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The increasing demands of development on Caribbean Islands frequently require dredging large volumes of sea sand for land fill, for cement making and for creating and improving passages and anchorage for pleasure boats and commercial crafts. As increasingly resort-oriented economies, we are faced with the dilemma, often too late perceived, of meeting the demands and needs of those who would enjoy our natural assets and contribute monies to our economy, while at the same time maintaining those assets in a state which will continue to attract visitors and investors and their money. Unfortunately, these two goals are fundamentally antithetical; that is, modification of nature always to some degree destroys it. This is so because of a simple fact of nature which may be stated: "Any addition, subtraction, or modification within a natural system will cause some change, will have some effect." The questions frequently asked by laymen; "If we do this, will it affect the environment? If we dump this in the bay or the river, will it affect the fish?" and so on -- these questions would be more properly put: "If we do such and such, will it have a noticeable or undesirable effect?" Ideally, what we should try to do is to restrain the degree of environmental modification, in the present case, shoreline sand-dredging and filling, below the level where it does not adversely affect the value of the area, judged in terms of what we have predetermined we want that area to be. We are all aware, I am sure, of cases in which the attractive natural beauty of an area has resulted in its destruction by overdevelopment so that the very beauty which once attracted visitors and developers has been destroyed, leaving only the developed area with a shadow of its former beauty.

Nature has a finite ability to tolerate changes and to maintain desirable conditions. This ability can be overtaxed and when individual organisms or whole systems are stressed beyond their tolerance limits disaster results. From this we can gain perhaps a better understanding of the word pollutant. A pollutant may be defined as any material which causes a change in the environment which is either too great to be tolerated by the system or by some individual species or which results in modifications which are undesirable. Such a pollutant is silt or clay in the sea. The purpose of this paper is to discuss some of the effects of this type of pollution resulting from uncontrolled dredging of sand from near shore waters. We will deal briefly with the major environmental modifications and routes of water pollution and reef destruction resulting from such operations. My experiences have been almost solely in the U. S. Virgin Islands, but what we have learned there can have regional applicability in the Caribbean.

Living coral reefs, because of their particular sensitivities, their intimate relationships with sand production, and their general importance to Caribbean economy deserve our concerned interest. Reefs are not only scenic, but are structurally and economically important. The major portion of present West Indian fishing is centered around reef complexes.

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The reef and its associated flora and fauna provide food and shelter for the young and adults of most of the regional seafood species. Sea sand, produced primarily by reef-building organisms, is in demand for making concrete, especially on smaller islands which lack terrigenous sand deposits. With increasing development in the Caribbean the demand for sand increases, but we have no reason to believe that its production in the sea is increasing. Many reefs, by their location, afford considerable protection to leeward coastal features by abating oncoming oceanic waves.

Sea sand is largely $CaCO_3$, although there are regional variations in its content of weathered silicate rock and volcanic ash in nearshore deposits. This $CaCO_3$ is precipitated from sea water by various marine organisms as part of their natural processes to make skeletal material. When such organisms are broken, eroded, or die, the skeletal parts break down to form sand grains.

Corals, of course, are the greatest source of this material, especially in the tropics where large reef-forming stony corals abound. Calcareous algae also contribute greatly to sand deposits and in some areas extremely large volumes of coarse algal fragments have accumulated over the years. Other marine organisms contribute in various proportions their hard-shells or skeletons. These include mollusks, echinoderms, foraminifera, and crustaceans.

Sand production depends on a very closely knit complex. The major contributors, corals, also provide the habitat for many of the minor contributors, including those which carry on the erosive processes. These are animals which bore into the coral to make their homes and those which eat it or other calcareous organisms. It has been estimated that fishes alone, by browsing on calcareous organisms and excreting the undigestible sand particles, contribute approximately 2.5 tons/acre/yr. of sand.

Sand therefore, is a renewable natural resource. Further, we cannot disregard the fact that it is economically valuable and can be harvested to good advantage. The problems associated with mining of sea-sand are, in a way, similar to those of logging trees, catching fish, or trawling shrimp. The rate of harvesting must not exceed the rate of production and the source of production must not be destroyed.

In the U. S. Virgin Islands we have had many instances of marine resource destruction caused by such operations, but only recently have begun to investigate these effects and make an effort to describe the results, mostly qualitatively, but increasingly in quantitative terms. Until this past year dredging in the U. S. Virgin Islands has been uncontrolled and not always in the best public interest. We now have several miles of dead reefs and bays with impoverished fauna and flora as a result of ill-planned and ill-managed dredging operations. In a few of these areas water quality and benthic communities have recovered quickly because of local conditions which we do not understand. The majority of the areas destroyed by chronic turbidity and siltation have not shown signs of improvement, some after three years post-dredging. Some, for reasons to be discussed here, may never recover their former character.

Our work in this area is executed for the Division of Environmental Health of the Virgin Islands Department of Health, which is the agency responsible for the whole gamut of environmental problems. In our surveys and monitors of dredging operations we rely heavily on direct underwater survey by our Institute staff using snorkel or SCUBA. In addition, we measure Secchi depth, light extinction rate (using a submarine photo cell) water color, suspended solids, dissolved oxygen, and pH. We of course obtain pre-dredge baseline data whenever possible. Recently, close working relationships with the local Department of Conservation has made this easier, since we could be notified of pending operations, applications for which must pass through this Department. In most cases of dredging the most pertinent and informative measurements are the transparency (Secchi depth and extinction rates) and, to a lesser degree, suspended solids. We are hoping in the near future to increase our sophistication by using settling plates to measure the rate of fallout, and direct, rather than inferred, current data to better understand transport and siltation.

EFFECTS OF DREDGING

Turbidity

Possibly the most damaging effect of dredging in most cases is clouding of the water by very fine suspended particles disturbed by the dredging operation. Most of this suspended material will usually be $CaCO_3$ sand fines, but depending on local sedimentological history, beds of other materials, (e. g. terrigenous clay deposits) if present, will also be disturbed by the dredge. In all operations which we have observed, enough of these fine materials remain in suspension to noticeably reduce submarine visibility for up to 2 years after the finish of dredging.

The primary effect of chronic turbidity is to cut down the amount of light which reaches plants on the bottom. Plants are the primary producers of food. In addition to food, they provide refuge for many species of animals. Without some minimum amount of light (the amount varies with the kind of plant), plants die and then the whole associated community is destroyed because of the loss of food and refuge. Of particular importance in these waters, however, is the effect of light loss on corals and other related reef organisms. Corals are animals, but the survival of reef building forms particularly, depends on the survival of symbiotic unicellular algae (zooxanthellae) which live within the coral tissues. There is a poorly understood nutrient relationship between the plant and animal, but it is known that when these corals lose their zooxanthellae they become unhealthy and die.

Turbidity due to sand fines is usually not repulsive to the average swimmer, water skiers and the like. These people are more tolerant of the chalky color than they are of the brown which results from mud. However, this turbid, chalky water is completely unattractive to snorkelers and SCUBA divers because one cannot see much and frequently there is nothing left to see.

The persistence of such turbidity depends on the interaction of several factors, the net result of which is surely different in each case. The settling time is primarily dependent on the size and shape of the particles and on the movement of the water which may either be slow enough to promote settling or strong enough to keep the particles in suspension and frequently continue suspending additional material from exposed beds of fines. Currents often transport plumes of such fines for great distances where they can seriously damage marine life far removed from the actual dredge site.

Siltation

Siltation is closely related to turbidity, being caused by solid particles. A great deal of siltation occurs during most dredging operations as heavier particles fall back to the bottom. Finer particles settle more slowly and siltation therefore can continue for some time after dredging and may occur at far removed sites. Its effects can be catastrophic for sessile organisms. If the rate of fallout is too great many sedentary organisms, particularly corals, are literally smothered because their ability to cleanse themselves is overloaded.

Beyond this, the coating of substrate by silt size particles is disadvantageous to the settling of most invertebrate larvae and so recolonization is obstructed. Such surfaces are favored by some species of algae which give the advantage of stabilizing the bottom, but also effectively exclude the establishment of reef-builders. In fact, such alteration of the environment has been known to banish corals forever from an area where they were formerly well developed.

Change in Sediment Dynamics

Until very recently, dredging elicited alarm only when it resulted in undesirable and unexpected mass transport of sand from beaches. The most often encountered case is that of a beach adjacent to a dredge hole being denuded because its sand cover has slipped out to sea and into the hole created by the dredge. Geologists have long recognized that beaches are dynamic systems constantly undergoing changes in profile especially marked on a seasonal basis. If for any reason the nearby submarine topography is changed, currents and wave action will reshuffle the surrounding bottom to reach a new dynamic equilibrium. The result could be the redistribution of sand within an entire bay.

Release of Toxins from the Sediments

Very significant harm can be done by disrupting chemically unstable deposits. This problem is usually encountered during dredging in quiet lagoons, salt ponds, swamps, or the placid headwaters of some bays. In many such places, because strong water movement does not aerate the sediment to promote rapid decomposition of detritus, the bottom sediments are largely dark, organic-rich deposits, which have a characteristic foul, sulfide odor when disturbed. Undisturbed as they usually are, however, these sediments pose no great problems and, in fact, such habitats have a rich infauna which feeds basically on the detritus. Being only partially decomposed, however, these sediments are strongly reducing, that is, they require and will remove from the water when they are dispersed, a great deal of oxygen. Suspension of such sediments therefore, in addition to problems of turbidity and siltation, will produce dirtier water, noxious odors and significantly decrease the dissolved oxygen in the water and the results can be severe for fish and other very active animals.

Effects on Associated Fauna

Although the destructive effects of ill-managed dredging operations can be observed directly only by underwater inspection, fishermen can frequently infer such changes from lowered catches of certain formerly abundant species. While the unfavorable effects of dredging do not usually cause direct harm to motile organisms, those which are closely associated with the reef will either migrate as their food and shelter are reduced or they will starve. Demersal fish and lobster are included here. On the other hand, the available evidence indicates that the death of a reef does not necessarily affect populations of midwater or migratory fish.

RECOMMENDATIONS

The relationships of progress (in terms of shoreline development) to conservation are assessments which must be made locally. However, the importance of conservative management of marine resources to insular economics, especially when tourism is a large component, should not be underestimated.

Dredging, consistent with sound planning, may be done conservatively. Our Institute has evolved a set of recommendations which we are urging in the U. S. Virgin Islands and which may be of interest to other States with similar problems.

The first of these is that, based on evaluation of local goals, some statement is necessary to define permissible dredging areas. Alternately, evaluation of individual proposals may be necessary to determine their possible effects on short and long-term goals. We have proposed in the U. S. Virgin Islands a total ban on further inshore dredging excepting that necessary for improvement and maintenance of harbors and channels. This recommendation is based on local dredging history, on present conditions, and on what we feel are realistic projections of future requirements.

Since a continuous sand supply is required for concrete production, land fill and beach reconstruction, which needs cannot be adequately met by maintenance and improvement of port facilities, we proposed, and have begun, a program of prospecting for mineable sand deposits offshore and in areas where ecological damage would be minimal.

In addition, there are several precautions which can be taken before and during any dredge operation. Such precautions can uncover problems likely to occur and minimize undesirable effects during operation.

Each person who desires permission to dredge (and dredging should not be allowed at a developer's whim) should ideally be required to submit to appropriate local authority sufficient justification for the operation; indicating how it would be in the public welfare. Specific boundaries of the proposed dredge area must be given and an evaluation made by competent professionals of the nature of the site, its suitability for such an operation and the probable effects of the dredging on the local and surrounding environments. In the American islands there is a fee of 25¢ per cubic yard which must be paid to the Federal Government for material removed and it is therefore desirable to have some sort of topographic survey of the dredge or spoil areas, or both, in order to determine the volume of material removed.

During the period of work, it is necessary to have some monitoring and control of conditions and methods to ensure compliance with requirements.

Several precautions can be taken in the actual operation. These include:

1. Proper diking to prevent runoff of suspended fines and to allow settling.

2. Controlling leaks in piping to prevent spilling of fines.

3. Dumping all spoils on land or barges.

4. Limiting the steepness and depth of the cut to avoid slumping of nearby sand into the hole.

5. Avoiding, where possible, direct reef removal.

6. Consideration of tides and currents where these may extend damage to nearby reef areas.

SUMMARY

Reef communities, especially their dominant and characteristic components, the corals, are extremely sensitive to prolonged turbidity and siltation. As individuals interested in the continued existence of both healthy, attractive environment, and continued economic growth (the latter being, undeniably dependent to a great and increasing degree on the former) we must apply to environmental manipulations, conservative policies and procedures which are based on available knowledge and which are designed to minimize undesirable ecological damages and so achieve the most good for all considerations. We must also strive to increase our knowledge of environmental processes so that as stresses and demands on the environment increase, as they surely will, we can more effectively avoid disasters.

Basically, the solution is one of thoughtful and comprehensive planning to determine:

1. The level of development and the quality of environment which we desire to attain and to maintain and,

2. The best course and precautions required to achieve these ends.

Because large scale uncontrolled dredging can, and frequently does, cause long-lasting damage to economically valuable resources, sound planning and vigilant control must be executed to minimize such damage.