ECOLOGICAL EFFECTS OF OFFSHORE DREDGING AND BEACH NOURISHMENT: A REVIEW

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ABSTRACT

A review of ecological effects of offshore dredging is presented, based on literature review and personal contacts, to provide a framework for determination of need for further knowledge. In general, little concrete effort aimed specifically at the determination of effects of offshore dredging was uncovered, although basic ecological works that are generally applicable are available. Much additional research of basic, but practical, orientation is needed to approach full understanding.

Report shows that the beach may be divided into three zones on the basis of moisture and biota found, and describes the possible effects on these biota resulting from offshore dredging and deposition of sediments on a beach.

Background descriptive material and impacts on both offshore dredged areas and nourished beaches, and suggestions for further research follow. A selected bibliography is included.

FOREWORD

This report, the first of a series, was prepared as a part of the Coastal Engineering Research Center (CERC) research program on the ecological effects of dredging sand from offshore borrow areas for beach nourishment and erosion control. It resulted from a literature search and state of knowledge study carried out by the University of Southern Mississippi under Contract No. DACW-72-71-C-0001 with CERC.

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At the time of publication, Lieutenant Colonel Don S. McCoy was Director of CERC; Thorndike Saville, Jr. was Technical Director.

NOTE: Comments on this publication are invited.

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I. INTRODUCTION

This report examines on two principal phases of interest to the Corps of Engineers: Effects upon the environment of (a) the removal from offshore areas of parts of the substrate, and (b) deposition of these materials ashore, primarily for nourishment or development of beach areas.

1. Aims and Objectives.

To provide a frame of reference for the remainder of the report, certain aims and objectives should be stated. Specifically they are to:

(a) Review ecological knowledge pertinent to offshore dredging and beach nourishment by examining, digesting, summarizing, and interpreting work completed or in progress.

(b) Delineate and discuss areas of insufficient knowledge where research is needed for rational planning.

(c) Suggest specific and general long- and short- range research projects needed to serve as bases for future action.

(d) Discuss possible management of commercial dredging contracts to reduce dredge damage.

(e) Determine possible beneficial ecological aspects of dredging activities.

(f) Provide an annotated bibliography.

In pursuing these aims, it was found that little work directly pointed at offshore dredging or beach nourishment has been accomplished. Nonetheless, many works provide some bases for decisions connected with these activities.

The study also has turned up many areas where research is needed. Research to be accomplished depends on a review of methods, instrumentation, and development of principles. Ecology is a relatively young science. It is only now coming into its own as a quantitive science distinct from natural history.

2. Compilation.

The literature in a field as wide as ecology is scattered and voluminous. Important papers are published in journals, major and obscure, in more than a dozen languages, and under several disciplines—geology, biology, chemistry, biochemistry, engineering, and others in addition to ecology itself.

Three catagories of aides have been used: (1) professional abstracts (*Biological Abstracts, Oceanic Index, Water Pollution Abstracts,* and others); (2) review papers with comprehensive bibliographies; and (3) authorities familiar with the more important literature sources.

In addition to searching back an average of 6 years in the abstracting series where available, certain classic works (e.g., Pearse, et al., 1942) of earlier periods that have set standards and provide bases for more recent work have been consulted. The bibliographies included do not reference standard textbooks of marine biology or ecology, because these are easily obtainable, are generally not specific, and are often outdated.

Much accomplished research takes 2 to 10 years to get into the literature. Thus, even a search of the existing literature may not reflect a true review.

To find the more outstanding references, personal interviews were conducted with scientists in Washington, D.C., and along the Atlantic coast, and the West coast and Hawaii. These interviews, backed by correspondence as necessary, provided a feel for the current status of research. Additional contracts were made at professional meetings and during academic duties.

This review showed that many of the projects are on the mechanical-descriptive level; little study was designed for the elucidation of principles. Much of the research is more technical than scientific. Many reports are merely raw data.

3. Complexity of the Problem and the Need for Broad-based Knowledge.

Ecology attempts to consider the whole biotic and abiotic environment, and the interrelations existing between its various components. We have much good work, as exemplified in the bibliography to this report, but we have an overconcentration in some fields at the expense of others. And, thus, we do not have a complete, or nearly complete, ecological picture of many, if any, ecosystems.

In the present problem—beaches and offshore sandy areas—the ecosystem problems are relatively simple compared with those of an estuary or the Continental Slope. It is surprising, then, that this ecosystem grouping has not been more intensively studied.

A list of research areas that would lead to usable knowledge follows immediately below, but is discussed later.

(a) Detailed studies of substrate composition, spatial structure, and stability in offshore sand and gravel and on beaches.

(b) Concomitant or immediately following studies on the relationships between substrate and overlying water column in regard to exchange and cycling of such substances as organic carbon, silicon, phosphates and nitrates, sulfur compounds, oxygen, carbon dioxide, and others.

(c) Studies of local currents and other physical features.

(d) Inventory studies of faunal and floral, constituents of substrate and overlaying columns, on as quantitative a basis as is feasible, to provide information on stock components and biomasses.

(e) Biotic-abiotic interdependency studies leading to knowledge of niches and changes of biotic community composition with changes in the physicochemical environment.

(f) Bioeneregetic (*tropic-dynamic*) studies of material and energy flow through communities, including group and individual contributions and drains, life histories, growth rates, food webs, and recognition of *key* species or groups leading to development of balance sheets and specific structural-dynamic information.

(g) Model studies.

(h) Studies in social and technological sciences.

4. Value Judgements and Reconciling Conflicts.

Once the ecological studies are well in hand, the task has merely begun. The basic ecological work must be layered with such sociological disciplines as the political, social, economic, aesthetic, cultural, and historical that may apply in the study area. Each of these must be examined as systematically, as objectively, as quantitatively, and within as well-developed a framework, as was the ecology. This is probably the more difficult undertaking, for here we deal with people.

An operations-research approach is a necessity. Inputs from the natural and social sciences should funnel into a coordinating group consisting of an abstract-sciences team of computer, statistics, and model-development specialists, ecological mentors, and representatives of the social groupings, and then to a decision-making body. Public relations are extremely important.

II. SYNOPSIS OF ECOLOGY FOR APPLICATION TO OFFSHORE DREDGING AND BEACH NOURISHMENT

1. Synopsis of Background Ecology.

There is a dearth of the ecological facts needed for decision making before making environmental modifications. Definite needs have not been met, and are not being met by most ecologists studying the environment.

Investigation of over 1,500 references showed only a small amount of research directed specifically at the "offshore dredging-beach fill" problem. This was expected because the use of offshore borrow pits is relatively new. On the other hand, it was expected that studies made for other reasons or in other situations would provide information applicable to the problem and or provide background knowledge. This has proved to be so, for the most part, but definite and important gaps still remain. Although beaches and the Continental Shelf have received a share of research attention commensurate with their apparent importance to man, much of the beach work has been more natural history than dynamic ecology, because hard data was lacking, and much of the work has been uncoordinated.

Search of the literature and interviews with persons engaged in coastal ecological work showed a need for: (a) coordination of effort, (b) directed imagination to accompany quantified raw data, (c) interdisciplinary work, and (d) the application of methods applying broad, general survey data to specific locations.

Knowledge of our coastal ecosystems is incomplete. Perhaps estuaries, extremely complex ecosystems in the coastal areas, are best understood as a result of recent concerted efforts. The estuarine work, and the methods and concepts derived from that work, should be applied to the more exposed beaches and offshore dredging sites.

There is little direct evidence to serve as guidance in predicting the effects of offshore removal of sand and gravel or of placing these materials for beach nourishment. The information available is broadly general, incomplete, and often conflicting. It is necessary to consider basic ecological mechanisms and principles plus applicable data gleaned from studies of navigation, dredging, and beach fill projects. The end result, while not as precise as would be hoped, turns out to be predictions based on more thorough study of principles and observations.

Two significant generalities can be stated at this point: (1) *There is no objective reason, uncovered in this study, why offshore dredging should not be carried out, providing it is carried out with certain precautions to be enumerated; nor is there any reason discerned, ecologically speaking, why the offshore material should not serve satisfactorily as beach nourishment material.* (2) Although the preceding statement, is couched in negative terms, it is based on a comprehensive and detailed review, which has as its major shortcoming that knowledge available (with few exceptions) deals with generalities, and detailed, local, on-the-scene investigations must still be considered as necessary preludes (and postludes) to cover local idiosyncracies and special local conditions. The remainder of this section is an overview of the type of ecological data considered in evaluating effects, and predicting the effects of action. It is a synthesis of material obtained from many sources and many research studies made in the past 40 years. Not all of this material is documented in the accompanying bibliographies, due to space limitations. The bibliography includes a selection deemed important as indicating trends, representing classic works, works with above-average bibliographies, reviews, or works especially pertinent to the current problem. Such a selection is necessarily subjective and reflects the mood and interests of the compiler.

There is in any ecological system a mass of obscuring detail. An attempt is made in the following summary of ecological background to provide a frame for discussion to emphasize the main flow.

2. Mainstream of Marine Coastal Ecology.

a. The Inorganic Environment. Ecologically, the physical environment—the substrate and the overlying water column with their contained characteristics—is important to organisms because it provides a source of support, attachment, shelter, and food. Substrate and water are important to life, as is the complex of interchanges between the two. Of particular importance are interface phenomena between water-air, water-substrate, and layers of substrate.

Since sandy substrates are of chief concern here, two fundamental substrate situations of great ecological importance are noted—unstable, shifting sand beds, and more stable, nonshifting beds, usually with a greater admixture of silt, clay, or other material. Dredging on unstable beds could be expected to have a less harmful effect, both short-range and long-range, than would dredging on the nonshifting bed, though effects on shifting sand areas would be more difficult to predict.

b. The Inorganic-organic Environment. Both the substrate and the water column have nonliving organic complexities due in large measure to biotic activities. These range from presence of phosphates, nitrates (and other nitrogenous compounds), and silicates, to dissolved organics—the important *external metabolites* of earlier British authors.

c. The Biotic Environment. The world of animal and plant life is a world of energy and material transformation and of cyclic phenomena, as life is a continuum.

The impact of engineering activities on this part of the environment has great import. To be considered are life stages, breeding and feeding conditions, environmental adaptations, and sustainable ranges of conditions for dwellers within and on the substrata, in the ecotone layer of water immediately above the bottom and filled with life equally dependent on bottom and water, or in part, in the remaining water column. Migratory capacities to repopulate disturbed areas must also be considered as well as occupation of niches.

What is the import of life in the water column above the bottom? The primary source of all energy is the sun. The primary producer or energy convertor is the green plant. All other living things depend on plants as an energy source. In the sea most of the primary energy production takes place near the surface as a result of photosynthetic activities of chlorophyll-containing, microscopic, planktonic algae. These marine algae are responsible for nine-tenths of the world's energy conversion. Secondary sources of conversion in shallow water are attached macroscopic algae (kelps and others) and rooted higher plants (eel grass and others), and to a lesser extent, (and less well-measured extent), benthic bacteria.

The algae that convert the sun's energy are consumed by small animals adrift in the water; or the algae sink to the bottom where they are eaten by bottom dwellers such as oysters, clams, some crustaceans, and annelid worms; or the algae are directly decomposed by bacteria. Assuming they are eaten by small animals, these in turn are eaten by larger consumers (predators), and so on in a complex food web with large energy losses at each step. Both the producers and the consumers continually are giving off into the water excretions and secretions which contribute to the organic part of what was earlier termed the inorganic-organic environment. Some organic materials remain mixed or dissolved in the water; much rains down on the bottom to become part of the substrate. This material is particularly concentrated on the water-substrate interface and is usually measured as dry weight of carbon.

On the bottom, the material is used directly as food by bottom-dwelling animals, which also continuously contribute their share of excretions and secretions. Eventually these and the dead bodies of larger plants and animals—consumers and producers—will be decomposed and converted by bacteria, freeing, expecially, phosphates, nitrates, and silicates for use by photosynthetic algae in reinitiating the energy cycle.

Study of plankton has, for years, fascinated marine biologists, and various collections have been analyzed in attempts to typify areas. Plankton data are available from the National Oceanographic Data Center, and the collections may be deposited at the

Smithsonian Sorting Center, Washington, D.C., or stand on dusty shelves in the marine laboratories of the world. Correlations may be made between the egg and immature stages of fishes and invertebrates in the plankton, and biomasses of the adults in given areas may be calculated.

Thus, for large-scale areas, including potential dredge areas, data are available on the characteristics of the overlying water masses and their biota, with some correlatable data on bottom-dwelling organisms. These data, however, must be supplemented with detailed local studies to be useful from an engineering standpoint. More detailed or more specific follow-up studies are needed.

3. Bottom Inhabitants and Associated Organisms.

Bottom-dwelling organisms, from bacteria to bottom-dwelling fish would bear much of the impact of dredging activities.

Sandy offshore bottoms that support a varied biota may be divided into two categories. First, there are those areas composed of shifting, usually pure, sand. This habitat is usually sparsely populated by animals that are mobile, relatively wide-ranging, and agile. Community structure is neither permanent nor intricate. Second, there are the more stable areas, usually composed of sand with silt, mud, or detritus, where the biota is richer, more varied, and more permanent. Though either catagory might be dredged this second habitat is of primary concern, for it presents greater ecological problems, and is of greater ecological importance.

Associated with the sandy substrate, especially the more stable, are a host of microscopic, semimicroscopic, and macroscopic organisms which are generally sessile and can best be sampled with a *grab*. A *grab* is an instrument somewhat like a small steamshovel bucket, which bites a predetermined volume of bottom material. Such sampling is known as *quantitative bottom sampling*, and from it is derived an estimate of *bottom biomass*. This estimate is often too low, but as the method is standard, it provides an index for comparing different areas. Such grab-derived estimates of richness or poverty of areas are available for broad comparisons from the National Oceanographic Data Center.

The oragnisms commonly taken by the grab on sandy bottoms are annelid worms, echinoderms, crustaceans, and molluscs in addition to the omnipresent bacteria, algae, and protozoans.

Most of these organisms lie on the bottom or are shallow burrowers. They serve as food for higher organisms including fish, and are responsible for the presence of the higher organisms. Several commercially important molluca such as surf clams and quahogs also fall in this category.

Immediately above the bottom, in the lowermost water layers, is a transition zone rich in fauna, known as an *ecotone*. This is an area at the junction of two interfaces presenting the ecological advantages of both, as the border between a field and a woodlot in a terrestrial situation. Here are found many bottom-dependent fishes and crustaceans which feed on the smaller burrowers, crustaceans, and smaller fish. Of these, the flounder, other flatfish, crabs, and shrimp are of great importance to man. Commercial fisheries operate on these sandy grounds.

4. **Other Significant Factors in the Living Environment.**

The offshore environment is dynamic and ever-changing. Seasonally it is characterized by stocks of migrating fish and numerous eggs and larvae of pelagic and bottom-dwelling organisms. Thus, the picture gained as a result of a short-term study probably would not typify the area. A study must consider the seasonal and cyclical year-to-year aspects. For an accurate picture of the biota of an area, it is also important to use a wide range of sampling gear designed for capture of the variety of types of life to be expected—both mature and immature—and to quantify the results.

A wide range of information concerning the life of a marine area can be obtained from the National Oceanographic Data Center, or major marine laboratories, in the form of raw data covering such characteristics of the environment as productivity and bottom biomass.

Attempts to piece together all the parts—from primary productivity to final consumption and the various ecosystem cycles—have been too few and are badly needed. Such attempts could provide a better ecological picture, bring out the more elusive interractions between the many components, and reveal the possible effects of man's interference. Such attempts can provide practical, usable information on which to base action, monitor effects, or evaluate impacts. Such syntheses that have been attempted have been largely in estuaries or sheltered bays. Offshore ecological syntheses are lacking.

The major purpose of this introduction to ecological continuity is to provide a sense of flow or integration to the consideration of ecological effects caused by interference with natural conditions. Thus, interference with worms could be as important as interference with fish or clams or other organisms of direct importance to man through changing the food-web flow.

5. **Ecological Impacts of Offshore Dredging.**

It must be recognized that the bottom provides homes for innumerable living organisms that are parts of energy webs culminating (from man's viewpoint) in commercially usable species.

Anything that affects the bottom, will necessarily affect or have impact on the ecological balance and ultimately man's use of coastal areas.

Dredging involves disturbance and removal of parts of the bottom. This affects the environment. What are the effects produced and how great are they? Several aspects should be considered.

a. Mechanical Disturbance. The most obvious effect on the offshore environment is mechanical, due directly to removal of substrate and indirectly to redeposition of suspended sediment and turbidity. Since a varied fauna depends on the substrate, removal or disturbance of the bottom material will reduce the fauna. The effect on the total system depends on the magnitude of the disturbance created. Factors to be considered include (a) nature of the grounds—shifting or stable, (b) type of dredging operation, (c) extent of dredging and amount of substrate removed, (d) temporal nature of the disturbance, and (e) ability of disturbed biota to withstand or recover from the disturbance.

These factors can be discussed separately to highlight needed research and indicate certain restraints to be exercised in the interim.

The use of shifting rather than more stable beds as a borrow site has several ecological advantages, as well the practical advantage of supplying clean sand since these beds are usually composed of coarse, pure sand in contrast to fine sands with admixtures of mud, silt, detritus and similar components of the more stable beds. Plants and animals are sparse on shifting beds, and are either transitory or highly mobile. These communities are less organized and usually are of less commercial and ecologic importance than those of the more stable bottom. Also, physical effects of dredging could be erased through filling, as indicated by the quick filling of borrow areas between reefs on some relatively shifting sand areas off Florida. (Walter R. Courtney, personal communication.)

Selection of such sites could be determined by grab samples and coring. Underwater towed observation vehicles such as the Remote Underwater Fishery Assessment System (RUFAS), developed by the National Marine Fisheries Service (NMFS), for faunal assessments could be used for rapid scanning before designing a complex survey system to identify bottom sediments and benthic animals.

Dredging shifting sands could be much more extensive without ecological harm than could operations on more productive, stable beds. This leads to the conclusion that *even extensive dredge operations on beds of shifting or unstable sands would have little direct long-range ecological effect on the immediate area.* The role these shifting sand areas play in natural beach nourishment or in nourishment of other areas is usually unknown, but should be determined before dredging.

Dredging on stable beds is apt to be more serious because of the richer, and more diverse nature of resources and the lesser mobility of most of the components of the biota.

It is on these more stable bottoms that shellfish and commercially important finfish occur in large numbers, because the more permanent and higher organized food-web structure attracts more fish. Although studies have been made of recovery of channel dredge areas and harbors (Reish, 1954), little helpful information is available about the recovery of stable offshore dredge areas, either physically or biologically. Minor excavations can hardly be viewed as serious; indeed they may be beneficial. Follow-up studies on minor excavation sites would provide needed information for evaluation of the effects of more extensive excavation. Expecially needed are data on (a) rates of filling of borrow areas under a wide range of conditions and bottom types, and (b) rates of repopulation of borrow areas by biota. In view of the needed research, *extensive dredging in stable sand areas should be preceded by studies on effects of minor dredging and collection of more complete ecological data before and after dredging.*

The type of dredge used is another factor to be considered. Hopper dredges are suited to offshore conditions, and appear to inflict the least ecological harm. To shallowly dredge sand deposits over extensive areas, and allow a layer of sand to remain might cause less harm than to dredge deep pits covering a limited area. Deep borrow areas hamper trawling and harm level-bottom communities. The disturbance would be spread over a greater area because a greater surface area would be involved in obtaining the same amount of material. Safeguarding against opening a different interface through removal of all of the sand and avoiding creation of precipitous sides of deep pits would result in a better habitat. The amount of sand that should be left to prevent damage would depend on requirements of the species in the area and would vary. Spreading dredging activities to avoid opening new or different interfaces and creating deep holes is practical with hopper-dredge operations.

The maximum size of the offshore dredging operation could be based on a proportionate removal of a deposit. Information is available from CERC of the sand survey of the Inner Continental Shelf to estimate amounts to be removed. Unfortunately, the quantitative effects of dredging on the fauna, quantitative substrate requirements of the fauna, or the adaptability of the fauna (long- or short-term) to dredging and substrate removal activities are unknown. Studies of minor or restricted dredging would provide an initial basis for predicting the effects of larger scale operations.

The amount of dredging and substrate removal required for beach-nourishment projects probably would not be harmful in most situations. Situations could be readily identified as potentially harmful before operations began. Commercial removals, on the other hand, might involve: (a) larger areas, (b) larger volumes, and (c) long-term use of sites. Commercial removal, if by leases or permits, should be controlled by detailed dredging specifications that should be strictly monitored and enforced. However knowledge on which to predict effects of extensive and continued offshore dredging is lacking. If commercial sand dredging operations are concerned with removal or extraction of minerals from the sands, then tailings and potential pollutants would also have to be considered. This, however, is a separate problem.

The two factors for which information is lacking and on which reasonable predictions of effects of extensive dredging activities must be based are: (1) fill-in rates or physical recovery rates in borrow pits, and (2) abilities of biotic components to withstand or recover from dredging activities. Solutions of these problems do not require complicated techniques, or complex instrumentation. Both are uncomplicated observation-type studies. However, dredging operations of various intensities in varying areas must be studied. Knowledge would result from monitoring studies made during and after dredging.

b. Turbidity and Sediment Effects. Sherk and Cronin (1970), have summarized the knowledge of turbidity and sediment effects in their bibliography, "The Effects of Suspended and Deposited Sediments on Estuarine Organisms." This work reveals little concrete, long-range detrimental effect due to either turbidity or sediment. The authors were concerned with estuarine areas, but the effects should be even less important in offshore areas, though perhaps less predictable.

Offshore dredging areas should lie beyond the oyster beds, of prime concern in silting and smothering studies, and far beyond coves and quiet bays where settling effects would be expected to be most pronounced and dangerous. Offshore sands and gravels, coarser than the average channel dredge material in inshore areas, would not cause such siltation effects as are caused by finer sediments. Scouring effects, however, may be serious where strong currents sweep coarse material across reefs. (Levin, 1970). The general conclusion, based upon available knowledge is that *turbidity and sediment effects on marine organisms from offshore dredging of sand and gravels are to be considered generally insignificant or short-term.*

Peculiar local bottom-current effects on sediment transport should be monitored on individual projects.

c. *Miscellaneous Effects and Considerations.* A prime concern of many authorities, (for example, Loosanoff, 1962, p. 13, Thorson, 1964, p. 99, and Wilson, 1958) is the effect of change in water clarity (effect of suspended solids) and the effects of bottom deposits on larval development and particularly larval settlement. Larvae of bottom-dwelling invertebrates have subtle requirements that must be met before the larval stages will leave the water column, settle to the bottom and transform into juveniles. The nature of dissolved organics in bottom deposits and other unknown conditioning factors influence the settling of larvae. Conclusive evidence for or against dredging effects on larval stages is not available. Periods of greatest larval incidences in the water column of those species important in the bottom communities should be observed. Ideally, dredging periods should be adjusted to allow settlement to take place with least interference.

Other factors of concern are effects of seabed topographic changes created by dredging, and other effects due to deepening areas. Both effects can be mitigated by shallow stripping operations when desirable. Manmade refuges through creation of deepened areas provide habitats for fish.

d. Dredge Operation—Monitoring and Management. Although no strong basis for disapproval of dredging for sands and gravels in offshore areas has been found, steps should be taken to include safeguards in dredging to ensure environmental quality or to meet other special conditions.

Proper environmental dredging management should include precautions to control adverse sediment effects by taking advantage of tidal currents and littoral currents to guide sediments put in suspension by dredging. Use of currents to control direction of suspended sediment flow could improve the environment through deposition of the sediments selectively and through directed dispersal of released nutrients.

Where green plants are present, water clarity during daylight hours is important for maintenance of primary productivity, and dredging only at night may be necessary. Conversely, studies of faunal day-night activity may show that dredging at night may harm the animal community, and dredging may have to be restricted to daytime hours. This emphasizes the need for many local studies.

Other controls could increase benefits by retention of an agreed percentage of the sand substrate, bypassing concentrations of valuable living resources, and otherwise planning dredging for ecosystem protection and enhancement, with the least cost and least harm.

Monitoring can be a positive rathern than a negative adjunct to dredge operations. As a part of dredging management, monitoring can supply on-site information to aid future management decisions. In a sequence of research involving *before, during, and after* studies, the monitoring team would ideally be the *during* research team, for the benefit of the operation and longer range research. Monitoring could and should be used much more.

6. Ecological Effects of Deposition of Fill (Nourishment) on Sand Beaches. Here the focus changes from offshore dredge sites to beaches where dredged material is deposited for beach restoration of nourishment. The same general ecological cycles and progressions—from the primary producers through the upper order carnivores, with bacterial breakdowns and replenishments of nutrients such as phosphates and nitrates—take place on the beaches as well as offshore, though details may differ.

Before considering the effects of depositing fill on the beaches, the normal ecosystem should be considered. Many studies of the general features of beach life have been made, beginning with the classic work of Pearse, et al., (1942) on North Carolina beaches and continuing through Dexter (1967, 1969a, and 1969b) and Trevallion, et al., (1970). Trevallion, et al., provide an excellent review of research, a comprehensive bibliography, and a comparison of world-wide beach features.

The beach surface presents a harsh environment. Temperature of the sand on a hot sunny day may be extremely high, but less than an inch below the surface, the temperature is lower and more conducive to life. Thus, most permanent residents of the upper parts of the beach are burrowers, and come out primarily at night. As in most harsh environments, the fauna and flora are limited in number of species, often in number of individuals, and the inhabitants include many examples of extreme adaptation to a specialized way of life. The beach not only has a harsh temperature environment, but also is constantly shifting and changing character which makes permanent residence difficult without special adaptations. Present are: blowing sand, bright sun, winds and rains, wave action, and predation from within the beach, from the sea, and from the dunes. The food chain is long—from bacteria through the usual marine categories, principally algae, crustaceans, mollusks, annelids, and echinoderms, and also including reptiles (lizards and snakes), birds, and man. Man, however, interferes little with normal workings of the beach community; he occupies the surface when most community members are not likely to be abroad.

For convenience, the beach environment is divided into component zones or parts, each with its own principal faunal and floral components. Dunes are not included.

a. Beach Zoning. Trevallion, et al., (1970), provide a scheme of zoning well suited for beach discussion and for further beach research. On the basis of fauna, they divide the beach into upper, middle, and lower zones, recognizing that there is a mobile element of the beach population not restricted to any zone. They state that there is amazing world-wide similarity in the faunal types occupying these zones.

The upper zone is characterized by populations of ghost crabs (*Ocypode*) and sand fleas or amphipods (*Talitridae*). This zone, dry except in storms, is backed by the dune areas, and reaches slightly above the waterline. In addition to crabs and amphipods, predatory and scavenger beetles and other transient animals are found in the upper zone. Typical inhabitants are high-order predators. Plants are scarce or absent, and this zone is dependent for production on lower zones or the dune areas. Wrack along the debris line provides some of the food and also shelter for many species. Bacterial decomposition of stranded fishes and algae takes place here, and provides most of the nutrients required for the production cycle. Animal activity cycles can be well traced by observing the marks left in the loose sand (Bider, 1968), providing an excellent way to study behavior and predator-prey relationships. The substratum sand in this zone is usually finer than that in the zone of uprush, but coarser than that of the dunes.

The middle zone is characterized by annelid worms, the small coquina clam, *Donax*, the mole crab *Emerita*, and various other crustaceans and mollusks. Most are found where the spent waves wash the sand; they alternately burrow and are uncovered by wave action. Most are excellent and rapid burrowers, an adaptation necessary to preserve their position where food is carried to them by the water. A number of interstitial animals are also found here, feeding among the sand grains on bacteria and unicellular algae. The zone contains an admixture of herbivores, primary carnivores, and some high-order carnivores such as the mole crab. Flora consists mainly of bacteria and unicellular algae; these play a large role in beach production. Humm, in Pearse, et al., (1942), discusses bacterial roles at some length. Habits and action of coquina and the mole crab have been thoroughly studied and reported. The annelid worms in this zone, are mostly tube dwellers, and are partly or wholly buried in the sands except when feeding. This zone is particularly harsh due to environmental fluctuations, and often is oxygen-poor. Thus, here is found a paucity of species, though large numbers of individuals, and species that are often curiously modified to meet the particular environmental requirements. As in the upper zone, the animals of this zone are not only agile and mobile, but are also capable of resisting long periods of environmental stress.

The lower zone, the zone under water all or most of the time, contains a relatively rich and varied fauna. Burrowing crustacea, such as the mud shrimps *Callionassa* or *Eupogebia* are often found here as are the sand dollars, *Mellita,* and many snails. In the water column, are small fish and crabs of the genera *Callinectes, Arenius,* and *Ovalipes.* A number of kinds of tube-dwelling annelid worms are also present. Most of the worms and carnivores rely on food washed in from the sea or off the beaches by waves. Though bacteria and unicellular algae contribute some primary productivity, it is probable that most of the production takes place in the sea, and the producers are swept in with the waves.

This then is a broad picture of the normal fauna and flora of a typical sand beach, with a nutrient and energy cycle not unlike that of submerged seabeds of nearshore waters, except that it is dependent to a greater extent on adjoining areas for products of primary production. The beach is also more difficult to study because the faunistic and topographic borders are less well defined.

b. Beach Stabilization. The beach is constantly changing. It is changed by waves, tides, longshore currents, wind, and man's activities. There are, however, stabilizing factors. The sum of all the interstitial (between-grain) fauna, such as the worms and crustaceans may provide a cementing action that is an efficient factor in holding beach sands together.

In addition, where present, beach grasses are holders of the substrate. Unfortunately, tourists like beaches composed of clean, clear sand, thus, the interstitial animals, which no one sees and about which few are concerned, remain the primary cementing agents.

c. *Biotic Dependence on Physical and Chemical Characteristics.* As elsewhere, there is a strong correlation between the types of life found and the characteristics of the substratum. This is marked in the lower zone of the beach that is especially rich in interstitial fauna. Such sediment factors as grain size, polarization, latticework structure, and even mineral content influence the fauna. In general, the smaller the sediment grains, the smaller the interstices, and the smaller the individuals of the fauna. Correlated with fine sand is a decreased capacity for holding oxygen. Organic content is also important in settlement of the larvae of the tube-dwelling worms and other groups. The bacteria and unicellular algae are usually present as films or patches on and around the sand grains. Differences in available surface area and in size of interstices markedly affect these organisms, which are important in primary productivity and as food for the herbivores.

d. *Ecological Effects of Deposition of Fill (Nourishment on Sand Beaches).* At first glance it would seem that to dump quantities of sand on top of the normal beach surface would have serious consequences on the biota. Mechanical disturbance alone would seem to have far-reaching disruptive qualities. But this is not entirely true. It has been shown that the animals of the beaches are accustomed to change—incorporating change into their daily lives. Further, most faunistic members are agile and capable of escape from or lengthy resistance to adverse conditions. Moreover, migrations from adjoining sides of the nourished area are likely either in the form of adult or larval organisms coming in to fill empty niches. Studies of succession in areas nourished with material taken inland, show a rapid invasion of fauna and little lasting harm is apparent.

The least effect would ensue if the sand placed on the beach resembled the original sand in grain size and other physical characteristics. The effects of change in profile could also be important. The three zones outlined earlier, are defined not only faunistically, but in relation to water levels—above water, water-land interface (alternately above and submerged), and totally submerged. Altering the profile would necessarily alter the proportion of surface available for each zone; hence, it would alter the proportion of fauna typifying each zone, with unknown, but possibly important, effects on the environment.

To summarize, no far-reaching or long-lasting effects from offshore dredging can be foreseen, nor can detrimental effects be foreseen from deposition of offshore sediments as beach fill. Further research is needed before the more subtle relationships that might prove disastrous are completely known. But, in the gross view, the conclusion stands. Design and monitoring of dredging operations and fill projects should receive careful attention to safeguard against damage, and to continue *before, during,* and *after* studies.

III. ECOLOGICAL ENGINEERING

If offshore sand dredging coupled with beach fill can be looked upon as a single operation, designed specifically and uniquely for improvement of the coastal environment, a major breakthrough could be gained in the improvement of the environment. By thorough planning, the synthetic ecosystem developed by beach nourishment could result in the establishment of permanent or temporary deepwater refuges in the borrow areas offshore combined with restored beaches for recreation and natural community succession inshore. Other bonus benefits could be anticipated as accompaniments.

Organizations whose mission require modifying the environment have lately been on the defensive. With intelligent multidisciplinary investigation beforehand, many engineering modifications of the environment could be turned into positive environmental enhancement programs. Such is the meaning of the term *ecological engineering.*

In the course of dredging or filling for purposes other than beach nourishment, consideration should be given to the chance for environmental improvement. This entails viewing the specific engineering undertaking from all possible angles–going beyond the strict initial purposes of the project to a total consideration of environmental, engineering, and social aspects.

Where navigation channels must be dredged and the spoil is not used for beach fill, spoil areas might be located to improve the local conditions for little added cost. Such locations would have to be carefully planned before starting the projects, and requirements specified in advance.

Use of ecological engineering offers exciting possibilities in connection with coastal engineering. Principles of ecological engineering usually have not been applied to the marine environment.

Deepwater refuges, such as borrow pits furnish protection for concentration points of many species of fish and shellfish. Effectiveness of these refuges depends on their relation to the geographical, hydrographical, and ecological requirements of the organisms involved. Establishment of such areas should be coordinated with commercial and sport fishing interests.

In many instances, such borrow refuges would be the natural result of normal operations. In other instances, slight changes in the initial plans might increase the effectiveness of the refuge. Truly effective ecological engineering would depend on the study of hydrographic conditions in local areas and of knowledge of fish and shellfish habits and preferences in local waters before dredging.

Sediment disturbances resulting from dredging can be advantageous in ecological engineering, if planning and operations are properly carried out. Nutrients released by dredging are valuable in the flow of energy and material (food) through a community as emphasized by Cronin, Gunther, and Hopkins (1969). A natural consequence of proper dredging would be stimulation of some or all aspects of community well-being. Further, controlled or partly controlled release and direction of sediment loads could be used to stimulate specific parts of the physical and biological community.

However, Cronin, et al., (1969), warn of the dangers of possible release of harmful substances as a result of stirring up of bottom deposits. Conceivably this could be properly directed and controlled, depending on (a) the nature of the released substances,

(b) selectivity of effects, and (c) local environmental and biotic factors. An example of the usefulness of release of substances normally considered harmful from dredging disturbances, could be cited as the control of unwanted parts of coastal communities that are more susceptible to the released substance than are the more desirable organisms.

Ecological engineering should be a part of the thinking of all who are required to modify the environment through engineering or other technological practices. Often it is just as easy to improve the environment as it is to create a neutral situation or to injure the environment.

IV. RESEARCH NEEDS

Though no reports of catastrophic results of offshore dredging or beach nourishment activities have been uncovered in this study, understanding of the underlying processes of the ecosystem is still far from complete. Thus, a great amount of research remains to be done, and imaginative interpretation of accomplished research is needed.

Many of the suggestions for research offered in this section have been brought together here for convenience. They can be divided into specific short-term project studies and more fundamental, long-range studies, though the difference is not always clear-cut.

1. Short-Term, Specific, Project-Oriented Research.

Connected with specific engineering projects are certain research activities necessary to provide base lines, guide details of engineering, direct attention to unique features, and provide for practical protection or enhancement of the environment. Major among these are the familiar *before, during* and *after studies* associated with operational monitoring. With dredge and fill operations, studies of sediment effects and rates of fill of borrow areas should be made. These types of studies are well recognized, and are more or less standard.

a. Before and After Studies. Before studies in some form are generally included in environmental modification proposals. The new requirement for environmental impact statements makes necessary some prior knowledge, the gathering of which constitutes a *before* study.

Biological or ecological *before* studies traditionally require a series of samples in the area where effects are expected. Such studies are usually inexpensive, and point out obvious environmental features and either environmental danger spots or stages in operation where advantageous modifications could result, and provide some sort of a base line for later comparisons and conclusions.

Determination of *what* is present is not enough. The very important *whys* and *hows* are also needed for prediction. *Why* are the species found in the area? Are they casual users or premanent residents? Do they represent seasonal groups come to breed or key members of the ecological food or energy web? *How* did they come to be there? Is the area a favorable larval settling area, nursery ground for juveniles or other advantageious site for concentration?

All of these questions should be answered in greater or lesser detail. Also, all major levels of the energy and food cycles—ecosystem cycles—need investigation, from primary productivity through the higher carnivores to the decomposers. Implied, therefore, is a connotation of larger and more intense complicated *before* studies. Standardization of investigation methods and instruments is needed for wider use of data, and greater comparability between sets of data from different institutions. Standardization is gaining ever-increasing importance among Federal agencies. Examples are the National Marine Fisheries Service (Department of Commerce, NOAA) with their Marine Resource Monitoring, Assessment, and Prediction System (MARMAP) and the Environmental Protection Agency (EPA), with their background and environmental monitoring studies.

b. Monitoring. The term *monitoring* is currently used in two senses in biology. The first and conventional sense implies watching over an operation or activity to safeguard conformity to set criteria. The second and more recent sense implies a long-term watch over the *normalcy* or well-being of a segment of the environment. It is an unfortunate term in either sense, because of its usually negative, watchdog connotation. It is the conventional monitoring that concerns us here.

The idea was previously developed of more positively oriented monitoring where managerial and research responsibilities are included as well as watchdog activities. Successful monitoring requires sampling at frequent intervals during activities to show what effects the operation is having on the environment. Feedback of this information can then be used to document the economical and environmental aspects of the operation for use as a management guide. Monitoring personnel could gather and compile data of value in before and after correlations and interpretations in predicting effects. Monitoring that does not included research and management responsibilities is inefficient and wasteful in normal operational situations.

Sediment and turbidity studies should form a part of the *during* monitoring activities just discussed, with additional study after the operation in and around the nourished beach and borrow areas. Sufficient background on sediment studies is provided in the bibliography compiled by Sherk and Cronin (1970), to show that these studies can readily be carried out. Though not generally considered a cause of long-range harm, sedimentation should be watched for possible short-term local effects.

On the other hand, little is known about rates of filling of borrow areas. Such *after* studies are needed for complete and effective environmental management and prediction of effects in connection with engineering activities.

Fill rates of borrow pits vary greatly from place to place. Governing factors are ill defined but include: type of substrate, currents, and tides. Studies of a succession of life forms during reestablishment of disturbed communities must also accompany observations of physical factors.

Observation of filling can be readily accomplished by use of scuba. Observations of the biota would require biological training and the usual equipment for measurement and assessment. It is possible that some studies would be long-term, but most would be moderately short, project-oriented studies.

2. Longer Range, More Fundamental Studies.

The preceding discussion has dealt in some detail with short-range, project-oriented studies designed for specific and generally immediate needs. More basic, and general studies that would provide broad base-line knowledge for prediction of environmental effects require more time. The resulting information would provide the necessary background for design of environmental monitoring and warning systems, and also provide knowledge for construction of beneficial modifications of environments.

The fields needing fundamental research are:

(a) Substrate characteristics.

(b) Interactions between the substrate and the overlying water column in regard to exchanges of nutrients, oxygen, carbon dioxide, and other organic and inorganic constituents.

(c) Detailed local hydrographic studies.

(d) Inventories of fauna, flora, and microbial populations, in and on the substrate and in the overlying water column, with attention to both developmental and adult stages of permanent and temporary inhabitants.

(e) Biotic-abiotic interdependency studies.

(f) Studies of material and energy flow through the ecosystem, including the decomposition and conversion steps of the energy and material cycles.

(g) Construction of mathematical models to aid in coordination and in interpretation of data.

(h) Studies in social and technological areas to complement the ecological studies.

Research in these areas has usually been uncoordinated with little standardization of methodology or instrumentation. Consequently results are difficult to compare. Encouraging signs are emerging of increased effort to provide standardization.

V. A GENERAL SELECTED BIBLIOGRAPHY

AMANIEU, M., "Ecological Research on the Faunas of the Sheltered Beaches of the Region of Atcachon," *Helgolander Wiss Meeresunters,* Vol. 19 No. 4, 1969, pp. 455-557.

ANDERSON, A. E., JONES, E. C., and **ODUM, H. T.,** "Alteration of Clay Minerals by Digestive Processes of Marine Animals," *Science,* Vol. 127, 1958, pp. 190-191.

ANIKOUCHINE, W. A., "A Model of the Distribution of Dissolved Species in the Interstitial Water in Clayey Marine Sediments," *Dissertation Abstract,* Order No. 66-7867, Sept. 1966, 70 pp.

ANSELL, ALAN D. and **TREVALLION, ANN,** "Behavioural Adaptations of Intertidal Molluscs from a Tropical Sandy Beach," *Journal of Experimental Marine Biology and Ecology,* Vol. 4, No. 1, 1969, pp. 9-35.

BAKER, W. J., "Wave Propagation Studies in Confined Sands," *Dissertation Abstract,* Order No. 66-11, Vol. 705, Dec. 1966, 317 pp.

BIDER, J. ROGER, "Animal Activity in Uncontrolled Terrestrial Communities as Determined by a Sand Transect Technique," *Ecological Monographs,* Vol. 38, No. 4, 1968, pp. 269-308.

BILIO, MARTIN, "The Aquatic Bottom-living Fauna of Salt Meadows of the North and Baltic Seas, III. The Influences of the Biotype on the Distribution of the Fauna, Laboratory Study of Contamination of Radioactive Mare, Initial Revision *Gesamten Hydrobiol,* Vol. 52, No. 4, Fiascherino, (LaSpezia), Italy, 1967, pp. 487-533.

BOUGHEY, ARTHUR S., *Man and the Environment. An Introduction to Human Ecology and Evolution,* Macmillan, New York, 1971, 472 pp.

BROWN, A. C., "Food Relationships on the Intertidal Sandy Beaches on the Cape Peninsular," *South African Journal of Science,* Vol. 60, 1964, pp. 35-41.

BROWN, A. D., "Seasonal Variation in Heterotrophic Bacterial Populations in Waters off Sydney," *Australian Journal of Marine and Fresh Water Research,* Vol. 15, No. 1, 1964, pp. 73-76.

BRUN, GUY, "Quelques Donnees sur les Temperature dans le Sable D'une Dune du Littoral Mediterraneen," (Some data on the Temperatures in the Sand of a Dune on the Mediterranean Shore) Lab. d'Ecole., Fac., Sci., Marseille, *Bull., Natur.,* Vol. 40, No. 3, Mus. Nat Hist. Marseilles, France, 1968, pp. 652-656.

BURTON, IAN, KATES, ROBERT W., and SNEAD, RODMAN E., "The Human Ecology of Coastal Flood Hazard in Megalopolis," Department of Geography, RP No. 115, University of Chicago, Chicago, 1969.

CAIN, STANLEY A., "The Importance of Ecological Studies as a Basis for Land-Use Planning," Biological Conservation, Vol. 1, No. 1, University of Michigan, Ann Arbor, Michigan, 1968, pp. 33-36.

CALLAME, BERNARD, "Interstitial Environment in Intertidal Sand Sediments," *Bull., Inst., Oceanog.*, Vol. 60, No. 1271, (English Summary), Monaco, 1963, pp. 5-30.

CALVERT, S. E., "Factors Affecting Distribution of Laminated Diatomaceous Sediments in Gulf of California," *Memoirs, American Association of Petroleum Geologists,* Vol. 3, 1964, pp. 311-330.

CHAMROUX, S., "A Contribution to the Study of Dentrifying Activity of Marine Sediments," *An. Inst. Pasteur.,* Vol. 109, No. 3, 1965, pp. 424-442.

CHANDRASCKHARA, RAO G., and GANAPATI, P. N., "The Interstitial Fauna Inhabiting the Beach Sands of Waltair Coast, *Proceedings of the National Institute of Science, Part B. Biological Science,* Vol. 34, No. 2, India, 1968, pp. 82-125.

CHENG, HWA-SHENG, "Role of Exchangeable Potassium and Magnesium on Caesium Absorption on Marine Sediments," *Nature,* Vol. 207, No. 5000, 1965, p. 1010.

CHOUDHURI, R. and BANERJI, K. C., "Some Studies of Shelf Sediments from the Western Coast off Bombay and Tatigiri," *Technological Quarterly Bulletin,* Vol. 5, No. 3, Planning Development Division, Fertlizer Corporation, India, 1968, pp. 192-203.

CLARK, MICHAEL BERNARD, "Distribution and Seasonal Dynamics of Animal Populations in San Diego Beaches," *Master's Thesis,* San Diego State College, California, 1969, pp. 193.

COLEMAN, J. M., "Coastal Sediments and Late Recent Rise of Sea Level, *Dissertation Abstract,* Order No. 66-6434, Vermilion, Iberia, and St. Mary Parishes, Louisiana, 1966, 123 pp.

CONNELL, J. H. and ORIAS, E., "The Ecological Regulation of Species Diversity," *American Naturalist,* Vol. 48, 1964, pp. 399-414.

CONOVER, ROBERT J., "Assimilation of Organic Matter by Zooplankton," *Limnology and Oceanography,* Vol. 11, No. 3, 1966, pp. 338-345.

CONOVER, R. J., "Factors Affecting the Assimilation of Organic Matter by Zooplankton and the Question of Superfluous Feeding," *Limnology and Oceanography,* Vol. 11, No. 3, 1966, pp. 346-354.

COURTOIS, G., "Possible Use of a Limited Number of Radioactive Grains in the Quantitative Study of Sedimentary Shifts," *International Journal of Applied Radiation and Isotopes,* Vol. 15, No. 11, 1964, pp. 655-663. (English Summary).

CROKER, ROBERT A., "Niche Diversity in Five Sympatric Species of Intertidal Amphipods (Crustacea: Haystoriidae)," *Dissertation Abstract,* No. 2541, Order No. 67-207, 1966, 221 pp.

CROKER, R. A., "Distribution and Abundance of Some Intertidal Sand Beach Amphipods Accompanying the Passage of Two Hurricanes," *Chesapeake Science,* Vol. 9, No. 3, 1968, pp. 187-192.

CROKER, R. A., "Intertidal Sand Microfauna from Long Island, New York," *Chesapeake Science,* Vol. 11, No. 2, 1970, pp. 134-137.

CRONIN, L. EUGENE, GUNTER, GORDON, and HOPKINS, SEWELL H., "Effects of Engineering Activities on Coastal Ecology," Interim Report to the Office of the Chief of Engineers, U.S. Army, Mimeographed Report, 1969, 40 pp.

CUBIT, JOHN, "Behavior and Physical Factors Causing Migration and Aggregation of the Sand Crab, *Emerita analoga* (Stimpson)," *Ecology,* Vol. 50, 1969, pp. 118-123.

DAHL, E., "Some Aspects of the Ecology and Zonation of the Fauna on Sandy Beaches," *Oikos,* Vol. 4, 1952, pp. 1-27.

DALES, R. PHILLIPS, "Symbiosis in Marine Organisms (Invertebrates, Fish)," *Symbiosis: I. Associations of Micro-organisms, Plants, and Marine Organisms,* Academic Press, New York, 1966, pp. 299-326.

DEFFEYES, KENNETH S., "Carbonate Equilibria: A Graphic and Algebraic Approach," *Limnology and Oceanography,* Vol. 10, No. 3, 1965, pp. 412-426.

DERIJARD, RAOUL, "Stands of the Sandy Marshy and Intertidal Marshy Sediments, Compacted or Fixed by the Vegetation, in the Area of Tulear (Madagascar)," *Rec. Trav. Sta. Mar. En Doume Marseille,* (Supplement 3), 1965, pp. 1-94.

DEVEZE, L., "Bacterial Activities and Organic Materials in Marine Sediments," *Colloquium of the Division of Soil Microbiology of the French Microbiology Society,* Ann. Inst. Pasteur, (Supplement 3), (English Summary), 1964, pp. 123-135.

DEXTER, D. M., "Distribution and Niche Diversity of Haystoriid Amphipods in North Carolina," *Chesapeake Science,* Vol. 8, No. 3, 1967, pp. 187-192.

DEXTER, D. M. (1969a), "Structure of an Intertidal Sandy-Beach Community in North Carolina," *Chesapeake Science,* Vol. 10, No. 2, 1969, pp. 93-98.

DRISCOLL, E. G., "Attached Epifauna-Substrate Relations," *Limnology and Oceanography,* Vol. 12, 1967, pp. 633-641.

DUANE, D. B., "Sand Deposits on the Continental Shelf, A Presently Exploitable Resource," *Transactions, National Symposium on Ocean Sciences and Engineering of the Atlantic Shelf,* Marine Technological Society, Philadelphia Section, 1968, pp. 289-297.

DUANE, D. B., "Sand Inventory Program in Florida," *Shore and Beach,* Vol. 36, No. 1, 1968, pp. 12-15.

DUANE, D. B., "Sand and Gravel Deposits in the Nearshore Continental Shelf, Sandy Hook to Cape May, New Jersey," *Abstract with Programs for 1969, Part 7.* Geological Society of America, 1969, pp. 53-54.

DUANE, D. B., "Sand Inventory Program; A study of New Jersey and Northern New England Coastal Waters," *Shore and Beach,* Vol. 37, No. 2, 1969, pp. 12-16.

DUANE, D. B. and MEISBURGER, EDWARD P., "Geomorphology and Sediments of the Nearshore Continental Shelf, Miami to Palm Beach, Florida," Coastal Engineering Research Center, U.S. Army Corps of Engineers, TM 29, 1969.

DUFFEY, ERIC, "An Ecological Analysis of the Spider Fauna of Sand Dunes," *Journal of Animal Ecology,* Vols. 1-27, 37, No. 3, Monks Wood Exposure Station, Abbots Ripton, Huntingdonshire, England, 1968, pp. 641-674.

EPPLEY, RICHARD W. and SLOAN, PHILLIP R., "Carbon Balance Experiments with Marine Phytoplankton," *Journal of Fisheries Research Board,* Canada, Vol. 22, No. 4, 1965, pp. 1083-1097.

ESTCOURT, I. N., "A Note on the Fauna of a Ripple-Marked Sandy Sediment in Western Cook Strait, New Zealand," *New Zealand Journal of Marine and Fresh Water Research,* Vol. 22, No. 4, 1968, pp. 654-658.

EVANS, J. W., "A Method for Measurement of the Rate of Intertidal Erosion," *Bulletin of Marine Science,* Vol. 20, No. 2, 1970, pp. 305-314.

FAGER, EDWARD W., "A Sand-Bottom Epifaunal Community: Invertebrates in Shallow Water," *Limnology and Oceanography,* Vol. 13, No. 3, 1968, pp. 448-464.

FAGER, E. W., "Marine Sediments: Effects of a Tube-Building Polychaete," *Science*, Vol. 143, No. 3604, 1964, pp. 356-359.

FEBVRE-CHEVALIER, COLETTE, "E'tude Bionomique des Substrats Meubles Dragables du Golfo de Fos," (Bionomic Study of Loose Dredgable Substrata of the Gulf of Fos.) *Tethys*, Vol. 1, No. 2, 1969, pp. 421-476.

FENCHEL, TOM, "The Ecology of Marine Microbenthos: IV. Structure and Function of the Benthic Ecosystem, Its Chemical and Physical Factors and the Microfauna Communities with Special Reference to the Ciliated Protozoa," *Ophelia*, Vol. 6, 1969, pp. 1-182.

FENCHEL, TOM and **JANSSON, BENGT-OWE**, "On the Vertical Distribution of the Microfauna in the Sediments of Brackish-Water Beach," *Ophelia*, Vol. 3, 1966, p. 161-M.

FINDENEGG, INGO (1965a), "Factors Controlling Primary Productivity, Especially with Regard to Water Replenishment, Stratification, and Mixing," *Memorie Inst. Ital. Idrobiol. Dott. Marco*, Marchi, Pallanza, Italy, Vol. 18, Supplement, 1965, pp. 271-289.

FINDENEGG, INGO (1965b), "Relationship Between Standing Crop and Primary Productivity," *Memorie. Inst. Ital. Idrobiol. Dott. Marco*, Marchi, Pallanza, Italy, Vol. 18, Supplement, 1965, pp. 271-289.

FLOC'H., JEAN-YVES, "On the Ecology of *Bonnemaisonia hamifera* in its Preferred Habitats on the Western Coast of Brittany (France)" *British Phycol Journal*, Vol. 4, No. 1, 1969, pp. 91-95.

FOURNIER, ROBERT O., "Some Implications of Nutrient Enrichment on Different Temporal Stages of a Phytoplankton Community," *Chesapeake Science*, Vol. 7, No. 1, 1966, pp. 11-19.

GAULD, D. T. and **BUCHANAN, J. B.**, "The Fauna of Sandy Beaches in the Gold Coast," *Oikos*, Vol. 7, 1956, pp. 293-301.

GINSBURG, ROBERT N., "Intertidal Erosion on the Florida Keys," *Bulletin of Marine Science*, Gulf & Caribbean, Vol. 3, 1953, pp. 55-69.

GINSBURG, R. N. and **LOWENSTRAM, H. A.**, "The Influence of Marine Bottom Communities on the Depositional Environment of Sediments," *Journal of Geology*, Vol. 66, 1958, pp. 310-318.

GLENNE, B., "Diffusive Processes in Estuaries," *Dissertation Abstract*, Vol. 27B, No. 3947, Order No. 67-5060, May 1967, 99 pp.

GOLD, KENNETH, ROELS, OSWALD, A., and **BANK, HARVEY,** "Temperature Dependent Destruction of Thiamine in Seawater," (Detected by use of Gyrodinum Cohnii), *Limnology and Oceanography,* Vol. 11, No. 3, 1966, pp. 410-412.

GOLDMAN, CHARLES R., "Micronutrient Limiting Factors and their Detection in Natural Phytoplankton Populations," *Memorie Inst Ital. Idrobiol. Dott. Marco,* Marchi, Pallanza, Italy, Vol. 18, (Supplement), 1965, pp. 121-135.

GOODING, E. G. B., "Observations on the Sand Dunes of Barbados, British West Indies." *Journal of Ecology,* Vol. 34, 1947, pp. 111-125.

GOT, H. A., GUILLE, MONACO, A., and **SOYER, J.,** "Sedimentologic Map of the Continental Shelf of the French Catalan Coast," *Mie Milieu,* Vol. 19, No. 2B, 1968, pp. 273-290.

GRAY, JOHN S., "The Attractive Factor of Intertidal Sands to *Protodrilus symboticus,*" *Journal Marine Biological Association,* United Kingdom, Vol. 46, 1966, pp. 627-645.

GRAY, J. S., (1967a.), "Substrate Selection by the Archiannelid *Protodrilus rubropharyngeus* (Jagerstern)," *Helgolander Wiss Meersunters,* Vol. 15, 1967, pp. 253-269.

GRAY, J. S.,(1967b), "Substrate Selection by the Archiannelid *Protodrilus hypoleucus* Armanante," *Journal of Experimental Marine Biology and Ecology,* Vol. 1, 1967, pp. 47-54.

GRAY, J. S. and **JOHNSON, ROY M.,** "The Bacteria of a Sandy Beach as an Ecological Factor Affecting the Interstitial Gastrotrich *Turbanella Hyalina* Schyltze," *Journal of Experimental Marine Biology and Ecology,* Vol. 4, No. 2, 1970, pp. 119-133.

GRILL, EDWIN VATRO, "A Model for the Biogeochemical Cycle of Silica in the Sea," *Dissertation Abstract,* Order No. 66-5839, July 1966, 125 pp.

HAMILTON, ROBERT DUNCAN, "The Utilization of Small Molecular Weight Organic Nitrogen Compounds by Some Marine Sediment Communities," *Dissertation Abstract,* Vol. 26, No. 2, 1228, Order No. 65-739, 1965, 166 pp.

HAMNER, W. M., "Orientation of the Sand-Beach Isopod *Tylos punctatus,*" *Animal Behavior,* Vol. 16, No. 4, 1968, pp. 405-409.

HANKS, ROBERT W., "Benthic Community Formation in a New Marine Environment (Manmade pond succession)," *Chesapeake Science,* Vol. 9, No. 3, 1968, pp. 163-172.

HANNAN, H. H. and **DORRIS, T. C.,** "Succession of a Macrophyte Community in a Constant Temperature River," *Limnology and Oceanography,* Vol. 15, No. 3, 1970 pp. 442-453.

HANSEN, DONALD V. and **RATTRAY, MAURICE, JR.**, "Gravitational Circulation in Straits and Estuaries," *Journal of Marine Research*, Vol. 23, No. 2, 1965, pp. 104-122.

HARLAN, R. W., "A Clay Mineral Study of Recent and Pleistocene Sediments from the Sigsbee Deep, Gulf of Mexico," *Dissertation Abstract*, Vol. 27b, April 1967, p. 3564.

HARRISON, WYMAN, "Environmental Effects of Dredging and Spoil Deposition," *Proceedings of the World Dredging Conference*, New York, May 1967, pp. 535-560.

HARRISON, W., **LYNCH, M. P.**, and **ALTSCHAEFEL, A. G.**, Sediments of Lower Chesapeake Bay, with Emphasis on Mass Properties, *Journal of Sediment Petroleum*, Vol. 34, 1964, pp. 737-755.

HARRISS, ROBERT C., "Biological Buffering of Oceanic Silica," *Nature*, Vol. 212, No. 5059, 1966, pp. 275-276.

HAZZAA, I. B., "A Radiographic Method for Investigation of the Movement of Sand and Sediment in Rivers Using P32," *International Journal of Applied Radiation and Isotopes*, Vol. 18, No. 5, 1967, pp. 273-278.

HEDGEPETH, J. W., "An Introduction to the Zoogeography of the Northwestern Gulf of Mexico with Reference to the Invertebrate Fauna," *Publication, Institute of Marine Sciences*, University of Texas, Vol. 3, 1963, pp. 110-224.

HERBICH, J. B. and **SNIDER, R. H.**, "Bibliography on Dredging," Sea Grant Publication, No. 203, Texas A&M, 1969, 20 pp.

HODGKIN, E. P., "Rate of Erosion of Intertidal Limestone," *Zeitschrift Geomorphology, N.F.*, Vol. 8, 1964, pp. 385-392.

HOLLAND, W. R., "Wind-Driven Circulation in an Ocean with Bottom Topography," *Dissertation Abstract*, Vol. 27, No. 3, 914, Order No. 66-9190, Sept. 1966, 135 pp.

HOLM-HANSEN, OSMUND and **BOOTH, CHARLES R.**, "The Measurement of Adinosine Triphosphate in the Ocean and its Ecological Significance," *Limnology and Oceanography*, Vol. 11, No. 4, 1966, pp. 510-519.

INGLE, R. M., "Studies on the Effect of Dredging Operations Upon Fish and Shellfish," Florida, State Department of Conservation Technical Services, Vol. 5, No. 23, 1952.

ISSACS, JOHN D., and **SCHWARTZLOSE, RICHARD A.**, "Migrant Sound Scatterers: Interaction with the Sea Floor," *Science*, Vol. 150, No. 3705, 1966, pp. 1810-1814.

JANNSON, B. O., "On the Ecology of *Derocheilocaris remanei* Delamare and Chappius (Crustacea, Mystacocarida)," Vie Milieu, Vol. 17, 1966, pp. 143-186.

JEFFREY, LELA M., "Lipids in Sea Water," *Journal American Oil Chemical Society,* Vol. 43, No. 4, 1966, pp. 211-214.

JOHNSON, PHYLLIS T., "Mass Mortality in a Bivalve Mollusc, (*Donax gouldi*)," *Limonology and Oceanography,* Vol. 11, No. 3, 1966, pp. 429-431.

JONES, N. W., "Marine Bottom Communities," *Biological Reviews,* Vol. 25, No. 3, 1950, pp. 283-313.

KELLAND, N. C., DICKSON, R. R., and KEY, D., "Research into Effects of Gravel Dredging on Fisheries and Sediment Movement," *Hydrospace,* Mar. 1971, p. 19.

KEMPF, M., "Notes on the Benthic Bionomy of the N-NE Brazilian Shelf," *Marine Biology,* Berlin, Vol. 5, No. 3, 1970, pp. 213-224.

KENSIER, C. B. and CRISP, D. J., "The Colonization of Artificial Crevices by Marine Invertebrates," *Journal of Animal Ecology,* Vol. 34, No. 3, 1965, pp. 507-516.

KHAN, C. M. ANWAR, "Sand Dune Rehabilitation in Thal, Pakistan," *Journal of Range Management,* Vol. 21, No. 5, 1968, pp. 316-321.

KHARKEVICH, N. S., "Data on the Development of Phytoplankton and the Effect of Humic Substances on It," *Referat. Zhur. Biol,* No. 14513, (Translation), 1960.

KING, C. A. M., *Beaches and Coasts,* Edward Arnold, Ltd., London (Distributed by St. Martins Press, Inc., N.Y.), 1959, 403 pp.

KING, ROGER C. and KINDEL, KARL K., "One-Step Control of Coastal Sand Dunes in Chile," *Journal of Forestry,* Vol. 67, No. 11, 1969, pp. 810-812.

KORNICKER, L. S., "Observations on the Behaviour of the Littoral Gastropof *Terebra sallena, Ecology,* Vol. 42, 1961, p. 207.

KRAUETER, JOHN and HAVEN, DEXTER S., "Fecal Pellets of Common Invertebrates of Lower York River and Lower Chesapeake Bay, Virginia," *Chesapeake Science,* Vol. 11, No. 3, 1970, pp. 159-173.

KRUMBEIN, W. C., "Size Frequency Distribution of Sediments," *Journal of Sediment Petrology,* Vol. 4, 1934, pp. 65-77.

KUREKNOV, I. I., "The Influence of Volcanic Ashfall on Biological Processes in a Lake," *Limnology and Oceanography,* Vol. 11, No. 3, 1966, pp. 426-429.

LAEVASTU, TAIVO, ZEITLIN, HARRY, and SONG, MOON KI, "Notes on Oxygen Consumption in Seawater," *Limnology and Oceanography,* Vol. 10, No. 1, 1965, pp. 144-146.

LaFOND, E. C. and RAO, R. PRASADA, "Beach Erosion Cycles Near Waltair on the Bay of Bengal," *Andhra University Memoris, Oceanography,* Vol. 1, 1954, pp. 63-77.

LEAR, D. W., JR., "Bacterial Participation in Phosphate Regeneration in Marine Ecosystems," *Dissertation Abstract,* Vol. 27 B, No. 347, Order No. 66-4407, Aug. 1966, 227 pp.

LEDOYER, MICHEL, "The Wandering Fauna of Fine Sands in Shallow Waters: Biónomic Significance of this Biotope from the Point of View of the Wandering Fauna," *Tethys,* Vol. 1, No. 2, 1969, pp. 275-280.

LEO, RICHARD F. and PARKER, PATRICK L., "Branched Chain Fatty Acids in Sediments," *Science,* Vol. 152, No. 3722, 1966, *pp. 649-650.*

LEVIN, JAS., "Literature Review of the Effects of Sand Removal on a Coral Reef Community," NSF Sea Grant Program, Grant No. GH93, UNIHI Sea Grant TR-71-01, Approved, 29 Apr. 1970.

LING, HSIN-YI, "A Micropaleontologic and Ecologic Investigation of Recent Sediments from Two Gulf Coast Cores," *Dissertation Abstract,* Order No. 64-2321, 1963, 98 pp.

LOESCH, H. C., "Studies of the Ecology of Two Species of *Donax* on Mustang Island, Texas," Publication, Institute of Marine Sciences, University of Texas, Vol. 4, 1957, pp. 201-227.

LOOSANOFF, V. L., "Effects of Turbidity on Some Larval and Adult Bivalves," *Proceedings Gulf, Caribbean Fisheries Institute 14th Session,* 1962, pp. 80-95.

LORENZEN, CARL JULIUS, "Nutrient Supply and State of Growth of Phytoplankton," *Dissertation Abstract,* Vol. 26, No. 2, No. 639, Order No. 64-13783, 1965, 36 pp.

LYFORD, J. H., JR., "Primary Productivity and Community Structure of an Estuarine Impoundment," *Dissertation Abstract,* Vol. 27, No. 2608, Order No. 67-725, Feb. 1967, 73 pp.

MACKENZIE, FRED T., "Silicates: Reactivity with Sea Water," *Science,* Vol. 150, No. 3692, 1965, pp. 57-58.

MACKIN, J. G., "Canal Dredging and Silting in Louisiana Bays," Publication Institute of Marine Sciences, Texas, Vol. 7, 1961, pp. 262-314.

MacNAE, W. and MiKALK, "The Fauna and Flora of Sand Flats at Inhaca Island, Mozambique," *Journal of Animal Ecology*, Vol. 31, 1962, pp. 93-128.

MATHEN, CLAUDE-CHARLES, "The Polish Seacoast: Phytoecological," *Soc. Botanique de France Bull.*, Vol. 115, No. 9, 1968, pp. 573-582.

MAUCHLINE, J., "The Biology of *Schistomysis spiritus* (Crustacea Mysidacea)," *Journal of the Marine Biological Association*, United Kingdom, Vol. 47, 1967, pp. 383-396.

MAUCHLINE, J., "The Biology of *Erythrops serrata and E. elegans*, (Crustacea Mysidacea)," *Journal of the Marine Biological Association*, United Kingdom, Vol. 48, 1968, pp. 455-464.

MAURIELLO, L. J., "Rehabilitation of Beaches with the Hopper Dredge," *Shore and Beach*, Vol. 34, No. 2, 1966, pp. 18-20.

MAURIELLO, L. J., "Experimental Use of a Self-Unloading Hopper Dredge for Rehabilitation of an Ocean Beach," *Proceedings of the (WODCON 67) First World Dredging Conference*, 1967, pp. 369-395.

McINTYRE, A. D, "The Meiofauna and Macrofauna of Some Tropical Beaches," *Journal of Zoology*, London, Vol. 156, 1968, pp. 377-392.

MEADOWS, P. S. and ANDERSON, J. E., "Micro-organisms, Attached to Sand Grains," *Journal of the Marine Biological Association*, United Kingdom, Vol. 48, 1968, pp. 161-175.

MEISBURGER, EDWARD P. and DUANE, D. B., "Shallow Structural Characteristics of Florida Atlantic Shelf as Revealed by Seismic Reflection Profiles," *Transaction, Gulf Coast Association of Geological Societies*, Vol. 19, 1969, pp. 207-215.

MENZEL, DAVID W. and GOERING, JOHN J., "The Distribution of Organic Detritus in the Ocean," *Limnology and Oceanography*, Vol. 11, No. 3, 1966, pp. 333-337.

MENZEL, D. W. and CORWIN, NATHANIEL, "The Measurement of Total Phosphorus in Seawater Based on the Liberation of Organically Bound Fractions by Persulfate Oxidation," *Limnology and Oceanography*, Vol. 10, No. 2, 1965, pp. 280-282.

MENZIES, R. J. and ROWE, GILBERT T., "The Distribution and Significance of Detrital Turtle Grass, *Thallassia testudinata*, on the Deep-sea Floor off North Carolina," *International Review of Gesmaten Hydrobiology*, Vol. 54, No. 2, 1969, pp. 217-22.

MERO, JOHN L., *The Mineral Resources of the Sea*, Else. Publication Company, Amsterdam, 1965, 312 pp.

MERO, J. L., "Review of Mineral Values on and Under the Ocean Floor," *Exploiting the Oceans. Transactions 2nd Annual Marine Technological Society Conference and Exhibit*, June 1966, pp. 61-77.

MOORE, H. B., "The Muds of the Clyde Sea, Area III: Chemical and Physical Conditions: Rate of Sedimentation and Fauna," *Journal of the Marine Biological Association*, United Kingdom, Vol. 17, 1931, pp. 325-358.

NEIMAN, A. A., "Some Data on the Bottom Fauna of the Northern Area of the Indian Ocean Shelves," ***Okeanologiya***, Vol. 9, No. 6, 1969, pp. 1071-1077.

NORTH, W. J., "Size Distribution, Erosive Activities, and Gross Metabolic Efficiency of the Marine Intertidal Snails, *Littorina planaxis and L. scutuiata," Biological Bulletin*, Marine Biological Laboratories Woods Hole, Vol. 106, 1954, pp. 185-197.

NYBAKKEN, JAMES WILLARD, "Intertidal Ecology of Three Saints Bay, Kodiak Island, Alaska," *Dissertation Abstract*, Order No. 65-14, 917, 1966, 281 pp.

ODUM, H. T., "Productivity Measurements in Texas Turtle Grass and the Effects of Dredging on Intracoastal Channels," *Publication, Institute of Marine Sciences*, Texas, Vol. 9, 1963, pp. 48-52.

ODUM, H. T., COPELAND,, B. J. and McMAHAN, ELIZABETH, "Coastal Ecological Systems of the United States," Report to FWPCA, Contract RFP68-128, Institute of Marine Sciences, (Unpublished), Morehead City, North Carolina, 1969.

PAMATMAT, MARIO MACALALAG, "The Ecology and Metabolism of a Benthic Community on an Intertidal Flat (False Bay, San Juan Island), Washington," *Dissertation Abstract*, Order No. 67-2185, 1967, 259 pp.

PARKER, ROBERT H., "Ecology and Distributional Patterns of Marine Macro-Invertebrates, Northern Gulf of Mexico," *Recent Sediments, Northwest Gulf of Mexico, American Association of Petroleum Geologists*, Tulsa, Oklahoma, 1960, pp. 302-337.

PEARSE, A. S., HUMM, H. J., and WHARTON, G. W., "Ecology of Sand Beaches at Beaufort, North Carolina," *Ecological Monogram*, Vol. 12, 1942, pp. 135-190.

PERKINS, E. J., "Food Relationships of the Microbenthos," *Natural History*, Series L, Vol. 13, 1958, pp. 64-77.

PHLEGER, FRED B., "Sedimentary Patterns of Microfaunas in Northern Gulf of Mexico," *Recent Sediments, Northwest Gulf of Mexico, American Association of Petroleum Geologists*, Tulsa, Oklahoma, 1960, pp. 267-301, 334-338, and 365-367.

PICHON, MIREILLE, "Contribution a l'etude des peuplements de la zone intertidal sur sables fin et sables vaseux non fixes dans la region de Tulear," (Contribution to the Study of Animal Distribution on the Intertidal Zone on Sandy and Marshy Beaches in the Vicinity of Tulear), *Recl. Trav. Stn. Mar.*, Endoume Marseille, fasc, Hors, Ser. Suppl., Vol. 7, 1967, pp. 57-100.

PILKEY, ORRIN H. and **HARRIS, ROBERT C.**, "The Effect of Intertidal Environment of the Composition of Calcareous Skeletal Material," *Limnology and Oceanography*, Vol. 11, No. 3, 1966, pp. 381-385.

POMEROY, LAWRENCE R., **SMITH, E. E.**, and **GRANT, CAROL M.**, "The Exchange of Phosphate Between Estuarine Water and Sediments," *Limnology and Oceanography*, Vol. 10, No. 2, 1965, pp. 167-172.

PRIESTER, L. E., JR., "The Accumulation and Metabolism of DDT, Parathion and Endrin by Aquatic Food Chain Organisms," *Dissertation Abstract,* Vol. 27B, No. 166l, Order No. 66-10936, 1966, 83 pp.

PURDY, E G., "Sediments as Substrates," *Imbrie and Newell (Ed's) Approaches to Paleoecology,* John Wiley & Sons, New York, 1954, 432 pp.

RANDALL, R. E., "Vegetation and Environment on the Barbados Coast," *Journal of Ecology,* Vol. 58, No. l, 1970, pp. 155-172.

REINECK, HANS-ERICH, "Sedimentation Movements on Small Ripples in Shoals," *Senck Enberg Leth. Aea.,* Vol. 42, 1961, pp. 51-67.

REISH, DONALD J. and **WINTER, H. A.**, "The Ecology of Alamitos Bay, California, with Special Reference to Pollution," *California Fish and Game,* Vol. 40, 1954, pp. 105-121.

REISH, D. J., "A Study of Benthic Fauna in a Recently Constructed Boatharbor in Southern California," *Ecology,* Vol. 42, No. 1, 1961, pp. 84-91.

REISH, D. J., "A Study of Succession in Recently Constructed Marine Harbors in Southern California," *Proceedings, First National Coastal and Shallow Water Resources Conference,* (abstract, p. 73), 1962, pp. 570-572.

REISH, D. J., "Further Studies on the Benthic Fauna in A Recently Constructed Boat Harbor in Southern California," *Bulletin, Southern California Academy of Science,* Vol. 62, No. 1, 1963, pp. 23-32.

REISH, D. J., "Discussion of the *Mytilus Californianus* Community on Newly Constructed Rock Jetties in Southern California," *Veliger,* Vol. 7, 1964, pp. 95-101.

REISH, D. J. and RICHARDS, T. L., "A Technique for Studying the Effect of Varying Concentrations of Dissolved Oxygen on Aquatic Organisms," *Air Water Pollution,* Vol. 10, No. 1, 1966, pp. 69-71.

RHOADES, D. C. and YOUNG, D. K., "The Influence of Deposit-Feeding Organisms on Sediment Stability and Community Trophic Structure," *Journal of Marine Research,* Vol. 28, No. 2, 1970, pp. 150-178.

ROBBINS, C. RICHARD, "Effects of Storms on the Shallow-water Fish Fauna of Southern Florida with New Records of Fishes from Florida," *Bulletin of Marine science,* Gulf Caribbean, Vol. 7, No. 3, 1957, pp. 266-275.

RODRIGUEZ, G., "The Marine Communities of Margarita Island, Venezuela," *Bulletin of Marine Science,* Gulf Caribbean, Vol. 9, 1969, pp. 237-280.

ROYCE, WILLIAM F., "Population Dynamics and Marine Ecology. Research Needs and Strategy," *Pollution and Marine Ecology,* Olsen, T. A. and Burgess, F. J., ed., John Wiley and Son, New York, 1967.

SAMEOTO, D. C., "Comparative Ecology, Life Histories, and Behavior of Intertidal Sand-Burrowing Amphipods (Crustacea Haustoriidae) at Cape Cod," *Journal of Fisheries Research Board,* Canada, Vol. 26, No. 2, 1969, pp. 361-388.

SANDERS, H. L., "Benthic Studies in Buzzards Bay, I. Animal-sediment Relationships," *Limnology and Oceanography,* Vol. 3, 1958, pp. 245-258.

SANDERS, H. L., "Benthic Studies in Buzzards Bay, III. The Structure of the Soft Bottom Community," *Limnology and Oceanography,* Vol. 5, 1960, pp. 138-153.

SCACCINI, ANDREA, "Preliminary Data on the Benthic Zoocenosis and on the Distribution of the Biomass in an Area of the Northern and Middle Adriatic Sea," *Lab. Biol. Mar. Pesca-Fano,* Vol. 2, No. 3, 1967, pp. 27-54.

SCHELTMA, R. S., "Metamorphosis of the Veliger Larvae of *Nassarius obsoletus* (Gastropoda) in response to Bottom Sediment," *Biology Bulletin,* Vol. 120, 1961, pp. 92-109.

SCHMIDT, PETER, "Quantitative Investigations on the Distribution and Population Dynamics of the Interstitial Fauna of Some Tidal Beaches of the North Sea Isle of Sylt, II. Quantitative Distribution and Population Dynamics of Individual Species," *International Review of Gesmaten Hydrobiol.* Vol. 54, No. 1, 1969, pp. 95-174.

SCHMIDT, PETER and TEUCHERT, G., "Quantitative Investigations on the Ecology of Gastrotricha on the Tidal Beach of the Island of Sylt, II, *Zoological Marine Biology,* Berlin, Vol. 4, No. 1, 1969, pp. 1581-1603.

SHERK, J. ALBERT, JR. and **CRONIN, L. EUGENE**, "The Effects of Suspended and Deposited sediments on Estuarine Organisms," Reference No. 70-19, Natural Resources Institute of the University of Maryland Chesapeake Biological Laboratory, Corps of Engineers Contract Study DACW73-70-C-0013, 1970, 62 pp.

SKOPINTSEV, B. A., "Investigation into Mineralization of Organic Substance of Dead Plankton Under Anaeorbic Conditions," *Symposium of Solid Earth Sciences of the Tenth Pacific Science Congress of the Pacific Science Association Pacific Science Congress Abstracting Symposium,* Honolulu, Hawaii, Vol. 10, 1961, pp. 386-387.

SOKOLOVA, M. N., "On the Distribution of Deep-water Bottom Animals in Relation to Their Feeding Habits and the Character of Sedimentation," *Deep Sea Research,* Vol. 6, 1959, pp. 1-4.

SOROKIN, J. I., "Carbon-14 Method in the Study of the Nutrition of Aquatic Animals," *International Review of Gesmaten Hydrobiol.* Vol. 51, No. 2, 1966, pp. 209-224.

SPENCER, C. P., "The Carbon Dioxide System in Sea Water," *Annual Review of Oceanography and Marine Biology,* Vol. 3, 1964, pp. 31-57.

SWEDMARK, B., "The Interstitial Fauna of Marine Sand," *Biological Reviews,* Vol. 39, 1964, pp. 1-42.

TANEY, N. E., "A Vanishing Resource Found Anew," *Shore and Beach,* Vol. 33, No. 1, 1965, pp. 22-26.

TANEY, N. E., "A Search for Sand," *Shore and Beach,* Vol. 34, No. 2, 1966, pp. 30-32.

THOMAS, H., "Studies on the Vertical Distribution of the Fauna in the Bottom of Shallow Waters with Special Reference to Insects," *Entomologist,* Vol. 97, No. 1215, 1964, pp. 177-192.

THORSON, GUNNAR, "Light as an Ecological Factor in the Dispersal and Settlement of Larvae of Marine Bottom Invertebrates," *Ophelia,* Vol. 1, No. 1, 1964, pp. 167-208.

TIETJEN, JOHN HENRY, "The Ecology of Estuarine Meiofauna with Particular Reference to the Class Nematoda," Dissertation Abstract, Order No. 67-5764, 1966, 238 pp.

TREVALLION, A., ANSELL, A.D., SIVADAS, P., and **NARAYANAN, B.**, "A Preliminary Account of Two Sandy Beaches in Southwest India," *Marine Biology,* Vol. 6, No. 3, 1970. pp. 258-279.

TYLER, AV GERMUND, "Current Problem I. Ecological Problems with Examples from Seashore Meadows," *Bot. Notiser,* Vol. 122, No. 1, 1969, pp.130-139.

VACCARO, RALPH F. and JANNASCH, HOLGER W., "Studies on Heterotrophic Activity in Seawater Based on Glucose Assimilation," *Limnology and Oceanography*, Vol. 11, No. 4, 1966, pp. 596-607.

VERNON, JAMES WESLEY, "Shelf sediment Transport System," *Dissertation Abstract*, Order No. 66-3833, 1966, 142 pp.

WANG, F. D., "The Strength Alteration of Rocks and Glass in Liquid Environments," *Dissertation Abstract*, Vol. 27(B), 1966, p. 847.

WARREN, CHARLES E., *Biology and Water Pollution Control*, W.B. Saunders, Philadelphia, 1971, p. xvi, and 434 pp.

WATT, KENNETH E. F. *Ecology and Resource Management. A Quantitative Approach*, McGraw Hill, New York, 1968, 450 pp.

WEBB, J. E., "Biologically Significant Properties and Pore Structure of Marine Sediments," *Deep Sea Research*, Vol. 12, No. 4, 1964, pp. 511-529.

WEBB, J. E. and THEODOR, J., "Irrigation of Submerged Sand Through Wave Action," *Nature*, London, Vol. 220, 1968, p. 682.

WEILER, R. R. and MILLS, A. A., "Surface Properties and Pore Structure of Marine Sediments," *Deep Sea Research*, Vol. 12, No. 4, 1965, pp. 511-529.

WESTLAKE, D. F., "Some Basic Data for Investigations of the Productivity of Aquatic Macrophytes," *Memorie Inst. Ital. Idrobiol. Dott. Marco*, Marchi, Pallanza, Italy. Vol. 18, (Supplement), 1965, pp. 229-248.

WHITTAKER, R. H., "Gradient Analysis of Vegetation," *Biological Reviews, Vol. 42, 1967, pp. 207-264.*

WIEDEMANN, A. M., "Contributions to the Plant Ecology of the Oregon Coastal Sand Dunes," *Dissertation Abstracts*, Vol. 27, No. 3005, Mar. 1967.

WILLIAMS, LOUIS G., "Possible Relationships Between Plankton-Diatom Species Numbers and Water-Quality Estimates," *Ecology*, Vol. 45, No. 4, 1964, pp. 809-823.

WILLIAMS, P. M., "Fatty Acids Derived from Lipids of Marine Origin," *Journal of Fisheries Research*, Canada, Vol. 22, No. 5, 1965, pp. 1107-1122.

WILLIAMS, P. M. and STRACK, P. M., "Complexes of Boric Acid with Organic Cis-Diols in Seawater," *Limnology and Oceanography*, Vol. 11, No. 3, pp. 401-404.

WILSON, D. P., "Some Problems in Larval Ecology Related to the Localized Distribution of Bottom Animals," *Perspectives in Marine Biology*, Buzzati-Traverso, University California Press, Los Angeles, 1958, pp. 87-104.

WILSON, RONALD FAY, "Studies of Organic Matter (Carbon Measurement Method)," *Aquatic Ecosystems, Dissertation Abstracts,* Vol. 25, No. 11, No. 6858, Order No. 64-11860, May 1965, 182 pp.

WORME, T. E., "Paleoecological Aspects of the Recent Ecology of Mugu Lagoon, California," *Dissertation Abstracts,* Vol. 27B, No. 3572, Order No. 67-4472, Apr. 1967, 458 pp.

YOUNG, G. A., "The Physics of the Base Surge," *Dissertation Abstract,* Vol. 27B, No. 261, Order No. 66-5711, July 1966, 293 pp.

ZATSEPIN, V. I., "Quantitative Distribution of Different Trophic Groups of Bottom Invertebrates in the Barents Sea," *Okeanologiya,* Vol. 10, No. 1, 1970, pp. 153-165.

ZINN, DONALD J., "Between Grains of Sand," *Underwater Naturlist,* Vol. 4, No. 2, 1967, pp. 4-8.

VI. SELECTED ANNOTATIONS*

ANIKOUCHINE, 1966. A mathematical description of the distribution of dissolved chemicals–silicate, oxygen, sulfate, and manganese–in the interstitial water of marine sediments.

ANSELL, 1969. A thorough consideration of intertidal animals, especially mollusks, stressing burrowing and emergence activities, agility, and environmental conditions of the stress situation represented by the intertidal zone. Also mentions crustaceans of intertidal zone. Good review. Emphasizes ability of these animals to survive under adverse conditions.

BIDER, 1968. Presents a method of tracking animal activity through swept-sand transects, of possible application to beach areas. Activities categorized as due to: (1) animal fluctuations, (2) phenological fluctuations (maintenance, reproduction, etc.), (3) meteorological fluctuations, and (4) climatological fluctuations.

BROWN, A. D., 1964. A discussion of heterotrophic bacteria and fluctuations in bacterial populations with seasons, chlorinity, and other factors. No correlation with temperature or organic phosphorus or with phytoplankton populations. Counts from samples ranged from 10 to 1,000 per mililiter. No species identifications attempted.

BURTON, KATES, and SNEAD, 1969. A lengthy and illustrative discussion of the coastal megalopolis, and the pro's and con's of coastal population increases. *Must* reading for persons concerned with coastal zonation and human coastal affairs.

CAIN, 1968. A discussion of the role of the ecologist as a synthesizer of knowledge and a component in the overall organization that includes also clutural anthropologists, economists, political scientists, and lawyers. A man-oriented discussion stressing interactions.

CHANDRASCKHARA and GANAPATI, 1968. A comprehensive study of fauna from protozoans through higher invertebrates in relation to sediments, ranked as fine, medium, and coarse. Majority of larger predators found in coarse-grained substrate; maximum faunal concentrations in medium-grained; life-poor or sparse in fine grained substrates (apparently corelated with absence of interstices of adequate size, oxygen-carrying capacity, and other factors). Cites texture of substrate, temperature, moisture, and food as primary distributional factors. Finds most intertidal animals of wide-spread geographical occurrence and widely adaptable.

CROKER, 1966. A discussion of interrelationships between species of amphipods. Great overlaps exist. Different horizontal distributions and some vertical. Includes a discussion of foods and feeding as well as of associated animals.

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*For complete reference, see A General Selected Bibliography, Section V.

CROKER, 1970. A comprehensive listing of interstital fauna from a Long Island beach area. Provides a base for further work on beach ecoystems.

CRONIN, GUNTER, and HOPKINS, 1969. An overview of predicted effects of engineering activities on coastal environment. Offshore-dredge and beach-fill comments indicate little long-range damage foreseen. Cautions are presented as to possible damage if all sediment removed by dredging, opening a new interface, and of release of damaging chemicals with sediments. Good general reference.

CUBIT, 1969. Explains migration and distribution of the mole crab *Emerita analoga*, in terms of water flow and behavioral responses and processes. This discussion of behavior and distribution of the Pacific species fits well with Pearse, et al. (1942), who describe the Atlantic species.

DEXTER, 1969b. A study of the community structure and faunal makeup of the intertidal area of sand beach. One of few community studies. Includes a species listing and discussion of diversity. Fair bibliography.

DRISCOLL, 1967. Contains a discussion of relations between the epifauna and the substrate as part of the comprehensive study of Buzzards Bay. Most abundant fauna found associated with medium-sized sand grains. Epifaunal organisms, prefer grains coarser than do infaunal components.

DUFFEY, 1968. A good discussion of sand dune habitats and usefulness of botanical classifications of niches to zoology. Also contains a good bibliography of dune research.

FAGER, 1964. The marine tube-building polychaete annelid *Owenia fusiformis*, builds tubes of sand grains. It and an associated small sea anemone act together to help stabilize the sand surface against movement by the wave surge. This allows establishment of a varied fauna and flora in the stabilized area. Also discusses ability of the annelid to concentrate hornblende at least 25 times by incorporating the mineral in its tubes.

FAGER, 1968. Results of studying a community of epifaunal invertebrates occupying a sandy substrate in shallow water for 6 years. A few-species environment. Discusses distribution in relation to settling and mortality, randomness and aggregation. Suggests that labeling some species in a community as important, and others as unimportant may not be a true reflection of fact, and might lead to the dismissal of those labeled unimportant in future studies to the deteriment of those studies. Found the community to exist as a steady-state system.

FEBVRE, 1969. A "before" study of faunas on differing substrates in conjunction with a proposed harbor construction project in France. Found definite community differences with bottom differences, with richest fauna on mixed sand and mud. Concludes that harbor building may well enhance some elements of the fauna by providing shelter and calm conditions.

FENCHEL, 1969. An extremely important paper that, though emphasizing ciliated protozoans, discusses the microfauna of coastal bottom areas in relation to the substrate, including mechanical properties of the sediments and their significance, energy flow, decomposition, redox-potential phenomena, laboratory model studies, significances of the microfauna (respiration of microfauna exceeds that of macrofauna as a rule, and ciliated protozoans are prominent among the former, especially on sand bottoms), and suggestions for future research. Also contains faunal listings. A basic and fundamental paper.

FENCHEL and JANSSON, 1966. Discusses the microfauna of bottom communities with regard to factors including temperature, salinity, grain size, oxygen, hydrogen-ion concentration, oxidation-reduction (redox) potential, and others as related to distribution. Vertical distribution developed with factors above as indicator factors.

FOURNIER, 1966. Discusses cycles of nourishment and enrichment in relation to phytoplankton responses and community limitations. A part of the primary productivity research that has received little attention. Discusses reliability of information in relation to enrichment periods.

GINSBURG and LOWENSTAM, 1958. Discusses the influences of organisms on sedimentation and stabilization through modification of water circulation patterns and bottom conditions. Modifications range from sediment trapping as achieved by some blue-green algae to formation of barrier reefs producing lagoon conditions in the tropics.

GRAY and JOHNSON, 1970. Discusses the value of bacteria in the food web. One of few such studies, although primarily concerned with the bacteria themselves. In this and previous papers, it is pointed out that interstitial organisms discriminate among bacterial species as food. An important aspect of food-web relations.

HARRIS, 1966. Suggests organisms (diatoms, radiolaria, sponges) may be responsible for controlling the concentration of oceanic silica. Another study in the too-small group of biotic-abiotic interaction studies.

HARRISON, LYNCH, and ALTSCHAEFEL, 1964. One of few papers failing to find significant correlations between fauna and bottom type. States that modifications to the natural bottom by dredging and spoil deposition had only a temporary effect on infauna. Resettlement of disturbed areas stated as rapid and a result of migration and distribution of juveniles by hydrodynamic phenomena.

LEVIN, 1970. A discussion of the effects of dredging on coral and associated fauna and flora of the coral community, especially in terms of turbidity, currents, shearing effect of coarse sediments, and also increased erosion. Discusses dredge management to reduce deleterious effects as much as possible. Actually issued in April 1971.

LING, 1963. A micropaleontological study confirming a close correlation between organisms and type of sediment—namely between foraminifera and grain size.

LOOSANOFF, 1972. A comprehensive study of turbidity effects on lamelli-branches, using laboratory studies for the most part. Results do not indicate conclusive long-range, large-scale detrimental effects from dredging.

MEADOWS and ANDERSON, 1968. A study of the micro-organisms abundantly attached to sand grains, relevant to study of interstitial feeding studies, larval settlement studies, and as a factor in substrate selection by adult invertebrates. Micro-organisms investigated include bacteria, blue-green algae, and diatoms.

MERO, 1966. A semipopular account of the ready availability of many minerals (listed) in the sea, and statement that extraction from sea is simpler than on land. Potential offshore greater than inshore, marine potential given as 5 to 10 times that onshore (as a group).

NORTH, 1954. One of the few papers giving efficiency factors for food usage by a coastal gastropod (*Littorina*) important in food-web calculations, and illustrative of a type of work that should be encouraged and extended.

ODUM, COPELAND, and McMAHAN, 1969. An exhaustive compilation of material descriptive of (mostly) inshore ecological systems. Hopefully this will be published and made more generally available. Much basic material included.

PAMATMAT, 1966. A thesis study important because it is one of the few concerning respiration rates and productivity on the sand flats; therefore, it forms a base for future studies, at least as far as basic concept.

PEARSE, HUMM, and WHARTON, 1942. A classic study of a sand beach community, comprising an early thorough study of ecological relationships on the east coast. Descriptions of the fauna, flora, and microbial elements of the community are included, with particular attention to life history and habits of *Emerita* as a typical intertidal animal and to the roles of bacteria in beach ecology. Contains biotic listings.

REISH, 1961. A study of repopulation of an area newly created in construction of a boat harbor. Designed as a succession study, it indicates that true succession did not take place; rather the principal species in the fauna were present from the beginning invasion. The fauna showed a peek in quantity after about 2 years. Relatively rapid migration into the area is indicated.

SANDERS, 1958. Discusses the relations between faunal elements and the substrate. Author finds filter feeders dominant in sand and deposit feeders in mud, as might be expected. Well-sorted fine sand was found to support the largest populations. Hydrodynamic factors relevant to the relations are discussed.

SANDERS, 1960. Soft-mud communities marked by presence of few species that are dominant, numerically and with regard to biomass. Mollusks and annelids perdominated.

SHERK and CRONIN, 1970. A thorough bibliography of effects of sediments, with reference to estuaries, but of broader application. Little direct information on subject available. Review of entries indicates little long-range disturbance of environment as a result of turbidity or sediment effect.

SOKOLOVA, 1959. Although concerned with deepwater fauna, correlates abundance of that fauna with amount of organic matter or deposit in the sediments, suggesting possible (though not necessarily so) homologies in coastal areas.

SWEDMARK, 1964. A basic review of interstitial fauna to the early sixties, an important source reference. Sets stage for follow-up studies. Emphasizes substrate-faunal interrelations, especially grain size correlations.

THORSON, 1964. A basic reference regarding larval responses to light levels. Sensitive to narrow ranges. Importance of this report lies in effects of disturbed sediments (turbidity) in modifying light levels and thereby interfering with larval development or spread and settling.

TIETJEN, 1966. Although an estuarine study, important in being one of the few studies failing to find correlation between size of population and sediment size. Contains, in addition, a discussion of relation between organic detritus and benthic microflora.

TRAVALLION, ANSELL, SIVADAS, and NARAYANAN, 1970. A comprehensive account of beach ecology, complete with summaries and bibliography as well as with zonation schemes, community relation studies, and zoogeographic comparisons—pointing out similarities between faunas of widely separated beach areas, within zones.

WARREN, 1971. A text of basic value to management ecologists and biologists in general. Although designed for water pollution biologists, its value should be appreciated far more widely. Applicable to any work associated with environment modification and man-oriented usage planning.

WEBB, 1969. Excellent and unique discussion of the effects of grain orientation, and effects of porosity and drainage for Amphioxus and many interstitial animals. Permeability, compaction, and capillary space listed also as important factors.

WEBB and THEODORE, 1968. Irrigation of submerged sands may be an important source of nutrients and correlated with productivity of benthic communities.

WEILER and MILLS, 1965. A discussion of surface properties and pore structure of substrate including a new method of determination worthy of consideration in attempts to standardize procedures. May be relatable to niches and other ecological aspects.

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13. ABSTRACT

A review of ecological effects of offshore dredging is presented, based on literature review and personal contacts, to provide a framework for determination of need for further knowledge. In general, little concrete effort aimed specifically at the determination of effects of offshore dredging was uncovered, although basic ecological works that are generally applicable are available. Much additional research of basic, but practical, orientation is needed to approach full understanding.

Report shows that the beach may be divided into three zones on the basis of moisture and biota found, and describes the possible effects on these biota resulting from offshore dredging and deposition of sediments on a beach.

Background descriptive material and impacts on both offshore dredged areas and nourished beaches, and suggestions for further research follow. A selected bibliography is included.

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