Sedimentation: Potential Biological Effects of Dredging Operations in Estuarine and Marine Environments

PURPOSE: During the process of dredging, sediments are excavated and relocated. At various points in the process some volume of sediment is injected into the water column, either at the dredging site or at the dredged material disposal site. The amounts may be relatively small (e.g., around operating hydraulic cutterheads) or substantial (e.g., unconfined open-water disposal). The fate of these resuspended sediments, even if uncontaminated, is a source of concern. Potential detrimental effects generally fall into two categories: water column effects (i.e. exposure to suspended sediments) and sedimentation effects. Potential impacts of suspended sediments on aquatic organisms have previously been reviewed (e.g., Newcombe and Jensen 1996; Wilber and Clarke 2001); however, only recently has the subject of sedimentation in the context of dredging effects received such attention (e.g., Berry et al. 2003). Much of the existing literature pertaining to detrimental effects of sedimentation focuses on freshwater streams rather than coastal water bodies. This technical note summarizes the current scientific literature with emphasis on effects of uncontaminated, bedded sediments on estuarine and marine organisms. This review consolidates existing information on sedimentation effects, identifies aspects of natural and anthropogenic sedimentation processes that may be problematic, and identifies gaps in the current state of knowledge necessary for prudent dredging project management and resource protection.

BACKGROUND: Sedimentation is the deposition of sediment over benthic habitat and is measured as either the rate of sediment accumulated per unit area of substrate (e.g., $g/m^2/hr$) or as overburden thickness (e.g., millimeters above the pre-existing sediment horizon). Sedimentation is a natural process that occurs at various rates on time scales characteristic of specific bodies of water, depending on sediment input from a range of sources. Organisms associated with aquatic habitats are generally adapted to tolerate conditions within some normal range. Many anthropogenic sources of sediment (e.g., agricultural runoff) can augment natural sedimentation rates, either in acute pulses or chronically over long periods of time. Dredging has been speculated to contribute to both sources. Although numerous dredging and dredged material disposal operations have been monitored over a span of decades, certain aspects related to sedimentation have proven to be very difficult to measure. Few studies have been conducted that address rates of dredging or dredged material disposal-induced sedimentation beyond the immediate vicinity of the dredging or disposal site. Likewise the responses of estuarine and marine organisms to pulses in sedimentation likely to occur during various types of dredging operations have seldom been directly quantified.

Most sessile or bottom-oriented aquatic organisms encounter some degree of sedimentation under natural conditions, and many have morphological, behavioral and/or physiological means of dealing with exposure to deposited sediments. Yet few generalizations can be made about tolerances of marine organisms to altered sedimentation regimes on temporal and spatial scales that accurately characterize dredging and dredged material disposal operations. In the absence of specific data on both the exposures and tolerances of key biological resources, it is difficult to assess how sedimentation impacts from dredging operations differ from those that occur under natural conditions, and moreover, whether populations are exposed to conditions that exceed their tolerance thresholds. It is also important to place dredging into perspective with other natural and anthropogenic sources. Figures 1 and 2 are images of the sediment-water interface taken in the vicinity of an open-water pipeline discharge of dredged material and shrimp trawling activities in Corpus Christi and Galveston Bay, Texas, respectively. In both cases a thin overburden of fine sediment has been deposited over the recent sediment surface. In either case, the effects of similar pulses in sedimentation can only be fully assessed if a great deal is known about both the physical environment and biological resources at the site. Even relatively thick deposits of sediment may have minimal effect if the layer does not persist. For example, sediments deposited during slack tide conditions may be resuspended during peak ebb or flood flows on a temporal scale of several hours. Hinchley et al. (in review) indicate that overburden stress, a measure of both burial depth and sediment bulk density, is a more appropriate measure of stress. These factors are considered below with reference to probable responses by organisms thought to be particularly susceptible to sedimentation effects.

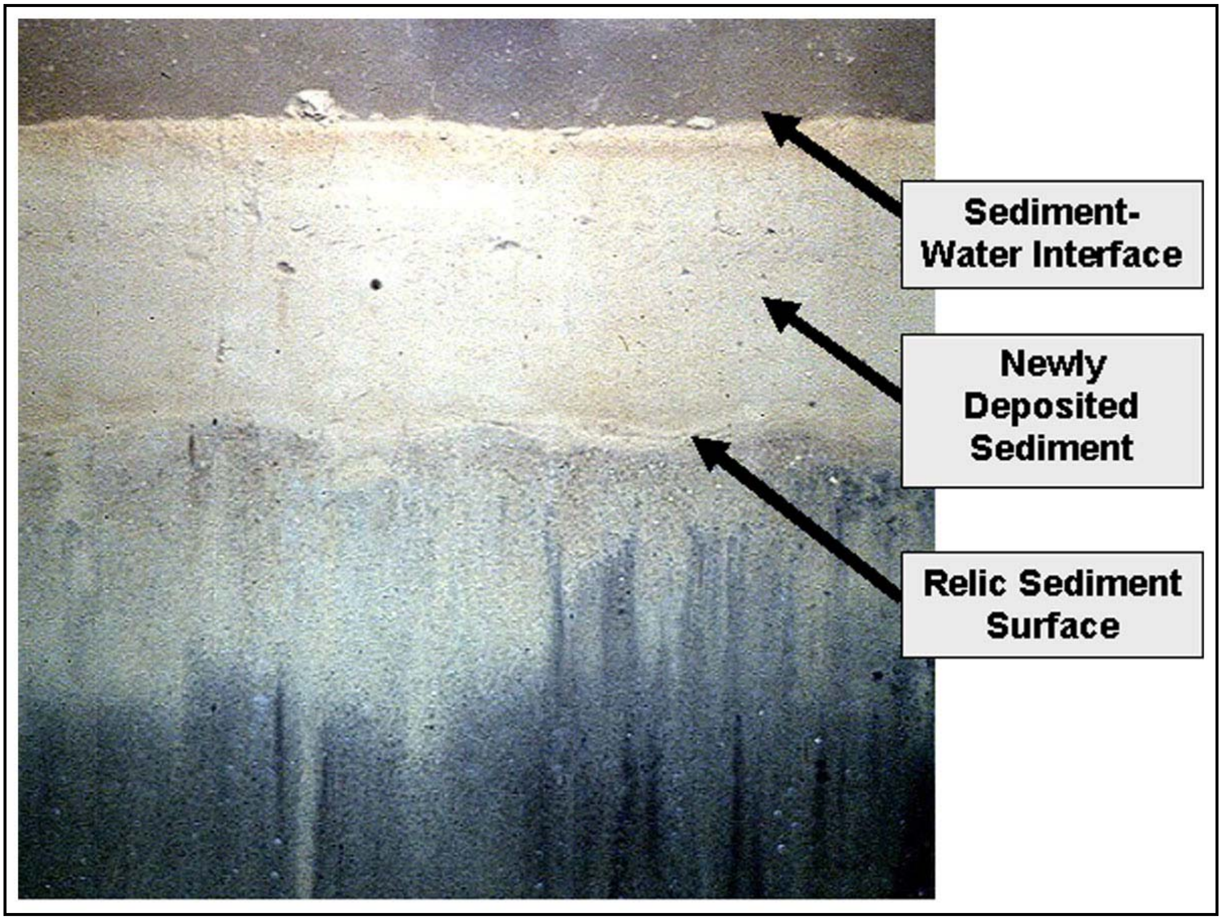

Figure 1. A vertical cross-sectional image showing an overburden approximately 5 cm thick that resulted from open-water discharge of dredged material in Corpus Christi Bay, Texas

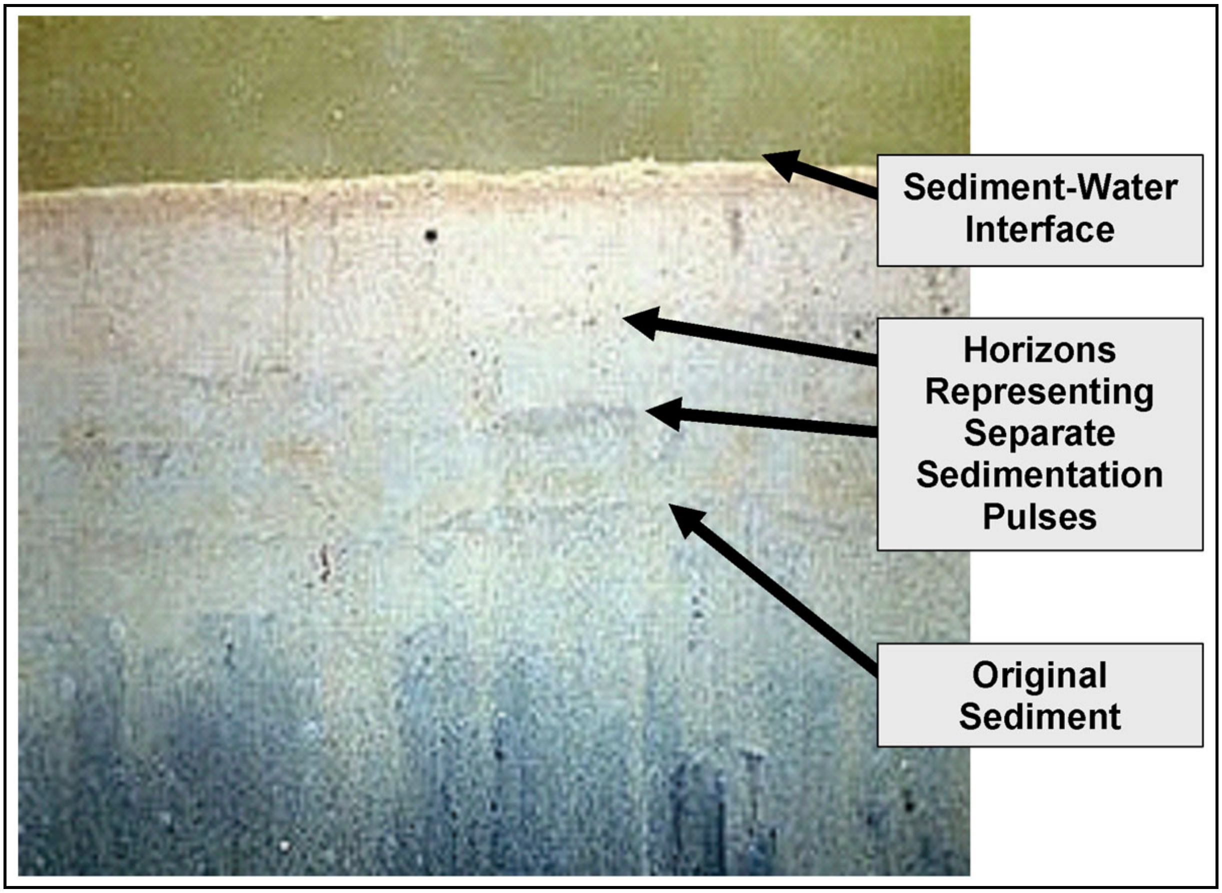

Figure 2. Vertical cross section of the sediment-water interface in Galveston Bay, Texas showing new sedimentation layers, each 1.5 to 2.0 cm thick, resulting from shrimp trawling activities

Although the scientific literature and monitoring reports frequently treat the effects of suspended sediments and sedimentation as a single topic, for the purposes of this note they are considered to be separate. The effects of suspended sediments on fish and shellfish have previously been reviewed by Wilber and Clarke (2001). Near-field sedimentation rates can be considered acute (i.e., rapid accumulation of an overburden >5 cm thick) for a variety of dredging operations. In such cases, burial of non-mobile organisms at the site is to be expected, although many benthic organisms have capabilities to vertically migrate through substantial overburdens (Maurer et al. 1978, 1986). The spatial scales of these events are relatively easy to determine with conventional monitoring techniques (e.g., Sediment Profile Imagery: Germano 1983, Rhoads and Germano 1990). Much more difficult to monitor and assess are far-field effects. Depending on hydrodynamic conditions prevalent at the dredging project site, in situ characteristics of the sediment being dredged, and operational features of the dredge plant, deposited overburden thickness beyond a specific distance from the source of resuspension can be less than 1 cm thick. With increasing distance from the source, sediment accumulations become thin veneers on a scale of less than several millimeters. Environmental assessments of far-field sedimentation rates or very thin overburdens are problematic due to inherent difficulties in precisely quantifying rates or detecting accumulations against ambient conditions (Soutar et al. 1977). Interpretation of the effects of sedimentation due to any anthropogenic source suffers from a lack of comparability in measurement methods and generally low precision. For example, data derived from sediment traps of numerous designs have been reported to be subject to various artifacts or sources of error due to trap geometry, plankton effects, deployment strategies, and decomposition (Coale 1992, Honjo et al. 1992). Likewise, acoustic techniques have generally been unreliable for detection of bathymetry changes less than 5 cm in magnitude, particularly when the deposited sediments consist of fine size fractions. Recent technological advances may allow measurement of thin layers of sediment in the near future (Thomas and Ridd 2004; Germano and Carey, in preparation).

Natural sedimentation rates vary widely both within and between habitats and depend on numerous environmental factors. In addition, where salt and fresh waters mix, flocculation (the aggregation of small particulates such as clay and organic detritus) may affect settlement rates. Since salinity, temperature, pH, and the type of sediments in suspension influence flocculation, predicting the transport and settlement of sediments under highly variable estuarine conditions may be problematic (Galtsoff 1964). Most shallow benthic habitats in estuarine and coastal systems are subject to deposition and resuspension events on daily or even tidal time scales (Oviatt and Nixon 1975). Many organisms have physiological or behavioral methods of dealing with sediments that settle on or around them, ranging from avoidance (e.g., motile organisms such as fish) to tolerance of attenuated light and/or anaerobic conditions caused by partial or complete sediment burial. However, above certain thresholds, natural perturbations in sedimentation rates (e.g., due to seasonal increases in suspended sediment loads, resettlement, or storms) may adversely affect organisms resulting in changes in distribution, abundance or mortality. The nature as well as the depth of the sediment being deposited has a substantial influence upon physiological or behavioral response. Maurer et al. (1978, 1986) have shown that overburdens of materials dissimilar to ambient sediments (e.g., mud on sand) have greater impact than deposition of like materials. Lohrer et al. (2004) have experimentally shown that layers of terrestrial sediments as thin as 3 mm can have detrimental effects on sand flat infauna. These effects are not transient, but may persist for prolonged periods of time (Cummings and Thrush 2004).

Effects of sedimentation on biota may be direct, indirect, or both. Direct effects include smothering (manifested by decreased gas exchange), toxicity (exposure to anaerobic sediment layers), reduced light intensity, and physical abrasion. Indirect effects include changes in habitat quality, particularly substratum characteristics (e.g., altered sediment composition resulting in reduced availability of infaunal prey species).

Potential sedimentation impacts from dredging operations are not limited to the initial deposition of the dredged material. Resuspension of dredged material overburdens is influenced by numerous factors, including grain size of the deposited sediments, the degree of sediment consolidation, and interactions among bioturbation, bottom current velocities, and critical sheer stresses. Morton (1977) identified two important physical impacts from dredging and unconfined, open-water dredged material disposal: (1) changes to bottom topography that could alter circulation patterns, and (2) sediment deposition on benthic resources, such as fish spawning ground, clam bed or oyster reef, from long-term erosion of the dredged material deposit and dispersion of eroded sediments. The former is generally not a concern linked to sedimentation unless shoals result from deposition over the course of multiple dredging cycles (e.g., as reported by May (1973)). The latter cases represent primary sources of environmental concern where individual dredging projects lie in the vicinity of sensitive habitats.

POTENTIAL IMPACTS

Submerged Aquatic Vegetation. Loss of seagrass habitat is a major environmental concern caused by various types of disturbances in coastal and estuarine environments. Declining water quality has been implicated in the loss of seagrass habitat in many systems. Eelgrass, *Zostera marina,* declines in the Chesapeake Bay have been linked to upland development, agriculture, and shoreline development (Orth and Moore 1983). Loss of seagrass habitat dominated by *Thalassia testudinum* in Florida has also been linked to poor water quality, including increased turbidity and nutrient loading (Zieman and Zieman 1989; Robblee et al. 1991; Durako 1994). Along the Texas coast, light reduction resulting from maintenance dredging was the suspected cause of a large-scale loss of *Halodule wrightii* (Onuf 1994).

Dredging impacts on seagrass habitat can be acute, i.e., the direct killing or removal of the plant; or chronic, through the creation of conditions in which individual species lose their ability to compete with other species for light, nutrients, and space (Zieman and Zieman 1989). Seagrasses have the ability to withstand limited burial through several species-specific mechanisms, involving the growth form, the depth to which the plant is covered, and the properties of the sediment (particularly the depth of the anaerobic layer). Direct mortality may result if plant elongation and growth rates are insufficient to surpass sediment accretion rates. If seagrasses are only lightly covered and the rhizome system is not damaged, re-growth through the sediment may be possible. Duarte et al. (1997) have experimentally documented variation in the response to burial by several species of Philippine seagrasses.

Moderate levels of sediment deposition can lead to increased vertical growth relocating the meristems (growth centers) closer to the sediment surface such that the photosynthetic portions are located in the proper light regime and effective gas exchange may occur. Duarte et al. (1997) have shown that vertical growth is triggered by a light-sensitive mechanism located in the shoot meristem. After burial in sand, seedlings of the European seagrass *Cymodoce* nodas whose shoot mersitems were artificially illuminated suffered greater shoot mortality, grew fewer new leaves, and had reduced vertical, internodal lengths than buried seedlings whose shoot mersitems had not been illuminated. In general, there are few empirical studies of how North American seagrass habitats respond to various extents of burial. Preliminary data for *Halodule wrightii* indicated that when 25 percent of the shoot is buried, 75 percent of the plants survived, but when 75 percent of the shoot was buried only 5 percent survived, which suggests an exponential decline in survival with percent burial (Fonseca et al. 1998). Thorhaug et al. (1973) found that construction of a canal that temporarily covered turtle grass, *Thalassia testudinum*, with up to 10 cm of sediment, killed the leaves, but not the rhizome system. Re-growth of the turtle grass occurred when the dredging operations ceased and currents carried the sediment away. In Southeast Asia, seagrass species richness and community leaf biomass declined sharply when the silt and clay content of the sediment exceeded 15 percent of the total volume (Terrados et al. 1998).

Resuspension of unconsolidated deposited sediments has been hypothesized to cause the decline of seagrass habitat. Altered substrate surfaces from dredge and fill operations may reduce the quantity of photosynthetically active radiation (PAR) available to submerged aquatic macrophytes and other aquatic plants (Onuf 1994, Dawes et al.1995, Tomasko et al.1996). Reduced PAR may result in lower productivity and limit the depth distribution of seagrass beds. Zimmerman et al. (1991) reported that depth distributions of *Zostera marina* could be limited more by extremes in turbidity than mean turbidity level. Moore et al. (1997) and Longstaff and Dennison (1999) have both documented deleterious impacts to seagrasses exposed to pulsed turbidity events lasting a month or more. Because dredged material deposits can initially be more readily resuspended than native sediments (Zieman and Zieman 1989), the duration of resuspension events and concentration of suspended sediments may be higher near dredged material disposal sites, thus affecting seagrass populations (Onuf 1994).

Mangroves. Mangroves dominate the intertidal zone of many tropical areas. Although they inhabit sedimentary environments and, in fact, promote sedimentation by reducing water movement, burial by increased sedimentation can have deleterious impacts. In a review of the scientific literature, Ellison (1999) has reported that most mangroves can tolerate sedimentation rates ranging from less than 5 mm to 10 mm per year. Burial of the aerial roots in 10 cm or more of sediment was generally lethal, although substantial differences existed among species. Similar differences in sensitivity to sedimentation rates have been shown in seedling survival and growth by Thampanya et al. (2002). Terrados et al. (1997) reported that accretion rates of 32 cm were lethal to *Rhizophora apiculata* seedlings. They suggest that attempts to restore mangroves in areas with deposition of more than 4 cm of sediment, particularly in sudden pulses characteristic of heavy floods, will be unsuccessful.

Shellfish. Benthic organisms use deposited sediments as habitat, substrate, and a source of nutrition. This group includes many commercially important invertebrates including mobile crustaceans (e.g., lobsters, crabs and shrimps) and sessile molluscs (e.g., oysters and clams).

Crustaceans. Many crustaceans are mobile macrobenthic predators that reside on or near the bottom where sedimentation occurs and can presumably emigrate from an area when it becomes inhospitable (unlike clams and oysters). Lobsters, crabs, and shrimp spend at least some portion of their life cycle in estuaries or nearshore coastal habitats where they are exposed to turbid water conditions. While these organisms are dependent on the stability of sediments, they show varying degrees of physiological and behavioral characteristics consistent with the sedimentation regimes of their respective habitats. Field studies indicate that both the American lobster *Homarus americanus* and spiny lobster *Panulirus argus* are sensitive to the effects of sedimentation. Juvenile American lobsters avoid gravel shelters that are covered with silt and clay (Pottle and Elner 1982) and the post-pueruli larval stage of spiny lobsters avoid settling in algal beds that are heavily silted (Herrnkind et al. 1988). The loss of suitable habitat used as shelter by juveniles of both species may increase competition for the remaining available shelters. Crowding reduces growth rates in lobsters and increases the time spent searching for non-silted areas, which may prolong exposure to predation and result in higher mortality rates.

Molluscs. Sedimentation on oyster habitats is a common natural phenomenon due to their location near the mouths of sediment-laden rivers. Siltation has resulted in the burial of oyster reefs in Atlantic and Gulf of Mexico estuaries, with some reefs found under more than 3 m of mud in Texas (Galtsoff 1964). Sedimentation impacts to oysters may occur by (1) direct morality caused by burial in a relatively deep sediment layer, (2) reduction in oyster growth, or (3) by the inhibition of settlement of oyster spat caused by a deposit of sediment as little as 1 or 2 mm thick. Sedimentation can also negatively affect organisms associated with oyster reef habitats such as fishes and crabs that rely on the interstices in the oyster shell as habitat for colonization (Bartol and Mann 1999) and refuge from predation (Posey et al. 1999). Larger interstitial areas among the oyster shells are also associated with enhanced oyster growth (Bartol and Mann 1999, O'Beirn et al. 2000*)*.

While burial of oysters (*Crassostrea virginica*) following dredging operations with sediment layers exceeding 5 cm has been reported to cause adult oyster mortality (Lunz 1938; Galtsoff 1964; Rose 1973), little is known about how sedimentation interacts with other factors such as current velocity and temperature to affect oyster survival. Dunnington (1968) reported preliminary results that indicated that oysters buried 1.25 cm or less could "usually clear their bills of sediment if the water was warm enough for active pumping." Burial of oysters in three inches of sediment resulted in mortality in two days in the summer and in five weeks in the winter (Dunnington 1968). Although a thin layer (several mm) of sediments may not be fatal to adult oysters, it may affect reproduction. Because larval oysters require hard substrata for settlement, the presence of even a few millimeters of sediment covering an oyster reef may inhibit larval recruitment (Galtsoff 1964; McKinney et al.1976). In addition, resuspension of sediments may affect feeding and growth of suspension feeders. Bivalves deal with resuspended particulates by reducing pumping rates and rejecting inorganic particles as pseudofeces. When suspended sediment concentrations rise above a threshold at which bivalves can no longer effectively filter material, a dilution of the available algal food occurs. In experiments where juvenile hard clams (*Mercenaria mercenaria*) were transplanted to sites representing a variety of conditions, juvenile clams demonstrated slower growth at sites with more exposure to muddy suspensions, but if the clams were raised approximately 30 cm above the bottom, growth was improved (Rhoads and Young 1970). The summer growth of the European oyster (*Ostrea edulis*) in the field was enhanced at low levels of sediment resuspension and inhibited as sediment deposition increased (Grant et al. 1990). Sediment chlorophyll in suspension at low levels may act as a food supplement, thus enhancing growth, but at higher concentrations may dilute planktonic food resources and suppress food ingestion.

Corals and Tropical Coral Reefs. Heavy sedimentation on corals is associated with reduced coral species diversity, less live coral, lower coral growth rates, greater abundance of branching forms, reduced coral recruitment, decreased calcification, decreased net productivity and slower rates of reef accretion (Rogers 1990). The distribution of some coral communities has been related to suspended sediment load (West and van Woesik 2001). Adverse impacts to corals and coral reef organisms from sedimentation may extend beyond the reef systems to tropical fisheries. Sedimentation that impacts corals and sponges may ultimately affect many fish and shellfish that use these resources for food and shelter. It has long been recognized that sedimentation, due to dredging as well as natural causes, is a major factor controlling the distribution and abundance of corals. Reefs in areas with low sedimentation rates are generally better developed, have more coral species, higher coral cover, and faster rates of framework accretion than those subject to heavy sedimentation (Loya 1976, Dodge and Vaisnys 1977).

Sedimentation affects coral growth in several ways including larval settlement (Te 1992). Coral larvae settle preferentially on vertical surfaces to avoid sediments and cannot successfully establish themselves in shifting sediment. An increase in site-specific substratum sediment load can affect total numbers of individuals recruiting to a particular location as well as relative species abundance. For adult corals, if sediment accumulates faster than the ability of the coral to remove it, the ensuing shading may compromise the ability of algal endosymbionts to photosynthesize and an anoxic layer may develop, which kills the underlying tissue. Even if sedimentation does not result in direct mortality, exposure to sediments may cause stress. The energy used to remove coarse sediment particles is energy that could be used for other activities, such as growth, feeding, skeletal repair, or reproduction (Dodge and Vaisnys 1977). Reigl and Branch (1995) have shown decreased photosynthetic production and increased respiration in scleractinian and alcyonacean corals exposed to increased sediment loads. Carbon loss was also elevated due to the increase in mucus production necessary to clear the feeding apparatus. Sediment rejection is a function of morphology, orientation, growth habit, and the amount and type of sediment that is deposited (Rogers 1990)**.**

Several species of coral are characteristically found in areas with high rates of sedimentation and resuspension. These corals, which include *Montastrea cavernosa, Diploria strigosa,* and *Siderastrea siderea,* are effective at clearing sediment, which appears to be an important adaptation in their ability to colonize and compete in areas where sedimentation is common (Lasker 1980). Wesseling et al. (1999) reported significant differences in the response of different species of Philippine corals to burial. Some species, such as *Acropora,* were invariably killed, while others recovered within a few weeks. The length of time that a species was buried was also a significant factor in severity of impact and the rate of recovery. In Puerto Rico, community structure of coral reefs was associated with the differing alluvial sediment loads of neighboring rivers (Loya 1976).

Resource managers in Florida are challenged with solving to the quandary of providing sand nourishment for highly developed and eroding shorelines in areas that are close to coral communities. In some Florida locations, beach nourishment may result in the creation of borrow areas close to offshore coral reefs and the burial of nearshore coral hard bottoms when sand is placed on the beach. In Bermuda, documented impacts on corals from a dredging event indicated higher coral mortality and reduced growth occurred in the dredged area (Dodge and Vaisnys 1977). In one of the few continuous, long-term studies of dredging-related sedimentation on intertidal corals, Brown et al. (1990, 2002) report recovery within two years despite substantial initial impacts on survival and growth. Rogers (1990) reviewed known instances of dredging-related sedimentation impacts on coral reef communities and recommended determination of specific threshold levels of sedimentation that negatively affect reef organisms. Rogers also summarized coral responses to sediment application in field (Table 1) and laboratory settings (Table 2).

Fishes: Although a considerable body of information exists on the effects of suspended sediments on fishes, particularly as it relates to dredging, little knowledge pertains to sedimentation. Much of what is known has recently been summarized by Berry et al. (2003). Adults and juveniles of most species of fish avoid areas of temporarily high sedimentation and return at a later time. Consequently, attention has been focused in other areas, such as effects on

Table 1
Coral Responses to Sediment Application in Field Experiments[1]

Coral Species	Treatment	Amount or Concentration	Dur.	Response
Field Studies				
Montastrea annularis	Field application of drilling mud	1000 to 1 dilution	65 h.	Death of colonies
Agaricia agaricites				Death of colonies
Acropora cervicornis				Death of colonies
Porites astreoides				No mortality
Porites divaricata				No mortality
Porites furcata				No mortality
Dichocoenia stokesi				No mortality
Montastrea cavernosa	Natural reef sediment			Cleared up to 345 mg sediment 25 cm^{-}2 d^{-}1
Porites asteroides	Dredging			Death of entire colony or portion
Madracis mirabilis				Decreased calcification
Agaricia agaricites				Decreased calcification
Montastrea annularis	Long-term resuspension of bottom sediment			Decreased growth
Acropora *palmata*	Field application of reef carbonate sand	200 mg cm^{-2}		Death of underlying tissue
Montastrea annularis		800 mg cm^{-2} 400 mg cm^{-2}		Death of underlying tissue Temporary bleaching
Diploria strigosa		200 mg cm^{-2}	Daily	No effect
Acropora cervicornis		200 mg cm^{-2}	Daily	No effect
Montastrea annularis		200 mg cm^{-2}	Daily	No effect
Montastrea annularis	Peat injected into respirometer	525 mg l^{-1}		Decreased net production Increased respiration
Acropora palmata	Reef sediments applied in respirometer	600 mg		Decreased net production
Montastrea annularis				Increased respiration
Diploria strigosa				

[1] Summarized from Rogers (1990), which provides original sources.

eggs of bottom-spawning species, survival of larval stages living in and around the substratum, and in substratum sediment composition. Demersal, or non-buoyant eggs, that may either remain adhered to spawning sites or be carried by bottom currents, are additionally exposed to sedimentation and burial (LaSalle et al. 1991).

Some consideration has been given to hatching success of fishes which spawn on gravel and the effects of sedimentation-induced changes from gravel to sand or silt substrata. Decreased gas exchange and reduced water velocity near the eggs generally occur in finer sediments. Hatching success of trout and salmon was experimentally found to be highest on coarse gravel, then decreased successively with increasing amounts of fine gravel, sand, silt and/or mud. Other species spawning on the substratum, such as minnows, darters, suckers, sculpins, rock bass, spotted bass, smallmouth bass, and walleyes were also affected by this phenomenon, but quantitative data appear to be lacking. Eggs of the white perch (*Morone americana*) were not affected by sediment layers up to 0.45 mm thick (or 0.5 egg diameter), but there was 50 percent

Table 2
Coral Responses to Sediment Application in Laboratory Experiments[1]

Coral Species	Treatment	Amount or Concentration	Dur.	Response
Laboratory Studies				
19 Caribbean species	Lab application of carbonate sand from the reef	430 mg cm^{-2}	Up to >24 h	*A. palmata, A. cervicornis, P. astreoides*, & *A. agaricites* least efficient *Colpophyllia natans, D. strigosa,* & *M. mirabilis*, among the most efficient Lethal to: *A. agaricites, M. annularis, D. stokesi, & Mycetophyllia aliciae*
Montastrea annularis	Drilling muds	100 ppm	6 wk	Calcification decreased 84 percent Respiration decreased 40 percent Oxygen production increased 26 percent Nitrate uptake decreased 48 percent Ammonia uptake decreased 49 percent Feeding response impaired Bleached corals and some mortality
Montastrea cavernosa *Montastrea annularis* *Diploria strigosa*	Lab application of drilling mud and pure $CACO_3$	25 ml of 1 part mud or $CACO_3$ and 1 part seawater		Mortality for all species from drilling mud. Faster cleaning rate for *D. strigosa* than others

[1] Summarized from Rogers (1990), which provides original sources.

mortality with layers 0.5-1.0 mm thick and 100-percent mortality with a 2.0-mm layer (Morgan et al. 1983). Once eggs have hatched, sedimentation may affect habitat quality since juveniles often use voids among the gravel as cover and protection from predators. Sediment deposited on herring spawn was reported by Messieh et al. (1991) to increase egg mortality. Resuspension of dredged material deposits inhibited the feeding of herring larvae and caused juvenile herring to avoid areas with resuspended concentrations at levels as low as a few milligrams per liter (Messieh et al. 1991). Early ontogenetic stages of fish were affected by the burial of nearshore hard-bottom habitats in southeast Florida, with a reduction in the number of individuals and species following deposition of dredged sediments (Lindeman and Snyder 1999).

Because the detrimental effects of sedimentation on fishes is largely restricted to early life history stages, seasonal restrictions on dredging during the spawning season are frequently considered to avoid potential impacts. Seasonal restrictions on dredging have been instituted to protect fish resources for many species throughout the coastal United States (LaSalle et al. 1991). Even if dredging activities occur in proximity to an identified spawning area, potential impacts can be minimal where low-flow conditions cause materials to drop out of suspension within short distances. The inclusion of coarse sand in suspended material may reduce the spatial extent of sedimentation (LaSalle et al. 1991).

SUMMARY: The literature available to determine whether elevated sedimentation rates associated with dredging and disposal can result in impacts to sensitive biological resources is generally inadequate. Certain life history stages are known to be particularly sensitive. For example, very thin veneers of sediment are known to adversely affect both settlement and recruitment of bivalve larvae. Some quantitative data on effects are available for demersal fish eggs with respect to layer thickness and changes to particle size composition of the substratum composition. Although there are documented, unambiguous, adverse effects of sedimentation on seagrasses and corals, available data are insufficient to discern thresholds for various levels of effect.

The affect that natural and dredging-induced sedimentation rates have on biological communities needs to be quantified. Data for all habitat types investigated are insufficient to establish dose-response models at scales appropriate to dredging. Research to date relating sedimentation to impacts on resources can generally be classified as either (1) manipulative experiments in which selected species are exposed to varying amounts of sediment, or (2) a posteriori determinations of causes and effects following major sedimentation events (e.g., dredged material disposal, storms). The latter retrospective approach suffers from confounding factors acting synergistically with or independently from sedimentation, such as elevated suspended sediment load, changes in nutrient supply, or other related environmental perturbations. Unfortunately, most reports of sedimentation impacts fall into the latter category. Hence predicting potentially harmful rates of sedimentation or establishing technically defensible guidelines for resource protection remains a challenge.

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