Coastal Bays Hard Clam Fishery Management Plan

Prepared by:
Maryland Department of Natural Resources
Coastal Bays Fishery Advisory Committee

February 2002

MARYLAND COASTAL BAYS

POLICY COMMITTEE

ENDORSEMENT STATEMENT

HARD CLAM FISHERY MANAGEMENT PLAN FOR MARYLAND'S COASTAL BAYS

We, the undersigned, endorse the 2002 Hard Clam Fishery Management Plan for Maryland's Coastal Bays. We agree to accept the 2001 Hard Clam Fishery Management Plan for Maryland's Coastal Bays as a guide to conserving the hard clam resource of the coastal bays, protecting its ecological and socio-economic value, and optimizing the long-term use of the resource. We further agree to support implementation, by the dates set forth in the Plan, the management actions recommended to assess the impact of *Hematodinium* (disease), conduct a comprehensive stock assessment, control crabbing effort and harvest rates, improve the quality of recreational crabbing, protect hard clam habitat, and implement effective enforcement.

We recognize that the 2002 Hard Clam Fishery Management Plan for Maryland's Coastal Bays is based on the science as we know it today, and not an endpoint. We recognize the need to commit long-term, stable, financial support and human resources to the task of managing the hard clam resource of the coastal bays and addressing important research needs. In addition, we ask the Maryland Department of Natural Resources to periodically review and update the Plan and report on progress made in achieving the Plan's management recommendations.

For Maryland Department of Natural Resources____________________________
Chuck Fox, Secretary

For Worcester County ____________________________
John Bloxom, Commissioner

Louise Gulyas, Commissioner

Jeanne Lynch,
Commissioner

James Purnell, Jr., Commissioner

Virgil Shockley, Commissioner

For Town of Ocean City

James Mathias, Mayor

For Town of Berlin

Rex Hailey, Mayor

For Ocean City Council

Rick Meehan, President

For U.S. Environmental Protection Agency

Donald Welsch, Region III
Administrator

For Maryland Department of Agriculture

Hagner Mister, Secretary

For Maryland Department of the Environment

Jane Nishida, Secretary

For Maryland Department of Planning

Roy Kienitz, Director

For Assateague Island National Seashore

Mike Hill, Superintendent

For MCBP Scientific Technical Committee

Don Boesch, Chairperson

For Local Citizens

Jack Burbage

Carolyn Cummins

Edward Lee

ACKNOWLEDGMENTS

The 2002 Hard Clam Fishery Management Plan (FMP) for Maryland's Coastal Bays was developed under the direction of the Coastal Bays Fishery Advisory Committee (FAC) which advises the Maryland Department of Natural Resources (MD DNR). The MD DNR would like to acknowledge the following members of the FAC who contributed to the development of this FMP:

Sherman Baynard, Recreational Fishing Community
Dave Blazer, MD Coastal Bays Foundation
Captain Mike Bloxom, MD DNR, Natural Resources Police
Sue Foster, Recreational Fishing Community
Joe Hall, Town of Ocean City
Monty Hawkins, Charterboat/Headboat Community
Ed Lynch, Commercial Crabbing Industry
Jeanne Lynch, Worcester County
Tom O'Connell, MD DNR, Fisheries Service
Joe O'Hara, Recreational Fishing Community
Tom Patton, Assateague Coastal Trust
Bill Ryan, Commercial Clamming Industry
Rick Savage, Local Citizen
Eric Schwaab, MD DNR, Fisheries Service, Director
Don Webster, Aquaculture Industry
Carl Zimmerman, National Park Service

The MD DNR and FAC would also like to acknowledge those individuals from the public who regularly attended and participated in the FAC meetings, and the following biologists from MD DNR who provided technical expertise and local knowledge in the development of this FMP:

Brett Brinkley, Natural Resources Police
Nancy Butowski, Fisheries Service
Dean Simpkins, Natural Resource Police
Mitch Tamowki, Fisheries Service

TABLE OF CONTENTS

SECTION 1. EXECUTIVE SUMMARY

In July 1999, a Comprehensive and Conservation Management Plan was adopted for Maryland's coastal bays. This Plan distinguished Maryland's coastal bays as a separate, unique ecosystem from the Chesapeake Bay, and included a recommendation that the Maryland Department of Natural Resources (DNR) address fishery issues specific to Maryland's coastal bays. Fishery issues were divided into three categories: finfish, shellfish, and blue crabs. This document specifically addresses the issues related to hard clams, and sets forth management strategies for improving the management of hard clams in the coastal bays.

The goal of the Hard Clam Fishery Management Plan (FMP) for Maryland's Coastal Bays is to manage hard clams in Maryland's coastal bays in a manner which conserves the coastal bay stock, protects its ecological and socio-economic value, and optimizes the long-term use of the resource. To achieve this goal, the following objectives have been defined: 1) Enhance and perpetuate hard clam stocks; 2) Manage for an economically stable commercial hard clam fishery; 3) Evaluate the feasibility of hard clam aquaculture opportunities; 4) Enhance and promote the recreational hard clam fishery; 5) Minimize conflicts between coastal bay user groups and commercial hard clam fishermen; 6) Minimize ecological impacts associated with the commercial and recreational hard clam fisheries; 7) Protect, maintain and enhance important hard clam habitats; 8) Minimize the impacts of non-indigenous species; and 9) Implement fisheries dependent and independent monitoring programs to obtain sufficient and accurate data for managing hard clams.

A series of management strategies have been developed to address the objectives of this FMP. The most significant action is limiting the number of individuals into the commercial hard clam fishery by permit only based upon participation rates in the fishery from the 1990/91 through 2000/01 harvest seasons. This action addresses three objectives in the FMP: maintaining an economically stable commercial fishery; minimizing conflicts between coastal bay user groups and hydraulic clam dredgers, and minimizing potential ecological impacts from hydraulic clam dredging.

Other significant actions aimed at minimizing user group conflicts include: prohibiting commercial clamming in the area above the Ocean City Airport at Marker 13 northward to the Rt. 90 Bridge on Saturdays (Sunday is currently closed) from September 15 through October 15 and April 15 through May 31; and establishing noise level requirements for commercial fishing vessels that are consistent with those that have been in place for recreational vessels (90 decibels).

The FMP also includes a report on an extensive literature review on the ecological effects associated with hydraulic dredging. The findings of this review concludes that the ecological effects of hydraulic dredging may be largely mitigated by the physical dynamics of the coastal bays ecosystem as well as the characteristics of the benthic faunal community that has developed under such conditions. The direct impact to submerged aquatic vegetation (SAV) can be significant, but Maryland Law, established in 1998, prohibits the use of hydraulic clam dredges in SAV beds. Further, regulatory restrictions reduce the impact of this activity by prohibiting harvesting in vulnerable SAV and through a closed season during the warmer months when biological processes (growth, feeding, reproduction) are at their peak.

Another point of interest in the FMP, is that the primary limiting factor to the abundance of hard clams in Maryland's coastal bays appears to be the survival of small clams (< 6 mm) due to predation by blue crabs with additional predation pressure by oyster drills, whelks, mud crabs and other organisms. Protection of broodstock (adults) is provided indirectly through areas closed to commercial clamming due to Maryland Department of Environment restricted areas, protected SAV, and shoreline setback areas. These areas currently closed to commercial clamming consist of approximately 40 percent (26,725 acres) of Maryland's entire coastal bays. The amount and distribution of these area closures should provide adequate broodstock protection.

In summary, it appears that the removals (harvest) of hard clams is not the limiting factor to the abundance of hard clams in the coastal bays. Management efforts to increase the abundance of hard clams need to be focused on improving bottom habitat to reduce predation on small clams. Most importantly, the FMP addresses the significant conflicts between coastal bays user groups and commercial hydraulic clam dredgers, and the strong perception among the coastal bays community about the ecological impacts that clam dredging has to the coastal bays ecosystem.

SECTION 2. GOAL AND OBJECTIVES

The goal of the Maryland Coastal Bays Hard Clam Fishery Management Plan is to manage hard clams in Maryland's Coastal Bays in a manner which conserves the coastal bay stock, protects its ecological and socio-economic value, and optimizes the long-term use of the resource.

To achieve this goal, the following objectives must be met:

1) Enhance and perpetuate hard clam stocks;

2) Manage for an economically stable commercial hard clam fishery;

3) Evaluate the feasibility of hard clam aquaculture opportunities;

4) Enhance and promote the recreational hard clam fishery;

5) Minimize conflicts between coastal bay user groups and commercial hard clam fishermen;

6)Minimize ecological impacts associated with the commercial and recreational hard clam fisheries;

7) Protect, maintain and enhance important hard clam habitats.

8) Minimize the impacts of non-indigenous invasive species.

9) Implement fisheries dependent and independent monitoring programs to obtain sufficient and accurate data for managing hard clams.

SECTION 3. BIOLOGICAL BACKGROUND

Life History

The hard clam (*Mercenaria mercenaria*) is a bivalve that is found in the intertidal and subtidal areas of the Atlantic coast from the Gulf of St. Lawrence to Texas. It is most abundant from Massachusetts to Virginia (Stanley & DeWitt 1983). Hard clams are also referred to as quahog, little-neck clam, or cherrystone clam. Hard clam distribution within coastal areas is mainly determined by salinity. They can be found in areas with salinities as low as 12 ppt but are more common in salinities greater than 18 ppt. Adult hard clams live in a variety of substrates but prefer sandy, muddy bottoms (VMRC 1997). They are found in a range of depths from the intertidal zone to greater than 18 meters. Adults use their muscular foot to burrow into the substrate and although they are capable of moving laterally, generally remain in the same location throughout their lives. The depth within the substrate at which the adults are found varies depending on the type of substrate. They usually burrow deeper in sandy substrates (average 2 cm deep) than muddy substrates (average 1 cm deep) (Stanley 1970). Since adults move very little, hard clam areas are determined by juvenile settlement. In areas where adult populations have been removed, repopulation is dependent on the transport of larvae to the area and several years of growth (Stanley & DeWitt 1983).

Hard clams are protandrous, consecutive hermaphrodites, i.e., they start off life as males and approximately half will change to females (VMRC 1997). Sexual maturity appears to be a function of size. Definitive sexes are discernable around 30 mm (1.2 inches) which usually takes two to three years to reach (Stanley & DeWitt 1983). Since spawning is dependent on size, slow-growing individuals will be older when they reach sexual maturity. Peak reproduction usually occurs around 60 mm (2.4 inches). There are conflicting reports on whether fecundity decreases with age. Besides size, spawning is also dependent on temperature and food availability (Roegner & Mann 1991). Spawning often occurs in pulses and can extend over several months. In the mid-Atlantic region, spawning generally begins in May when the temperature rises above 20-23°C (Stanley & DeWitt 1983) and ends in October (Roegner &.Mann, 1991). The spawning period in Maryland has been reported to occur from the beginning of June through August (Sieling 1956). Hard clam fecundity (the number of eggs per individual) is high. Females can release between 1 and 24 million eggs per spawn, the number usually increasing with increasing clam size (Davis & Chanley 1956; Stanley & DeWitt 1983).

Hard clam eggs are pelagic and subject to the tides, currents, and winds. As the embryo develops, it goes through the usual development stages of bivalve molluscs; the free-swimming trochophore larval stage, the veliger larval stage, the pediveliger stage, and metamorphosis into a juvenile seed clam. During the larval stages, hard clams feed on dinoflagellates and other planktonic organisms. The duration of each of the larval stages is dependent on environmental conditions and can extend between 7 and 24 days (Roegner & Mann 1991). The distribution of clam spat set is the result of passive transport and active site selection. During the last larval stage, the pediveliger alternates between swimming and crawling on the bottom which allows it to test the bottom for optimal settling sites. Metamorphosis from the last larval stage to the juvenile seed clam is inhibited at salinities below 17 ppt and ensures that seed clams set in areas that are favorable for adults (Stanley & DeWitt 1983).

Years with low freshwater flows generally produce good clam sets (Hibbert, C.J. 1976). Seed clams prefer a bottom habitat with a few small rocks and shells and are more densely aggregated in sand rather than mud. Juvenile seed clams will move to their ultimate habitat after their first year. When they reach 10 mm in length, they assume the burrowing behavior of adults (Stanley & DeWitt 1983). The mortalities associated with spat and seed clams due to predation are high (VMRC 1997). Without some sort of cover such as oyster shells or stones, seed clams generally disappear (Stanley & DeWitt 1983). Entire clam sets have been eliminated due to predation. As a result, there is a poor relationship between the size of the stock and the number of young recruited into the adult population. Theoretically, a few adults can produce enough spat to sustain the population (Stanley & DeWitt 1983). In the Chesapeake Bay, the Virginia Marine Resources Commission has designated hard clam sanctuaries as a means to protect broodstock and increase hard clam reproductive potential. In the Maryland coastal bays, there are currently over 26,000 acres that are closed to commercial clamming due to Maryland Department of the Environment restricted areas, submerged aquatic vegetation, and shoreline buffer areas. These acres have the potential to also protect hard clam broodstock.

Ecological Role

Hard clams are suspension feeders, i.e., they filter plankton and microorganisms from the water column while they are buried in the bottom substrate. Therefore, the clams participate in benthic-pelagic coupling, that is, they facilitate the transfer and recycling of materials and energy between the water column and sediment through their filter-feeding, pseudofeces production, digestion, absorption, excretion and elimination processes (Grizzle et al. 2001). These transfers work both ways, for in addition to removing phytoplankton the clams release ammonia as a waste product back into the water column, where it is utilized by the microalgae. It is speculated that the filtering ability of the clams has the potential to decrease turbidity and microalgae concentrations, improving water quality. On the other hand, mesocosm experiments found that phytoplankton biomass was not reduced by clam filter-feeding at densities of 16 clams/m^2 (Grizzle et al. 2001).

The primary predator on juvenile hard clams is blue crabs with additional predation pressure by oyster drills, whelks and mud crabs. Other important predators include sea stars, cownose rays, horseshoe crabs, herring gulls, waterfowl, and finfish especially tautog, puffer, black drum and flounder (Roegner & Mann 1991). The intensity of predation is related to the size of a hard clam. Smaller clams have thinner shells making them more vulnerable to gastropods and other predators. Crabs are capable of crushing small clams and can seriously impact clams that are less than 6 cm by chipping away at the edges of their shells. As clams grow larger and their shell thickens, they are less vulnerable to predation (Kraeuter & Castagna 1980). Predation may account for the absence of small clams and explain the skewed size-frequency distributions of populations toward larger individuals (Roegner & Mann 1991). Shell aggregations are important habitat features for hard clams since they provide some protection from predators; seagrasses may also shelter young hard clams, depending on the type of predator involved (Peterson et al. 1984, Beal 2000). Natural mortality on larger, adult hard clams is low. There are a number of diseases that can affect hard clams but their occurrence is not well-documented. An unknown pathogen referred to as Quahog Parasite Unknown (QPX) has been found in hard clams under aquaculture conditions and there is some concern about its presence in the wild. The Virginia Institute of Marine Science (VIMS) initiated a study to examine the presence of QPX and it was found in Chincoteague Bay in 1996. The disease poses no human health risks. There also are some parasitic infestations of hard clams but their occurrence is also low.

Habitat Requirements

Temperature is the most important factor in hard clam growth and reproduction (Stanley & DeWitt 1983). In general, the early larval stages have a narrower temperature tolerance than adults. Optimum survival has been reported between 22 and 25°C for larvae and between 21 and 31°C for adults (Roegner & Mann 1991). Salinity also plays a role in survival and is most critical during the egg and larval stages. Optimum growth and survival to settlement and metamorphosis occurs around 26 - 27 ppt. Hard clams can withstand a range of pH levels (7.0-8.75) which are normally encountered in their habitats.

Hard clams exhibit a high tolerance to low levels (0.5 mg/L) of dissolved oxygen (DO) and can withstand short periods of anoxic conditions; adult clams can tolerate less than 1 mg/L for three weeks and still burrow (Stanley & DeWitt 1983). However, growth rates decrease when DO is consistently below 4 mg/L. Dissolved oxygen levels below 5 mg/L would be considered stressful for hard clams (Roegner & Mann 1991).

The amount of suspended material in the water column or turbidity can affect hard clams. Heavy sediment loads have negative effects on hard clam growth. Laboratory studies on the effects of high concentrations of silt on hard clams indicate decreased feeding rates and growth rates. Embryos exhibited normal development at silt loadings below 3000 mg/L and larvae tolerated silt concentrations of 4000 mg/L, although growth was depressed by 500 mg/L of clay (Stanley & DeWitt 1983).

History of Hard Clam Fishery in the Maryland Coastal Bays

The fortunes of the Maryland coastal bays shellfish industry, indeed, the very complexion of the ecosystem itself, has been dictated by catastrophic storms which have periodically ripped open and subsequently closed the inlets connecting these lagoons to the ocean. Aside from Chincoteague Inlet, these passages were ephemeral, lasting from a few months to several decades. The breaching of an inlet allowed oceanic water to flood into the bays, dramatically raising salinities. Conversely, when an inlet closed the bays gradually reverted to a more brackish regime. Salinity is one of the most important factors in the distribution of estuarine organisms, with each species limited by its tolerance range. For the hard clam *Mercenaria mercenaria* (Linnaeus), the lower salinity limit is about 15-20 ppt, as compared to oysters which can tolerate brackish water down to 5 ppt. Hence, as the inlets formed and closed, so did the clam population expand and contract. The only persistent population was in southern Chincoteague Bay, where the salinity remained consistently high enough for clams to survive.

The earliest harvesters of the hard clam in the coastal bays were the indigenous people belonging to subgroups of the Nanticocke tribe (Truitt & Les Callette, 1977). The native Americans gathered the clams by feeling for them with their feet, or treading in clammer's parlance. In addition to being items of food, the clams were highly valued as a source of purple shell for making wampum beads, the common currency of exchange among tribes all along the Atlantic coast.

Little has been recorded concerning clamming activities during the colonial period through the 19th century, save to say that they were harvested most likely on a sustenance basis rather than for commercial trade. During the colonial period there was a substantial connection between Sinepuxent Bay and the Atlantic known as Sinepuxent Inlet, which probably allowed clams to inhabit most of the coastal bays system.

During the 1860's and 1870's Chincoteague Bay had a second inlet at Green Run large enough to let ocean going ships to pass through (Truitt & Les Callette, 1977), which should have resulted in an abundance of clams. However, Ingersoll (1887) in his treatise on commercial shellfishing in the United States, dismissed clamming in this region as too trivial to mention. Consumer preferences in general during this period and the particular socioeconomics of this region would have limited commercial clamming. Oysters were the primary source of inexpensive protein to the rapidly burgeoning populations in the cities along the eastern seaboard, and even into the hinterlands, thanks to the railroads.[1] Clam consumption was a distant second, increasing in the summer months when oysters were out of season. However, most of the harvesters in the Chincoteague region were farmers who worked part time at shellfishing, generally in the colder months when they were not farming (Earll, 1887). The oyster trade was extremely lucrative for them, since Chincoteague oysters, with their distinctive salty flavor, were particularly prized in the high end markets of New York and Philadelphia, with some even shipped to Europe (Ingersoll, 1881). It seems likely, then, that the Chincoteague baymen were tending their crops during the peak demand for clams. Most of the commercial hard clam harvesting during this time was on the Chesapeake side in Pocomoke and Tangier Sounds (Ingersoll, 1887). Nevertheless, one record indicated that 40,000 lbs.[2] of hard clams valued at $2,000 were landed in the coastal bays during 1880 (Earll, 1887).

In the 1890's hard clams, in particular the smaller littlenecks, became fashionable delicacies (Mackenzie, 1997a). Landings from the coastal bays were fairly respectable, with over 100,000 lbs. of meats being reported (Murphy, 1960). By this time, however, Green Run Inlet had closed and the resulting decline in salinity undoubtedly caused the hard clam population to contract back to the southern part of Chincoteague Bay. Catches steadily declined so that within ten years the figure had dropped to less than a third of the early 1890's and by 1908 only 8,400 lbs. were caught (Murphy, 1960).

Over the years there was talk of constructing a new inlet expressly to improve conditions for growing shellfish. At least two schemes were approved by the state legislature, which would have leased large tracts of bay bottom to the construction companies upon completion of the inlet. Little beyond the paperwork was accomplished, however, and depressed salinities persisted in the coastal

---

[1] The shipments of oysters from all sources to New York City alone were enough to provide every family with an oyster meal twice per week (MacKenzie, 1997).

[2] It is uncertain whether this figure represents whole clams in their shells or just meat weight (likely the former).

bays for almost 40 years, until a winter storm in 1920 cut a passage through Assateague Island about three miles below Ocean City. Within a few years hard clam landings shot up (landings were110,000 lbs. in 1925), with harvesters earning up to $30-35 per day, a very good living by contemporary accounts (Md. Fish, 1931; Conserv. Dept., 1933). This inlet closed up in 1929, and clams were subsequently added to the list of stocks that crashed that year[3].

The benefits to the seafood industry of a second inlet was not lost upon state conservation officials, scientists[4], and most importantly, legislators. In 1931, the Maryland General Assembly set aside $500,000, with the federal government contributing another $250,000, to construct a permanent inlet in the vicinity of Ocean City. The specific intent was to provide a port for ocean going fishing vessels and to improve conditions for growing and harvesting shellfish, both clams and oysters, as well as blue crabs (Cons. Dept. 1931, 1933). In addition, access to the ocean for recreational and charter fishing boats was viewed as a boon to tourism in the area. Also in 1931, a law was passed requiring commercial clammers to obtain a license (LoM 1931, Ch. 431). The law was to become effective when $125,000 of bonds for the new inlet were sold, essentially linking the sale of licenses to the benefits the inlet would provide to the hard clam industry.

Before work began, however, a terrible storm[5] tore open a new inlet just south of Ocean City in August, 1933. Since the money for an inlet had already been allocated, the Army Corp of Engineers was able to begin stabilizing it almost immediately. Salinities quickly rose in the lagoons, allowing hard clams to flourish, with populations expanding throughout the coastal bays system.

After an initial jump in 1936, hard clam landings steadily climbed through the next decade and a half, peaking in the late 1940's, after which a long decline set in. The number of clamming licenses paralleled the harvests, reaching highs ranging between 162 and 189 between 1942 and 1947 before dropping off. During this period harvesting was primarily by hand tongs, hand rakes or treading, the latter two methods being confined to shallower waters. Clamming by these methods was legal all year round. The breakdown for commercial gears for the period 1944-48 was as follows: tongs - 41%, rakes - 45%, treading - 13%, dredges - 1% (Sieling, 1956). The dredges, which were similar to oyster dredges but with longer teeth, came into more widespread use during the winter of 1952-53 (Wells, 1957). By 1955, dredges and the Shinnecock rake, which had been legalized that year (LoM 1955, Ch.707), accounted for 40% of the commercial harvest even though there were seasonal restrictions imposed on them (Sieling, 1956). These gear allowed for more efficient harvesting, particularly in deeper waters. As a result, harvests began to climb again, soon surpassing the post-war peak (Murphy, 1960; Boynton, 1970). At some point during the mid- 1950's dredges were declared illegal. During this period approximately 100 clammers held commercial licenses, of which an initial 25 Shinnecock rake

---

[3] Actually, landings held through 1930, when 81,000 lbs. were reported, then fell precipitously the following year to 2,000 lbs. (Murphy, 1960).

[4] Most notably Dr. R. Truitt, head of the recently established Chesapeake Biological Laboratory and a native son of Boxiron, Md. near Chincoteague Bay.

[5] The storm was extremely destructive both along the coast and in the Chesapeake region (Cons. Dept., 1933).

licenses were issued, later declining to about 14 (Md. Bd. Nat. Res. 1958). A 1956 study estimated that recreational clamming took about as much if not more than commercial harvesting (Sieling 1960).

During the 1960-61 season the number of clamming licenses surged to an all time high of 215, almost tripling the harvest from the previous season. Interestingly, only 6 Shinnecock rake licenses were issued that season. Handscrapes (small dredges) were again legalized in 1961 (LoM 1961, Ch. 338) and the number of combined Shinnecock rake/handscrape licenses climbed to 64, with the latter gear probably accounting for the increase. After a couple of more seasons with record harvests, commercial landings again sagged in the mid-1960's. The Board of Natural Resources, blaming overfishing as the primary culprit, argued for increased regulation of the industry, including the imposition of a minimum size limit, the establishment of broodstock sanctuaries, and the legalization of the hydraulic escalator dredge, which reputedly did much less damage to clams in the bottom, hence less wastage, than the Shinnecock rake or clam dredge (Md. Bd. Nat. Res. 1966, 1967). It was also mentioned that many clamming areas in Isle of Wight and Assawoman Bays had been dredged up and used as fill in the Ocean City Area, pointing to the need for information on the distribution and abundance of hard clam stocks (Md. Bd. Nat. Res. 1964).

Nineteen sixty-seven was a landmark year for hard clam management in the coastal bays. For the first time, a minimum size limit - one inch measured transversely - was imposed (LoM 1967, Ch. 404). In addition, the General Assembly granted the Dept. of Chesapeake Bay Affairs (successor to the Board of Natural Resources) regulatory authority over the hard clam fishery in matters of permissible harvest gears, quantity and size limits, and clamming areas. Using this authority, the Department allowed hydraulic dredging that same year with certain restrictions (Reg. No. 158, 15 Oct. 1967). Probably the most important of these was the imposition of a daily harvest limit (another first) of 100 bushels per boat (about 20,000 clams per boat-day), in recognition of the greater harvesting efficiency of the hydraulic dredge over previous methods. The following year this was further reduced to 8,000 clams per boat-day, primarily due to market concerns (Boynton, 1970). Allowance of this gear was codified into law the next year (LoM 1968, Ch.369).

It seemed almost inevitable that the hydraulic escalator dredge arrived at the coastal bays. This gear was developed in Maryland to harvest the untapped quantities of soft clams *Mya arenaria* (Linnaeus) from the subtidal waters of the Chesapeake. Initially, it was viewed with suspicion by many concerned about its impacts, resulting in it being banned from many areas, including the coastal bays (LoM 1953, Ch. 744). Eventually this gear became more accepted, though still with restrictions, both legislative and departmental. It was only a matter of time before seaside clammers started advocating its use. They found an ally in the Department, which viewed the gear as a boon to the sagging industry by boosting production while conserving the resource by reducing the number of broken and unusable clams (Md. Bd. Nat. Res. 1966, 1967). In addition, studies conducted in the Chesapeake concluded that the dredge had minimal impact except when it directly tore into oyster bars or grass beds (Manning, 1957). This further encouraged the Department to legalize hydraulic dredging in the coastal bays, where the old shell bars no longer supported oyster populations and seagrass beds were limited in extent since they were just beginning to return.

Predictably, with the introduction of the hydraulic dredge harvests jumped over the previous year. By the following season, 42 hydraulic dredges were licensed, as well as 7 Shinnecock rakes, 3 hand scrapes, 2 clam rakes, and 2 tongs (Boynton, 1970). The older gears rapidly disappeared, so that by the 1969-70 season only 2 clam rakers and 1 tonger were still active aside from 46 dredge boats. This boom lasted only four seasons before harvests started to slide precipitously, despite tighter regulation of the fishery and the new gear type that were supposed to advance the cause of conservation.

At face value, it would appear that the hydraulic dredge was too efficient for the fishery and the stocks were rapidly depleted. Delaware managers cited this decline when arguing against legalizing this gear some ten years later (DNREC, 1979). Certainly, harvests immediately following the introduction of the hydraulic dredge reversed a three year decline in catches. With the exception of the peak year of 1969, however, annual harvests were within the range of the Shinnecock rake and handscrape years.

The situation leading the precipitous drop in hard clam landings was complicated by external market factors. During this period, vast reserves of surf clams began to be exploited in the coastal waters of the Atlantic, flooding the market with a cheap, abundant, and consistently available product. Hard clams from the Maryland coastal bays were mostly of the larger chowder sizes (Drobeck et al., 1970), which, in addition to bringing the lowest prices, were the size most vulnerable to competition from surf clams for the large-scale chowder and clam strip trade.[6] The surf clam was superior for these purposes in terms of size and meat yield per clam (double that of hard clams). As a result, prices for hard clams (chowders) plummeted, from $2.00 per bag during the 1968-69 season to $1.20 in 1970-71 (J. Casey, MDNR, unpubl. data).

Nearby states with significant surf clam landings also experienced sharp drops in hard clam harvests during this period. In both Virginia and New Jersey, peak hard clam landings during the mid-1960's were followed by extended declines, although neither state allowed hydraulic escalator dredges for harvesting hard clams (Ford, 1997; MacKenzie, 1997b). Concomitantly, surf clam landings increased dramatically, more than doubling from 39.9 million pounds in 1968 to 82.3 million pounds in 1973; Virginia and New Jersey accounted for 79% of the surf clam landings that year. (In comparison, the highest hard clam harvest in Maryland was 759.8 *thousand* pounds in 1969). Chincoteague, Virginia became a major surf clam landing port, as did Ocean City, Maryland.

Due to this loss of market and the inability of the resource to make up the difference in prices, many clammers abandoned the hard clam fishery, with some undoubtedly entering the lucrative surf clam fishery out of Ocean City and Chincoteague. The number of hydraulic dredge licenses declined from 46 in 1969 to 23 only three years later; by 1975 only 11 dredge licenses were issued (Brey, 1979).

The hard clam industry remained marginal for the next 20 years, to the point where MDNR ceased compiling catch records. Anecdotally, only about three boats were working in Chincoteague Bay and three to five boats in the upper bays through the 1980's and early 90's (Capt. G. Marshall, pers. comm.).

---

[6] The aforementioned DNREC (1979) report ignored the economic situation in Maryland, even though this was plainly stated in a memo from W. Brey of the National Marine Fisheries Service Statistics Branch and included as App. C of the report: "In 1970 the surf clam made inroads on the hard clam market. Due to the fact that almost all of the Maryland hard clams are of the chowder size they were competing with the surf clam. Demand for the chowder size hard clam declined because it could not compete price-wise."

During this period MDNR initiated some innovative projects in an attempt to enhance the fishery. The most ambitious of these was seeding commercial and recreational areas with hatchery reared hard clams. Between 1972 and 1977, over four million seed clams were planted throughout the coastal bays (Casey 1972, 1974, 1978). Unfortunately, mortality rates were extremely high due to predation (J. Casey, MDNR, pers. comm.), despite several plantings on relic oyster bars where it was hoped that existing shell would provide cover to the young clams (Casey, 1974). Another project planted surf clam shell in Chincoteague Bay to provide a refuge for naturally setting clams (Scott, 1981). Although successful in enhancing recruitment,[7] financial and logistical constraints limited this project to only two plantings (R. Scott, MDNR, pers. comm.).

In the mid-1990's successful hard clam recruitment, particularly in Isle of Wight and Sinepuxent Bays, in combination with a scarcity of softshell clams in Chesapeake Bay, led to a resurgence of clamming activity in the coastal bays. Landings rose gradually at first, then jumped abruptly in the 1998-99 season when approximately 25 boats were working. Although landings were well below the heyday of the 1960's, the value of the catch was close to record breaking, especially since a large percentage of the population was of prime littleneck size. Harvest totals for the following season were almost identical, then declined during the 2000-01 season as the number of boats dropped to about 16. The focus of harvesting shifted from the upper bays to Chincoteague Bay, which had experienced good hard clam recruitment in recent years.

During this period the most significant legislation regulating the hard clam fishery since the legalization of the hydraulic escalator dredge went into effect, making it illegal to use a hydraulic clam rig in seagrass beds. In addition to protecting the seagrasses, this restriction results in a *de facto* sanctuary for clams within the grassbeds. Since the seagrass beds had considerably expanded over the past decade, this effectively eliminated approximately one-third of the coastal bays from clamming. Combined with the seagrass beds, restrictions in shoreline set-backs, poor water quality areas, privately leased bottom, and a recreation-only clamming area bring to a total an estimated 40% of the coastal bays that is off-limits to commercial clamming. The law provides for annual redelineations of the seagrass closures, so that as the grassbeds expand clamming areas will continue to contract.

---

[7] Many years later, the shell was still enhancing recruitment. The 1996 Hard Clam Survey found numerous small clams on these plantings, whereas the adjacent unshelled areas had few if any (M. Tarnowski, unpubl. data).

SECTION 4. MANAGEMENT STRATEGY

OBJECTIVE 1: Enhance and perpetuate hard clam stocks.

Problem 1.1: Mortality of Small Clams - The primary limiting factor to the abundance of hard clams in the coastal bays appears to be the survival of small clams (< 6 mm.) due to predation by blue crabs with additional predation pressure by oyster drills, whelks, mud crabs and other organisms. Protection of broodstock is provided indirectly through areas that are closed to commercial clamming due to Maryland Department of the Environment restricted areas, submerged aquatic vegetation, and shoreline setback areas. These areas currently closed to commercial clamming consist of approximately 40 percent (26,725 acres) of Maryland's coastal bays. The amount and distribution of these area closures should provide adequate broodstock protection. Management efforts to increase the abundance of hard clams should focus on minimizing predation of small clams.

Action 1.1.1: Investigate the importance of habitat closures (MDE restricted areas, SAV closures, and shoreline setback areas) to recognize their benefits as hard clam broodstock protection areas.

Implementation: Ongoing

Actions 1.1.2: Develop an action plan for improving hard bottom habitat (i.e shell or other suitable substrate) to reduce predation on small clams. The action plan will include the identification of:

a) Planting materials and sources;
b) Enhancement areas; and
c) Funding sources (i.e. improved reporting of commercial hard clam harvest will increase funding generated through the shellfish tax which could be used towards bottom enhancement activities).

Implementation: Initiate in 2002

OBJECTIVE 2: Manage for a viable commercial hard clam harvest to maintain an economically stable fishery.

Problem 2.1: Potential Economic Hardship to Commercial Clammers Caused by the "Boom and Bust" Nature of the Fishery - Commercial clammers have been satisfied with the economics of the coastal bays hard clam fishery, but are concerned that the economics of the fishery may become jeopardized if the number of commercial clammers exceeds levels experienced during the 1990s.

Action 2.1.1: DNR will limit the number of individuals into the commercial hard clam fishery by permit only based upon those individuals who have landed at least 100 bags of hard clams (as documented by DNR dealer reports) in Maryland's coastal bays in at least 2 years between the 1990/91 and 2000/01 seasons. Using this criteria, a total of 22 individuals would qualify for this permit. This permit should be transferable with a license, or to an individual who purchases a clam rig from an individual who meets the criteria stated above, and relinquishes their permit to the new clam rig owner. DNR will evaluate this action within 3 years to determine if the desired outcomes are being achieved. This action is consistent with actions 5.1.2 and 6.1.3.

Implementation: 2002

Action 2.1.2: DNR will develop a plan (i.e. reporting requirement from commercial clammers) to improve the collection of catch, effort and economic data from the commercial hard clam fishery to assist managers in evaluating the impacts of future management decisions.

Implementation: 2002

OBJECTIVE 3: Evaluate the feasibility of hard clam aquaculture opportunities.

Problem 3.1: Establishing Hard Clam Aquaculture - The hard clam aquaculture industry is expanding in most Atlantic coast states, but while there appears to be potential for production from Maryland's coastal bays few have made a serious effort. The process for obtaining a aquaculture permit in Maryland is complicated and time consuming, and few pilot studies have been conducted to determine the feasibility and economic potential of hard clam aquaculture in Maryland's coastal bays.

Action 3.1.1: Evaluate the legal, institutional and economic incentives and barriers to private aquaculture at the local, state, and federal level in Maryland.

Implementation: 2002

Action 3.1.2: Identify problems with the permitting process, and make recommendations to specific agencies to solve those problems.

Implementation: Initiate in 2001

Action 3.1.3: Simplify the application process, and designate a single point contact at DNR to assist potential applicants with aquaculture permits, questions related to the regulatory requirement, guidance through the permitting process and fulfilling of regulatory obligations, tracking permit applications, and coordinating state agency permitting activities to aquaculture permits.

Implementation: Ongoing

Action 3.1.4: DNR will evaluate the feasibility of hard clam aquaculture in Maryland's coastal bays by:

a) Identifying potential areas and size of area for hard clam aquaculture;
b) Initiating and providing funding for pilot hard clam aquaculture studies;
c) Investigating the economic impact of hard clam aquaculture; and
d) Assessing the ecological impacts associated with hard clam aquaculture.

Implementation: Initiate in 2002

OBJECTIVE 4: Enhance and promote the recreational hard clam fishery.

Problem 4.1: Limited Access and Knowledge of Recreational Clamming Opportunities in Maryland's Coastal Bays - Approximately 23,000 acres (total area closed to commercial clamming minus areas closed due to water quality and oyster leases) of bottom habitat in Maryland's coastal bays can be considered as recreational only clamming areas because of areas unavailable to commercial clamming. These areas are relatively evenly distributed throughout the coastal bays and are suitable for recreational clamming. Few people, however, currently participate in this activity because of limited access to these areas. A water-use assessment survey conducted in 2000 indicated that 6% of boaters actively engage in recreational clamming, and 17% go recreational clamming some time in Maryland's coastal bays. An additional 18% of those interviewed indicated that they would go clamming in Maryland's coastal bays if they had more opportunities or knew of more areas to go clamming (J. Falk, University of DE, personal communication).

Action 4.1.1: DNR will develop and distribute a public outreach brochure illustrating recreational clamming areas, access points, methods and harvest restrictions.

Implementation: 2002

Action 4.1.2: DNR will work with the Town of Ocean City and Worcester County to improve access to recreational clamming areas.

Implementation: Initiate in 2002

Action 4.1.3: DNR will investigate the feasibility of planting seed to establish and/or enhance areas for recreational clamming, and if feasible, develop a seeding strategy.

Implementation: Initiate in 2002

Problem 4.2: Recreational Catch Limits - The recreational catch limit for hard clams is currently 1 bushel per person per day. Those is Virginia and Delaware are 250 and 100, respectively. Reducing the recreational catch limit may appear to be contradictory of this objective, but those involved in the development of this fishery management plan have indicated that the current 1 bushel catch limit is excessive, and reducing it will be in the best long-term interest of recreational clammers.

Action 4.2.1: DNR will reduce the recreational catch limit for hard clams from 1 bushel to 250 hard clams per person per day.

Implementation: 2002

OBJECTIVE 5: Minimize conflicts between coastal bay user groups and commercial hard clam fishermen.

Problem 5.1: Conflict Between Recreational Fishermen and Commercial Clammers - There is a social conflict between recreational fishermen and commercial hydraulic clam dredgers. The satisfaction of recreational fishermen targeting finfish (i.e. summer flounder, seatrout, striped bass) in the early fall and late spring is affected by the turbidity plumes generated from the disturbance of bottom substrate by hydraulic dredging activity. Recreational fishing activity during the late fall and early spring is concentrated in the northern bays and is highest on weekend days. Commercial clamming is prohibited on Sundays during the open season of September 15 through May 31, but Saturdays are currently open at which time this conflict is most significant.

Action 5.1.1: DNR will prohibit commercial clamming in the area between the Ocean City

Airport at Marker 13 northward to the Rt. 90 Bridge on Saturdays (Sundays currently closed) between September 15 through October 15, and April 15 through May 31.

Implementation: 2002

Action 5.1.2: DNR will limit the number of individuals into the commercial hard clam fishery by permit only based upon those individuals who have landed at least 100 bags of hard clams (as documented by DNR dealer reports) in Maryland's coastal bays in at least 2 years between the 1990/91 and 2000/01 seasons. Using this criteria, a total of 22 individuals would qualify for this permit. This permit should be transferable with a license, or to an individual who purchases a clam rig from an individual who meets the criteria stated above, and relinquishes their permit to the new clam rig owner. DNR will evaluate this action within 3 years to determine if the desired outcomes are being achieved. This action is consistent with actions 2.1.2 and 6.1.3.

Implementation: 2002

Action 5.1.3: DNR will reduce the bycatch allowance of hard clams for recreational purposes in the hydraulic dredge fishery from 1 bushel to 250 hard clams per person per day.

Implementation: 2002

Problem 5.2: Conflict Between Shoreline Property Owners and Commercial Clammers - The noise generated from hydraulic clam dredgers working close to shore during the morning has resulted in complaints from shoreline property owners. Complaints are related to commercial clammers working close to shore, in legal areas, just outside of the shoreline setback area, and those individuals who obtain written permission to clam within the setback area.

Action 5.2.1: DNR will establish a maximum noise level limit for commercial vessels consistent with the recreational limit.

Implementation: 2002

Action 5.2.2: DNR will increase the shoreline setback distance for which a person may not catch hard clams with a hydraulic dredge in front of federal or state-owned property from 150 to 300 feet.

Implementation: 2002

Action 5.2.3: DNR's Natural Resource Police will monitor the causes of reported noise complaints to facilitate future management decisions related to this issue.

Action 5.2.4: DNR will investigate the impacts of prohibiting or restricting the written permission provision that allows an individual to catch hard shell clams with a hydraulic dredge within the shoreline setback restriction of 300 feet.

Implementation: 2002.

OBJECTIVE 6: Minimize ecological impacts associated with the commercial and recreational hard clam fisheries.

Problem 6.1: Community Concern on the Ecological Effects of Commercial Hydraulic Clam Dredging -There is a strong public perception in Maryland's coastal bays community that commercial hydraulic clam dredging has a significant detrimental impact to the ecology of the coastal bays. In response to this concern, DNR conducted a literature review of the ecological effects of hydraulic dredging (Appendix I). The results of this literature review concluded that the ecological effects of hydraulic escalator dredging may be largely mitigated by the physical dynamics of the coastal bays ecosystem as well as the characteristics of the benthic faunal community that has developed under such conditions. Regulatory restrictions further reduce the impact of this activity by prohibiting harvesting in vulnerable seagrass beds and through a closed season during the warmer months when biological processes such as feeding, growth, reproduction, and recruitment are at their peak. Outreach efforts are now necessary to inform the public on the results of this literature review, and the actions DNR has taken to minimize the ecological impacts of hydraulic clam dredging.

Action 6.1.1: DNR and Maryland's Coastal Bays Program will educate the public on the ecological effects of hydraulic clam dredging and the importance of the commercial hard clam fishery to the coastal bays community.

Implementation: 2002

Action 6.1.2: DNR will encourage studies to evaluate the ecological impacts of hydraulic clam dredging in Maryland coastal bays.

Implementation: Initiate 2002

Action 6.1.3: DNR will limit the number of individuals into the commercial hard clam fishery by permit only based upon those individuals who have landed at least 100 bags of hard clams (as documented by DNR dealer reports) in Maryland's coastal bays in at least 2 years between the 1990/91 and 2000/01 seasons. Using this criteria, a total of 22 individuals would qualify for this permit. This permit should be transferable with a license, or to an individual who purchases a clam rig from an individual who meets the criteria stated above, and relinquishes their permit to the new clam rig owner. DNR will evaluate this action within 3 years to determine if the desired outcomes are being achieved. This action is consistent with actions 2.1.2 and 5.1.2.

Implementation: 2002

Problem 6.2: Direct Impact to Submerged Aquatic Vegetation (SAV) by Commercial Hydraulic Clam Dredging - The direct impact of the hydraulic escalator dredge on SAV beds is significant. Dredging uproots plants, leaving behind trenches that may persist for lengthy periods of time due to the energy dampening and sediment stabilizing effects of SAV beds. In 1998, Maryland Law §4-1006.1 was established prohibiting the use of hydraulic clam dredges in SAV beds, and requiring the State to delineate existing SAV beds as necessary to maintain this protection over time as SAV beds change in size/shape. Since the early 1990s, SAV beds in Maryland's coastal bays have tripled in acreage despite an increase in harvesting activity during this same period.

6.2.1 **Action 6.1.1:** DNR will continue to prohibit the use of hydraulic clam dredges in SAV beds, and delineate existing SAV beds as necessary to maintain this protection over time.

6.2.1a **Action 6.1.1a:** The Maryland Coastal Bays Fishery Advisory Committee shall become the local group to develop and provide recommendations to DNR regarding the delineation of SAV closure areas to harvest from hydraulic clam dredging.

6.2.1b **Action 6.1.1b:** DNR will continue to foster the support among legislators to make recommended changes in the SAV law which would benefit all stakeholder groups by making the delineation and enforcement process more manageable, and the closure areas consistent over a longer period of time.

6.2.2 **Implementation:** 6.1.1 - Ongoing; 6.1.1a - 2001; and 6.1.1b - Ongoing

Action 6.1.2: DNR and the National Park Service will investigate the feasibility and funding options for using Global Positioning System (GPS) units to improve the ability for clammers to comply with SAV closure areas and offset the maintenance cost associated with using buoys to identify SAV closure areas.

Implementation: 2002

<u>Problem 6.3: Potential Impact to Overwintering Blue Crabs by Commercial Hydraulic Clam Dredging</u> - There is concern that hydraulic clam dredging activity may have a negative impact on overwintering blue crabs, but data is unavailable to assess this concern.

Action 6.2.1: DNR will evaluate the need to restrict hydraulic dredging in important female blue crab overwintering areas by:

a) Delineating female blue crab overwintering areas;
b) Determining the significance or contribution of these overwintering crabs to the coastal bays blue crab population;
c) Determining the magnitude of overwintering blue crab bycatch in the hydraulic clam dredge fishery; and
d) Assessing the impact of dredging activity on overwintering female blue crabs.

Implementation: a) Ongoing; b) Dependent on funding; c) Dependent upon funding; and d) Dependent on funding.

OBJECTIVE 7: Protect, maintain and enhance important hard clam habitats.

<u>Problem 7.1: Water Quality</u> - In spite of the state's effort to balance economic growth with environmental protection, population growth has resulted in increased land disturbing activities in the coastal areas. This has caused a closure of more than 2,500 acres shellfish growing areas due to fecal coliform contamination.

Action 7.1.1: Develop strategies to restore water quality in areas closed to harvesting hard clams because of pollution.

Implementation: Ongoing

<u>Problem 7.2: Hard Bottom Habitat</u> - The quantity and quality of hard bottom habitat is essential to minimizing predation of small hard clams which is a limiting factor to their abundance.

Action: 7.2.1: Develop an action plan for improving hard bottom habitat (i.e shell or other suitable substrate) to reduce predation on small clams. The action plan will include the identification of:

a) Planting materials and sources;
b) Enhancement areas; and
c) Funding sources.

Implementation: Initiate in 2002

<u>Problem 7.3: Navigational Channel Dredging and Dredge Disposal</u> - Dredging activities can impact hard clam populations, and should be coordinated in a manner to minimize any such impacts.

Action 7.3.1: The MD Coastal Bays Navigation and Dredging Advisory Group (NADAG) will seek comments from DNR's Shellfish Program on the potential impacts of proposed dredging activities on hard clams.

Implementation: Ongoing

<u>Problem 7.4: Growth of Noxious Algal Blooms</u> - In recent years, noxious algal blooms such as brown tides have become more prominent in Maryland's coastal bays. Factors attributing to noxious algal blooms are currently unknown. Research suggests that brown tides may affect growth and reproduction of hard clams.

Action 7.4.1: DNR and MCBP will identify potential funding sources to support the following research and monitoring activities:

1) Assess the potential impact that noxious algal blooms have on hard clam populations; and
2) Identify factors which might contribute to noxious algal blooms.

Implementation: Ongoing

OBJECTIVE 8: Minimize the impacts of non-indigenous invasive species.

<u>Problem 8.1: Green Crabs</u> - The green crab (*Carcinus macnas*) first appeared in the Ocean City inlet and has since expanded its range north and south in the coastal bays. Green crabs prey upon bivalves and other crab species. The effect that green crabs have on the hard clam population in the coastal bays is speculative at this time.

Action 8.1.1: DNR with the advice of Maryland's Coastal Bays Fishery Advisory Committee will implement measures to minimize the impact of green crabs and Japanese shore crab on the hard clam population in Maryland's coastal bays, and coordinate this effort with Delaware and Virginia.

Implementation: 2002

Action 8.1.2: DNR will continue to work with Maryland's Non-indigenous Species Task Force to examine invasive species issues, and develop an Aquatic Nuisance Species plan to become eligible for Federal funding.

Implementation: Ongoing

OBJECTIVE 9: Implement fisheries dependent and independent monitoring programs to obtain sufficient and accurate data for managing hard clams.

Problem 9.1: Stock Assessment - Assessments of the coastal bays hard clam stock historically have been sporadic with many years between surveys. Since 1993, DNR's shellfish program has been conducting population surveys on an annual basis.

Action 9.1.1 - DNR will continue to survey the hard clam resource on annual basis in Maryland's coastal bays to facilitate management decisions.

Implementation: Ongoing

Problem 9.2: Assessment of Bottom Enhancement Activities - Bottom enhancement activities need to be assessed to determine if these efforts are improving clam recruitment.

Action 9.2.1: Design and implement a program to monitor the efficacy of bottom enhancement activities.

Implementation: Dependent on funding.

Problem 9.3: Commercial Catch, Effort and Economic Data - The present system does not provide adequate reporting of harvest information. Improving the commercial reporting system for hard clams will facilitate management and generate additional funding through the shellfish tax for bottom enhancement activities. Catch information is currently obtained through dealer reports that are believed to be under-reporting the harvest.

Action 9.3.1 - DNR will establish, implement and evaluate a commercial reporting program to obtain accurate catch, effort and economic data from anyone harvesting hard clams in Maryland's coastal bays. This action is consistent with action 2.1.2.

Implementation: 2002

Problem 9.4: Recreational Catch, Effort and Economic Data - There is no information on harvest, effort, and economic impact of recreational clamming in the coastal bays.

Action 9.4.1: DNR will facilitate the design and implementation of a recreational clamming survey in Maryland's coastal bays.

Implementation: Dependent upon funding.

References

Beal, B.F. 2000. The importance of temporal and spatial replication of field experiments: effects of seagrass cover on the growth and survival of cultured juveniles of the soft-shell clam, *Mya arenaria*, and hard clam, *Mercenaria mercenaria.* 20th Milford Aquaculture Seminar (abstract).

Boynton, W. 1970. The commercial fisheries of Chincoteague Bay - past, present, and future. *In*: Assateague Ecological Studies, Part I: Environmental Information. Nat. Res. Inst. Univ. Md. Contrib. no. 446.

Brey, W.E. 1979. Appendix C. National Marine Fisheries Service clam landings for Maryland. *In*: DNREC, Shellfisheries Management Plan for: Indian River, Indian River Bay, and Rehoboth Bay.

Casey, J. 1972. Experimental seed clam planting in Maryland's oceanside bays begun. Commer. Fish. News. 5(6): 4.

Casey, J. 1974. Hard clam planting program by DNR continues in Maryland's oceanside bays. Commer. Fish. News. 7(3): 2.

Casey, J. 1978. DNR continues hard clam repletion program. Commer. Fish. News. 11(1): 3.

Conservation Department of the State of Maryland. 1931. Ninth Annual Report, p. 23-25.

Conservation Department of the State of Maryland. 1933. Eleventh Annual Report, p.18-21.

Davis, H. C. and P.E. Chanley. 1956. Spawning and egg production of oysters and clams. Proc. Natl. Shellf. Asoc. 46:40-58

Delaware Department of Natural Resources and Environmental Control (DNREC). 1979. Shellfisheries Management Plan for: Indian River, Indian River Bay, and Rehoboth Bay.

Drobeck, K., H. Hidu, J.M. Odell and W. Boynton.1970. Chincoteague and Sinepuxent Bay benthos. *In*: Assateague Ecological Studies, Part I: Environmental Information. Nat. Res. Inst. Univ. Md. Contrib. no. 446.

Earll, R.E. 1887. Maryland and its fisheries. *In*: G.B. Goode (ed.), The Fisheries and Fishery Industries of the United States. Sec. II. p. 424-426. Gov. Print. Off., Wash.

Ford, S.E. 1997. History and present status of molluscan shellfisheries from Barnegat Bay to Delaware Bay. *In*: C.L. Mackenzie, Jr., V.G. Burrell, Jr., A. Rosenfield, and W.L. Hobart (eds.). The history, present condition, and future of the molluscan fisheries of North and Central America and Europe, Vol.

1, Atlantic and Gulf Coasts. U.S. Dept. Commer., NOAA Tech. Rep. 127, p. 119-140.

Grizzle, R.E., V.M. Bricelj, and S.E. Shumway. 2001. Physiological ecology of *Mercenaria mercenaria*. In: Biology of the Hard Clam. J.N. Kraeuter and M. Castagna (eds.). Elsevier, Amsterdam. 751 pp.

Hibbert, C.J. 1976. Biomass and production of a bivalve community on an intertidal mud-flat. J. Exp. Mar. Biol. Ecol 25(3): 249-261.

Ingersoll, E. 1881. The oyster industry. *In*: G.B. Goode (ed.), The History and Present Condition of the Fishery Industries. Gov. Print. Off., Wash., 251 pp.

Ingersoll, E. 1887. The oyster, scallop, clam, mussel, and abalone industries. *In*: G.B. Goode (ed.), The Fisheries and Fishery Industries of the United States. Sec. II. p. 507-626. Gov. Print. Off., Wash.

Kraeuter, J. and M. Castagna. 1980. Effects of large predators on the field culture of the hard clam, *Mercenaria mercenaria*. Fish. Bull. Vol. 78 (2): 538-541.

Mackenzie, C.L. Jr.1997a. The U.S. molluscan fisheries from Massachusetts Bay through Raritan Bay, N.Y. and N.J. *In*: C.L. Mackenzie, Jr., V.G. Burrell, Jr., A. Rosenfield, and W.L. Hobart (eds.). The history, present condition, and future of the molluscan fisheries of North and Central America and Europe, Vol. 1, Atlantic and Gulf Coasts. U.S. Dept. Commer., NOAA Tech. Rep. 127, p. 87-117.

Mackenzie, C.L. Jr.1997b. The molluscan fisheries if Chesapeake Bay. *In*: C.L. Mackenzie, Jr., V.G. Burrell, Jr., A. Rosenfield, and W.L. Hobart (eds.). The history, present condition, and future of the molluscan fisheries of North and Central America and Europe, Vol. 1, Atlantic and Gulf Coasts. U.S. Dept. Commer., NOAA Tech. Rep. 127, p. 141-169.

Manning, J.H. 1957. The Maryland soft-shell clam industry and its effects on tidewater resources. Md. Dep. Res. Educ. Resour. Study Rep. 11. 25 p.

Maryland Board of Natural Resources. 1958. Fifteenth Annual Report, p. 39.

Maryland Board of Natural Resources. 1966. Twenty-third Annual Report, p. 40.

Maryland Board of Natural Resources. 1967. Twenty-fourth Annual Report, p. 35.

Maryland Fisheries. 1931. Salting the bays of Worcester County. 9: 10-11.

Murphy, G.L. 1960. Commercial fisheries catch statistics of major species landed in Worcester County, Maryland. Md. Dept. Res. & Edu., CBL, Ref. No. 60-5.

Peterson, C.H., H.C. Summerson, and P.B. Duncan. 1984. The influence of seagrass cover on population structure and individual growth rate of a suspension-feeding bivalve. *Mercenaria mercenaria*. J. Mar. Res., 42: 123-138.
Roegner, G.C. and R. Mann. 1991. Hard clam, *Mercenaria mercenaria*. In: Habitat Requirements for Chesapeake Bay Living Resources, eds. S.L. Funderburk, J. A. Mihursky, S.J. Jordan, and D. Riley. Living Resources Subcommittee, Chesapeake Bay Program.

Scott, R. 1981. Shell planted on public bottom in Chincoteague Bay to aid hard clam set. Tidewater Fish. News, 14(5): 2-3.

Sieling, F.W. 1956. The harshell clam fishery in Maryland waters. Md. Tidewater News. Vol. 12 (10), Suppl. No. 9. 2 pp.

Stanley, J.G. and R. DeWitt. 1983. Species Profiles: Life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) - Hard Clam. U.S. Fish Wildl. Serv. FWS/OBS-82/11.18. U. S. Army Corps of Engineers, TR EL-82-4. 19 pp.

Stanley, S.M. 1970. Relation of Shell Form to Life Habits of the Bivalvia (Mollusca). Geol. Soc. Amer., Mem. 125. 296 pp.

Truitt, R.V. & M.G. Les Callette. 1977. Worcester County, Maryland's Arcadia. Wo. Co. Hist. Soc., Snow Hill, Md. 579 pp.

Virginia Marine Resources Commission (VMRC). 1997. Virginia Fisheries Management Plan, Hard Clam.

Wells, H.W. 1957. Abundance of the hard clam, *Mercenaria mercenaria*, in relation to environmental factors. Ecology 38: 123-128.

Appendix I. A literature review of the ecological effects of hydraulic escalator dredging.

A LITERATURE REVIEW
of
THE ECOLOGICAL EFFECTS of HYDRAULIC ESCALATOR DREDGING

REPORT TO THE
COASTAL BAYS FISHERIES ADVISORY COMMITTEE

Prepared by
Mitchell Tarnowski

Maryland Department of Natural Resources
Fisheries Service
Shellfish Program

September, 2001

TABLE OF CONTENTS

I. EFFECTS ON SUBSTRATE

II. BIOLOGICAL EFFECTS

Clams

Other Benthic Fauna

Submerged Aquatic Vegetation

III. THE COASTAL BAYS ECOSYSTEM

Limitations on the Fishery

EXECUTIVE SUMMARY

At the request of the Coastal Bays Fishery Advisory Committee, MDNR Shellfish Program staff undertook a literature review on the ecological effects of the hydraulic escalator dredge. In order to accommodate a wider range of studies, the review was expanded to include not only the hydraulic escalator dredge but other comparable fishing gear and natural disturbances of similar or larger scale. Because of the sheer volume of material on the subject of ecosystem disturbances, this review is by no means exhaustive. Nonetheless, the papers are a fair representation of this topic that can be applied to the Maryland coastal bays.

As the hydraulic dredge moves along, the hydraulic jets cut into the bottom, leaving behind a trench. The width of the cut generally conforms to the width of the dredge; in Maryland the water manifold across the leading edge of the dredge cannot exceed 36 in. The depth of the track is largely determined by the target species. Since hard clams live close to the surface of the substrate, a coastal bays hydraulic escalator dredge is typically set to cut 2.5 - 4 in. below the bay bottom, leaving behind a trench four to eight inches deep. Prop wash in shallow water can scour out deeper trenches. The tracks have been reported to persist anywhere from a few hours to three years, depending on the erosional characteristics of the site; the majority of the studies found that the tracks disappeared within one to two months. Because of the shallow nature of the Maryland coastal bays, wind events can readily disturb the bottom, resulting in short persistence times for dredge tracks. The primary exception is in vegetation beds, where trenches were noticeable for at least a year due to the energy dampening and sediment stabilizing effects of the seagrasses.

The amount of incidental sedimentation outside of the dredge track depends on the type of substrate being worked as well as currents and depth of cut. The maximum distance of detectable deposits resulting from hydraulic dredging was 75 ft. from independent studies in Maryland and Virginia. Another study in Maryland found negligible sedimentation at 15 ft. from a dredging site.

The silt/clay particles stirred up by the hydraulic dredge remain in suspension the longest, resulting in a turbidity plume. Hence, the total amount of suspended solids in the plume and its duration depends on substrate composition, while the distance and direction the plume travels is a function of water currents. The depth of the cut will also affect sediment loadings. In an extreme case, suspended solids measured at the conveyor belt of a dredge working in a silt/clay mud flat dropped by an order of magnitude within a distance of 200 ft., although a plume was still visible. Values at the dredge were about 30% higher than background silt loadings; at 200 ft. plume concentrations were well below maximum background levels. Other studies have shown that natural environmental factors such as wind and tidal-induced events can produce background particle loadings that equal or exceed levels resulting from dredging.

The winnowing of sediments by the dredge can leave the track with a lower silt/clay content, depending on the initial sediment makeup. Changes in sediment composition in the coastal bays due to clam dredging likely are insignificant compared to natural processes. This system is a high energy, erosion/deposition environment, resulting in the addition of both silt/clays and sand into the bays. Biological processes also play a factor, with previously sandy bottoms in seagrass beds accumulating a surface covering of fine particles and organic detritus. Thus, as seagrasses expand there is a net loss of surficial sand substrate.

The effect of hydraulic dredging on cultch (shell or other hard fragments that provide habitat for epibenthic organisms) depends on the environment and circumstances in which it occurs. Exposed cultch located immediately downcurrent from dredging can be buried by a layer of displaced sediment. The distance the cultch will be affected is influenced by sediment type and currents. On the other hand, there is evidence that the hydraulic escalator dredge can expose previously buried shell, leaving it accessible to organisms.

Toxic contaminants in the sediment such as heavy metals and hydrocarbon compounds, if resuspended, can be concentrated by filter-feeding organisms. One study concluded that in areas of low initial concentrations contaminant resupension from hydraulic escalator dredging is not a problem. Aside from the relatively low contaminant levels in the Maryland coastal bays, there are other ameliorating factors concerning this issue. Clam dredging only superficially penetrates the substrate compared to activities such as channel dredging and sand borrows. Contaminant accumulation is unlikely to build up in clamming areas due to naturally occurring surficial sediment disturbances such as storms and bioturbation. In addition, since biological activity is lowest during the winter months when much of the clamming takes place, potential bioaccumulations of contaminants through filtration is minimal.

In contrast to a conventional dredge which forces its way into the bottom, the hydraulic escalator dredge uses jets of water to cut through the substrate, suspending animals and floating them onto the conveyor belt. As a result of this jetting action the majority of the catch is largely undamaged. Mortalities of the fragile softshell clam averaged 5% due to a hydraulic dredge, compared with a 50% mortality associated with hand digging. Juvenile clams were no more prone to incidental damage from the hydraulic dredge than the adults. Hard clams, because of their thick and heavy shell, are even less susceptible to breakage, with about one in 2,000 clams damaged by the hydraulic escalator dredge. One of the rationales for legalizing this gear in the coastal bays was that it would reduce incidental clam mortalities compared with the conventional dredges in use at the time. Both juvenile and adult hard clams have the ability to dig through the thin overburden of sediment cast by the dredge. Hydraulic dredging does not seem to have a negative impact on clam recruitment, but whether settlement and recruitment is enhanced by tilling the substrate with the hydraulic harvester is uncertain.

Predatory species such as crabs and fish may benefit from exposure of prey items by dredging. However, much of the clamming season occurs during the colder months when predators are either inactive or have left the area.

Benthic faunal communities in high disturbance areas such as coastal ecosystems readily recover and persist in the face of environmental perturbations, whether acute or chronic. Recovery of community parameters such as abundance, diversity, structure, and function is usually on the order of months, largely depending on the reproductive cycles of the constituent species. A study evaluating four years of intensive dredging within a confined (1 km^2) area found no effect on the functioning and production of the zoobenthic community, despite a decrease in overall biomass due to the harvesting of two comparatively large, slow growing target species.

The direct impact of dredging on seagrass beds is catastrophic, with plants completely uprooted in the process. Vegetative recolonization can be slow, on the order of two years or more. Repeated dredging within a bed can greatly restrict or completely inhibit recovery. Dredge tracks, which persist for longer periods in rooted vegetation, can be subjected to disturbances which may suppress seed germination, further delaying recovery.

The impact of turbidity plumes on seagrasses is less clear. The possibility of localized effects on the grass beds is reduced by a number of factors. Most of the seagrass beds are located adjacent to sandy areas which produce less of a plume due to fewer silt/clay particles; even plumes in siltier substrate can be expected to be largely dissipated within 100 meters. Wind, the primary agent of water movement in Chincoteague Bay, does not always direct the plumes towards the seagrass beds. In addition, during the course of a season clammers move around to different areas and are not necessarily in close proximity to the seagrass beds. Despite an increase in harvesting activity over the past few years, seagrass acreage in the Maryland coastal bays has tripled during this same period. Whether the rate or extent of seagrass increase was indirectly affected by clam dredging is unknown.

In summary, the ecological effects of hydraulic escalator dredging may be largely mitigated by the physical dynamics of the coastal bays ecosystem as well as the characteristics of the benthic faunal community that has developed under such conditions. Regulatory restrictions further reduce the impact of this activity through a closed season during the warmer months when biological processes such as feeding, respiration, growth, reproduction, and recruitment are at their peak and by prohibiting harvesting in vulnerable seagrass beds. If concerns regarding these issues still persist among resource management and user groups, they can be properly addressed only through directed studies.

INTRODUCTION

Since its introduction in the early 1950's, the hydraulic escalator dredge has been met with reactions ranging from vociferous opposition to healthy scepticism and cautious acceptance to enthusiastic embrace. As a result, a number of studies on the impact of this device have been conducted over the years in Maryland, where it was invented, as well as other regions. The earliest studies investigated its effect on softshell clam and neighboring oyster populations, including physical alterations to the habitat. Later research attempted to take a more comprehensive approach, looking at various ecosystem components such the benthic faunal community and seagrasses.

At the request of the Coastal Bays Fishery Advisory Committee, MDNR Shellfish Program staff undertook a literature review on the ecological effects of the hydraulic escalator dredge. Since many of these studies were narrowly focused, the review was expanded to accommodate a wider range of impacts, including other comparable fishing gear and natural disturbances of similar or larger scale. Because of the sheer volume of material on the subject of ecosystem disturbances, this review is by no means exhaustive. Nonetheless, the papers are a fair representation of this topic that can be applied to the Maryland coastal bays.

I. EFFECTS ON SUBSTRATE

Dredge Tracks

As the hydraulic dredge moves along, the hydraulic jets cut into the bottom, leaving behind a trench. The width of the cut generally conforms to the width of the dredge; in Maryland the water manifold across the leading edge of the dredge cannot exceed 36 in. (COMAR 08.02.02.03). The depth of the track is largely determined by the target species. Softshell clams in Chesapeake Bay live deep in the substrate; consequently dredges are set to cut between 18 in. and 24 in. below the surface of the bay floor (Glude, 1954). On the other hand, hardshell clams, with their shorter siphons and heavier shells, live close to the substrate surface. Typically, a coastal bays hydraulic escalator dredge is set to cut 2.5 - 4 in. below the bay bottom.

The trench is partially backfilled by heavier sediment particles coming almost immediately out of suspension as well as clumps of sediment deposited off the end of the escalator belt. The degree of backfilling is determined primarily by sediment characteristics. Fine sediments tend to remain in suspension longer and may be carried away from the track by currents. At the same time, sediments with high clay content tend to stay clumped so that they are redeposited off the belt. Although propeller wash can assist in filling in the trench (Glude, 1954), in very shallow water prop wash can actually scour out the backfill, deepening and widening the track (Manning, 1957; MacPhail, 1961; Godcharles, 1971). This can be remedied by use of a simple prop guard or shield (MacPail, 1961). The drawback is that it reduces boat speed by about 15%.

The length of time required for the dredge tracks to fill in is highly variable, depending on location as well as the original depth of the trench. Factors that affect track persistence include sediment type, depth, wind and tidal currents, vegetation, and whether an area is subtidal or intertidal.

Sandy bottoms appear to recover quickly, often on the order of days. Glude (1954), using the recently developed SCUBA, observed an area of coarse sand in the Miles R. (Maryland) which had been extensively clammed. The bottom appeared fairly uniform with wave produced ripples and an occasional depression 4 - 10 in. deep. Nowhere were deep furrows or holes found. He does not comment on how recently clamming activity had taken place in the area. In Virginia, Haven (1970), using a hard-clam hydraulic dredge on sandy bottom, observed trenches up to 4 - 6 in. deep; these filled in within one to two months. Godcharles (1971) found that sand in high energy areas recovered almost immediately (one day). Other sand trenches lasted one week with no evidence whatsoever after three months; they had firmed up over that period of time. Caddy (1973), citing another study, states that clamming tracks last several days; no details are provided. The track of a hydraulic dredge 4 ft. wide and 9 in. deep through silty sand was difficult to recognize after 24 hours (Meyer et al., 1981). Hall et al. (1990), using a suction dredge on sandy bottom at a depth of 7 m. (23 ft.), saw no evidence of dredging after 40 days, despite the initial presence of holes 3.5 m wide and 0.6 m deep (11.5 ft. by 2 ft.). The intervening period was characterized by stormy conditions which stirred the bottom. Eleftheriou and Robertson (1992), dragging a scallop dredge on sand in depths less than 10 m (33 ft.), observed that although furrows were evident initially (1.2 m/4 ft. wide by 0.04 m/1.5 in. deep), they were eliminated shortly after the four days of experimental dredging had ended. They concluded that track persistence depended on wave action and tidal condition; the experiment site was characterized as a high energy embayment.

Dredge tracks persist longer in bottoms with lower potential for erosion. These include both fine, consolidated sediments and coarser grained substrates such as gravel, some intertidal flats, established vegetation beds, and probably most importantly, areas with low energy regimes including deeper regions removed from wave action.

Fine, consolidated sediments in low energy systems allow tracks to persist, as in the Lagoon of Venice, where tracks originally 9 ft. wide and 4 in. deep in a silt bottom were still evident two months later[8] (Pranovi & Giovanardi, 1994). The extent of recovery over this period was not described. In comparison, Manning (1957) found that tracks in a firm, muddy bottom had filled in from an average of 5 in. to an average of 3 in. deep four to six days after dredging. These were obliterated in a relatively short period of time (no specifics provided) but some of the tracks remained soft after four months. The difference is that a strong tidal current (up to 1 kn.) existed at the Manning study site. Tracks through coarse sediments such as gravel (1 cm diameter) can also persist for extended periods, particularly in low current environments, although no time estimate was provided (Caddy 1973).

Dredging in an intertidal setting may increase track persistence. Hydraulic escalator dredge tracks through an intertidal flat of compact mud in Maine were noticeable for up to one and a half years, while cuts in an intertidal silty sand flat in Washington were observed for up to three years (Kyte & Chew, 1975). Kyte and Chew (1975) speculate that intertidal flats are more compact and stable than comparable subtidal habitats due to draining and drying when the tide is out, resulting in much more persistant cuts. However, they do not comment on the energy regimes of these study sites. In contrast, Beukema (1992) noted that dredge tracks through an intertidal sand flat in Holland comparable to those of a Maryland clam dredge were erased in a matter of days by tidal currents.

---

[8] These may also have been in *Zostera* beds (see paragraph below on vegetation beds).

Established vegetation beds can stabilize the substrate and dampen the effect of waves and currents, allowing dredge tracks to remain longer. Godcharles (1971) observed evidence of trenching in submerged aquatic vegetation (*Thallassia*) from one to ten months. The most long-lived track he recorded, 11 months, was through a cover of *Caulerpa*[9], a macroalga that establishes persistent, non-transient beds by means of rhizomes which maintained the shape of the trench. This was also in shallow water where the prop wash scoured the bottom, so that some of the trenches were up to 18 in. deep. Although at most of Godcharles' sites the substrate within the trench hardened to pre-dredging consistency inside of a month, some spots in the vegetation beds remained soft for over 500 days.

Sedimentation

Immediately after suspension by the water jets of the dredge, the heaviest material such as pebbles, coarse sand, and shell fragments settle out, followed by progressively smaller particles from medium to fine and very fine sand, and finally the silts and clays. Thus the amount of incidental sedimentation outside of the dredge track depends on the type of substrate being worked as well as currents.

From an experiment in which an escalator dredge worked on a section of muddy creek bottom for nine hours, Manning (1957) estimated that sedimentation was not detectable beyond 75 ft. downstream of the dredged area. All dredging was done on ebb tide with currents approaching 1 kn. The boat ran aground several times, displacing additional sediments by prop wash. Intermediate distances downcurrent of the dredged area had sediment deposits of about 1.2 in. at 25 ft. and 0.6 in. at 50 ft. Haven (1970), testing a hydraulic escalator dredge in Virginia, concurred that deposition of sediments is negligible 75 ft. downcurrent from dredging. In comparison, Drobeck and Johnston (1982), repeating the Manning study but in sandy substrate, found sedimentation greatly reduced. Sediment accumulation was approximately ⅛ in. at 15 ft. downcurrent of the dredging zone. In addition to the difference in substrate type, Manning's Cox Creek site was considerably more narrow and shallow than the later experimental site in the Patuxent River, which had maximum currents of 0.27 kn.

Black and Parry (1999) are in agreement with the above studies. A 10 ft. wide scallop dredge towed at 6 kn over fine sand and muddy fine sand bottoms deposited 2 mm (0.08 in.) of sediment within a few meters of the dredge; at 20 m (66 ft.) deposition was negligible (0.1 mm/0.004 in.).

Turbidity Plumes

The silt/clay particles stirred up by the hydraulic dredge remain in suspension the longest, resulting in a transient turbidity plume. Thus, the total amount of suspended solids in the plume and its duration depends on substrate composition, while the distance and direction the plume travels is a function of water currents. The depth of the cut, hence the volume of displaced sediments, will also affect the concentration of suspended particles.

---

[9] *Thallasia* (turtlegrass) is replaced by *Zostera* (eelgrass) in more northern areas, including Maryland. *Caulerpa* or equivalent rhizomatous macroalgae species that establish stable beds are not found in the coastal bays; most of the species there are drift macroalgae or those attaching to structure, particularly seagrasses, and are usually transient.

Values as high as 584 mg/l of suspended solids were recorded at the conveyor belt of a dredge working in a silt/clay mud flat (Kyte & Chew, 1975). This value rapidly dropped to 89 mg/l at a distance of 61 m (200 ft.) from the dredge, although a plume was still visible. Background silt loadings at the site varied from 4 to 441 mg/l.

Using a 10 ft. wide scallop dredge, Black and Parry (1999) conducted a detailed analysis of plume dynamics. They found particle concentrations in a sediment plume to be 2-3 orders of magnitude higher (2000 - 5000 mg/l) than background levels in the first 20 sec. after dredging. This quickly dropped so that after 9 min. suspended sediment concentrations were equivalent to values during a large storm, and after 30 min. sediment loadings had dropped 98%, bringing them back to natural background levels. After one hour particle concentrations were extremely low (10 mg/l or 0.2% of initial values); by this time the plume had moved 350 m. Plume sediments beyond 50 m of the dredge were entirely silts and clays. These values were for a muddy sand (30% mud) bottom; plumes in sandier areas dropped out more rapidly. The authors concluded that low concentrations of suspended fine grain particles (silt and clay) may be present for several hours but that suspended sediment concentrations more than 100 m (328 ft) from a dredge are insignificant and would not induce far-field effects.

Ruffin (1995) studied the effects of softshell clam dredging on turbidity in the Chester River, Maryland. Although there are key differences between this system and the coastal bays in geomorphology, hydrodynamics, energy input, substrate composition, and clamming methodology (eg. dredging depth), this is the only study to have looked at the plumes resulting from this activity in terms of light attenuation and persistence. The greatest increase in turbidity was found in shallow water with fine-grained sediments. The plumes dissipated rapidly at first as the larger particles settled out. Estimates of time to return to background levels were much higher than those of Black and Parry (1999), averaging 2.9 hours for turbidity and 4.8 hours for light attenuation; generally, values approached background levels much sooner than these averages (i.e. plume dissipation was exponential rather than linear, except in the shallowest areas). Eulerian (fixed location) time-series in shallow water were even longer, taking up to 22 hours for the light attenuation coefficient to return to background levels. Plumes in shallows persisted longer than in deeper areas. Based on aerial photos, the plume area was extremely variable among boats and river systems, averaging 8 ha/boat in the Chester River and 4.5 ha/boat in the Wye River.

Natural environmental factors can produce background particle loadings that equal or exceed levels resulting from dredging. A study in Washington found values of 32 to 54 mg/l in the vicinity of a hydraulic escalator dredge, while a nearby river mouth produced levels of 39 to 63 mg/l (Kyte & Chew, 1975). Light transmission varied from 4 to 80 percent at the dredge and 2 to 65 percent at the river mouth. The investigators concluded that the effects of the clam harvester on water quality were minor compared to the river. Drobeck and Johnston (1982) arrived at a similar conclusion, stating that wind and tidal-induced events may have a more profound effect on the total suspended sediment load at their experiment site in the Patuxent River than does dredging. Control values ranged from 51 to 101 mg/l in the three days before the dredging experiment; average levels for these control days were 89.7 mg/l, 81.0 mg/l, and 68.15 mg/l. The mid-impact zone immediately prior to dredging had levels between 37 and 75 mg/l, averaging 55.2 mg/l, while during dredging these ranged between 37.5 and

112 mg/l with an average of 64.4 mg/l. Bioturbation, the reworking of sediment by benthic fauna, can also elevate turbidity, with values as high as 35 mg/l within 3 m of the bottom reported by Rhoads (1973).

Bottom Composition

The winnowing of sediments by the dredge can leave the track with a lower silt/clay content, depending on the initial sediment makeup. In relatively homogenous, muddy sediments there was no detectable difference in sediment composition after dredging (Kyte & Chew, 1975). Sandier areas showed varying degrees of change and recovery, depending on the heterogeneity of the substrate and the energy regime of the area. Immediately after dredging, Haven (1970) reported a decline of fines in a predominantly sand bottom; no change in bottom composition was detected beyond 75 ft. Recovery time was not investigated. Godcharles (1971) found that two of six stations showed measurable losses of silt/clay particles after dredging. One station recovered to pre-dredging proportions but the changes persisted at the second station over a one year monitoring period. Pfitzenmeyer (1972) did not observe a loss of fines from a low silt/clay content bottom in Chesapeake Bay. Also, organic carbon content was not significantly different after dredging. Working in a high energy area with a predominantly sand bottom, Eleftheriou and Robertson (1992) found no change in sediment grades or organic carbon content after a scallop dredge had been dragged through the same track up to 25 times. In Washington, reduced levels of silt/clay particles and organic carbon persisted for several months (Kyte & Chew 1975). Details such as degree of change and length of time were not provided.

In certain situations, long-term intensive harvesting may result in a shift in bottom composition. In the Lagoon of Venice, a "moderate/low energy" ecosystem in Italy, clamming is concentrated in a relatively confined portion of the lagoon (~18 km^2 /7 mi^2) using large (9 ft. wide) hydraulic dredges (Pranovi & Giovanardi, 1994). Despite the fact that it was prohibited by law, this activity had markedly increased in the five to ten years prior to this study. Experimental dredging did not significantly affect particle size immediately before and after the treatment, both in clamming areas and non-clamming areas. However, the results of a sediment study conducted in the clamming areas a few years before clamming intensified showed a significant shift to sandier substrate over the intervening period. No such change had occurred in the non-clamming area.

Rice et al. (1989), found a slight but statistically higher amounts of very fine sand, silt, and clay in non-clamming areas when compared to clamming areas in Rhode Island, but there was no difference in the total organic carbon between the two sites. The non-clamming areas had been closed since the 1930's. The authors noted that clamming activity, using tongs and bullrakes, stirs up the sediments.

Changes in sediment composition in the coastal bays due to clam dredging likely are insignificant compared to natural processes. This system is a high energy, erosion/deposition environment, resulting in the addition of both silt/clays and sand into the bays (Bartburger & Biggs, 1970; Boynton & Nagy, 1993). Biological processes also play a factor, with previously sandy bottoms in seagrass beds accumulating a surface covering of fine particles and detritus sometimes ankle deep (pers. observ.). Thus, as seagrasses expand there is a net loss of sandy substrate.

Cultch

The effect of hydraulic dredging on cultch (shell or other hard fragments that provide habitat for epibenthic organisms) depends on the environment and circumstances in which it occurs. Exposed cultch located immediately downcurrent from dredging can be buried by a layer of displaced sediment (Manning, 1957; Drobeck & Johnston, 1982). The distance the cultch will be affected is influenced by sediment type and currents.

On the other hand, evidence suggests that the hydraulic escalator dredge can retrieve previously buried shell, leaving it accessible to organisms. The Canadian Department of Fisheries demonstrated the dredge's ability to clean oyster bars (MacPhail 1961). As a result of escalator dredging, Haven (1970) reported surface shell covering 20% of what had been bare sand bottom. Godcharles (1971) noted that buried shell had been dredged up and redeposited in and alongside the dredge track, leaving it exposed on the bottom. In contrast, although Drobeck and Johnston (1982) observed oyster shell on the escalator belt, there was no evidence of this shell at the substrate surface; only softshell clam shells were seen. Presumably the heavier oyster shell had been reburied in the deeper track of the softshell clam dredge.

Apparently, cultch skimmed with a shallow dredge setting from a thick shell base would be less likely to get reburied because there is no sediment involved save what had been on the shells. A hydraulic escalator dredge recently was used to clean relict oyster bars in the seaside bays of Virginia (J. Wesson, VMRC, pers.com.). This year, MDNR will experiment with this technique to retrieve buried shell in Chesapeake Bay.

Chincoteague Bay has relatively little in the way of exposed cultch. Most of the old oyster bars have long been buried to varying degrees through natural sedimentation (Sieling, 1960; Tarnowski, 1997). Although the hydraulic escalator dredge can bring up lightly buried shell, whether this shell remains exposed when returned to the bottom is unknown. The more deeply buried shell probably would not be exposed through routine dredging operation.

Substrate Contaminants

Toxic contaminants in the sediment such as heavy metals and hydrocarbon compounds, if resuspended, can be concentrated by filter-feeding organisms. After conducting an elemental analysis of the silt/clay fraction at their experiment site, Drobeck & Johnston (1982) concluded that in areas of low initial concentrations contaminant resupension is not a problem as the fine particles are diluted in distribution.

The Maryland coastal bays have generally low levels of substrate contaminants (EPA 1996). Of the 45 compounds and elements tested, none exceeded effects-range medium (ER-M) values in the bays proper, using the stringent Long and Morgan thresholds[10]. It should be noted that only one sample each was taken in Assawoman and Sinepuxent Bays (exclusive of the dead- end canals), while four samples were obtained from Chincoteague Bay. Effects-range low (ER-L) values were barely exceeded for at most three contaminants at these sites. These were nickel, arsenic, and DDT as shown

---

[10] The U.S. EPA (1996) used these particular thresholds because values were available for most of the contaminants tested. According to their report, this method is more conservative than other means of determining contaminant thresholds, such as the EPA Sediment Quality Criteria. When applied to this study, the standard EPA criteria and other alternative approaches reduced the apparent number and geographic extent of exceedences.

in Table 1a for the "remaining Maryland" sites (specific sites were not characterized in the report; values were lumped into either artificial lagoons, St. Martin River or remaining Maryland). Three other compounds listed by the MCBP (1997) report as potential problems in the combined Delaware-Maryland coastal bays system were below thresholds in the Maryland bays proper (Table 1b), as were the remaining contaminants tested for by the EPA (1996). In contrast, more contaminants were found with higher concentrations in the dead-end canals due to their poor flushing characteristics and proximity to sources.

Aside from the relatively low contaminant levels in the Maryland coastal bays, there are other amelioratory factors concerning this issue. Contaminant accumulation is unlikely to build up in clamming areas due to naturally occurring surficial sediment disturbances such as storms and bioturbation (Rhoads, 1973; Kraeuter & Fegley, 1994). Furthermore, clam dredging only superficially penetrates the substrate compared to activities such as channel dredging and sand borrows. In addition, since biological activity is lowest during the winter months when much of the clamming takes place, potential bioaccumulations of contaminants through filtration is minimal.

II. BIOLOGICAL EFFECTS

Clams

Market Clams

A towed, non-hydraulic dredge captures the targeted species by mechanically forcing its way through the bottom; towed Shinnecock or bull rakes function in a similar fashion. In comparison, the hydraulic dredge use jets of water to cut through the substrate; the leading edge or knife of the dredge collects the objects suspended by the jets but generally is not forced through the bottom. Also, the conveyor system helps reduce incidental damage. A non-conveyor dredge, as it begins to fill, drops in efficiency so that animals are cast aside rather than gathered into the dredge (Meyer et al. 1981). Those animals are often left damaged or exposed to predators. In addition, more fragile species can be crushed as the dredge travels along the bottom accumulating its catch; some dredges can collect hundreds or even thousands of pounds of shellfish. The conveyor belt of the hydraulic escalator dredge prevents the catch from accumulating by continuously moving animals and debris away from the head of the dredge, keeping them spread out and reducing the possibility of them being damaged.

The hydraulic escalator dredge was developed in Maryland originally to harvest subtidal populations of softshell clams (*Mya arenaria*), which as the name implies have thin, fragile shells. As a result, most of the early research concerning impacts from this device focused on softshell clams as well as neighboring oyster bars.

In New England and eastern Canada, digging softshell clams manually results in non-catch mortalities of about 50%, contributing to the decline of the populations in these areas during the 1950's (MacPhail, 1961; Kyte & Chew, 1975). In contrast, softshell clam mortalities due to the hydraulic escalator dredge averaged about 5% with 10% as an extreme (Medcof 1961). Kyte and Chew (1975) offer a slightly higher average of 9.6% which they attributed to operator inexperience and the extremely compact nature of the substrate. Incidental mortalities of clams left in the bottom was almost non-existent since the harvester is over 95% efficient (MacPhail 1961).

Hard clams, because of their thick and heavy shell, are even less prone to breakage. In Virginia, Austin and Haven (1981) found about one in 2,000 clams were damaged by the hydraulic escalator dredge. One of the rationales for legalizing this gear in the coastal bays was that it would reduce incidental mortalities compared with the conventional dredges in use at the time (Md. Bd. Nat. Res., 1967).

Juvenile Clams

The effect of the hydraulic escalator dredge on juvenile softshell clams has been systematically studied (Medcof, 1961; Haven, 1970; Pfitzenmeyer, 1972; Kyte & Chew, 1975). As with adults, mortalities attributable to this gear are slight. Small clams either slip through the belt or are carried off the end of it; most of the clams are redeposited back in the track or immediately adjacent to it (Medcof, 1961). The juveniles can readily reburrow because of the softened sediment in the track (Medcof, 1961; Pfitzenmeyer & Drobeck, 1967). However, redigging times are variable and in the interim the small clams are vulnerable to predation. Kyte and Chew (1975) suggest that mortalities of softshell clams in Maine were probably higher than the breakage rate due to the inability of the clams to reburrow into the hard, compact sediments of an intertidal flat, leaving them as prey to gulls. Highly motile predators such as crabs and fish have been observed moving into dredge tracks within an hour of dredging (Caddy, 1973). Hard clam juveniles, possessing stout shells that they can close tightly, are less vulnerable than softshell clams of comparable size, which have thin shells that gape. Nevertheless, predation of redeposited hard clam juveniles can possibly be a problem during the warmer months. As temperatures cool predation drops off; predators are either inactive or leave the area during the colder months when most clamming takes place. Blue crabs, one of the most important predators of hard clams, stop feeding when water temperatures drop below 10°C (Van Heukelem, 1991). In Maryland, Drobeck and Johnston (1982) did not consider predation to be a serious factor by mid-October. Haven (1970) states that predators become active around the beginning of May in Virginia.

Hard clams, both juveniles and adults, have the ability to dig through the thin overburden of sediment cast by the dredge, since they can escape burial in 10 - 85 cm of native sediment (Kranz, 1974; Maurer et al., 1980). Young clams can dig out of sediment depths at least five times their shell height (approximately seven times their length) (Stanley & DeWitt, 1983). Burrowing takes place even at winter temperatures and burial survival is enhanced during this period (Maurer et al. 1980).

Suspended sediments can reduce filtration and growth in hard clams (Roegner & Mann, 1992). Sediment plumes from dredging are ephemeral, however, quickly subsiding after operations cease for the day (Black & Parry 1999), particularly in the sandy substrate where clams are more abundant and where harvesters would more likely be working (Wells, 1957; Drobeck et al., 1970). The eggs and larvae of hard clams are sensitive to high levels of suspended sediments, but these stages occur when the clamming season is closed (Stanley & DeWitt, 1982; Roegner & Mann, 1992).

Settlement and Recruitment

Hydraulic dredging does not seem to have a negative impact on clam recruitment. In Maryland, softshell clam harvest areas consistently produced clams on annual to triannual cycles (Manning, 1957; MacPhail, 1961). Despite being confined to a relatively small area, the Venetian Lagoon clamming fishery continued and expanded in intensity over a period of years (Pranovi & Giovanardi, 1994), suggesting continued recruitment in this region.

Whether settlement and recruitment is enhanced by tilling the substrate with the hydraulic harvester is unclear. Beginning in the early 1900's, bottom cultivation was carried on in Massachusetts to enhance bivalve settlement (Rice et al. 1989). Neither Haven (1970) in Virginia nor Pfitzenmeyer (1972) in Maryland found increased settlement of softshell clams as a result of hydraulic dredging. Pfitzenmeyer did find enhanced survival and recruitment of juveniles in dredged areas, but Haven found no differences between worked and unworked areas. Ten months after dredging in a Maine intertidal flat, softshell clam populations within the dredge tracks had increased several-fold over predredging levels (Kyte & Chew, 1975). In a study of Rhode Island hard clam populations, settlement and recruitment in a clamming area occurred at a significantly higher rate than in areas closed to clamming (Rice et al. 1989). The investigators suggest that the higher clam densities in the closed areas (190 clams/m^2) may have inhibited settlement; alternatively, the reduction of the silt/clay fraction in the sediment due to clamming activity may enhance setting rates, since hard clams prefer sandier substrates. On the other hand, low and irregular settlement is characteristics of hard clam populations in Georgia regardless if the area is harvested or not (Walker, 1987).

Other Benthic Fauna

Potential Impacts

The potential effects of the hydraulic harvesters on the benthic fauna are essentially the same as for clams. No systematic studies have been found that evaluate the direct mechanical effect of this type of dredge on incidental species. Anecdotally, because of the way it works the hydraulic escalator dredge would appear to do little damage to the bycatch, including such soft bodied animals as polychaetes and nemertean worms (Manning, 1959; Godcharles, 1970), although some percentage of the smaller, more delicate forms may get caught in the machinery (pers. observ.). Drobeck and Johnston (1982) surmised that the majority of the small animals washed through the dredge unharmed. It has even been suggested using this gear as a collection device for benthic fauna, providing the receptacle for the animals contained water to cushion the fall off the end of the belt (Manning, 1959; Godcharles, 1970). In contrast, gears that are forced into the bottom, such as scallop dredges, can kill or damage epifaunal and large infaunal organisms, sometimes in large numbers (Caddy, 1973; Eleftheriou & Robertson, 1992).

This is not to say that benthic populations are unaffected within and immediately adjacent to the dredge tracks, but to what degree is uncertain. An experiment in Maine found temporary declines in the infauna that quickly recovered, although no details were provided (Kyte & Chew, 1975). Animals can be displaced from the trench by the hydraulic jets or removed and redeposited outside of it by the conveyor. Some of these are probably lost to predation or damaged by the dredge. The relative importance of each possible fate is undetermined, although predation declines during the colder months (see above). No lasting effects of hydraulic escalator dredging on the benthic community have been observed (see *Response to Disturbance* section).

Regarding sedimentation, presumably most of the infaunal species can dig their way out of the light sediment covering (McCauley et al. 1977; Maurer et al., 1980; Beukema, 1995). However, filtering may be temporarily disrupted. Godcharles (1971) found no evidence of mass mortalities due to sedimentation from dredging. Motile epifauna should not be affected by sedimentation, but non-motile species could be buried. Dredging related oyster mortalities due to smothering were 100% at a distance of up to 25 ft. for adults and 75 ft. for spat (Manning, 1957; Drobeck & Johnston, 1982)[11]. One of the most conspicuous sessile epifaunal forms in Chincoteague Bay that could be impacted by sedimentation are sponges; however, these generally occur in the seagrass meadows. Much of other sessile epifauna are associated with hard substrate which would not be affected by clamming (eg. riprap, pilings, etc.), except perhaps on some of the remnant oyster shell bars.

Predators such as crabs and fish are undoubtedly sources of mortality to animals returned to the bottom. Manning (1957) reported crabs and several fish species attracted to areas of active dredging, but specifics were not given. Caddy (1973) directly observed predators, especially winter flounder but also sculpin and rock crabs, attracted to scallop dredge tracks within one hour of dredging at densities up to 30 times those outside the tracks. Similarly, Eleftheriou and Robertson (1992) noted congregations of fish, primarily pleuronectids, gadoids, and gobies, feeding in scallop dredge tracks, as well as seastars and a large variety of crustaceans. Meyer et al. (1981) categorized two types of predators of surf clams exposed by a hydraulic dredge: scavengers such as lady crabs, rock crabs, and spot feeding on damaged clams and those that preyed on undamaged clams including seastars, horseshoe crabs, and moon snails. Caddy (1973) estimated that the large scale scallop fishery on Georges Bank could have substantially benefitted bottom foraging fish populations.

Concern has been expressed about the possible impact of hydraulic escalator dredging on overwintering blue crab populations in the coastal bays. It is generally believed that crabs remain buried and inactive during the winter, which might leave them vulnerable to smothering from dredging. The literature reviews on blue crabs make no mention of this issue, probably because adult crabs in the Chesapeake Bay overwinter in waters deeper than the operating limit of hydraulic escalator dredges. One study found that locomotor activity in juvenile blue crabs ceased when water temperatures dropped to 5.5°C (Van Heukelem, 1991). However, another study has shown that at low temperatures crabs are still capable of some activity and mentioned that Truitt found overwintering females moving about in schools in the lower Chesapeake (Van Heukelem, 1991).

Response to Disturbance

The primary question concerning the benthic community is how it responds to disturbance. Few studies have been directed toward evaluating the effect of the Maryland hydraulic escalator dredge on the benthic faunal community. In Florida, Godcharles (1971) discovered no lasting impacts on the benthic populations. Using three gear types (benthic corer, trynet trawl, hydraulic escalator dredge) to sample both infauna and epifauna from 5,200 ft.^{2} plots, all but one vegetation station (from benthic core samples) showed little difference between control and experimental dredging sites. Based on the benthic core data, it appeared that recovery was slowest in some of the vegetated areas, which were completely stripped of plants by the dredge. No faunal differences between control and experimental plots, including the vegetated stations, were evident at any time in the trynet samples, which captured

---

[11] No subtidal oyster populations currently exist in the coastal bays (Tarnowski, 1997).

mostly the larger epibenthic species. Because stations had varying intervals between the experimental dredging and the final evaluation sampling with the benthic corer, the time course of infaunal recovery is unclear, with a maximum of thirteen months possible. The only definitive estimate was given as within eight months at one station. Similar results were observed in South Carolina, although no details were provided (Kyte & Chew, 1975). A study in Maine found temporary declines initially but full recovery within ten months (Kyte & Chew, 1975). Closer to the coastal bays, a study in the Patuxent River, Maryland reported rapid reestablishment of the benthic infauna, with no significant differences between the dredged and impact zones and the control area within five months of experimental dredging (Drobeck & Johnston, 1982). The general conclusion of these studies was that the benthic infaunal community was capable of recovery in a relatively short period of time.

Because of the limited number of studies involving the hydraulic escalator dredge, the present review was expanded to include the impacts of comparable gears, as well as larger scale natural and anthropogenic disturbances (Tables 2, 3). A variety of coastal habitats from around the world were included. Surrogates were sought which produce similar or greater disruptions to the benthos, including larger hydraulic (non-escalator) dredges, suction dredges, clam "kicking", scallop dredges, oyster shell dredges, channel dredging, dredge spoil dumping, pollution, and natural perturbations. The scale of the impacts ranged from experimental plots to a square mile dredge spoil site to entire estuaries (Table 2). The common thread of these studies is that they attempted to measure the response of the benthic faunal community to disturbance.

With few exceptions recovery was rapid, in most cases on the order of months (Table 3). This resiliency of the benthos is characteristic of shallow-water coastal and estuarine systems, which are subjected to continual disturbances (Turner et al., 1995). Studies with multiple locations showed that recovery times could vary due to differences in habitat (Godcharles, 1971; Kyte & Chew 1975; Pranovi and Giovanardi,1994; Thrush et al. 1995), community (Kyte & Chew 1975; Beukema, 1995; Thrush et al. 1995), and time of year (Hall & Harding, 1997).

Recovery time was largely tied to the reproductive cycle of the constituent species. Disturbances that disrupt the this cycle (elimination of spawners and/or offspring, inhibition of gametogenesis, interference with settlement, etc.) can delay re-establishment until the next spawning period. One community took 11-13 months to recover from a red tide outbreak occurring during the height of the reproductive season (Simon & Dauer, 1977). In temperate climates, the majority of the species reproduce during the warmer months. These usually have planktonic larvae which can travel some distance to recolonize areas. Some repopulation also takes place through active migration and passive transport of post-metamorphosed juveniles and adults from outside the disturbed area, as well as through the re-establishment of animals originally displaced within the affected zone.

During the recovery process, a successional pattern has been observed (Thistle, 1981). Community parameters including total numbers of individuals and species rebound quickest, often exceeding levels in comparable control locations. These species may be characterized as "opportunistic" species which are adapted to rapidly exploiting disturbed habitat. During the course of succession, the opportunists are then replaced by more established species of the community, leading to the re-establishment of species structure and hierarchy. Biomass is the parameter slowest to recover, since it is dependent on the growth rates of newly settled individuals or the immigration of adults into the disturbed zone. Small-scale (subsystem) disturbances create a spatial and temporal mosaic of successional states, allowing certain species to persist in a community where they were competively inferior (McCall, 1977; Thistle, 1981). This results in an increase in diversity within the community.

The few studies where recovery was incomplete can be divided into two classes. The first of these includes those where studies were conducted for a relatively short time period. Pranovi and Giovanardi (1994) looked at the impact of hydraulic dredging in commercial clamming and non-clamming areas of the Venice Lagoon in Italy over a two month period. By the end of this interval, the benthic community in the clamming area had essentially recovered save for biomass[12], which is consistent with the successional process given the brief time period that had elapsed. Within the non-clamming area, no statistical differences were detected immediately after dredging. However, after two months several community parameters (number of individuals, number of species, biomass) within the experimental plot had fallen significantly below levels in the control plot, although diversity indices were similar. The authors partly attributed these results to macroalgae (*Ulva*) accumulation in some segments of the dredge track of the non-clamming station. This station was within a seagrass bed, a habitat where tracks persist longer and macroalgae tends to accumulate, which could explain why the clamming station was not similarly affected. The actual interval for recovery at the non-clamming station is unknown since the study ended after two months.

Thrush et al. (1995), using a scallop dredge, also found differences in recovery between two sites, with neither location fully restored after three months (the length of the study). These were believed to be related to differences in initial community composition and environmental characteristics. Hall and Harding (1997), investigating the effects of two types of suction dredges, considered recovery essentially complete after 56 days despite some small but statistically significant differences. Also, recovery processes varied between the two gears, which they felt was probably due to the different times of year the experiments were conducted (the location was the same). They concluded that recovery was rapid and the overall effect on the infaunal community was low.

The second class of impact studies involved large-scale, tributary/ecosystem-wide disruptions where recovery was incomplete after two years. Dean and Haskin (1964) followed the recovery of an entire estuary from decades of pollution after a massive abatement project was completed. This study extended from the mouth of the Raritan River to its fresh water reaches, a distance of 20 km. The abatement resulted in rapid recolonization within six months. After 2.5 years the distribution of species number and abundance along the length of the study area showed a classic V-curve, suggesting re-establishment of the benthic community in terms of these parameters. However, interannual variations in species composition and structure might have been an indication that the community had not yet stabilized, although this could be the result of natural variability in these populations. The extent of the impact precluded establishing proper reference stations for comparison. Boesch et al. (1976) studied the effects of Tropical Storm Agnes on the benthos of several Virginia estuaries. At a 10 m deep mud site in the lower York River, salinity stratification due to the storm resulted in intermittent hypoxic conditions for over a month, devastating the benthic community. The community had not returned to pre-Agnes conditions after two years, although this may have also been affected by unusual

---

[12] Biomass was measured as wet weight, including shells.

environmental conditions during this period. In contrast, a nearby 3 m deep station was impacted for a much shorter period of time by fresh water (but not hypoxia) and was largely recovered after five months.

Although most of the studies concluded that the disturbances caused no long-term effects on the benthic faunal community, two papers expressed reservations. Both were concerned with the effects of chronic fishing disturbance on benthic habitat. Pranovi and Giovanardi (1994) showed a significant change of bottom composition in areas of the Venetian Lagoon which had been intensively dredged for a number of years. They felt that the shift to sandier substrate would modify the community to the detriment of species associated with finer particles, which is generally found in the remainder of the lagoon. Unfortunately, although control sites existed for both fished and unfished areas, the respective community structures were not statistically compared. The potential impact of dredging on seagrass colonization in the dredging areas was also discussed as seagrasses were common around the clamming grounds (for further discussion on seagrass impacts see Submerged Aquatic Vegetation section below). The authors' objections to dredging essentially was that dredging may result in a habitat distinctly different from its surrounding environment. In contrast, Thrush et al. (1995) were concerned about the homogenisation of bottom characteristics due to long-term, large scale scallop dredging. They argued that habitat heterogeneity is important to the diversity, stability, and functioning of ecosystems. The authors also commented on the possible impact to community structure by removing larger, longer-lived sedentary species. Their conclusions were more cautionary than dire, suggesting ways to better predict potential large-scale impacts.

Most of the studies in Table looked at the effects of one time, acute perturbations. Beukema (1995) had an opportunity to investigate a chronic, intensive disturbance over an extended time period when a lugworm (*Arenicola marina*) dredge began harvesting at one of his long-term benthic monitoring sites in the Dutch Wadden Sea. This activity continued for four years within a 1 km^2 sandy intertidal area. The dredge created tracks similar to a Maryland hydraulic escalator dredge, and in fact softshell clams (*Mya arenaria*) were a secondary target species for harvest. At the end of the four year dredging period total biomass had declined. This was to be expected since the two target species accounted for almost 80% of the biomass. In addition to removal through harvesting, many of the non-harvested softshell clams were subjected predation and breakage by the dredge. Because *Arenicola* and *Mya* are slower growing, long-lived species, biomass recovery took about five years. With one exception, the remaining non-target species showed no negative effects from dredging. One polychaete worm species was adversely impacted but rapidly recovered after dredging ceased. On the other hand, the population of a small clam species, *Macoma balthica*, an important constituent of the biomass, was enhanced during the dredging period. The author concluded that even though the benthic community biomass structure took an extended period to recover, "the functioning of the community appeared to be hardly affected". This is because the biomass decline was primarily confined to the removal of a relatively low number of larger animals with low production:biomass ratios, whereas the remaining species were responsible for the bulk of benthic faunal production.

Submerged Aquatic Vegetation

One of the major concerns about the hydraulic escalator dredge is its impact on seagrass beds. Maryland law currently prohibits this gear in designated submerged aquatic vegetation areas.

Direct Impacts

The direct impact of dredging in seagrasses is catastrophic. Dredging uproots plants, leaving behind trenches that may persist for lengthy periods of time (Godcharles, 1971; Peterson et al., 1987). Recovery by vegetative propagation is slow, on the order of two years or more (Godcharles, 1971; Peterson et al., 1987). Restoration is facilitated by natural reseeding, but may be limited by disturbances within the track. The cuts may trap drift macroalgae (Pranovi & Giovanardi, 1994) which commonly accumulate in seagrass beds, possibly suppressing seed germination. Also, stingrays utilize the open spaces through the seagrass beds created by the dredge and can be very disruptive to the bottom by digging pits (J. Orth, pers.com.). Repeated harvesting within a vegetation bed can greatly restrict or completely inhibit recovery (Manning, 1957).

Burial also adversely affects seagrasses, suppressing the ability of the leaves to function and diminishing the plant's activities. The shoots and leaves of some SAV species can become buried by just a few centimeters of sediment (Stephan et al. 2000). In sand substrates, measurable quantities of displaced sediment can be expected at least within 15 ft. of the dredge[13] (Drobeck & Johnston, 1982). The seagrass area closure largely mitigates this concern, except perhaps for plants within the sedimentation zone if boats are working along the closure boundary.

Indirect Impacts

The indirect effects of hydraulic escalator dredging, specifically turbidity plumes, on seagrasses is less clear. Ruffin (1995) states that light attenuation was great enough to potentially inhibit the growth of redhead grass (based on inference rather than direct observation) in the shallower portions of the Chester River where the proportion silts and clays was higher, depending on how often the plants were shaded. Shading was a function of winds, tide, bottom type, and the location of the clam boats, all of which were variable. Since this study was essentially a "snap-shot" on a daily time-frame, the author suggested that long-term research on this issue was needed. In contrast, Black & Parry (1999) concluded that for sand substrates, suspended particles drop out over relatively short distances, with far-field effects on seagrasses unlikely beyond 100 m of the dredge.

The possibility of localized plume effects on the Maryland coastal seagrass beds is reduced by a number of factors. Since most of the seagrass meadows in the coastal bays are located adjacent to sandy areas (Bartberger & Biggs, 1970; Orth et al., 1993) which produce less of a plume due to fewer silt/clay particles, the effect of plumes would be expected to be less in the coastal bays than in the muddier tributaries of the Chesapeake. Also, the hard clam dredge displaces less sediment than the deeper cutting softshell clam dredge. Wind, the primary agent of water movement in Chincoteague Bay, may not always direct the plumes towards the seagrass beds. Seasonal wind patterns tend to blow from the cooler ocean to the warmer land during the spring and summer, keeping the plumes away from the

---

[13] Drobeck and Johnston (1982) measured displaced sediment accumulations of 0.3 cm at 15 ft.

majority of the beds, which are located along Assateague Island[14]. In addition, during the course of a season clamming activities shift around to different areas and are not necessarily in close proximity to the seagrass beds.

The Atlantic States Marine Fisheries Commission defines impacts of "significant concern" as those "that result in loss of SAV-habitat", which is considered to be meadows or patches of SAV but not individual plants (Stephan et al., 2000). Despite an increase in harvesting activity over the past few years, seagrass acreage in the Maryland coastal bays has nearly tripled during this same period (Orth et al., 1993, 2000). Whether the rate or extent of seagrass increase was indirectly affected by clam dredging is unknown.

III. THE COASTAL BAYS ECOSYSTEM

Although all of the aforementioned studies were conducted outside of the Maryland coastal bays, they or at least portions of them have some applicability to the situation in this region. Three factors are of importance in assessing the potential impact of the hydraulic escalator dredge on the coastal bays ecosystem: the physical environment, the characteristics of the benthic faunal community that has developed in this environment, and the nature of the fishery.

Physical Environment

The coastal bays are a physically dynamic environment (Truitt, 1968; Bartberger & Biggs, 1970). Although tidal currents can be strong in the vicinity of the inlets, wind is the main agent of disturbance in this system. Sustained winds of 20 mph or greater were recorded on 33 days during the year 2000 at the Assateague Island weather station; gusts of 20 mph or greater occurred on 236 days (NPS, unpubl. data). McCall (1977) found that a 25 kn wind in Long Island Sound was capable of disturbing the sea floor as deep as 66 ft. Depths in the coastal bays average 4 ft. and seldom exceed 8 ft. Winds capable of disturbing the bottom vary in intensity and duration from summer afternoon on-shore breezes and squalls to three days of hard westerlies and winter nor'easters up to the occasional hurricane (Truitt, 1968). Waves pound along the western shore, eroding away the banks, while storm overwashes and Aeolian transport deposit fine sand from Assateague Island into the bays. The net result is a very active system geologically speaking, so much so that the bays and their barrier islands are actually migrating westward (Bartberger & Biggs, 1970). From this perspective the effect on the physical environment of hydraulic escalator dredging at its current scale is negligible and in most cases is probably erased in relatively short order. The primary exception is in seagrass beds, where the energy dampening effect of the plants and sediment stabilization by the root/rhizome system allow physical disturbances to persist for longer periods.

---

[14] For the year 2000, daily average wind directions at the Assateague I. weather station (National Park Service, unpubl. data) were calculated for 12 hr. periods corresponding with clamming activity. The longitudinal axis of Chincoteague Bay was taken to run 34°/214°T. Winds blowing from east of or along this line (from 34° up to 214°T) were assumed to be keeping turbidity plumes away from the major seagrass beds. During March-May and September (2nd half) winds blew from east of this axis 68% of the days, shifting to 48% in October and 27% in November.

Two other parameters of the physical environment need to be considered, not because they directly interact with clam dredging but for their role in defining the benthic and pelagic communities. C an annual basis water temperatures can vary from -2°C (28°F) to as high as 35°C (95°F). Owing to the shallowness of the bays, water temperatures are heavily influenced by air temperatures and can fluctuate sharply over a short period of time. The waters of Chincoteague Bay can approach hypersaline (higher than seawater) conditions during very dry summers[15]. These extremes in temperature and salinity create a harsh environment, restricting organisms to those that can tolerate or are adapted to changing conditions.

Benthic Faunal Community

The Maryland coastal bays belong to a highly changeable system, with extremes in conditions including both regular, seasonal fluctuations and unpredictable, sometimes catastrophic disruptions. Historically, as inlets were created by storms and filled in again, salinity regimes in the bays rose and fell. It is within this set of conditions that the benthic faunal community has developed over the past seven decades. The environment of the upper bays was very different prior to the stabilization of the Ocean City inlet in 1933[16]. These were so brackish that oysters occasionally suffered mortality from freshets as far south as the upper portion of Chincoteague Bay and oysters did not inhabit the bays above South Point (Grave, 1912).

Natural physical disturbance is recognized as a structuring force in many communities (Thistle, 1981). Since communities can become established in dynamic, naturally disturbed environments such as the Maryland coastal lagoons, they are necessarily adapted to accommodate disruption. Adaptation to disturbance allows a particular suite of organisms to form a community within the boundaries of their habitat requirements while excluding other, less tolerant species. Barring some fundamental, long-term change that deleteriously alters the environment of the constituent species (eg. salinity regime, disease, etc.), these communities are characterized by their resilience and persistence in the face of disturbance (Turner et al., 1995).

Many of the species that presently inhabit the coastal bays can rapidly exploit new habitats resulting from disruptions. In one documented example, hard clams, which require higher salinities, were not found in the brackish water bays above Chincoteague Bay during the early twentieth century. Then, a winter storm in 1920 created an inlet below Ocean City, elevating the salinity and allowing hard clams to quickly recolonize Sinepuxent Bay. Within five years this population had flourished to the extent that harvesters could make a decent living ($35/day), with hundreds of thousands to nearly two million clams harvested annually (Md. Conserv. Dept., 1929;1931). This inlet subsequently filled in during the late 1920's and the hard clam population disappeared as the salinity once again declined.

Limitations on the Fishery

---

[15] Low salinity has not been much of an factor as it is in riverine estuaries since the stabilization of the Ocean City inlet, but prior to 1933 it was probably the major influence in species distribution in the coastal bays (Grave, 1912).

[16] Except for the 1920's, which was a period of higher salinities (see below).

Time Restrictions

Regulatory restrictions pertaining to time may mitigate possible negative impacts. The most important of these is the seasonal restriction. The prohibition on hydraulic escalator dredging for hard clams from June through the first half of September is during the period of peak biological activity, including feeding, respiration, and reproduction, and when the most vulnerable stages in the life cycles of many species occur. Predators are most active and abundant during this time. It should be noted that some of these biological processes are ongoing during the season (eg. eelgrass has its highest growth rates in the spring and fall), but decline with lower water temperatures while others may cease altogether (eg. larvae production). Also, during the season clamming activity is limited by time of day restrictions, Sunday closures, and daily catch limits. Non-regulatory factors such as weather, mechanical failure, market prices, and catch per unit effort may also reduce fishing time.

Area Restrictions

The most significant legislative action in recent years to govern the hard clam fishery is the closing of the seagrass beds to hydraulic escalator dredging. To protect the seagrass beds and its associated faunal community, dredging is restricted from approximately 25% of the coastal bays. This has also created a *de facto* hard clam broodstock sanctuary which may ultimately benefit the fishery. Other restricted areas include shoreline buffers, pollution closures in the St. Martin River and smaller areas, and a handful of leased grounds. In addition, factors including weather and clam densities can compel boats to work different areas, so that effort does not remain concentrated in one location for an extended period of time.

CONCLUSIONS

With the closure of seagrass beds to dredging, three basic biological issues regarding the hydraulic escalator dredge remain: 1) the impact of transient turbidity plumes on seagrass populations, 2) the effect of dredging on benthic populations and communities and 3) concern about overwintering blue crabs. Little or no information exists about the crabs that overwinter in the coastal bays, including overwintering areas, the size of this population, the contribution and significance of these crabs to the overall coastal bays population, and the actual impact of hydraulic escalator dredging on overwintering crabs, so that no conclusions can be made regarding this issue. As for seagrasses, the physical attributes (seasonal wind patterns, current regimes, sediment composition) of the coastal bays and the nature of clamming operations reduce the individual probabilities of plume impacts. Lastly, a review of the literature indicates that, in most instances, impacts on the benthic fauna are local and relatively short term. However, although an attempt was made to look at a variety of disturbances, locations, habitats, and scales, the fact remains that none of the studies were conducted in the Maryland coastal bays. Thus, conclusions can be drawn only through the extrapolation of findings from other areas.

Based on these studies, it would appear that the ecological effects of hydraulic escalator dredging is largely mitigated by the physical dynamics of the coastal bays ecosystem as well as the characteristics of the benthic faunal community that has developed under such conditions. Regulatory restrictions further reduce the impact of this activity by prohibiting harvesting in vulnerable seagrass beds and through a closed season during the warmer months when biological processes such as feeding, respiration, growth, reproduction, and recruitment are at their peak. If there are still concerns regarding these issues among resource management and user groups, they can be properly addressed only through directed studies.

TABLES

Table 1a. Substrate contaminant levels exceeding Long and Morgan effects-range low thresholds in the mainstem coastal bays of Maryland (EPA, 1996).

Contaminant	**Highest Level**	**Median Level**	**ER-L**	**ER-M**
Nickel	24.1 ppm	17.4 ppm	20.9 ppm	51.6 ppm
Arsenic	12.1 ppm	8.4 ppm	8.2 ppm	70.0 ppm
DDT	2.06 ppb	1.08 ppb	1.58 ppb	46.1 ppb

Table 1b. Substrate contaminant levels below Long and Morgan effects-range low thresholds in the Maryland mainstem coastal bays, but which exceeded these thresholds in other areas of Maryland and Delaware (EPA, 1996) and were of concern in the MCBP (1997) report. The remaining 39 analyzed contaminants of the EPA study were also below ER-L levels in the Maryland mainstem coastal bays.

Contaminant	**Highest Level**	**Median Level**	**ER-L**
Dieldrin	0 ppb	0 ppb	0.02 ppb
Chlordane	0.49 ppb	0 ppb	0.5 ppb
Benzo(a)anthracene	14.2 ppb	0 ppb	261 ppb

Table 2. Extent and duration of natural and anthropogenic disturbances reviewed for this report. Not all of the studies mentioned in the text are included (see Table 3).

Impact	Study	Impact Size	Duration/Coverage
Hydraulic Escalator Dredge	Godcharles 1971	484 m^2/sta. x 6 sta.	4@100%;40%;50%
Hydraulic Escalator Dredge	Drobeck & Johnston 1982	11,250 ft^2	4.5 hrs.
Hydraulic Suction Dredge	Hall et al. 1990	5,000 m^2/sta. x 5 sta.	5 hrs./sta.
Hydraulic Suction Dredge	Hall & Harding 1997	7,850 m^2/plot x 10 plots	20 min./plot
Tractor Dredge	Hall & Harding 1997	225/900/2025 m^2/plot x 8	100 %
Mechanical Dredge	Beukema 1995	1 km^2	4 yrs.
Hydraulic Dredge	Pranovi & Giovanardi 1994	1 track x 2 sta.	?
Prop Wash Kicking	Peterson et al. 1990	1,225 m^2/sta. x 6 sta.	39-230 min./sta.
Scallop Dredge	Thrush et al. 1995	700 m^2/sta. x 2 sta.	?
Oyster Shell Dredge	Connor & Simon 1979	2,500 m^2; 30,000 m^2	4 hrs.; 10 days
Dredge Spoil	Haskin et al. 1978	1 mi^2	2 mos.
Channel Dredging/Spoil Dump	McCauley et al. 1977	8,000 yd^3 x 2 areas	?
Red Tide	Simon & Dauer 1977	300,000 m^2	1-2 mos.?
Winds	Turner et al. 1995	9,000 m^2/sta. x 6 sta.	69 d/yr (winds>33 km)
Pollution	Dean & Haskin 1964	~20 km^2 (Raritan estuary)	Decades
Hypoxia (TS Agnes)	Boesch et al. 1976	~65 km^2 (L.York estuary)	~6 wks

Table 3. Recovery times of coastal and estuarine benthic fauna to disturbance. The impact abbreviations can be interpreted from Table 2. ✓=recovered; ×=incomplete; ✓/×=mixed results from different sites; nd = not determined by end of study period.

Impact	Study	Study Area	Study Length	Time to Equilib.	# Indiv.	Species Number	Species Makeup	Biomass	Comm. Struct.
HED	Godcharles 1971	Fla.	500 d	<8 mo	✓	✓	✓		
HED	Kyte & Chew 1975	Me.		<10 mo	✓	✓	✓		
HED	Drobeck & Johns. 1982	Md.	11 mo	<5 mo	✓	✓	✓		✓
HSD	Hall et al. 1990	Scot.	40 d	<40 d	✓	✓	✓		✓
HS/TracD	Hall & Harding 1997	Scot.	56 d	56 d	✓/×	✓/×	✓		
MD	Beukema 1995	Neth.	13 yr	<6 mo	✓	✓	✓	×	×
HD	MacKenzie 1982	N.J.	6 mo	0-6 mo	✓	✓	✓		
HD	Pranovi & Giov. 1994	Ita.	2 mo	nd	✓/×	✓	✓/×	×	
Kicking	Peterson et al. 1990	N.C.	1 yr	<6 mo	✓	✓	✓		
ScDr	Thrush et al. 1995	N.Z.	3 mo	nd	✓/×	×			×
OyShDr	Connor & Simon 1979	Fla.	12 mo	6-12 mo	✓	✓	✓	✓	✓
Dr Spoil	Haskin et al. 1978	N.J.	16 mo	3 mo	✓	✓	✓		
ChannelDr	McCauley et al.1977	Ore.	56 d	28 d	✓	✓	✓		
Dr Spoil	“ ” “ ” “	“	56 d	14 d	✓	✓	✓		
Red Tide	Simon & Dauer 1977	Fla.	2 yr	11 mo	✓	✓	✓/×		✓/×
Storms	McCall 1977	Conn.	13/3 mo	3 mo	✓	✓	✓		✓
Winds	Turner et al. 1995	N.Z.	5.5 yr	NA	✓	✓	✓		✓
Pollution	Dean & Haskin 1964	N.J.	3 yr	nd	✓	✓	×		×
Hypoxia	Boesch et al. 1976	Vir.	2 yr	nd	✓	✓	×		×
Exp.Tray	Lu & Wu 2000	HongKong	15 mo	12 mo	✓	✓	✓		✓

LITERATURE CITED

Austin, H.M. and D.S. Haven. 1981. A report on the operation of a hydraulic escalator dredge on private ground on Hampton Flats, James River, during October 1980. Mar. Res. Rep. 81-3, VIMS, Gloucester Pt., Va. 41 p.

Bartberger, C.E. and R.B. Biggs. 1970. Sedimentation in Chincoteague Bay. *In*: Assateague Ecological Studies. Nat. Res. Inst., U. Md. NRI Contrib. No. 446, p. 70-89.

Beukema, J.J. 1995. Long-term effects of mechanical harvesting og lugworms Arenicola marina on the zoobenthic community of a tidal flat in the Wadden Sea. Neth. J. Sea Res. 33: 219-227.

Black, K.P. and G.D. Parry. 1999. Entrainment, dispersal, and settlement of scallop dredge sediment plumes: field measurements and numerical modelling. Can. J. Fish. Aquat. Sci. 56: 2271-2281.

Boynton, W. and J. Hagy. 1993. Maryland's Coastal Bays: An Assessment of Aquatic Ecosystems, Pollutant Loadings, and Management Options. Final Rep. to MDE. UMCEES Ref. No. 93-053 CBL. Solomons, Md.

Caddy, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. J. Fish. Res. Bd. Can. 30: 173-180.

Conner, W.G. and J.L. Simon. 1979. The effects of oyster shell dredging on an estuarine benthic community. Est. Coast. Mar. Sci. 9: 749-758.

Dean, D. and H.H. Haskin. 1964. Benthic repopulation of the Raritan River estuary following pollution abatement. Limnol. Oceanogr. 9: 551-563.

Drobeck, K.G. and M.L. Johnston. 1982. Environmental impact of hydraulic escalator dredging on oyster communities. Final Rep. to MDNR. UMCEES Ref. No. 82-5 CBL. Solomons, Md. 97 p.

Drobeck, K., H. Hidu, J.M. Odell and W. Boynton. 1970. Chincoteague and Sinepuxent Bay Benthos. *In*: Assateague Ecological Studies. Nat. Res. Inst., U. Md. NRI Contrib. No. 446, p. 173-241.

Eleftheriou, A. and M.R. Robertson. 1992. The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. Neth. J. Sea Res. 30: 289-299.

Hall, S.J., D.J. Basford and M.R. Robertson. 1990. The impact of hydraulic dredging for razor clams *Ensis* sp. on an infaunal community. Neth. J. Sea Res. 27: 119-125.

Haskin, H.H., R.C. Murray, S. Pollock, and C. Van Dover. 1978. The effects of overboard spoil disposal from the Cape May ferry terminal on the biota of lower Delaware Bay. Center Coast. Envir. Studies, Rutgers Univ. 77 p. and apps.

Haven, D.S. 1970. A study of the hard and soft clam resources of Virginia. U.S. Fish Wildl. Serv., Comm. Fish. Resources Devel. Act, Final Contract Report. 69 p.

Glude, J.B. 1954. Observations on the effect of Maryland soft-clam dredge on the bottom. U.S. Fish Wildl. Serv. 4 p. [Unpublished manuscript].

Godcharles, M.F. 1971. A study of the effects of a hydraulic clam dredge on benthic communities in estuarine areas. Fla. Dep. Nat. Res. Tech. Ser. 64. 51 p.

Grave, C. 1912. Fourth Report of the Shell Fish Commission of MD., p. 242-246.

Kraeuter, J.N. and S.R. Fegley. 1994. Vertical disturbance of sediments by horseshoe crabs (*Limulus polyphemus*) during their spawning season. Estuaries 17: 288-294.

Kranz, P.M. 1974. The anastrophic burial of bivalves and its paleoecological significance. J. Geol. 82: 237-265.

Kyte, M.A. and K.K. Chew. 1975. A review of the hydraulic escalator shellfish harvester and its known effects in relation to the soft-shell clam, *Mya arenaria*. Washington Sea Grant Program WSG 75-2. U. Wash. 30 p.

MacKenzie, C.L. 1982. Compatability of invertebrate populations and commercial fishing for ocean quahogs. N. Amer. J. Fish. Man. 2: 270-275.

MacPhail, J.S. 1961. A hydraulic escalator shellfish harvester. Bull. Fish. Res. Board Can. 128. 24 p.

Manning, J.H. 1957. The Maryland soft-shell clam industry and its effects on tidewater resources. Md. Dep. Res. Educ. Resour. Study Rep. 11. 25 p.

Manning, J.H. 1959. Commercial and biological uses of the Maryland soft clam dredge. Proc. Gulf and Caribb. Fish. Inst., 12th Sess. Pp. 61-67.

Maryland Board of Natural Resources. 1967. Twenty-Fourth Annual Report, p. 35.

Maryland Coastal Bays Program. 1997. Today's Treasure for Tomorrow: An Environmental Report on Maryland's Coastal Bays. Md. Dept. Nat. Res., MCBP 97-02. 36 p.

Maryland Conservation Department. 1929. Seventh Annual Report.

Maryland Conservation Department. 1931. Maryland Fisheries 9: 10-11.

Maurer, D., R.T. Keck, J.C. Tinsman, and W.A. Leathem. 1980. Vertical migration and mortality of benthos in dredged material-Part I: Mollusca. Mar. Environ. Res. 4: 299-319.

McCall, P.L. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. J. Mar. Res. 35: 221-266.

McCauley, J.E., R.A. Parr, and D.R. Hancock. 1977. Benthic infauna and maintenance dredging: a case study. Water Res. 11: 233-242.

Medcof, J.C. 1961. Effects of hydraulic escalator harvesters on undersized soft-shell clams. Proc. Nat. Shellfish. Assoc. 50: 151-161.

Meyer, T.L., R.A. Cooper, and K.J. Pecci. 1981. The performance and environmental effects of a hydraulic clam dredge. Mar. Fish. Rev. 43(9): 14-22.

Orth, R.J., J.F. Nowak, G.F. Anderson & J.R. Whiting. 1993. Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries and Chincoteague Bay - 1992. Final Rept. to U.S. EPA, Ches. Bay Prog. Office, Annapolis, Md. 277 p.

Peterson, C.H., H.C. Summerson, and S.R. Fegley. Ecological consequences of mechanical harvesting of clams. Fish. Bull. 85: 281-298.

Pfitzenmeyer, H.T. 1972. The effects of the Maryland hydraulic clam dredge on populations of the soft-shell clam, Mya arenaria. Final contract rep. Bur. Comm. Fish. (cited in Kyte & Chew, 1975).

Pfitzenmeyer, H.T. and K.G. Drobeck 1967. Some factors influencing reburrowing activity of soft-shell clams, *Mya arenaria*. Ches. Sci. 8: 193-199.

Pranovi, F. and O. Giovanardi. 1994. The impact of hydraulic dredging for short-necked clams, *Tapes* spp., on an infaunal community in the lagoon of Venice. Sci. Mar. 58: 345-353.

Rhoads, D.C. 1973. The influence of deposit-feeding benthos on water turbidity and nutrient recycling. Amer. J. Sci. 273: 1-22.

Rice, M.A., C. Hickox, and I. Zehra. 1989. Effects of intensive fishing effort on the population structure of quahogs, *Mercenaria mercenaria* (Linnaeus 1758), in Narragansett Bay. J. Shellfish Res. 8: 345-354.

Roegner, G.C. and R. Mann. 1992. Hard Clam *Mercenaria mercenaria*. *In*: Funderburk, S.L., S.J. Jordan, J.A. Mihursky, ansd D. Riley, eds. Habitat Requirements for Chesapeake Bay Living Resources. Chesapeake Research Consortium, Solomons, Md. p. 5.1-5.17.

Ruffin, K.K. 1995. The effects of hydraulic clam dredging on nearshore turbidity and light attenuation in Chesapeake Bay, Maryland. MS Thesis, Univ. Md. 97 p.

Sieling, F.W. 1960. The Resources of Worcester County Coastal Waters. Md. Dep. Res. Ed. Ref. No. 60-10.

Simon, J.L. and D.M. Dauer. 1977. Reestablishment of a benthic community following natural defaunation. *In*: Coull, B.C. (ed.) Ecology of Marine Benthos. Univ. South Carolina Press, Columbia. P. 139-154.

Stanley, J.G. and R. DeWitt. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic) - Hard Clam. U.S. Fish Wildl. Ser. FWS/OBS-82/11.18. Washington, D.C. 19 p.

Stephan, C.D., R.L. Peuser, M.S. Fonseca. 2000. Evaluating fishing gear impacts to submerged aquatic vegetation and determining mitigation strategies. Atlantic States Mar. Fish. Comm. workshop report. Wash., D.C. 35 p.

Tarnowski, M.L. 1997. Oyster populations in Chincoteague Bay. *In*: Homer, M.L., M.L. Tarnowski, R. Bussell, and C. Rice. Coastal Bays Shellfish Inventory. Final Rept. to Coast. Zone Manage. Prog., MDNR. Contract No. 14-96-134-CZM010. Annapolis, Md. p. 140-151.

Thistle, D. 1981. Natural physical disturbances and communities of marine soft bottoms. Mar. Ecol. Prog. Ser. 6: 223-228.

Thrush, S.F., J.E. Hewitt, V.J. Cummings, P.K. Dayton. 1995. The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments? Mar. Ecol. Prog. Ser. 129: 141-150.

Truitt, R.V. 1968. High Winds...High Tides. A Chronicle of Maryland's Coastal Hurricanes. Nat. Res. Inst., Univ. Md. Ed. Ser. No. 77. 35 p.

Turner, S.J., S.F. Thrush, R.D. Pridmore, J.E. Hewitt, V.J. Cummings, M. Maskery. 1995. Are soft-sediment communities stable? An example from a windy harbor. Mar. Ecol. Prog. Ser. 120: 219-230.

U.S. EPA, 1996. Assessment of the Ecological Condition of the Delaware and Maryland Coastal

Bays. EPA/620/R-96/004. U.S. Environ. Protect. Agency, Ofc. Res. & Develop., Wash., D.C. 78 p. & append.

Van Heukelem, W.F. 1991. Blue Crab *Callinectes sapidus. In*: Funderburk, S.L., S.J. Jordan, J.A. Mihursky, ansd D. Riley, eds. Habitat Requirements for Chesapeake Bay Living Resources. Chesapeake Research Consortium, Solomons, Md. p. 6.1- 6.24.

Walker, R.L. 1987. Hard Clam, *Mercenaria mercenaria* (Linné), populations of coastal Georgia. Univ. Georgia Sea Grant College Program, Grant #04-7-158-4126. [Unpublished manuscript]

Wells, H.W. 1957. Abundance of the hard clam, *Mercenaria mercenaria*, in relation to environmental factors. Ecology 38: 123-128.