UNIHI-SEA GRANT-TR-71-01

A LITERATURE REVIEW OF THE EFFECTS OF SAND REMOVAL ON A CORAL REEF COMMUNITY

By
JAMES LEVIN

DECEMBER 1970

Prepared under the
National Science Foundation
SEA GRANT PROGRAM
(Grant No. GH-93)

DEPARTMENT OF OCEAN ENGINEERING
UNIVERSITY OF HAWAII

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Approved by Charles L. Bretschneider
Chairman, Dept. of Ocean Engineering

Date April 29, 1971

FOREWORD

The University of Hawaii is receiving Sea Grant institutional support for investigations into the possible utilization of offshore sand in Hawaii. The investigations are a combined effort by the Hawaii Institute of Geophysics and the Ocean Engineering Department. The former is concerned with inventorying offshore sand deposits throughout the Hawaiian Islands. The Ocean Engineering Department is interested in the feasibility of recovering this sand.

The initial phase of the Ocean Engineering Department's investigations are covered in two previously published reports. The reports are concerned with the uses of sand, present sources of sand in Hawaii, standards and criteria for various uses, sand inventory projects in other states, factors affecting recovery and underwater sand coring (Casciano and Palmer, 1969; Casciano and Palmer, 1970).

This report is a continuation of the Ocean Engineering Department's efforts to determine the feasibility of recovering offshore sand. It attempts to deal with the possible ecological effects on Hawaii's shallow marine environment as a result of sand mining. Since the shallow water environment surrounding the Hawaiian Islands consists largely of fringing coral reefs, the report concentrates on the effects of sand dredging on coral reefs.

The report is divided into three sections: (1) a summary of the available literature on the possible effects of sand removal on a coral reef community; (2) abstracts of selected references; and (3) bibliography with some annotations. The first section summarizes the probable and possible effects and offers some factors to be considered by those concerned with the problem. The abstract section contains summaries of selected references that were reviewed. The bibliography contains additional references related to the problem.

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1. SUMMARY OF AVAILABLE LITERATURE ON THE POSSIBLE EFFECTS OF SAND MINING ON A CORAL REEF COMMUNITY

1.1 Introduction

Coral reefs are among the most biological productive and taxonomically diverse of any ecological community (Johannes, 1970). A reef community may include representatives of every phylum of the animal kingdom and many forms from the plant kingdom. Such a community may exceed 3,000 species, each with its own environmental requirements, but still mutually dependent on each other (Newell, 1969).

Most authorities believe that corals do not account for the major fraction of the total reef community biomass or metabolism. However, when the coral dies or is destroyed, the reef community degenerates due to the subsequent death or migration of the associated reef fauna. As a result, "the resistance of a reef community to environmental stresses cannot exceed that of its coral component" (Johannes, 1970).

The Hawaiian Islands are located at the northern margin of coral growth. Due to the relatively cool water (compared to tropical seas) surrounding the islands, coral reefs do not flourish as they would in the warmer waters of the South Pacific. Edmondson (1928) stated, "When compared with more tropical localities in the South Pacific..., the inferior development of shallow water corals about the Hawaiian Islands is especially noticeable."

Fringing reefs are the most common type of reef surrounding the Hawaiian Islands (Moberly and Chamberlain, 1964). They grow out from the land mass but still remain connected to the land.

Because of their location, fringing reefs are subjected to environmental stresses as a result of coastal or nearshore water activities. Also, Hawaii's relative northern location produces environmental conditions less than favorable to flourishing coral growth. Thus, if damaged, coral recovery could be a slow process, if recovery takes place at all.

Johannes (1970) stated, "When a reef community is destroyed, the ecological conditions that follow cannot be expected to coincide with those which preceded the initial development of the community. Thus, it cannot be taken for granted that the reef community will ever replace itself". Such was the case in Bermuda. Thirty years ago corals were destroyed by siltation due to dredging and filling in Castle Harbor, Bermuda. Presently, only scattered small colonies of coral persist (Johannes, 1970).

Coral reefs are a very important resource of the Hawaiian Islands. The marine life that is associated with the reef community is a source of food for the people of Hawaii. Coral reefs are also used extensively for recreation including, fishing, snorkling, and scuba diving. Many science and ecology classes, both at the public school and university levels, use the reefs as a natural laboratory.

The reefs are also responsible for producing the excellent surfing waves for which Hawaii is famous. The tourist industry takes advantage of the reefs through glass bottom boat tours and with skin diving and surfing lessons. Probably the most important function of the coral reefs is the protection they offer the islands of Hawaii against erosion.

Therefore, anything that adversely affects the coral reef community, will likewise affect the entire life style of the Hawaiian Islands. When considering sand mining, it is of the utmost importance that such effects do not occur.

Sand mining is most generally carried out by hydraulic dredging means. Dredging will always produce some alterations in the area of ecology. These may be minor and of short duration or major and of a more permanent nature, the latter being the more significant. Dredging changes the original interface between the water and the bottom and: (1) creates new deep water areas; (2) increases the potential for the release of toxic or nutrient materials from the bottom; (3) causes suspended sediments which eventually result in turbidity and deposition (Cronin, 1969). All of these conditions can affect a coral-reef community.

1.2 Effects on Corals

Because corals are the most essential organism to the well being of a reef community, emphasis was placed on determining the effects of sand removal on corals. Initially, the actual operation of hydraulic dredging of sand results in minimum physical damage to the reef. However, associated with dredging are varying amounts of suspended and deposited sediments. Therefore, the suspended and deposited sediments as a result of the dredging activities and their effects on corals are the prime areas of interest.

Literature concerning the effects of dredging on corals is sparce; however, references relating the effects of suspended sediments, turbidity and deposition on corals, which have been caused independently of any dredging activity, is plentiful. Consequently, since it is known that dredging causes the three above-mentioned conditions, the assumption has been made that the effects from dredging will be the same or very similar to those caused by suspended sediments, turbidity, and deposition.

1.21 General Biology of Corals

It is necessary to acquire a general knowledge of the biology of corals in order to understand the possible effects that sand dredging can have on corals.

Hermatypic corals (reef formers) and coralline algae are the most common reef formers of the present day. Their growth is largely confined to the tropical regions; but where conditions are favorable, their growth may extend slightly north or south of the tropics (Shepard, 1963). Hermatypic corals live to a depth of 90 meters, with the majority living in depths less than 50 meters. The most vigorous growth takes place in depths of 25 meters or less. Temperatures between 25° - 29° C promote the most vigorous coral growth; however, corals can survive for short periods of time at extreme temperatures of 13° C and 36° C. Corals are also dependent on salinity and live within a range of $21^{\circ}/oo$ to $40^{\circ}/oo$ (Newell, 1959; Shepard, 1963; Wells, 1957).

Hermatypic or reef forming corals contain symbiotic algae (zooxanthellae) that are embedded in the coral's endoderm and skeleton. The role of the zooxanthellae is not completely understood and results of studies and observations as to their function and importance vary (Moore, 1958). Most authorities believe that the algae obtain their food and carbon dioxide from the coral and in turn the coral receives oxygen and possibly carbohydrates from the algae (Clarke, 1954; Newell, 1959).

The zooxanthellae require sunlight for photosynthesis. This is why the most vigorous coral growth takes place in depths of less than 25 meters. Deeper than 25 meters, the intensity of radiant energy falls to very small percentages of its incident surface value (Wells, 1957).

Verwey (1930, 1931a) presented evidence that indicated a strong correlation between the penetration of light and the depth of reef growth. This suggests that the depth limit of coral growth is dependent upon the light requirements of the symbiotic algae (zooxanthellae) for photosynthesis. It has been reported that coral can grow in darkness, or after their zooxanthellae have been destroyed by previous subjection to darkness (Moore, 1958). However, according to Moore, "... the colony [coral] may well be less efficient in the absence of the zooxanthellae, and it is possible that the effect is sufficient to limit reef formation to depths where photosynthesis is possible."

Corals are also dependent on the presence of light for calcium carbonate deposition (Goreau, 1963; Kawaguti and Sakumato, 1948). It is this calcium carbonate deposition by the hermatypic corals and coralline algae that is essential to reef building. Studies by Goreau (1959) showed that calcium uptake from seawater by corals increases with increasing temperature, light intensity, and exposure time.

1.22 Effects of Suspended and Deposited Sediments Upon Coral Growth

1.221 Reduced Light Intensity

Turbidity caused by suspended sediments and the deposition of the suspended sediments are effects usually attributable to dredging activities. These changes in the natural environment can produce conditions which are harmful to healthy coral growth.

Turbidity reduces the light penetration into the water column and sediment deposition blankets coral, shielding it from much of the available light; thus, less light is available for the photosynthetic activity of zooxanthellae.

Reduced light intensity as a result of turbidity becomes more critical to deeper water corals and plants where, under otherwise normal conditions, a limited amount of sunlight is available for photosynthesis. Thus, a chronic increase in turbidity can be expected to reduce coral and plant growth in deeper water, eventually causing their death (Johannes, 1970).

Edmondson (1928) studied the resistance of 17 species of Hawaiian corals to total darkness. Species of *Pocillopora* and *Porites* were the least resistant to absence of light, most being dead after 18 days. Four species of coral were still alive after 45 days, but were reported to be injured and very much paler than at the beginning of the experiment. Table 1 shows the results of Edmondson's study.

Under natural conditions corals would very rarely, if ever, be subjected to prolonged periods of total darkness as a result of turbidity. Therefore, Edmondson's results do not actually duplicate natural conditions. The study, however, does indicate the species relatively most sensitive to a decrease in light intensity.

TABLE 1

Resistance of 17 Hawaiian Corals to Total Darkness (Edmondson, 1928)

	18 da.	33 da.	38 da.	45 da.
Pocillopora meandrina var nobilis	D			
Pocillopora ligulata	D			
Pocillopora cespitosa	D			
Porites evermanni	D			
Porites lobata forma lacera	A	D		
Porites lobata forma centralis subforma alpha	D			
Porites lobata forma centralis subforma beta	D			
Porites compressa forma granimurata	D			
Porites compressa forma angustisepta	D			
Montipora verrucosa	D			
Montipora flabellata	A	D		
Pavona varians	A	A	D	
Stephanaria stellata	A	A	A	A
Cyphastrea ocellina	A	D		
Favia hawaiiensis	A	A	A	A
Leptastrea agassizi	A	A	A	A
Fungia scutaria	A	A	A	A

Corals suspended in a light-proof box anchored on Waikiki reef. D = specimen dead, A = alive at end of specified period.

K. Roy (personal communication) suggests that if coral has adapted to living in a clear water environment, it may undergo shock reaction when suddenly subjected to turbid sediment laden water. The shock could lower the coral's resistance, leaving it susceptible to infection and attack by other organisms.

1.222 <u>Smothering</u>

Temporary water turbidity doesn't seem to have a serious affect on a shallow-water reef community unless the suspended particles form a layer of sediments over the reef (Johannes, 1970). At Fanning Island, it was found that living corals covered 62 percent of a clear water area and 31 percent of a turbid water area. It is assumed that the absence of corals in the turbid water area is the result of the deposition of sediments rather than the diminished light intensity (Roy and Smith, 1970).

A coating of deposited sediment not only reduces the light reaching the corals but may also have a smothering effect (Roy and Smith, 1970). Most corals possess some capacity to remove sediments from their surfaces by ciliary action (Marshall and Orr, 1931; Vaughan, 1916). This capacity varies according to the species, being lowest among corals living on the outer reef edges (Vaughan, 1916).

Corals can live for limited periods after having their surfaces covered with silt (Marshall and Orr, 1931; Vaughan, 1916). However, no species will survive when buried beneath sediments caused by rapid prolonged deposition (Vaughan, 1916).

Edmondson (1928) showed that the species of coral least resistant to siltation are those of Pocillopora and Porites. His experiments consisted of burying the corals with four inches of sand and silt. The results are shown in Table 2. Even though such conditions are unlikely to occur on a reef, Edmondson's results are the best available indication of the relative resistance to siltation of each species.

Marshall and Orr (1931) also reported that species of Porites on the Great Barrier Reef were vulnerable to the effects of deposition. The Edmondson, Marshall, and Orr's findings are important when considering Hawaiian corals, because Porites is one of the major reef builders in Hawaiian waters (Johannes, personal communication).

The location of coral colonies on the reef complex plays a part in determining the extent of damage the coral will suffer as a result of deposition. Johannes (personal communication) indicates that coral living on a sloping bottom or reef slope would be less harmed by siltation than corals living on a flat bottom because there is less settling of sediments on a sloping bottom than on a flat area. Also, a somewhat related item, sediments would be more easily removed from a sloping bottom by wave and current action.

Corals located on the outer reef edges are especially liable to harm from deposition (Vaughan, 1916). Because these corals have adapted to living in an environment relatively free of siltation, their ability to remove sediments from their surfaces is not as effective as those corals that live closer to the shoreline.

James Maragos of the Department of Oceanography, University of Hawaii, is studying the effects of siltation on corals in Kaneohe Bay, Oahu, Hawaii, with Sea Grant funding. His preliminary observations show that a large amount of silt enters the bay as a result of erosion caused by improper land use practices. The silt is piling up on the bottom burying the deeper corals.

Presently, coral growth is limited to water depth of 15 feet and less in the inner bay. Ten to fifteen years ago coral growth existed down to the 30-35 foot depth in this area. In some cases the silt content of the water is high enough to kill the corals now living in shallower water (personal communication; Maragos, 1970). The literature contains a number of references citing coral damage caused by siltation in nearshore waters resulting from poor land management practices (Fairbridge and Trichert, 1948; Van Eepoel and Grigg, 1970).

Deposition of suspended sediments can also produce a soft, unstable, shifting bottom. Edmondson (1928) believed such a bottom condition resulted from dredging operations in the construction of a swimming pool near the southern boundary of the Waikiki Reef. He felt this was responsible for the paucity of corals he observed in the area.

Planulae, the free swimming larva of the coral, need a hard surface on which to settle (Hida, 1932; Wells, 1957b). Therefore, a soft unstable, shifting bottom would hinder the settling of coral planulae. Thus, if such bottom conditions were created by dredging, regeneration of the damaged corals would be quite difficult if not impossible. K. Roy (personal communication) points out that planulae need only a very small hard surface on which to settle, such as a piece of broken shell; if it were not on an unstable, shifting bottom.

TABLE 2

Resistance of 23 Hawaiian Corals When Completely Buried Under 4 Inches of Sand and Silt (Edmondson, 1928)

Corals	12 hrs.	17 hrs.	24 hrs.	28 hrs.	40 hrs.	48 hrs.	75 hrs.	96 hrs.	5 da.
Pocillopora meandrina var. nobilis	D	D							
Pocillopora ligulata	D								
Pocillopora cespitosa	A	A	D						
Porites evermanni	A	A	D						
Porites lobata forma lacera	A	A	D						
Porites lobata forma infundibulum	A	A	D						
Porites lobata forma centralis subforma alpha	A	A	D						
Porites lobata forma centralis subforma beta	A	?	D						
Porites lobata forma centralis subforma gamma	A	D							
Porites compressa forma granimurata	A	A	D						
Porites compressa forma angustisepta	A	D							
Montiopora verrucosa	A	A	D						
Montipora flabellata	A	A	A	A	D				
Montipora verrilli	A	A	A	A	D				
Montipora patula	A	?	D						
Pavona varians	A	A	A	A	D				
Pavona duerdeni	A	A	A	A	A	A	D		
Stephanaria stellata	A	A	A	A	A	A	A	A	A
Stephanaria brighami	A	A	A	A	A	A	A	A	A
Cyphastrea ocellina	A	A	A	A	D				
Favia hawaiiensis	A	A	A	A	A	A	A	A	A
Leptastrea agassizi	A	A	A	A	A	A	A	A	D
Fungia scutaria	A			A	A	A	A	?	?

D = specimen dead, A = alive at end of specified period.

Strong currents and wave action aid in preventing deposition from silt-laden waters (Johannes, 1970; Marshall and Orr, 1931; Verwey, 1931b). Johannes (1970) observed a flourishing shallow water reef community at Kahe Point, Oahu, Hawaii. The area was continuously subjected to turbid water for a year, as a result of beach excavations. He reported, "The currents are fairly strong in this area, little silt settled out on the reef and casual observations indicated that no obvious damage occurred to the community on the reef surface." However, E. S. Reese reports that the inshore reef area off Kahe Point is now dead (Reese, 1970).

1.223 Abrasive Action

If currents become too strong, the suspended sediments and moving bottom material may cause abrasion to the corals thus inhibiting coral growth. Bourne (1888), and Crossland (1927, 1928), considered the importance of sand abrasion on coral growth and found it to be a limiting factor. Wein (1962) concluded that mechanical scour occupies one of the dominant roles in the destruction of a reef, particularly at the reef margins. Crossland (1907) reported that coral growth is less vigorous than would be expected in certain areas of the Red Sea due to the abrasion by silt, carried by currents, that prevent fixation of planulae.

Storr (1964) reported from his studies at Abaco Island, Bahamas, that the reef presents a frictional barrier to the flow of tidal currents. As a result, the currents are accelerated through channels and breaks in the reef. The accelerated flow causes erosion within the channels or breaks, thus inhibiting coral growth on the bottom. However, the current encourages coral growth along the margins of the channel.

1.23 Studies Concerned with the Direct Effects of Dredging

Brock et al., (1965, 1966) reported in detail on the destruction of corals, and the decrease in populations of fish and echinoderms at Johnston Island due to siltation as a result of dredging. Approximately 2,800 hectacres (1 hectacre = 10,000 square meters) of reef and lagoon were seriously affected by silt laden water and 440 hectacres of reef were totally destroyed by dredging.

Dr. F. H. Talbot, director of the Australian Museum, has personally observed coral on Heron Island where a harbor had been dredged from the reef structure. He stated, "On the floor and vertical faces of this harbor there is no regeneration of coral two years since the completion of the harbor....Outside the harbor in scraped areas there has been regeneration of coral species....but this is at present still extremely slow." He further mentioned that the coral looked undamaged a short distance away from the dredging in spite of silty deposits in the area. "Even 50 yards away from the dredged area coral is flourishing, although for long periods there was heavy silt deposition in that area" (Talbot, personal communication).

H. Eckels, Acting Director of the Office of Marine Affairs, U.S. Department of the Interior, stated that representatives of the Smithsonian Institution reported that sand dredging near St. Croix in the Virgin Islands caused vast amounts of suspended material which clouded the water for several weeks (Eckels, personal communication). No estimate or survey of the damage to marine life was mentioned.

Dredging was conducted in Hanauma Bay, Oahu, Hawaii in July, 1970. Hanauma Bay is a protected marine sanctuary with a flourishing coral reef and an abundance of fishes and invertebrates. The dredging was carried out in conjunction with planned construction of an offshore breakwater, a swimming area, and a passage for divers through the reef to deep water.

At the onset of dredging, ecologists feared that silt from the dredging activities would greatly harm the coral growth (Norris, 1970). However, surveys to date have indicated that relatively little harm was suffered by the corals even though the water was turbid around the dredging activity (Altonn, 1970).

In 1969, plans proposed for sand removal from Kaneohe Bay, Oahu, (for beach nourishment) were halted by efforts of ecologists who feared the dredging would cause heavy siltation. The fear was that this activity would adversely affect the biota as well as the aesthetic qualities of the Bay (Reese, 1969).

1.24 <u>Additional Factors to be Considered</u>

Certain factors should be taken into account before dredging commences, thereby minimizing the possibility of damage to the marine environment.

Sand dredging will likely be carried out by hydraulic suction means without use of a cutterhead; thereby minimizing direct physical damage to the coral. Stirring of bottom sediments and resulting turbidity will not be as severe as when using a cutterhead or mechanical dredging forms such as clam shells or bucket ladders. However, some suspended sediments will be associated with the dredging activity.

Sand mining activities should attempt to capture the large part of the dredged material in a barge or hopper or pump it directly ashore. This is compared to channel and harbor dredging which frequently entails dumping the spoil into the water a short distance from the dredge site. Nevertheless, some turbidity will result from the overflow of silt-laden water from the barge or hoppers.

The degree and nature of sediment deposition resulting from a sand mining operation will depend in part upon the grain size distribution of the material as well as wave and current action in the area of interest. Although the major constituent of the suspended load is expected to be the very fine material contained in the hopper overflow, some coarse material will also be placed in suspension.

The larger particles will probably be deposited near the site, while the fines may be carried great distances by prevailing currents, before deposition. In areas of tidal influences the currents change direction, resulting in a wider dispersal of the suspended material.

Sediments deposited on a reef may be suspended again at a later date by changing wave and current conditions. This is especially true for the finer sediments. When deposition takes place on a portion of the reef that is elevated above its surroundings, resuspension of sediments is likely. This is caused by water deflecting upward and current velocities increasing as the water passes over the elevated sections of reef (Ingle, 1952). Thus, elevated portions of a reef are also vulnerable to excessive abrasion by sediment laden waters.

Sediments can be moved on and off a reef with changing tidal conditions. This might at first appear to be desirable because the sediments would be prevented from being deposited for any length of time at any one location. However, consolidation of flocculated sediment can occur due to the reversing tidal currents, causing a layer to form of sufficient strength to eventually resist the shear forces produced by these currents. This can result in permanent deposition (Masch, 1965).

The reef presents a friction barrier to tidal flow; therefore channels and breaks in the reef develop accelerated tidal currents (Storr, 1964). Sediment-laden water flowing through the breaks and channels in the reef may cause excessive abrasion to the areas of the reef bordering the breaks and channels.

1.3 Effects on Other Reef Life

Suspended and deposited sediments, destruction of the original water bottom interface, general deepening of the area, and possible release of nutrient or toxic materials from bottom sediments are conditions that can result from sand mining. Each of these conditions can adversely affect some members of the vast community of life associated with a coral reef.

The extensive life found in the many crevices of a typical coral reef are probably more sensitive to siltation than the corals. Sediments settling on a reef tend to fill these cavities. While poorly understood, the contribution of this varied biota probably plays a significant role in the functioning of a coral reef community (Johannes, 1970).

Suspended sediments can clog and damage the gills of fish (Brehmer, 1965; Cronin, et al., 1969). Feeding activity by filter-feeding shellfish can also be inhibited by a high concentration of suspended solids (Brehmer, 1965). Suspended sediments reduce photosynthetic production of aquatic plants which are essential to many fishes for egg attachment and shelter (Cronin, et al., 1969; Phinney, 1959). Flocculation of the suspended sediments can mechanically entrap phytoplankton and carry them to the bottom (Barsch, 1960).

The nature and particle sizes of sediments determine the type of bottom fauna that will populate the area (Moore, 1958; Storr, 1964). Deposition of sediments can: physically alter the bottom habitat, and smother benthic species (Brehmer, 1965); create a coating which interferes with the attachment of many sessile benthic species (Cronin, et al., 1969); act on leaves of higher plants, as a physical barrier preventing free exchange of gases (Phinney, 1959).

Unstable bottom material, as a result of deposition, will not usually support benthic animals. With the elimination or decrease in the benthic population, the food chain can be broken. As a result, some fish will leave the area or starve (Hollis, et al., 1964).

Removing the bottom water interface and underlying substrates necessarily means removing the infauna and epifauna organisms that populate these habitats. It is believed that the effects of such a removal will usually be localized, and reestablishment of the populations could possibly take place in one or two years. The most severe effects can be expected if the removed sediments are replaced by an entirely different surface such as rock. The least damage will occur when maintenance dredging merely opens a new face of the same type of material (Cronin, et al., 1969).

The general deepening of an area can be significant. The effects of this deepening, however, are uncertain. At times the deepening can have desirable effects by creating new habitats for many species of fish (Cronin, et al., 1969). The Coastal Engineering Research Center, U.S. Army Corps of Engineers, is conducting research on the ecological significance of bottom topography and bottom type. Their findings will possibly be used to guide offshore sand mining so as to uncover or create "reefs" or other bottom conditions favorable to the growth and concentration of fish and shellfish populations (U.S. Army Corps of Engineers, undated).

Deepening also extends the depth of the water column and reduces the light available on the bottom for photo-synthetic activity (Reese, personal communication). Deepening may also create lower bottom-water temperatures more favorable to bottom fauna which did not appear in the original sand strata. These can in turn attract new species of fish to the area.

The removal of sand from a reef pocket can also bare new surfaces of dead coral. If oligotrophic conditions prevail in the surrounding waters (nutrient poor), it is probable that these surfaces will be colonized by new corals. In eutrophic waters (nutrients rich), algae growth can ensue (Reese, personal communication).

Chemical compounds are frequently found in coastal sediments. These include heavy metals, pesticides, and nutrient salts, among others. When the sediments are disturbed by dredging the chemicals are released. The results can vary from biological stimulation by nutrients to toxicity from poisons (Cronin, et al., 1969).

In summary, dredging will affect the other organisms of a reef community; however, these effects are poorly researched. The relative importance of the effects must be evaluated for each situation.

1.4 Miscellaneous Effects of Dredging

Chesher (1969) suggests that blasting and dredging activities on reefs may provide an abnormally large area where the Crown of Thorns starfish (*Acanthaster planci*) larvae may settle. In a personal communication

Dr. Chesher documents instances where starfish infestations began on Guam on Ponape following dredging and blasting activities. "There has been considerable blasting activity along the reefs of Guam.... a few months later a large population of juvenile Acanthaster appeared adjacent to the blasting zone. Blasting and dredging activities also occurred on Rota in the vicinity where that infestation apparently began....there has been approximately three years of blasting and dredging associated with construction of a jet air strip on Ponape. A major infestation of starfish is now underway on Ponape, and it apparently began in the very area where dredging and blasting was going on." He further suggests that there are probably many other factors associated with the starfish explosion, but that localized damage to a coral reef through blasting and dredging might result in an ecological disruption, causing widespread damage to the ecosystem.

Randall (1958) points to the correlation between availability of new surfaces in the reef environment, the rapid growth of algae, and the development of ciguatera (toxicity in normally edible reef fish). It has been observed that algae are among the first organisms to colonize any new surface area in the reef community. Such surfaces are created by blasting and dredging and in areas with newly deposited sediments (Brock, et al., 1965-1966). Also dead skeletons of corals left by feeding Acanthaster provide large new surface areas (Chesher, 1969).

It is theorized that the rapidly growing algae are eaten by the reef fish, and are the beginning of a toxic food chain that sometimes results in serious illness and even death to humans.

1.5 Summary and Recommendations

Sand mining and other dredging activities alter the reef environment by producing suspended and deposited sediments, removing the original bottom-water interface and deeper substrate material, creating new deep water areas, and possibly causing the release of chemicals from the sediments. All of these conditions can adversely affect the life of a coral reef community. In some instances the effect may be of short duration with the rapid re-population of an area; in others the effects may be of long duration with the ultimate degradation of the reef community. There is some possibility that dredging may result in advantageous alteration, but this seems remote.

The most harmful consequences to healthy coral growth are the suspended and deposited sediments. These result in reduced light necessary for photosynthetic activity of the zooxanthellae, smothering, abrasion, and loss of suitable bottom areas for the settling planulae.

The reef life forms other than corals are not only affected by suspended and deposited sediments, but also by the other environmental alterations produced by dredging. Suspended and deposited sediments decrease light penetration necessary for photosynthetic activity of plants.

Fish and shellfish may also be injured by suspended sediments. Deposited sediments may smother bottom life and create unstable shifting bottom material that may not support benthic populations. This may result in breaks in the food chain with the subsequent starvation or migration of various species.

Removal of bottom sediments may result in general deepening of the area. Effects of this deepening are poorly researched. Release of chemicals from the sediments can variously result in increased biological activity or the production of toxic conditions depending on life forms affected and conditions disturbed.

Studies have also suggested a possible relationship between dredging activities and the occurrence of the starfish Alcanthaster which is known to destroy large areas of coral reef. It has also been hypothesized that new surfaces caused by dredging increases the occurrence of ciguatera in reef fish.

The effects of dredging will vary with the type and duration of the environmental alterations that are created, the location of the sand mining operation (sand pockets surrounded by coral reefs or large flat areas of sand outside of the reefs), the species of organisms in the area of dredging activity, and the meteorological and oceanic conditions under which dredging takes place.

Therefore, it can be concluded that the effects of dredging will vary with each separate dredging activity. The following general recommendations are offered to minimize impact on the reef community.

1. Conduct a thorough physical and biological survey at and adjacent to the mining site before dredging commences.

This will provide an indication of the relative ecological importance to be placed on the various expected effects of the sand removal operation. Thus, a decision can be arrived at as to whether or not it would be advisable to proceed. The survey will assist in planning an operation with minimum damage to the environment. Also, it will provide a reference with which to compare observations during and after the mining.

It is suggested that the survey be conducted to determine the following:

a. Major habitats and the nature, form, and abundance of life in the general area.

b. The prevailing currents, waves, wind, and depth of water at site.

c. The physical nature of the sand deposit; i.e., the areal extent, thickness, grain size distribution, and its location with respect to other sand deposits and surrounding reefs.

d. The types and amounts of epifauna and infauna dwelling in the sand.

e. The chemical properties of the sand.

f. The nutrient qualities of the water.

g. The general clarity of the water.

h. The extent of deposition present.

2. Select dredging techniques and equipment that will minimize the introduction of suspended sediments into the water and physical damage to the reef.

3. Consider the time of the year in determining when to dredge. In temperate climates, dredging during the summer is preferable because more sunlight penetrates the water column. Therefore, decreased light intensity as a result of suspended sediments would have less severe effects on the biota in the summer than in the winter.

The same is true in Hawaii; in the winter less sunlight penetrates the water column because there are more cloudy days, more suspended sediments in the water due to rain runoff from the land, and more storms stirring bottom material.

4. Dredge according to local conditions. Attempt to dredge, if possible, during current conditions that will carry the suspended sediments toward deep water.

5. Carry on continual surveillance of the marine life of the area. This should be conducted by a qualified marine biologist. Dredging should be halted when conditions exceed predetermined tolerance levels. This means that the dredging operations, as well as the contract agreement, should be flexible enough to handle periodic shutdowns.

a. Methods should be devised to measure the rate of deposition in the surrounding area. Several methods have been used successfully during dredging operations in estuaries (Masch, 1965; United States Army Corps of Engineers, 1968).

b. Test corals or specified portions of the reef could be used to indicate deleterious conditions. Such procedures (test oysters) have been used when dredging near live oyster beds (Masch, 1965; U.S. Army Corps of Engineers, 1968).

Finally, experimental research is needed in all areas pertaining to the effects of sand mining on reef comunities. In particular the following areas are suggested.

a. The effect of sand abrasion on coral growth.

b. The effect of deepening an area, and exposing new surfaces, upon succession populations of fish and invertebrates.

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2. SELECTED ABSTRACTS

These abstracts deal with the effect upon marine organisms of suspended loads, sediment deposition, and other physical changes which are consequential to dredging operations. Although special attention was directed toward obtaining information directly relating to the Hawaiian environment, many of the references abstracted pertain to forms of marine life not prevalent to Hawaii, or to the organisms of the fresh water environment. These, however, are valuable in that they provide a basic understanding of the problems associated with dredging.

Similarly most of the references concerning dredging relate to channel or harbor dredging often carried out in mud or clay, commonly with discharge of this spoil directly into the water nearby. This will have much more severe consequences than sand dredging which is retained aboard or pumped ashore.

In this case again, these have relevance to the problem especially as no studies have been conducted, to the author's knowledge, of the effects on the environment of sand mining.

Allen, G. W. and Conlon, D. M. 1969. Dredge spoil surveillance in shellfish areas. In Proceedings, Civil Engineering in the Ocean II. American Society of Civil Engineers, pp. 823-834 (held in Miami Beach, December 10-12, 1969).

Development and maintenance of navigation channels in estuarine areas could damage or completely destroy producing shellfish beds if the spoil discharge is not controlled. Fourteen miles of maintenance dredging in the Bon Secour area at Mobile Bay was monitored for possible damage to oyster beds.

Sample stations were set up to determine the silt drift pattern and test oysters were placed at two test locations. Data collected was insufficient to establish definite sedimentation and silting patterns, but sediments were observed to be transported approximately 1,200 feet from the point of discharge.

Sediment deposition on the oyster beds was negligible with no damages incurred.

Localized scouring on the irregular bottom and water traffic kept the sediment in a dynamic state of continuous re-suspension. Winds were responsible for increased sediment movement more than any other factor.

A discussion on the collection of sediments is included.

Angino, E. E. and O'Brien, W. J. 1967. Effects of suspended material on water quality. International Association of Science Hydrology Publication: 78, pp. 120-128 (17 ref.).

Suspended material contributes to turbidity, hardness, alkalinity, water color, affects photosynthetic activity and may be harmful to organisms.

Suspended particles reduce the light penetration by reflection, refraction, diffusion, diffraction and absorption. Less light induces a reduction in photosynthesis in the water, thereby reducing the phytoplanktonic action. This eventually causes a drop in the oxygen content of the stream. In streams where the oxygen content is 25-90% of saturation, the drop in oxygen is crucial. Also, absorption of oxygen onto the suspended material and the B.O.D. demand of some at the suspended material compounds the problem.

The surface of suspended material may act as a substrate for microorganisms. Consequently, the dissolved oxygen concentration, PH and other physical and chemical characteristics of the water are altered. If the activity takes place on the stream bottom there is a chance that anaerobic conditions may develop, thus, giving rise to complex physical and chemical reactions. Other sections concentrated on the physical and chemical effects of suspended material.

Barnes, J. H. 1966. The Crown of Thorns Starfish as a destroyer of coral. Australian Natural History. December, 1966, pp. 257-261.

A very general discussion is presented on the infestation of the Great Barrier Reef near the Green Island Reef by the Crown of Thorns Starfish. Previous environmental imbalances due to _A planci_ have not been recorded. Ten years ago, the Crown of Thorns Starfish was a rarity but by 1964 the infestation was of overwhelming proportions. No hypothesis as to the cause of the infestation is considered.

Bartsch, A. F. 1960. Settleable solids, turbidity, and light penetration as factors affecting water quality. In Biological problems in water pollution, edited by C. Tarzwell. U.S. Public Health Service Publication No. W60-3, pp. 118-127 (31 ref.).

Settleable solids, turbidity and light penetration can be studied separately, but since they are so interrelated it is advisable to consider them as a single factor affecting the environment.

The following is excerpted from the Report Abstract:

> "Settleable solids include inorganic particles from soil erosion and various industrial operations as well as living and dead suspended organic matter of natural or man-influenced origin. Particles that settle on the bottom can destroy fish food organisms, interfere with successful hatching of fish eggs, obliterate otherwise suitable spawning areas and carry unstable organic matter to the bottom where undesirable decomposition products are formed. While suspended, particles in sufficient concentration or of sufficient hardness and size may directly injure fishes and fish food animals. Specific cases that exemplify some of these effects are described.

Suspended particles also affect the optical properties of water so as to create turbidity. By impairing light penetration, turbidity diminishes the thickness of the euphotic zone and this limits basic productivity. Quantities of phytoplankton in clarified and turbid waters of the Missouri River are another expression of impairment of basic productivity by turbidity. Turbidity may also affect temperature relations. In sport fishing waters, turbidity limits the distance at which sport fish can see the lure and thus affects both the yield and attractiveness of fishing waters."

Brehmer, M. L. 1965. Turbidity and siltation as forms of pollution. Journal Soil Water Conservation, Vol. 20, No. 4, pp. 132-133.

The biological effects of inorganic, suspended solids in an estuarine biological community are complex and very difficult to quantify. As the suspended solids content of the water increases, the depth of light penetration decreases. Therefore, the compensation depth (i.e., the level at which the rate of photosynthesis equals the rate of respiration) decreases, or approaches the surface. As a result, if the respiration exceeds the productivity, the system has a negative energy flow, and the biological community undergoes degradation.

Flocculation and aggregation of the suspended solids can mechanically entrap microscopic plants and carry them to the bottom. The effects of inorganic suspensoids on zooplankton and higher forms of aquatic life are difficult to evaluate. Shellfish and finfish are vulnerable to damage by inorganic suspended solids. Feeding activity by filter-feeding shellfish is inhibited by high suspended solid concentrations.

The transition zone between fresh and salt water is a nursery area for many species of fish. This area is also the zone of highest suspended solids load of any part of the tidal system. The seasonal fluctuations of the fish species may be partly caused by the high suspended solids load in the transition zone.

Dredged spoil disposal can destroy infaunal forms by smothering. Siltation can smother benthic forms while producing unstable bottom conditions thereby preventing re-establishment of the populations.

The effects of turbidity and siltation on intended recreational uses of the water are also mentioned.

Brock, V. E., Jones, R. S., and Helfrich, P. 1965. On ecological reconnaissance of Johnston Island and the effects of dredging. Hawaii Marine Laboratory Technical Report, No. 5. The Hawaii Marine Laboratory, University of Hawaii.

The objectives of the survey were:

1. To determine the major habitats of the reef and lagoon ecosystem at Johnston Island, map their boundaries, and characterize them by differences in faunal composition and physiography.

2. Measure the effects of dredging, turbidity and siltation on the coral and coralline algae.

3. Estimate the prevalence of ciguateric fishes and changes in their occurrence in relation to dredging and to patterns of ecological succession following the dredging.

Turbidity caused by the dredging was measured by using a 20 cm. Secchi disk. Disappearance depth ranged from 1.66 meters to 4 meters with respective extinction coefficients of 1.02 to 0.42. Sedimentation rates were measured at three stations ranging from .186 to .556 millimeters per month.

Nine areas were selected as representatives of distinctive habitats in or adjacent to the dredged areas. Detailed surveys of these areas included location, description of area, fauna, and dredging influences. The three most northerly habitats had a rapid flow of water across them from the open sea. All had vigorous coral growth and were not effected by dredging. The most westerly area had a flow of water from within the lagoon to the sea. This area was covered with a fairly heavy layer of silt from the dredging operation. Much of the once flourishing coral was dead, but there seemed to be little damage done to the fish population.

Two out of three habitat areas located further into the lagoon were covered with a fine layer of silt with little damage. Two habitats located in a lee lagoon area were affected by siltation to varying degrees. The site of dredging activities and places where fill was deposited were not examined in detail.

Broch, V. E., Van Heukelem, W., and Helfrich, P. 1966. On ecological reconnaissance of Johnston Island and the effects of dredging, Second Annual Report. Hawaii Marine Laboratory Technical Report No. 11. Hawaii Institute of Marine Biology, University of Hawaii.

This is a continuation of the previous report (Brock et al., Jan. 1965). The objective was to describe four additional areas in regard to physical and faunistic characteristics, each encompassing a portion of reef not affected by dredging and a portion which had been recently removed by the dredging operation. Also, the relation of the occurrence of ciquatera in reef fish as a result of dredging was investigated.

The following is excerpted from the report:

> "A total area well in excess of 8,000 acres was affected by the dredging operation, most of it through the continuous or intermittent occurrence of silty water. Over 7,000 acres of reef and lagoon were more or less seriously affected by silty water. Over 1,100 acres of reef was destroyed though the dredging of almost 700 acres for vessel operations.
>
> The reduction in the percentage of living coral in silty water areas varied from none to 40% with, very roughly, 10% as an average figure. A parallel reduction in the number of echinoderm and fish species also occurred. In some of the dredged areas rather thick algal mats had developed over the whole bottom. The blue-green algae Lyngbys majescula was the dominant species. In the areas affected by silt, the algal growth was noted on the dead corals suggesting the possibility of a change in both the absolute and relative abundance of algal species in these areas."

Three species of herbivorous fishes not found to be toxic in the previous survey (1964) were toxic in 1965. All of the species feed mainly on algae. It is possible that they obtained the toxic from an algae which has recently become part of the dense algal mat covering the bottom of the newly dredged areas.

Buck, D. H. 1956. Effects of turbidity on fish and fishing. North American Wildlife Conference, Transactions: 21, pp. 249-261, (1 ref.).

The two-year study reports the effects of turbidity on fish growth, reproduction, food production, and fishing success in farm ponds, reservoirs and hatchery ponds. The turbidity was created artificially in the hatcheries, whereas, the turbidity was natural in the farm ponds and in one reservoir. Another reservoir was clear, thus, fish populations and public fishing success were sampled under varying conditions.

At the end of two growing seasons, the average total weight of fish in clear farm ponds was approximately 1.7 times greater than in ponds of intermediate turbidity and approximately 5.5 times greater than in muddy ponds. Differences were due to faster growths and greater reproduction.

Average volume of net plankton in surface waters of clear ponds during one growing season was eight times greater than in ponds of intermediate turbidities and 12.8 times greater in the most turbid ponds.

The number of species, as well as individuals, of all scaled fishes was low in the turbid reservoir due to the less successful reproduction and competition with the turbidity-adapted catfish. The volume of net plankton in the surface water of the clear reservoir averaged 13.5 times greater than in the clear reservoir.

Burt, W. V. 1955. Interpretation of spectrophotometer readings on Chesapeake Bay Waters. Journal Marine Research, Volume 14, pp. 33-46, (22 ref.).

The study was conducted to determine quantitative facts about the attenuation of light in turbid natural waters and to examine the materials causing the attenuation. Extinction of light in the Chesapeake Bay is primarily due to absorption and scattering of light by the suspended material. A large part of the extinction is caused by particles that are less than one micron in radius and occurring in concentrations ranging from 1 to 60 ppm by volume.

Casciano, F. M. and Palmer, R. Q. 1969. Potential of Offshore Sand as an Exploitable Resource in Hawaii. Department of Ocean Engineering, University of Hawaii. Prepared under the National Science Foundation, Sea Grant Program. (Grant No. GH-28), (139 ref.).

Sand has many commercial uses but since Hawaiian sand is chiefly calcareous, its uses can be narrowed to beach restoration and aggregate in concrete. To be suitable for use in concrete, sand must be coarse-grained and relatively free of clay, loan, silt, and vegetable matter. For beach restoration controlling factors are grain size, color, odor, resistance to abrasion, amounts of organic material and particle shape.

Land sources of sand in Hawaii are dwindling, therefore, the search for sand has moved offshore. Many factors such as size of deposits, location of deposit, delivery cost of mined sand and ecological considerations must be taken into account to determine the economic and technical feasibility of offshore sand recovery.

Short discussions on sand inventory and recovery projects in other states and the present outlook for offshore sand exploitation in Hawaii are included.

Chesher, R. H. 1969. Destruction of Pacific corals by the sea star Acanthaster planci. Science, Volume 165, pp. 280-283, (6 ref.).

The following is taken from the Abstract of the report:

> "Acanthaster planci, a coral predator, is undergoing a population explosion in many areas of the Pacific Ocean. Data on feeding rates, population movements, and stages of infestation were collected along coral reefs of Guam and Palau. Direct observations on destruction of Guam's coral reefs indicate that narrow, fringing reefs may be killed as rapidly as 1 kilometer per month. In a 2 1/2-year period, 90 percent of the coral was killed among 38 kilometers of Guam's shoreline."

The greatest mortality of A planci must occur during the larval stages. Destruction of reefs by blasting, dredging and other human activities has provided fresh surfaces, free of filter feeder (such as coral), that are capable of eating the larvae. Therefore, suitable settlement areas are provided where enough larvae can concentrate together, thus, providing the necessary seed population for an infestation. Infestations near Guam, Rota and Johnston Island were first noted near blasting and dredging activities.

Chesher, R. H. 1969. Acanthaster planci impact on Pacific coral reefs. Report to U.S. Department of Interior, (13 ref.).

The purpose of the survey was to ascertain population levels of A planci in the U.S. Trust Territory, determine the extent of coral damage, and gather data on possible causes and controls of infestations. Of the 19 Trust Territory islands surveyed, 10 were clearly infested, showing extensive coral damage and exceedingly large populations of A planci. Three islands had populations large enough to be producing areas of dead coral and six islands were not infested.

Overwhelming evidence is that the current population explosion is not a limited, local occurrence or a cyclic reef phenomenon. There are two likely possibilities for the rapid population growth: a change in the environment or a change in the animal. Changes in the physical environment that result in improved survival of A planci or biological changes that result in release of pressure from predators at some stage in the A planci life cycle are considered. Most evidence points to biological changes as the most likely cause of infestation. Such a biological change could be caused by blasting and dredging activities that occur on the reefs.

Mechanical damage to coral reefs caused by dredging or blasting may decrease the predation pressure on starfish larvae by corals. Settling areas for the larvae are provided by the dredging and blasting thus, leading to sudden large increases in population through increased survival in localized areas.

This hypothesis seems to apply to Guam, Rota, Ponape, Truk and Nukuoro but not to Ant or Australia. There is some question as to its applicability to Tinian, Saipan and Palau, where there are infestations but dredging and blasting are not common. Yap, Lamotrek, Ifalik and Woleai with no recent physical damage to their reefs and no infestations would fit the theory. Arguments against the theory state that the reefs were damaged during WWII without causing an infestation, but on the other hand, it is felt that damage of this type would be much less likely to provide suitable coral surfaces for larvae growth.

Other theories of causes including the reduced predation on adult starfish by the collection of tritons by shell collectors are discussed. The report also contains detailed discussions of the surveys of the individual islands, conclusions, and recommendations for study and control.

Cronin, E. L., Gunter, G. and Hopkins, S. H. 1969. Effects of engineering activities on coastal ecology. Interim Report to the Office of Chief of Engineers. U. S. Army Corps of Engineers.

Eleven types of engineering activities are briefly discussed. These include: dredging, filling, dams, diversions, jetties and groins, beach nourishment, land-cut canals, weed control, hurricane barriers, finger-type developments, and oceanic waste disposal. Principal attention is payed to the nature and importance of possible ecological effects on coastal areas and to the research which would be of greatest value toward improving predictions and evaluations of such effects.

Dredging always affects the ecolog of the surrounding area to some degree. These may be short duration, and insignificant effects or permanent and highly significant ones. Dredging changes the original interface between the water and the bottom, it creates new deep water areas, increases the potential for release of toxic or nutrient materials from the bottom, and causes suspended sediment and deposition.

Edmonson, C. H. 1928. The ecology of an Hawaiian coral reef. Bernice P. Bishop Museum Bulletin No. 45. Honolulu, Hawaii, (27 ref.).

The history of a living coral reef is not one of constant and progressive activity. At times, coral and other reef inhabitant experience conditions favorable to rapid development, while at other times conditions may cause a general retardation of growth. Under extreme environmental conditions, coral reefs may undergo partial or complete destruction. This can take place over a relatively long period of time or occur very rapidly.

Ability to adapt to changing environmental conditions such as temperature, light intensity, salinity and wave and tidal conditions, is necessary if a coral community is to flourish. Environmental conditions considered favorable to vigorous coral growth are: depth of water to 45 m; firm bottom with no silty deposits, good circulation of water, good food supply, strong light, minimum annual temperature not less than 18^{o}c, and salinity between 27 and 38 percent.

A section of the Waikiki Reef was studied by conducting various experiments on the species of coral found on the reef. The experiments tested the resistance of various corals to rising and falling temperatures, silt, sunlight, drying, and total darkness.

Settling silt may have a smothering effect upon weak and low lying coral colonies. Of the 23 species tested, Pocill opora, Porites and some Montipora were the least resistant to silt when completely buried, some dying within 24 hours. The species most resistant were Stephanaria stellata, Stephanaria brighami, Fauia hawaiiensis, Leptastrea agassizi, and Fungia scutaria.

Dredging operations in the construction of a swimming pool in the southern part of the reef increased the accumulation of sand in the area. This may be responsible for the general paucity of corals in the immediate area. The predominate species of the area, Pacillopora cespitosa, lives on the rocks above the reach at the shifting sand bottom. The influence of sand and silt is greatest near the northern and southern boundaries of the reef than in the middle portion. In the middle portion a larger variety and vigorous growth of coral are characteristic.

Ellis, M. M. 1936. Erosional silt as a factor in aquatic environments. Ecology, Vol. 17, No. 1, pp. 29-42 (6 ref.).

Erosional silt can affect living organisms by causing physical and chemical changes in the water and through alterations in the bottom conditions resulting from the settling out of the silt. Findings show that silt laden waters change the aquatic environment by screening out light, by blanketing the stream bottom, by changing the heat radiation, and by retaining organic material and other substances which may create unfavorable bottom conditions. Some specific results of experiments are mentioned.

Fisher, J. L. 1969. Starfish infestation. Science, Vol. 165, p. 645.

This paper offers another hypothesis as to the cause of the starfish infestation of the Pacific coral reefs. In contrast to Chesher's hypothesis that the infestation is caused by destruction of reefs by blasting and dredging, it is felt that possibly the widespread use of insecticides is to blame.

Dredging and blasting are not new in the Pacific, but the extended use of insecticides is new. Perhaps population of A planci are normally kept under control by predators which have become depleted by ingesting excessive amount of insecticide.

Harrison, W. 1967. Environmental effects of dredging and spoil deposition. 1967 Proceedings of World Dredging Conference, pp. 535-560. (Held in New York City, May 6-8, 1967.) (1 ref.)

The following is taken from the Introduction:

> "The questions most frequently asked by those concerned with environmental pollution by dredging activity have to do with the effects of dredging or spoil deposition on the local marine life. Most concern is usually directed

> toward the marine organisms found upon or within the bottom in the affected areas, rather than toward the organisms in the water column itself. The problem of documenting such effects usually resolves into obtaining adequate data on changes in local bottom elevations, suspended sediment concentrations, and animal populations. What may be considered adequate data for one study will quite often be irrelevant for another, due basically to differing requirements or environmental populations. It is the purpose of this paper to review two recent studies that were designed to determine the effects of dredging or spoil disposal on benthic organisms in lower Chesapeake Bay."

Data indicated that dredging and spoil disposal in two areas temporarily destroyed the infaunal populations, but resettlement and recovery were fairly rapid. The resettlement occurred by migration of active species and by hydrodynamic distribution of many species while in the free-swimming or free-floating larval stages.

Hauck, R. 1959. Mining and dredging wastes. Proceedings of the Fifth Symposium-Pacific Northwest on Siltation--its sources and effects on the aquatic environment. U.S. Public Health Service, Portland, Oregon, pp. 32-33. (March 23-24, 1959).

Experiments conducted with dredge mining wastes showed that in every case the mortality of eggs, fry and fingerlings was greater in silt-ladened water than in clear water.

Helfrich, P. and Kohn, A. J. 1955. A survey to estimate the major biological effects of a dredging operation by the Lihue Plantation Co., Ltd., on North Kapaa Reef, Kapaa, Kauai, preliminary report. Library, Hawaii Institute of Marine Biology, University of Hawaii, (11 ref.).

The following is from the introduction of the report:

> "This survey has been undertaken to estimate the major biological effects of a dredging operation that will produce a definite alteration of the topography of one section of North Kapaa Reef. The fish and invertebrates found on and about North Kapaa Reef that are important to the local population are dependent to varying degrees on the substrate and the other organisms it supports. Therefore alteration of the substrate will affect all of the organisms in this area."

The standing crop of resident fishes might be markedly altered by excavation of the bottom, because they are dependent on the substrate for their existence. Octopus may be rather sensitive to changes in the environment. The direction that silt created by dredging will move and depends largely on the velocity and direction of prevailing currents.

Hollis, E. H., Boone, J. G., DeRose, C. R., and Murphy, G. I. 1964. A literature review of the effects of turbidity and siltation in aquatic life. Department of Chesapeake Bay Affairs Staff Report. (Annapolis, Maryland) (78 ref.)

Turbidity and siltation are detrimental to aquatic life. Siltation traps organic matter on the bottom which may result in anearobic conditions. Silt often damages or destroys fish eggs by suffocation or by reducing the flow of water containing oxygen past the eggs. Suspended silt can harm or clog gills of fish. Unstable silts and shifting sands form a false bottom that will not usually support benthic animals; this can break the food chain with the result that some fish will starve.

Silt destroys planktonic algae by absorbing light needed for photosynthesis, and by flocculating and precipitating algae cells. Encrusting algaes are smothered by a silt coating. The abrasive action of inorganic particles may damage algae cells. Aquatic plants which are needed by many fishes for egg attachment and cover can be destroyed by silt through elimination of light. Silt can also interfere with gas exchange through the leaves. Shellfish beds can be destroyed by siltation. Determination of the effects of turbidity is complex.

Huet, M. 1965. Water quality criteria for fish life. In Biological problems in water pollution, ed. by C. Tarzwell. U.S. Public Health Service Publication 999-wp-25., pp. 160-167. (32 ref.)

Discussed are the qualities of water needed to support fish life, such as the essential chemical and physical characteristics of the water. Suspended matter causes turbidity which acts unfavorably on the productivity of the water. Turbidity, whether natural or man-made, can reduce the nutritive value of the environment and can also directly harm fish; this results when suspended particles damage or block the gills. However, fish can tolerate turbidity for long periods except when accompanied by acids, allkalies or substances that are harmful to the gills or interferes with their normal functioning.

Deposition of suspended solids may interfere with or prevent fish reproduction by destruction of eggs or breeding places.

Ingle, R. M. 1952. Studies on the effect of dredging operations upon fish and shellfish. Florida State Board of Conservation, Technical Series 5, (23 ref.).

Investigations were made to determine the effects of dredging operations upon fish and shellfish in Mobile Bay about 3 miles offshore of Great Point Clear, Alabama. Every attempt was made to find some evidence of mortality or harm to fish and shellfish as a result of the dredging activites. Findings failed to show a single instance of deleterious action to the estuarine animals. However, careless operation of dredges could result in harm to the organisms. No attempts to discover beneficial influences in dredging were made, but certain observations seem to support the idea.

The direction of flow of the water current determines the direction of transport of the sediments. In areas where there is a tidal influence, the current reverses resulting in a wider dispersal of suspended material. The distance suspended material is carried depends on the current and size of particles. The larger sizes being deposited after a shorter distance of transport. Sediments deposited on higher elevations than the surrounding bottom are commonly disturbed by currents which causes resuspension resulting in the finer particles being transported elsewhere. Water moving over a given level is deflected upward and speeded up as it passes over a ridge, causing resuspension of sediments.

Controlled dredging should be practiced which anticipates various changes in the environmental conditions. Under controlled dredging constant surveillance by persons capable of evaluating the various conditions would be required. Frequent checks by silt collectors placed at various distances from the dredge, biological checks and trawling would be conducted in the vicinity of the dredge. With this monitoring it would be possible to adjust the activities of the dredge to changing conditions.

Johannes, R. E. 1970. Coral reefs and pollution. Department of Zoology, University of George. (Unpublished review written for the FAO technical conference on marine pollution, held in Rome, December, 1970). (65 ref.)

The following is from the Abstract to the Report:

> "Coral reefs are among the most biologically productive, taxonomically diverse and esthetically celebrated of all

communities. They also constitute the most extensive shallow water community on earth. Despite these characteristics, the widespread degradation of coral reef communities by man has gone almost unnoticed. This is probably due to the essential invisibility of coral reefs to all but the skin diver.

The contamination of reef communities by sewage and industrial wastes is commonplace. Siltation and water stagnation brought about by dredging and filling have created serious problems on some reefs. The destruction of reef communities by silt-laden, low-salinity water from floods has been exacerbated by poor land management. Since tropical marine organisms live within only a few degrees of their upper thermal limits, thermal pollution by power plants threatens to become a serious problem. Devastation of Pacific coral reefs by the starfish, Acanthaster planci, is thought to stem from man's unconscious shifting of ecological equilibria in the reef community.

Although corals do not appear to account for the major fraction of total reef community biomass or metabolish, when they die the reef community degenerates due to the subsequent death or emigration of other reef fauna. Thus, the resistance of this community to environmental stresses cannot exceed that ot its coral component. Although the impact of man's activities on reef communities as a whole is very poorly understood, considerable information is available on the tolerance of various coral species to some of the physiological stresses which accompany pollution. This information should be used as a guideline for setting up provisional reef conservation regulations. Obviously we must investigate the responses of the entire reef community to pollution, but we cannot afford to wait until such knowledge is available before taking steps to reduce reef pollution.

The teaching of conservation and ecology in the schools is a vital mechanism for developing an awareness of the value and fragility of coral reefs and a concern for their protection."

Most corals have the ability to cleanse themselves of sediments falling from above, but they are unable to live for any appreciable time if heavily coated or buried. The abundance of corals in

Kaneohe Bay, Hawaii, have decreased rapidly in the past few years. As a result of sedimentation and exposure to low salinities due to flood runoff.

Blasting and dredging of channels through the reefs are particularly harmful to a reef community. This is documented for Johnston Island. Temporary turbid water resulting from man's activities appears not to affect a shallow water reef community seriously unless it settles out forming a heavy coating of silt. However, if the water becomes turbid over deep water coral, the decrease in light intensity may cause retarded growth and even death. Blasting and dredging may also be a cause for the outbreak of the starfish *Acanthaster planci*.

Other topics dealt with are low salinities, thermal pollution, desalination plants, sewage pollution, cause of the starfish infestation, oil pollution, ciguatera, miscellaneous pollutants, and the fate of damaged reef communities.

Jones, D. and Willis, M. S. 1956. The attenuation of light in sea and estuarine waters in relation to the concentration of suspended solid matter. Journal Marine Biological Association, U.K. Vol. 35, No. 2, pp. 431-444, (8 ref.).

Investigations into the relationships between Secchi disc readings, concentration of suspended matter and the attenuation coefficient of tungsten light in sea water are described.

For sea and estuarine waters the attenuation coefficient, measured in situ, was 2.5 m^{-1} for 10 mg/l, and it increased less rapidly for higher concentrations, reaching 4.5 m^{-1} at 28 mg/l. The method used to determine the concentration of suspended solids is described. The Secchi disc visibility was inversely proportional to the attenuation coefficient.

Kelly, D. W. 1959. Effects of siltation on production of fish food organisms. Proceedings of the Fifth Symposium - Pacific Northwest on Siltation - its sources and effects on the aquatic environment. U.S. Public Health Service. Portland, Oregon, pp. 13-15. (March 23-24, 1959.)

Siltation can smother bottom fauna. Many fish are browsers and need plant life for food. Anything that affects plant life, particularly microscopic plant life, is going to affect fish food organisms.

Turbidity and siltation may destroy shelters used by fish. One advantage of turbidity is that it carries absorbed minerals which support growth if the turbidity is not sufficiently intense to limit light penetration.

Klim, D. G. 1969. Interactions between sea water and coral reefs in Kaneohe Bay, Oahu, Hawaii. University of Hawaii, Hawaii Institute of Geophysics, Report No. 69-19, (35 ref.).

The study, covering a period of eight months, was undertaken to determine if measurable changes in characteristics occur in sea water passing over a shallow coral reef. The parameters studied include salinity, temperature, current velocities, dissolved oxygen, pH, dissolved organic carbon and particulate organic and suspended inorganic carbon.

Coral reefs and atolls provide shelter and surface for immense concentrations of living organisms. Various studies are mentioned that deal with the productivity of a coral reef and the importance of zooxanthellae. Coral reefs are extremely efficient ecological units which support large biomass in the relatively barren oceanic environment. Still, too little is known about the interactions between reef inhabitants and their environment.

Masch, F. D. 1965. Shell dredging as a factor in estuarine sedimentation. Coastal Engineering Santa Barbara Specialty Conference, October, 1965. American Society of Civil Engineers, pp. 627-644, (4 ref.).

Industrial demands for buried shell have been increasing. Shell deposits are often covered with several feet of silt and clay which are pumped on board the dredge with the shell. The shell is washed and screened and the silt and clay are pumped overboard with the wash water. Continuous dredging can place large quantities of sediments into suspension. Uncontrolled dredging can produce serious depositional problems such as damaging shellfish beds and filling small craft channels.

If the sediments are composed of sands, rapid deposition will take place near the dredge. If sediments are clays and silts, flocculation will occur in salt water, and density currents may form transporting the sediments considerable distances. Larger dredges operate with few interruptions and discharge wash waters of high rates, thereby, producing great amounts of sediments.

Reefs that rise above the bottom are less susceptible to deposition. Tides, currents and waves move sediments on and off reefs. If allowed to go unchecked, consolidation of the flocculated particles will occur, and the deposited layer will eventually have sufficient strength to resist the shear stresses produced by the waves, currents or tides. Continued dredging in such an area aggravates the problem.

A short discussion on instrumentation to measure sedimentation and a literature review are included.

Milliman, J. D. 1965. An annotated bibliography of recent papers on corals and coral reefs. Atoll Research Bulletin, No. 111. (Issued by the Pacific Science Board, National Academy of Sciences, National Research Council, Washington, D.C.) (400 ref.)

The bibliography concentrates on the geological aspects of modern coral reefs. Articles dealing with organisms other than corals are listed when the organisms have an effect on the corals themselves, their ecology or their related sediments. The bibliography is categorized into five sections: (1) geological features, (2) ecology, (3) the animal-coral, (4) bibliographies containing additional references, and (5) an author index.

Moberly, R., Jr., and Chamberlain, T. 1964. Hawaiian beach systems, final report. Hawaii Institute of Geophysics, Report No. 64-2, University of Hawaii.

The report concentrates mainly on the sand budget of the Hawaiian Islands including individual descriptions of 112 beaches.

Contained in a section on marine geology is a short discussion of reefs in Hawaii, as summarized in the following excerpt from the report:

> "Fringing reefs are the most common type of reef around the larger islands of the southereastern end of the Hawaiian archipelago. The reefs comprise three general types, with gradations between them: (1) wide and moderately shallow reefs off windward coasta, (2) wide and very shallow reefs along some leeward or otherwise protected coasta, and (3) deeper and more irregular reefs off northern and some open leeward coasta. All these reef types in Hawaii may be traversed by sandy-bottom channels, 5 to 30 or more

feet deeper than the adjacent reef flat, and generally seaward of stream valleys. The channels were cut during a lower stand of the sea in the Pleistocene, and since then have remained as topographic features because coral and calcareous algal growth has been inhibited on the channel bottoms by the sand trapped or transported downslope in them."

The fringing reef between Koko Head and Pearl Harbor on the south coast of Oahu has been greatly modified through dredging and filling. The western end of the fringing reef between Kanaha west to Kolo on Maui is being buried by silt with the advancing mangrove forest.

The only reef in the Hawaiian Islands resembling a barrier reef is at Kaneohe Bay, Oahu. Some of this reef has been dredged for ship channels.

Moberly, R. Jr., and Campbell, J. F. 1969. Hawaiian shallow marine sand inventory. Hawaii Institute of Geophysics, University of Hawaii. Prepared under the National Science Foundation, Sea Grant Program. (Grant No. GH-28), (86 ref.).

Shallow water sand deposits are being located and mapped in the Hawaiian Islands. One such body of sand is the Ahu O Laka Sand Deposit, Kaneohe Bay, Oahu. The deposit is located on the lagoon-ward edge of a large barrier-reef flat and is estimated to be at least one million cubic yards in size. Removal of the sand would not affect the shores of the Bay.

The possibility of ecological damage to the adjacent patch reefs west and northwest of the deposit by dredging are discussed. It is concluded that the possibility of damage is slight, because the sand size is too coarse-grained and currents in the bay are not turbulent enough to support much suspension. It is proposed that before dredging commences, a detailed current study be undertaken and care in selecting a dredging method that will minimize crushing the sand. Also, a marine biologist should monitor the reefs during dredging.

Naval Oceanographic Office. 1969. Report of the initial survey in a study of the effect of dredging on the coral reef development-Autec Site 1. Naval Oceanographic Office, Informal Report No. 69-90, (7 ref.).

A biological survey was conducted at Site 1 of the Atlantic Undersea Test and Evaluation Center (AUTEC). This survey was the initial investigation to determine the effects of future channel dredging on the nearby coral reef communities.

Nine areas, each 10 meters square were surveyed. A grid system was set up by using concrete blocks and a wire. Sketches and photographs recorded the condition of each survey area.

The numerous sponges found on the reef are extremely sensitive to siltation. Therefore, they are expected to provide an indicator of the effects of future dredging.

Future plans call for a dye study to predict the probable route of silt-laden water during various conditions on the reef. Possible additional surveys two to three months after dredging and one year or more after dredging have been proposed. These surveys would determine immediate and long lasting effects to the reef community as well as aid in detecting only reef regeneration.

Newell, N. D. 1959. The questions of coral reefs. Natural Histroy. Volume 68, No. 3, pp. 118-131.

A general discussion of the origins of coral reefs is presented. Darwin's "subsidence theory", Daly's "glacial control theory" are considered.

The reefs in the West Indian region were disturbed at the beginning of the Tertiary, and late in the Miocene, by Mountain uplifts resulting in widespread deposition of muddy sediments. These unfavorable changes in the physical environment have had deleterious effects on the coral reefs. The mid-oceanic reefs of the Indo-Pacific region were far removed from the sedimentation. This may be one factor that lead to a general deterioration of the West Indian reefs as compared to the reefs of the Indo-Pacific area.

Newell, N. D. 1959. The biology of corals. Natural History. Volume 68, No. 4, pp. 226-235.

Newell presents a general discussion on the biology of corals. A reef community may include representatives of every phylum of the animal kingdom and several primitive forms of the plant kingdom. Such a community may exceed 3,000 species, each with its own biological requirements, but mutually dependent on each other. Since the coral polyps are in a fixed condition, a food supply must be brought to them by circulating water. Reef corals possess symbiotic algae, zooxantholle, which are found in the corals endoderm. The algae obtains its food and carbon dioxide from the coral and the coral receives its oxygen and possibly carbohydrates from the algae. These algae require sunlight for photosynthesis. Thus, corals are mostly found in shallow water.

Phinney, H. K. 1959. Turbidity, sedimentation and photosynthesis. Proceedings of the Fifth Symposium-Pacific Northwest on Siltation--its sources and effects on the aquatic environment. U.S. Public Health Service. Portland, Oregon, pp. 4-12. (March 23-24, 1959), (17 ref.).

A turbid medium causes a reduction in light intensity, in all wave lengths, that is approximately proportional to the concentration of suspended particles. The rate of photosynthesis is proportional to the amount of available light. Therefore, as turbidity increases, the rate of photosynthesis decreases.

The physical effect of a layer of sediment is that of a mechanical barrier to gas exchange between benthic organisms and the surrounding medium. If this occurs, gas exchange cannot be accomplished solely by diffusion with sufficient rapidity to maintain life processes in most aerobic organisms.

When relating physical and biological factors concerning populations existing in turbid waters, the following must be considered:

1) What is the metabolic status of the population ($CO_2/0_2$ ratio).

2) What are the light transmitting qualities (absorption, diffuse scattering) of the medium.

3) What are the characteristics of the suspensoids, and the color that is controlling light transmission.

A full analysis must be made if one is to determine the effects of turbidity and sedimentation on the aquatic environment.

Seventeen references are cited.

Pollock, J. P. 1928. Fringing and fossil coral reefs of Oahu. Bernice P. Bishop Museum Bulletin, No. 55. Honolulu, Hawaii.

The organisms chiefly contributing calcium carbonate to both fossil and fringing reefs are corals and coralline algae. The algae contribute more than the corals. The algae are called by the general name of lithothamnium.

The nodular forms of lithothamnium are able to grow in turbid water, where they are covered by mud at low tide, but where the mud is stirred up at high tide.

No live corals were found in water that was turbid at every high tide.

Roy, K. J. and Smith, S. V. 1970. Sedimentation and coral reef development in turbid water: Fanning Lagoon. Hawaii Institute of Geophysics, Contribution No. 358, (33 ref.).

Coral reefs will not develop in an environment in which the light intensity is less than some minimum value or in one having a sediment deposition rate greater than some tolerable limit. However, extreme water turbidity and muddy bottoms do not mean that the limiting values are exceeded; such is the case at Fanning Lagoon.

Fanning Lagoon has a turbid water area (visibility, 2m) and a clear water area (visibility, 10 to 15m). Both areas have muddy bottoms. The calcium carbonate suspended load is approximately 3.5 mg/l in the turbid water and 1.0 mg/l in the clear water.

Suspended load can have two effects on coral--blockage of light and smothering of organisms by deposition. At any given depth the relative light intensity is 10-20 percent higher in the clear water than it is in the turbid water. Because of the shallow depth of Fanning Lagoon and the light-scattering effect of the suspended material, the light intensity at the bottom is never less than 5 percent of the incident light at the water surface. As a result, light is not a limiting factor in the turbid water reef development. Also, the cleaning mechanisms of the corals of Fanning Lagoon are frequently sufficient to handle the deposition.

Live corals cover 62 percent of the clear-water area and 31 percent of the turbid-water area. The absence of coral is the turbid area is a result of deposition of sediment in the upwind portion of the area. The effects of deposition decreases downwind where maximum coral development is seen. Reefs in the turbid water are ecologically different from the ones in celar water, but they are still living reefs. Ramose corals make up 55 percent of the individuals in the turbid water and only 10 percent of those in the clear water. This difference is reflected in the structure of the reefs; those in clear water are massive and steep-sided, while those in the turbid water have gentler slopes and are more open with sediment infill.

Shepard, F. P. 1963. Submarine geology 2nd. Ed. Chap. 12, Coral and other organic reefs. Harper and Row, New York.

The definition of organic reefs, the six types of reefs and reef ecology are discussed. The most common reef formers presently are the hermatypic corals and coralline algae which are confined to the tropical areas, although extending north and south of the tropic if conditions are favorable. Favorable condition usually consist of depth of 25 fathoms or less, temperatures between $18^{o}c$-$30^{o}c$ and salinity within 27 to 40 percent.

It is mentioned that coral reefs cannot grow on a soft mud bottom, but coral reefs were found, by borings in West Sumatra, to overlie mud deposits. Studies of the reef at Waikiki suggest that mud from a stream had prevented growth of the reef in the vicinity of the mouth of the river. At the southern end of the Queensland Great Barrier Reef there is an absence of reefs which is apparently related to muddy water in the area.

On the other hand, reference is made to the reefs off the Rewa River in the Fiji Islands where tremendous amounts of silt exists without killing the reefs. Also, reefs are found to exist off the south coast of Molokai, Hawaii, though the area is characterized by muddy water, while on the north side of the island, few reefs exist in the relatively clear water. It is suggested that the low salinity of the water at the mouth of rivers is more important than muddy water in restricting reef growth.

Sherk, J. A., Jr. and Cronin, L. E. 1970. The effects of suspended and deposited sediments on estuarine organisms, an annotated bibliography of selected references. Chesapeake Biological Laboratory, Solomons, Maryland. Natural Resources Institute, University of Maryland.

The following are excerpts from the introduction to the Report:

> "Interest in the effects of suspended loads and deposited sediments on estuarine organisms has been accelerated by the present need to establish water quality criteria and standards on a national scale and by a wide variety of coastal engineering projects which involve temporary or enduring changes in the suspended loads and deposition of sediments in rivers, bays, sounds, channels, or coastal areas. Estuarine sites selected for projects are often inhabited by unusually important biotic communities which become centers of conflict among navigational, recreational, commercial fisheries, conservation, and municipal interests. This set of abstracts and summaries of pertinent reports has been prepared to assist in the evaluation of probable effects of suspended and deposited sediments.
>
> The bibliography was prepared by screening approximately 1200 published articles, papers, books, and unpublished reports. The literature search centered on the identification of references that contained information on field and laboratory studies of the biological effects of suspended loads and deposited sediments in estuaries, although several pertinent references from fresh water studies have been included. Special attention was directed towards obtaining material which dealt specifically with coastal engineering projects such as harbor development and maintenance, shell and sand dredging, dredge spoil disposal, and the biological effects of these environmental modifications. Several papers dealing with offshore dumping of sewage sludge, dredge spoil and acid wastes are included. A bibliography of bibliographies (18 references) follows the annotated section (161 references). Both sections are arranged alphabetically by author."

Storr, J. F. 1955. Ecology and Oceanography of the coral reef tract, Abaco Island, Bahamas. Geological Society of America, Special Paper No. 79.

Coral growth and structures are related to different ecologic factors, including waves, light and currents.

Reef corals show a distinct preference for high light intensities. Light promotes coral growth through its effects on the zooxanthellae. Reduced light intensity due to suspended sediments may limit the growth of coral. Reduced light intensity due to suspended sediments may limit the growth of coral. Reduced light intensity also affects plant growth. The depth to which light intensity is reduced to 1 percent of the surface value, is the limit for plant growth.

Deposition of sand can smother coral. Wave action can sweep corals clean of sediments. Sand movement on the bottom may erode coral reefs, particularly, during high waves. Wave action may break off coral projections if they have been weakened by erosion.

The gradient in grain size of the bottom sediments determines the type of bottom organisms that live in the area.

A reef presents a frictional barrier to tidal flow, therefore, tidal currents are accelerated through channels and breaks in the reef. The accelerated currents produce erosion that inhibits coral growth on the bottom, but the tidal currents encourages coral growth along the margins of the channel.

U.S. Army Corps of Engineers, Engineering District, Mobile, Alabama. 1968. Surveillance program of sedimentation effects of hydraulic dredging, Gulf, Intracoastal Waterway, Bon Secour Bay section, July-December, 1967.

The dredging project consisted of 14 miles of maintenance dredging in which a total of 1,717,225 cubic yards was excavated and discharged into designated spoil areas. The primary objectives of the surveillance program were:

1) Prevent damage to the oyster producing areas due to sedimentation.

2) Determine the lateral transport distance of the spoil material from the point of discharge.

3) Monitor the spoil deposition of dredging operations.

4) Obtain data in sufficient time to modify the dredging if required to prevent damage to oyster beds.

5) Gain knowledge as to the effect of wind, waves, and tides upon the sediment conditions.

6) Develop methods and techniques of collecting sedimentation samples in estuarine and salt water areas.

The following conclusions were drawn:

1) Sediment deposition on the oyster producing beds was negligible causing no damage or adverse conditions. Spoil discharge was controlled and sediment deposition was within predetermined areas.

2) Definite sedimentation and silting patterns within the embayment could not be established.

3) Lateral sediment transport from the point of discharge was in the range of 1,200 feet.

4) Weather factors played a greater role in moving sediments than the dredging operations.

5) Test oysters proved to be a reliable method of evaluating sediment damage to oyster beds.

6) The monitoring of sedimentation did not require sophisticated equipment.

It was recommended that dredging projects be monitored in order to prevent damage to shellfish productlng bottoms. Also, dredging operations should be flexible to allow for alteration of spoil methods if conditions appear which may create pollution problems.

Vaughan, T. W. 1916. The results of investigations of the ecology of the Floridian and Bahaman Shoalwater corals. National Academy Science Proceedings, Volume 2, No. 2, pp. 95-100.

Four possible factors which tend to limit the downward extent of reef forming corals are: 1) effect of sediment, 2) decrease in supply of small animal plankton, 3) decrease in intensity of light, and 4) lowering of the temperature.

Conditions necessary for vigorous coral reef development are: 1) depth of water less than 45 meters; 2) bottom firm or rocky without silty deposits; 3) water circulating; 4) abundant supply of small animal plankton; 5) strong light; 6) annual minimum temperature greater than 18°c.; and 7) salinity between 27 to 38 percent.

Most corals possess some capacity for removing sediments from their surfaces. This capacity varies according to the species, being lowest among corals which occur on the outer reefs. Some corals can endure having their surfaces covered with silt for some time, but no species of coral will survive when actually buried beneath sediments caused by rapid deposition. Branching forms of many corals are less likely to accumulate large amounts of sediments on their surfaces.

Wagner, R. 1959. Sand and gravel operations. Proceedings of the Fifth Symposium-Pacific Northwest on Siltation--its sources and effects on the aquatic environment. U.S. Public Health Service, Portland, Oregon, pp. 34-35. (March 23-24, 1959.)

This is a short discussion on the effects of gravel removal from stream beds. Silt can settle in pockets and pools in the stream bed which have provided shelter areas for some fish.

Wells, J. W. 1957. Coral reefs. In Treatise on marine ecology and paleoecology. Volume I, Ecology, ed. by J. W. Hedgpeth. Geological Society of America Memoir 67, pp. 609-631, (23 ref.).

The existence of a reef community is largely determined by the ecological requirements of hermatypic corals and calcareous algae. Light intensity and radiant energy is more important in determining the number of species of reef corals than the oxygen supply and temperature. Included are discussions on atoll reefs (seaward, leeward and lagoon reefs), barriers, fringing and platform reefs.

Wells, J. W. 1957. Corals. In Treatise on marine ecology and paleoecology. Volume I. Ecology, ed. by J. W. Hedgpeth. Geological Society of America Memoir 67, pp. 1087-1104.

The ecological conditions that affect hermatypic (reef forming) and ahesmatypic (non-reef forming) corals is discussed including food, water movement, depth and illumination, temperature, salinity, sediment, and substratum.

Depth has a limiting effect on coral life due to the decrease in the intensity of radiant energy, essential to the life of the zooxanthellae contained in the coral. Likewise, suspended sediment is harmful only when it causes sufficient turbidity to diminish light penetration.

Corals rarely survive or grow where sedimentation is heavy or where sediments are shifted over the bottom by waves and currents. Planulae settle only on firm substrate. Rapid sedimentation can smother coral.

Approximately 200 annotated references are listed, including many dealing with the environmental factors influencing coral development.

Wickett, W. P. 1959. Effects of siltation on success of fish spawning. Proceedings of the Fifth Symposium-Pacific Northwest on Siltation--its sources and effects on the aquatic environment. U.S. Public Health Service. Portland, Oregon, pp. 16-22, (March 23-24, 1959).

Silt can produce harmful effects on fish eggs. Specific examples are given.

Wilson, J. N. 1960. The effects of erosional silt and other inert materials on aquatic life. In Biological problems in water pollution, ed. by C. Tarzwell. U.S. Public Health Service Publication, No. W60-3, pp. 269-271, (5 ref.).

The paper is a short discussion of the adverse effects of silt and turbidity on aquatic life. Turbidity interferes with the penetration of light into the water column. Deposits of silt fill cracks between rocks and smooths out the bottom, thereby, reducing the surface area available for growth of attached algae and higher plants. Suspended solids often cause abrasive action which results in a sharp reduction in plant and animal life.

Deposited silt can destroy eggs by reducing the flow of water over a rough bottom, thereby, reducing the necessary oxygen. The effects of silt and turbidity upon the capacity of natural waters to assimilate wastes and upon estuarine shellfish are also considered.

3. ANNOTATED BIBLIOGRAPHY

Most of the annotations were obtained from the following references:

Milliman, J. D. 1965. An annotated bibliography of recent papers on corals and coral reefs. Atoll Research Bull. No. 111, Pac. Sci. Bd., National Acad. of Sci., National Res. Council, Washington, D.C.

Sherk, J. A., Jr. and Cronin, L. E. April 1970. The effects of suspended and deposited sediments on estuarine organisms. Natural Res. Insti., Univ. Md. Ref. No. 70-19.

Wells, J. W. 1957. Corals. In Treatise on Marine Ecology and Paleoecology, Vol. 1, ed. by J. W. Hedgpeth, Geological Society of America, Memoir 67, pp. 1087-1104.

Agassiz, A. 1889. The coral reefs of the Hawaiian Islands. Harvard Col. Mus. Compar. Zool. Bull., Vol. 17, pp. 121-170.

________ 1903. The coral reefs of the tropical Pacific. Harvard Univ. Mus. Compar. Zool., Memoir 28.

Anon. 1967. Annotated bibliography of hydrology and sedimentation 1963-1965. U.S. Gov't Printing Office.

Arnold, E. L., Jr. 1964. Man's alterations of estuaries by dredging and filling a grave threat to marine resources. Ann. Conf. S. E. Assoc. Game and Fish Comm., Proc. 18, pp. 269-273.

Banner, A. H. 1968. A fresh water kill on the coral reefs of Hawaii. Hawaii Inst. of Mar. Biol. Tech., Report No. 15.

Biggs, R. B. 1967. Overboard spoil disposal: I - Interim report on environmental effects. In P. L. McCarty and R. Kennedy, National Symposium on Estuarine Pollution, Proc. Stanford Univ. Press, Stanford, Calif.

Bourne, G. C. 1888. The atoll Diego Garcia and the coral formations in the Indian Ocean. Proc. Roy. Soc. London, Vol. 43, pp. 440-461.

Chesapeake Biological Laboratory. Biological and geological research on the effects of dredging and spoil disposal in the upper Chesapeake Bay.

Eleven reports were published:

1966a	- Ref. No. 66-73,	First progress report.
1966b	- Ref. No. 66-73A,	Second progress report.
1967a	- Ref. No. 66-73B,	Third progress report.
1967b	- Ref. No. 67-33A,	Fourth progress report.
1967c	- Ref. No. 67-34,	Interim report on gross physical and biological effects of overboard spoil disposal.
1967d	- Ref. No. 67-33B,	Fifth progress report.
1967e	- Ref. No. 67-33C,	Sixth progress report.
1968a	- Ref. No. 68-2A,	Seventh progress report.
1968b	- Ref. No. 68-2B,	Eighth progress report.
1968c	- Ref. No. 68-2C,	Ninth progress report.
1970	- Ref. No. 70-3,	Gross physical and biological effects of overboard spoil disposal in upper Chesapeake Bay. Final Report to the U.S. Bureau of Sport Fisheries and Wildlife (Contract 14-16-0005-2096).

Clarke, G. L. 1954. Elements of ecology. John Wiley and Sons, Inc., New York.

________ 1927. Marine ecology and coral formations in the Panama region, Galapagos and Marquesas Islands, and the Atoll of Napuka. Roy. Soc. Edinburgh Trans., Vol. 55, pp. 531-554.

In Marquesas Porites forms weak reefs; coral colonies are pedestaled due to the abrasive action of bottom sediments. In the Bay of Panama, sedimentation is heavy and reef corals are limited in downward growth by mud bottoms.

________ 1928. Coral reefs of Tahiti, Moorea, Rarotonga. Linnean Soc. London Jour. Zool., Vol. 36, pp. 577-620.

Discusses the zonation of fringing reefs of Tahiti and the importance of sand abrasion inhibiting coral growth. The decline of Tahitian reefs is also partly due to the inflow of laterite muds. The sedimentation of Moorea is less than Tahiti and the coral growth is more extensive.

In still water accumulation of sediment inhibits coral growth; in heavy currents there is abrasion by fragments of coral and sediments.

Breuer, J. P. 1962. An ecological survey of the lower Laguna Madre of Texas. 1953-1959. Pub. Inst. Mar. Sci. (Texas), Vol. 8, pp. 153-185.

Major ecological changes caused by dredging spoil took place in South Bay between the Rio Grande and the Brownsville ship channel. Turbidity was greater over a silt or clay bottom than over a sand bottom. Heavy bottom vegetation decreased the turbidity considerably.

Brown, C. L. and Clark, R. 1968. Observations on dredging and dissovled oxygen in a tidal waterway. Water Resources Research, Vol. 4, No. 6, pp. 1381-1384.

Maintenance dredging effects on oxygen and light penetration in the Arthur Kill were studied. Dissolved oxygen was compared for samples taken during dredging and non-dredging days. Lower D.O. during dredging may be a result of the oxygen demand of the re-suspended sediments and the reduction of light penetration resulting in less photosynthetic activity. Dissolved oxygen saturation is lower with higher temperatures; thus, a low D.O. may be critical to aquatic life during the warmer months.

Burt, W. V. 1952. Scattering of light in turbid water. Ph.D. thesis, Univ. Calif. Los Angeles.

Cairns, J. Jr. 1968. Suspended solids standards for the protection of aquatic organisms. Purdue Univ. Eng. Bull., No. 129, Pt. I, pp. 16-27.

Suspended solids can have the following ecological effects: 1) abrasive action 2) blanketing action 3) reduction of light penetration 4) more surface for the growth of microorganisms 5) absorption and/or absorption of chemicals and 6) reduction of temperature fluctuations. Literature review included.

Chandler, D. C. 1942. Limnological studies of western Lake Erie, II Light penetration and its relation to turbidity. Ecology, Vol. 23, No. 1, pp. 41-52.

Davis, H. C. 1960. Effects of turbidity producing materials in sea water on eggs and larvae of the clam (Mercenaria mercenaria). Biol. Bull., Vol. 118, No. 1, pp. 48-54.

Davis, H. C. and Hidu, H. 1969. Effects of turbidity producing substances in sea water on eggs and larvae of three generations of bivalve mollusks. The Veliger, Vol. 11, No. 4, pp. 316-323.

Day, J. H. 1964. The origin and distribution of estuarine animals in South Africa. In D.H.S. Davis (ed.), Ecological studies in South Africa. Monographiae Biologicae, Vol. 14, Dr. W. Junk, The Hague, Netherlands.

Environmental conditions and estuarine faunas are compared for clear estuaries and turbid estuaries in South Africa.

Ditsworth, G. R. 1966. Environmental factors in coastal and estuarine waters, bibliographic series, Vol. I, Coast of Oregon. F.W.P.C.A. Pub. No. wp-20-2.

________ 1967. Index to research on coastal and estuarine waters, bibliographic series, Vol. I. Coast of Oregon, F.W.P.C.A. Pub. No. wp-20-2.

________ 1968. Environmental factors in coastal and estuarine waters, bibliographic series, Vol. II, Coast of Washington. F.W.P.C.A. N.W. Region, Pac. N.W. Water, Corvallis, Oregon.

Dodgen, H. D. and Baughman, J. L. 1949. A brief summary presented by the Texas Game, Fish and Oyster Commission on the disposal of spoil from the maintenance dredging of the Sabine-Niches Canal. Annual Report Mar. Lab., Texas Game, Fish and Oyster Comm., 1948-1949.

Any change in the bottom that is able to cause shifting sediments, salinity changes, turbidity changes, temperature changes, intensive silting, decrease in oxygen, or an increase in noxious compounds, may result in destruction of organisms. By destroying a firm bottom, siltation can reduce nursery grounds of young fish and crabs.

Edmonson, C. H. 1929. Growth of Hawaiian corals. B. P. Bishop Mus. Bull. 58, Honolulu, Hawaii.

________ 1933. Reef and shore fauna of Hawaii. B. P. Bishop Mus. Spec. Pub. 22, Honolulu, Hawaii.

Emery, K. O. and Stevenson, R. E. 1957. Estuaries and lagoons, I. Physical and chemical characteristics. In Treatise on Marine Ecology and Paleoecology, Vol. 1, ed. by J. W. Hedgpeth, Geolo. Soc. of Amer., Memoir 67, pp. 673-693.

Fairbridge, R. W. and Teichert, C. 1948. The Low Isles of the Great Barrier Reef, a new analysis. Geogr. Jour., Vol. 111, pp. 67-88.

Flemer, D. A., Dovel, W. C. Pfitzenmeyer, H. J. and Richie, D. E., Jr. 1967. Spoil disposal in upper Chesapeake Bay, II. Preliminary analysis of biological effects. In P. L. McCarty and R. Kennedy, National Symposium on Estuarine Pollution, Proc. Stanford Univ. Press, Stanford, Calif., pp. 152-187.

Biological effects of suspended and deposited sediments caused by dredging and overboard spoil disposal are considered. Reduced transparency in the soil disposal was temporary. Zooplankton abundance and composition was apparently not affected. No damage to fish larvae could be related to the dredging and spoil disposal. Some benthis organisms were smothered in the disposal area but regulation occurred. Also adult fish were not affected by the dredging or spoil disposal.

Galtsoff, P. S. 1959. Environmental requirements of oysters in relation to pollution. In Biological Problems in Water Pollution, ed. by C. Tarzell. U.S. Public Health Service Pub. No. W60-3, pp. 128-134.

Factors which may have harmful effects on oysters are sedimentation, human activities, competition, predatation and disease. Pollution can increase the rate of sedimentation. Dredging and spoil can change the bottom configuration, alter circulation, smother oysters, and release toxic substances that are held in the sediments.

Gardiner, J. S. 1898. The coral reefs of Funafuti, Rotuma and Fiji together with some notes on the structure and formation of coral reefs in general. Cambridge Phil. Soc. Proc., Vol. 9, pp. 417-503.

Analysis of reef environments and ecology.

_________ 1931. Coral reefs and atolls. A course of lectures delivered at the Lowell Institute, Boston, Feb. 1930. London, Macmillan.

Written from author's personal experience.

Goreau, T. F. 1959. The ecology of Jamaican coral reefs, I. Species composition and zonation. Ecology, Vol. 40, No. 1, pp. 67-89.

A listing of species present and the ecological zonations. Ecological factors affecting the reef growth are mentioned.

________ 1959. The physiology of skeleton formation in corals, I. A method for measuring the rate of calcium deposition by corals under different conditions. Biol. Bull., Vol. 116, No. 1, pp. 59-75.

Calcium uptake increases with increasing temperature, time exposed and light intensity.

________ 1961. Problems of growth and calcium deposition in reef corals. Endeavour, Vol. 20, pp. 32-40.

________ 1963. Calcium carbonate deposition by coralline algae and corals in relation to their roles as reef builders. Ann. N.Y. Acad. Sci., Vol. 109, No. 1, pp. 127-167.

Corals are dependent on light for calcium carbonate deposition.

________ 1963. On the predation of coral by the spiny starfish Acanthaster planci (L.) in the southern Red Sea. Sea Fish Res. Stat., Haifa Bull., Vol. 35, pp. 23-26.

________ 1964. Mass expulsion of zooxanthellae from Jamaican reef communities after Hurricane Flora. Science, Vol. 145, No. 3630, pp. 383-386.

Lowered osmotic pressure on the surface of the sea may have caused the expulsion of the zooxanthellae, rather than sedimentation or fouling.

________ 1964. Fore-reef slope: structure, sediment and community relationships (abs.). Geol. Soc. Amer. Prog., 1964 Ann. Meeting, p. 76.

Reviews previous papers. Little sediment accumulates on the fore-reef slope; most is transported to deeper waters.

Goreau, T. F. and Goreau, N. I. 1959. The physiology of skele-formation in corals, II. Calcium deposition by hermatypic corals under various conditions in the reef. Biol. Bull., Vol. 117, pp. 239-250.

Growth rate differ with species, individuals, ages, and parts of the same colony.

Grigg, R. W. and Kiwala, R. S. 1970. Some ecological effects of discharged wastes on marine life. Calif. Fish and Game, Vol. 56, No. 3, pp. 145-155.

Gulf Universities Research Corporation. 1969. Case studies of estuarine sedimentation and its relation to pollution of the estuarine environment. Report to F.W.P.C.A. (Contract 14-12-445).

Sedimentation pollution was evaluated in four estuarine areas along the coastal sections of the Gulf of Mexico. Each estuarine system is associated with a major population center. Each of the four systems is dealt with comprehensively by different authors. The four estuarine complexes include Galveston Bay, Mississippi River Delta, Mobile Bay and Tampa Bay. The sedimentation had varying effects on beneficial use of each of the four estuarine systems.

Gunnerson, C. G. and Emery, K. O. 1962. Suspended sediment and plankton over San Pedro Basin, Calif. Limnology and Oceanography, Vol. 7, No. 1, pp. 14-20.

Evidence of entrainment and sinking of plankton with suspended sediments.

Gunter, G. 1957. How does siltation affect fish production? National Fisherman, Vol. 38, No. 3, pp. 18-19.

Damaging sediments and turbidity are confined to a very small area in the vicinity of dredging activity. The lighter materials are widely scattered in amounts which cause no damage. Mudshell dredges may be beneficial by bringing up organisms in the dredge that other marine life can feed on. Also, nutrients buried in the sediments can be released into the water.

Guppy, H. B. 1884. Coral soundings in the Solomon Islands. Ann. Mag. Nat. Hist., Vol. 13, pp. 460-466.

The seaward reef slope in Choiseul Bay collects sediments and this inhibits reef growth. This occurs in shallow water where otherwise conditions would be favorable for reef growth.

Herbich, J. B. and Snider, R. H. 1969. Bibliography on dredging. Texas A & M University, Sea Grant Pub. No. 203.

Hiatt, R. K. 1957. Factors influencing the distribution of corals on the reef of Arno Atoll, Marshall Islands. Proc. 8th Pac. Sci. Congr. 3A, pp. 929-970.

Ecological zonations of corals are described and influencing factors are assessed.

Hida, Y. A. 1932. A note of the early stages of colony formation with coral, Pocillopora Caespitos Dana. Sci. Rep. Tohoku Imp. Univ., Vol. 6, No. 4, pp. 425-431.

Planulae become fixed to clean surfaces. They are not found on silt covered bottoms.

Irwin, W. H. 1960. Informal group discussion of the effects of erosion, silt and other inert materials on aquatic life. In. C. M. Tarzwell, Seminar on Biological Problems. Robt. A. Taft Sanitary Eng. Center, U.S. Dept. Health Ed. and Welfare, Cincinnati Ohio, Tech. Rept. W60-3, April 1959, pp. 20-24.

________ 1966. Settleable solids and their effects on aquatic organisms. Preprint Ann. Meeting Fisheries Soc., Kansas City, Mo., Sept. 12, 1966.

Jackson, H. 1963. Effect of silt on aquatic forms. Div. Water Supply and Poll. Cont. S.E.C. Lecture.

Jullander, L. and Brune, K. 1950. Light absorption measurements on turbid solutions. Acta. Chem. Scand., Vol. 4, pp. 870-877.

Kawaguti, S. and Sakumato, D. 1948. The effect of light on the calcium deposition of corals. Oceanogr. Inst., Taiwan Bull., No. 4, pp. 65-70.

Experiments on reef corals seem to indicate that calcium is accumulated from the sea water in the presence of light.

Kornicker, L. S. 1962. Biogeology of a living coral reef complex on Campeche Bank, guide book to field trip to peninsula of Yucatan. New Orleans, Geol. Soc., Feb. 1-5, 1962, pp. 73-84.

The general ecology and geology of the reef are discussed.

Kornicker, L. S. and Boyd, D. W. 1962. Shallow water geology and environment of Alacran reef complex, Campache Bank, Mexico. Bull. Amer. Assoc. Petroleum Geol., Vol. 46, No. 5, pp. 640-673.

The ecology of the reef is discussed, along with the ecological zonations of the reef-building organisms.

Kuenen, Ph. H. 1933. Geology of coral reefs. In Geological results, the Snellius Experition. E. J. Brill, Leiden, Vol. 5, pt. 2.

Refers to floods covering a reef with silt without killing it.

Ladd, H. S. 1956. Coral reef problems in the open Pacific. Pac. Sci. Congr. 8th, Philippines, Vol. 2A, pp. 833-848.

Discussion of work carried out on coral reefs since 1945.

Lauff, G. (ed.) 1967. Estuaries. Amer. Assoc. for the Adv. of Sci., Publ. No. 83, Washington, D. C.

Livingstone, R. Jr. 1965. A preliminary bibliography with KWIC index on the ecology of estuaries and coastal areas of the eastern United States. U.S. Dept. Int., Fish and Wildl. Ser., Spec. Sci. Rept. Fish, No. 507.

Loosanoff, V. L. 1961. Effects of turbidity on some larval and adult bivalves. Proc. of the Gulf and Carib. Fish. Inst., 14th Ann. Sess., pp. 80-95.

Loosanoff, V. L. and Tommers, F. D. 1948. Effect of suspended silt and other substances on the rate of feeding of oysters. Science, Vol. 107, pp. 69-70.

Lunz, G. R. 1942. Investigation of the effects of dredging on oyster leases in Duval County, Florida. In Handbook of Oyster Survey, Intracoastal Waterway Cumberland Sound to St. Johns River. Spec. Rept. U. S. Army Corps of Eng., Jacksonville, Florida.

Serious effects resulted only where spoil actually buried and smothered oysters. Tides and winds are able to remove sediments from the oyster beds. Oysters exposed to runoff from spoil areas for a maximum of 148 hours survived. The number of spat setting was more than double the acceptable minimum for good oyster cultivation.

Mackin, J. G. 1961. Canal dredging and silting in Louisiana Bays. Publ. Inst. Mar. Sci. (Texas), Vol. 7, pp. 262-314.

Silt was transported a maximum distance of 1300 feet from the dredge. Turbidities beyond a few hundred feet from the dredge did not exceed natural levels. Experiments showed no harmful effects on oysters.

Mahadevan, S. and Nayar, K. N. 1969. Distribution of coral reefs in the Gulf of Mannar and Palk Bay and their exploitation and utilization. Mar. Biol. Assoc. of India, Symposium on Corals and Coral Reefs, Jan. 1969, pp. 12-16.

Manton, S. M. and Stephenson, T. A. 1935. Ecological surveys of coral reefs. Sci. Repts. Great Barrier Reef Expedition, Vol. 3, No. 10, pp. 273-312.

Marshall, A. R. 1968. Dredging and filling. In Marsh and Estuary Management Symposium, Proc. ed. by J. D. Newsom, T. J. Moran's Sons, Inc., Baton Rouge, Louisiana, pp. 107-113.

Direct and indirect effects of dredging and filling on fish and wildlife resources of Florida's estuarine and freshwater habitats are reported. Specific examples are cited. Discussed are the destruction of the bottom, destruction of spawning and nursery areas by siltation, reduced light penetration into the water column, formation of anaerobic conditions and the reduction of nutrient outflow from swamps and marshes.

Marshall, S. M. and Orr, A. P. 1931. Sedimentation on Low Isles Reef and its relation to coral growth. Great Barrier Reef Expedition. 1928-1929. Sci. Rept. Brit. Mus. (N.H.), Vol. 1, No. 5, pp. 94-133.

Corals can and do live in slightly turbid waters, and for a limited period can withstand large quantities of sediment falling from above. Water movements and ciliary action of the corals...are the effective agents in removing sediment. Sediment coming from below kills in a day or two all polyps thus covered.

Masch, F. D. and Espey, W. H. 1967. Shell dredging--a factor in sedimentation in Galveston Bay. Center for Research in Water Resources, Univ. of Texas, Tech. Rept. No. 7.

The formation and movement of sediment density layers are discussed. Dredging operations in sand did not produce density flows. Wash water with 80% or more by weight of silt and clay with approximately 50% in the clay size range will tend to flocculate into density layers if the concentration is greater than 10 g./l. Sediment movement is mostly a result of gravity and tidal action and may be different from the prevailing currents in the area.

Reef topography influences the movement of a density layer. Elevated reef topography produces turbulence which causes resuspension or actually prevents deposition. Low spots can trap sediments. Consolidation of sediments could occur on the reef if sediments continually washed back and forth over the reef.

Density differences of 2g./l. were sufficient to cause the formation of a density layer. The suspended sediment concentration at the dredge site are primarily responsible for the establishment of a density layer.

Monitoring a dredging operation must consider the type and amount of sediment, number of operating dredges, reef and bottom topography, and bottom currents.

Mayor, A. G. 1918. Ecology of the Murray Island coral reef. Carnegie Inst. Wash. Pub. No. 213.

Includes quantitative data on temperatures, organic associations, resistance to silt and exposure. Order of importance of factors determining distribution of corals on the reef is: 1) temperature, 2) silt, 3) water movements and 4) organic competition.

________ 1924. Structure and ecology of Samona reefs. Carnegie Inst. Wash. Pub. No. 340, pp. 1-25.

McCarty, P. L. and Kennedy, R. (chairman). 1967. National Symposium on estuarine pollution. Stanford Univ. Press, Stanford Univ. Press, Stanford, Calif.

Moore, H. B. 1958. Marine ecology. Wiley, New York.

Motoda, S. 1939. Submarine illumination, silt content and quantity of food plankton or reef corals in the Iwayama Bay, Palao. Palao Trop. Biol. Stat. Studies, Vol. 1, No. 4, pp. 637-649.

Common reef corals can flourish in 30-40% of surface light; 0.7cc/20 liters of silt does not hinder vigorous growth at 10 meters.

________ 1940. Comparison of the conditions of water in bay, lagoon and open sea in Palao. Palao Trop. Biol. Stat. Studies, Vol. 2, pp. 41-48.

Transparency and illumination are far higher in the open sea than in the lagoon, and least in the bay, but coral growth is luxuriant in the bay's turbid waters.

Muscatine, L. and Cernichiari, E. 1969. Assimilation of photosynthetic products of zooxanthellae by a reef coral. Biol. Bull., Vol. 137, pp. 506-523.

Newell, N. D. 1958. American coral reefs. Trans. New York Acad. Sci. Ser. 2, Vol. 21, No. 2, pp. 125-127.

Principal biotic zones, structures and the functions of the reefs are discussed.

Newell, N. D., Imbrie, J., Purdy, E. G. and Thurber, D. L. 1959. Organism communities and bottom facies, Great Bahama Bank. Bull. Amer. Mus. Nat. Hist., Vol. 117, No. 4, pp. 177-228.

The coral zonations and dominant species are described with insights into the reasons for limited growth.

Odum, E. P. 1959. Fundamentals of Ecology, 2nd ed. Saunders Co., Phila.

Odum, H. T. 1963. Productivity measurements in Texas turtle grass and the effects of dredging on intracoastal channel. Publ. Inst. Mar. Sci. (Texas), Vol. 9, pp. 48-52.

Associated with dredging silt was a decreased productivity and an imbalance of respiration over photosynthesis in turtle grass flats. The penetration of light was reduced. Shoaling of a wide area with resultant damage was probably due to spoil discharged into shallow water less than .5 meters.

Odum, H. T. and Odum, E. P. 1955. Tropic structure and productivity of a windward coral reef community on Eniwetok Atoll. Ecol. Monogr., Vol. 25, pp. 291-320.

Olson, T. A. and Burgess, F. J. (eds.) 1967. Pollution and marine ecology. Interscience Pub., New York.

Rabinowitch, E. L. 1951. Photosynthesis and related processes, Vol. II, Pt. 1. Spectroscopy and flourescence of photosynthetic pigments; kinestics of photosynthesis. Interscience Pub., New York.

________ 1956. Photosynthesis and related processes, Vol. 11, Part II, New York.

Rainford, E. H. 1925. Destruction of the Whitsunday group fringing reefs. Aust. Mus. Mag., Vol. 2, pp. 175-177.

Randall, J. E. 1958. A review of ciguatera tropical fish poisoning with a tentative explanation of its cause. Bul. Mar. Sci. Gulf Carib., Vol. 8, No. 3, pp. 236-267.

________ 1963. An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Carib. J. Sci., Vol. 3, pp. 31-48.

Reid, G. K. 1967. Ecology of intertidal zones. Rand McNally & Co., Chicago.

Rhoads, D. C. and Young, D. K. 1970. The influence of deposit-feeding organisms on sediment stability and community tropic structure. Jour. of Mar. Research, Vol. 28, No. 2, pp. 150-178.

Riley, G. A. 1948. Practical aspects of coral reef growth. Office of Naval Res. Cont. N6 orl-195, T. oll NR-083-003. Tech Rept., No. 3, Woods Hole Ocean. Inst.

Information about dredgings and growth of corals in harbors.

Risebrough, R. and Bodine, R. H. 1968. More letter in the wind. Environment, Vol. 12, p. 16.

Sargent, M. C. and Austin, T. S. 1954. Biologic economy of coral reefs. U. S. Geol. Sur., Prof. Paper 260-E, pp. 293-300.

Schwartz, F. J. 1961. Effects of external forces on aquatic organisms. Chesapeake Biol. Lab. Contrib. No. 168.

Servizi, J. A., Gordon, R. W. and Martens, D. W. 1969. Marine disposal of sediments from Bellingham Harbor as related to sockeye and pink salmon fisheries. Int. Pac. Salmon Fish. Comm. Prog. Rept. No. 23.

Four factors should be taken into account when disposing sediments into the marine environment: turbidity, oxygen demand of the sediment, toxicity due to oxygen sulfide release during disposal and the production of hydrogen sulfide after deposition. Observations are reported as to the conditions produced by the disposal of silts.

Slack-Smith, R. J. 1960. An investigation of coral deaths at Peel Island, Moreton Bay in early 1956. Univ. Queensland Papers, Dept. Zool., Vol. 1, pp. 261-318.

Smith, F. G. W. 1948. Atlantic reef corals. Univ. Miami Press.

Summary of ecology, habitats and associates of reef corals.

Squires, D. F. 1962. Corals at the mouth of the Rewa River, Viti Leuu, Fiji. Nature. No. 4839, pp. 361-362.

Coral increased in number and species away from the river, as salinity increased and turbidity decreased.

Stephenson, W. R. E, Endean, R. and Bennet, I. 1958. An ecological survey of the marine fauna of Low Isles, Queensland, Aust. Jour. Mar. and Freshwater Res., Vol. 9, No. 2, pp. 261-318.

Effects of a cyclone on the reef. General ecology investigated; death of corals owed to heavy swell and sediment.

Taylor, J. L. and Saloman, C. H. 1968. Some effects of hydraulic dredging and coastal developments in Boca Ciega Bay, Florida, U. S. Fish and Wildl. Serv. Fishery Bull., Vol. 67, No. 2, pp. 213-241.

Discussed is the reduction of light penetration in dredged bottoms due to depth and turbidity, soft bottom deposits in dredged canals being unstable for most bottom invertegrates and phosphorus concentrations of dredged locations.

Thompson, S. H. 1961. What is happening to our estuaries. N. Amer. Wildl. Conf. Trans. 26, pp. 318-321.

The effects of dredging and filling operations are considered.

Twenhofel, W. H. 1961a. Treatise on sedimentation. Vols. 1 & 2. Dover Pub. Inc., New York.

Van Eepoel, R. P. and Grigg, D. I. 1970. Survey of the ecology and water quality of Lindberg Bay, St. Thomas. Water Poll. Rept., Carib Res. Insti., Jan. 1970.

Van Osten, J. 1945. Turbidity as a factor in the decline of Great Lakes fishes with special reference in Lake Erie. Trans. Amer. Fish. Soc., Vol. 75, p. 281.

Vaughan, T. W. 1912. The coral reefs and the life history of corals. Carnegie Inst. Wash. Year Book 11, pp. 159-162.

________ 1914. Reef corals of the Bahamas and of southern Florida. Carnegie Inst. Wash. Year Book 13, pp. 222-226.

________ 1919. Corals and the formation of coral reefs. Ann. Rept. Smithsonian Inst., Vol. 17, pp. 189-238.

Laboratory and fish investigations on the physical factors limiting the growth and distribution of reefs.

Verduin, J. 1954. Phytoplankton and turbidity in western Lake Erie. Ecology, Vol. 35, No. 4, pp. 550-561.

Verwey, J. 1930. Depth of coral reefs and penetration of light with notes on the oxygen consumption of corals. Fourth Pac. Sci. Congr., Vol. 2A, pp. 277-299.

Correlation of light penetration with depth of living reef corals.

________ 1931. Coral reef studies, geomorphological notes--the coral reefs of Batavia Bay. Treubia, Vol. 13, pp. 199-215.

Reefs can develop and grow in silt-laden water if currents are sufficient to prevent settling of silt.

________ 1931. Coral reef studies, the depth of coral reefs in relation to their oxygen consumption and the penetration of light in the water. Treubia, Vol. 13, pp. 169-198.

Light is a limiting factor with respect to depth. There is a good correlation between the amount of suspended silt and the depth of reef growth.

Voss, G. L. and Voss, N. A. 1955. An ecological survey of Soldier Key, Biscaye Bay, Florida. Bull. Mar. Sci. Gulf and Carib., Vol. 5, No. 3, pp. 203-229.

Porites is found where sedimentation is slight enough to allow a minimal growth.

Wallen, I. E. 1951. The direct effect of turbidity on fishes. Bull. Okla. Agric. and Mech. Coll. Biol. Ser. 2, Vol. 48, pp. 1-27.

Weber, J. N. 1969. Disaster at Green Island--other Pacific islands may share its fate. Earth Mineral Sci., Vol. 38, No. 5, pp. 37-44.

Weins, H. J. 1962. Atoll environment and ecology. Yale Univ. Press, New Haven.

Wilson, J. N. 1956. Effects of turbidity and silt on aquatic life. Biological Problems in Water Pollution. Trans. of Seminar, April 23-27, 1956. Robert A. Taft, Sanitary Eng. Cen., U.S. Dept. of Health, Ed. and Welfare Cincinnati, Ohio, pp. 235-239.

Woodburn, K. D. 1965. A discussion and selected annotated references of subjective or controversial marine matters. Florida State Board of Conser. Tech. Ser. No. 46.

Wood-Jones, F. 1907. On the growth forms and supposed species in corals. Zool. Soc. London Proc., pp. 518-556.

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