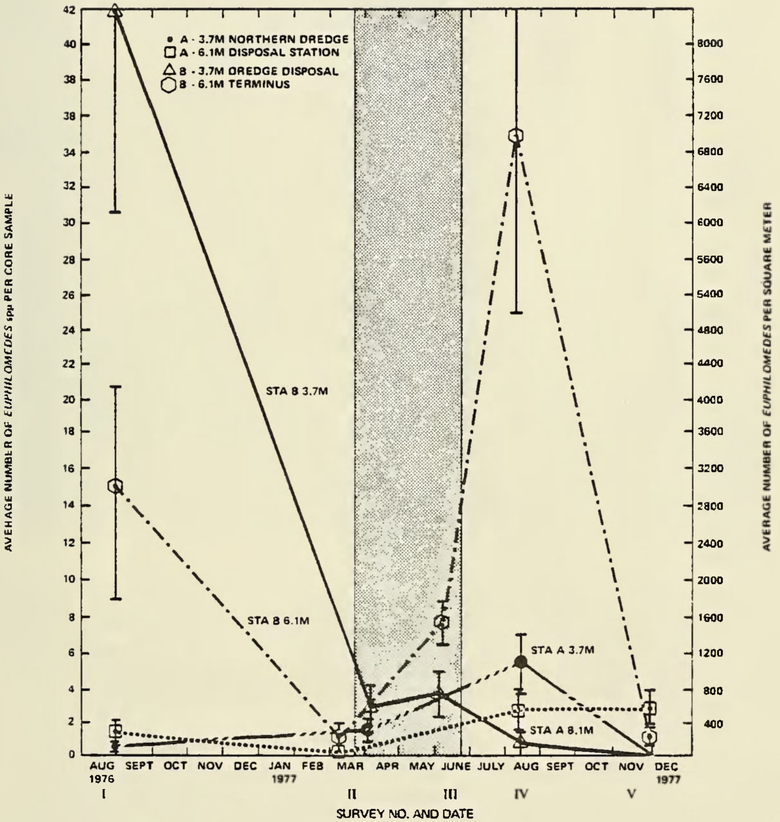

Figure 33. Mean number per core sample and estimated abundances per square meter for *Euphilomedes* spp. (ostracods) at 3.7- and 6.1-meter stations.

(4) *Trichophoxus epistomus* (Amphipod). Four species of this genus were collected at Imperial Beach, but only *T. epistomus* was abundant. This species ranked 6th in abundance intertidally, 5th at 3.7 meters, and 11th at 6.1 meters (Table 11). The geographic range of *T. epistomus* extends from California to Panama.

Abundances of this species were highest at the 3.7-meter depth. The average was from 200 to 550 per square meter (Fig. 34); the pattern of abundance agrees well with Barnard (1963) who reported 55 per square meter from inshore depths of 2 to 5 meters with numbers decreasing offshore. However, abundance was 4 to 10 times that found by Barnard (1963) and probably reflects different sampling methods (diver core samples versus remote grab samples). Intertidal zone abundances were 10 to 91 per square meter and were highest during beach replenishment (91 per square meter, Table 10, Fig. 35). At the 3.7-meter depths, abundances fluctuated greatly with maximum estimated densities of 1,127 per square meter being encountered at station B, survey II (6 April 1977). As this survey was conducted 15 days after the start of beach replenishment, this response by a mobile species such as *T. epistomus* might be expected. No response was noted at station A during survey II, and this impacted station did not differ from the control station. At this time dredge disposal of sediments was localized near station A (1.2 kilometers north from station B) and station B had not been impacted by this operation. Consequently, it appears that the large increase in density at station B was unrelated to beach replenishment and may have resulted from changes brought about by the severe erosion of intertidal station B between surveys I and II. The large decrease observed at station B, 3.7 meters, for survey III (concurrent with beach replenishment) may have been due to beach replenishment, but abundances were not significantly different ($p<.05$) than station C.

(5) *Mandibulophoxus gilesi* (Amphipod). This species ranked seventh in abundance at the 3.7-meter stations and reached densities in excess of 600 per square meter (Table 11, Fig. 36). This species was also more abundant at that depth than intertidally or at 6.1 meters. Beach replenishment had no discernible effect on this species.

(6) Cumaceans. Three species of cumaceans were common in nearshore sediments at Imperial Beach. These showed strong depth preferences. *Leptocuma forsmani* ranked 12th and 14th in abundance at 3.7- and 6.1-meter depths, respectively, and was not found intertidally. This species was found consistently at all offshore stations during all surveys except survey V when only three specimens were collected at station B, 6.1 meters.

Diastylopsis tenuis was common only at the 6.1-meter stations ranking sixth in abundance. Densities reached over 800 per square meter (Table 15) but populations fluctuated greatly. Barnard (1963) reported 100 per square meter in southern California inshore sands. *Cyclaspis* sp. B, an undescribed species, ranked third in

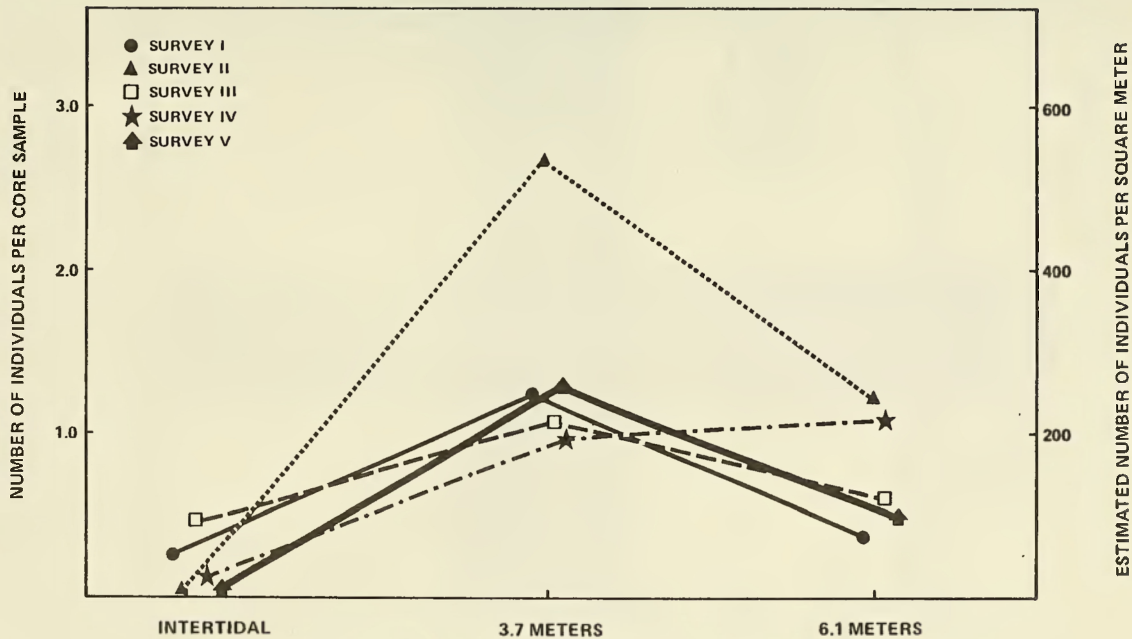

Figure 34. Mean number per core sample and estimated abundances per square meter for *Trichophoxus epistomus* (amphipod). Stations combined for each depth stratum.

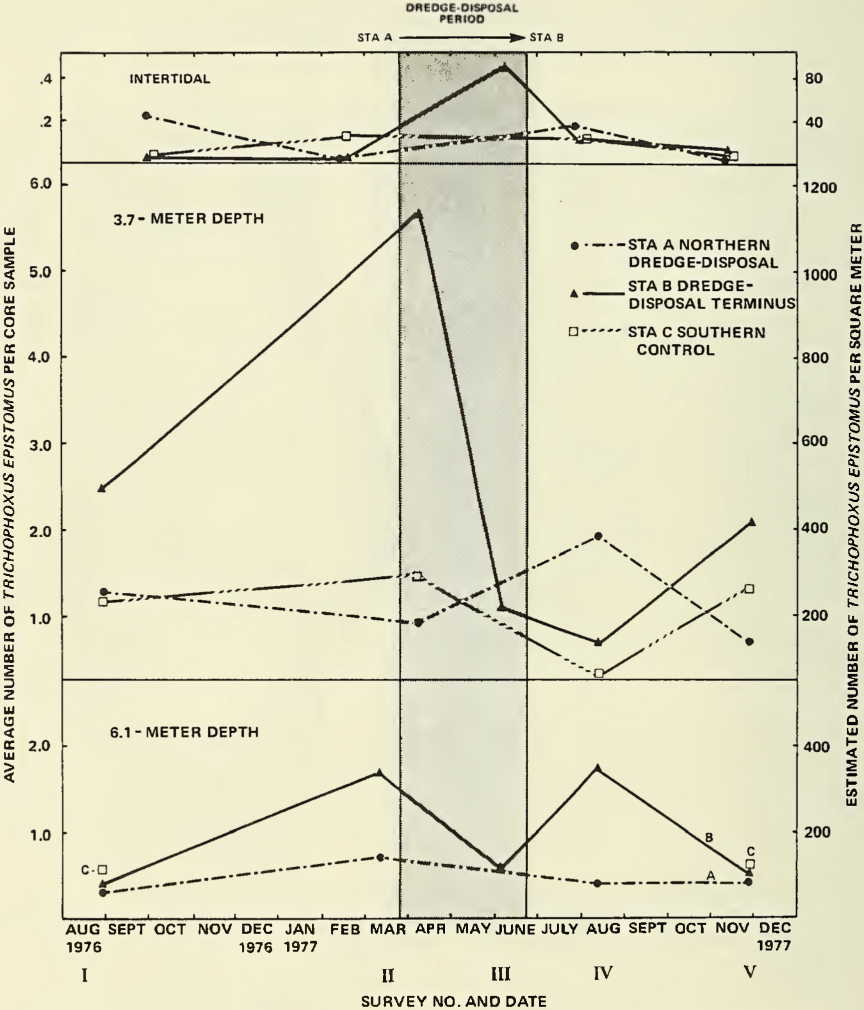

Figure 35. Mean number per core sample and estimated abundances per square meter for *Trichophoxus epistomus* (amphipod) for each depth stratum.

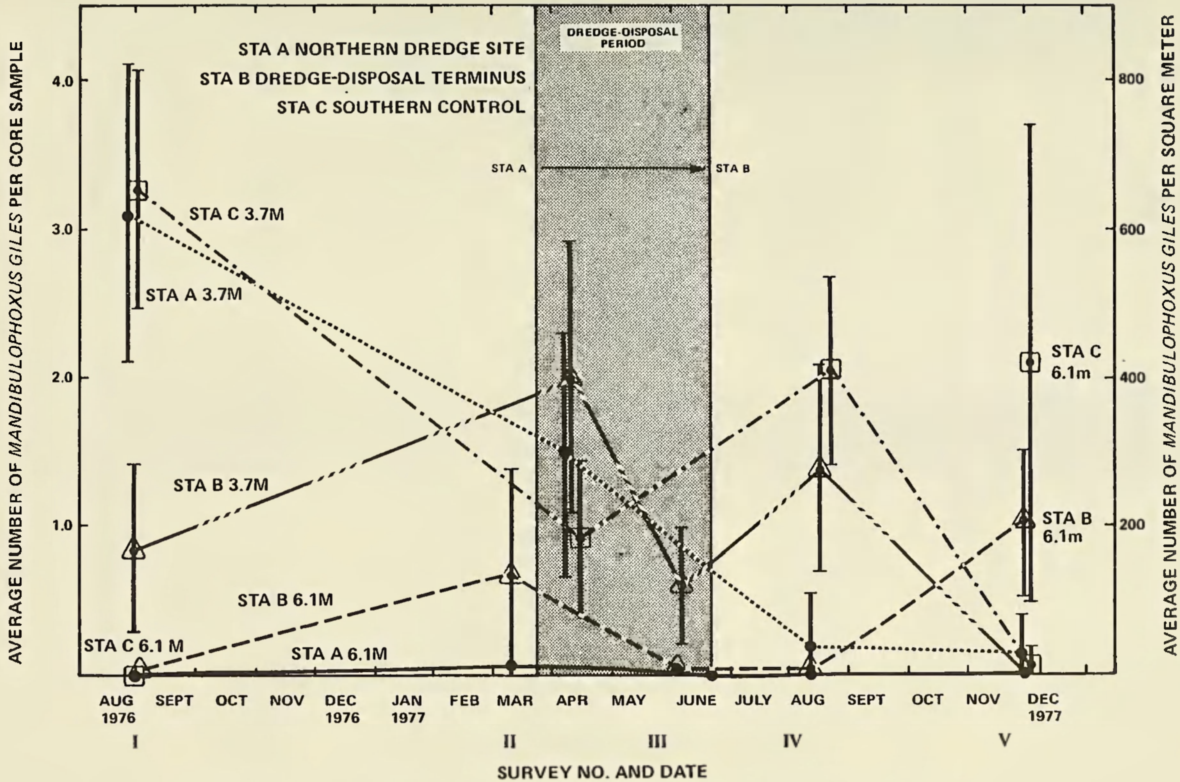

Figure 36. Mean number per core sample and estimated abundances per square meter for *Mandibulophoxus gilesi* (amphipod) at 3.7- and 6.1-meter stations.

abundance in the intertidal zone and eighth at the 3.7-meter stations (Table 11). Maximum abundance was at the 3.7-meter depth where estimated densities exceeded 1,200 per square meter (Table 14). Intertidally, abundances reached 293 per square meter (Table 10) for survey IV (postdisposal) and this was the only time they were not found at the offshore stations. This correlates with a period of low wave energies and possibly indicates an onshore movement of this species during periods of calm weather (Fig. 7). There was no significant detectable response of cumacean species to beach replenishment.

(7) Decapods (Crabs). Many of the nearshore decapods are significant components of the nearshore biomass. Their densities were generally low and they tended to be highly aggregated.

(a) *Blepharipoda occidentalis* (Spiny Sand Crab). Adults of this large crab were only found intertidally and their biomass accounted for 45 to 78 percent of the station biomass (Table 16). Less than two per square meter were generally found. Juveniles were offshore and their densities were higher. This possibly indicates an onshore migration with maturity.

(b) *Emerita analoga* (Sand Crab). This sand crab ranked fourth in abundance (Table 11) and was taken consistently in the intertidal zone but never collected offshore. Estimated densities varied from 2 to 142 per square meter with the highest densities occurring at intertidal stations A and B for survey IV (postdredge disposal). This may have been due to seasonal recruitment at this time, but high numbers were not observed at station C. However, at this time the upper intertidal of station C had eroded to cobble and this probably lowered the biological attractiveness of this station for *Emerita* (see Fig. 4). In survey V, abundances of *Emerita* were not significantly different between stations. Beach replenishment may have had some positive effect on *Emerita* densities, but at best this was a short-lived phenomena. There appears to be no long-lasting adverse effects of beach replenishment on this species. This species is noted for its longshore movement, and patchy distribution and recruitment patterns (Barnes and Wenner, 1968).

c. Polychaetes. The significant role that polychaetes play in the dynamics of soft-bottom communities was reviewed by Knox (1977). Five species of polychaetes that were numerically abundant are discussed in relation to their response to beach replenishment.

(1) *Apoprionospio pygmaea*. This polychaete worm ranked second in abundance at the 3.7- and 6.1-meter stations and reached densities estimated at 4,700 per square meter (Fig. 37, Table 11). On the east coast, this species was a numerical dominant in the repopulation of a protected intertidal area following defaunation of the sediments (Dauer and Simon, 1976). However, in California the response of this opportunistic species to disturbance gradients shows no consistent trend (Oliver, 1977). Densities fluctuated over hundredfold

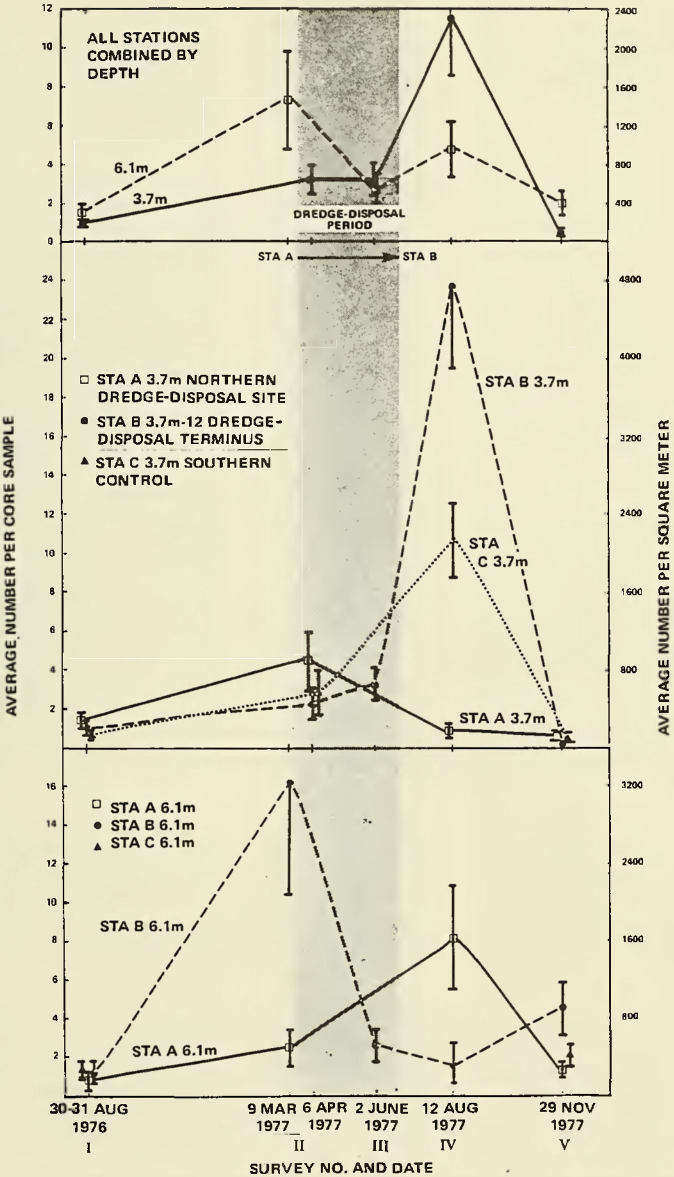

Figure 37. Mean number per core sample and estimated abundances per square meter for *Apoprionospio pygmaea* (polychaete) at 3.7- and 6.1-meter stations.

approximately every 3 months at a depth of 7.6 meters in another California sand-bottom community (Diener and Parr, 1977). In this study, densities fluctuated greatly with no consistent pattern that could be related to added beach sediments, seasonality or measured sediment parameters.

(2) *Scolelepis squamata*. This polychaete ranked 10th in abundance intertidally, 4th at the 3.7-meter stations and was rare at the 6.1-meter stations (Table 11). This species not only had a strong preference for shallow water, but also was highly seasonal in its recruitment to the nearshore habitat (Fig. 38). Abundance was high at all 3.7-meter stations, survey II (6 April 1977), and estimated densities were 1,600 per square meter (Table 14). Abundance decreased significantly at all stations for the next survey and subsequently abundance was either very low or the species was absent. The decrease observed at station B, 3.7 meters, during survey III (2 June 1977) may be attributable to beach replenishment or to normal population fluctuations. However, since the control station was not sampled in survey III, no decision is possible. It is significant that on survey IV (12 August 1977), densities were very low at station C at 3.7 meters. This species also recruited in high numbers to an area obviously physically impacted by beach replenishment (station A, 3.7 meters, 6 April; Figs. 8 and 9).

(3) *Magelona pitelkai*. This polychaete was found only once in the intertidal zone but it ranked sixth and seventh in abundance for the 3.7- and 6.1-meter stations, respectively (Table 11). It appears to have responded with increased settlement (densities to 1,300 per square meter) at impacted stations A and B during beach replenishment (Fig. 38). This increase in density was not found at control station C which implies that this dense settlement may not have been a seasonal effect but a response to the changed physical conditions produced by beach replenishment.

(4) *Scoloplos armiger*. This polychaete worm ranked 9th in abundance intertidally, 11th at 3.7 meters, and 9th at 6.1 meters (Table 11). This species was found at all depths at all surveys. Maximum density was 910 per square meter (Fig. 38, Table 15) found at station A, 6.1 meters (9 March 1977) before beach replenishment began. Changes in population densities do not appear related to beach replenishment or any of the sediment parameters.

(5) *Owenia fusiformis collaris*. This cosmopolitan species builds tubes and lives in the subtidal bottom off Imperial Beach. These sand-bottom, tube-dwelling organisms increase the stabilization of sediments (Rhoads, 1974). Occurring in small clumps or larger patches, the tubes are able to stabilize marine substrates much the way plants do to soil in terrestrial ecosystems.

Owenia sorts out and concentrates the mineral hornblende in the process of tube building and repair (Fager, 1964). Since hornblende comprises about 50 percent of the sediment at Imperial Beach, it

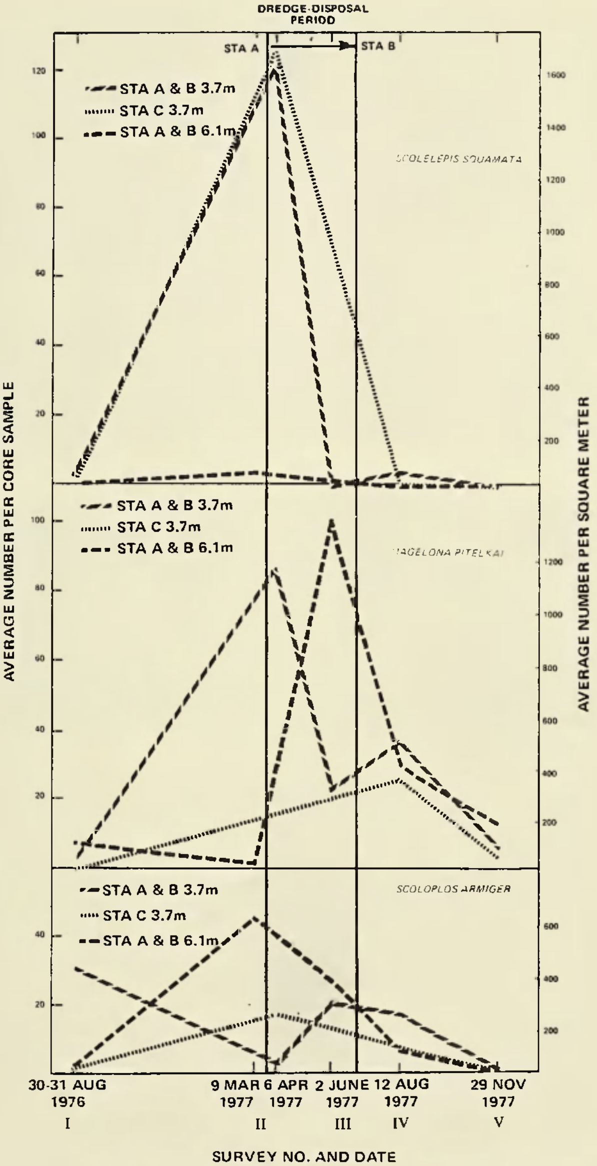

Figure 38. Mean number per core sample and estimated abundances per square meter for *Scolelepsis squamata*, *Magelona pitelkai*, and *Scoloplos armiger* (polychates) at 3.7 and 6.1 meter stations.

is not surprising that *Owenia* is at times a significant component of the subtidal macrofauna. This species ranked fifth in abundance at the 6.1-meter stations (Tables 11 and 15). Fager (1964) reported that newly settled *Owenia* appeared throughout the year in southern California. A maximum density of 15,000 per square meter was reported, but average densities within aggregations were 500 to 1,000 per square meter. *Owenia* appeared sporadically in Imperial Beach samples and occurred in comparatively large numbers at station A, 6.1 meters and station C, 3.7 meters during survey IV following beach replenishment. The density of *Owenia* tubes within these areas was 4,097 and 373 per square meter, respectively. This survey was preceded by a period of relatively calm wave activity (Fig. 7) which allowed successful settlement in the shallow water. By survey V after storm activity (November 1977), this species was absent from station C, 3.7 meters and densities had been reduced to 13 per square meter at station A, 6.1 meters. The ephemeral nature of a large population buildup of *Owenia* and its subsequent decline suggests that some factor other than beach replenishment was instrumental in the successful recruitment of this worm. Such rapid population declines are typical of opportunistic species with short lifespans (Grassle and Grassle, 1974).

d. Nematodes. Roundworms are one of the most numerous and widespread of all multicellular organisms, but their taxonomy and role in marine sediments are poorly understood. This assemblage ranked third in abundance at the 3.7- and 6.1-meter stations (Table 11). Marine nematodes are small organisms, with the majority able to pass through a 0.5-millimeter screen (Reish, 1959; Warwick and Gage, 1975). This study was not designed to sample this group, because such a design is not cost-effective for the purpose of the study. Estimates of numbers based on the nematodes that were retained on a 0.5-millimeter screen showed densities approaching 3,000 per square meter with numbers fluctuating greatly (Tables 14 and 15).

e. Mollusks. Mollusks, which are primarily planktonic in their larval form before settling in the sediments, are major infaunal components of the biomass.

(1) *Tivela stultorum* (Pismo Clam). The Pismo Clam is the only large bivalve in the surf zone along the southern California coast. This thick-shelled clam may reach a length of 12 centimeters or more and live for 7 years or more (Fitch, 1950). Individuals up to 6 centimeters long were collected at Imperial Beach, indicating successful recruitment within the previous 1 to 2 years. Population density estimated from combined intertidal stations and surveys was 2.1 per square meter. A comparison of clams collected at each station showed a significant decrease ($p<.05$) in average density (1.17 ± 0.97 to 0.14 ± 0.27) following beach replenishment. The deposited sediments may have affected density, though the estimates were based on very few individuals. A special sampling program would have to be designed to obtain good estimates. Populations of large, relatively low density species cannot be estimated unless extensive dredging is employed to obtain large samples (see Loesch, 1974).

(2) *Donax gouldii* (Bean Clam). The bean clam is noted for its tremendous temporal variations in abundance (Coe, 1953). However, this species appeared consistently at all intertidal stations for all surveys except during beach replenishment (survey III, station B intertidal). Densities found in other surveys ranged from 2 to 36 per square meter. This typically intertidal species was occasionally found offshore at the 3.7- and 6.1-meter stations. Beach replenishment may have been responsible for the absence of *Donax* intertidally during survey III when they were possibly buried by silt, but later postdisposal densities at impacted stations A and B were equal to or higher than those observed at the beginning of this study.

(3) *Tellina modesta*. This small deposit-feeding bivalve is considered a community dominant between depths of 9 and 27 meters (Barnard, 1963). At Imperial Beach it was consistently taken only at the 6.1-meter stations where it ranked eighth in abundance (Table 11). Densities varied from 13 to 769 per square meter (Table 15). Beach replenishment appears to have had no discernible effect on the abundance or persistence of this species.

f. Vertebrates (Fish). *Leuresthes tenuis* (Grunion)is the only fish reported in this study because it spawns in the upper intertidal on a series of receding high tides. Alterations of beach topographies and sediment parameters caused by beach replenishment could conceivably affect the spawning of this species. Grunion are known to spawn at Imperial Beach.

Eggs and larvae of this species were found in cores only at the dredge impacted stations A and B for survey IV (postdredge disposal). Evidently, the beach replenishment which terminated 37 days before survey IV did not prevent grunion spawning in the project area.

VI. CONCLUSIONS

Adverse effects of beach replenishment were few except for the direct burial of less mobile organisms. There was an increase in diversity and abundance of organisms correlating with increased sediment silt fractions which were increased significantly by beach replenishment. However, this biological enhancement also correlated with the summer low wave energy and the corresponding less physically disturbed nearshore area. The relative individual contribution of these two factors on diversity and abundance is difficult to discern. The positive response of organisms to beach replenishment was of short duration (less than 2 months) and largely exhibited by the mobile crustaceans. A longer lasting response of most organisms in the community appears to be associated with the relatively stable bottom in the summer and fall. With the onset of winter storms and the concomitant offshore movement of sediments, abundances declined significantly and diversity was lower for most of the 3.7- and 6.1-meter stations.

Burial of offshore organisms by fines transported from the beach replenishment material could have a greater adverse impact than intertidal burial. This is because offshore population densities are higher and dominant species with high biomass (e.g., the sand dollar, *Dendraster excentricus*) are long-lived; they successfully recruit to form new beds only sporadically and modify the nearshore habitat (stabilize sediments and enhance diversity). Burial of sand dollar beds at Imperial Beach does not appear to have any induced significant immediate mortality but questions of delayed mortality and recruitment success require longer term studies.

At the termination of the field study (November 1977), other than changes in beach profiles and increased coarseness of the deposited material, there appeared to be no other long-lasting measurable physical changes at Imperial Beach due to beach replenishment.

To minimize biological impacts of beach replenishment, dredged sediments should closely match the composition of indigenous sediments at the deposition site. This may conflict with other project objectives, such as increasing sand coarseness to slow erosion or the availability of appropriate sediments for dredging. The percentage of fine sediments (smaller than 125 micrometers) should be low to minimize siltation and consequent anoxic sediment conditions offshore.

The nearshore community at Imperial Beach is adapted to seasonal transport of sediments. Consequently, the deposition of some sediments on the beach is part of a natural cycle. The nearshore community appears to be highly resilient to this type of perturbation; however, offshore the biological community is more diverse and does not regularly receive high sediment loads. Consequently, the organisms appear less adapted to this type of perturbation and are less resilient. In conclusion, if clean sandy sediments are disposed of in the sandy nearshore environment, deposition in the intertidal area probably has the least biological impact.

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APPENDIX A

IMPERIAL BEACH DREDGING/DISPOSAL OPERATION SCHEDULE

Date (1977)	Volume of Material (M^3)	Composition (pct by volume)[1]							
		G	Sd	C	M	H	St	Sh	Sl
Naval Air Station North Island Aircraft Carrier Quay Wall/No. 1 Groin (North Groin)									
March									
22	6,270		80					15	5
23	5,429		85					10	5
24	11,010		85					10	5
25	14,145		85			-[2]		10	5
26	11,698		85				-[2]	10	5
27	------[3]								
28	3,747		85					10	5
29	7,417		85					10	5
30	4,437		85	-[2]				10	5
31	15,139		80	5				5	10
April									
1	19,268		80					10	10
2	14,145		85					5	10
3	------[3]								
4	8,487		90					5	5
5	5,811		90					5	5
6	11,545		85	5				5	5
7	10,704		90	-[2]				5	5
8	9,863		85	5				5	5
9	14,069		85					10	5
10	------[3]								
11	10,246		85					5	10
12	11,240		85					5	10
13	13,916		75	10				5	10
14	13,686		70	5				15	10
15	------[3]								
Naval Air Station North Island Aircraft Carrier Quay Wall/No. 1 - No. 2 Groin									
April									
16	10,399		85					10	5
17	9,863		80					15	5

APPENDIX A

Date (1977)	Volume of Material (M^3)	Composition (pct by volume)[1]							
		G	Sd	C	M	H	St	Sh	Sl
April									
18	11,851								
19	------[3]								
20	------[3]								
San Diego Unified Port District Area 1 at 10th Avenue Marine Terminal/ No. 1 - No. 2 Groin									
April									
21	4,741		98	1				-[2]	-[2]
22	4,205	-[2]	75					20	5
23	15,368	-[2]	75					20	5
24	16,057		75					15	10
25	15,521		75					15	10
26	10,475	-[2]	75					15	10
San Diego Unified Port District Area 1 at 10th Avenue Marine Terminal/ No. 2 Groin									
April									
27	13,533		80					10	10
28	12,157		70					20	10
29	10,475		80					10	10
30	10,322		80					10	10
May									
1	------[3]								
North Bay Sliver North of TRANSBAY Utilities/No. 2 Groin									
2	12,998	-[2]	75					15	10
3	12,845	-[2]	60	15				15	10
4	11,619		50	25				10	15
5	11,622		50	20				10	10

APPENDIX A

Date (1977)	Volume of Material (M^3)	Composition (pct by volume)[1]							
		G	Sd	C	M	H	St	Sh	Sl
Corner "A" of North Bay Entrance Channel/No. 2 Groin									
May									
6	10,092	5	55	20				20	10
7	11,928	5	60	15				10	10
8	------[3]								
9	3,440	-[2]	70	10				10	10
Corner "B" of North Bay Entrance Channel/No. 2 Groin									
May									
10	10,246	5	70	15				10	10
11	10,092	10	80					5	5
Corner "B" of North Bay Entrance Channel/No. 2 Groin - Pier									
May									
12	7,570	10	80					5	5
13	2,829	15	75					5	5
Corner "B" of North Bay Entrance Channel/Pier									
May									
14	5,352	15	70					10	5
15	6,881	25	65					5	5
16	6,040	15	50					5	5
								cobbles	15
17	3,288		75					10	15
Corner "C" of North Bay Entrance Channel/Pier									
May									
18	13,533		70					10	20
19	15,292		75					15	10
20	7,799		75					15	10
21	19,574		80					10	10
22	------[3]								

Date (1977)	Volume of Material (M^3)	Composition (pct by volume)[1]							
		G	Sd	C	M	H	St	Sh	Sl
May									
23	15,063		80					10	10
24	16,210		80					10	10
25	11,851		85					5	5
26	9,863		75					10	15
Corner "C" of North Bay Entrance Channel/Pier									
May									
27	10,857		80					10	10
28	19,115		75					10	15
29	------ [3]								
30	------ [3]								
Corner "D" of North Bay Entrance Channel/Pier									
May									
31	4,281		85	- [2]				5	5
June									
1	10,934	5	70	5				10	10
2	3,747		75					15	15
3	7,111		80					10	10
4	10,475		80					15	5
5	13,151		85					10	5
6	17,662		85					10	5
7	7,034	5	70	10				10	5
8	4,970	10	75	- [2]				10	5
Corner "D" of North Bay Entrance Channel/Pier - No. 1 Groin									
June									
9	9,175		80					15	5
100 Fathom "dogleg"/Pier - No. 1 Groin									
June									
10	6,958		80					15	5
11	------ [3]								

APPENDIX A

Table (Continued)

Date (1977)	Volume of Material (M^3)	Composition (pct by volume)[1]							
		G	Sd	C	M	H	St	Sh	Sl
June									
12	------[3]								
13	------[3]								
14	------[3]								
Navy - 7th Street Channel/Pier - No. 1 Groin									
June									
15	5,887		80					15	5
16	3,364		80					15	5
Navy - 7th Street Channel/Pier									
June									
17	4,493		80					15	5
Fishing Pier - No. 1 Groin									
June									
18	2,523		80					15	5
Navy - 7th Street Channel/Pier - No. 2 Groin									
June									
19	8,487		80					15	5
20	7,288	10	70					10	10

[1]Material: G Gravel, Sd Sand, C Clay, M Mud, St Stone, Sh Shell, Sl Silt, H Hardpan

[2]-- = Trace

[3]No work

NOTE: Data taken from Corps of Engineers Daily Dredging Reports prepared by General Western Construction Company.

APPENDIX B

SPECIES LIST

Taxa found in core samples during the five survey periods at Imperial Beach, California.

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
COELENTERATA																
Anthozoa																
Renilla kollikeri	OCOE 11											-[2]				
Hydrozoa (Hydroids)											X					
ROTATORIA																
Rotifer unidentified	OROT 1	X			X	X										
NEMATODA																
Unidentified	ONMT I	X	X		X	X	X	X	X	X	X	X	X	X	X	X
NEMERTINA																
Nemertean A	ONEM 3			X	X					X					X	
Nemertean B	ONEM 4	X	X	X	X		X	X	X	X	X	X			X	X
Nemertean F	ONEM 7									X					X	
Nemertean G	ONEM 8															X
Nemertean K	ONEM 12		X	X	X											
PLATYHELMINTHES																
Flatworm #3	OPLA 5											X				
Flatworm #5	OPLA 7						X									
GASTROTRICHA																
Gastrotrich unidentified	OGAS 1				X											

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
POLYCHAETES																
Ampharetidae, unid.	PAMP 90														X	
Amphinomidae																
Pareurythoe californica	PAPN 01					X										
Capitellidae, unid.	PCAP 90	X										X				
Amastigos acutus	PCAP 01		X								X		X			X
Mediomastus acutus	PCAP 21						X		X			X	X	X	X	
Mediomastus sp.	PCAP 29			X												
Notomastus tenuis	PCAP 31											X				
Chaetopteridae, juv.	PCHA 90						X					X				
Spiochaetopterus costarum	PCHA 01						X					X			X	X
Cirratulidae, juv.	PCIR 90															
Chaetozone setosa	PCIR 13												X		X	
Chaetozone sp.	PCIR 19											X				
Glyceridae, juv.	PGLY 90													X		X
Glycera convoluta	PGLY 01						X			X		X	X			
Glycera sp. A	PGLY 06														X	
Glycera sp.	PGLY 09						X						X			
Hemipodus borealis	PGLY 11	X	X	X	X	X										
Goniadidae	PGON 90													X		
Glycinde polygnatha	PGON 01											X				
Goniada littorea	PGON 12						X	X				X	X	X	X	X
Hesionidae	PHES 90									X						X
Podarkeopsis brevipalpa	PHES 02												X		X	
Lumbrineridae																
Lumbrineris sp.	PLUM 09			X				X		X						

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Magelonidae																
Magelona pitelkai	PMAG 01	X					X	X	X	X	X	X	X	X	X	X
Magelona sacculata	PMAG 02						X			X		X	X	X	X	X
Magelona sp.	PMAG 09							X							X	
Nephtyidae																
Nephtys caecoides	PNEP 01						X	X	X	X	X	X	X		X	X
Nephtys californiensis	PNEP 02	X	X	X	X	X	X	X			X	X				X
Nephtys sp.	PNEP 09						X		X			X	X	X	X	
Nephtys sp., juv.	PNEP 09							X		X	X					X
Nereidae, juv.	PNER 90						X					X				
Nereis mendocinana	PNER 03										X					
Onuphidae, juv.	PONU 90									X		X				
Diopatra splendidissima	PONU 02														X	
Nothria iridescens	PONU 11											X				
Onuphis eremita	PONU 21						X					X				
Opheliidae																
Armandia bioculata	POPH 01														X	
Travisia gigas	POPH 21														X	
Orbiniidae																
Euzonus mucronata	PORB 41	X	X	X												
Haploscoloplos elongatus	PORB 01					X										
Scoloplos armiger	PORB 22	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Scoloplos sp.	PORB 29									X	X	X				
Oweniidae																
Owenia fusiformis collaris	POWE 01						X			X		X			X	X

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Paraonidae																
Acesta catherinae	PPAR 01							X		X			X	X	X	X
Paraonella platybranchia	PPAR 43	X	X	X	X	X										
Paraonella sp. C	PPAR 42							X					X			
Pectinariidae																
Cistena (Pectinaria) californiensis	PPEC 01														X	
Phyllodocidae																
Anaitides williamsi	PPHY 01									X		X			X	
Anaitides sp. juv.	PPHY 09								X					X		
Eteone dilatae	PPHY 11		X	X	X	X	X				X	X	X	X		
Pilargidae																
Ancistrosyllis hamata	PPIL 01														X	X
Pisionidae																
Pisione remota	PPIS 01					X										
Polynoidae, juv.	PPOL 90							X								
Sabellidae																
Chone sp.	PSAB 09			X												
Sigalionidae, unid.	PSIG 90													X	X	
Sthenelais verruculosa	PSIG 01						X	X		X			X		X	X
Stenelais sp.	PSIG 09											X				
Thalenessa spinosa	PSIG 21						X			X		X	X	X	X	X
Spionidae, juv.	PSPI 90		X		X							X			X	
Apoprionospio pygmaea	PSPI 43						X	X	X	X	X	X	X	X	X	X
Dispio uncinata	PSPI 91	X	X		X		X	X	X	X	X	X	X	X	X	X
Minuspio cirrifera	PSPI 41											X				X
Polydora sp.	PSPI 39							X								
Scolelepis acuta	PSPI 61	X	X	X	X	X	X	X		X		X				
Scolelepis squamata	PSPI 63				X	X	X	X		X		X	X			X
Spiophanes bombyx	PSPI 71						X	X		X		X	X	X	X	X

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Spiophanes missionesis	PSPI 72						X			X			X		X	
Spiophanes sp.	PSPI 79									X		X				
Syllidae																
Exogone lourei	PSYL 02			X												
Exogone uniformis	PSYL 03							X								
Streptosyllis sp. A	PSYL 21															X
Typosyllis hyalina	PSYL 42						X	X	X	X	X	X	X	X	X	X
ARTHROPODA																
Crustacea																
Amphipoda																
Ampelisca cristata	CAMP 9	X														
Aorides columbiae	CAMP 16											X				
Atylus tridens	CAMP 23							X	X		X	X		X		
Caprella gracilior	CAMP 21							X								
Caprella verrucosa	CAMP 24							X				X				
Caprella sp. (juv.)	CAMP 22							X								
Eohaustorius spp.	CAMP 27	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gammaropsis thompsoni	CAMP 31							X				X				
Hyalidae, unid.	CAMP 49	X	X			X										
Jassa falcata	CAMP 34		X		X						X	X				
Listriella sp.	CAMP 37											X				
Mandibulophoxus gilesi	CAMP 47	X	X		X	X	X	X	X	X	X	X	X	X		X
Megaluropus longimerus	CAMP 50				X	X				X	X					X
Monoculodes hartmanae	CAMP 53											X				
Orchestoidia benedicti	CAMP 81	X														

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Orchestoidia californiana	CAMP 82	X[2]	X[2]	–[2]	X											
Photis cf. *californica*	CAMP 69							X					X			
Sympleutes subglaber	CAMP 54							X								
Synchelidium spp.	CAMP 73	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tiron biocellata	CAMP 77						X	X		X		X			X	
Trichophoxus bicuspidatus	CAMP 58						X	X	X			X		X		X
Trichophoxus epistomus	CAMP 59	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trichophoxus cf. *floridanus*	CAMP 67						X									
Trichophoxus heterocuspidatus	CAMP 60						X					X				
Trichophoxus (juv.)	CAMP 99								X	X				X	X	
Tritella laevis	CAMP 80										X		X			X
Copepoda																
Calanoid	CCOP 2						X	X	X		X					X
Cyclopoid	CCOP 5							X			X	X				
Harpaticoid	CCOP 9	X									X	X			X	X
Cumacea																
Campylaspis cf. *rubromaculata*	CCUM 9														X	
Cyclaspis sp. B	CCUM 22	X	X	X	X	X	X	X	X		X	X	X			X
Diastylopsis tenuis	CCUM 29	X					X	X	X	X		X	X		X	
Lamprops cf. *carinata*	CCUM 38						X	X		X		X				X
Leptocuma forsmani	CCUM 44						X	X	X	X		X	X	X	X	X
Hemilamprops californica	CCUM 36						X									

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Decapoda																
Blepharipoda occidentalis	CDEC 6	X					X				X		X			X
Callianassa cf. *californiensis*	CDEC 4						X	X	X	X		X	X		X	X
Cancer antennarius	CDEC 7														X	
Cancer gracilis	CDEC 8											$-^2$			X	
Cancer (juv.)	CDEC 10								X	X						
Emerita analoga	CDEC 12	X^2	X^2	X	X	X										
Heptacarpus taylori	CDEC 14											X				
Hippidae (juv.)	CDEC 18				X											
Isocheles pilosus	CDEC 16						X		X	X^2	X^2	X^2			X	$-^2$
Lepidopa myops	CDEC 21	X	X	X	X	X	X			X						X
Pinnixa barnharti	CDEC 33															X
Pinnixa tubicola	CDEC 34											X			X	
Pinnixidae (juv.)	CDEC 32											X	X	X		
Caridean shrimp	CDEC 38							X								
Zoea larvae	CDEC 39							X								
Crab (juv.) unidentified	CDEC 45															X
Mysidacea																
Acanthomysis macropsis	CMYS 2						X	X								
Acanthomysis sculpta	CMYS 3							X								
Archeomysis maculata	CMYS 5	X	X		X	X					X					
Metamysidopsis elongata	CMYS 7									X				X	X	
Mysidopsis californica	CMYS 11											X				
Neomysis rayii	CMYS 14						X									

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Isopoda																
Ancinus depressus	CISO 3	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Edotea sublittoralis	CISO 6						X					X	X		X	
Excirolana chiltoni	CISO 9	X	X	X	X	X										
Munna ubiquita	CISO 16							X					X			
Tylos punctatus	CISO 24	X														
Ostracoda																
Euphilomedes spp.	COST 10	X					X	X	X	X		X	X	X	X	X
Parasterope sp.	COST 8							X				X				
Rutiderma rostrata	COST 16											X		X		
Podacopa (unid.)	COST 14														X	
Pycnogonida																
Callipalene pacifica	CPYC 2									X					X	
Arachnida																
Halacaridae (mite)	CHAL 1					X		X								
Hexapoda																
Emplenota arenaria		X	X		X											
MOLLUSKS																
Pelecypoda																
Donax gouldii	MPEL 16	X[2]	X[2]		X	X		X	X		X				X	
Nemocardium centritilosum	MPEL 61														X	
Nuculana sp.	MPEL 35											X	X		X	
Macoma (juv.)	MPEL 8									X			X			
Modiolus neglectus	MPEL 29							X		X	X				X	
Orbitella sp.	MPEL 62								X					X		
Psephidia cymata	MPEL 43							X	X		X		X	X	X	X
Siliqua lucida	MPEL 39														X	
Solen rosaceus	MPEL 40						X								X	
Solen sicarius	MPEL 41									X						

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Tellina modesta	MPEL 46											X	X	X	X	X
Tellina bodegensis	MPEL 47						X				X					X
Tellina cf. *meropsis*	MPEL 45						X	X		X		X			X	
Tivela stultorum	MPEL 50	X[2]	X[2]		X											
Bivalve A (unid.)	MPEL 63										X	X			X	X
Bivalve B (unid.)	MPEL 48											X			X	
Bivalve (juv., unid.)	MPEL 99											X		X		
Myidae (juv.)	MPEL 63			X												
Gastropoda																
Gastropods (juv.)	MGAS 99											X				
Kelletia kelleti	MGAS 19											-[2]				
Balcis sp.	MGAS 5													X		
Crepidula sp.	MGAS 11											-[2]				
Fartulum occidentale	MGAS 20					X										
Kurtziella plumbea	MGAS 25												X			
Nassarius perpinguis	MGAS 28						X					X[2]			X	-
Neverita altus	MGAS 33						X					X[2]	X			
Neverita sp.	MGAS 32											X			X	X
Olivella baetica	MGAS 38						X	X			X[2]	X	X	X		X
Olivella biplicata	MGAS 39	X[2]					X									
Odostomia sp.	MGAS 35															X
Terebra sp.	MGAS 54											X				
SIPUNCULA																
Sipunculid (unid.)	OSIP 1											X				
ECHIURA																
Echiuran (juv., unid.)	OECH 1				X											
ECHINODERMATA																
Echinoidea																
Dendraster excentricus	OECH 2						X[2]	X[2]	X[2]	X[2]	X	X	X	X	X[2]	X

SPECIES		INTERTIDAL					SUBTIDAL (3.7 m)					SUBTIDAL (6.1 m)				
NAME	Program Code[1]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Asteroidea																
Pisaster brevispinis	OEAS 4						–[2]									
Ophiuroidea																
Amphipholis pugetana	OEOP 3											X				
Amphipholis squamata	OEOP 4											X	X			
HEMICHORDATA																
Hemichordate (unid.)	OCHH 3									X						
CHORDATA																
Branchiostoma californiense	OCHP 3									X						
Leuresthes tenuis eggs and larvae	CFIS 1				X											

[1] Species code utilized for programming purposes.

[2] Extralimital observations (Organisms observed but not taken in core sampler).

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