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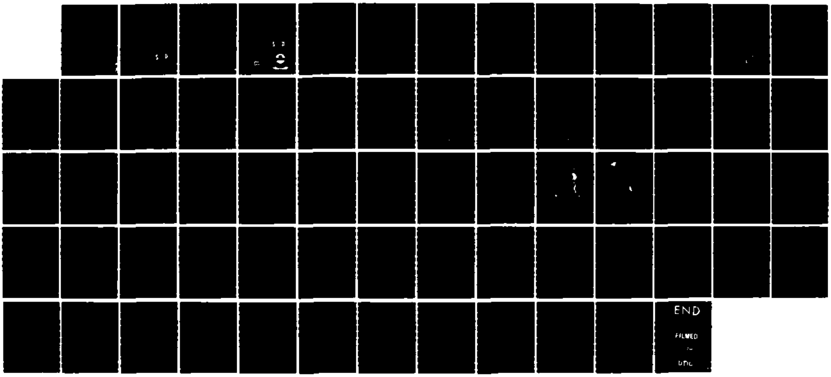

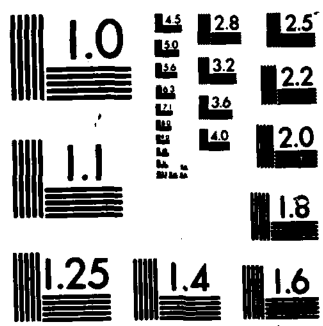

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Report recommends a period of restricted dumping at NDS during Sept-Oct time period to avoid impacts to blue crab and croaker larvae.

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Report B- 23

JRB ASSOCIATES
A Company of Science Applications, Inc.

TECHNICAL REPORT:

AN ASSESSMENT OF THE POTENTIAL IMPACTS ON ZOOPLANKTON AND FISH OF OCEAN DREDGED MATERIAL DISPOSAL AT THE NORFOLK DISPOSAL SITE

EPA Contract No. 68-02-6388
JRB Project No. 2-813-03-852-88

Submitted to:

U.S. Environmental Protection Agency
Region III
Environmental Impact/Marine Policy Branch

Submitted by:

JRB Associates
A Company of Science Applications International Corporation
8400 Westpark Drive
McLean, Virginia 22102

Kim Devonald - Work Assignment Manager
Seth Ausubel - Technical Staff

September 7, 1984

ABSTRACT

The potential impacts on fish, fisheries and zooplankton of uncontaminated dredged material disposal at the proposed Norfolk (Virginia) disposal site was assessed through literature search and worst-case impact calculation. Emphasis was placed on analysis of the spatial and temporal distribution of ichthyoplankton and blue crab (Callinectes sapidus) larvae at the disposal site, and in the ocean waters adjacent to Chesapeake Bay.

Available evidence indicated that the proposed site does not have any special importance to plankton, fish or fisheries. Most planktonic species have broad spatial distributions, and local impacts from dredged material disposal are therefore expected to have neglibible effects on plankton populations. However, blue crab larvae and Atlantic croaker (Micropogon undulatus) larvae of the lower Chesapeake Bay and adjacent coastal ocean exhibit spatial distributions that may be determined in part by current patterns that retain the larvae in the vicinity of the Chesapeake Bay mouth. Therefore, the distribution of larvae available for recruitment may be spatially limited relative to most planktonic organisms. Based on available information on spatial distribution patterns, and using worst-case impact calculation, the possibility of a measurable effect of disposal on year-class strength of blue crab and croaker could not entirely be ruled out. Therefore, a period of restricted dumping during peak recruitment of blue crab and croaker larvae (September - October) was recommended.

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1.1 LOCATION AND BATHYMETRY OF THE PROPOSED SITE

The proposed site is a circular area 4 nautical miles (7.4 km) in radius, centered on a point at 36°59' N latitude and 75°39' W longitude. The center point is approximately 17 nautical miles (31 km) offshore (Figure 1).

Depths in the disposal area range from 13.1-26 meters (43-85 feet). The sea floor (Figure 2) slopes from 13.1 meters at the northwest edge of the site to 26 meters on the eastern edge.

1.2 COE DISPOSAL OPERATIONS

1.2.1 Location of Channels to be Dredged

The Norfolk disposal site may receive dredged material from Norfolk District Corps of Engineers (COE) dredging sites in the Chesapeake Bay, Hampton Roads Harbor, the Elizabeth River, Thimble Shoal Channel, Atlantic Ocean Channel, and Cape Henry Channel (COE, 1981), if the sediments meet the requirements for ocean dumping detailed in the Implementation Manual (EPA/COE, 1978), which is based on requirements set forth by the Marine Protection, Research and Sanctuaries Act of 1972 (MPRSA: U.S.C. 1401 et seq.,45 Fed. Reg. 3053 Jan. 16, 1980). The location of these dredging sites is shown in Figure 3.

1.2.2 Sediment Types and Amounts Expected

Sediments to be dumped at the proposed site are mainly unconsolidated fine sands and coarse silts (COE, 1984b): Sediment from the inner Thimble Shoal Channel, from Norfolk Harbor to approximately 2 nautical miles west of the tunnel, are primarily silt. The outer Thimble Shoal Channel, from 2 nautical miles west of the tunnel to Cape Henry, contains mainly sand. Cape Henry Channel sediment is mostly fine sand and silt, and the Atlantic Ocean Channel contains fine to medium sand.

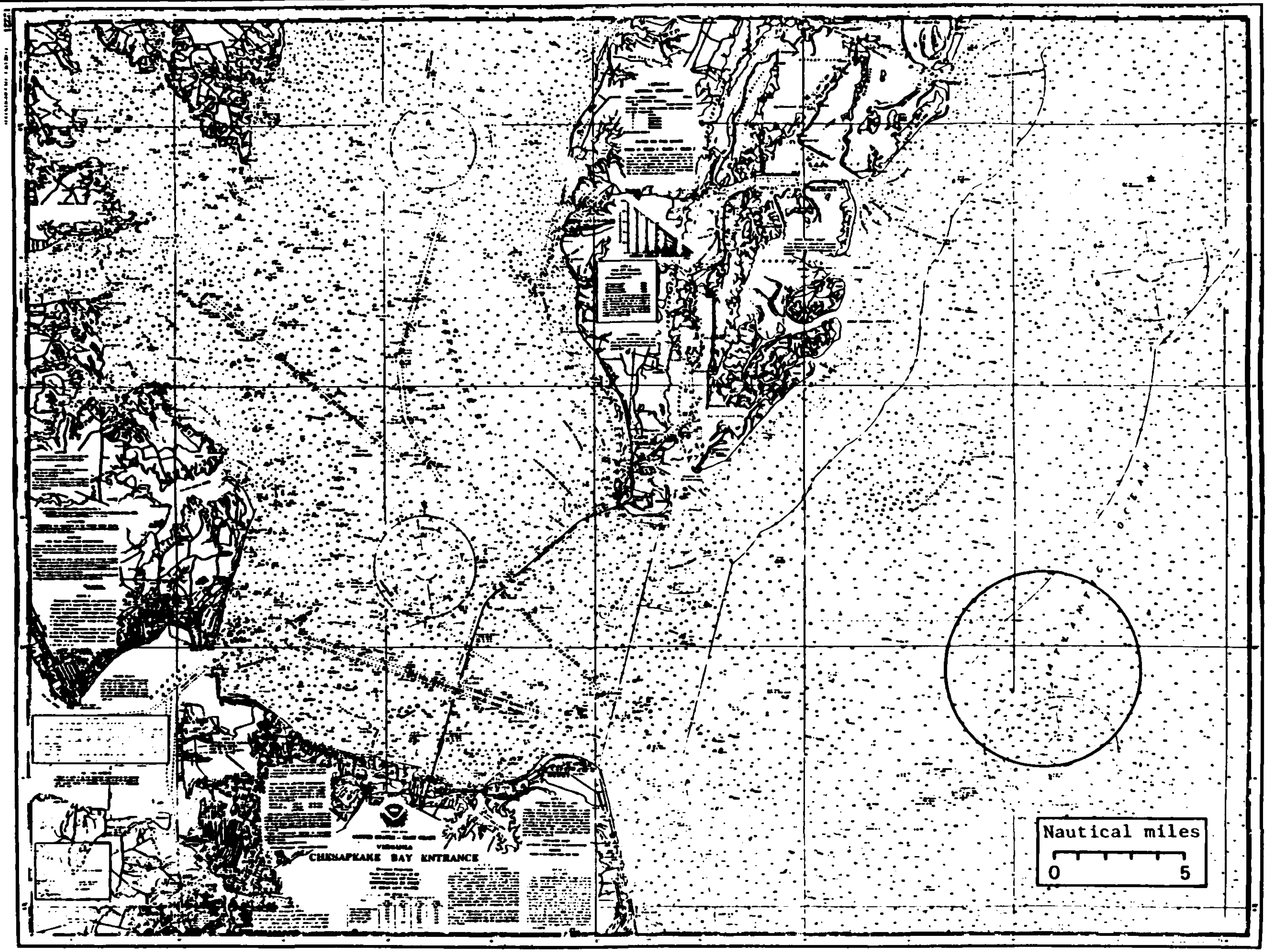


Figure 1. Location of the proposed Norfolk ocean dredged material disposal site.

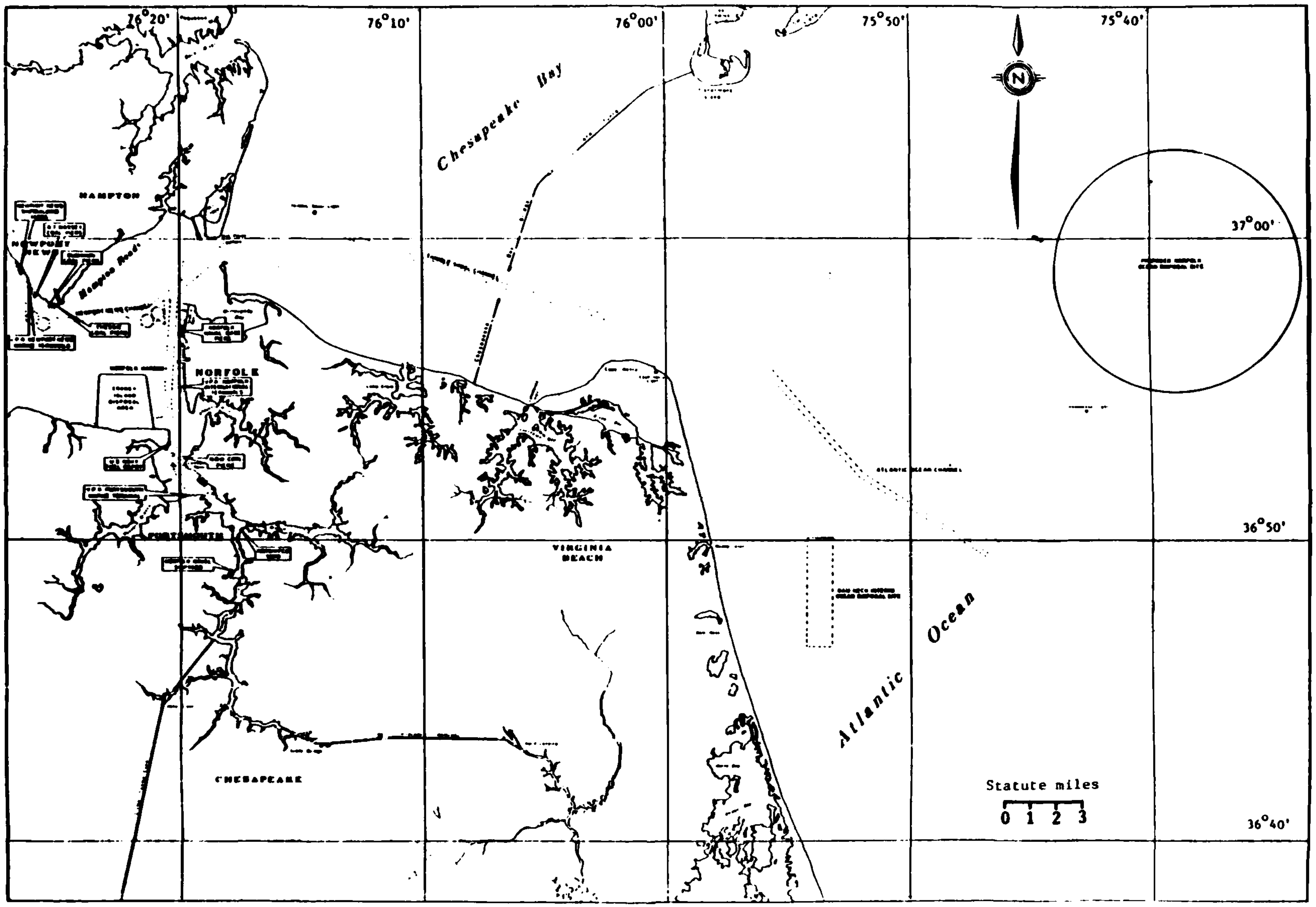


Figure 3. Location of channels to be dredged.

According to Meisburger (1972), the dominant surface sediment of the Chesapeake Bay entrance is a homogeneous gray, fine to very-fine sand, usually well sorted and often silty. Typical grain sizes are from 0.062-0.25 mm (Figure 4). However, in the channels gray silt is the dominant sediment type and sands are rare, occurring in patchy outcrops. In Thimble Shoal Channel near the bay mouth, the only sizeable surface concentration of medium and coarse sand (grain sizes 0.09-1.5 mm, Figure 5) occurs. This sediment is distributed in outcrops among the gray silty sediments. COE drilling logs from the Thimble Shoal Channel (COE 1984c) confirm these sediment distributions and grain sizes.

The Norfolk disposal site may receive approximately 12.5 million cubic yards of material per year during the seven-year construction period of the Norfolk Harbor and Channels deepening project, and approximately 2 million cubic yards per year in the maintenance phase (COE 1980, addendum). Table 1 provides a more detailed listing of dredged material volumes associated with this work.

1.2.3 Disposal Logistics

COE will probably employ hopper dredges of 5,000-8,000 cubic yard hopper capacity for disposal at the Norfolk site (COE, pers. comm. 1984a). Dredges will be either the split-hull or bottom-dump design (COE, pers. comm. 1984b). The larger bottom-dump dredges have a draft of about 30 feet (about 10 m) and consequently release material at greater depth than split-hull dredges (COE, pers. comm. 1984a).

A time interval of approximately 1 hour is required to fill the dredge, and a travel time (including discharge of dredged material) of 2 to 3 hours is required for the dredge to reach the disposal site (COE, pers. comm. 1984b). Assuming that only one dredge is operating, the disposal frequency is on the order of 4-6 hours (COE, pers. comm. 1984b). A series of test dumps intended to be representative of typical disposal operations was conducted at the Norfolk site (Darby et al., 1981). The dispersion characteristics of released materials as measured in those test dumps will be summarized in Section 2.2 of this report.

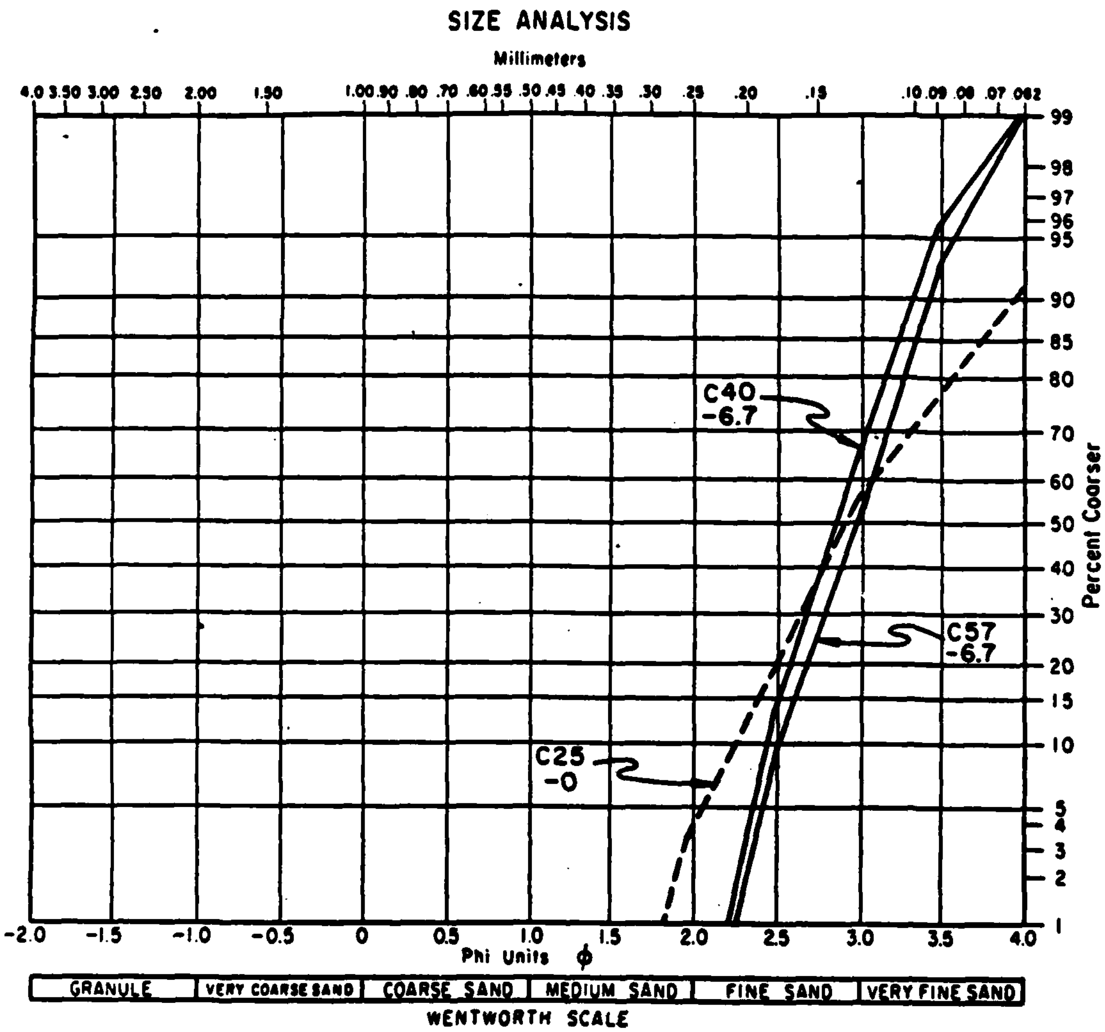


Figure 4. Size distribution for typical samples from the fine gray sand that is the dominant sediment in the Chesapeake Bay mouth region. From Meisburger 1972.

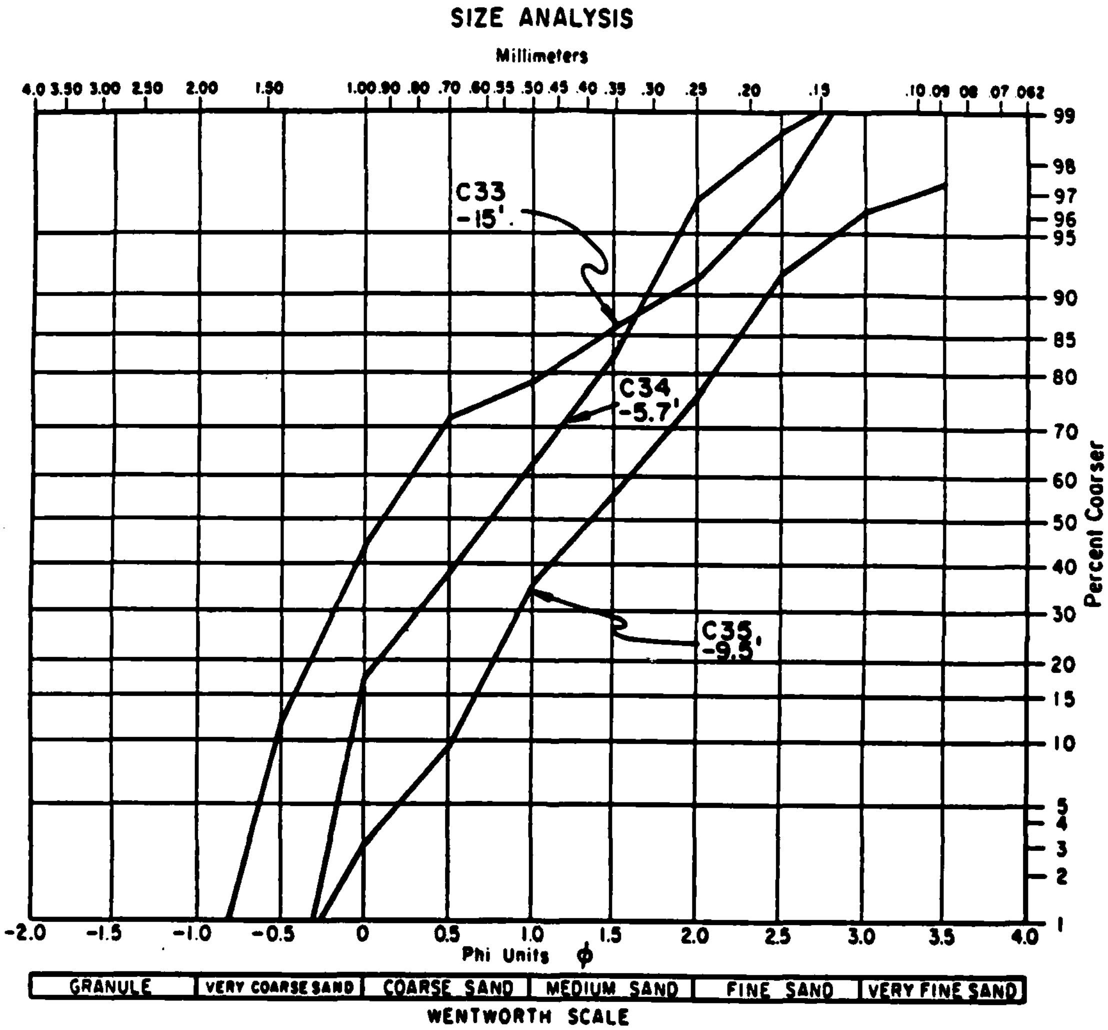


Figure 5. Size distribution for typical samples of medium and coarse sand that occurs in outcrops in Thimble Shoal Channel. From Meisburger 1972.

Table 1. Quantities of dredged material from inner harbor.*

Location	Total quantity of dredged material (cubic yards)	Quantity of dredged material for ocean disposal (cubic yards)
New Work		
Norfolk Harbor Channel 55'	27,862,000	20,896,000
Channel to Newport News 55'	11,187,000	11,187,000
Elizabeth River and Southern Branch 45'	7,206,000	1,802,000
Southern Branch 40'	2,235,000	2,235,000
Mooring Area 55'	1,374,000	1,374,000
Access Channels and Berthing Areas 55'	1,015,000	761,000
Access Channels and Berthing Areas 45'	272,000	204,000
Access Channels and Berthing Areas 40'	118,000	118,000
TOTAL	51,269,000	38,577,000
Annual Maintenance		
Norfolk Harbor Channel 55'	1,683,000	1,262,000
Channel to Newport News 55'	152,000	152,000
Mooring Area 55'	15,000	15,000
Circular Anchorages (Norfolk and Newport News)	171,000	171,000
Elizabeth River and Southern Branch 45'	421,000	105,000
Southern Branch 40'	115,000	115,000
Permit Activities	1,511,000	1,133,000
Naval Shipyard	32,000	0
Craney Island Rehandling Basin	380,000	285,000
TOTAL	4,480,000	3,238,000

* From COE (1980) addendum.

2. PHYSICAL PROCESSES

2.1 PHYSICAL OCEANOGRAPHY

2.1.1 Transport In and Out of Chesapeake Bay

The transport of water in and out of Chesapeake Bay is caused mainly by the classical estuarine circulation and the semidiurnal tidal circulation (though wind forcing can dominate this flow over short time intervals during the winter) (Boicourt, 1981). The estuarine circulation consists of a characteristic two-layer flow: Low salinity water from rivers and other fresh water inputs moves seaward in the upper layer, while high salinity shelf water is drawn into the bay in the lower layer (Pritchard, 1955). Superimposed on the estuarine circulation is the tidal circulation. Tidal velocities near the bay mouth may be in excess of 40 cm/s, a great deal faster than the flow rates of the estuarine circulation (Boicourt, 1981).

The Chesapeake Bay inflow is, on the average, broadly distributed and occurs mainly from the north and east (Bumpus, 1973). However, the source of the inflowing water is affected by wind direction (Boicourt, 1981; Figure 6). The net outflow is confined to a narrow "jet" to the south along the Virginia and North Carolina coasts (Figure 7).

2.1.2 Transport in Coastal Ocean Waters

The flow of water on the inner continental shelf is dominated by wind forcing, especially in shallow areas such as the disposal site (Boicourt, 1981). During winter prevailing winds are northerly (from the north), causing a net flow southward in the shallow shelf waters adjacent to Chesapeake Bay (Figure 8). During summer prevailing winds are southerly, causing a net

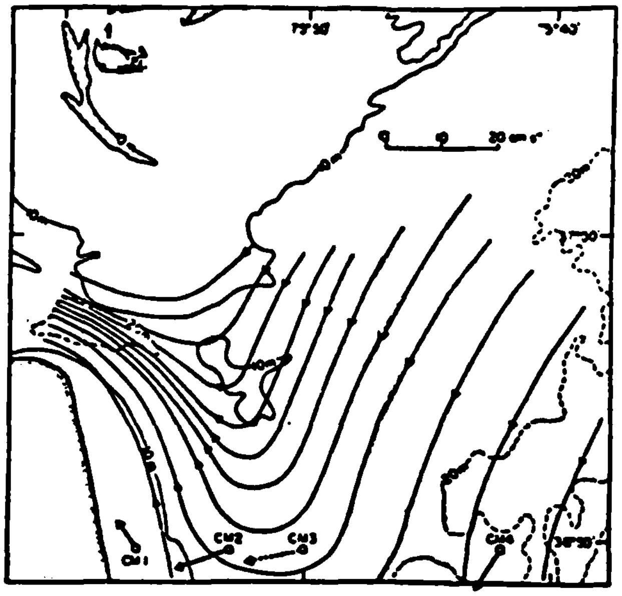


Figure 6a. Inflow (lower layer) streamline pattern for periods of calm or northerly winds. From Boicourt 1981.

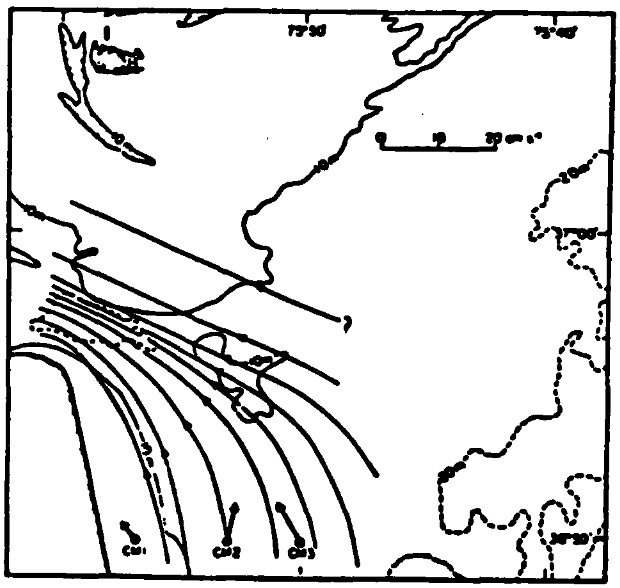


Figure 6b. Inflow (lower layer) streamline pattern for periods of southerly winds. From Boicourt 1981.

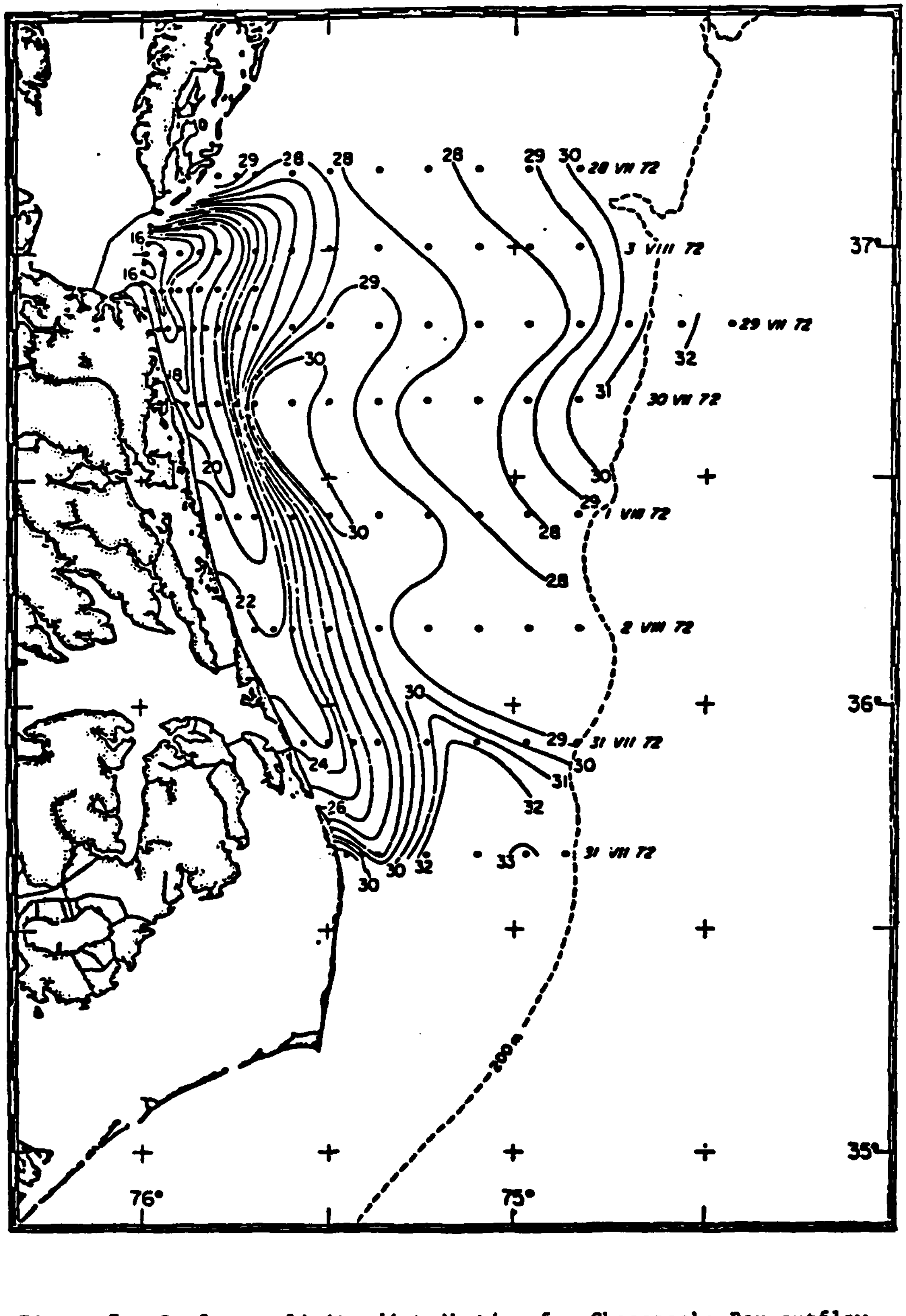


Figure 7. Surface salinity distribution for Chesapeake Bay outflow "Jet" along Virginia coast, July-August 1972. From Boicourt 1981.

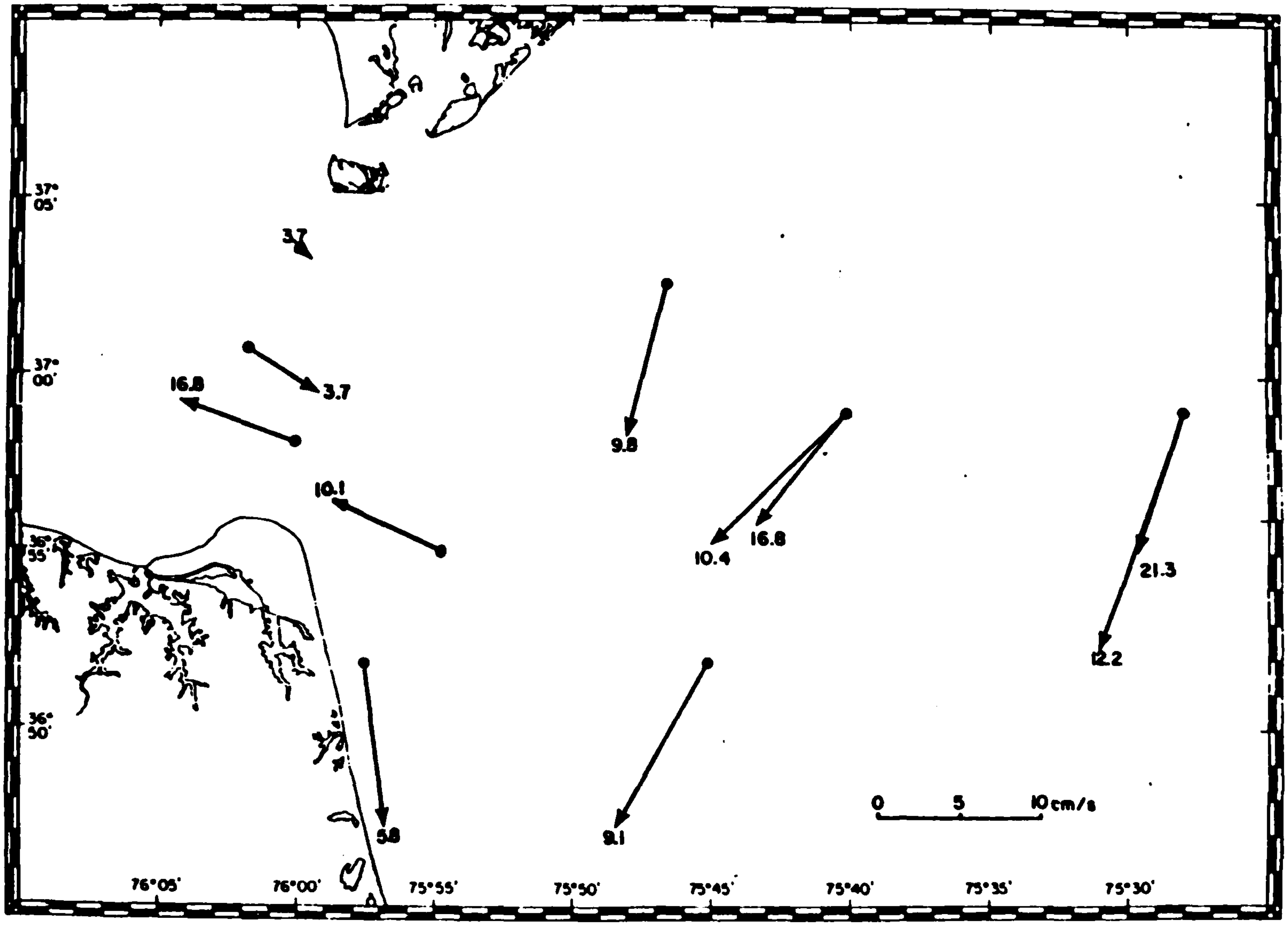


Figure 8. Mean velocities for 240-hr interval beginning 0000 4 February 1979. Depth of measurements are indicated (in meters) at the head of the velocity arrows. From Boicourt 1981.

flow to the north in shallow shelf waters (Figure 9). The combination of the southward, nearshore bay-outflow "jet", and the northward wind-driven flow offshore on the shelf creates a current gyre that may be important in the retention of the larvae of the blue crab (Callinectes sapidus) or other planktonic organisms in shelf waters near the bay mouth. Subsequent recruitment of blue crab larvae back into the bay may be enhanced by favorable southerly winds (McConaugha et al., 1983). This phenomenon may enhance retention and aid recruitment of a variety of coastal meroplankton (the planktonic larvae of non-planktonic adult organisms), and will be discussed in detail later in this report.

2.1.3 Seasonal Stratification

The presence of a pycnocline, (a sharp, vertical density gradient due to temperature and salinity gradients at some depth in the water column) is an important environmental cue for initiation of spawning or vertical migration of larvae aiding retention and recruitment in many species of fish (Parrish et al., 1981; Norcross, 1983; Peterson and Ausubel, 1984) and in many brachyuran crab larvae (Johnson, 1982). A pycnocline may also cause turbidity maxima that persist in the water column for relatively long periods after dredged material disposal, thus increasing exposure of planktonic organisms to high suspended sediment concentrations. No detailed vertical hydrographic data are available at the location of the Norfolk disposal site. However, Boicourt (pers. comm. 1984) believes that it is unlikely that a marked pycnocline will occur during the spring and summer spawning seasons, at the disposal site. Spawning seasons of Norfolk-area biota are discussed in Chapter 3 of this report.

Data indicate that stratification occurs in inshore shelf waters off the lower Delmarva peninsula and Chesapeake Bay mouth during spring and summer (Boicourt, 1981). In 1976, the onset of seasonal stratification on the inner shelf occurred about the last week of March, and lasted until the end of August (Ruzecki et al., 1977). In waters off the lower Delmarva peninsula, about 35 km (19 nmi) north of the proposed disposal site and of depth similar to the disposal site (about 25 m, or 80 feet deep), a distinct pycnocline was present on March 22-23, 1976, measured at that time at depths of about 10-15 m. Sigma-t values (measurements of water density) increased from about 23.70 to 25.00 over this depth interval (Ruzecki et al., 1977).

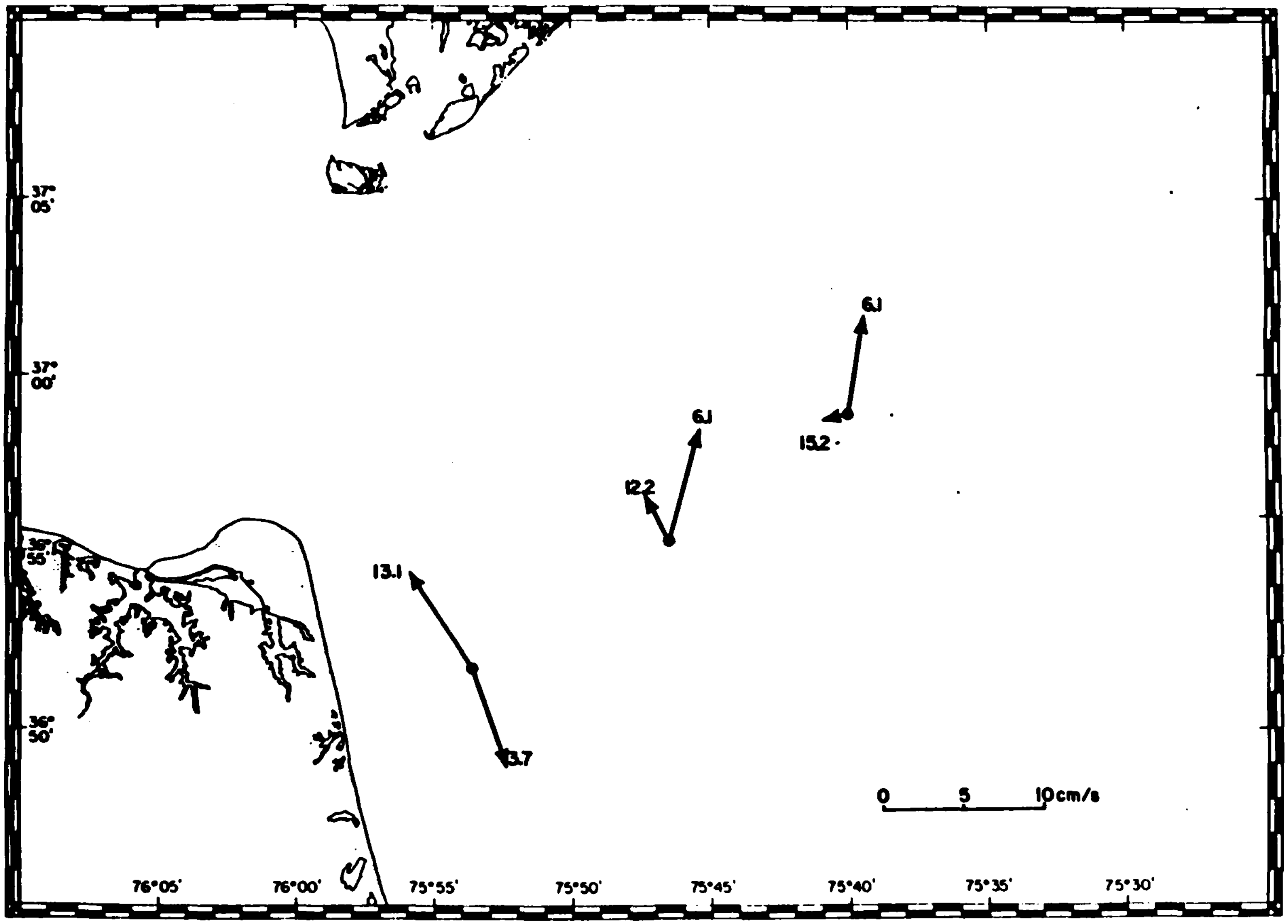


Figure 9. Mean velocities for 38-day interval beginning 23 June 1980. Depth of measurements indicated near head of arrows. From Boicourt 1981.

2.2 SEDIMENT TRANSPORT AND RESUSPENSION

2.2.1 Potential for Transport and Resuspension at the Norfolk Disposal Site

During winter, currents at the disposal site are southward with relatively high velocity (Boicourt, 1981). At this time of year, there is a high potential for intense storms. Transport and resuspension of sediment dumped at the Norfolk disposal site may occur quite frequently under these conditions (Boicourt, 1981). The principal direction of transport in winter is to the south. During summer, currents at the disposal site are mainly northward, but at low velocity. Intense storms are infrequent, and little potential for sediment transport and resuspension exists (Boicourt, 1981).

2.2.2 Review of Test Dumps at the Norfolk Disposal Site

Darby et al. (1981) monitored three COE dumps at the Norfolk disposal site during October 1981. These dumps were intended to be representative of typical dumping procedures (COE, pers. comm. 1984b). A split-hull design hopper dredge was used and dumps were monitored to assess the short-term (< 3 hour) changes in water quality, and to determine the initial dispersion of dumped material. The sediment dumped had been dredged during routine maintenance of the Thimble Shoal Channel. Sediment composition was mostly fine sand with less than 15 percent coarse silt.

The hopper dredge, moving at approximately 5 m/s (10 knots), completed each dump in 2-4 minutes over a distance of 0.6-1.2 km. The bulk of its load (total approximately 2,000 m^3) was discharged within a distance of about 150 m. During three hours after the dump, a sampling vessel traversed several times through the dredged material plume area, obtaining water samples at several depths within and outside the plume. Samples were analyzed for suspended solids, Mn, TKN, NH_4, and petrohydrocarbons. Acoustic profiles of sediment plumes were taken, and observation dives conducted to assess bottom topography before and after dumping.

Analysis of water samples showed that none of the parameters measured had average values changed enough to be statistically different before versus immediately after the test dumps, or within versus outside the plume. For example, values for suspended solids averaged 3.3 mg/l before the dumps, 5.0 mg/l 3-38 minutes after the dumps (an elevation, but not significant because of small sample numbers), and 3.0 mg/l 1.2-1.9 hours after the dumps. The highest individual suspended sediment concentration recorded within a dredged material plume was 9.0 mg/l. The timing of individual measurements of elevated turbidities indicated that the bulk of the material settled quickly (within 1 hour) to the bottom. Based on the sediment grain-size distribution data of COE (1984c) and Meisburger (1972), a worst-case estimate of sediment settling time should use grain sizes of about 0.05 mm. JRB (1984) calculated the sinking rate of such grains to be 0.2292 cm/s in still water. In a water column of 26m (85 feet) depth, the settling time is 3.15 hours.

Acoustic profiles revealed that the discharge of the hopper dredge created a 17m-wide vertical plume extending less than 600 m along the track of the dredge. Settling velocities measured ranged from 0.7-22 cm/s, corresponding to grain diameters of 0.092-0.5 mm. The average settling velocity of the last acoustically visible plume sediment was 1.09 cm/s, corresponding to a settling time of less than one hour. A small portion of low density material was observed as surface slicks after dumping. Slicks were observed 620 m from the dump track within 36 minutes after the dump. This material is organic-rich, and might be largely removed from the dump site and transported long distances by advection. The material could potentially affect neustonic organisms (organisms of the upper water layer), which are often in contact with the air-sea interface.

As stated above, most material settles quickly, and planktonic organisms should be exposed to high suspended sediment concentrations for only short periods of time. Based on repeated traverses, measured settling rates, and acoustic profiles, most of the dumped material was deposited within 300 m of the discharge track (within an area of 0.39 km^2). Observation dives before the test dumps, and during a six-week period after the last test dump, indicated that most material remained at the point of deposition over this interval despite the normally rough sea conditions from October to December.

3. BIOTA

3.1 OCEAN FISHERIES OFF VIRGINIA AND RELATED FISHERIES OF THE CHESAPEAKE BAY

3.1.1 Major Fisheries

Based on available evidence there is no particular attribute of the Norfolk disposal site that would render this area of special importance to natural fish populations or commercial or recreational fisheries.

The total Virginia commercial landings of fish and shellfish from the Atlantic Ocean in 1977 were about 65 million pounds, compared to 544 million pounds from the Chesapeake Bay (NOAA, 1984b). Thus, from a commercial standpoint, the bay is much more productive than adjacent ocean waters. The major commercial ocean fisheries of the state of Virginia in 1977 (NOAA, 1984b) were: Surf clam (landed value $8.7 million), sea scallop ($5.5 million), summer flounder or fluke ($1.9 million), and unclassified finfish (mostly menhaden, $1.3 million). Other important commercial species caught in ocean waters were hard clam, black seabass, oyster, blue crab, croaker, tuna, weakfish, and porgy. Of these species, menhaden, hard clam, oyster, blue crab, croaker, and weakfish are primarily bay fisheries, with only a small percentage of the total catch coming from the Atlantic Ocean. Also, landings of hard clam, oyster, and blue crab listed as caught in the Atlantic Ocean occur primarily in bays and river mouths of the eastern Delmarva peninsula, rather than in open coastal marine waters such as those of the proposed disposal site (NOAA, 1984b).

In terms of total catch per unit area, inland waters are much more important than offshore ocean waters such as those of the proposed site for recreational as well as commercial fisheries. The major recreational fisheries of the Middle-Atlantic Bight are for bluefish, summer flounder, spot, weakfish, silver hake, porgy, winter flounder, sea robin, black seabass, and croaker (NOAA, 1984a). In 1980, approximately 60 percent of the recreational catch in the Mid-Atlantic Bight region occurred in inland estuarine waters, while only 16 percent was taken in the ocean more than three miles (4.8 km) offshore (NOAA, 1984a).

3.1.2 Seasonality and Stock Distributions of Important Ocean Fisheries

In general, fish populations and fisheries of the Middle-Atlantic Bight are distributed over wide areas (Grosslein and Azarovitz, 1982). The importance of a small area such as the Norfolk disposal site for an entire fishery is likely to be insignificant because of the small portion of each spawning area to be affected by disposal impacts, and also because fishes are highly mobile and can avoid disturbed areas if any prolonged elevations of turbidity levels occur.

Commercial and recreational fisheries in the ocean off Virginia are highly seasonal. Fishing activities of all kinds peak in late spring, summer, and early fall and are lowest during late fall and winter (NMFS, pers. comm. 1984a). Important commercial fisheries for porgy (scup), squid, summer flounder, and some other species exist during winter but only far offshore, in water deeper than that of the proposed disposal site (about 80 to 200 meters, or 40 to 100 fathoms, and deeper) (NMFS, pers. comm. 1984a). Inshore summer fisheries for summer flounder and black seabass are localized and centered around the lower Delmarva peninsula (NMFS, pers. comm. 1984a), at least 15 km (9 miles) northwest of the disposal site. Nearshore commercial ocean fisheries for species such as striped bass, croaker, spot, bluefish, and weakfish occur primarily in April to May and September to October, when fish are migrating in (spring) and out (fall) of the Chesapeake Bay for summer spawning and feeding (NMFS, pers. comm. 1984a). Peak commercial fishing for menhaden and mackerel occurs during spring (Grosslein and Azarovitz, 1982).

There are important dredge fisheries for sea scallop and surf clam along Virginia's ocean coast. Surf clam are present at the disposal site, but are not ėspecially abundant there (Alden et al., 1981). The major concentrations of surf clam off Virginia and North Carolina occur at depths of 10 to 20 fathoms (18-37 m), with an extensive distribution to the north and south along the Mid-Atlantic seaboard (Ropes, 1980). Fishing occurs year-round. Sea scallop are cold-water organisms and are restricted to depths where the summer temperature does not exceed 20°C (68°F) (NOAA, 1983). In the Middle-Atlantic Bight, aggregations sufficiently dense to support a commercial fishery occur at depths of 20-50 fathoms (about 40-100 m, Grosslein and Azarovitz, 1982). Alden et al. (1981) did not find sea scallop at the disposal site. As with the surf clam, the commercial sea scallop fishery operates year-round, and scallop beds are widely distributed (Grosslein and Azarovitz, 1982).

3.2 AVAILABLE INFORMATION ON ZOOPLANKTON AT THE NORFOLK DISPOSAL SITE

3.2.1 Important Species, Seasonality, and Distribution

Tarantino (1981) characterized zooplankton at the Norfolk disposal site. Sampling was extremely limited, and only one station was occupied in the disposal site. One sample was taken at the surface and one at the bottom in June and November 1980. A 350-micron mesh, 0.5 m diameter net was used. The collections were dominated by the copepods *Acartia tonsa*, *Centropages typicus*, *Temora turbinata*, and *C. hamatus*. *A. tonsa* was the single most dominant species in spring, while *C. typicus* was the most dominant in fall.

Statistical analysis revealed strong seasonal patterns of species composition; many species were found only in the spring collection. These include many meroplanktonic forms (planktonic larvae of species whose adults are not planktonic) such as gastropod veligers, barnacle cyprids and nauplii, decapod crustacean larvae (including those of the blue crab, *Callinectes sapidus*), and fish eggs. Relatively few species were found only in the fall collection, and of these the copepod, *Eucalanus pileatus*, was most common.

Grant (1979) performed a more detailed analysis of zooplankton abundance and species composition in the Mid-Atlantic Bight. Sampling was conducted quarterly from November 1976 to September 1977 at twelve stations extending from the coasts of New Jersey and the lower Delmarva peninsula to the continental shelf edge. Bongo nets of mesh size 202 microns and 505 microns were used. Samples were obtained from sub-surface waters and the neuston (the upper water layer within about 50 cm of the surface). One station (Station L1) was located about 25 miles (40 km) north of the disposal site, off the lower Delmarva peninsula, and at a similar distance (about 20 miles or 36 km) offshore. Since currents in the Middle-Atlantic Bight generally flow parallel to the shoreline (Boicourt, 1981), there is little reason to believe that gross circulation patterns could cause significant differences in zooplankton species composition or abundance at locations similar distances offshore in a given region, such as station L1 and the proposed site. Olney (pers. comm, 1984) confirmed that these two areas are hydrographically and biologically similar.

The dominant species found by Grant (1979) at Station L1 were generally similar to those found by Tarantino (1981) at the disposal site. During the fall, the dominant (most abundant) zooplankton species was the small copepod Paracalanus sp. (from 202 micron mesh net collections), the larger copepod Centropages typicus (in 505 micron mesh net collections), and the large copepod Eucalanus pileatus (from neuston net collections). In winter C. typicus dominated all collections at Station L1.

There was a very diverse assemblage of zooplankton species present in the spring. The copepods Oithona spp., Centropages hamatus, and C. typicus were common, as was the cladoceran Evadne nordmanni. Many meroplanktonic forms were also present, and were often dominant, in spring samples, especially in neuston samples.

Summer collections were characterized by species diversity even greater than that observed in the spring. Dominant forms at Station L1 included coelenterates (Penilia avirostris, Liriope tetraphylla), copepods (Temora longicornis, Labidocera aestiva), chaetognaths (Sagitta elegans), and blue crab larvae.

These findings indicate a seasonal succession of zooplankton communities, with cold-water fauna occurring in winter and early spring and warm-water fauna occurring in summer and early fall. Biomass and the diversity of species present were highest in spring and summer and lowest in fall and winter. Most species had extensive spatial distributions related to water temperature and distance from shore. The importance of the spring and summer period for the spawning of many species is clearly indicated by the presence of their meroplanktonic larvae. Also evident is the importance of the neuston as a habitat for the larvae of decapod crustaceans (including blue crab) and fishes. These larvae are often among the most abundant forms present in spring and early summer neuston collections. Grant (1979) notes that widespread destruction of the habitability of the surface layer during the spring peak in reproduction could therefore adversely affect the survival and recruitment of many commercially important species. The potential for any detrimental effects from dredged material disposal at the Norfolk site will be examined in detail in Section 4 of this report.

Larvae of the commercially important surf clam (Spisula solidissima) were found in plankton collections at Station L1 in fall, winter, and spring, though not in great abundance. Tarantino (1981) did not find surf clam larvae in the plankton samples from the disposal site. At typical ambient temperatures of about 22°C (72°F), larval development of this species takes 18 to 21 days (Ropes, 1980). During this time the planktonic clam larvae may be transported long distances by ocean currents (Grosslein and Azarovitz, 1982). Any localized sources of mortality are therefore likely to be insignificant to the surf clam population as a whole. The same probably applies to the larvae of the sea scallop, Placopecten magellanicus. Sea scallop larvae have never been clearly identified in any natural plankton collections (Grosslein and Azarovitz, 1982). However, the duration of the planktonic phase has been determined in the laboratory to be about 35 days at 15°C (59°F) (Culliney, 1974), so it can be assumed that the larvae are transported long distances during their planktonic existence, as surf clam larvae are. Localized impacts such as those from the proposed use of the Norfolk site are therefore expected to have negligible effects on reproductive success of the sea scallop population.

In general, the zooplankton analysis of Tarantino (1981) conforms with the more detailed analysis of Grant (1979). However, Grant points out that internannual differences in zooplankton species composition and abundance may be drastic. Unusual weather or current patterns on a seasonal (or perhaps shorter) time scale may determine the characteristics of the zooplankton community in any particular sampling area. This reveals the inadequacy of short-term baseline studies for characterizing local zooplankton communities. Without baseline data collected in several years under varying oceanographic conditions, conclusions on the types and abundances of planktonic organisms present near the site can be no more than informed speculation. However, as available evidence indicates that no species has planktonic stages with distributions limited to the area near the site (i.e., within even 20 or 30 miles of the site), local impacts of disposal would be expected to have negligible effects on entirely planktonic species. Possibilities of effects on fish or benthic species with planktonic larvae are discussed in the following sections.

3.3 ICHTHYOPLANKTON AT THE NORFOLK DISPOSAL SITE

3.3.1 Important Species

Specific information on ichthyoplankton occurrence at the Norfolk disposal site is extremely limited. Tarantino (1981) identified only fish eggs (probably anchovy, Anchoa sp.), larvae of sand lance (Ammodytes sp.) and spot (Leiostomus xanthurus) from collections at the disposal site. Undoubtedly, many more species are present at the site at various times, depths, and concentrations.

Fortunately, a great deal of information is available on the distribution and abundance of commercially and biologically important fish species and their larvae in the Middle-Atlantic Bight. The work of Grosslein and Azarovitz (1982) for the Marine Ecosystem Analysis (MESA) program, as well as the National Oceanic and Atmospheric Administration's MARMAP data (Smith et al., 1983), the work of Wang and Kernehan (1979) on ichthyoplankton of the Delaware estuaries, and Olney's (1983) study of ichthyoplankton of the lower Chesapeake Bay, give a basis for describing the ichthyoplankton likely to be found at the Norfolk disposal site.

The Middle-Atlantic Bight is an important nursery area for many commercially, and ecologically, important fish species. Over the bight as a whole, sand lance (Ammodytes sp.) are unequivocally the single most abundant type of fish larva. Sand lance composed 83 percent of the winter catch, and 61 percent of the spring catch of ichthyoplankton during MESA cruises in 1965-1966 (Grosslein and Azarovitz, 1982). Today, abundances are even higher; estimates of sand lance abundance from 1977-1980 exceed 470 billion larvae per year (Smith et al., 1983). Other numerically dominant larvae in the bight are Atlantic mackerel (Scomber scombrus), hake (Urophycis sp.), anchovy (Anchoa sp.), yellowtail flounder (Limanda ferruginea), winter flounder (Pseudopleuronectes americanus), menhaden (Brevoortia tyrannus), and northern searobin (Prionotus carolinus) (Grosslein and Azarovitz, 1982). Dominant larvae in the lower Chesapeake Bay are anchovy, weakfish (Cynoscion regalis), hogchoker (Trinectes maculatus), seaboard goby (Gobiosoma ginsburgi), feather blenny (Hyphsoblennius hentzi), and blackcheek tonguefish (Symphurus plagiusa) (Olney, 1983). Other species are not numerically dominant in the Mid-Atlantic Bight as a whole, or in the lower Chesapeake Bay, but are important constituents of the ichthyoplankton community of the southern Middle-Atlantic Bight and Virginia coastal ocean. These species include bluefish

(Pomatomus salatrix), black seabass (Centropristis striata), windowpane (Scophthalmus aquosus), Atlantic croaker (Micropogon undulatus), summer flounder (Paralichthys dentatus), and spot (Leiostomus xanthurus) (Grosslein and Azarovitz, 1982).

3.3.2 Spatial Distribution of Spawning, and Transport and Larval Retention

Table 2 provides a detailed summary of the spawning seasons and principal spawning areas of important fish species of the Mid-Atlantic Bight and lower Chesapeake Bay region. Most species have extensive spawning grounds, covering thousands of square miles of continental shelf waters (Smith et al., 1983). However, some species have relatively localized spawning areas, with larval distributions determined in large part by prevailing currents that retain larvae in particular areas (Sette, 1943; Nelson et al., 1977; Parrish et al., 1981; Boicourt, 1982; Norcross, 1983). These species receive special consideration here because localized spawning could lead to an increase in the susceptibility of the larval population to local dredged material impacts.

Some species that spawn in the bight are unlikely to be significantly affected by local dredged material disposal at the Norfolk site either because their principal spawning areas are located elsewhere, or because the larvae have such extensive spatial distributions that local effects are negligible in terms of recruitment of the population as a whole.

Species that spawn over most or much of the Mid-Atlantic Bight continental shelf include hake, summer flounder, sand lance, mullets (Mugil sp.), mackerel, goosefish (Lophius americanus), menhaden, bluefin tuna (Thunnus thynnus), and many others. Species that spawn primarily in bays or ocean waters within 3 miles of shore are weakfish, anchovy, Atlantic silverside (Menidia menidia), and butterfish (Peprilus triacanthus). Species such as windowpane, hakes, Atlantic herring (Clupea harengus harengus), tautog (Tautoga onitis), cunner

Table 2. Spawning seasons and principal spawning areas of important fish species of the Mid-Atlantic Bight and lower Chesapeake Bay region.

Scientific Name	Common Name	Spawning Season	Principal Areas	Source
Alosa aestivalis	blueback herring	April-June	rivers of Chesapeake Bay	Grosslein and Azarovitz. 1982
Alosa pseudoharengus	alewife	Mar.-Apr.	freshwater tidal rivers	Grosslein and Azarovitz, 1982
Alsoa sapidissima	American shad	Mar.-Apr.	freshwater tidal rivers	Grosslein and Azarovitz, 1982
Ammodytes spp.	sand lance	Nov.-Apr.	mainly offshore, wide dist.	Norcross et al., 1961
Anchoa mitchilli	bay anchovy	May-Aug.	mainly within bays	Olney, 1983
Brevoortia tyrannus	Atlantic menhaden	Nov.-Mar.	mid-continental shelf	Grosslein and Azarovitz, 1982
Centropristis striata	black sea bass	June-Aug.	shallow cont. shelf	Grosslein and Azarovitz, 1982
Citharichthys arctifrons	Gulf stream flndr	Apr.-Nov.	well offshore, wide dist.	Smith et al., 1983
Clupea harengus harengus	Atlantic herring	Aug.-Oct.	Georges Bank and north	Grosslein and Azarovitz, 1982
Cynoscion regalis	weakfish	May-Oct.	nearshore, wide dist.	Grosslein and Azarovitz, 1982
Enchelyopus cimbrius	fourbeard rockling	Apr.-Oct.	northern Mid-Atlantic Bight	Smith et al., 1983
Etropus microstomus	smallmouth flndr	Apr.-Nov.	inshore, wide dist.	Smith et al., 1983
Gadus morhua	Atlantic cod	Nov.-Feb.	Georges Bank, Gulf of Maine	Grosslein and Azarovitz, 1982
Gasterosteus aculeatus	threespine stickleback	Mar.-Aug.	shallow inshore bay	Wang and Keruehan, 1979
Gobiosima ginsburgi	seaboard goby	May-Oct.	lower bay-ocean	Olney, 1983
Hyphsoblennius hentzi	feather blenny	June-Sept.	mainly within bays	Olney, 1983
Leiostomus xanthurus	spot	Oct.-Mar.	innershelf, VA-NC	Grosslein and Azarovitz, 1982
Limanda ferruginea	yellow tail flndr	Mar.-July	offshore, N. of Chesapeake Bay	Grosslein and Azarovitz, 1982
Lophius americanus	goosefish	Spring/Early Fall	continental shelf	Grosslein and Azarovitz, 1982
Lopholatilus chamaeleonticeps	tilefish	Mar.-Sept.	outer continental shelf	Grosslein and Azarovitz, 1982
Macrozoarces americanus	ocean pout	Sept.-Oct.	northern Mid-Atlantic Bight	Grosslein and Azarovitz, 1982
Menidia menidia	Atlantic silverside	Apr.-Aug.	inshore bays	Wang and Kernehan, 1979
Merluccius bilinearis	silver hake	May-Nov.	continental shelf	Wang and Kernehan, 1979
Micropogon undulatus	Atlantic croaker	Aug.-Dec.	inner shelf, VA-NC	Grosslein and Azarovitz, 1982
Morone saxatilis	striped bass	Mar.-June	upper Chesapeake Bay	Grosslein and Azarovitz, 1982

Table 2. Spawning seasons and principal spawning areas of important fish species of the Mid-Atlantic Bight and lower Chesapeake Bay region. (Continued)

Scientific Name	Common Name	Spawning Season	Principal Areas	Source
Mugil cephalus	striped mullet	Dec.-Feb.	outer continental shelf	Wang and Kernehan, 1979
Mugil curema	white mullet	Apr.-June	continental shelf	Wang and Kernehan, 1979
Paralichthys dentatus	fluke	Nov.-May	continental shelf	Smith, 1973
Paralichthys oblongus	fourspot flndr	May-Oct.	continental shelf	Grosslein and Azarovitz, 1982
Peprilus triacanthus	butterfish	June-Aug.	inshore, wide dist.	Grosslein and Azarovitz, 1982
Pholis gunnellus	rock gunnel	Nov.-Mar.	northern-Mid-Atlantic Bight	Colton and Marak, 1969
Pollachius virens	pollock	Nov.-Feb.	shallow offshore, wide dist.	Colton and Marak, 1969
Pomatomus saltatrix	bluefish	June-Aug.	N.Y. Bight, wide dist.	Grosslein and Azarovitz, 1982
Prionotus carolinus	northern searobin	May-Nov.	72 mi. offshore, wide dist.	Wang and Kernehan, 1979
Pseudopleuronectes americanus	winter flndr	Feb.-Apr.	Georges Bank, Chesapeake Bay	Grosslein and Azarovitz, 1982
Scomber scombrus	Atlantic mackerel	Apr.-June	mainly cont. shelf, wide dist.	Ausubel, 1983
Scophthalmus aquosus	windowpane	Apr.-Dec.	nearshore, N of Ches. Bay	Grosslein and Azarovitz, 1982
Spoeroides maculatus	northern puffer	May-Aug.	nearshore	Wang and Kernehan, 1979
Stentomus chrysops	scup	May-Aug.	N.Y. Bight, S. New England	Grosslein and Azarovitz, 1982
Symphurus plagiusa	black cheek tonguefish	June-Oct.	offshore, southeast coast	Wang and Kernehan, 1979
Syngnathus fuscus	Northern pipefish	May-Oct.	mainly lower bays. wide dist.	Wang and Kernehan, 1979
Tautoga onitis	tautog	May-July	northern Mid-Atlantic Bight	Colton and Marak, 1969
Tautogolabrus adspersus	cunner	May-Aug.	northern Mid-Atlantic Bight	Colton and Marak, 1969
Thunnus thynnus	bluefin tuna	May-June	cont. shelf, wide dist.	Grosslein and Azarovitz, 1982
Trachinotus carolinus	permit	most of year	Gulf Stream	Wang and Kernehan, 1979
Trinectes maculatus	hogchoker	May-Aug.	lower bays-ocean	Wang and Kernehan, 1979
Urophycis chuss	red hake	May-Oct.	offshore, north of Ches. Bay	Grosslein and Azarovitz, 1982
Urophycis regius	spotted hake	Sept.-Apr.	offshore,	Wang and Kernehan, 1979

(*Tautogolabrus adspersus*), and cod (*Gadus morhua*) spawn primarily in the northern Mid-Atlantic Bight. Other species are anadromous, and spawn in waters of low salinity. Some examples are striped bass (*Morone saxatilis*), American shad (*Alosa sapidissima*), and blueback herring (*A. aestivalis*).

Inshore areas, especially near the mouths of estuaries, can be important in retention of oceanic fish larvae that return to estuaries as they mature (Norcross, 1983). Sette (1943), Parrish et al. (1981) and Nelson et al. (1977), among other authors, have concluded that year-classes of fish such as mackerel, anchovy, and menhaden may be enhanced when strong onshore transport occurs, retaining larvae in nearshore waters which aids recruitment of juveniles into estuaries, or is favorable for larval feeding and growth.

In waters near the Chesapeake Bay mouth, croaker, spot, mackerel, and windowpane exhibit some localized principal larval concentrations (Figure 10), though the larval distributions of the species as a whole may be quite broad (Grosslein and Azarovitz, 1982). In the case of croaker larvae, Norcross (1983) has evaluated potential mechanisms for larval retention and shown that strong year-classes of croaker coincide with years of favorable winds, which cause currents that aid in the retention of larvae near the Chesapeake Bay mouth. Young croaker larvae remain in the upper water column where winds may transport them onshore or offshore. Larvae and juvenile croaker migrate to the lower strata of the water column and become demersal before recruitment into the Chesapeake Bay (Norcross, 1983). Therefore, croaker may be especially susceptible to dredged material disposal because demersal larvae would be subjected to high levels of suspended sediment for longer time intervals than larvae in the upper strata of the water column.

During years with favorable onshore transport, many croaker larvae are retained near the bay mouth. As larvae metamorphose into juveniles, they descend in the water column and are entrained in the net estuarine inflow and thereby recruit into Chesapeake Bay. In years of poor onshore transport many larvae

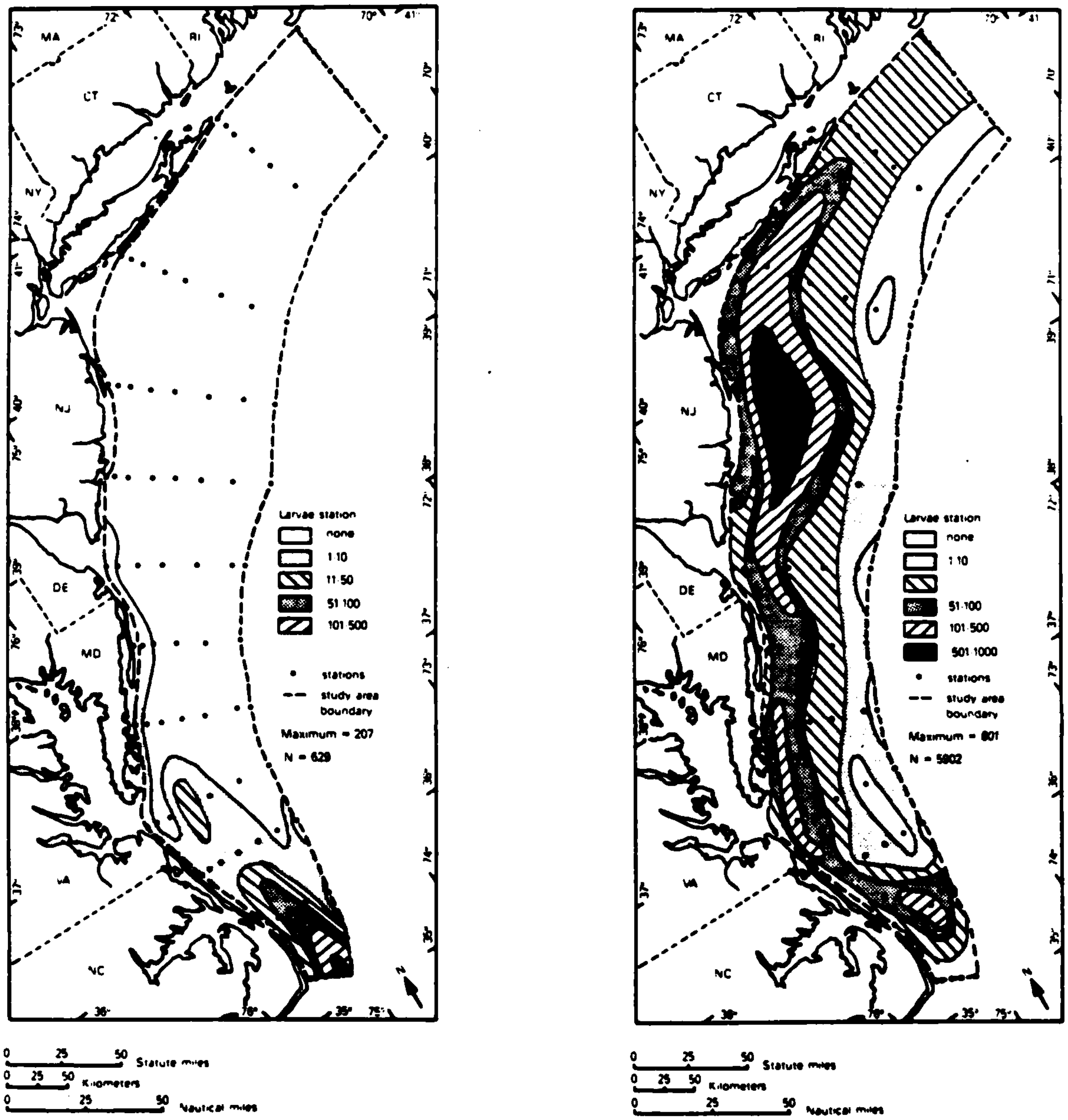


Figure 10a: Larval distribution of Atlantic croaker (left) and windowpane (right). These species use ocean waters off the Chesapeake Bay mouth as principal and relatively localized spawning areas. From Grosslein and Azarovitz (1982).

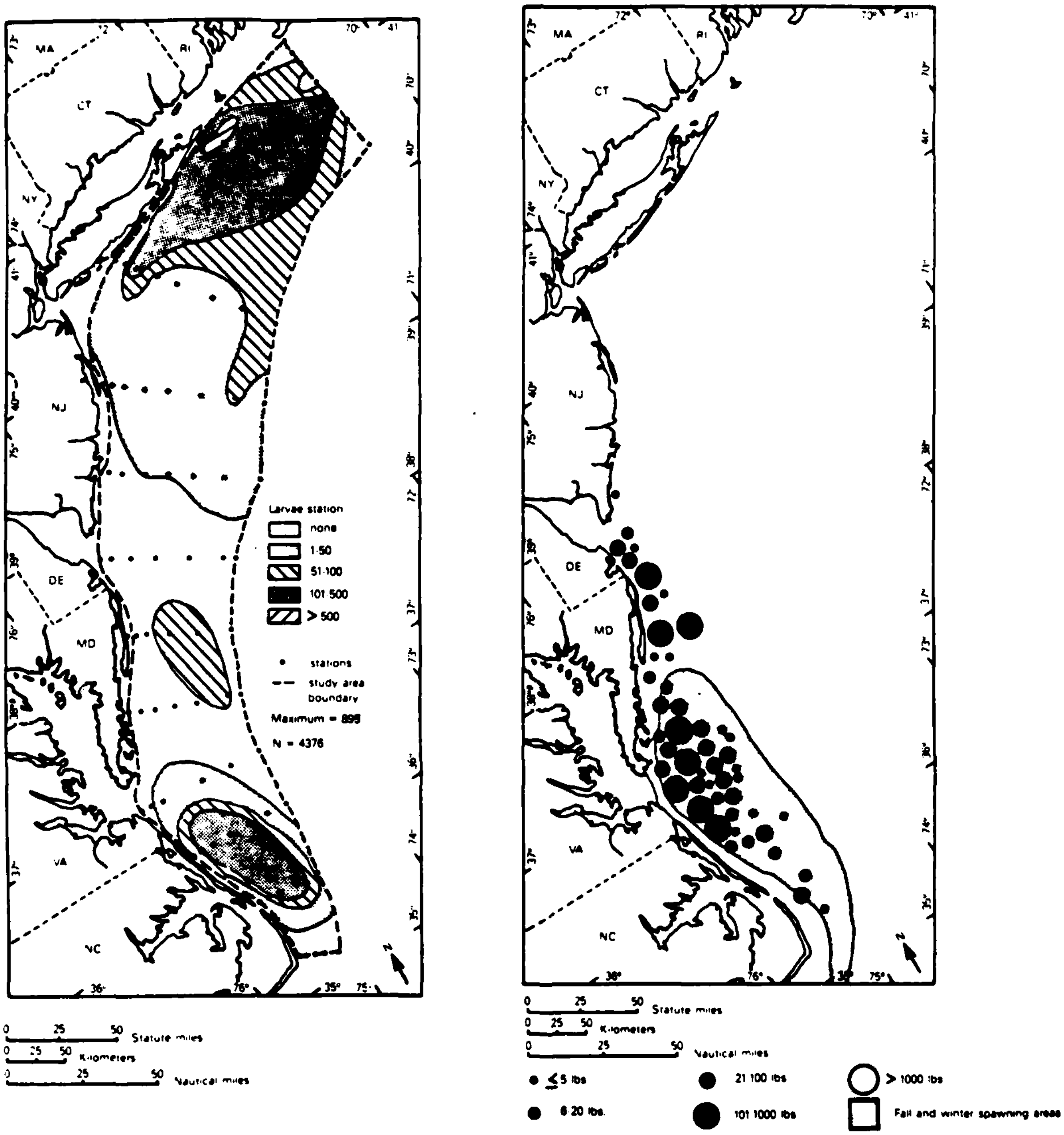


Figure 10b: Larval distribution of Atlantic mackerel (left) and distribution and spawning areas of adult spot (right). These species use ocean waters off the Chesapeake Bay mouth as principal and relatively localized spawning areas. For spot, solid circles represent catch in pounds during individual trawl samples. From Grosslein and Azarovitz (1982).

are far offshore where estuarine influence is weak. Thus, they cannot use the net lower-layer inflow to assist transport into the bay, and poor recruitment to the adult population of the bay results.

For mackerel, croaker, spot, and windowpane, the area of high larval concentration, though localized, is still large compared to the disposal site. The crucial determinant of whether local impacts may be significant is whether the high larval concentrations reflect distinct populations in the area of the site, (with limited immigration from neighboring populations). For windowpane and spot this is probably not the case because spot spawn mainly to the south of the study area and windowpane are abundant throughout the Mid-Atlantic Bight (Figure 10, Grosslein and Azarovitz, 1982). Croaker also spawn mainly to the south of the bay mouth. Investigation of the spawning of mackerel (Sette, 1943; Ausubel, 1983) indicates that larval concentrations probably do not reflect distinct stocks. Behavioral and meristic evidence suggests that fish of this species do not seek specific spawning grounds, but spawn over broad areas where favorable hydrographic and feeding conditions are encountered.

On the basis of spatial distribution, it is likely that most Mid-Atlantic Bight larval fish would be unaffected by local dredged material disposal, even assuming the worst case situation that any larvae coming in contact with dredged material might perish. However, the possibility cannot be entirely ruled out, given existing data, that fish with localized spawning and larval concentrations near the Chesapeake Bay mouth will be affected by disposal operations. This is especially true for croaker, which may depend upon onshore transport toward the Chesapeake Bay mouth for successful recruitment.

3.3.3 Seasonality of Spawning

Table 2 shows that most of the principal fish species of the area spawn during the spring and summer. During June, the peak month, 32 of 48 species spawn (Figure 11). Commercially important marine fish and shellfish of

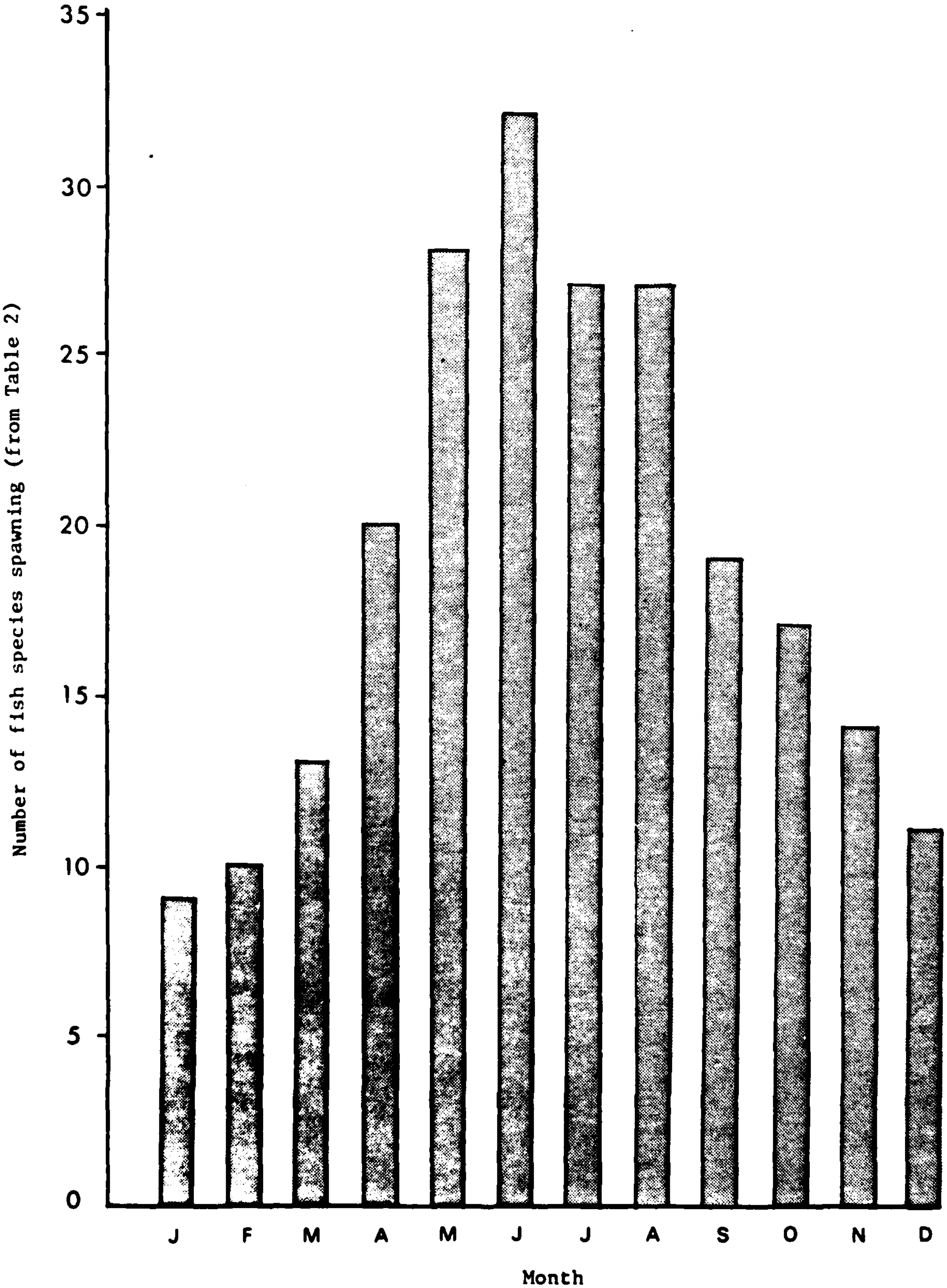


Figure 11. Temporal distribution of spawning fishes common to the Middle-Atlantic Bight and lower Chesapeake Bay. From Table 2.

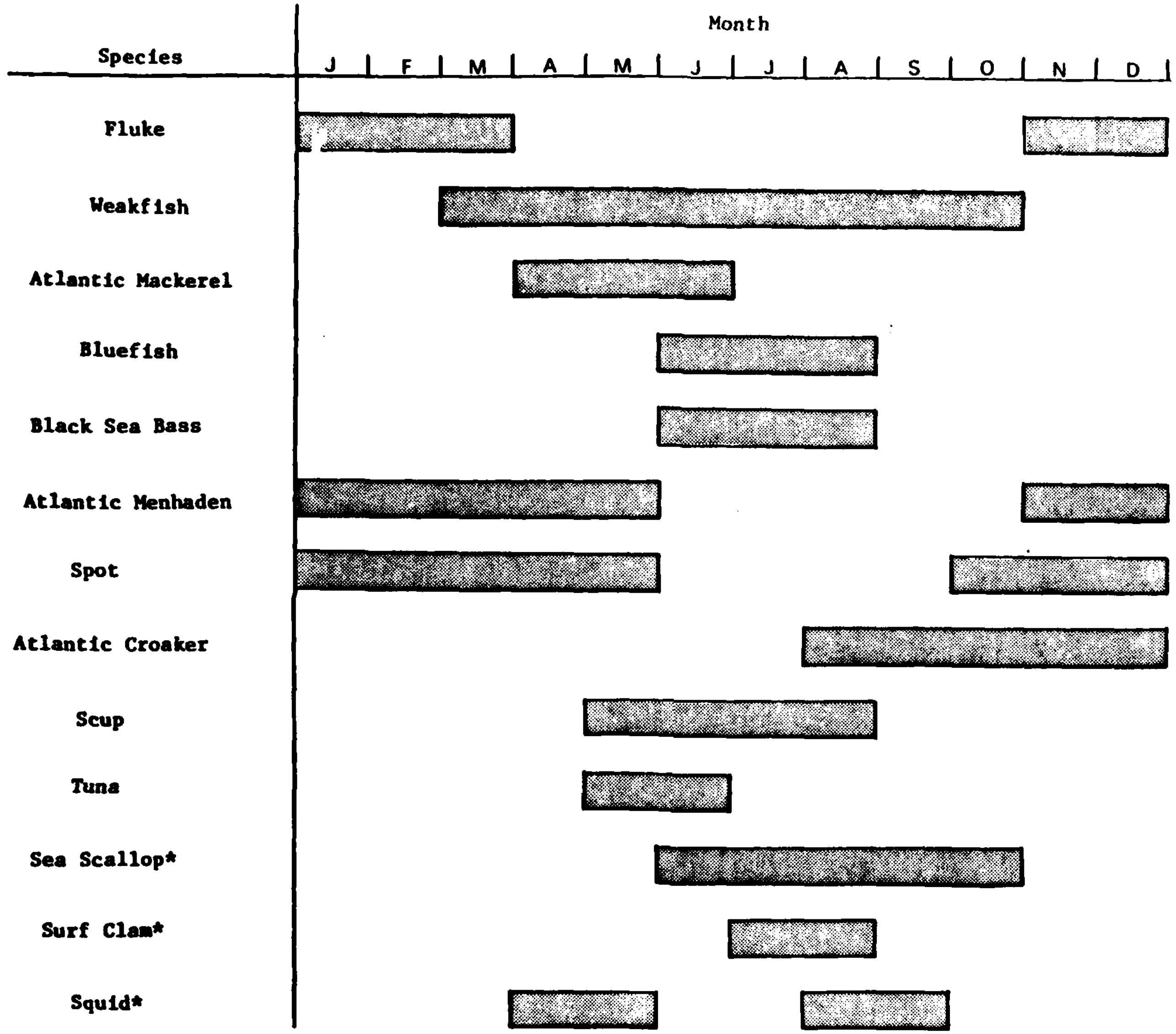
Virginia that spawn in the open ocean also usually spawn during spring or summer (Figure 12). Principal fish species that spawn primarily during winter are sand lance, menhaden, spot, summer flounder, hake, mullet, and cod. Fish spawning primarily in fall are croaker, herring, and pout (Macrozoarces americanus).

Comyns (1984) has provided unpublished data on ichthyoplankton abundance at Station L1. These data are worth summarizing here because they are site-specific to Station L1, which is nearby and hydrographically and biologically similar to the disposal site (Olney, pers. comm. 1984).

During May 1977, Comyns found hake (36 percent of the total collection), fourbeard rockling (Enchelyopus cimbrius; 33 percent of the total collection), and bluefish (16 percent) dominant in neuston collections at Station L1. Windowpane was dominant (35 percent of total collection) in subsurface bongo net samples. In August 1977, hake (59 percent), bluefish, and blackcheek tonguefish (Symphurus plagiusa) (10.5 percent each) dominated neuston collections, while smallmouth flounder (Etropus microstomus; 41 percent) and blackcheek tonguefish (29 percent) dominated bongo collections. Fall collections (November) revealed domination by hakes (63 percent) and weakfish (22 percent) in the neuston, and weakfish (89 percent) in bongo collections. Winter samples, taken during February 1977, were totally dominated by sand lance which composed 98 percent of neuston collections and virtually 100 percent of bongo collections. None of these species have localized spawning patterns which might result in measurable population impacts due to dredged material disposal during their spawning seasons.

3.3.4 Conclusion

For most fishes that spawn at or near the Norfolk site, it is not expected that disposal operations at the site could have measurable or significant effects on larval mortality and subsequent reproductive success of the



* from Grosslein and Azarovitz, 1982.

Figure 12. Spawning seasons of some commercially important fish and shellfish species of the Atlantic Ocean off Virginia.

populations. To ensure that no effects at all would occur on any commercially important species, a limitation of disposal operations during peak spawning periods might be recommended; this would involve prohibiting or limiting dumping in the late spring and the summer.

One species, the Atlantic croaker (Micropogon undulatus), is believed to have a relatively restricted spawning range in the Norfolk site/Chesapeake Bay mouth area, and so would perhaps warrant protection through a seasonal limitation on dumping. The croaker spawns in the fall; a no-dumping period in September and October would be expected to reduce possible impacts on this species to a minimum.

3.4 BLUE CRAB (CALLINECTES SAPIDUS) LARVAL LIFE HISTORY

3.4.1 Developmental Stages and Larval Retention

The American blue crab (Callinectes sapidus Rathbun) is found on the Atlantic coast of the United States from Massachusetts to southern Texas, and is especially abundant in estuaries (Churchill, 1919). In the Chesapeake Bay ovigerous (egg-bearing) females are found from April to September (Van Engel, 1958), but peak spawning activity occurs from mid-July to mid-August (McConaugha et al., 1983). The larvae are planktonic and pass through several molts before reaching the juvenile stage and settling into a nonplanktonic existence (Churchill, 1919).

The newly-hatched larva is called a zoea. Development through the zoeal stage requires 7-8 molts and takes approximately 5 weeks at 25°C (Sulkin, 1975). The final zoeal molt produces the megalopa larva. Megalopal development requires 7-11 days at 25°C (77°F) (Costlow, 1967). The megalopa molts to produce the juvenile, which resembles a small crab (Churchill, 1919).

Recent evidence indicates that larval development occurs in the waters of the continental shelf adjacent to Chesapeake Bay (Sandifer, 1975). Larvae are found from the beach zone to about 65 km offshore in the shelf waters of the southeastern United States (Nichols and Keney, 1963). Prevailing summer current patterns near the mouth of Chesapeake Bay, combined with larval behavior, serve to transport larvae out of the estuary and retain them in the Middle-Atlantic Bight near the bay mouth (Provenzano et al., 1983; McConaugha et al., 1983).

Ovigerous female crabs migrate to the lower estuary to spawn (Van Engel, 1958). Behavioral studies indicate that newly-hatched zoeae are strongly surface-oriented, and actively seek the upper strata of the water column (Sulkin et al., 1980). In the lower bay, newly-hatched zoeae have been found in the neuston (upper water layer) in great abundance (up to almost 7,000 m^{-3}) prior to the nighttime ebb tide, and are carried out of the bay towards the south as the tide flows out (Provenzano et al., 1983). As discussed in Chapter 2 of this report, the prevailing winds during the summer are southerly (from the south), causing a northward-flowing current in nearshore waters off the southern Virginia coast and the mouth of the Chesapeake Bay (Boicourt, 1981; 1982). This current may affect recruitment because larvae entrained in it may be retained in the waters of the Mid-Atlantic Bight near the bay mouth. Larvae not entrained in the northward-flowing current would presumably be advected southward and entrained in the waters of the Gulf Stream off Cape Hatteras, thus being lost from the population (Sulkin, pers. comm. 1984). The shelf waters off the Chesapeake Bay mouth therefore may be an important nursery ground for local blue crab stocks (McConaugha et al., 1983). During years of favorable winds, larvae develop into megalopae in the ocean near the bay mouth, and are then available for recruitment back into the estuary in late summer or early fall (McConaugha et al., 1983). This retention mechanism is entirely dependent upon southerly winds of sufficient magnitude to drive a northward current. Since the winds are variable, substantial loss of larvae from the Mid-Atlantic Bight system probably occurs as larvae are carried south in the Chesapeake Bay outflow plume during wind shifts. In this situation, influx of larvae spawned near other estuarine areas to the north (i.e., the Delaware estuaries) may also occur, thus helping to replenish the Chesapeake stocks (Sulkin, pers. comm. 1984).

In either case, the area from the Bay mouth out to the proposed Norfolk disposal site would be expected to serve as a passage area, and perhaps a retention area, for larvae available for potential transport into Chesapeake Bay.

As was discussed in section 3.3.2 for croaker larvae, a general retention mechanism may exist near the Chesapeake Bay mouth. Many species of planktonic organisms that are present in the upper strata of the water column during mid to late summer when favorable winds prevail may potentially be entrained in northward or onshore currents and thus be retained near the bay mouth (Sulkin, pers. comm. 1984). In this situation, dredged material disposal at the Norfolk site could perhaps affect the populations of a number of species with localized spawning in the area, including croaker and blue crab.

3.4.2 Spawning Season and Larval Occurrence

Blue crab spawning may occur from April to September in Chesapeake Bay, as ovigerous females are found throughout this time (Van Engel, 1958). However, McConaugha et al. (1983) found Stage I zoeae from June through late September, indicating that this was the temporal extent of spawning during 1980, when samples were taken. Though spawning may occur over a four-month period, McConaugha et al. found 92 percent of Stage I zoeae between mid-July and mid-August, indicating that peak spawning was restricted to this period. Interannual variability in spawning of blue crab has not been sufficiently addressed in the literature as few studies have sampled the larvae at sufficient temporal and spatial intervals to accurately determine the period of peak spawning. Interannual variation in water temperature probably has an overriding influence on the exact timing of spawning (Churchill, 1919; McConaugha et al., 1983), and we believe that a leeway period of ± two weeks should be sufficient to encompass any variation in spawning due to unusual water temperatures.

As will be discussed in the following section, megalopae are the planktonic stage of Callinectes sapidus that may be available for recruitment into the adult population upon return to the estuary from the ocean retention area. Therefore, analysis of the "worst-case" potential impact on blue crab larvae and recommendations based on this analysis should be focused upon protecting this life history stage (Van Engel, pers. comm. 1984). Development to this stage requires about 5 weeks at 25°C (77°F) (Sulkin, 1975), so we would expect peak numbers of megalopae to occur in early September. McConaugha et al. (1983) found 62 percent of megalopae from late August through September in 1980. In the case of blue crab larvae, recommendation of a restricted dumping period, if necessary, will be focused on this time period.

3.4.3 Spatial Distribution of Larvae

Early stage zoeae of Callinectes sapidus are found within and near the bay mouth. Peak abundance of successive stages are found progressively farther offshore and peak numbers of megalopae are found mainly inshore of peak numbers of late stage zoeae (McConaugha et al., 1981). This reflects the offshore transport of zoeae and subsequent reinvasion by megalopae and juveniles (Johnson, 1982). Maximum megalopal abundances were reported to occur in the neuston about 30 km (19 miles) offshore of the Chesapeake Bay mouth (McConaugha et al., 1981; Johnson, 1982). High megalopal concentrations may therefore be quite common in the disposal site. The size of the larval retention area is related to current regimes. McConaugha (pers. comm. Aug. 31, 1984) found about 80 percent of blue crab larvae within an area extending from about 15-25 miles (34-40 km) north of the Chesapeake Bay mouth to 35-50 miles (56-80 km) south of the bay mouth, and to perhaps 30 miles (48 km) offshore (Figure 13).

The spatial distribution of blue crab larvae is reported to be patchy (Johnson, 1982; Provenzano et al., 1983). Patchiness of early-stage zoeae is presumably related to synchronous hatching and transport offshore during ebb tides. Over time, these patches should tend to disperse diffusively, resulting

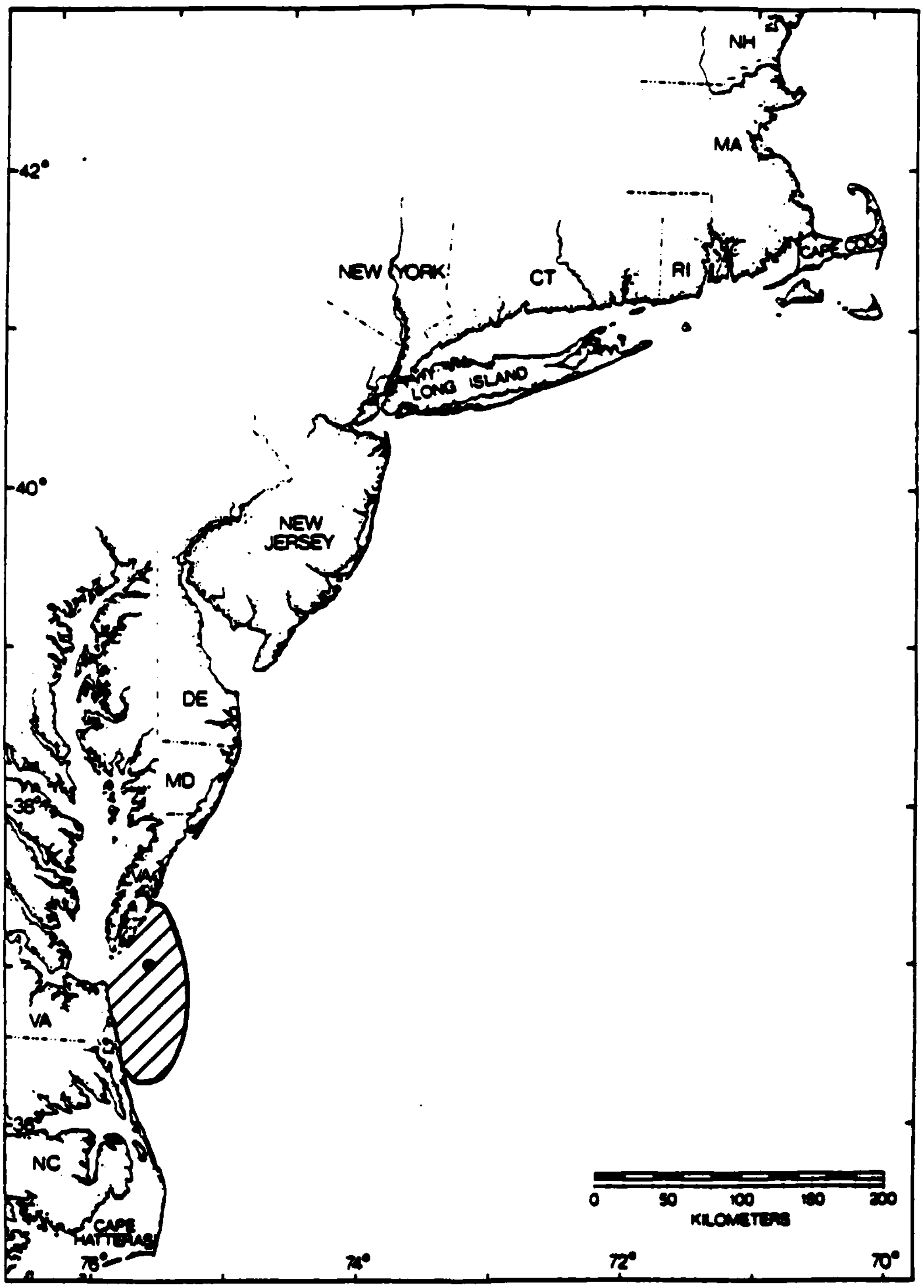


Figure 13: Approximate extent of Chesapeake Bay larval retention area (indicated by cross-hatching) for blue crab (McConaugha, pers. comm. 1984). The area extends perhaps 40 km to the north of the bay mouth, and 80 km to the south. The area extends about 50 km offshore of the bay mouth. The location of the Norfolk disposal site is indicated by the solid circle.

in a relatively homogeneous distribution of megalopae. However, megalopae may exhibit an extremely patchy distribution. Epifanio et al. (1984) reported an apparent "swarming" of blue crab megalopae, resulting in well-defined, high density patches. Johnson (1982) collected 216 samples in the Chesapeake Bay mouth and adjacent shelf waters containing Callinectes megalopae, only 3 of which contained the megalopae at abundances greater than 100 m^{-3}. Megalopal density in these three samples averaged 227 m^{-3}, 2-3 orders of magnitude greater than typical densities found in the 216 samples. An additional 11 samples contained Callinectes megalopae at abundances between 10 and 100 m^{-3} (average 28 m^{-3}). High-density patches were usually found in the neuston. The remaining 202 samples averaged 1.06 megalopae m^{-3}. Assuming that all sample volumes were roughly similar, it can be calculated that about 82 percent of Callinectes megalopae captured by Johnson (1982) occurred in only 6 percent of the samples. This distribution could lead to substantial mortality of megalopae in the unlikely event that dredged material disposal coincided with the location of a high-density patch.

4. DREDGED MATERIAL IMPACTS ON BIOTA

4.1 SUSPENDED SEDIMENT EFFECTS

4.1.1 Effects on Fish Eggs and Larvae

Relatively little research has focused on suspended sediment effects on the eggs and larvae of marine fishes. The responses of aquatic organisms to uncontaminated suspended sediment are due to a variety of causes including the following: concentration of suspended solids, particle sizes, densities, shape, mineralogy, sorptive properties, organic matter content and antagonistic and synergistic effects (Stern and Stickle, 1978). Thus, laboratory experiments are difficult, and must incorporate these effects to obtain results that are applicable to natural systems. Responses of different species may vary widely, but immobile benthic forms are usually most severely affected by suspended sediments from dredged material disposal because they are subjected to high concentrations over long intervals relative to planktonic or mobile organisms (Peddicord and McFarland, 1978). Organisms are typically much more sensitive to suspensions of sediment contaminated with one or more toxins than to uncontaminated suspensions (Peddicord and McFarland, 1978). This discussion will consider only uncontaminated sediments, because contaminated sediments may not be disposed of at ocean disposal sites such as the proposed Norfolk site, under the Marine Protection Research and Sanctuaries Act (See Section 1.2.1 of this report.)

During ocean disposal of sandy and silty sediment from the Norfolk Harbor system ichthyoplankton would be subjected to high concentrations of suspended sediment for short periods of time, as particles in this size range will sink rapidly. Effects would be more severe with particles in the size range of mud or clay because these particles would remain in the water column for much longer intervals, perhaps on the order of days, creating a situation of chronic exposure; but for the types of silty and sandy sediments expected to be disposed of at the Norfolk site, such long-term exposure would not occur.

An immediate and severe effect of dredged material disposal might be caused by the physical impact of being dumped on. A large load of sediment might sweep eggs and larvae with it as it sinks rapidly. The effects on eggs and larvae not immediately below the spot where the bulk of the dredge's load is dumped are more difficult to evaluate. However, short-term exposure to high sediment concentrations is likely the rule.

Darby et al. (1981) measured suspended sediment concentrations of up to 9 mg/l during test dumps at the Norfolk site. This value is not extremely high compared to the naturally occurring suspended loads which were about 3 mg/l during the test dumps. Masch and Espey (1967) found concentrations exceeding 10,000 mg/l in dredge discharge plumes. However, barring the possibility that persistent turbidity maxima form, such extreme concentrations are likely to be experienced by plankton for time periods on the order of only one to several minutes after dredge discharge for grain sizes in the sand-silt range (O'Connor et al., 1977). An evaluation of the "worst-case" possibility for planktonic organisms being exposed to harmful suspended sediment concentrations will be given in Section 4.2, following this review of literature reports on what concentrations may be harmful to ichthyoplankton.

The literature on suspended sediment effects on fish eggs and larvae is focused on anadromous and freshwater species whose early life stages occur in waters with typical suspended sediment loads far exceeding coastal ocean waters. The eggs and larvae of these species are probably more tolerant of suspended sediment than oceanic ichthyoplankton, so caution must be exercized in the extrapolation of results presented below to marine eggs and larvae.

In general, fish eggs and larvae have been found to be extremely tolerant of uncontaminated suspended sediment. Substantial mortality is probably rare even in extremely turbid environments. Mortality may be more severe in the case of intense physical impact from rapidly sinking dredge loads, or in the case of burial of eggs or larvae below sediment layers (Schubel et al., 1977).

An extensive literature review of suspended sediment effects on the eggs and larvae of freshwater and anadromous fishes is provided by Schubel et al. (1977). This review emphasizes ichthyoplankton of the C and D Canal, a turbid environment. Average suspended loads found by Schubel et al. during four cruises in March 1971 ranged from 95 mg/l near the surface to about 270 mg/l at 12 m depth. Several studies have considered suspended sediment effects on ichthyoplankton common to the C & D canal (Morgan et al., 1973; Schubel and Wang, 1973; Auld and Schubel, 1974; Wakeman et al., 1975). The species most studied were striped bass (Morone saxatilis), white perch (M. americanus), yellow perch (Perca flavescens), American shad (Alosa sapidissima), blueback herring (A. aestivalis), alewife (A. pseudoharengus) and several species of trout and salmon (Salmonidae).

Hatching success of fish eggs exposed to continuous concentrations of fine-grained (clay or silt) suspended sediment ranging from 20 to 5,250 mg/l was generally unaffected at levels below 1000 mg/l. Above this level hatching success of the species tested (striped bass and white perch) was reduced (Auld and Schubel, 1974). Schubel et al. (1977) emphasize that eggs of the species tested can tolerate extremely high suspended sediment levels for many hours, and estimate 500 mg/l is a conservative maximum limit to which striped bass and white perch eggs may be subjected over the entire incubation period.

Though hatching success of fish eggs is generally unaffected by suspended sediment up to 1000 mg/l, egg development rate is affected. Schubel and Wang (1973) found that striped bass eggs subjected to suspensions of fine-grained sediment at 100 mg/l hatched 4-6 hours after control eggs. The hatching of yellow perch eggs under similar conditions was delayed 6-12 hours. There is no evidence that a short delay in hatching is, by itself, a detrimental effect of suspended sediment. Delays on the order of one-half to one day are well within the range of observed variation in incubation period in the field (Schubel et al., 1977). However, it is possible that increased duration of the egg stage might increase predation.

Auld and Schubel (1974) examined the effect of continuous exposure to suspended sediment concentrations up to 1000 mg/l on the larvae of shad, striped bass, and yellow perch. Significant lethal effects were found at concentrations of 500 mg/l for exposure times of 2-4 days. Shad larvae were less tolerant of suspended sediment than were striped bass or yellow perch.

The authors concluded that of the species tested, only shad larvae would likely be affected by dredging or disposal operations, if within about 100 meters of the activity.

The effects on estuarine organisms of high suspended sediment concentrations generated by open-water hopper dredge disposal have been considered by Wakeman et al. (1975). Eighteen species of finfish and invertebrates were tested. The authors recorded suspended solid concentrations at various depths after hopper disposal and found that even at 0.5m above the bottom, suspended sediment concentrations above 2000 mg/l were present for only about 25 minutes after dumping. The authors conclude that dumping and resultant suspended loads, even near the bottom, does not normally affect even sensitive fish species. However, the effects of disposal operations may be more severe if (1) persistent turbidity maxima form, thus increasing exposure time to high suspended loads, and (2) the dumped material comprises a large fraction of organic material, which might reduce the oxygen content of bottom waters (Wakeman et al., 1975). Persistent turbidity maxima are unlikely in the open and relatively turbulent waters of the Norfolk disposal site (Boicourt, pers. comm. 1984).

Because ichthyoplankton at the Norfolk disposal site will probably be subjected to high suspended sediment concentrations for only short periods of time, it can be considered very unlikely that eggs and larvae not physically abraded or subjected to extreme turbulence or concentrations above approximately 1000 mg/l will be affected by disposal of sandy and silty sediments at the Norfolk site. Data on impacts of turbidity on strictly marine fish eggs and larvae would be needed to establish exactly what sediment concentrations would be harmful in the open ocean environment.

4.2 "WORST-CASE" SCENARIO OF IMPACT ON BLUE CRAB POPULATION

An estimate of the potential impact of disposal operations on the blue crab population indicates that even if all environmental and biological parameters are assumed to be at values most likely to expose larvae to harmful turbidity concentrations (with uncertain parameters multiplied by safety factors to account for data inadequacies), no detectable population effect would be expected. Development of this worst-case scenario is described in this section.

The lowest suspended sediment concentration for which any harmful effect has been reported to occur on a planktonic organism is 40 mg/l, at which concentration Stern and Stickle (1978) found that feeding rates of the copepod Acartia tonsa were substantially decreased. This concentration is somewhat high relative to ambient, open coastal marine concentrations, but is actually within the range of naturally occurring conditions found in some bays and estuaries. Because it is not greatly different from natural levels, and because it is the lowest level reported to harm any organisms, this is a reasonable, quite conservative level to use as a threshold value for expected harmful effects in a worst-case dredged-material impact scenario.

As discussed in Chapter 1 of this report, the volume of dredged material released in a typical single dumping operation is expected to be about 2000 m^3. This corresponds to an approximate mass of 4000 to 6000 metric tons (4 million to 6 million kg), given that typical sandy or silty dredged material densities are about 2300 to 2700 kg/m^3. For the worst-case scenario, a disposed material mass of 6000 metric tons will be assumed.

The calculation of the greatest population impact to be expected from disposal operations will be based on the following assumptions:

- The conservative assumption will be made that all of the dredged materials will remain in the water column for the full period of time until horizontal diffusion has diluted the material to below the assumed threshold level for biological damage. (This is conservative because in fact sinking should remove much of the material from the water column before that time).

- It will be assumed that all planktonic organisms coming in contact with this suspended sediment plume will be killed.

Based on these assumptions, the area of water throughout which all planktonic organisms would be killed (the "impact area") is calculated as follows:

$$\text{Area} = \text{Volume} \div \text{Depth}$$

where: Area = Impact area, with water at above-threshold density,
Volume = Volume of water at above-threshold density,
Depth = average water depth (20 meters)

and:

$$\text{Volume} = \text{Mass} \div \text{Density}$$

where: Mass = Mass of released materials (6000 metric tons)
Density = Threshold density harmful to organisms (40 mg/l)

The volume of water in the impact area is thus calculated as:

$$\text{Volume} = 6000 \text{ tons} \times \frac{10^3 \text{ kg}}{\text{ton}} \times \frac{10^6 \text{ mg}}{\text{kg}} \times \frac{1 \text{ liter}}{40 \text{ mg}}$$

$$= 1.25 \times 10^{11} \text{ liters} = 1.25 \times 10^8 \text{ m}^3$$

And thus the worst-case impact area is calculated as:

$$(1.25 \times 10^8 \ m^3) \div 20 \ m = 6.25 \times 10^6 \ m^2$$
$$= 6.25 \ km^2$$

Thus, an area of maximum-size 6.25 square kilometers would be expected to contain dredged material concentrations in excess of its assumed biological threshold of 40 mg/l. This area is only a small percentage of the principal area described by McConaugha (1984, pers. comm.) as being inhabited by blue crab larvae.

As discussed in Chapter 3, and shown in Figure 13, McConaugha (1984, pers. comm.) found the bulk of the larvae of all stages to extend throughout an area from about 56-80 km south of the Norfolk site, to about 24-40 km north of the site, and about 48 km offshore from the Chesapeake Bay mouth, a total area of roughly 5000 to 6000 km^2. Megalopae are reported by McConaugha, Johnson (1982) and Van Engel (1984, pers. comm.) to inhabit primarily the portion of this area to the north and west of the site, extending into the Bay mouth, an area in a size range on the order of 1000 km^2.

Thus, the expected "worst-case" impact area is an area only about 6:6000 or 0.1% as large as the principal blue crab larval distribution area, and about 6/1000, or less than 1%, as large as the principal blue crab megalopal distribution area.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 MAJOR CONCLUSIONS

5.1.1 Duration of Exposure of Plankton to Dredged Material

Sediment to be dumped at the proposed site consists of grain sizes in the sand-silt range. Little or no sediment of mud/clay is expected to be dumped. Sediment of sand/silt should sink rapidly (within one hour) to the bottom and therefore planktonic organisms should be exposed to high suspended sediment levels for only short time intervals. Formation of persistent water column turbidity maxima is unlikely.

5.1.2 Importance of the Proposed Site to Adult Fish and Fisheries

Based on available evidence there is no particular attribute of the proposed site that would render this area of special importance to natural fish populations or commercial or recreational fishing activity.

Because fishes are highly mobile, and stocks are distributed widely along the continental shelf, dredged material disposal at the Norfolk site is unlikely to have substantial adverse effects on fish populations.

5.1.3 Potential Impact of Local Dredged Material Disposal on Zooplankton

Zooplankton populations of the Middle-Atlantic Bight generally have broad spatial distributions. Therefore, local dredged material disposal at the Norfolk site is unlikely to have substantial adverse effects on zooplankton populations.

5.1.4 Potential Impacts of Local Dredged Material Disposal on Ichthyoplankton and Blue Crab Larvae

Most fish species of the Middle-Atlantic Bight spawn over large areas. Larval distributions are also generally broad. Therefore, local dredged material disposal will probably have no substantial adverse effect on ichthyoplankton populations.

Atlantic croaker and blue crab larvae exhibit relatively localized larval retention areas off the mouth of the Chesapeake Bay. Though most organisms are quite tolerant of high concentrations of suspended sediment, "worst-case" impact calculations reveal that a maximum of about 1 percent mortality of blue crab megalopae larval stocks on the continental shelf may occur from dredged material disposal at the Norfolk site. The possibility that a worst-case impact could measurably affect year-class strength of croaker cannot entirely be ruled out. Like blue crab, croaker larval distribution is spatially limited and in addition, the late-stage larvae live close to the sea-floor, where turbidity effects from dumping would be most prolonged.

5.2 RECOMMENDATIONS

5.2.1 Designation of the Proposed Site

Based on the available evidence there is no attribute of the Norfolk disposal site that would render it of particular importance to fish, zooplankton, or most ichthyoplankton. Furthermore, the area is less important to the spawning of commercially important species, and to commercial and recreational fisheries than inshore waters closer to the highly productive Chesapeake Bay. We therefore can recommend designation of the proposed Norfolk disposal site to receive suitable dredged material from the Norfolk Harbor system. The following contingencies apply:

5.2.2 Dredged Material Disposal Window

While the evidence examined in this report has generally indicated that no persistent adverse effects on plankton and fish occur from ocean disposal of uncontaminated dredged material, we believe that there is enough uncertainty in worst-case impact calculations to warrant protection of species with spatially limited larval distributions, in particular blue crab megalopae and the larvae of Atlantic croaker.

The probability of substantial impact on any particular kind of organism may be minimized by the recommendation of a dredge disposal "window", as has been recommended, for example, by Schubel and Wise (Figure 14). If disposal at the Norfolk site were restricted or banned during September and October, when peak recruitment of croaker larvae and blue crab megalopae occurs, it could be assured that no measurable mortality of these organisms would be caused by disposal operations. The sparsity of published data on seasonal occurrence and distribution of these larvae means that without such a window, the possibility of measurable impacts on these two species cannot be entirely ruled out.

5.2.3 Protection of the Neuston

The neuston (the upper half-meter of the water column) has been demonstrated to be the most important habitat for ichthyoplankton and blue crab larvae in the Norfolk region. Therefore, it is recommended that the COE employ bottom-dump rather than split-hull hopper dredges whenever possible for disposal at the Norfolk site. Bottom-dump dredges release material at greater depth than do split-hull dredges, thus helping to minimize dredged material input into the neuston. The use of bottom-dump dredges is especially important during May-October, when the planktonic stages of most commercially important fish and shellfish are present in the water column.

5.2.4 Field and Experimental Data Needed

To refine information on what impacts are likely to occur from dumping at various times in this region, additional sampling and laboratory experimentation are needed. Field sampling should focus on temporal as well as spatial patterns of abundance of zooplankton, ichthyoplankton, and blue crab larvae at the

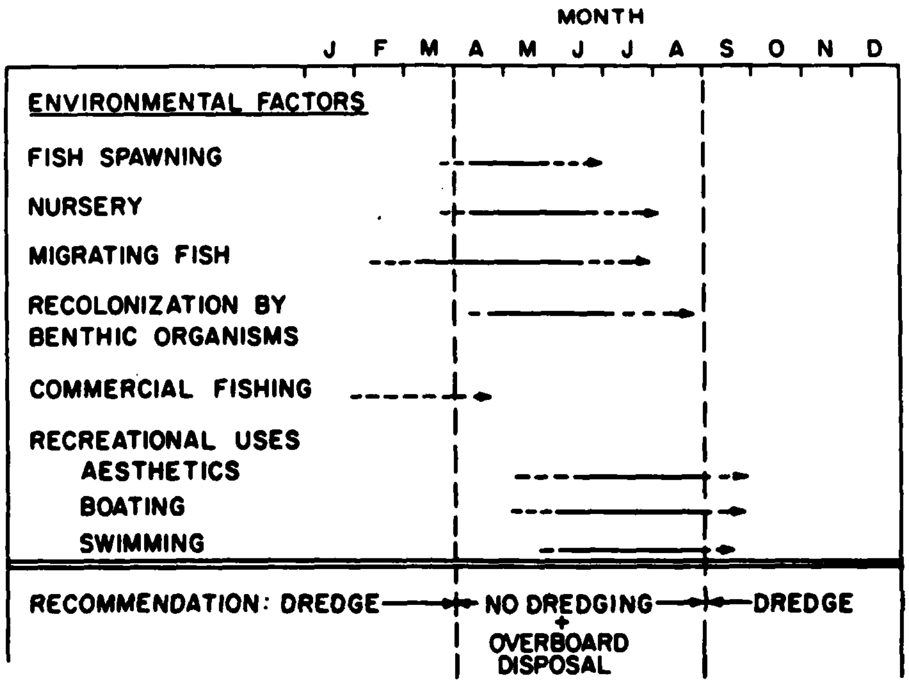


Figure 14: Recommended dredging window for the Maryland portion of the Chesapeake Bay. From Schubel and Wise (1979). For the Atlantic Ocean off Virginia the dredge disposal window might be shifted to cover the period September-October to protect spawning and recruitment of blue crab and croaker.

disposal site and in adjacent ocean waters. Sampling of the neuston is important, as is sampling the lowest strata of the water column to better determine the distribution of croaker and other demersal (bottom-dwelling) fish larvae. Plankton surveys should comprise several years (3-5 years) of quarterly or monthly samples at perhaps 10-20 stations.

Laboratory experiments should focus on quantification of effects of uncontaminated suspended sediments on truly marine rather than estuarine ichthyoplankton, and on blue crab larvae. Of particular importance is information on short-term (several hours) exposure to concentrations in excess of 1000 mg/l, and long-term effects of exposure to lower concentrations.

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