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Potential Impacts of Sand Mining Offshore of Maryland and Delaware: Part 2—Biological Considerations

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ABSTRACT

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The mining of sand resources from the inner continental shelf for beach nourishment may lead to impacts or increase stress on commercial and noncommercial living resources that utilize these areas. The objective of our work was to characterize benthos present in areas likely to be mined and to predict impacts of sand mining. In 1998 and 1999 we used a combination of methods (grab samples, sediment profile cameras, video sled, and trawl) to collect data on the benthos, both fishes and invertebrates, which utilized several potential sand mining areas. We found benthic communities and fish assemblages to be typical of middle Atlantic sandy inner continental shelf habitats. A sand mining scenario that removed the top meter of sand from Fenwick Shoal would disturb approximately 7.7 km^2 with the potential acute impact on noncommercial sessile species being the loss of about 150×10^6 individuals representing 300 kg of wet weight biomass that could have functioned as trophic support to fishes. In addition, mobile species would be displaced and have to search for replacement habitat. To minimize impacts and promote recolonization of mined areas the total removal of substrate should be avoided. Small areas with a project area should be left to serve as refuge patches that would promote recolonization and serve as habitat for mobile species. Predicted impacts on demersal fishes would be lessened by a rapid recolonization, particularly the recovery of mobile epifaunal crustacean that serve as the primary trophic support species. Project timing and engineering could also be used to lessen impacts on fishes by reducing stress on crustaceans. For example, mining activities that ended in time for Spring/Summer recruitment would favor crustaceans while a Fall/Winter end would favor annelids.

ADDITIONAL INDEX WORDS: *Recolonization, benthos, juvenile fishes, EFH, sand mining, trophic transfer, secondary production, demersal fishes, sand shoals, continental shelf.*

INTRODUCTION

The demand for sand to nourish eroding beaches has risen to the point that sand resources on the inner continental shelf are being mined. This demand for continental shelf sand is expected to increase with time considering the amount of erosional shoreline in the middle Atlantic Bight (GALGANO *et al.*, 2003). The impacts of sand mining activities on benthic living resources on the shelf are of concern because of the scale (potential for removal of millions of cubic yards of sand) and potential for cumulative impacts of mining activities as either the area mined expands or the same area is mined again. From a biological perspective, mining sand from the continental shelf would directly disturb benthic communities and indirectly disturb trophically dependent pelagic species.

The potential disturbances resulting from sand mining are important because of the highly interactive and dynamic biological and physical conditions on the continental shelf. By altering the submarine topography, mining will influence the dynamics of the water movement, which would directly impact sediment dynamics and indirectly benthic organisms. These direct and indirect responses occur on differing time and spatial scales (CUTTER and DIAZ, 2000). A companion paper (MAA *et al.*, this volume) presents a consideration of the physical oceanographic impacts associated with the same study.

The impacts of acute disturbances related to sand mining, which are primarily removal of resident organisms and exposure of subsurface sediments, are modulated by the physical dynamics on the shelf. Dredging will directly alter topographic features with subsequent impacts on water column dynamics, thence the substrate and recovery rates of the benthos. Impacts to the biological resources include removal of infauna, epifauna, and some benthic fishes and alteration of the available substrate. Prediction of the short-term responses of the benthos is considerably more difficult that of the long-term because of asynchronous and naturally variable short-term population fluctuations (MAURER *et al.,* 1976). Contrastingly, long-term responses can be considered in terms of a spatial problem in that the community structure

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eventually should respond to the components of the substrate and primary alterations of the substrate should be limited to the vicinity of the mining site.

This portion of the mid-Atlantic coast is also an important foraging and spawning ground for a wide variety of benthic and pelagic fishes with most species being transients or seasonal residents and few year-round residents. This predominantly transient pattern of use by fishes is related primarily to the extreme range of sea temperature, one of the largest for our world oceans (MUSICK, 1999). The suite of mobile or transitory species that pass through the area annually includes boreal, temperate, and sub-tropical species (MUSICK *et al.,* 1986). OLNEY and BILKOVIC (1998) list and discuss many of the fishes that occur within the study area. Late spring and summer months are the periods when the greatest number of species spawn or pass egg and larval life-history stages in the area. The fewest are present in January, February, and March.

The pre- and post-mining benthic resources occur over several scales of spatial and temporal variation. Water depth or topography, the substrate's sedimentalogical characteristics, and benthic community attributes vary at small (cm) to regional (km) scales. This great range in scales requires that attention be given to sample design for detecting impacts from sand mining. Similarly, there is wide variation in temporal scales with differing levels of importance. Diurnal use of habitat occurs relative to protection from predators and foraging for prey (DIAZ *et al.*, 2003) and seasonal changes in recruitment and species turnover (MUSICK *et al.,* 1986; OLNEY and BILKOVIC, 1998). Strom events are also important in structuring the benthos and while individual storms are less predictable the rough seasonality and approximate number of events has a relatively narrow interannual range.

This paper reports upon some of the biological consequences that are likely to occur should large quantities of sand be mined from beneath the waters offshore of Maryland and Delaware along the mid-Atlantic coast of the United States (Figure 1). The work reported upon herein is a summary of studies conducted from 1998 to 1999 (HOBBS, 2000; HOBBS, 2002; DIAZ *et al.,* 2003).

METHODS

The states of Delaware and Maryland with the Minerals Management Service (MMS) identified five regions of interest (ROI) in the study area. Two, Indian River and North Bethany Beach, were offshore of the Indian River Inlet and three were on major shoals of Fenwick, Weaver, and Isle of Wight offshore of Ocean City Inlet. Most the focus in this paper will be on the shoals off of Ocean City inlet. We conducted two extensive sampling cruises to collect data from these areas. Scientific operations were conducted 24 hours a day to collect data on day/night differences in habitat use by mobile species.

The first cruise, May 1998, encompassed the five ROI and some surrounding areas whereas the June 1999 cruise concentrated on the three shoals ROI. During the 1998 cruise data were acquired from fixed stations on a regular lattice with sediment profile cameras to characterize both physical and biological aspects of the benthic habitat. Grab samples for grain-size and benthos were collected at random picked stations within the lattice. A towed camera sled, with both video and still cameras, was used on transects within and across the lattice. During the 1999 cruise grab samples were collected at a subset of the stations sampled in 1998. See CUTTER and DIAZ (2000) for details on the sampling design.

A Young grab having a surface area of 0.044 m^2 was used for benthos and sediment samples. Grab samples were washed through a 500-um sieve, sorted, and all organisms identified to the lowest practical taxonomic level (LPTL), usually species. Individuals were grouped by LPTL and placed in two percent Formalin until wet weight measurements were completed. Sediment profile images (SPI) were obtained on Fujichrome 100 ASA color slide film with a Hulcher model Minnie Sediment Profile Camera. The VIMS Bottom Imaging Sled was deployed with video cameras and water quality sensors and towed at speeds $<$1 knot when possible. On the 1999 cruise, we deployed an eight-foot (2.4 m) beam-trawl to collect juvenile fish, epibenthos, and megabenthos. Trawl locations were selected based on benthic habitat data collected in 1998. Two physically dominated sandy and gravelly-shelly habitats with little evidence of biogenic structure along the northeastern and northwestern sides of Fenwick Shoal and two more biologically accommodated *Diopatra*- and *Asabellides*-tube-field habitats on the southeastern and southwestern sides were sampled with the trawl. Each location was trawled during the day and night to assess diurnal differences and the trawl was equipped with a meter wheel to enable estimation of fish abundance per unit area (DIAZ *et al.,* In press). See CUTTER and DIAZ (2000) for details on sample processing and data reduction methods.

RESULTS

Transitions in the local environments occur over different scales near the shoals at rates that appear related to the topographic slope. The southeast faces of the three major shoals off Ocean City Inlet were the steepest. The bathymetric change between Fenwick and Weaver Shoals was the greatest. The area between these shoals also had the greatest range of habitats with the most abrupt changes between habitat types. Within a few tens of meters, the substrate changed from medium to coarse sand to clayey-silty mud.

Sediments from Indian River ROI were coarser than those from the Ocean City shoal ROI based on grain-size from the grab samples. When assessing only the sand-fraction, mean grain size at Indian River ROI stations was 0.52 mm (1.06 phi) compared to 0.42 mm (0.86 phi) for the Ocean City shoals ROI stations. Standard deviations were 0.17 and 0.19mm (0.39 and 0.41 phi) respectively. Sediment profile images (SPI) yielded additional data on sedimentary habitat characteristics such as biogeochemical features, sediment-water interface properties, and counts of organisms and biogenic features. At the Ocean City shoals ROI, the depth of the redox potential discontinuity layer, RPD, averaged 7.8 cm in 1998 and 6.1 cm in 1999. At the Indian River ROI, sampled only in 1998, RPD depth averaged 7.4 cm. The RPD layer indicates the depth to which oxygen penetrates into the sed-

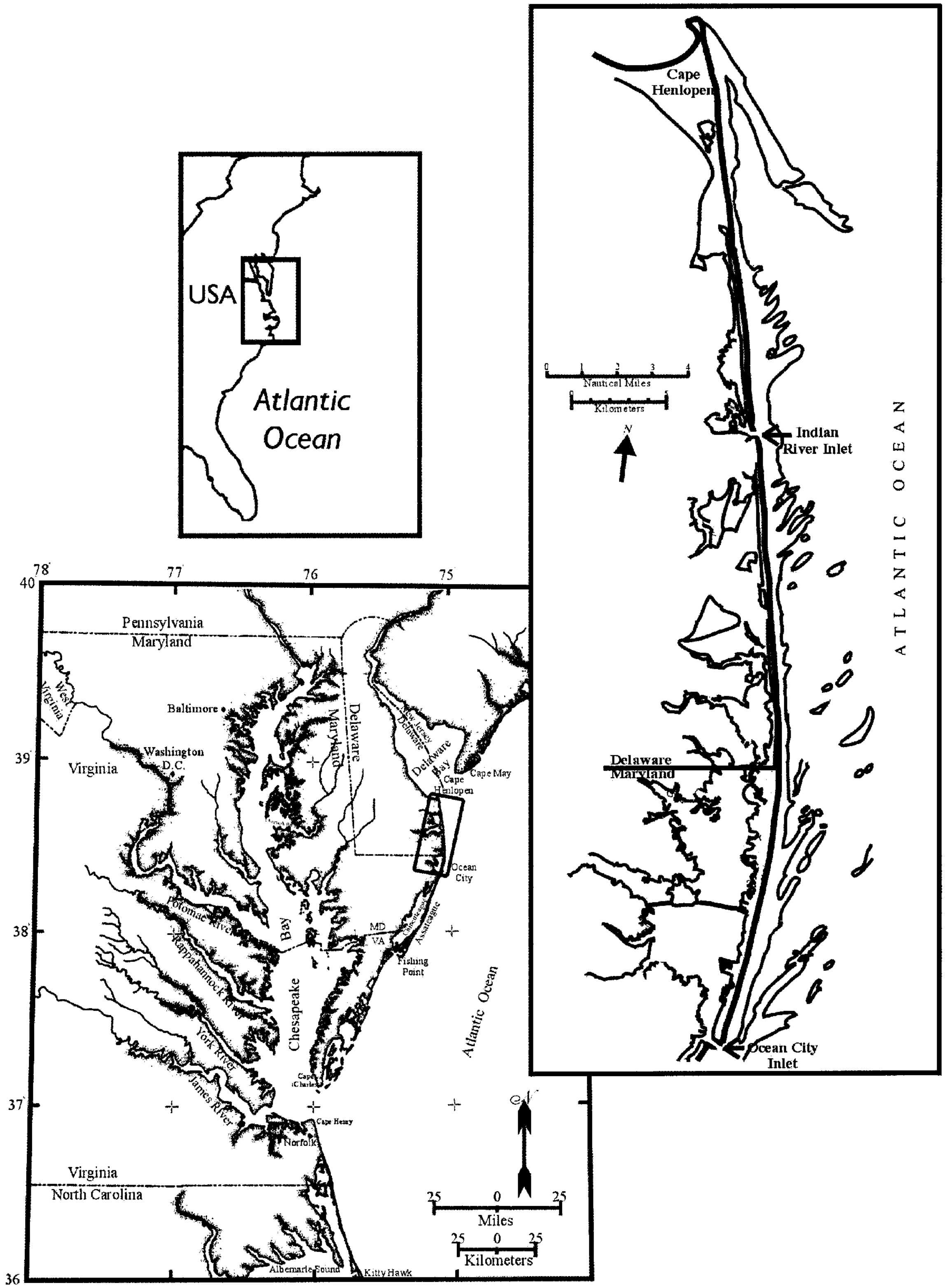

Figure 1. General location of Indian River Inlet and Ocean City Inlet ROI.

Table 1. *Abundance of benthic dominants from all ROI in 1998 and Ocean City shoal ROI in 1999. Includes all taxa that were at least one percent of the total abundance in either May 1998 (52 grab samples) or September 1999 (20 grab samples).*

		Total Occurrences			Taxa Abundance (individuals/m^2)		
Major Taxa	Taxa	98&99	98	99	Ave. 98&99	98	99
Annelida	*Spiophanes bombyx*	39	29	10	5800	9710	1889
Annelida	Oligochaeta	58	43	15	1615	2789	445
Bivalvia	*Tellina* spp.	47	29	18	640	889	391
Annelida	*Spio setosa*	16	8	8	490	167	813
Annelida	*Aricidea (Acmira) cerrutii*	37	32	5	465	889	43
Nemertinea	Nemertinea	55	37	18	410	689	128
Annelida	*Asabellides oculata*	20	13	7	335	554	114
Annelida	*Brania wellfleetensis*	23	18	5	235	442	33
Crustacea	*Unciola irrorata*	30	17	13	230	286	175
Annelida	*Aricidea (Acmira) catherinae*	32	25	7	225	341	108
Annelida	*Aphelochaeta* sp.	25	20	5	175	314	32
Crustacea	*Pseudunciola obliquua*	17	11	6	175	167	180
Bivalvia	*Astarte* spp.	21	14	7	165	279	50
Crustacea	*Byblis serrata*	17	9	8	150	34	267
Bivalvia	*Mytilus edulis*	17	13	4	145	277	10
Annelida	*Hesionura elongata*	21	14	7	125	229	17
Annelida	*Parapionosyllis longicirrata*	30	25	5	120	227	11
Bivalvia	*Crenella glandula*	23	12	11	120	181	56
Crustacea	*Protohaustorius wigleyi*	29	22	7	115	202	25
Crustacea	*Tanaissus psammophilus*	22	16	6	100	165	33
Annelida	*Caulleriella* sp. B	16	16	0	95	192	0
Annelida	*Hemipodus roseus*	21	15	6	55	94	15
Annelida	*Nephtys* spp.	20	16	4	55	98	11
Annelida	*Streptosyllis pettiboneae*	15	11	4	55	92	16
Crustacea	*Chiridotea coeca*	17	12	5	55	89	20
Cnidaria	Anthozoa	15	9	6	50	82	19
Bivalvia	*Spisula solidissima*	15	12	3	30	53	5
Bivalvia	*Lyonsia hyalina*	15	9	6	25	37	13
Crustacea	*Pseudoleptocuma minor*	16	13	3	25	48	5
Cephalochordata	*Branchiostoma caribaeum*	18	8	10	20	23	17

iments, which is a key factor in determining benthic habitat quality (Rhoads and Germano, 1986). Thus any sand mining operation removing more than 10 cm of sand would expose anaerobic sediments that would affect recolonization by benthos (Diaz and Schaffner, 1990).

During the May 1998 cruise, a total of 10,634 individuals representing 152 taxa identified to LPTL were collected from 52 grab samples. Benthos abundance varied from 90 to 70,600 individuals/m^2 with the mean and median abundance being 5,100/m^2 and 1,950/m^2 respectively. Annelid worms were the most abundant followed by molluscs and crustaceans. At a finer taxonomic scale, 15 percent of the annelids were oligochaetes and 85 percent polychaetes, 97 percent of the molluscs were bivalves and 3 percent gastropods, and 60 percent of the crustaceans were amphipods. The number of taxa (LPTL) per sample varied from three to 35. Wet weight biomass varied 6,000 fold from 0.3 to 2,000 g/m^2. The lowest biomass occurred at a station on the crest of the shoals and the highest on the Indian River flats. The large difference in biomass was a due to the occurrence of a few large individuals, usually molluscs. Molluscs accounted for about 87 percent of the biomass followed by polychaetes, gastropods, and amphipods with about 6, 3, and 1 percent, respectively.

A total of 6,145 individuals representing 108 taxa were obtained from 20 samples collected in June 1999. Infaunal abundance varied from 230 to 30,400 individuals/m^2 with the mean and median being 7,680 and 2,187/m^2. Again, annelid worms were the most abundant followed by about equal numbers of crustaceans and molluscs. Polycheates accounted for about 92 percent and oligochaetes for about 8 percent of the annelids, 92 percent of the molluscs were bivalves and 8 percent gastropods and 92 percent of the crustaceans were amphipods. The number of species per sample varied from 6 to 40 with a mean of 20.4. Wet biomass varied from 0.3 to 2,000/m^2 with the lowest on the shoals and the greatest in the Indian River area.

While 166 taxa were collected during the course of the two cruises, 31 occurred in at least 15 samples and were considered the dominants (Table 1). Of these 31 dominant taxa, oligochaete worms were the most widely distributed, occurring at 58 stations. The surf clam, *Spisula solidissima,* occurred at 15 stations but was 66 percent of the total biomass on both cruises and dominated wet weight biomass. The other 30 dominant taxa made up 30 percent of the total biomass and the remaining 135 taxa 4 percent. The basic patterns in the distribution of the benthos were driven by species-habitat or species-sediment preferences. For the dominant taxa patterns were primarily related to sediment grain size with Nemertina, *Astarte* spp., *Crenella glandula, Mytilus edulis,* and *Byblis serrata* characteristic of coarser sediments and with *Asabellides oculata, Spio setosa, Spiophanes bombyx, Tellina* spp., and *Unciola irrorata* associated with the finer, in some cases silty, sediments.

The dominant taxa have a broad range of life history traits.

Table 2. *Life history traits summary for dominant taxa from the Ocean City shoals ROI. See CUTTER and DIAZ (2000) for sources.*

Species Name	Preferred Substrate	Feeding Mode	Mobility	Spawns/Year	Larval Mode	Spawning Times	Lifespan
Ampelisca spp.	Medium to Coarse Sand	Suspension	Tube Builder	Twice	Brooding	Spring/Summer	Annual
Byblis serrata	Medium to Coarse Sand	Suspension	Tube Builder	Multiple Events	Brooding	Late Spring/Summer	Annual
Protohaustorius wigleyi	Fine Sand	Suspension	Burrower	Multiple Events	Brooding	Late Spring/Summer	Annual
Pseudounciola obliquua	Medium to Coarse Sand	Suspension	Tube Builder	Multiple Events	Brooding	Late Spring/Summer	Annual
Unciola irrorata	Coarse to medium Sand	Deposit/Suspension	Lives in tubes of other organisms	Once	Brooding	Spring/Early Summer	Annual
Astarte spp.	Muddy Fine Sand	Deposit/Suspension	Limited Mobility	Once	Lecithotrophic eggs on substratum	Fall	20 years
Ensis directus	Medium to Fine Sand, Muddy Sand	Suspension	Limited Mobility	Multiple Events	Planktonic	?	>1
Mytilus edulis	Hard Substrates, Coarse Sand, Gravel	Suspension	Sessile	Once or Twice	Planktonic	Late Fall/Winter	7 years
Nucula proxima	Muddy	Deposit	Limited Mobility	?	Planktonic	Late Summer/Early Fall	>1
Spisula solidissima	Coarse Sand	Suspension	Limited Mobility	Twice	Planktonic	Late Summer/Fall	20 to 35 Years
Tellina agilis	Medium to Fine Sand, Muddy Sand	Surface Deposit	Limited Mobility	Twice	Planktonic	Spring/Fall	2 Years
Branchiostoma caribaeum	Coarse to Fine Silty Sand	Suspension	Mobile	?	Planktonic	?	?
Anthozoa	Coarse to Fine Sand	Carnivore/Suspension	Sessile	?	Asexual/Planktonic	?	Annual?
Oxyurostylis smithi	Fine Sand	Suspension	Burrower/Limited Mobility	Continuous	Brooding	Early Winter	Annual
Pseudoleptocuma minor	Fine Sand	Suspension	Burrower/Limited Mobility	Continuous	Brooding	?	Annual
Busycon canaliculata	Coarse to Muddy Fine Sand	Carnivore	Mobile	Once	Direct Development	?	>5 years
Nassarius trivittatus	Coarse to Fine Sand	Scavenger	Mobile	?	Direct Development	?	>1
Politolana concharum	?	?	Limited Mobility	?	Brooding	Winter/Early Spring	?
Nemertinea	Coarse sand to Muds	Carnivore	Burrower	?	Direct Development or Planktonic	?	Annual?
Oligochaeta	Coarse to Fine Sand, Muds	Deposit	Burrower/Interstitial	Continuous	Direct Development	Spring/Summer/Fall	Annual
Aphelochaeta sp.	?	Surface Deposit	Tube Builder	Multiple Events	Lecithotrophic eggs	Spring/Summer	?
Aricidea spp.	Muddy, Silty-Fine Sand	Subsurface Deposit	Burrower	?	Brooding	?	?
Asabellides oculata	Sand, Silty Sand	Surface Deposit	Tube Builder	Once	Brooding	Winter, Early Spring	Annual
Brania wellfleetensis	Muddy, Muddy Sandy	Deposit	Burrower	Once	Brooding	Fall	?
Hemipodus roseus	Coarse Sand	Carnivore	Burrower	Once	Planktonic	?	?
Hesionura elongata	Medium to Coarse Sand	Carnivore	Burrower	Once	Planktonic	?	?
Mediomastus ambiseta	Muddy Fine Sand	Deposit	Tube Builder	Once	Planktonic, Non-Feeding	Late summer/fall	Annual
Nephtys spp.	Coarse to Very Fine Sand	Carnivore/Omnivore	Burrower	Twice	Planktonic	Spring/Fall	4 Years
Parapionosyllis longicirrata	Muddy Sand, Shells	?	Burrower	?	Brooding	Fall	?
Protodorvillea kefersteini	Coarse to Fine Sand	Carnivore	Burrower	Once	Direct Development	Summer/Late Fall	?
Spio Setosa	Muddy Fine Sand	Deposit/Suspension	Tube Builder	Twice	Broods Spring Planktonic Fall	Spring/Fall	Annual
Spiophanes bombyx	Fine Sand, Muddy	Deposit/Suspension	Tube Builder	Once	Planktonic	Late Summer	Annual
Streptosyllis pettiboneae	Medium Fine Sand	Carnivore	?	Once	Brooding	Spring/Early Summer	Annual

Table 3. *Predicted recruitment potential of dominant benthos found at the Ocean City shoal ROI.*

Major Group	Species Name	Recruitment Potential		
		Year Round	Spring/Summer	Fall/Winter
Cnidaria	Anthozoa	Poor	Poor	Poor
Nemertinea	Nemertinea	Good	Good	Good
Oligochaeta	Oligochaeta	Good	Good	Good
Polychaeta	*Aricidea* spp.	Poor	?	?
	Hemipodus roseus	Poor	?	?
	Hesionura elongata	Poor	?	?
	Brania wellfleetensis	Poor	Poor	Good
	Mediomastus ambiseta	Poor	Poor	Good
	Parapionosyllis longicirrata	Poor	Poor	Good
	Aphelochaeta sp.	Poor	Good	Poor
	Spiophanes bombyx	Poor	Good	Poor
	Streptosyllis pettiboneae	Poor	Good	Poor
	Asabellides oculata	Good	Good	Good
	Nephtys spp.	Good	Good	Good
	Protodorvillea kefersteini	Good	Good	Good
	Spio Setosa	Good	Good	Good
Gastropoda	*Busycon canaliculata*	Good	Good	Good
	Nassarius trivittatus	Good	Good	Good
Bivalvia	*Astarte* spp.	Poor	Poor	Good
	Mytilus edulis	Poor	Poor	Good
	Nucula proxima	Poor	Poor	Good
	Ensis directus	Good	Good	Good
	Spisula solidissima	Good	Good	Good
	Tellina agilis	Good	Good	Good
Cumacean	*Oxyurostylis smithi*	Good	Good	Good
	Pseudoleptocuma minor	Good	Good	Good
Isopoda	*Politolana concharum*	Good	Good	Good
Amphipoda	*Ampelisca* spp.	Poor	Good	Poor
	Byblis serrata	Poor	Good	Poor
	Protohaustorius wigleyi	Poor	Good	Poor
	Pseudounciola obliquua	Poor	Good	Poor
	Unciola irrorata	Poor	Good	Poor
Cephalochordata	*Branchiostoma caribaeum*	Good	Good	Good

According to the literature, shallow continental shelf macrobenthic communities are primarily controlled by sediment grain size and bottom topography. Many life history traits reflect an accommodation to the influence of physical processes and cycles. For example, some taxa are restricted to either coarse or fine sands. The majority of the dominants were either suspension feeders, common to high energy and high particulate habitats, or carnivores (Table 2). Many had combinations of life history traits that would give them a good ability to recruit into sand mine disturbed areas (Table 3).

The potential of a species to recruit or recolonize a mined area is a function its life history traits. Three categories of recolonization potential were considered: Year Round, Spring/Summer, and Fall/Winter. A species was considered to be a Year Round colonizer if it had a broad range of sediment preferences, spawned more than once a year over multiple seasons, and had a life span of a year or less. Species with good dispersal or mobility were considered good colonizers (Table 3). For example, oligocheates can recolonize a habitat at any time of the year by being transported with the (sediment) bed transport. Good Spring/Summer or Fall/Winter colonizers were those species that recruited during the appropriate time period and had good mobility. Of the species considered, 15 were rated as good and 18 as poor Year Round colonizers, eight were good Spring/Summer and seven were good Fall/Winter colonizers. There was insufficient information to categorize four of the dominant taxa.

Twenty species of fish were collected from the four previously determined habitats. The most abundant fish was the hake, *Urophycis regia,* followed by *Etropus microstomus,* together accounting for about 70 percent of the fish caught. All the fishes caught were the common members of the shallow continental shelf fish assemblage (ABLE and FAHAY, 1998). Cluster analysis indicated that there were day/night differences in the fish assemblage in the south west *Asabellides* tube and the north west sand habitats. Overall, the association between fishes and habitats appeared to be related to sediment grain-size, bed roughness, and the presence (or absence) of biogenic structures.

DISCUSSION

Sand mining activities will physically alter the local habitat and impact benthos. Assuming substantial excavation and removal of all benthic organisms the mining area, it is possible to predict the potential nature of recolonization communities based primarily on the occurrences and proximity of the other community groups in the vicinity. Predictions are based upon three elements: First, that neighboring commu-

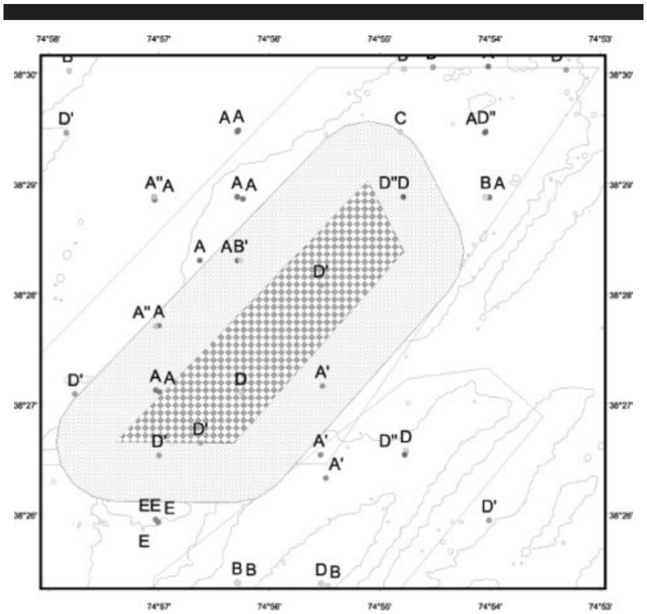

Figure 2. Sand mining scenario for the Fenwick Shoal ROI, off Ocean City Inlet, Maryland. Benthic recolonization of the mined area (coarse stippling) would proceed from community groups in the buffer zone (fine stippling) and from outside the mined area. Letters refer to cluster groups based on benthic grab data.

nity groups, species compositions and abundances of major taxa that surround the mined area are the primary source of recruits. Second, incorporation of available data on the likely nature of the newly exposed substrate. Third, the effect of season on recolonization would have to be assessed with consideration of the life histories of the species available for recolonization. Several of the dominants, oligochaetes, nemerteans, *Protodorvillea, Tellina,* and *Asabellides,* likely would recruit in any season while the amphipods (*Bybilus, Pseudunciola,* and *Parahaustorius*) likely would recruit better in spring/summer than in fall/winter. The polychaete *Brania* and the bivalve *Nucula* would do better in fall/winter. Overall it is probably that larval and juvenile recruitment would be better after a spring/summer dredging than after a fall/winter disruption. Recruitment by adults during any season is more apt to be regulated by factors such as storms that affect passive transport. While the active transport of mobile species such as epifaunal mysids or *Crangon septemspinosa* might be more rapid during the warm months when the species are more active, it would also take place during the winter but at a reduced rate.

As an example of potential recolonization considers the scenario of removing at least the top meter of sand from Fenwick Shoal and that the grain-size characteristics of the new substrate are the same as the original. The disturbed area would be approximately 7.7 km^2 (Figure 2). The average density of the infauna of the dominant and subdominant species would be approximately 1900 individuals/m^2 and the average (wet) biomass about 3.8 g/m^2. Thus the acute impacts would be a loss of approximately 150×10^6 individuals with a combined wet biomass of about 300 kg. A mining operation with a subsequent recruitment in the spring/summer would favor crustaceans while a fall/winter recruitment would favor annelids (Table 4). After a single spring/summer recruitment it is likely that the level of benthic resources would be sufficient for a return of demersal fishes. Indeed the recruitment potential of the crustaceans is such that the habitat might be slightly enhanced. However, following a fall/winter recruitment the benthic resource value might not be as great as annelids might not be utilized by demersal fishes to the same extent as crustaceans. Should the post-exploitation substrate have a finer grain size than the original, it might favor annelids and bivalves that might in the long-term reduce the resource value for demersal fishes.

Table 4. *Scenarios depicting the effect of season and climatology on infaunal recolonization trajectory. Habitat and faunal characteristics for the combination of season and climate are listed in each cell.*

Climate Immediately After Mining:	Season When Sand Mining Conducted:	
	Spring/Summer	Fall/Winter
Stormy/Energetic	Transport of small to large individuals into and out of mined area Dispersal of organic matter and fine sediments Dispersal of individuals form mass recruitment events Lower potential for shift in community structure Recolonization rate intermediate Production lowered	Transport of small to large individuals into and out of mined area Dispersal of organic matter and fine sediments Physical and physiological stress highest, sensitive life history stages eliminated Recolonization slowed to lowest rate High potential for delay of community structure recovery Production at lowest point
Calm/Quiescent	Deposition of water column primary production Fine sediments accumulate in mined area Recruitment of warm water larval forms favored Surface and subsurface deposit feeders favored Species that queue on fine sediments favored Recolonization proceeds at highest rate Highest potential for shift in community structure Extended quiescence may lead to hypoxia, regionally or within mined area Highest production	Fines accumulate in mined area Recruitment of cold water larval forms favored Recolonization rate intermediate High potential for shift in community structure Pulse of high production

JUTTE and VANDOLAH (1999) found that a year after sand mining in two areas offshore of Hilton Head, SC that the silt-clay content of the surface sediments increased by 13 percent and that the benthic resources had changed from the original and hand not recovered to the original community structure. However they also found that in an area offshore of Myrtle Beach, SC that the surface sediments had not fined and that the infaunal community recovered in about two years.

In order to ensure that the biological assemblages that recolonize a mined area resemble that prior to the disturbance, it would be beneficial to avoid total removal of the substrate. Leaving selected small, untouched areas to serve as refuges (refuge patches) within the disturbed zone should minimize the potential alteration of community structure and function and, therefore, reduce potential effects upon trophically dependent species. Refuge patches from mining should be of higher priority in areas where the tops or ridges of shoals are to be mined for two main reasons: 1) the shoal-ridge communities are different from the mid-shoal and trough communities and 2) potential recruits from adjacent shoals, if any, likely would suffer high mortality from exposure to predators during the open water transit and, thus, would have limited chance for successful recolonization. By contrast, if local refuge patches are retained, travel distances and exposure times for transiting organisms would be minimized with a concomitant increase in success. Marine refuge patches should promote similarity between the pre- and post-mining benthic communities and related or dependent nekton.

The impacts of sand mining on mobile fisheries resources also are connected to the rate and success of benthic recolonization. Many fishes use the shallow continental shelf as a nursery ground (ABLE and FAHEY, 1998; OLNEY and BILKOVIC, 1998; MUSICK, 1999) and, depending on when their demersal life history stages utilize a particular area, any impacts could be minimized by insuring that their cover or food source not be disrupted. For the most part this would mean minimizing impacts to crustaceans. Conversely, any aspect of sand mining that would enhance production of crustaceans likely would improve habitat quality for demersal fishes.

CONCLUSIONS

Sand mining activities should be designed to minimize impacts to biological resources and to ensure the biological assemblages that recolonize a mined area functions in a similar manner to that present prior to mining; the primary function being trophic support of fishes. Avoiding total removal of surficial substrates and retaining small patches within the mined area could do this, in part. These patches would serve as refuges for established benthic species and facilitate recolonization by providing a local source of potential recruits. Facilitating rapid recolonization of a mined site by established community members would minimize alteration of community structure and function and reduce potential effects upon trophically dependent fishes. Impacts to demersal fishes would be connected to the rate and success of benthic recolonization, as many fishes utilize the shallow continental shelf as a nursery ground, which would be connected to the seasonal timing of sand mining (Table 4). We found juvenile demersal fishes to overwhelmingly feed on epifaunal and infaunal crustaceans, thus any aspect of sand mining that would enhance the production of crustaceans would likely also improve habitat quality for demersal fishes.

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