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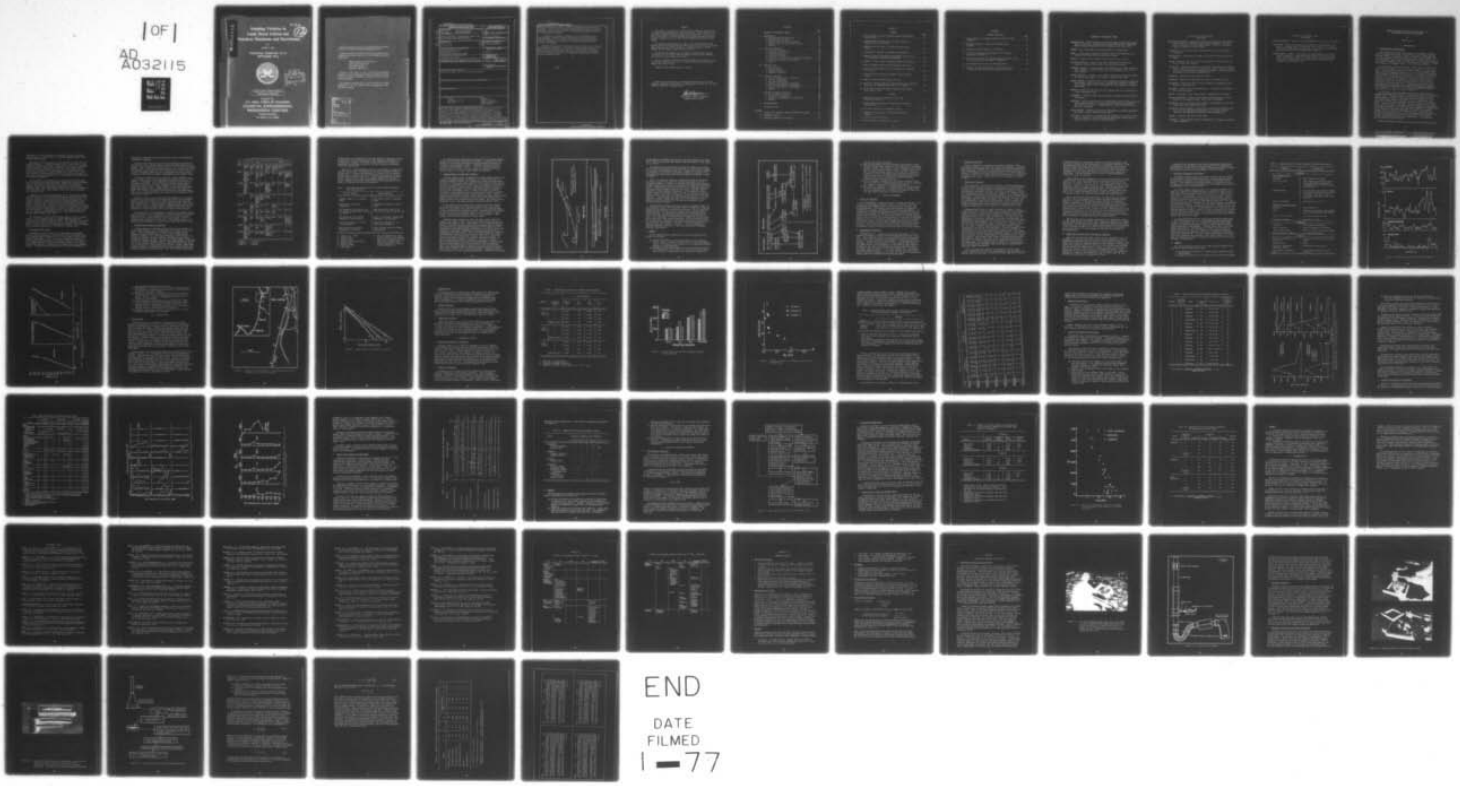

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Sampling Variation in Sandy Beach Littoral and Nearshore Meiofauna and Macrofauna

by

James L. Cox

TECHNICAL PAPER NO. 76-14
SEPTEMBER 1976

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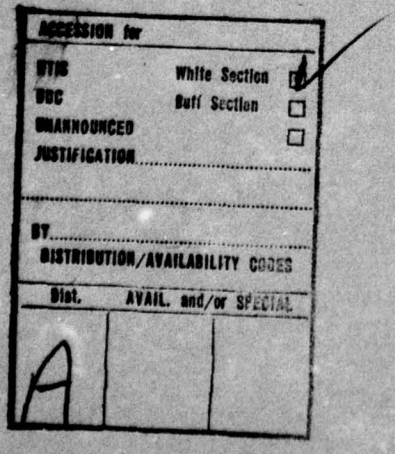

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: TP-76-14 (19) (18) CERC	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle): SAMPLING VARIATION IN SANDY BEACH LITTORAL AND NEARSHORE MEIOFAUNA AND MACROFAUNA (6)	5. TYPE OF REPORT & PERIOD COVERED: Technical Paper / 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): James L. Cox (10)	8. CONTRACT OR GRANT NUMBER(s): DACW72-75-C-0014 (15) New
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Hopkins Marine Station / Stanford University / Pacific Grove, California 93950	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 631266
11. CONTROLLING OFFICE NAME AND ADDRESS: Department of the Army / Coastal Engineering Research Center (CERRE-EC) / Kingman Building, Fort Belvoir, Virginia 22060	12. REPORT DATE: September 1976 (11) / 13. NUMBER OF PAGES: 72 (12) 74 pp.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED / 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Beaches
Interstitial system
Macrofauna
Meiofauna
Sampling analysis
Spatial heterogeneity
Trophidynamics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study evaluates sampling procedures and statistical methods for analysis of the fauna associated with high-energy sandy beaches. An intensive, one-season sampling of selected physical attributes and fauna of a relatively undisturbed beach site in central Monterey Bay, Calif~~ornia~~ was used as a basis for this evaluation. Organisms were sorted and identified to the lowest possible taxonomic level and numerical abundances were computed. Existing techniques for the quantitative sampling of macrofauna in the littoral zone are adequate for quantitative base-line studies, but many

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samples must be taken to ensure reasonable confidence limits on density estimates. It may not be practical to attempt density estimates of certain macrofaunal species, such as the mole crab (*Emerita analoga*), which show extreme spatial heterogeneity.

A procedure was devised for sampling surf-zone macrofauna using a suction dredge. Surf-zone fauna differs greatly from littoral macrofauna and appears to be a separate ecological unit. Area sampling the surf zone is difficult due to surge, so a "time-of-pumping" standardization is recommended.

Meiofauna shows distinct intertidal zonation patterns both in density and taxonomical composition. Considerable variation from one beach site to another can occur and this may be related to small changes in physical factors, especially the interstitial space. Procedures for subsampling and counting meiofauna are described along with recommendations from statistical treatment of data.

(1473B)

PREFACE

This report is published to provide coastal engineers with data on the sampling and evaluation of sandy beach fauna. Such information may be used to determine possible changes which may occur as a result of beach nourishment. 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 Dr. James L. Cox, Research Associate, Hopkins Marine Station of Stanford University, Pacific Grove, California, under CERC contract DACW72-75-C-0014. Professor Donald P. Abbott, Hopkins Marine Station, supervised the project.

The author acknowledges the assistance of David Bracher, marine technician, and the staff of Hopkins Marine Station, in the planning and execution of all stages of the work.

Mr. A. K. Hurme was the CERC contract monitor for the report, under the general supervision of Mr. R. M. Yancey, Chief, Coastal Ecology Branch, Research Division.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

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

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GLOSSARY OF BIOLOGICAL TERMS

ANOMURAN CRABS - Crabs belonging to the group Anomura within the Decapod order of Crustacea, including Hermit crabs and certain intermediate groups between shrimps and crabs. Commonly called Mole crabs.

BIOMASS - The total amount of living material in a given area.

BIOME - A term used to characterize major types of environments; e.g., northern coniferous forests constitute a biome.

BIVALVE - Having a shell composed of two valves; e.g., a clam.

CAPITELLID ANNELID - Family of the order Capitellida in the phylum Annelida. Worms of this family form mucus-lined tunnels.

CIROLANDI ISOPODS - A family of the order Isopoda in the class Crustacea. These Isopods are semicylindrical and their adbomens have six distinct segments.

DECAPOD CRUSTACEA - Animals in the order of Crustaceans having five pairs of thoracic appendages; e.g., shrimps, lobsters, and crabs.

DEPOSIT FEEDERS - Organisms which live in sediments and feed by ingesting the sediment itself and passing it through their digestive systems, where usable organic matter associated with the sediment is digested and removed.

ENDEMISM - Refers to the distribution of species which are restricted to a small geographic range.

EPIPSAMMIC - "Upon the sand," usually refers to organisms which attach to sand grains.

EPISTRATE - Refers to the surface of a substratum, which in the case of the sandy beach environment, is the surface of individual sand grains. An epistrate browser is an organism which scrapes food from the surface of a sand grain.

FILTER FEEDERS - Organisms which drive food energy by removing suspended particulate organic matter from the water.

FOOD CHAIN - The sequence of production and predation in a natural community of organisms. Plants are eaten by herbivores (plant-eaters) which are eaten by carnivores (flesh-eaters).

Glossary of Biological Terms
(continued)

HARPACTICOID COPEPODS - Copepods of the order Harpacticoida with movable joint between the fourth and fifth thoracic segments. The body is nearly cylindrical with the abdomen almost as wide as the thorax--tapered as opposed to bottle-shaped.

HALACARIDAE - Family of the order Acari (marine mites) in the phylum Arthropoda.

HERMAPHRODISM - Having gonads (primary sex glands) of both the male and female.

INFAUNA - Organisms that live within the sediment or construct tubes or burrows within the sediment.

INTERSTITIAL - Describes organisms living within the pore spaces between closely placed objects; e.g., sand grains. These organisms can move freely in spaces without displacing any sediment. Also describes the environment in which these organisms live.

MACROFAUNA - Organisms larger than 1 millimeter.

MEIOFAUNA - Multicellular organisms less than 1 millimeter in size.

MESOPSAMMIC - "Within the sand," usually referring to organisms living buried in sandy deposits.

METAZOANS - Animals which are multicellular-- in contrast to protozoans, which are unicellular.

MYSIDS - Crustaceans of the order Mysidea, resembling small shrimps.

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

PROCERIATE - Used in reference to the family, Procerodidae, in the class Turbellaria (free-living flat worms).

SCAVENGING DETRITUS FEEDERS - Highly mobile animals which feed upon carcasses of dead and decaying organisms; e.g., certain Isopods (pillbugs) and Amphipods (beach fleas and sand hoppers).

SESSILE - Attached, not free to move about.

STENOTOPIC - Having a narrow range of adaptability to changes in environmental conditions.

Glossary of Biological Terms
(continued)

TALITRID AMPHIPODS - Family of the order Amphipoda in the class Crustacea.

TAXA, TAXON - Refers to the plural and singular of a generalized reference to a taxonomic level or grouping; e.g., "species" is a taxon. Other taxa include genus, family, order, class, etc. in a hierarchial structure used for the classification of organisms.

TROPHIDYNAMICS - Refers to the process of energy exchange occurring in natural communities, from green plants (which initially fix solar energy into chemical potential energy) through the exchanges which occur when the green plants are consumed by an animal and thence consumed by other animals, etc.

SAMPLING VARIATION IN SANDY BEACH LITTORAL AND NEARSHORE MEIOFAUNA AND MACROFAUNA

by

James L. Cox

I. INTRODUCTION

1. The Meiofauna and Macrofauna.

Sandy beaches on exposed coasts support a mesopsammic community which is significantly lower in biomass than most littoral and sublittoral systems. In general, there is a decrease in abundance from the coarse sediment of the most exposed beaches, where diversity of taxa is maximal, toward finer sand sediments. However, maximum density of infauna is reached in the very fine sediments of mudflats, although here diversity of taxonomic groups is lowest (Pollock, 1971).

Two essentially separate biological systems occur in the exposed sandy beach environment. These systems correspond to the size categories of the resident populations. Smaller organisms, termed *meiofauna*, are those organisms which pass a 1-' to 0.5- millimeter screen. Larger organisms, retained by such screens, are generally referred to as *macrofauna*. The distinction between them is primarily one of practicality, since different techniques are used to extract the two groups from the sand. Macrofauna is retained by screens (usually 1-millimeter mesh) which allow sediment particles to pass through. Meiofauna is about the same size as sand grains and cannot be separated using a sieving technique. The meiofauna must be separated from the sand environment by a combination of decantation and filtration techniques. A listing of the littoral and nearshore benthos identified in this study is given in Appendix A.

The macrofauna of exposed sandy beaches consists primarily of peracarid crustacea when abundance is measured by number of individuals (Dexter, 1972). Bivalve mollusks and decapod crustacea, although never numerically dominant, may constitute a major fraction of the total macrofaunal biomass, if present. Various schemes have been devised to describe the macrofaunal community in terms of intertidal zones. The most commonly referenced zonation scheme is that of Dahl (1952) who divided north temperate sandy beach macrofaunal communities into three intertidal zones. The high beach community is characterized by the presence of talitrid amphipods, the midbeach by cirolanid isopods, and the lower beach by anomuran crabs. In exposed sandy beaches in the study area, these zones are characterized respectively by talitrid amphipods of the genus, *Orchestoidea*, the cirolanid isopods, *Excirolana linguifrons* and *Excirolana* cf. *vancouverensis*, and the anomuran, *Emerita analoga*.

Subtidal macrofaunal communities are known from relatively stable

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water areas. Little information is available on surf zone fauna, although species living in the surf zone are generally forms found in other environments.

Macrofauna is often important in the transfer of energy from the infaunal community. External predators such as birds and fish feed on various macrofaunal species. Sea otters are known to be extremely efficient predators upon bivalve mollusks in high-energy beaches. Historical records indicate pismo clams were once abundant in the exposed sandy beaches of central Monterey Bay (Ricketts and Calvin, 1962); however, evidence gathered in this study shows an absence of the clams, apparently removed partly by clam diggers intertidally and by sea otters subtidally.

The meiofauna is considerably more diverse than the macrofauna. Typical exposed sandy beach meiofaunal communities contain representatives of most major invertebrate taxa, including the Nematoda, Copepoda, Turbellaria, Oligochaeta, Ostracoda, and Halicaridae (Renaud-Debyser, 1963; Renaud-Debyser and Salvat, 1963; Govindankutty and Balakrishnan Nair, 1966; Schmidt, 1968, 1969; Gray and Rieger, 1971; Hulings, 1974).

Unfortunately, for the understanding of the meiofauna of exposed sandy beaches, most of the published ecological work has been done on nontidal beaches in low salinity areas such as the Baltic Sea. In nontidal beaches, oxygen availability and the heterogenous distribution of particles of different size are significant ecological factors (Jansson, 1968). Ecological factors are different in tidal beaches of greater wave exposure. Patterns of distribution of exposed, tidal sandy beach meiofauna appear to be more related to water content and flow, exposure to disturbance by surf, and organic matter availability (Ganapati and Chandrasekhara Rao, 1962; Renaud-Debyser and Salvat, 1963; Schmidt, 1968, 1969).

The meiofauna of exposed sandy beaches appears to be an isolated system. Little evidence exists of outside predation upon this characteristic meiofauna (McIntyre, 1969). The organisms live entirely within the pore spaces between sand grains, and are adapted to move freely in this space without displacing any sediment. The environment and the resident organisms are referred to as *interstitial*.

2. The Interstitial System.

Maintenance of the interstitial system depends upon sediment mobility, since lessened wave stress results in the accumulation of finer sediments which essentially "fill in" the space of the interstitial environment. In such a case, the indigenous community is replaced by a meiofauna which is *burrowing*, rather than interstitial i.e., maintenance of the indigenous, natural community of a high-energy beach requires a dynamic balance between erosion and sedimentation. If erosion exceeds sedimentation, the beach disappears; if

sedimentation predominates over erosion and sorting, the interstitial environment disappears.

Studies of the effects of grain-size distribution on natural populations show that a characteristic interstitial fauna cannot exist in sediments with a median-grain diameter (M_d) of less than 200 micrometers (Wieser, 1959). This value has been referred to as *critical grain size* and sediment characterized by such a median diameter as *critical sand.* It may be significant that this size corresponds to the most mobile particles in the erosion-transport-sedimentation cycle (Boaden, 1968).

The physical dimensions of the capillary network influence interstitial animals as well as the permeability and water content of sandy sediment. Consequently, the interstitial meiofauna has evolved in convergent directions. These evolutionary changes converge upon an interstitial type which is small, elongated or flattened, fragile, possessing adhesive organs, reduced number of eggs, and direct larval development (Remane, 1952; Delamare-Deboutteville, 1960; Swedmark, 1964). The salient biological features of the major taxonomic groups found in this unique environment are summarized from pertinent literature sources in Table 1.

The water content of the interstitial environment is an important determinant of the distribution of organisms within that environment. Usually, interstitial fauna is limited to sediments containing more than 10 percent of its saturation water capacity (Pennak, 1951; deZio, 1965; Enkell, 1968). The major factors influencing water content are beach slope, porosity, median diameter of sediment particles, tidal movements, distance from water level, and degree of wave exposure.

The permeability of the sediment is related to the sediment structure and particularly to the proportion of particles of 200-micrometer diameter or less. Fine sediments retain all but superficial water during low tide and water stagnates in the pore spaces. Coarser sediments readily drain out at low tide. This drainage tends to lag behind seawater movements for several hours (Emery and Foster, 1948).

3. Sulfide Layer and Beach Filtration.

A common feature of tidal and nontidal beaches with moderate to minimal water movement is the establishment of an anoxic layer in the sand. A direct consequence of a relative lack of oxygen is that decomposer organisms will begin to reduce sulfate from seawater. Sulfate is commonly used by decomposer organisms (mainly bacteria) as alternative terminal electron acceptors in metabolism when oxygen availability becomes limiting. The reduced sulfate appears in the form of the toxic compound hydrogen sulfide. This compound binds to ferrous ions in the unstable ferrous sulfhydryl compound ($Fe(SH)_2$) that gives the sulfide layer its characteristic black color. Gordon (1960) demonstrated a hyperbolic relationship between the percentage of fine sand in marine beaches and oxygen tension. The coarse sand of high-energy

Table 1. Basic features of major meiofaunal groups from exposed sandy beaches.

Taxon	Reproduction[1]	Vertical[2,3]	Tidal Height[2]	Attachment[1]	Locomotion[1]	Feeding[1]	Density[2] (No./10cm)[4]	Taxes
Nematoda	Copulation; generation time, 25 to 70 days.	Abundant at all depths; greatest near surface.	Greatest abundance at high to mid-beach.	Caudal adhesive gland; semi-sessile.	Writhing; semi-sessile Epsilouematidae; use "inch-worm" locomotion.	1) Predators; 2) Epistrate scrapers and pump suckers; 3) Detritus eaters.	Usually most abundant group, 100 to 4,000.	Thigmotactic
Copepoda	Copulation; Separate sexes; three to four egg sacs; generation time, 1 month; three to four generations yearly.	Mid to greater depth.	Midbeach shows greatest density; sparse in subtidal surf zone.	Motile, but can grasp with appendages.	Gliding or writhing.	Epistrate browsers.	Usually next most abundant, 0 to 3,000.	Negative phototaxis; reacts in salinity and temperature gradients; thigmotactic.
Oligochaeta	Hermaphrodism and cross-fertilization; two to three generations yearly; mildly seasonal.	All depths.	Most abundant in high beach.	Attachment glands.	Writhing; may remain attached by means of glands in region of posterodorsal setae; some peristaltic burrowers.	Detritus eaters.	0 to 500.	Reacts in salinity and temperature gradients.
Turbellaria		All depths vary by type.	All zones; more abundant subtidally and low beach in high-energy system.	Adhesive discs; may be semi-sessile in some habitats.	Ciliary gliding; some with adhesive discs.	Predators	0 to 150	No information
Ostracoda		>20 cm deep or at surface occasionally.	Most abundant at mid-beach.	Not attached.	Crawling.	Epistrate browsers; suspension feeding.[5]	0 to 700	No information
Halacaridae	Separate sexes; spermatophores.[5]	Mid to greater depth.	Midbeach (may occur subtidally).	Not attached; motile.	Crawling; hooklike appendages.	Predators; some are detritivores.	0 to 300.	No information
Archiannelida	Separate sexes; spermatophores[6]; brood pouches.	Mid to lower depths.	Lower beach and subtidal	Not attached; affixed eggs with pelagic larvae.	Peristalsis may have adhesive lobes[7]	Epistrate browsers	40 to 60 when present	Strong negative phototaxis[8]; gregarious[9]; reacts in temperature and salinity gradients[10]; chemical attract.
Polychaeta	Some hermaphroditic; some separate sexes; spermatophores.	Varies by type	Subtidal and upper beach	Not attached	Writhing; marginally interstitial, some actually small burrowing forms.	Predators[5]	0 to 20	No information
Gastrotricha	Some hermaphroditic, some separate sexes; young may be brooded; spermatophores.	Middepth.	Abundant at mid-beach.	Adhesive disc semi-sessile	Ciliary gliding; some with peristaltic movements; adhesive glands.	Detritus eaters.	<10	No information

1. Swedmark (1964)
2. This study
3. Schmidt (1968, 1969)
4. McIntyre (1969)
5. Newell (1947)
6. Riedl and McMahan (1974)
7. Jouin (1971)
8. Gray (1966a)
9. Boaden (1963)
10. Gray (1966b)

sandy beaches is so permeable and its pore spaces so frequently allowed to contact air that oxygen tension is high throughout; therefore, no sulfide layer can form. This trend in the effect of wave stress on oxygenation of subsurface layers can be seen in Gherini and Swanson (1972) for Monterey Bay.

Pugh, et al. (1974) performed studies of two beaches in North Wales, one less exposed with a sulfide layer, and one more exposed without a sulfide layer. Although establishment of a sulfide layer in sediment depends upon the complex interplay of physical and biological factors, studies such as that of Pugh, et al. (1974) suggest that certain quantitative measures can be used to distinguish beaches of each type. Table 2 summarizes data from several sources which characterize tidal beaches of moderate and heavy wave exposure.

Table 2. Distinguishing characteristics of tidal beaches of greater and lesser exposure.

Greater exposure	Lesser exposure
Steeper, about 2 to 11 percent grade[1]	Less steep, usually <1-percent grade[1]
Interstitial water well-oxygenated[2]	Pronounced O_2 gradient; sulfide layer[2]
Low proportion of particles <250 μm[3]; median diameter (M_d) >180 μm[1]; M_d >250 μm[4]	High proportion of particles <250 μm[1]; M_d <180 μm[1]; M_d <250 μm[4]
Well-developed interstitial community[5]; high diversity[6]	Small or nonexistant interstitial community[5]; low diversity[6]
Low carbon content: 70 to 400 μg C/g sediment[1,7]	High carbon content: 220 to 2,250 μg C/g sediment[1]
High turnover rate with no accumulation of carbon[8]	Lower turnover rate with carbon accumulation[8]

1. Pugh, et al. (1974)
2. Gordon (1960)
3. Pollock (1971)
4. Gherini and Swanson (1972)
5. Wieser (1959)
6. McIntyre (1969)
7. This study
8. This generalization is speculative; however, the limited depth of fine sediment over sulfide layers suggests that turnover rates are limited by oxygen availability.

The foregoing data interpretation stresses the distinction between beaches with a sulfide layer and those without. It appears that the majority of soft bottom environments develop anaerobic reducing conditions in their subsurface layers. Sediments developing sulfide according to McConnaughey (1974) ". . .may well constitute the most extensive biome on earth." In this light, the exposed sandy beach habitat appears to be unique among sediment environments.

4. Trophidynamics of Sandy Beach Infauna.

The open, porous nature of exposed sandy beach sediment permits the relatively unimpeded passage of seawater. It essentially acts as a seawater filtration system. The significance of this filtration mechanism has only been appreciated recently. Early studies of the diet of interstitial organisms by gut content analysis frequently showed diatom frustules (McIntyre, 1969); however, specialized feeding on diatoms may have been overestimated because often diatoms may be ingested by chance (Riedl and McMahan, 1974). Diatoms are doubtless of small consequence as food energy source as evidenced by the quite low annual production of epipsammic diatoms (Steele and Baird, 1968). Recent evidence indicates that the bulk of food energy input comes from dissolved organic matter which is ultimately used by bacteria growing on the abundant surface area provided by the sand grains. This "beach-filter-mechanism" (Fig. 1) has been proposed by Riedl and McMahan (1974).

It has generally been assumed that larger detritus and plankton which have been washed up on the beach constitute the major energy source for high-energy sandy beach communities. Such material rarely, if ever, penetrates the interstitial space. Macrodetritus and plankton constitute the major food energy source for filter feeders, deposit feeders, and scavenging detritus feeders of the macrofauna. Their feeding activities are confined to surface layers.

Seawater usually contains at least ten times as much dissolved organic carbon (DOC) as the carbon in particulate matter such as the macrodetritus (Menzel, 1974). This larger pool of dissolved materials cannot be directly utilized by metazoans or bacteria because, despite the relatively high concentration relative to particulates, the concentrations do not permit uptake by diffusion, i.e., DOC as such is not available to organisms. Mechanisms are known by which DOC can be transformed into particulates. First, air bubbling through a seawater column produces extremely fine particulate matter which can support the growth of marine invertebrates (Menzel and Vaccaro, 1964). The surf of high-energy beaches is an effective bubbling mechanism, so particle production is greatly enhanced in such areas. Second, DOC is readily absorbed onto solid liquid interfaces, and these interfaces are preferential sites for the growth of bacteria which may exploit the local enrichment of organic carbon near the interface. Again, the high-energy beach is provided with an abundance of surface area which is subjected to a continuous exposure to seawater because of its interstitial space and high permeability. Beach sand can support

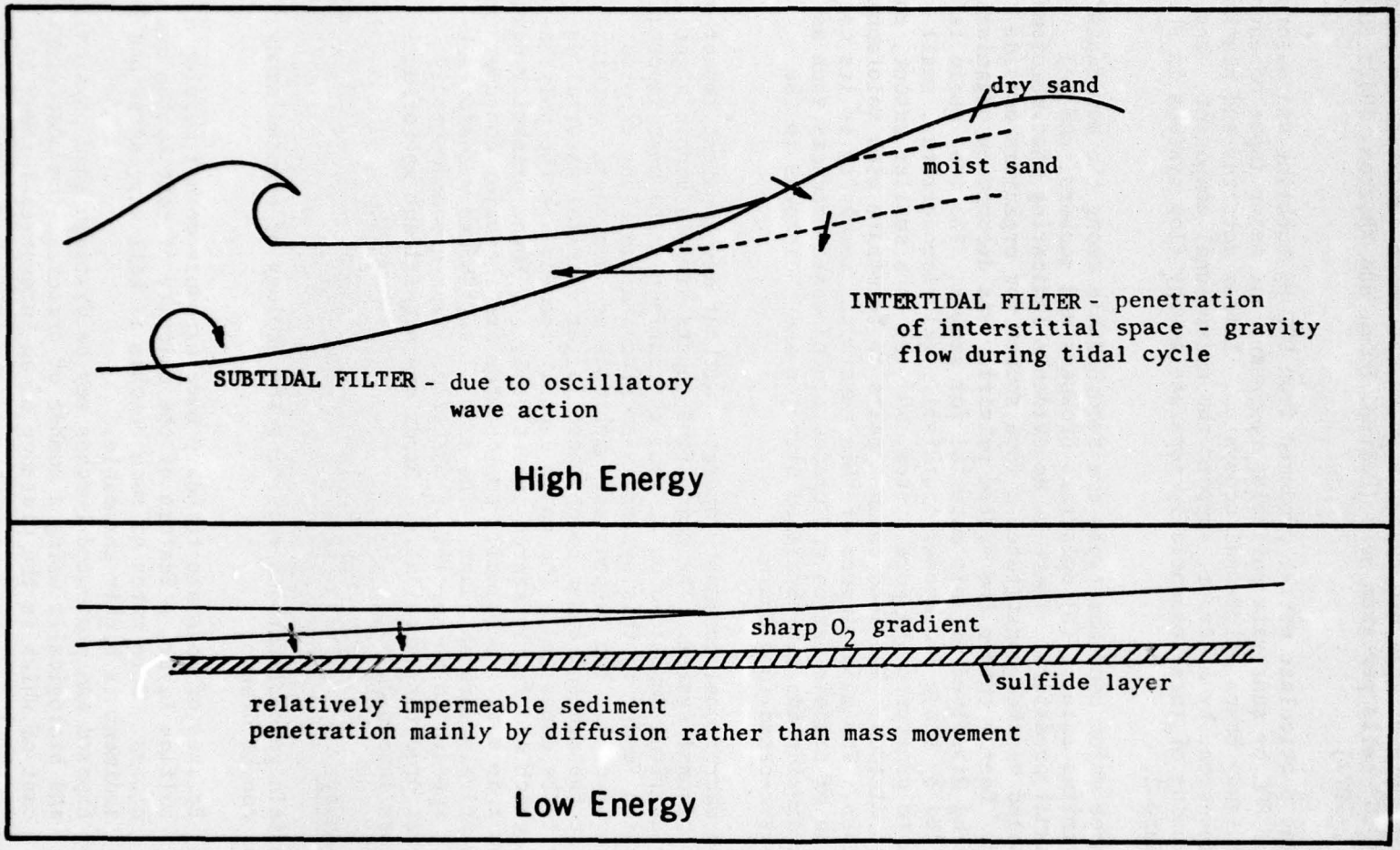


Figure 1. Comparison of water penetration in low- and high-energy beaches.

large numbers of attached bacteria which can reach densities in excess of 2 X 10^5 cells per gram sand (Pearse, Humm, and Wharton, 1942; Pugh, et al., 1974).

Fine particulate matter produced from DOC by bubbling and adsorption of DOC by substrate particles represent the major input of energy to the sandy beach meiofaunal ecosystem. Larger detritus and plankton in suspension, by contrast, support the macrofaunal component. The functioning of these essentially separate energy flow systems is shown in Figure 2.

Three major consumer types are recognizable among the meiofauna: (a) Detritus eaters, (b) epistrate browsers and suckers, and (c) meiofaunal predators. There is no evidence indicating that meiofauna of exposed beaches constitutes a food source for organisms outside the system. Energy enters the system primarily via decomposer organisms, utilizing dissolved organic material for growth. The food chain is supported by these decomposer organisms: (a) microdetritus, small enough to penetrate the pore system, and (b) to a smaller extent, epipsammic diatoms. The food chain appears to terminate with meiofaunal predators. The major impact of this meiofaunal community is its consumption of organic carbon and production of waste products such as carbon dioxide and remineralized nitrogen and phosphorus in the decomposer-based food chain.

The macrofaunal community operates without any apparent impact on the meiofaunal system. The major food inputs are planktonic algae and larger detritus deposited on or near the surface. The most important suspension feeder in this system is *Emerita analoga* along exposed Pacific beaches. The isopods and amphipods are scavenging detritivores in the mid and upper beach where larger detrital material is likely to be deposited. The major deposit feeders are the polychaete worms, which are fairly scarce intertidally and found primarily near the low tide mark. Subtidally polychaetes are the major consumers and are relatively more abundant. The major invertebrate predator subtidally appears to be species of *Olivella*. Fish are undoubtedly important predators subtidally. Birds are significant macrofaunal predators intertidally.

5. Summary.

Certain generalizations regarding the ecology of exposed sandy beaches can be drawn:

(a) Beaches of moderate to heavy wave exposure do not develop a sulfide layer, a feature of the majority of soft bottom communities. Pore water of such beaches is well oxygenated and beach sediment is highly permeable.
(b) Exposed and protected beaches may be distinguished physically and biologically using a number of criteria, the most significant of which is the presence of an interstitial fauna of

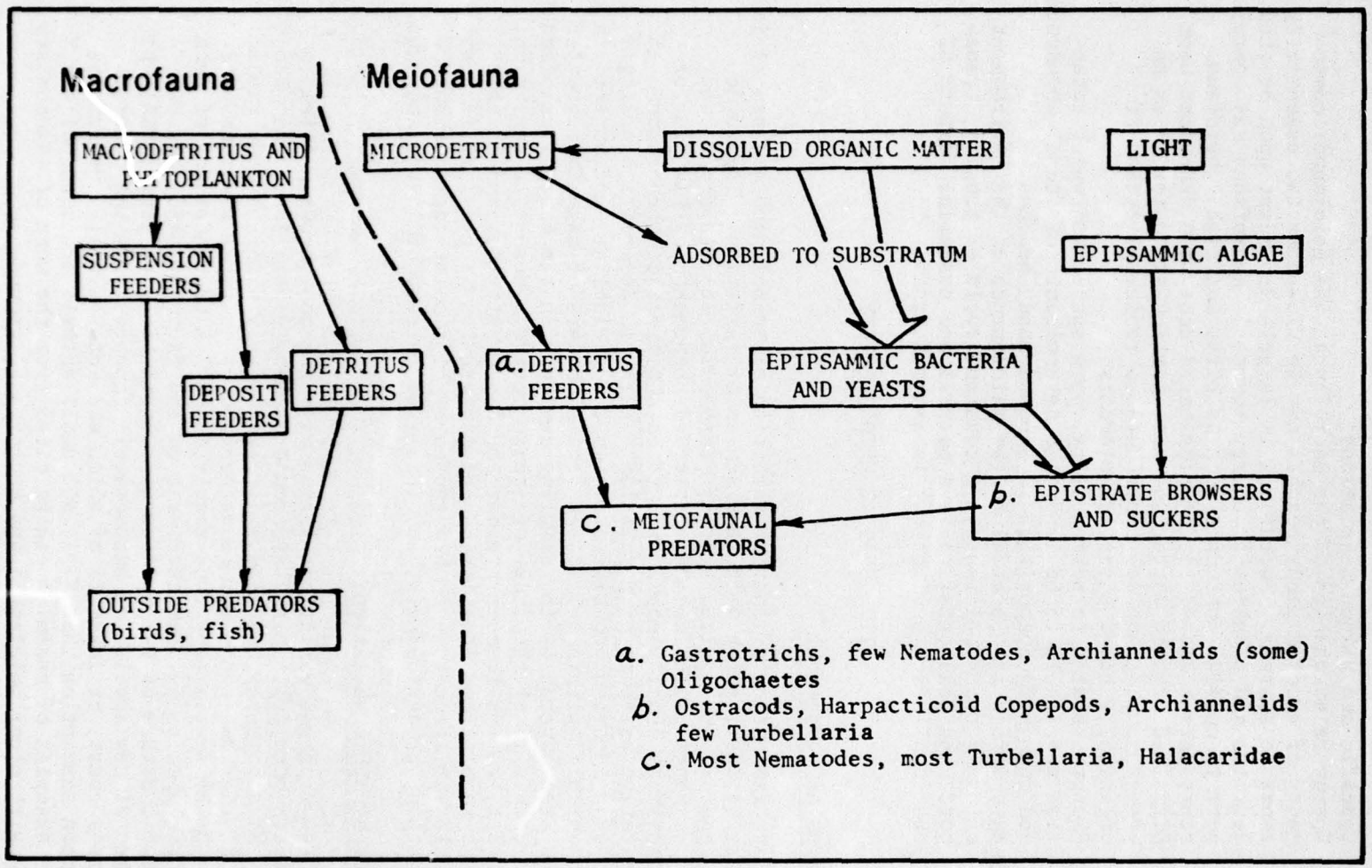


Figure 2. Trophidynamic relationships in sandy beach meiofauna and macrofauna.

specific and unique adaptations.

(c) Energy relationships of the macrofaunal and meiofaunal components of exposed sandy beaches can be viewed as two essentially separate systems. Macrofauna is largely dependent upon beached detritus and plankton as energy sources. Macrofauna may contribute to outside consumers such as birds and fish. Meiofauna represents a closed, decomposer-based ecosystem dependent upon dissolved organic matter and microparticulate material as an energy source, and may contribute to remineralization of organically bound essential elements.

(d) Factors related to permeability, pore space, and water retention are likely to be important determinants of faunal abundance and community composition in exposed sandy beaches.

(e) Wave stress is essential to the maintenance of the environment of sandy beach meiofauna. A constant cycle of erosion, transport, and sedimentation is a natural and essential feature of the sandy beach environment in exposed areas.

II. SPATIAL HETEROGENEITY

1. Scales of Variation.

In an examination of spatial variation of animal populations, it is necessary to distinguish different scales of variation. The three scales generally recognized are (a) *microscale*, (b) *mesoscale*, and (c) *biogeographic*. The commonly observed phenomenon of clumping or "patchiness" is usually considered to be a microscale phenomenon. If a quantitative estimate of population density is desired for a single location, an important consideration is the variability encountered in an area which is within only a few decimal orders of magnitude greater than the area covered by the sampling device. In the case of meiofaunal sampling, this is of the order of square meters. Mesoscale variation, by contrast, refers to much broader abundance patterns, and is more likely to result from locally induced differences in physical factors. Microscale variation is probably caused by biotic interactions such as predation, gregariousness, and localized release of larvae and eggs.

2. Biogeographic Variation.

Biogeographical variations are usually the best known. A few species are cosmopolitan and are found at many global locations (Rao, 1972). More commonly, species exist exclusively within a home range; limits of the home range may be determined by critical environmental factors or by specialized food requirements. A preponderance of such stenotopic species is characteristic of the fauna of sandy beaches. The endemic nature of the meiofauna is exemplified by Lang (1965) who described 81 new species of harpacticoid copepods from the central California coast, at least 11 of which are interstitial. He refutes the common assumption that ". . .all small animals are cosmopolitan." Similar examples of endemism can be cited from the work of taxonomists working with other meiofaunal and macrofaunal groups.

3. Mesoscale Variation.

Little information is available on mesoscale variation. Most quantitative studies which have used statistical techniques to compare beach fauna from different areas have emphasized obvious differences in beach morphology, grain size, and exposure as causing significant differences in meiofaunal and macrofaunal abundance. No prior evidence is available to indicate the extent of mesoscale variation in an apparently homogenous beach system. This subject will be discussed in Sections IV and V.

4. Microscale Variation.

The dispersion of individuals of a species in their environment is affected by both physical processes and biologically related movements and activities. Although patterns of dispersion are intrinsically interesting to biologists, they may also create a problem in sampling. Most dispersion patterns of animals are contagious or clumped. Contagious distributions always show definite clumps or local aggregations of individuals. The dispersion pattern depends upon the size of the clumps, the distance between clumps, the spatial distribution of clumps, and the distribution of individuals within clumps. These features of the dispersion pattern affect the distribution of values in a series of samples and necessitate certain statistical procedures before comparisons of sample means and variances can be made (Elliott, 1971).

Sampling distributions of organisms which are clumped in their natural environment invariably show a distribution which is positively skewed relative to a normal, bell-shaped distribution. Statistical procedures usually require that the underlying distribution of the sampling statistics have a normal distribution. In other words, the distribution of individual estimates of the population mean must be symmetrically apportioned about the sample mean. In positively skewed distributions, the arithmetic mean is always larger than the value at the peak in the distribution; hence, the condition of symmetry is not met. In order to perform statistical tests which assume a normal distribution, the data must be transformed. The most frequently used transformation for normalizing positively skewed distributions in biological field data is the logarithmic transformation. Each sample mean estimate is transformed into a logarithm (usually to the base ten) and the average of these logarithmically transformed values is called the *log mean*. The antilog of this value is the *geometric mean*, and it represents the value at the center of the transformed distribution. This value is a better reflection of the population density than the arithmetic mean. The arithmetic mean is subject to a positive bias due to the occasional extremely high values which are encountered in sampling clumped distributions.

Little is known about patterns of dispersion in beach fauna. Vitiello (1968) and Gray (1971) have demonstrated that the number of samples taken and the sample size are of critical importance in estab-

lishing statistically significant differences between different areas on a beach sampled for the documentation of meiofaunal densities. Total meiofauna and major groups were shown to be contagiously distributed. Gray and Rieger (1971) showed that total meiofauna and major group counts yielded indexes of dispersion (Greig-Smith, 1964) significantly different from the random expectation, hence indicating clumped distributions. The log transformation was used to perform parametric statistical tests on the data.

Efford (1965) studied aggregation in the sand crab (*Emerita analoga*) on the Pacific coast and documented the extreme patchiness of this species. In a patch, densities exceed 4,000 adults per square meter and 50,000 juveniles per square meter. These aggregations show a tidal migration. Edges of a single patch are quite discrete and patches are evidenced by areas of rough, disturbed sand. Large variability is associated with repetitive sampling for *Emerita*. Efford (1965) found that a 213.7-square centimeter quadrat yielded zero estimates 47 to 89 percent of the time; occupied areas showed very high densities.

Dexter (1972) found that the isopods, *Cirolana mayana* and *Ancinus*, species A and B were significantly clumped and their sampling distribution in 0.1-square meter quadrats gave a good fit to a negative binomial distribution. Maximum likelihood estimates of the parameter k of the negative binomial for these species ranged from 0.59 to 0.15. The variance to mean ratios of all major species encountered in her samples greatly exceeded unity (range: 5 to 168), indicating that contagious distributions are the rule among species of beach macrofauna. An examination of Patterson (1974) and Adams, Price, and Clogston (1974) data from California beaches reveals clumped distributions in all major beach macrofauna, verifying the results of Dexter (1972).

The existence of such clumped distributions is significant because (a) the large variance associated with quantitative sampling of clumped distributions necessitates large sample numbers for statistically valid comparisons, and (b) data from clumped distributions must be transformed to fit a normal distribution so that the most powerful of parametric statistical tests, i.e., the analysis of variance, can be used for such comparisons.

5. Clump Size and Core Area in Meiofaunal Sampling.

Gray (1971) showed that tubular cores of 3.15 centimeters and 3.75 centimeters in diameter gave more constant density estimates of major meiofaunal groups than a larger corer of 5.95-centimeter diameter. The larger corer yielded a higher proportion of low estimates. Theoretical studies of clumped distributions (Elliott, 1971) predict that variance will be maximal when sampling area is equal to clump size, thus Gray's (1971) data suggest a clump size of 6 centimeters or larger. Gray normalized his data using a logarithmic transformation, for statistical comparisons. However, he presented no data to confirm that the logarithmic transformation did normalize his data.

Because of the uncertainty regarding the appropriate normalizing transformation for meiofaunal data, and because of the suggestion of some regularity in the scale of clumping, additional data were gathered on microscale variation in the meiofauna of the study beach.

6. Microscale Variation of Meiofauna.

Preliminary calculations using tubular core data from the sampling plan outlined in Table 3 showed that a more intensive sampling would be necessary to establish the characteristics of meiofaunal distributions. This intensive sampling was designed to determine the size and spacing of clumps, and to generate data for determining normalizing transformations for the transect data.

Forty-nine standard tubular cores (3.17-centimeter diameter) were taken to a depth of 10 centimeters along a 4-meter line laid out at a right angle to the main beach transect at locality C, 2 meters above mean lower low water (MLLW). Forty cores were spaced evenly along the 4-meter line; the remaining nine were positioned at random. Totally randomized placement was judged unnecessary since core coverage and placement were of a smaller scale than expected clump size. The cores were extracted using the magnesium chloride ($MgCl_2$) method and enumerated for major faunal groups. In each case, the entire contents of the core were counted to eliminate subsampling variability. The results of these counts are shown in Figure 3. An examination of this figure shows that clumping patterns are quite variable. Clump size appears to be variable with an approximate diameter of 0.5 meter. Densities within the clumps (except *Anurida maritima*) appear to be about two to three times greater inside than outside the clumps.

Log-transformed data from the counts were plotted on probit paper to test the assumption that such a transformation would approximate a normal distribution (Fig. 4). *Arenopontia dillonbeachia*, *Anurida maritima*, and Turbellaria appear to fit a normal distribution after simple logarithmic transformation. Nematoda counts show a distinctly bimodal distribution. This bimodality is due to the occurrence of higher peak values in the last 2 meters of the microscale transect. These peak values are apparently reflected in abundances of *Anurida maritima* and Turbellaria. The exact nature of the functional relationships which produced these patterns is not known; however, it is evident that significant changes in population density can occur over the distance of a few meters.

7. Summary.

The following generalizations may be made about the spatial variability of exposed sandy beach infauna:

(a) Biogeographical endemism is a characteristic feature of sandy beach infauna.
(b) Clumped distributions are characteristic of both the meiofauna

Table 3. Sampling plan for study of normal California beach fauna.

Sampling	Description
MEIOFAUNA	
Grid (tubular cores)	
Transects	Three (spaced 1 km apart)
Grids at 1/16 m^2	Four sampling locations per transect (three grids per transect intertidally; one cluster of cores in surf zone)
Subsample cores	Six cores per grid (selected randomly from the 25 squares of the grid); surf zone: six cores closely clustered around marker flag taken by divers.
Total core samples	Seventy-two (3 X 4 X 6)
Vertical (ring-lined corer)	
Transects	One (transect C)
Cores	Six (one in surf zone, five equally spaced along transect intertidally)
Three-cm core sections	Ten core sections per core
Total core sections	Sixty (1 X 6 X 10)
MACROFAUNA	
Transects	Three (same as meiofauna)
Three-m segments	About 10 segments per transect
Total trench samples	Thirty (3 X 10); 36 actually taken
Surf zone airlift samples	Six (two per transect)
PHYSICAL	
Vertical distribution of grain size	Sixty core sections (same as meiofauna)
Beach profiles	Three
Salinity, temperature, carbonate, carbon	One physical sampling unit
Total physical sampling units	Twelve (three transects, four stations)

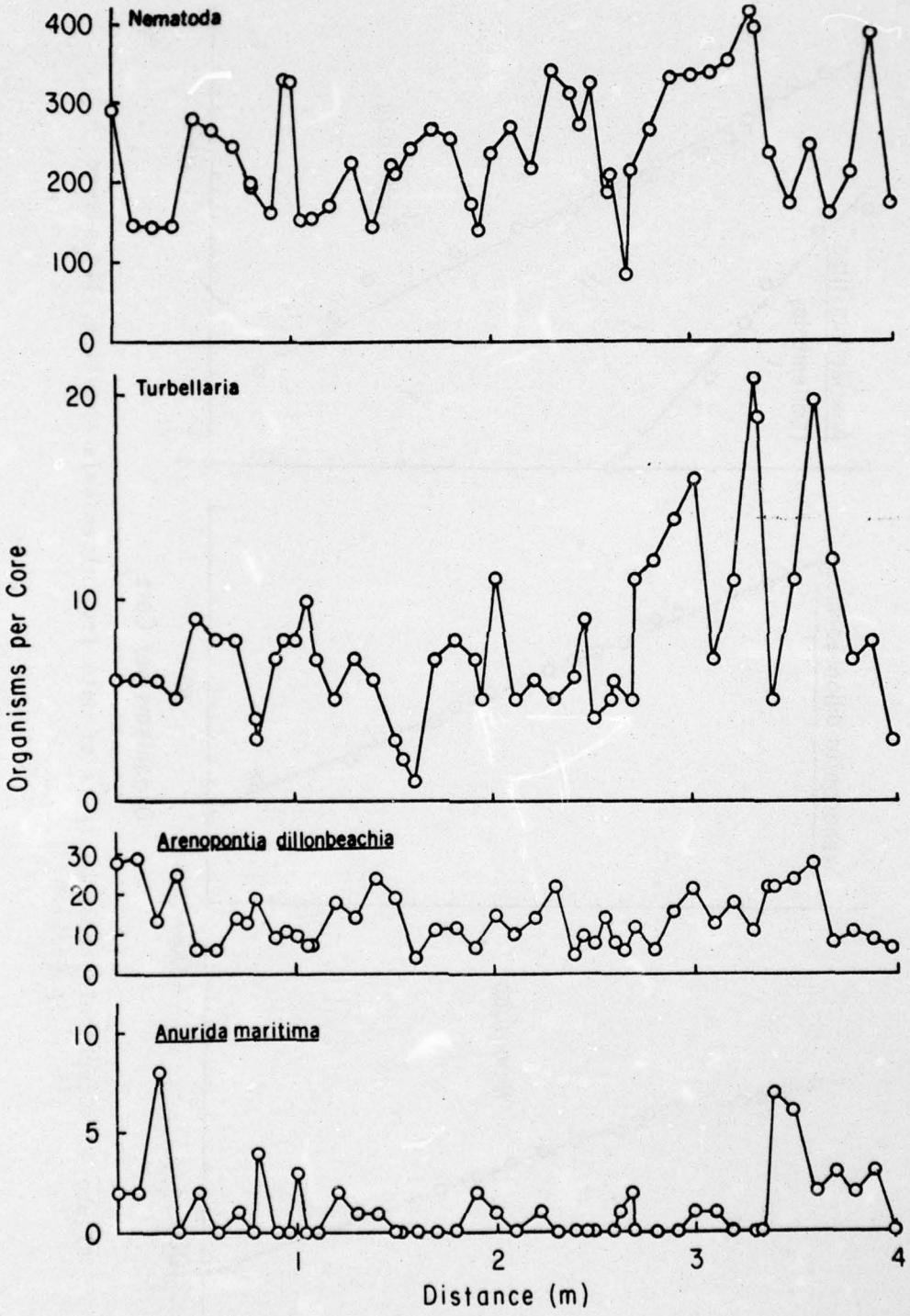


Figure 3. Microscale variation in meiofaunal species.

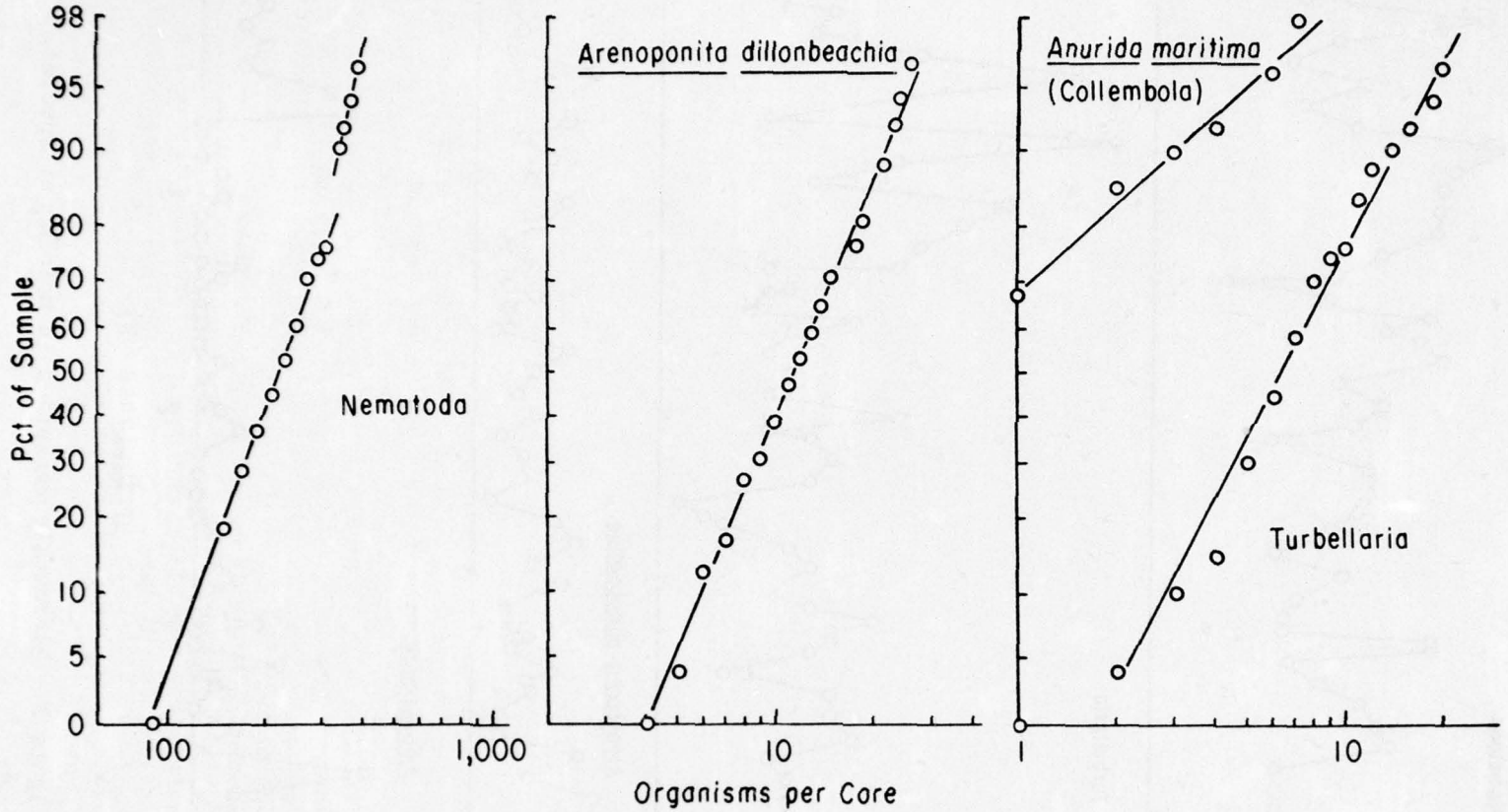


Figure 4. Graphical probit analysis of data from microscale sampling; lines were fit by inspection.

and macrofauna of exposed sandy beaches.

(c) Mathematical distributions such as the negative binomial and the lognormal are appropriate descriptions of sampling distributions for sandy beach infauna.

(d) Clumping in meiofauna is irregular and may show aggregations on the order of 0.5 meter with greatest density at the clump center. Broader patterns in variability may occur over a distance of a few meters.

(e) Simple logarithmic transformation is appropriate for normalizing meiofaunal counts and presumably, macrofaunal counts.

(f) Extreme behavioral aggregation is known for the sand crab (*Emerita analoga*), which might necessitate special collection and data analysis procedures for this organism.

(g) Biological interactions may play an important role in determining clumping patterns in meiofauna.

III. SAMPLING PLAN

1. Site Location.

A preliminary survey of potential sampling sites in southern Monterey Bay revealed sand mining as an unexpected possible source of artificial perturbation of the sandy beach environment in that area. There are three sand mining locations between the Salinas River and Sand City (Fig. 5). Since the prevailing longshore current is from north to south, it is likely that if these mining activities affect sand fauna communities, much of the coastline to the south of the Salinas River will be affected. To avoid the possible effects of such perturbation, a sampling site just to the north of the Salinas River was selected (Fig. 5). In addition to being free from the possible effects of sand mining, the sampling location has historically been subject to minimal human use since no access route existed until 2 years ago when a beach-front condominium development was constructed along with an access road to an area about 1 kilometer away from the development.

Three transects were located approximately 1 kilometer apart at the sampling site (Fig. 5). The transects were plotted and designated A, B, and C. Beach profiles in each location were obtained through the intertidal zone by using Emery's (1961) method. Intertidal positions were determined by comparing water level at the sampling site at the time of the survey with water level at a known bench mark at Hopkins Marine Station in Pacific Grove. Intertidal sampling locations at 2, 1, and 0 meters above MLLW were then graphically determined and their location relative to a permanent beach marker was determined. Each intertidal sampling location can now be determined in the field by measuring a calculated distance from the beach marker. Beach profiles for transects A, B, and C are shown in Figure 6.

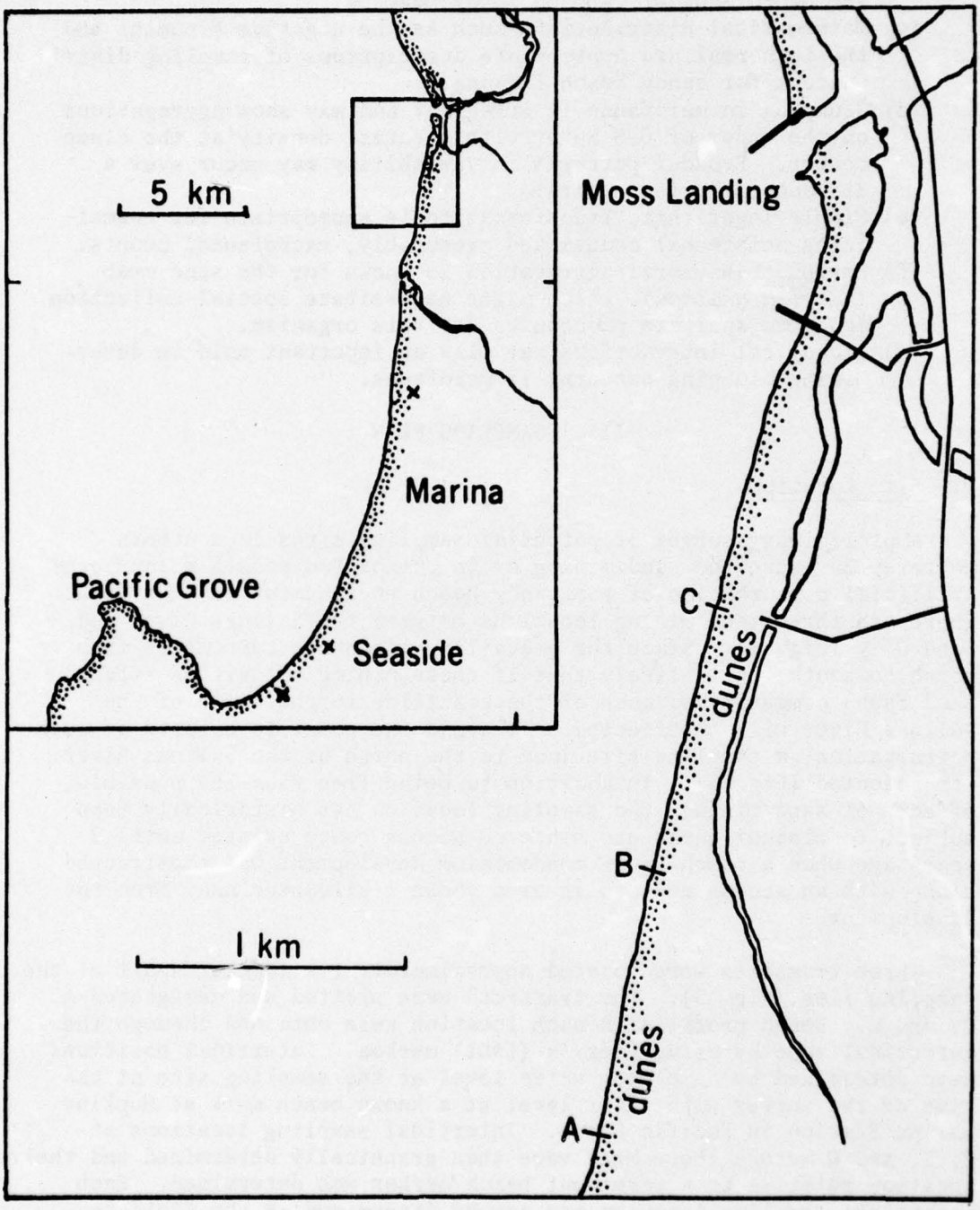


Figure 5. Location of beach transects. Sand mining activities are indicated by "x" on the inset map.

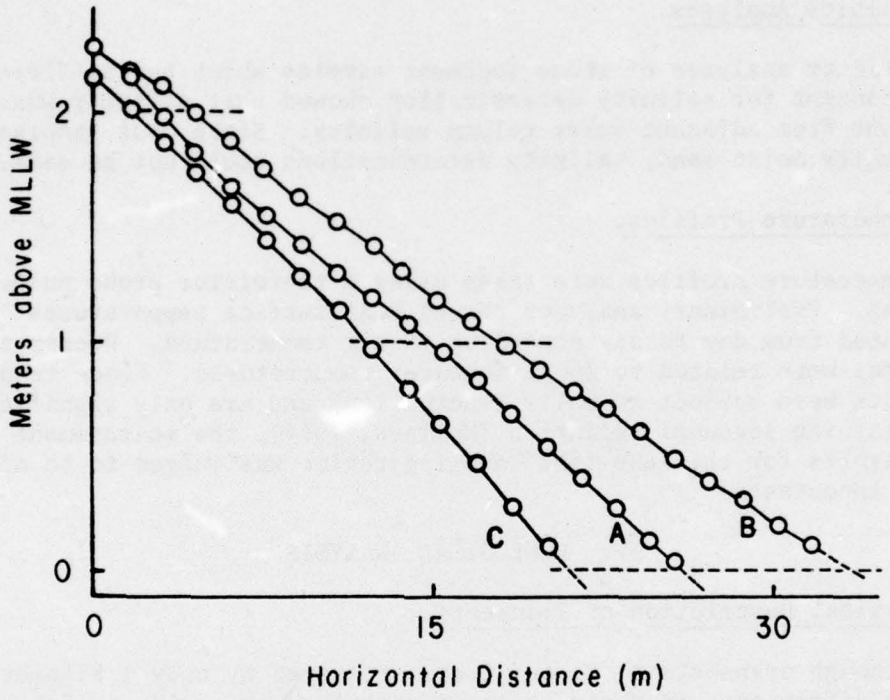


Figure 6. Beach profiles at transects A, B, and C.

2. Sampling Plan.

The sampling plan for studying the normal fauna of an exposed sandy beach was constructed to reveal features of horizontal and vertical zonation of beach fauna, and to establish statistical measures of requisite sample size and number for comparisons of different beach areas and treatments. *A priori* considerations, partially discussed in the preceding sections, lead to the plan summarized in Table 3.

3. Salinity Analyses.

Salinity analyses of those sediment samples which had sufficient water content for salinity determination showed that salinity was not different from adjacent water column salinity. Since most samples were essentially moist sand, salinity determinations could not be made.

4. Temperature Profiles.

Temperature profiles were taken using a thermistor probe pushed into the sand. Preliminary analyses showed that surface temperatures fluctuated from day to day according to air temperature. Deeper temperatures were related to local seawater temperatures. Since temperature gradients were subject to daily fluctuations and are only significant in explaining seasonal variation (Hulings, 1974), the measurement of temperatures for this one-time sampling regime was judged to be of little importance.

IV. ECOLOGICAL ANALYSIS

1. Physical Description of Transects.

Although transects A, B, and C are separated by only 1 kilometer, certain differences in their physical structure are evident (Table 4). Transect C has greater slope and significantly larger median grain size than transects A and B. Carbon content and carbonate (see App. B) did not vary significantly from transect to transect; however, two patterns were clearly shown in the carbon and carbonate data: (a) Carbon content increased with increasing tidal immersion in all three transects (Fig. 7), and (b) carbonate content, though only a small fraction of the predominant siliceous sediment, showed an inverse relationship with median particle size (Fig. 8). The carbonate values agreed with other values found in boreal siliceous beaches (Schmidt, 1968).

2. Transect Differences.

Differences in the physical structure between the transects were reflected dramatically in meiofaunal abundances. Total meiofauna, Copepoda, and Nematoda were more numerous in the coarser sediment of transect C (Table 5). Differences in total meiofauna are possibly due to the greater capacity of a steeper, coarser beach to allow organic matter to percolate through the substratum. Another factor is the space-

Table 4. Granulometric analysis of sediment from transects.

Transect	Sampling location (m)	Grain diameter			
		Median[1] (mm)	16[2] (mm)	84[2] (mm)	σ [3] phi
A (slope 1:11.6)	2	0.323	0.40	0.190	1.32
	1	0.316	0.36	0.182	0.98
	0	0.332	0.43	0.195	1.24
	Subtidal zone	0.500	1.15	0.260	1.05
B (slope 1:14.6)	2	0.317	0.38	0.195	0.96
	1	0.399	0.98	0.255	1.94
	0	0.332	0.45	0.200	1.17
	Subtidal zone	0.326	0.43	0.193	1.16
C (slope 1:9.8)	2	0.453	0.76	0.252	1.59
	1	0.649	1.43	0.283	1.30
	0	0.316	0.37	0.185	1.00
	Subtidal zone	0.304	0.35	0.151	1.21

1. Obtained by interpolation.
2. Obtained by graphical methods.
3. Computed by Inman's (1952) method: $\sigma_\phi = \phi_{84} - \phi_{16/2}$.

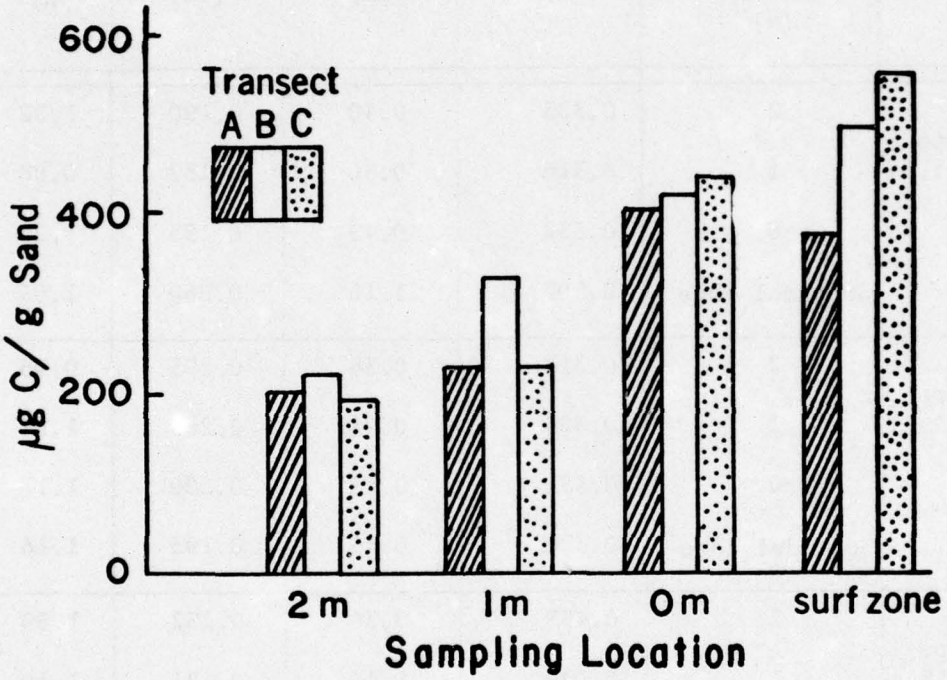


Figure 7. Carbon content at different sampling locations in the transects.

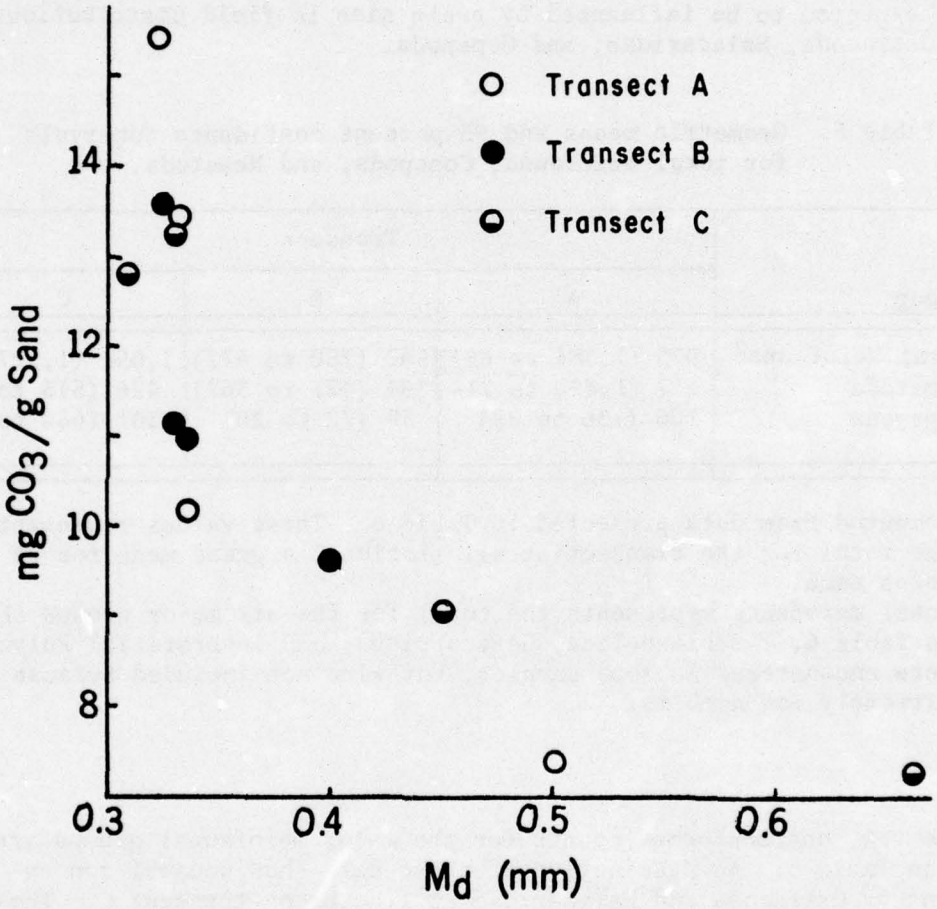


Figure 8. Carbonate content as a function of median grain diameter (M_d).

limiting property of the sediment itself. Sediment with a larger median diameter generally produces greater internal dimensions of the pore space between sediment particles. A higher proportion of small particles less than 0.2-millimeter diameter act to "fill in" the interstitial space. Interstitial organisms without contractile bodies usually show distinct grain-size preferences in laboratory studies and may be expected to be influenced by grain size in field distributions, e.g., Ostracoda, Halacaridae, and Copepoda.

Table 5. Geometric means and 95-percent confidence intervals for total meiofauna, Copepoda, and Nematoda.[1]

Group	Transect		
	A	B	C
Total Meiofauna[2]	975 (1,384 to 687)	562 (750 to 422)	1,054 (1,527 to 728)
Nematoda	637 (1,892 to 214)	394 (421 to 367)	426 (515 to 353)
Copepoda	106 (136 to 82)	38 (72 to 20)	307 (630 to 150)

1. Computed from data presented in Table 6. These values represent the total for the transect at all stations, a grand mean for 24 cores each.
2. Total meiofauna represents the total for the six major groups shown in Table 6. Archiannelida, Gastrotricha, and interstitial Polychaeta were encountered in some samples, but were not included because of extremely low numbers.

The raw, untransformed counts for the major meiofaunal groups are shown in Table 6. An examination of these data show unusual concentrations of Ostracoda and Halacaridae at 1 meter on transect C. These concentrations are attributable to the larger median diameter of sediment at that location. Ostracoda are least adapted by body shape for an interstitial existence, so it is not surprising that these organisms are limited to the coarsest of intertidal sediment. Halacaridae are active, predaceous organisms which need to move freely in the interstitial environment. Thus, the organisms are likely to be closely related to critical grain sizes. Turbellaria, Nematoda, and to a lesser extent, Oligochaeta are capable of a burrowing existence and are less affected by changes in the dimensions in the interstitial environment. Although trends are observable in these groups from transect to transect, it is not likely that these trends are directly the result of the space-limiting property of the sediments.

The response of the Copepoda, Ostracoda, and Halicaridae to rela-

Table 6. Summary of counts of major taxonomic groups of meiofauna.

Group	Transect A replicate cores						Transect B replicate cores						Transect C replicate cores					
NEMATODA																		
2 m	501	735	667	688	567	732	875	904	832	717	402	743	416	315	373	344	387	186
1 m	524	581	886	688	636	574	488	756	832	516	732	530	645	530	545	645	1,177	703
0 m	358	344	338	359	961	373	301	459	172	229	230	121	588	430	631	516	430	487
subtidal	230	1,736	1,478	2,095	330	1,923	359	201	431	115	230	158	387	244	172	660	273	219
COPEPODA																		
2 m	473	430	932	574	530	473	43	43	14	14	57	14	1,464	703	875	774	1,081	674
1 m	0	0	14	14	14	86	43	430	445	101	230	101	1,219	1,449	1,765	2,037	2,081	2,654
0 m	43	115	101	129	287	130	72	43	0	28	14	36	215	201	273	258	330	301
subtidal	101	158	287	259	0	115	14	14	230	0	48	28	14	14	14	57	0	0
OLIGOCHAETA																		
2 m	43	157	215	101	215	57	287	703	86	115	0	244	101	0	14	14	57	0
1 m	373	416	272	230	401	144	14	0	28	14	0	0	215	230	230	143	431	143
0 m	28	0	0	14	28	0	0	0	0	14	0	0	0	0	0	0	0	0
subtidal	0	0	144	14	14	0	14	0	0	0	0	0	43	0	0	14	0	0
HALICARIDAE																		
2 m	14	14	14	28	0	28	14	0	0	0	0	0	187	0	28	43	14	0
1 m	0	0	0	0	0	57	0	0	0	0	0	0	201	14	273	143	316	430
0 m	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
subtidal	0	43	0	14	57	273	14	0	0	14	14	0	14	0	0	14	14	0
TURBELLARIA																		
2 m	28	43	0	28	14	101	0	0	0	0	28	0	57	86	157	115	101	186
1 m	28	72	186	43	28	0	57	43	72	43	43	43	43	43	28	86	29	0
0 m	0	28	14	57	57	14	0	0	43	57	14	17	0	0	14	0	0	0
subtidal	0	0	0	43	0	0	101	28	28	43	72	144	0	28	0	0	0	14
OSTRACODA																		
2 m	0	0	0	0	0	0	0	0	0	0	0	0	129	28	14	29	0	22
1 m	0	0	0	0	0	0	0	0	0	0	0	0	631	316	344	230	517	258
0 m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
subtidal	0	0	14	14	14	0	0	14	14	0	0	0	0	0	0	0	0	0

tively small differences in the grain-size structure of the beach suggests that they may have importance as indicator organisms for certain processes of sand transport and deposition.

3. Eggs and Larval Forms.

Examination of the meiofaunal samples showed no evidence of fish eggs. Occasionally, spherical bodies were seen which were interpreted as eggs of invertebrates. Identification of these bodies was not possible. Nauplii of harpacticoid copepods were seen infrequently; their numerical abundance was too low for adequate quantification. Two factors mitigate against enumeration of meiofaunal larval forms. First, most meiofauna of sandy beaches produce adhesive eggs that cannot be removed by the extraction procedure, or they brood their young. Second, larvae that are released are usually smaller than the screen used to retain the meiofauna.

Larval amphipods were seen in the meiofaunal samples on a few occasions. No information was available for their identification, and their abundance was too low for adequate quantification.

4. Analysis and Zonation of Meiofauna.

The dominant groups of meiofauna are presented in Table 7. Nematoda and Copepoda are clearly the most abundant. Oligochaeta, Turbellaria, and Ostracoda are generally less abundant, occasionally yielding reliable estimates of mean abundance. Remaining major groups yielded estimates with 95-percent confidence intervals (C.I.) exceeding 80 percent of geometric means.

The meiofaunal numbers for each transect were totaled and plotted as a function of position relative to the MLLW datum. For comparison, the surf zone station at -10 feet was assumed to be 3 meters below MLLW. The values are shown in Figure 9. Total meiofauna and major faunal groups are also shown from the six ring-lined cores taken at transect C. The following important features are evident from this data:

(a) Population densities are highest at 1 meter above MLLW. This peak of abundance in the midbeach region has been documented in several studies of exposed beach meiofauna (Bush, 1966; Schmidt, 1968; Harris, 1972).
(b) Copepoda are most abundant lower on the beach, at the 0.5-meter mark or lower.
(c) Turbellaria are more abundant higher on the beach. Usually turbellaria have been found in peak abundances on the lower beach, the "Otoplana zone" (Remane, 1933); the existence of the Otoplana zone has been confirmed by many studies. High-energy beaches can lack this characteristically dominant turbellarian fauna, as indicated by Schmidt's (1968) study of West Beach and in this study.

Table 7. Major meiofaunal groups meeting dominance criterion.

Transect	Sampling location (m)	Taxon	Geometric mean	95-pct C.I.	95-pct C.I. as pct of geometric mean[1]
A	2	Nematoda	643	566 to 729	25
A	1	Nematoda	638	548 to 743	31
A	2	Copepoda	549	436 to 688	46
A	1	Oligochaeta	287	205 to 401	68
B	1	Nematoda	630	519 to 758	40
B	0	Nematoda	229	159 to 335	77
B	1	Turbellaria	49	41 to 58	35
C	2	Nematoda	320	257 to 414	49
C	1	Nematoda	680	537 to 862	48
C	0	Nematoda	512	446 to 578	26
C	2	Copepoda	884	698 to 1,122	48
C	1	Copepoda	1,809	1,442 to 2,275	46
C	0	Copepoda	259	221 to 303	31
C	1	Oligochaeta	215	154 to 299	67
C	2	Turbellaria	108	76 to 154	71
C	1	Ostracoda	357	259 to 494	66

1. Calculated as $\frac{\text{95-percent confidence interval}}{\text{geometric mean}} \times 100$.

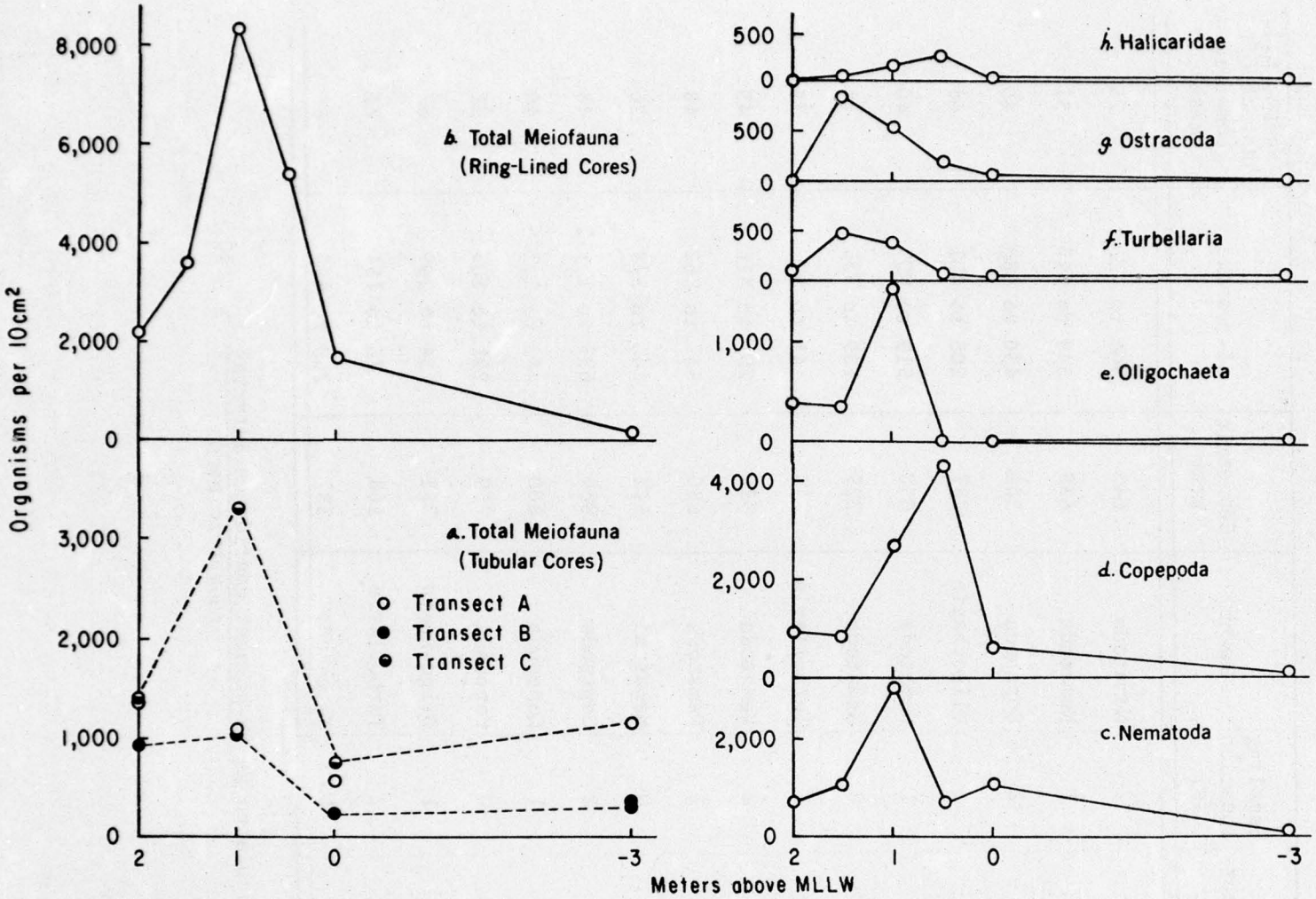


Figure 9. Intertidal zonation patterns of meiofauna: (a) Envelope of total meiofauna values from the tubular core series; (b) total meiofauna values from the ring-lined core series; (c to h) fauna components of b.

(d) Surf zone meiofaunal numbers can be fairly substantial, possibly exceeding that at MLLW, but generally are considerably lower than intertidal meiofauna.

The distinct zonation patterns of major meiofaunal groups from the six stations sampled with the ring-lined corer (Fig. 9, c to h) show some peaks which might be missed on a four-station transect. Three intertidal stations are apparently inadequate to sample peak abundances of Copepoda, Ostracoda, and Halicaridae.

A summary of more detailed faunal analysis of the core samples from the three transects appears in Table 8. Groups are listed on the left in approximate order of numerical abundance. Nematoda are invariably the most abundant group. Monhysteroidea and Chromadoroidea, primarily bacterial grazers (McIntyre, 1969), are dominant at all tidal levels. The Enoploidea appear to be exclusively intertidal.

Copepods closely follow the Nematoda in overall abundance. *Arenopontia dillonbeachia* occurs at all tidal levels, but dominates at the 2-meter station, where it comprises over 99 percent of the Copepod fauna. *Paramesochra* sp. dominates at the 0-meter sampling location, where it exceeds 99 percent of the copepod fauna. The highest diversity of copepods is encountered at the 1-meter sampling location where overall copepod numbers are greatest. Diversity is intermediate in the surf zone. *Shizopera californica* and species D are apparently exclusively subtidal.

Proseriate turbellaria were characteristic of the surf zone turbellarian fauna. These fairly large organisms are more easily recognized in the Formalin-preserved state than groups from the inter tidal zone.

Archiannelids, Polychaeta, and Gastrotricha are often reported as major groups in surveys of exposed sandy beaches (Govindankutty and Balakrishnan Nair, 1966; Schmidt, 1968, 1969; Hulings, 1974); however, they were relatively scarce in the samples taken for this study. All three groups were encountered most frequently at the 0-meter sampling location and in the surf zone.

The meiofaunal communities of transects A, B, and C (Table 8), though quite similar, do show differences. These differences may be explained partially on the basis of random mesoscale variation. However, the distinct differences in the physical structure of the different sites (Table 4) may exert a controlling influence in determining these differences.

5. Vertical Distribution of Meiofauna.

Results of meiofaunal sampling using the ring-lined corer are shown in Figure 10. Corresponding grain-size analyses are shown in Figure 11. The particle-size distribution reveals a lag deposit of slightly coarser

Table 8. Summary of faunal analysis of core samples for transects A, B, and C[1].

TAXON	2 m above MLLW			1 m above MLLW			0 m above MLLW			surf zone		
	A	B	C	A	B	C	A	B	C	A	B	C
NEMATODA												
Order Monhysteroidea	379 (44%)	++[2]	96 (80%)	364 (46%)	176 (46%)	258 (54%)	++	135 (80%)	264 (27%)	++	++	++
Order Chromadoroidea												
Species A[3]	-[4]	-	45 (49%)	+[5]	233 (40%)	++	++	++	141 (70%)	-	-	-
Epsilonematidae	+	-	-	+	+	+	+	+	+	-	+	-
Other	74 (25%)	++	107 (42%)	+	+	++	++	++	54 (70%)	++	++	++
Order Axonlaimoidea	++	+	++	++	-	++	+	++	++	-	-	-
Order Enoploidea	161 (24%)	+	++	++	170 (48%)	171 (50%)	+	+	++	-	-	-
COPEPODA												
Arenopontia dillonbeachia	549 (46%)	++	884 (48%)	++	++	615 (73%)	+	+	+	+	+	+
Paramesochra sp.	+	+	+	+	+	++	++	++	259 (31%)	+	+	+
Ameira parasimulans	+	+	+	++	++	651 (72%)	+	+	+	+	+	+
Arenosetella kaiseri	-	-	+	++	++	127 (80%)	-	-	-	-	-	-
Interleptomesochra reducta	-	-	-	++	++	++	-	-	-	-	-	-
Schizopera californica	-	-	-	-	-	-	-	-	-	+	+	+
Bastigerella abbotti	-	+	+	+	-	+	?[6]	?	?	-	-	-
Species C[7]	+	+	+	+	+	++	-	-	-	-	-	-
Species D[7]	-	-	-	-	-	-	-	-	-	++	++	++
Other	-	+	+	+	+	+	-	-	-	-	-	-
TURBELLARIA	++	+	108 (71%)	++	49 (35%)	++	+	+	++	++	++	++
OLIGOCHAETA												
Marionina subterranea[8]	+	+	?	231 (68%)	+	174 (67%)	+	-	-	-	-	-
Enchytraeus sp.[8]	+	+	?	+	+	+	-	-	-	-	-	-
Lumbricillus sp.[8]	+	+	?	-	-	+	-	-	-	-	-	-
Paranais litoralis[9]	-	-	-	-	-	-	-	-	-	+	+	?
Other	-	-	-	-	-	-	-	-	-	+	+	?
HALACARIDAE												
Scaptognathus sp.	-	?	-	-	-	+	-	-	-	+	-	-
Actacarus sp.	+	?	+	+	-	+	++	+	-	+	+	+
OSTRACODA	-	-	++	+	-	357 (66%)	-	-	-	+	+	-
ISOPODA (juvenile)	-	-	-	-	-	+	+	+	+	-	-	-
ARCHIANNELIDA												
Trilobodrilus sp.	-	-	-	-	-	-	+	+	+	?	?	-
Saccocirrus sp.	-	-	-	+	+	+	+	+	+	?	?	-
Other	-	-	-	?	?	?	+	+	+	?	?	-
COLLEMBOLA												
Anurida maritima	+	+	++	+	+	+	-	-	-	-	-	-
POLYCHAETA												
Stygocapitella subterranea	-	-	-	-	-	-	+	+	+	+	+	+
Unidentified Syllid	-	-	-	-	-	-	+	+	+	+	+	+
Other	+	+	+	+	+	+	+	+	+	+	+	+
GASTROTRICHA												
Species A	-	-	-	-	-	++	-	-	-	+	+	+

1. Dominant organisms (defined as those groups which have a 95-percent confidence interval of less than 80 percent of the mean) are shown with geometric mean followed by the 95-percent confidence interval as percentage of geometric mean in parentheses.
2. Presence in greater abundance, but not dominant.
3. Species A tentatively assigned to the Order Chromadoroidea.
4. Absence.
5. Presence in low abundance.
6. Insufficient material available for taxonomic analysis.
7. Documented in the photographic record.
8. Family Enchytracidae.
9. Family Naididae.

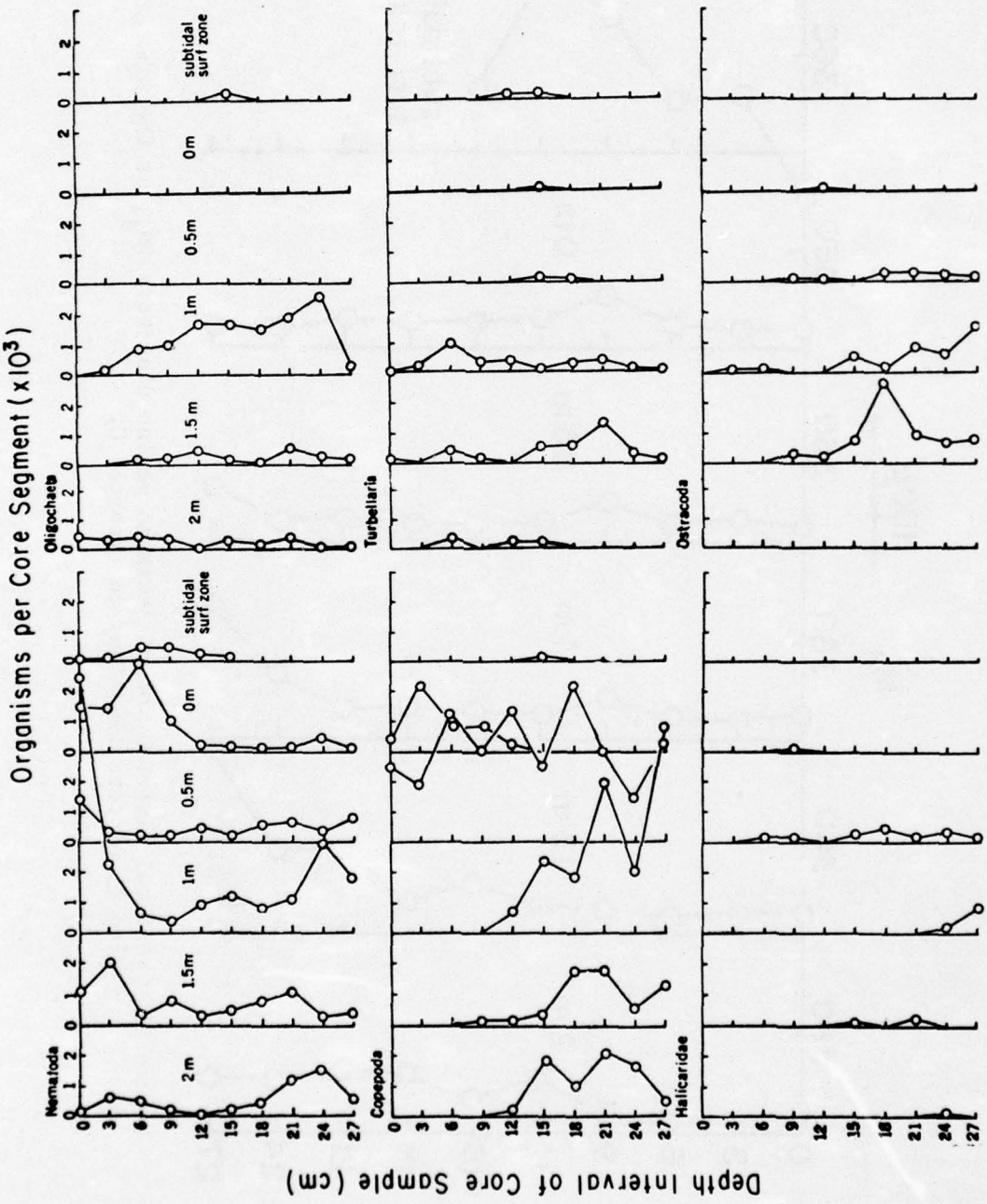


Figure 10. Vertical distribution of meiofauna at six sampling locations in transect C.

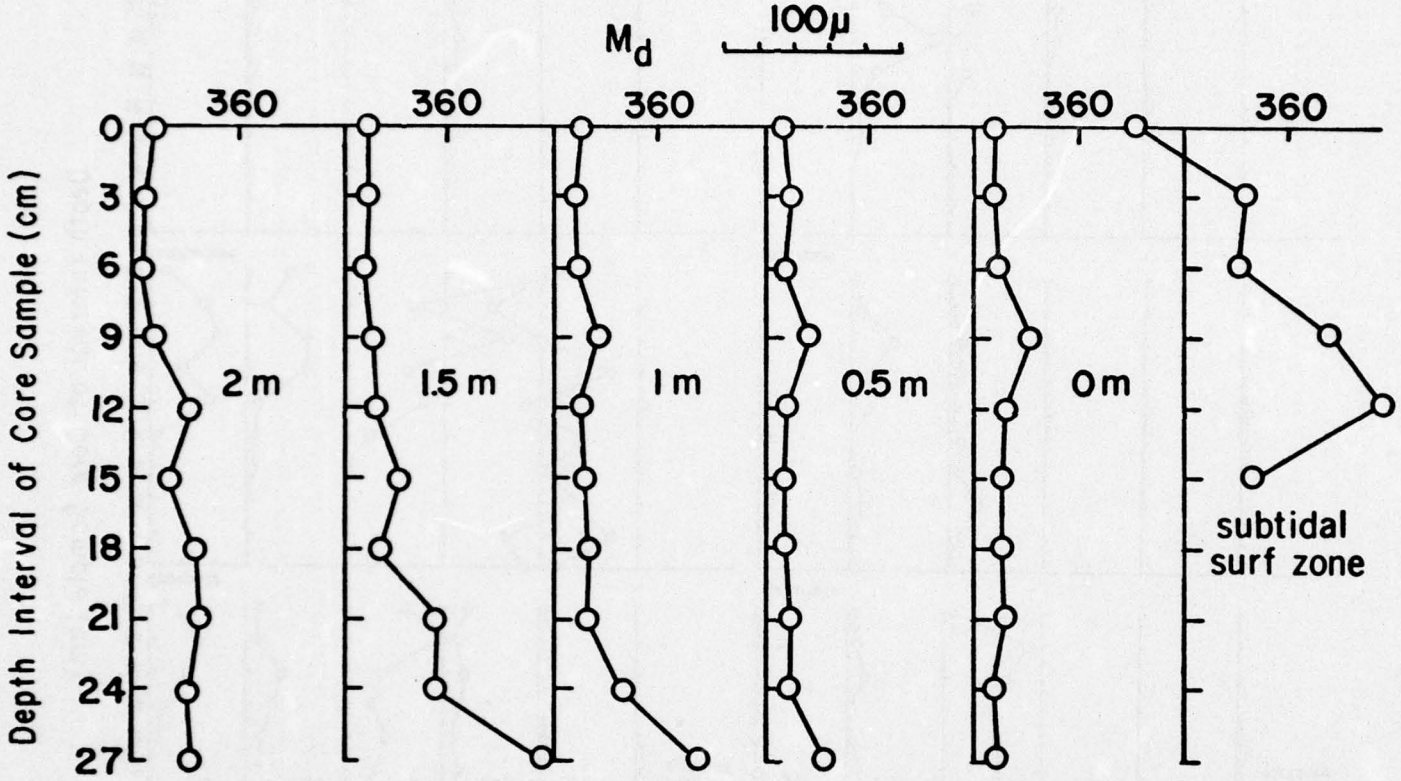


Figure 11. Vertical distribution of sediment median diameters (M_d) at the six ring-lined core locations in transect C.

sediment at the 9- to 12-centimeter level between 1 and 0 meter. Coarser sediment is also found at greater depth from 2 to 1 meters, possibly resulting in an increase in Ostracoda in that region (Fig. 10). In general, however, the sediment is much more homogenous in vertical profile than sediment from less exposed, nontidal beaches (Jansson, 1966), and may not influence vertical distributions to a significant extent in these samples.

Nematoda and Copepoda distributions show evidence of substantial numbers deeper than 30 centimeters at higher locations. Copepoda follow the generally recognized pattern of deeper occurrence higher in the intertidal (Harris, 1972). Cores of 10-centimeter depth used by some workers for sampling exposed sandy beaches are inadequate (Gray and Rieger, 1971).

Sorting is poor in the surf zone, showing a surface layer of relatively finer sediment which may account for the extremely low abundance encountered there. An impenetrable layer of shell fragments was encountered at 18 centimeters.

6. Analysis and Zonation of Macrofauna.

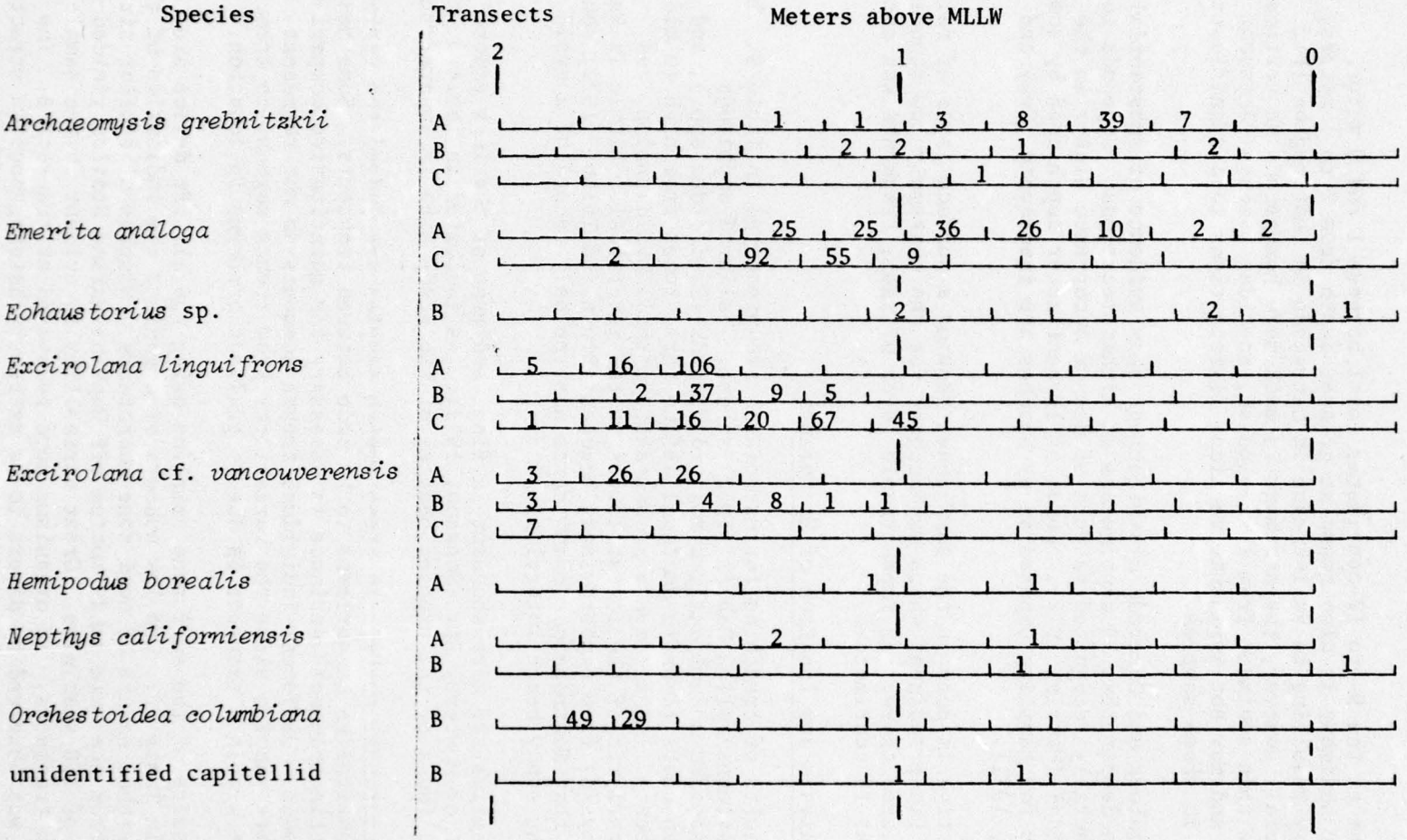
Results of trenching for macrofauna are presented in Table 9. Zonation patterns follow Dahl's (1952) scheme. Talitrid amphipods (*Orchestoidea columbiana*), cirolanid isopods (*Excirolana* spp.), and anomuran crabs (*Emerita analoga*) define three zones from high to mid-lower beach. *Archaeomysis grebnitzkii*, a small mysid shrimp, was characteristic of the lowest levels in the intertidal. Little is known about mysids from exposed sandy beaches; Brown and Talbot (1972) concluded that *Gastrosaccus psammodytes* was the only record of a mysid from the sandy beach intertidal.

Annelids are more abundant in finer sediment of the less exposed beaches of Monterey Bay (Johnson, 1972). As indicated in Table 9, the annelid fauna of the exposed beaches of the study site is impoverished.

Macrofaunal numbers in these trench samples are judged too variable for quantitative comparisons to be made between transects. Some measure of "within transect" variance is necessary for quantitative comparisons to be made. Different individual trench segments do not represent replicate samples since the variability from trench segment to trench segment within a transect is due to gradient patterns in zonation.

Results of the surf zone sampling using the airlift device are shown in Table 10. The low numbers of organisms are indicative of the impoverished nature of surf zone macrofauna. Samples of similar size taken from the calm sandy bottom off Hopkins Marine Station yielded in excess of 100 specimens. Great variability is evident in the samples between transects. No organisms were recovered at transect B. The bottom was observed by divers to be extremely heterogenous in structure, with alternating patches of fine and coarse sand at the surface.

Table 9. Distribution of intertidal macrofauna from trenching samples.



Occasional large aggregations of sand dollars, *Dendraster excentricus* were observed.

Table 10. Summary of surf-zone macrofaunal samples.

Taxon	Replicate samples from transects					
	A		B		C	
	1	2	1	2	1	2
GASTROPODA						
Olivella biplicata	-	-	-	-	8	16
Olivella pyera	-	-	-	-	5	10
NEMERTEA						
fragment species A	-	-	-	-	-	1
fragment species B	-	-	-	-	-	1
BIVALVIA						
Siliqua patula	-	-	-	-	-	1
POLYCHAETA						
Scolopos armiger	-	3	-	-	1	4
Spiophames bombyx	-	1	-	-	-	-
Scolelepis foliosa occidentalis (?)	-	1	-	-	-	-
Platynereis bicanaliculata	-	1	-	-	-	-
Nothria elegans	-	1	-	-	-	-

7. Summary.

The following points summarize the ecological analysis of macrofauna and meiofauna at the study site:

(a) Distinct differences in the physical structure of the beaches at transects A, B, and C were reflected in the abundance of several meiofaunal groups. Copepoda, Ostracoda, and Halacaridae appear to be affected by grain size, all favoring coarser sediment.
(b) Population densities of meiofauna were highest at 1 meter above MLLW, and generally lower in the surf zone. This abundance peak may be due to the high filtration rates of seawater

through the sediment of this zone due to constant tidal emersion and subsequent drainage.

(c) Specific intertidal zonation patterns are evident for both macrofauna and meiofauna. Two species of harpacticoid copepods, an oligochaete, species of Proseriate turbellaria and a gastrotrich are characteristic of the surf zone meiofauna. Surf zone macrofauna differs significantly from intertidal macrofauna; species of *Olivella* and several annelid species are found exclusively in the surf zone.

(d) Quantitative comparisons of macrofauna require replication at each site. Trenching is gradient sampling suitable for establishing zonation patterns, but is not suitable for density comparisons.

V. ANALYSIS OF SAMPLING VARIATION

1. The Dominance Criterion.

The majority of meiofaunal groups yielded counts which were judged to be too variable for mean values to be reliable. Of the major groups, only 16 of the 72 group-tidal height-transect categories yielded mean estimates with a 95-percent confidence interval of less than 80 percent of the mean (referred to as the dominance criterion), a generally accepted reliability level (Elliott, 1971). These means are shown in Table 7 for major groups and in Table 8 for subgroups.

A technique which was originally proposed involved the calculation of parameters of the negative binomial distribution from sample data to estimate probable confidence limits. This technique is described in detail in Appendix C. The appropriate normalizing transformation for the negative binomial is:

$$\log\ (x + \frac{\hat{k}}{2});$$

however, the previously discussed microscale variation study showed that a simple log transform is an adequate normalizing procedure, and has the advantage of being easier to calculate. The mean standard error and 95-percent confidence interval are computed using transformed data of familiar procedures. The antilog of the transformed mean is the geometric mean for the sample; the 95-percent confidence interval can be computed as a percentage of the geometric mean.

The importance of the dominance criterion is that it allows decisions to be made regarding the feasibility of quantitative descriptions of subgroups. If a major group mean cannot be reliably estimated, there is little chance of reliably estimating means for its components. The functioning of this decision process is depicted in a flow chart (Fig. 12).

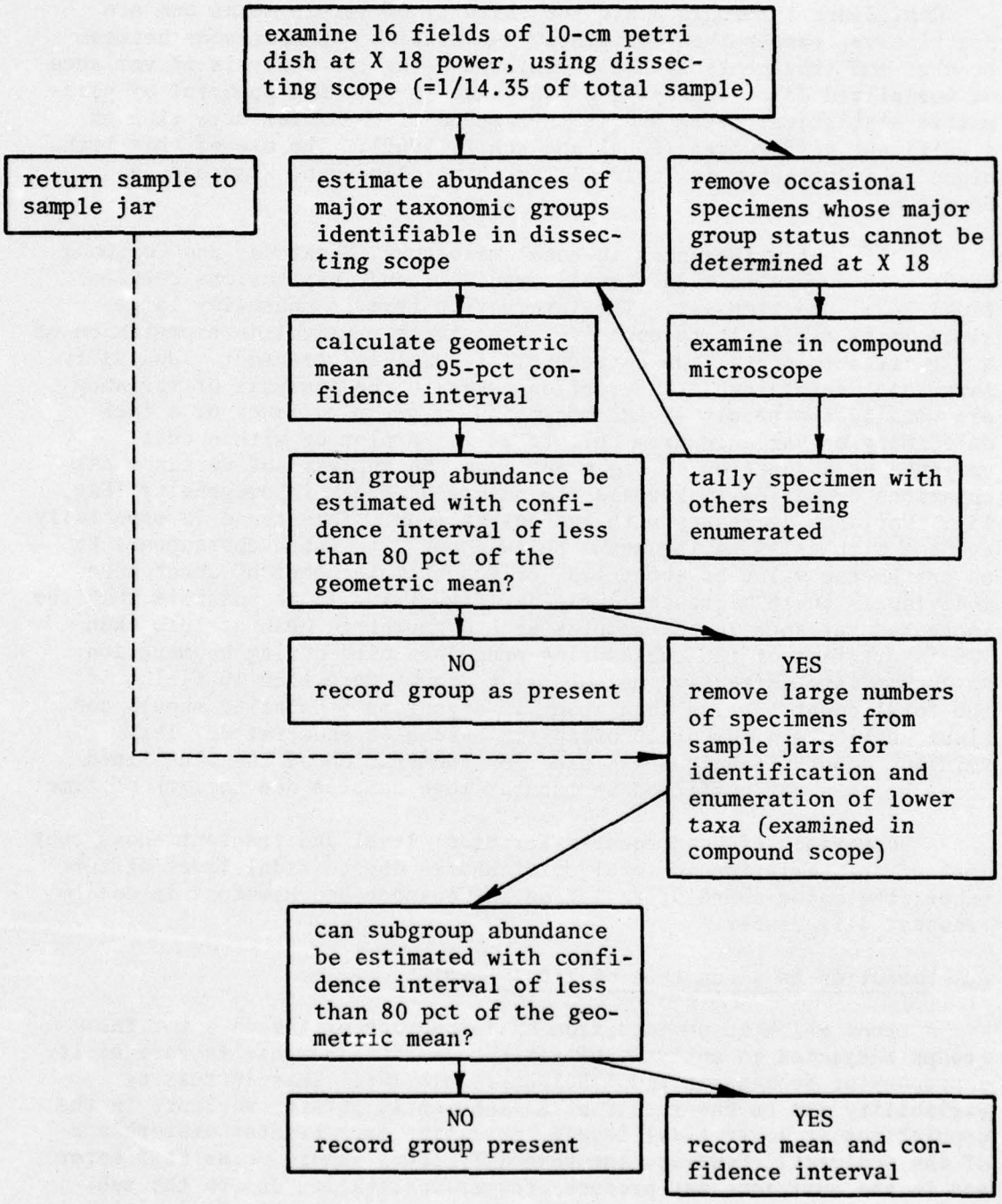


Figure 12. Flow diagram for analysis of meiofaunal cores.

2. Statistical Comparisons.

Confidence intervals state the validity of sample means and are descriptive, rather than comparative statistics. Comparisons between beaches and treatments are best achieved using the analysis of variance of normalized data. Analysis of variance is the most powerful of parametric statistical tests and is the method of choice for detection of significant differences (Sokal and Rohlf, 1969). The use of this technique is illustrated in Table 11 for total meiofauna, Nematoda, and Copepoda.

Significant differences in total meiofauna, Nematoda, and Copepoda occur with regard to tidal level, transect, and interactions between tidal level and transect. The interaction term is unusually large since it is difficult to conceive of a simple physical interpretation of a significant interaction between tidal level and transect. Unusually large and unexplainable interaction terms in the analysis of variance are usually the result of *inhomogeneity of error variance* or a lack of uniformity of variance from cell to cell. A plot of within cell variance as a function of log means from the analysis of variance calculations dramatically reveals the nature of their inhomogeneity (Fig. 13). Variance decreases with increasing mean. This trend is especially evident with cells having means below about 2.1, which corresponds to an arithmetic value of about 125, or a subsample count of about nine individuals in 16 microscopic fields (Fig. 12). It is possible that the increased variance in the samples with a geometric mean of less than 125 is artifact of the subsampling procedure used during enumeration. An appropriate corrective measure is to count more than 16 fields if the total count is less than about 10 organisms. Counting should continue until a minimum of 10 organisms have been enumerated. This "minimum count" technique was used for enumeration of the ring-lined cores but was not performed on tubular core samples due to lack of time.

A comparison of mean squares for tidal level and transect shows that most of the variation in total meiofauna is due to tidal level differences; the major share of variation in Copepoda and Nematoda is due to transect differences.

3. Variation as a Function of Tidal Level.

A trend which is obvious from an inspection of the data for the groups subjected to analysis of variance is the increase in variability accompanying decreasing tidal height (Table 12). This increasing variability may be the result of an inherently greater variance in the populations at lower tidal levels, resulting from greater disturbance of the sediment. However, the generally lower sample means at 0 meter and in the surf zone may produce greater variability due to the subsampling artifact discussed above. The data do not allow a decision to be made between these alternative explanations.

Table 11. Results of two-way analysis of variance for total meiofauna, Nematoda and Copepoda from tubular core samples.[1]

Source	Sum of squares	Degrees of Freedom	Mean squared	Variance ratio
Meiofauna				
Tidal Level	3.568	3	1.189	19.2[2]
Transect	1.061	2	0.531	8.6[2]
Interaction	1.602	6	0.267	4.3[2]
Deviation (within)	3.721	60	0.062	
Nematoda				
Tidal Level	0.715	3	0.238	2.87[3]
Transect	0.600	2	0.300	3.61[3]
Interaction	1.570	6	0.262	3.16[4]
Deviation (within)	2.092	60	0.083	
Copepoda				
Tidal Level	5.170	3	1.723	19.5[2]
Transect	9.744	2	4.872	55[2]
Interaction	15.178	6	2.530	28[2]
Deviation (within)	5.305	60	0.088	

1. Values shown in this table are based on decimal logarithms of actual counts of organisms. The rationale for log transformation is discussed in the text.
2. Significant difference at greater than the 0.005 probability level.
3. Significant difference at greater than the 0.05 probability level.
4. Significant difference at greater than the 0.01 probability level.

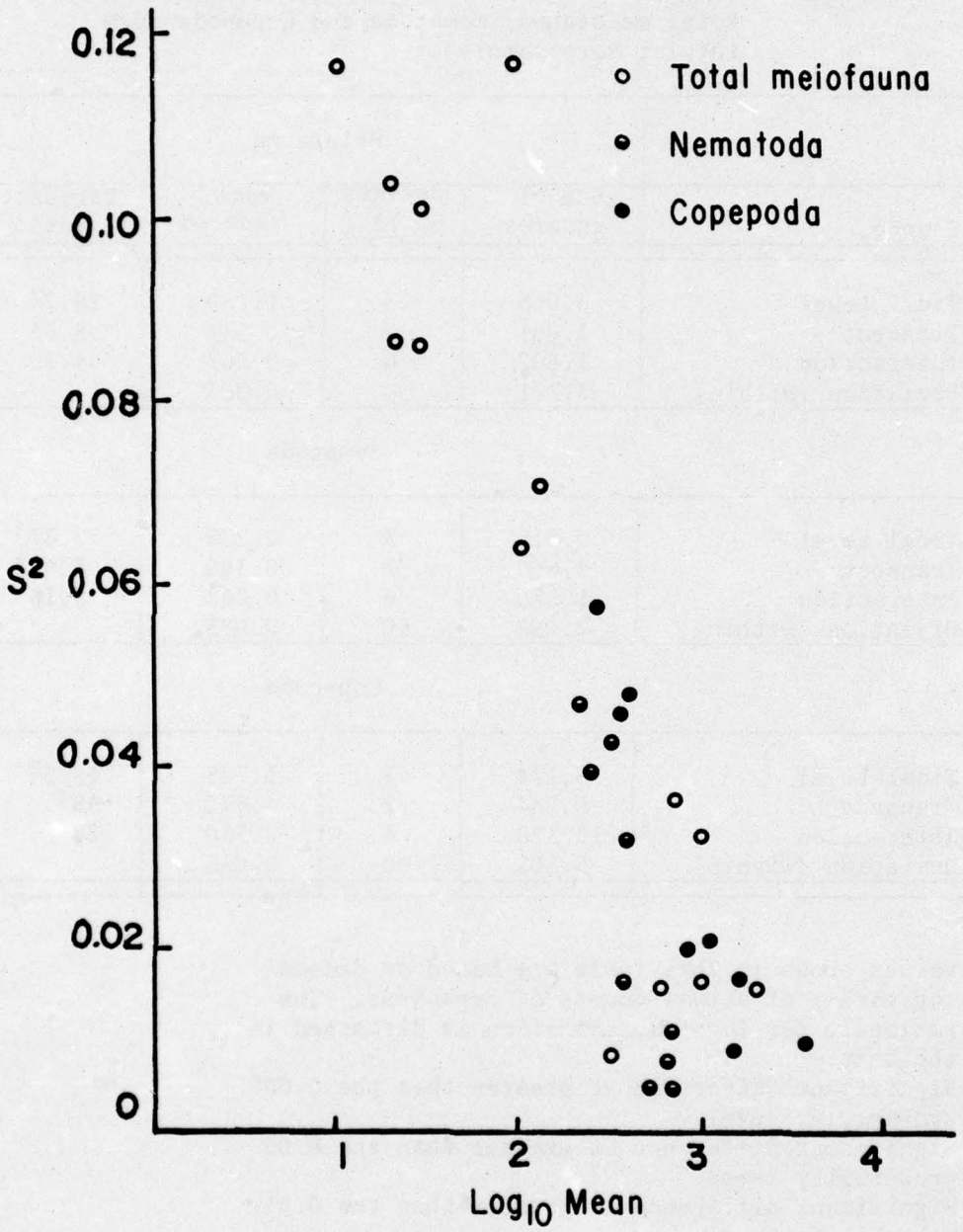


Figure 13. Variance of within cell counts as a function of the log mean for the analysis of variance in Table 11.

Table 12. Variability of total meiofauna, Nematoda, and Copepoda from tubular cores.

Taxon	Sampling location (m)	Transects A (95% C.I. as pct of geometric mean[1])	B	C	Average
Nematoda	2	25	52	49	42
	1	31	40	48	40
	0	70	77	26	58
	subtidal zone	177	84	39	100
Copepoda	2	46	116	48	70
	1	126	167	46	113
	0	102	129	31	87
	subtidal zone	236	193	117	182
Total Meiofauna	2	31	66	46	48
	1	26	68	36	43
	0	70	76	20	55
	subtidal zone	152	88	82	107

1. Calculated as $\frac{\text{95-percent confidence interval}}{\text{geometric mean}} \times 100$.

4. Summary.

a. Decisions regarding the continued counting of subgroups of a major meiofaunal group can be based on an arbitrary criterion of a 95-percent confidence interval of less than 80 percent of the mean.

b. Analysis of variance allowed significant differences to be detected in Nematoda, Copepoda, and total meiofauna of the three transects studied.

c. Significant interaction terms in the analysis of variance were probably an artifact of the subsampling procedure which produced an abnormally large error variance in samples with smaller means. A possible additional explanation is an inherent increase in variability due to the greater disturbance and heterogeneity of sediment at lower tidal levels. Future studies should correct the counting procedure to test the hypothesis of subsampling artifacts.

VI. RECOMMENDATIONS

The existing scheme for sampling and analysis of meiofauna appears to be sufficiently sensitive to detect quantitative differences from one beach area to another. Presumably, it could also detect differences due to beach nourishment, if they were to occur. Significant differences which are detectable for a synoptic sampling of transects separated by 1 kilometer suggest that mesoscale variation must be accounted for in any study of changes after beach nourishment, i.e., significant changes due to nourishment alone are not likely to be detected unless more than one transect is studied.

The use of a subsampling procedure for enumeration of meiofauna, a necessary consequence of the large numbers of organisms per core, may induce greater variability in estimates yielding low mean values. A possible remedy is to establish a "minimum count" criterion for major groups and to test for independence of means and variances.

Because of the narrow occurrence of abundance peaks of meiofauna in the intertidal zone, it may be advisable to increase the number of sampling stations per transect from four to six.

Ring-lined cores do not appear to reveal significant vertical inhomogeneities of sediment in a normal sandy beach to the extent that meiofaunal abundances are affected. However, changes in sediment composition between transect stations and between transects are important determinants of relative meiofaunal abundance. The primary cause of such abundance differences is apparently a change in the dimensions of the interstitial space. It would be advisable to measure this property directly in future studies, using Williams' (1971) technique.

Because of difficulties associated with detailed taxonomic analyses of most of the major groups, it may be advisable to concentrate efforts on groups which are better known from the California fauna, such as the

Copepoda. Generally, diversity trends within major taxonomic groups are a good reflection of overall community diversity. Since it is impossible in any practical sense to develop a comprehensive species list for the total meiofaunal community, it seems reasonable to study diversity by emphasizing a single major group.

Macrofaunal sampling using the trenching technique, although it is the most desirable method for documenting gradient changes in intertidal zonation, does not lend itself to statistical comparisons. Replicate 0.1-square meter quadrats (probably six per station) at 2, 1.5, 1, and 0 meters probably represent an adequate sample series for comparisons. Surf zone samples should be correspondingly increased in numbers.

The calculation of diversity indexes is meaningful in situations where species information can be generated on the majority of organisms present in a sample. This situation clearly does not apply to the meiofauna, where a detailed species analysis of all major groups is technically not feasible. Macrofaunal species numbers were too low and too variable for reasonable application of diversity indexes. An alternative approach might involve use of percent similarity analysis for comparisons of species structure. This technique was successfully applied by Patterson (1974) to the macrofauna of southern California beaches, and is recommended for use in future studies.

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APPENDIX A

LITTORAL AND NEARSHORE BENTHOS IDENTIFIED IN STUDY

PHYLUM	CLASS	SUBCLASS	ORDER	SCIENTIFIC NAME (COMMON NAME)	Meiofauna = * Macrofauna = o
PLATYHELMINTHES (Flatworms) Unsegmented, usually flattened, soft-bodied worms without appendages	Turbellaria (free living)				* o
RHYNCHOCOELA (NEMERTEA) (Ribbon Worms) Unsegmented, cylindrical or flattened, contractile, soft-bodied worms without appendages					o
ASCHELMINTHES [Rotifers (wheel animalcules), Gastrotrichs, Hairworms, Roundworms]	Gastroricha Minute, elongate centrally flattened animals, with spines, scales, or bristles and usually with one or more pairs of adhesive tubules; transparent.				*
	Nematoda (Roundworms) Cylindrical thread-like worms; body covered with a cuticle, either smooth or ringed, usually white or pale yellowish, often with bristles, warts or ridges. The body tapered at both ends.		Monhysteroidea Enoploidea Chromadoroidea		* o
MOLLUSCA (snails, bivalves, chitons, octopuses, and squids)	Gastropoda (Snails and Slugs)			*Olivella biplicata* *Olivella pycra* *Siliqua patula* (Razor Shell clam)	o o o
	Bivalvia (Shells with two valves)				
ANNELIDA (segmented worms)	Polychaeta (Bristle worms)			*Hemipodus borealis* *Nepthys californiensis* *Nothria elegans* *Platynereis bicanaliculata* *Scoloplos armiger* *Scolelepis foliosa occidentalis* *Spiophanes bombyx* *Stygocapitella subterranea*	o o o o o o o *
			Archiannelida	*Trilobodrilus* sp. *Saccocirrus* sp. *Enchytraeus* sp.	* * *
	Oligochaeta (Aquatic and Terrestrial "earthworms")			*Marionia subterranea* *Lumbricillum* sp. *Paranais litoralis*	* * *

LITTORAL AND NEARSHORE BENTHOS IDENTIFIED IN STUDY (CONTINUED)

PHYLUM	CLASS	SUBCLASS	ORDER	SCIENTIFIC NAME (COMMON NAME)	Meiofauna = * Macrofauna= o
ARTHROPODA (joint-legged animals)	Arachnida		Acari (Mites)	*Scaptognathus* sp.	*
				Actacarus sp.	*
	Insecta		Collembola (Springtails)	*Anurida maritima*	* o
	Crustacea	Ostracoda Small, unsegmented crustacea with bodies that are laterally compressed and enclosed in a bivalved, hinged carapace.			
		Copepoda Small Crustacea with cephalothoraxes and 5 or 6 pairs of thoracic limbs. No or only a few appendages on the abdomen.		*Arenopontia dillonbeachia*	*
				Hantigerella abbotti	*
			Harpacticoida	*Ameira parasimulans*	*
				Arenosetella kaiseri	*
				Interleptomesochra reducta	*
				Paramesochra sp.	*
				Schizopera californica	*
		Malacostraca	Isopoda (Pill bugs)	*Excirolana* cf. *vancouverensis*	o
				Excirolana linguifrons	o
				Cirolana mayana	o
				Ancinus	o
			Amphipoda (Beach fleas, Sand hoppers)	*Orchestoidea columbiana*	o
				Orchestoidea sp.	o
				Eohaustorius sp.	o
			Mysidacea (Mysid shrimps)	*Archaeomysis grebnitzki*	o
				Gastrosaccus psammodytes	o
			Decapoda (Shrimps, Crayfish, Lobsters and Crabs)	*Emertia analoga* (Mole crab)	o
ECHINODERMATA	Echinoidea (Sea Urchins, Sand dollars)			*Dendraster excentricus* (Sand dollar)	o

APPENDIX B

CARBONATE ANALYSIS

1. Outline of Procedure.

   a. Weigh sand samples into tared test tubes. Three to six grams of sample have proven to be about right for sampling sites A, B, and C.
   b. Add 10 milliliters of 1 normal (N) sulfuric acid (H_2SO_4) from automatic zeroing volumetric pipette, to all samples, blanks and standards.
   c. Heat all test tubes in block heater for 1 to 2 hours at 95° to 110° Celsius.
   d. Remove from heat and cool about 15 minutes.
   e. Proceed one tube at a time (starting with blanks, then standards, then samples) adding 10 milliliters of approximately 0.9 N sodium hydroxide (NaOH) (see below, Reagents) and transfer contents quantitatively to a 50-milliliter beaker with magnetic stirrer. Titrate with 0.10 N NaOH to an endpoint of pH 7.

2. Determination of Blank.

   With each set of samples a set of blanks is run to determine the amount of 0.10 N NaOH needed to adjust the acid-base imbalance between the 10 milliliters of 0.9 N NaOH plus 10 milliliters of 1 N H_2SO_4 to a pH of 7. This is accomplished by following steps a to e in the above outline with the modification that it has proven useful to add about 1 milliliter of pH 7 buffer to the transferred solution in the 50-milliliter beaker before titration to better duplicate the endpoint of the effectively buffered sample. A mean of six blank determinations have typically provided a standard deviation of ±0.03 milliliters or better. If the expected amount of carbonate is in the 20 to 70 milligrams per gram wet weight region, the acid-base balance of the 1 N H_2SO_4 and the 0.9 N NaOH is conveniently adjusted to produce a blank of about 15 milliliters. If sample concentrations vary, this or the wet weight of sample added may be modified to fit the circumstances, provided the amount of carbonate present does not exceed the capacity of the 1 N H_2SO_4 solution to convert carbonate to CO_2 within the given reaction time and temperature.

3. Reagents.

   Reagents are made up from distilled water (Dis-H_2O) which has been boiled for 30 minutes to reduce residual carbonate content, and are used immediately after cooling to room temperature in sealed bottles.

   a. 1 N H_2SO_4. 51 grams of H_2SO_4, reagent grade, are added to 500 milliliters of Dis-H_2O and subsequently made up to 1 liter and cooled before use to room temperature.

b. 0.9 N NaOH. 36.10 grams of reagent grade NaOH pellets are dissolved in 0.9 L of Dis-H_2O and made up to 1 liter.
c. 0.10 N NaOH. A carbonate-free readymade standard was used for the titrating solution such as Acculute, or Dilut-it, J.T. Baker Chemical Company, Phillipsburg, New Jersey.

4. Equipment.

2 - Stopcock type automatic rezeroing volumetric pipettes
1 - Rezeroing 10-milliliter burette, 0.05 milliliter per division or better (Kahl or Ace Glass).
1 - Block heater for test tubes capable of 100° Celsius.
1 - Expandomatic pH meter, Beckman Model 76A.

5. Calibration and Standards.

Assuming the use of an analytical concentrate for the 0.1 N NaOH, calibration should not be required. Using a formula weight of 100.09 for calcium carbonate ($CaCO_3$) we would expect a value of the equivalent of 5.004 milligrams of $CaCO_3$ for every milliliter of 0.10 N NaOH with which we titrate. Weighed amounts of $CaCO_3$ standard provide a factor slightly higher than this, experimentally determined. A mean of five standards typically provides a factor of 5.10 ± 0.09.

6. Calculation of Results.

Factor F is defined: $$F = \frac{\text{mgs } CO_3 \text{ std}}{(R_b - R_s)},$$

where R_b is blank in milliliters and R_s is sample in milliliters.

$$\text{Milligrams } CaCo_3 \text{ per gram wet weight (parts per thousand)} = \frac{(R_b - R_s)F}{\text{grams of sample}}.$$

Samples are run in duplicate or triplicate replication providing a value and a standard deviation for each sand sample. Including the error introduced by the possible nonhomogeneity of subsamples, replication has been plus or minus about 0.20 at the 10 parts per thousand level where $n = 2$.

Note. Since both NaOH pellets and concentrated H_2SO_4 are highly hygroscopic, values provided for making 1 N H_2SO_4 and 0.9 N NaOH may have to be varied slightly to adjust for a usable blank value, due to variations in reagent batches of NaOH and concentrated H_2SO_4.

APPENDIX C

BIOLOGICAL SAMPLING AND ANALYSIS

1. Macrofaunal Sampling and Extraction.

Quantitative sampling techniques for macrofauna of sandy beaches have been quite variable, although the basic approach involves excavation of sand to a prescribed depth within the confines of a predetermined quadrat. Some procedures have involved excavation of the contents of a square coring device driven into the sand. Other procedures call for excavation under a frame placed on the surface of the sand. More recently, trenching has been used (Klapow, 1971). Trenching involves excavation of a continuous trench extending from the low water line to the swash mark of the preceding high tide, consisting of a series of contiguous samples 3 meters long, 10 centimeters wide, and 10 centimeters deep. If a transect is over 30 meters in total length, alternate 3-meter intervals are sampled along the transect.

Macrofaunal extraction was achieved by shoveling parts of the sand excavated from the trench into a sieve box. Both the sieve box and shovel used for this purpose are illustrated in Figure C-1. The sieve box was then carried to the swash zone where it was agitated to separate most of the sand from the infauna. Four or five individual washings per 3-meter trench segment were found to be a workable arrangement for separation of organisms. This corresponds to a sand volume of 5 to 6 x 10^{-3} cubic meters per individual washing.

A number of different studies suggest that a minimum of 0.1 square meter be sampled for an adequate quantitative measure of macrofauna (Holme, 1971). Many of the benthic samplers capable of such area coverage are designed to be operated from a large vessel in calm seas, clearly a condition which does not apply to surf zone sampling. Of the samplers which have been described, only two are diver-operable and also capable of sufficient area coverage for quantitative sampling. Suction samplers have been described by Brett (1964) and Emig and Lienhart (1967), which are driven by surface or *in situ* hydraulic pumps. Although this system of sampling is highly recommended, the cost involved in constructing such samplers was high. Airlift samplers, first described by Barnett and Hardy (1967), are less expensive to construct and appear to work quite well, so this design was chosen for preliminary trial.

A modified version of the Barnett and Hardy (1967) airlift sampler was constructed and tested in relatively calm water at a depth of 2.1 meters. Construction details of this device are shown in Figure C-2. Basically, the operation of this system is as follows: A diver places a quadrat frame (0.1 square meter) into the substratum, turns on the source of compressed air (either from surface-operated compressor or *in situ* scuba tank), and adjusts the flow rate by means of a needle valve; compressed air then flows into the manifold surrounding the

Figure C-1. Use of the trenching shovel and sieve. The shovel is a small modified garden spade folded and welded so that the blade is 10 centimeters wide and is flanked by the folded-up edges. The seive is a wooden box with a stainless steel screen bottom of appropriate mesh size.

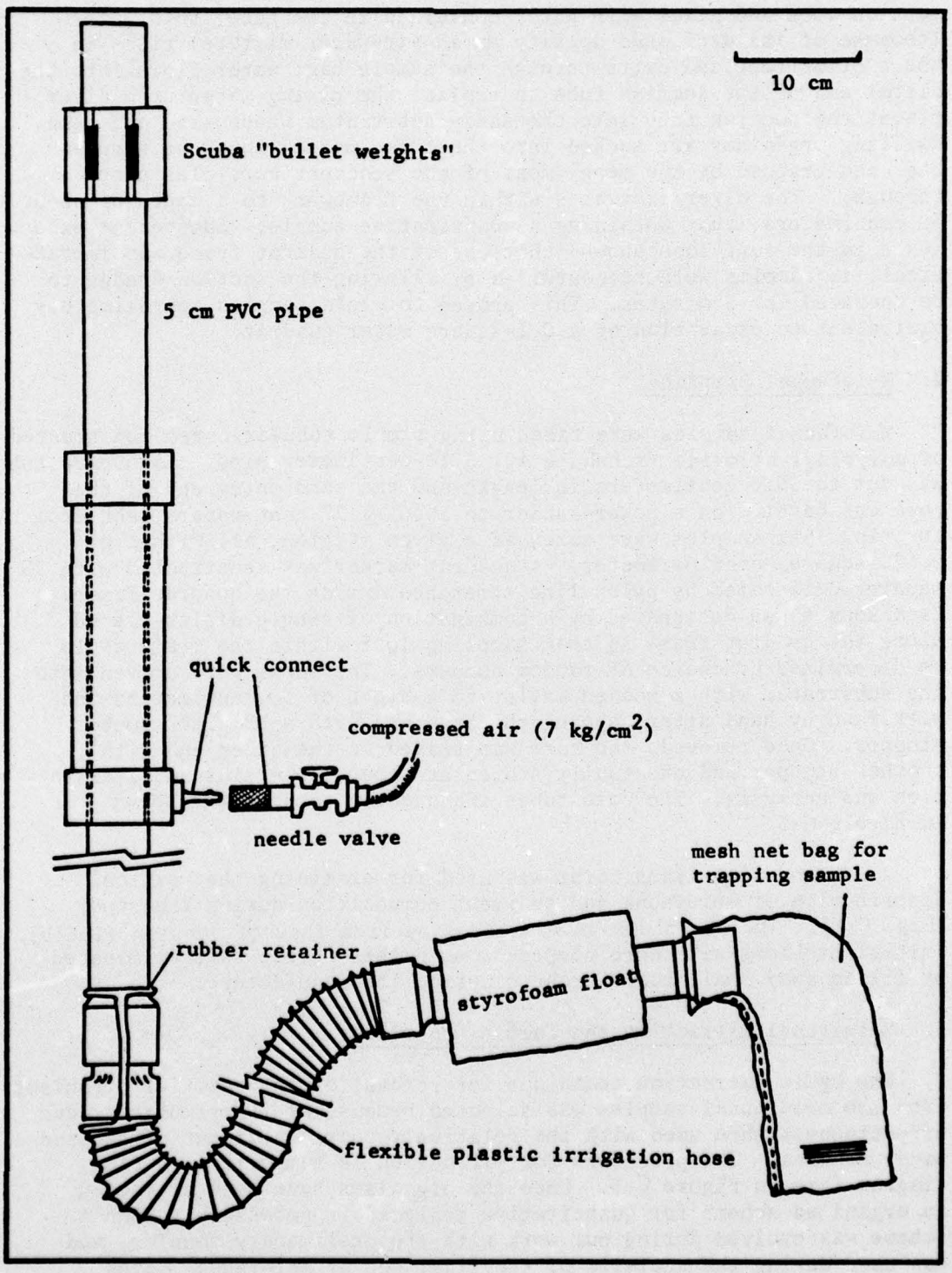

Figure C-2. Airlift section dredge.

suction tube and mixes with water contained in the tube; this water (because of its decreased density as an air-water mixture) rises in the suction tube and exits through the sample bag; water flows into the distal end of the suction tube to replace the rising water; the diver places the suction tube into the sandy substratum where sand and sand-dwelling organisms are sucked into the tube, passed into the sample bag, and trapped by the mesh (most of the sediment particles pass through). The diver excavates within the framework to a depth of about 30 centimeters, thus obtaining a quantitative sample. Subsequent experience in the surf zone showed that use of the quadrat frame was impractical, so samples were standardized by allowing the suction dredge to be operated for 5 minutes. This proved to yield samples approximately equivalent to excavation of a 0.1-square meter quadrat.

2. Meiofaunal Sampling.

Meiofaunal samples were taken using simple tubular cores constructed of polyvinyl chloride (schedule 40) 3.18-centimeter pipe. Each core tube was cut to 35.6 centimeters in length and the sand entry end of the core was beveled on a power sander to about 1.27 centimeters back from the tip. Six samples were taken at a given station, all within a 0.625-square meter perimeter. A quadrat marker was constructed with 25 squares delineated by nylon line stretched inside the quadrat frame. Each square was designated by a combination of single digits placed along the quadrat frame so that sampling loci within the frame could be determined by choice of random numbers. The cores were driven into the substratum with a wooden mallet to a depth of 30 centimeters and withdrawn by hand after capping the free end with a #8 black rubber stopper. Once removed, the core was sealed at the other end with another stopper and eventually stored at about 1° Celsius until extraction and analysis. The core tubes and quadrat locater are shown in Figure C-3.

A Jansson ring-lined corer was used for examining the vertical distribution of meiofauna and sediment composition during the study (Fig. C-4). The basic design was modified from that of Jansson (1967b). Initial problems with core compression in this device were eliminated by filing away small burrs created during its manufacture.

3. Meiofaunal Extraction and Sample Processing.

The $MgCl_2$ extraction technique for removal of interstitial organisms from the meiofaunal samples was selected because of its simplicity and effectiveness when used with the relatively coarse sediment of exposed sandy beaches. The procedure for extraction is summarized in flow diagram form in Figure C-5. Once the organisms have been extracted, an organized scheme for quantitative analysis is necessary. Such a scheme was evolved during our work with the preliminary samples, and was used during the analysis of the final set of meiofaunal cores. The basic features of this scheme are depicted in flow diagram form in

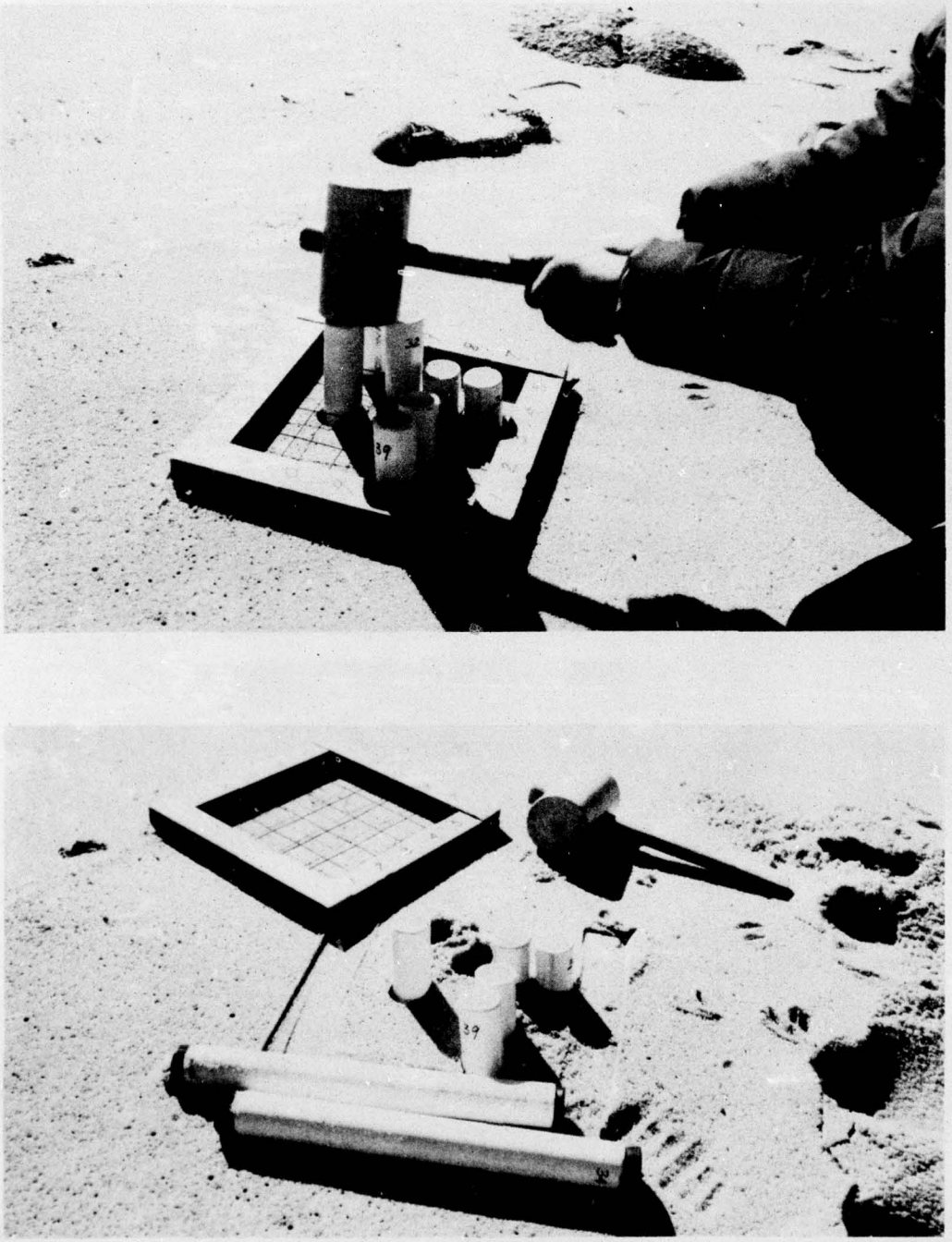

Figure C-3. Tubular meiofaunal cores and quadrat locater.

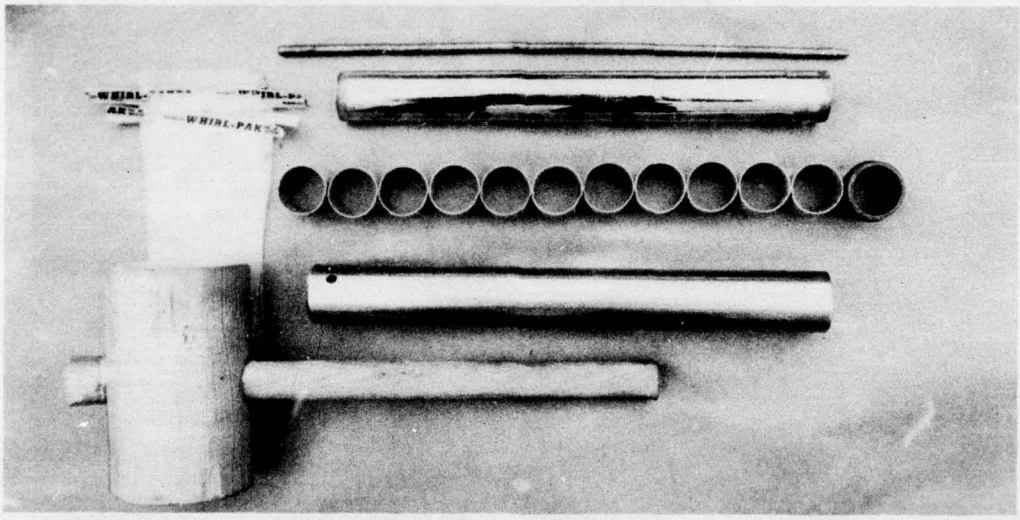

Figure C-4. Jansson ring-lined corer. The lower tube is constructed of stainless steel and threaded to accept the brass beveled tip, which serves as a stop for the aluminum liner rings. The tube on top is used to push out the rings.

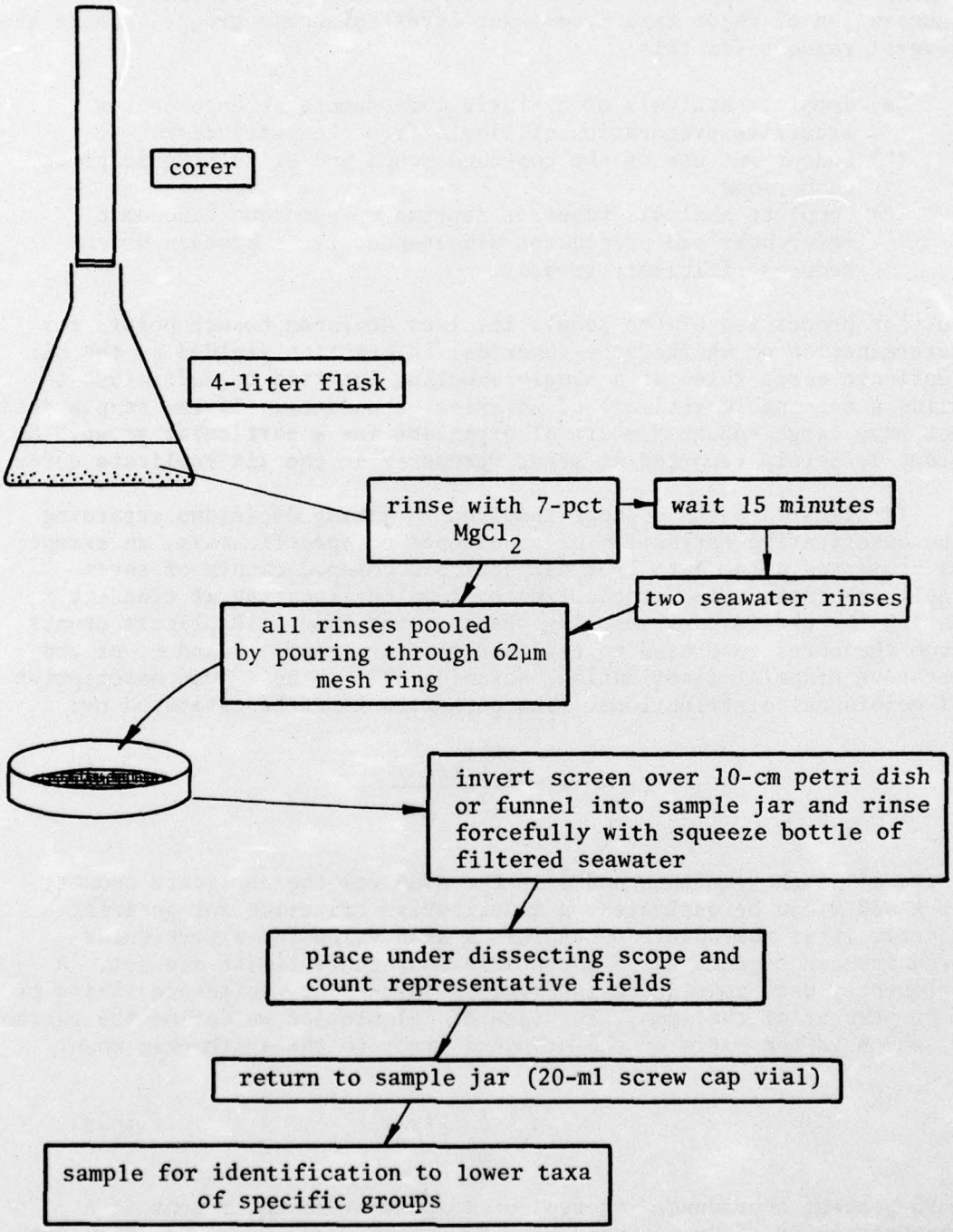

Figure C-5. Flow diagram for extraction of meiofaunal cores.

Figure 12. The approach involves separation of the processes of enumeration of major taxa from lower level taxonomic groups. There are several reasons for this:

(a) Complete analysis of a single core sample at once causes excessive evaporation of liquid from the petri dish.
(b) Concurrent use of the compound scope and dissecting scope is cumbersome.
(c) Complete analysis requires setting up numerous taxonomic references and procedures simultaneously, a process which reduces efficiency greatly.

Further processing of the sample involves decision branch points for determination of whether the numerical information yielded by the six replicate cores taken at a single sampling location is sufficient to allow a reasonable estimate of numerical abundance. If the sample does not have large enough numbers of organisms for a particular group, the group is merely reported as being "present" in the six replicate cores.

To illustrate the concept involved in making decisions regarding the quantitative estimation of abundances of specific taxa, an example is presented using data from harpacticoid copepod counts of seven replicate cores taken at the 1-meter sampling location at transect A during the preliminary sampling phase of the study. Replicate counts from the cores were used to estimate the parameters, k and x, of the negative binomial distribution, assuming this to be a good description of meiofaunal distributions. The parameter k can be estimated by:

$$\hat{k} = \frac{\bar{x}^2 - (s/n)}{s^2 - \bar{x}} , \qquad \text{(C-1)}$$

where s^2 is the variance and $\bar{x}$ is the mean for the replicate counts. If $\hat{k}$ and $\bar{x}$ can be estimated, a quantitative criterion for deciding whether it is reasonable to express a mean value for a particular organism can be derived if acceptable confidence limits are set. A frequently used confidence interval is 95-percent confidence limits of ± 40 percent of the mean. For ease of calculation we define the variable D, which is the ratio of the standard error to the arithmetic mean:

$$D = \frac{1}{\bar{x}} \; s^2/_n . \qquad \text{(C-2)}$$

A 95-percent confidence interval of 40 percent is equivalent to a standard error of 20 percent, so D is set at 0.2. D can be calculated for a negative binomial distribution according to:

$$D = 0.2 = \frac{1}{\bar{x}}\frac{\bar{x}}{n} + \frac{\bar{x}^2}{n\hat{k}} \quad . \qquad \text{(C-3)}$$

For the example described above, we know that $n = 7$, so rearranging equation C-3, we obtain:

$$0.28 = \frac{1}{\bar{x}} + \frac{1}{\hat{k}} \ ,$$

which expresses the quantitative criterion for deciding whether or not the group in question can be estimated with the required precision--the sum of the reciprocals of $\bar{x}$ and $\hat{k}$ must be less than 0.28. Table C-1 shows the results of application of this principle to the counts from the preliminary samples, and compares results from the computation of means, standard errors, and 95-percent confidence limits from log-transformed data. Using either the criterion derived under the assumption of a negative binomial distribution or the direct computation of a 95-percent confidence limit using transformed data, the first three copepod species in the list are too few in these samples to be reliably estimated. If the number of specimens examined for species identification were increased (a total of 30 from each of the seven cores were examined), the variance and confidence intervals would decrease to the point that they would all meet the dominance criterion. However, for practical purposes, another arbitrary limit must be predetermined for the dominance criterion to function properly--the size of the subsample taken for lower taxon determination.

Table C-1. Analysis of counts of harpacicoid copepods from preliminary core sample[1].

Species	$\hat{k}$	$\bar{x}$	s^2	Geometric Mean	95-pct C.I.	A[2]	B[3]
Ameira parasimulans	0.29	22.7	226	10	430	-	-
Arenosetella kaiseri	1.21	34.2	880	20	313	-	-
Schizopera californica	3.79	71.5	1,360	57	119	-	-
Interleptomesochra reducta	7.50	105.7	1,559	98	70	+	+
species C	42.72	107.8	379	107	28	+	+
Paramesochra sp.	12.51	395.0	12,699	380	56	+	+

1. One-meter station, transect A.

2. Dominance criterion based on: $1/\hat{k} + 1/\bar{x} > 0.28$.

3. Dominance criterion based on 95-percent confidence interval less than 80 percent of geometric mean, based on log transformed data.

Cox, James L.

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Bibliography : p. 54.
This study evaluates sampling procedures and statistical methods for analysis of the fauna associated with high-energy sandy beaches. An extensive one-season sampling at a relatively undisturbed beach site in central Monterey Bay, California, was used as a basis for the evaluation.
1. Marine fauna - Monterey Bay, Calif. I. Title. II. Series : U.S. Coastal Engineering Research Center. Technical paper no. 76-14. III. U.S. Coastal Engineering Research Center. Contract DACW72-75-C-0014.

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