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# DREDGING ACTIVITIES AND THE POTENTIAL IMPACTS OF SEDIMENT RESUSPENSION AND SEDIMENTATION ON OYSTER REEFS

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## ABSTRACT

Although the ecological importance of oyster reefs is widely known, oyster habitat has been degraded throughout the world through human activities such as pollution, over-fishing, and increased suspended sediment loading. Because remaining oyster populations in many areas are a fraction of historical population sizes and are commonly stressed by factors such as poor water quality and destructive harvesting practices, environmental managers are concerned that additional stresses may further limit oyster habitat viability. Restrictions on dredging activities are commonly proposed to minimize the probability that the resuspension of sediments during dredging and dredged material disposal operations will cause either the direct burial of oyster beds or reductions in filtration efficiency, respiration rates, and/or reproduction and settlement. In this paper, we review literature that is relevant to assessing dredging-related impacts on oysters and consider how factors such as sediment grain size, hydrodynamic conditions, presence or absence of contaminants and time of year may affect biological impacts.

Although oysters are capable of filtering sediments and commonly occur in naturally turbid environments, high sediment loads can negatively affect an oyster reef. Detrimental impacts may occur through several mechanisms that differ for each life history stage. For instance, larval oysters require a clean hard bottom for attachment, therefore, sediment deposited on oyster reefs in layers as little as 1 or 2 mm thick may inhibit settlement of oyster spat. Juvenile and adult oysters may experience physiological impacts such as reductions in respiration and feeding rates. Heavy sedimentation on oyster reefs can cause mortality of oysters as well as the loss of the foraging and shelter functions of the habitat for associated reef fishes and crustaceans when sediments fill the interstitial spaces among the oyster shells. Because the ecological impacts of sedimentation on oyster reefs can be severe, dredging operations must be carefully designed and implemented to successfully avoid detrimental effects.

**Keywords:** turbidity, siltation, bivalve, filter feeder, shellfish.

## INTRODUCTION

The importance of oyster reefs in providing habitat for benthic macroinvertebrates and fishes has long been established (e.g., Gunter 1955, Menzel et al. 1966). Oyster reefs are used as sites for foraging, nesting, and refuge from predation (e.g., Coen et al., 1999, Posey et al. 1999). Other important ecosystem services include improving water quality via filtration (Dame et al. 2001) and the reduction of shoreline erosion (Meyer et al. 1997; Piazza et al. 2005). Despite the recognized ecological importance of oyster reefs, they have been degraded throughout most of their natural range. The decline of oyster habitat in the United States from historic levels is clearly exemplified by the loss of approximately 90% of oyster reef habitat in the Chesapeake Bay, the site of a once thriving oyster fishery, (Rothschild et al. 1994, Smith et al. 2005). Overharvesting, degraded water quality, and increased sediment loads are among the major anthropogenic causes that are associated with the decline of oyster populations (Lenihan and Peterson 1998). Historically, creation of new navigation channels did remove viable oyster habitat, which in certain cases was mitigated by restoration programs involving placement of cultch (shell) in appropriate alternative locations (e.g., Visel 1988). Although dredging through existing oyster reefs seldom occurs any longer, sedimentation attributable to maintenance of navigation channels is commonly cited as an adverse impact on oysters despite the widespread occurrence of oyster habitat in highly turbid environments (Kennedy 1989, Coen 1995) and is cited as a contributing factor to oyster susceptibility to disease (Lenihan et al. 1999, Volety et al. 2000). Because oyster populations are under stress in many areas, the additional disturbance created by sediment resuspension during dredging projects is a source of concern for natural resource managers. Potential mechanisms of disturbance include burial of reefs from sedimentation and physiological impacts from elevated suspended sediments

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concentrations. In addition, dredging in some areas can release contaminants from sediments resulting in their bioaccumulation in exposed oysters (Wirth et al. 1996, Hedge et al. 2009). Dredging may also release nutrients that lead to the depletion of oxygen following high phytoplankton production. This review will focus primarily on the potential impacts of uncontaminated sediment resuspension and settlement associated with dredging projects. Although sedimentation is cited as a detrimental environmental impact on oyster reefs, there is no comprehensive review of how the timing and amount of sediment deposition affects oyster populations. We review the relevant literature to ascertain what information gaps exist so that management of dredging projects in proximity to oyster reefs can be improved.

**Suspended Sediments and Sedimentation under Natural Conditions**

Throughout their range, oysters occur in naturally turbid environments and thus, have adapted a filtering mechanism to separate inorganic particulates from food in suspension. Oysters reject inorganic particulates through the production of pseudofeces, in which the sediments are expelled along with a layer of mucus without passing through the digestive tract. The efficiency with which sediment particles are filtered by oysters is dependent on particle size with smaller particles (1 to 2 microns) filtered at less than half of the efficiency of larger (3 to 4 micron diameter) particles (Haven and Morales-Alamo 1970). Increased levels of suspended sediments could reduce pumping rates in oysters (Loosanoff and Tommers 1948). Some information on physiological responses of oysters to suspended sediment exposures can be derived from the control concentrations used in contaminant studies. For instance, Chu et al. (2002) found no significant effects on hemocyte activities, plasma protein, condition index, or disease progression on oysters exposed to up to 1g/L of suspended clay particles for 40 days. Suspended sediment impacts to larval oysters have been suggested to occur at high concentrations through interference with the feeding apparatus (Carriker 1986).

A wide range of sediment deposition under natural conditions in and around oyster habitat has been observed. Hinchey et al. (2006) summarized the range of sediment deposition observed over short time scales in the lower Chesapeake Bay, which include 5-30 cm of ephemeral sediment during springtime neap tidal cycles in the York River estuary (Kniskern and Kuehl, 2003), < 5 cm sediment deposition in the lower Chesapeake Bay (Dellapenna et al. 1998), and 25 cm of muddy sediments deposited in a single ebb-tide in the Hudson River estuary (Traykovski et al., 2004). In the Delaware Bay sandflats, 1 cm of daily sediment deposition was recorded during non-storm periods compared to 3-17 cm during a “nor’easter” storm event (Miller et al. 2002). Thus, the range of burial depths that may occur under natural circumstances ranges up to 25-30 cm.

**Sedimentation Impacts on Oyster Recruitment**

Larval oysters settle on hard substrates and prefer to settle on adult oyster shell, thus leading to the formation of reefs. Settlement is greatest on surfaces that are free of sediment. The presence of even a few millimeters of sediment covering an oyster reef may inhibit larval recruitment (Galtsoff 1964; McKinney et al. 1973, Mackenzie 1983). Oyster recruitment can also be affected by reductions in dissolved oxygen levels associated with elevated suspended sediment events. In experiments, oyster settlement was reduced significantly in hypoxic treatments and practically no settlement occurred in anoxic treatments (Baker and Mann 1992). Oyster recruitment and survival was reduced in sediment stressed areas of a Virginia lagoon, where 4-9 mm of sediment accumulated over a 2-4 month period (Thomsen and McGlathery 2006).

Soniat et al. (2004) theorized that oyster settlement on vertically rather than horizontally oriented shells would differ based on sedimentation rates in the environment with higher settlement and survival on vertically oriented shells when sedimentation was high. Through laboratory and field experiments, they found that oyster larvae preferentially settle on horizontal surfaces, but will settle on vertical surfaces in the presence of heavy sedimentation. The heaviest field sedimentation depths ranged from 1 to 8 mm.

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### Sedimentation Impacts on Juveniles and Adults

The widely held concern that dredging activities lead to substantial sedimentation on oyster habitat is understandable given the catastrophic loss of oyster reefs to non-dredging related sedimentation events. For example oysters in Coos Bay, Oregon were smothered following a forest fire and heavy rains. Extensive oyster populations in San Francisco Bay were buried by sedimentation from gold mining activities (Beck et al. 2009). In the Chesapeake Bay, surveys conducted using an acoustic seabed classification system and underwater videography documented extensively sedimented oyster habitat (Smith et al. 2005). On average, oyster restoration sites were highly sedimented within 5.5 years of shell placement, rendering the areas unsuitable for oyster recruitment and development of successful oyster habitat. The cause of such severe sedimentation is not connected to a single source, but may have resulted from increasing urbanization throughout the Chesapeake watershed and resultant runoff in combination with destructive fishing practices that lower the vertical profile of reefs. Runoff from agriculture is another land-based activity that increases sedimentation through the erosion of topsoil. Agricultural activities have also been associated with increased suspended sediment loads in the Chesapeake Bay and the decline of oyster reefs (Rothschild et al. 1994). When oyster growth is slower than long-term sediment deposition, recruitment will suffer and the reef will not be sustained.

Elevation of oyster reefs off the bottom is important in allowing oyster to avoid anoxic conditions and burial from sedimentation (Lenihan and Peterson 1998). Oyster restoration sites with more vertical relief in the Wicomico River, VA were successful, whereas low relief reefs were covered with sediment (Figure. 1), thus, suitable

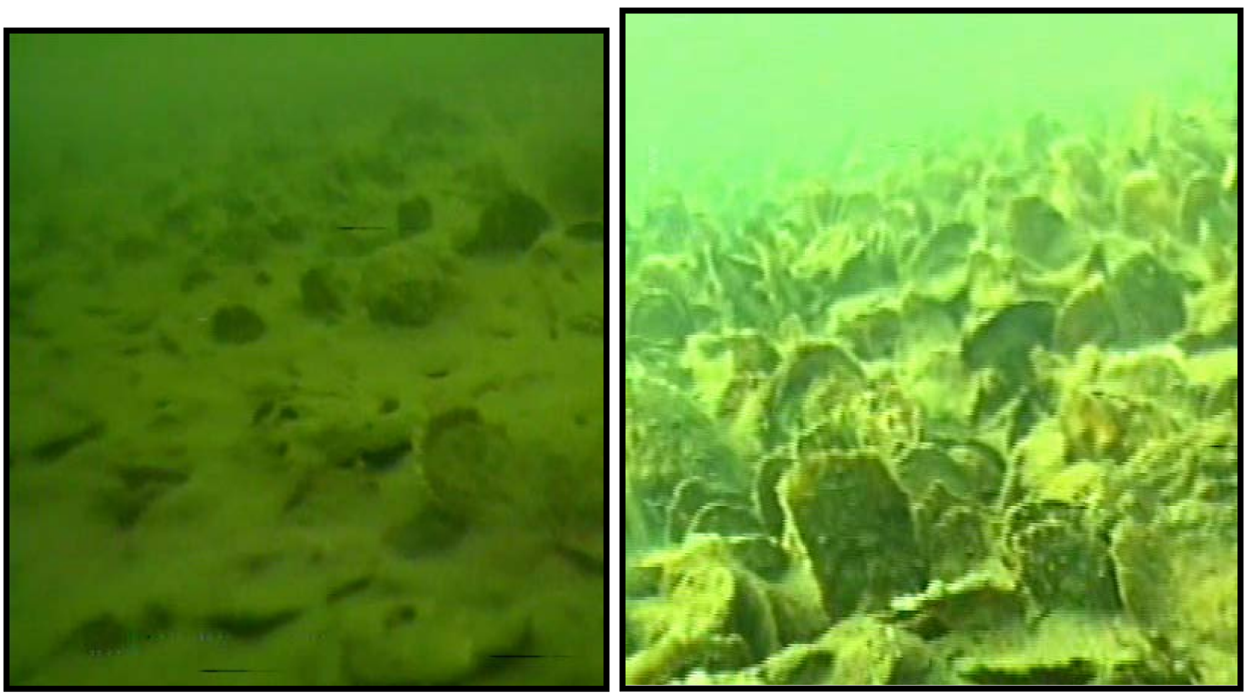

**Figure 1. Subtidal restored oyster reefs in Great Wicomico River, Virginia, US, with substantial sedimentation on low relief (left) and minimal sedimentation on high relief (right) reefs. Photos courtesy Schulte et al 2009.**

recruitment surfaces were unavailable to sustain the reef community (Schulte et al. 2009). Direct studies of sedimentation impacts on juvenile and adult oysters require an assessment of biological responses relative to burial depth. We are aware of only one study that quantifies this relationship for oysters. In a laboratory experiment, Hinchey et al. (2006) assessed survival, ventilation, and feeding activity in juvenile oysters (9-12 mm shell length) buried for six days in up to 5 mm of sediments collected from the York River (Chesapeake Bay). Treatment levels in this experiment were "acute burial" (5 mm of sediments) and "partial burial" (2 mm). The authors speculated that the juvenile oysters survived burial for six days by resorting to anaerobic metabolism, which is consistent with results obtained by Widdows et al. (1989) in which juvenile oysters survived anoxic conditions for six days, but 100% mortality resulted on day 7. Ventilation was observed for some oysters buried under 2 mm of sediment, but not in the 5 mm burial treatment.

For other studies, sedimentation impacts can be inferred either from field observations (e.g., Hadley et al. 2010) or from experimental studies that tested responses to suspended sediment, but allowed sediments to settle on oysters. For instance, Volety and Encomio (2006) investigated the effects of silt and clay kept in suspension by tank aeration on oyster condition index (ratio of dry meat weight to dry shell weight) and glycogen content. Glycogen is the primary form of carbohydrate storage in mollusks and thus may serve as a sensitive indicator of sediment impacts. Reduced glycogen stores may indicate a stressed organism that may have lower reproductive potential and survival capacity. Suspended sediment concentrations were estimated to be approximately 400 mg/L and 800 mg/L for an exposure duration of five weeks. The authors, however, indicated the actual exposure amounts may have been much lower due to uncontrolled factors. At the highest suspended sediment concentration, glycogen content was reduced in oysters held for five weeks in 10 gallon aquaria to which 30 grams of sediment were added (the authors converted this treatment to the suspended sediment concentration of 800 mg/L). Silt elicited more of a response than clay. In one trial, oyster dry weight and condition index were also significantly lower in the highest sediment concentration treatment for one of the three replicate trials (Volety and Encomio 2006).

Sedimentation has been measured on intertidal oyster reefs in South Carolina (Hadley et al. 2010) using overhead photographs and digital determinations of the percent cover by sediments (Figure 2). These estimates of surficial sediment coverage provide an indication of the remaining surface area on a reef that is comprised of hard oyster shell, which is the preferred settlement substrate for oyster larvae.

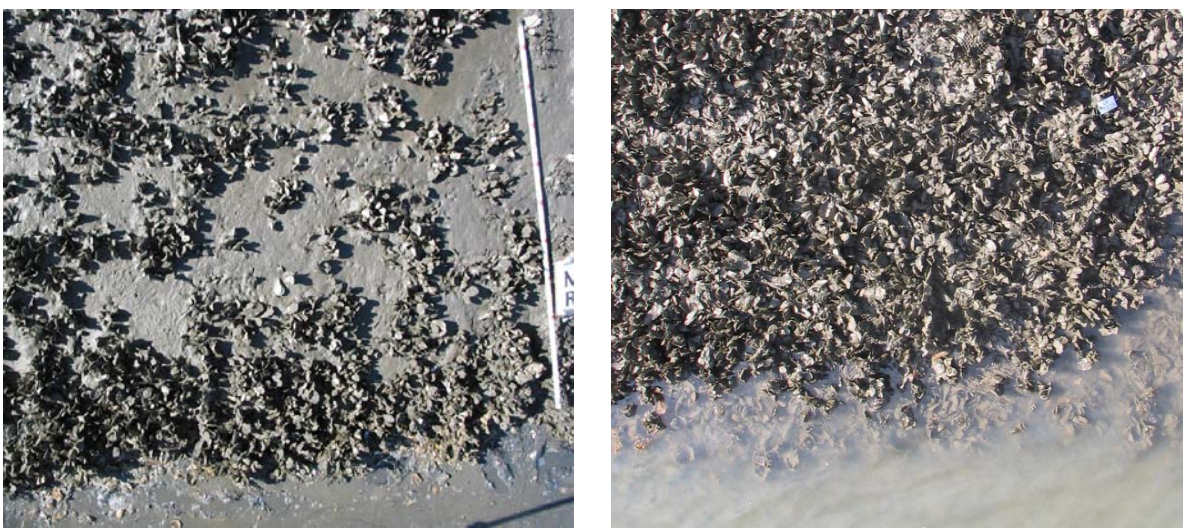

**Figure 2. Overhead photograph of an intertidal oyster reef at Murrell's Inlet (left) and Cape Romain (right), South Carolina, demonstrating the reduction in intertidal oyster habitat that occurs from sedimentation. Photos courtesy of Nancy Hadley, South Carolina Department of Natural Resources.**

By quantifying the amount of surface area covered by sediments, potential correlations can be tested between this metric and biological factors such as oyster size and the abundances of oysters and associated organisms. Percent cover estimates do not provide information on the amount of interstitial space that is filled by sediments, therefore, loss of shelter and foraging habitat functions for associated reef organisms is not directly known. The percent cover on restored oyster reefs at five locations in South Carolina ranged from 4 to 71% (Figure 3, Hadley et al. 2010). Sedimentation did not prove to be a very reliable indicator of reef restoration performance. Within sites, sediment coverage was negatively correlated with the abundances of several species; however, there was no indication that sediment coverage within the range observed prevented reef habitat development at any site. For instance, one site with average sediment coverage of 60% had the largest oysters at the highest densities. Abundances of two resident crab species, one mussel species, and the abundances of oyster recruits were negatively correlated with sediment coverage at some sites (Hadley et al. 2010).

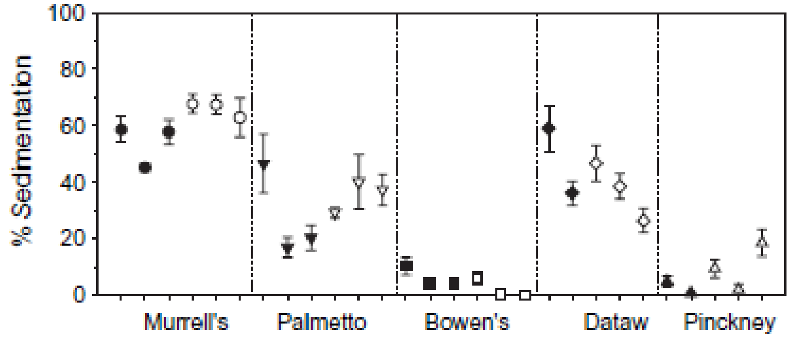


**Figure 3. Mean (+ 1 standard error) percent sediment coverage on five restored oyster reefs in South Carolina, US that were created three (black symbols) and one (open symbols) year prior to sampling (Hadley et al. 2010).**

Negative impacts of sedimentation on intertidal oyster reefs have been documented in central Florida and linked to the resuspension of sediments from boat traffic (Wall et al. 2005). In the Indian River Lagoon, dead margins of disarticulated oyster shells exist on the seaward edges of reefs adjacent to major boating channels, whereas these dead margins are not present on reefs located away from navigation channels. Total sediment loads, percent silt/clay, and relative water motion were significantly higher on the impacted reefs and juvenile oyster survival was significantly reduced on these reefs. Percent silt/clay ranged from 17% to 27% on the impacted reefs and from 5% to 12% on the non-impacted reefs. This study documented reduced oyster success on impacted reefs and thus provided the first demonstration that recreational boating activity increases oyster mortality.

Another activity linked to suspended sediment and sedimentation impacts on oyster reefs is commercial peat harvesting in New Brunswick Canada (Mallet et al. 2005). Ingestion of peat particles may interfere with food absorption and reduce growth rates. Experiments that used an excess algal diet indicated that the presence of peat particles did not affect oyster biochemical composition, gonad maturation or survival over a three to five week period (Mallet et al. 2005).

Determining the depth of sediment burial that induces mortality in oysters is complicated and related to several environmental factors (Wilber et al. 2005). For example burial of oysters *(Crassostrea virginica)* following dredging operations with sediment layers exceeding 5 cm was reported to cause adult oyster mortality (Lunz 1938; Galtsoff 1964; Rose 1973). The interaction of sedimentation with other factors such as current velocity and temperature is not well understood. 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 (7.62 cm) of sediment resulted in mortality in two days in the summer and in five weeks in the winter (Dunnington 1968).

**Dredging-Related Burial of Oyster Reefs**

There are few published accounts of dredging-related impacts resulting in sedimentation on oyster reefs. Whether this fact accurately reflects the incidence of dredging-related sedimentation impacts on oyster reefs is not clear. The few cases in the published literature are decades old. Rose (1973) recounts that Galtsoff (1964) reported 20 to 30 cm of sediment were deposited on and destroyed oyster habitat in Buzzard's Bay, Massachusetts. Ingle (1952) reported no oyster mortality within 366 m of a dredging operation and concluded that hydrodynamics in the area were sufficient to prevent serious impacts. Sedimentation from dredging projects near oyster leases have been the subject of several lawsuits. Sedimentation was linked to the demise of commercial oyster cultivation enterprises in Scotland, however, clearly associating the cause as a nearby dredging project proved to be beyond the evidence available (Kirby 1994). Sedimentation caused by a bucket dredging operation in Louisiana was found to increase oyster mortality by 40% within 595 m of the dredged material placement site (Rose 1973).

## CONCLUSIONS

Despite many years of attention given to issues related to protection of oyster resources during dredging operations, an accurate assessment of risks must focus upon site and project-specific factors. For example, at one extreme dredged material has effectively been used as a substrate for establishment of oyster reefs (Clarke et al. 1999, Priest et al. 1999). Nevertheless the threat of sedimentation impacts remains an important ecological consideration for all dredging operations that occur in proximity to oyster reefs. Although diffuse and often in obscure or old sources, the available scientific literature suggests that oysters are generally tolerant of exposures that would be induced by many dredging operations (Wilber and Clarke 2001). Sedimentation rates or sustained suspended sediment concentrations sufficiently high to trigger sublethal or lethal responses by oysters are unlikely to occur beyond relatively short distances from dredging operations. However, open-water dredged material placement operations may disperse a problematic mass of sediment if in close proximity to establish beds. In the latter case assessments of potential impacts can be based on knowledge of prevailing water current velocities and directional vectors, in tandem with knowledge of the properties of the *in situ* sediments being dredged and the mode of dredging and placement (e.g., mechanical versus hydraulic). Newly developed predictive dredging process simulation models provide a means to examine probable exposures of oysters and other bottom-dwelling organisms to both suspended sediment concentrations and net deposition rates based upon site-specific conditions (e.g., Lackey et al. 2008). Dredging activities can often be managed to minimize suspended sediment plumes through such measures as choice of dredging equipment, turbidity and suspended sediment controls (e.g., slower bucket hoist speeds, hopper overflow restrictions, etc.). Accurate knowledge of hydrodynamic conditions at the project site can be used to predict the fate of suspended sediment plumes and the probability that sedimentation on oyster reef habitat will occur. Predictive models can be especially valuable when dredging must occur during seasons when oyster reproduction and recruitment is particularly susceptible to suspended sediment or sedimentation impacts. Properly verified and calibrated models can support informed decisions on the need for appropriate management practices, including environmental windows as appropriate. Anecdotal evidence exists that oysters are in general tolerant of exposures associated with dredging operations. For example, shoal immediately adjacent to navigation channels in several Atlantic and Gulf of Mexico estuaries that represent historical dredged material placement sites are often viable oyster reef habitat. Our examination of the literature therefore leads us to the conclusion that oyster reefs do indeed require prudent consideration in planning dredging projects. Dredging as routinely conducted, however, does not generally represent a severe threat to existing oyster resources. Site-specific conditions and factors that influence exposures should be fully incorporated into project execution. For example, “buffer zones” or “safety distances” can be used to ensure that risks of problematic exposures are minimized or completely avoided.

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