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Jay D. Andrews
Virginia Institute of Marine Science

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J. D. Andrews

Virginia Institute of Marine Science and

School of Marine Science,

College of William and Mary

Gloucester Point, VA 23062

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ABSTRACT

The seed-oyster area is located in a low-salinity sector of the James River where seasonal riverflows and resulting salinities vary widely. Low spring salinities, usually below 10 $^{o}/oo$ in April or May, eliminate most predators and diseases. Prior to 1960, spatfalls were regular and moderate in intensity each year. High quality seed oysters 2 to 3 inches in size were produced with 1000 to 2000 thick-shelled oysters per bushel for use by private-ground planters. Following the advent of M. nelsoni (MSX) in Chesapeake Bay in 1959, setting declined to about one-tenth previous levels and there were spatfall failures in many years. Thick beds of fossil shells provided cultch for setting oysters and little repletion by shell planting was attempted. In the 1950's a gradient of deceasing spatfall with distance from the mouth of the river was observed. Setting was continuous for about 90 days each year with peak spatfalls in late August or early September. After 1960, setting was irregular by years, and sporadic within the seed area, with no patterns. Larvae were scarce and flushing of larvae out of the estuary appeared to require higher brood-oyster populations.

Introduction

Over the past 34 years, I have been involved in studies of oyster reproduction in Virginia. For 22 years (1946-1967), I monitored oyster populations in the major rivers with extensive sampling of public oyster beds each fall. Seasonal shellbags, weekly shellstrings and asbestos plates were exposed in many rivers to monitor setting through those years. Special attention was given to the James River seed oyster area and other potential seed oyster rivers. Most of the data from these studies was published in the monograph by Haven et al. (1978). Historical accounts of Virginia's oyster fishery and the Baylor survey of public grounds in 1893 may be found in Wharton (1957) and Winslow (1884).

The primary purpose of this report is to describe the biology of reproduction of oysters as it relates to individual oysters. Setting patterns and survival of oysters are well known in Virginia (Andrews, 1954), but larval behavior and the factors involved in transport of larvae are much less understood. In this report, much emphasis is placed on concepts of larval life and the physical conditions of individual river systems that determine distribution and intensity of spatfall. The term spatfall is the equivalent of setting or "strike" of young oysters.

This paper is a review of oyster reproduction in Virginia and it is not intended to be a fully documented scientific paper. There are hints for improvement of management practices and summaries of broad concepts about oyster farming. A summary of hydrography and geomorphometry of major Virginia rivers is given; for oyster farming is strongly dependent on these physical conditions. A map of lower Chesapeake Bay shows major rivers and salient geographic areas and land points relating to oyster culture in Virginia (Fig. 1).

Season of Spawning and Setting

In Virginia, oysters begin developing spawn (eggs and sperm) in May and are ready to release these sexual products by the last week in June. Mass spawning is essential to insure fertilization of eggs. Males are ready earlier than females and releases of sperm stimulate females to spawn. In Virginia, spawning does not usually occur until water temperatures have reached 25°C (77°F), whereas oysters in New England spawn when temperatures reach 20°C (68°F) (Loosanoff and Nomejko, 1951a). In cold climates, often all eggs and sperm in individual oysters are released in one massive spawning. Because of long warm seasons, temperature is far less important to Virginia races of oysters, therefore, several intermittent spawnings occur during the summer. In the James River before 1960, spat usually set every week from about 1 July to 1 October each year (Table 1). This means there was significant spawning on some beds of oysters in the seed area for 12 consecutive weeks (Andrews, 1949, 1951).

In Virginia, a long setting period each summer requires that much effort be expended in catching pelagic larvae in nets and exposing shells or other cultch to predict and to follow setting of spat. In areas with colder waters, the periods of planktonic larvae and setting may be as short as 2 weeks, thereby permitting daily sampling and intensive monitoring (Quayle, 1969). Only two intensive, large-scale programs of sampling larvae (1950 and 1964) have been conducted in Virginia (Pritchard, 1952, Wood and Hargis, 1971, Andrews, 1979).

Although setting is prolonged in Virginia rivers, it exhibits one or more peaks that may be several weeks long. In most rivers in Chesapeake Bay early setting in July from the first major spawning is most common and typical. Auxillary spatfalls may occur later at irregular times. However, occasional years of late sets in August or September often result in the most widespread and intensive spatfalls for the area. The James River is exceptional in timing of spatfalls in that late sets are regular, typical, and most important, whereas July never produces over 10% of a year's spat (Andrews, 1951). Long spawning and setting seasons in Virginia expose oyster larvae to a long summer of predation by other planktonic organisms and by filter-feeding and bottom-dwelling animals such as adult oysters, mussels, barnacles and sea anemones. There may be some advantage to distributing larvae in numerous broods or swarms over the summer to compensate for storm losses and heavy predation by schools of fish fry, e.g. Whereas the proportion of larvae surviving to achieve spatfall is very low, some broods are likely to find favorable conditions of food supply, hydrography and reduced predation. Spatfalls are typically consistent in achieving a commercial level every year in James River. They are less intensive than in most other seed areas along the Atlantic coast.

Patterns of Larval Distribution and Setting

Two basic types of estuaries are postulated in Chesapeake Bay (Andrews, 1979) in respect to larval distribution during the 10-14 day planktonic larval phase:

a) Open-circulation type rivers with steep horizontal salinity gradients induced by large discharges of fresh water and absence of a sill at the mouth, or free access to high-salinity waters.

b) Trap-type estuaries with limited drainage areas and deep narrow channels. There are limited exchanges of water with the source of salty water due to a sill, or to the position on Chesapeake Bay and limited access to salty water. Seaside bays of Eastern Shore have modified trap-type systems that depend upon salt marshes to retain larvae and bay water in their exchanges with the ocean.

There are all kinds of intermediate and modified systems because morphometry, amount of freshwater runoff, configuration of channels, depth of sills, effects of tributaries, and sources of salt water affect the exchange rate with the sump (usually Chesapeake Bay), and thereby physical losses of larvae. The biotic components of the system may also affect the survival of larvae, for example, the abundance of jellyfish, combjellies, small fishes, and other predators.

These two physical types of rivers in respect to larval survival result in two patterns of setting respectively:

a) Moderate gradient setting declining progressively with distance upriver from the mouth. The James River is the prime example (Table 2). The setting gradient is related to the salinity gradient. Spatfall is usually heaviest in wet years when vertical salinity gradients persist into the summer. This enhances the salt-wedge larval transport system. Cool late summers that delay spawning are favorable, too, e.g. 1958.

b) Intensive estuary-wide setting in trap-type systems, usually fairly well distributed throughout, but often heaviest near the head of the system, or where deep channels end. Dry summers favor retention of larvae in these estuaries.

The open-circulation, gradient-setting estuaries are exemplified by James River, Rappahannock River, Potomac River, York River and the open bay of Chesapeake Bay in Maryland. Each of these estuaries exhibits a pattern of decreasing spatfall from the mouth upriver. Intensive-setting trap-type estuaries include Piankatank River, Corrotoman River, Great Wicomico, St. Mary's River, and Eastern Shore tributaries of the Bay such as Manokin River (Carter, 1967). Eastern Bay and Choptank River fall into the trap-type systems mostly because of morphometry.

Survival of Spatfall

If one relies upon counts of spat on natural bottom cultch in the fall, a deceptively low opinion of the potential setting rates is acquired. Seasonal shellbags laid on the bottom, consisting of one-quarter to one-half bushel of clean shells in wire mesh bags always catch more spat than bottom shells. These collectors sticking up a few inches above the bottom also permit more spat to survive. Weekly shellstrings, consisting of clean oyster shells strung face down on a wire, catch more total spat per season than shellbags left throughout the setting season. These shellstrings are hung slightly off the bottom to avoid crawling predators, but they catch spat regularly at any level in the water. There is high mortality of tiny spat (0.3 mm at setting) the first week or two after setting from fouling organisms, smothering by silt, and predators (drills, flatworms and probably many opportunistic predators such as mud snails). Newly set spat open their shells very widely and are easy prey because of fragile, thin shells. Repeatedly, it was noticed that spat on shells exposed for two weeks were essentially the same size and number as those on shells exposed one week, indicating new sets and poor survival of the earlier spat. However, spatfalls on beds upriver in low-salinity waters always exhibited higher percentages of survival than those downriver when related to total weekly sets (Andrews, 1951). Fewer predators live in these low-salinity waters. Lifting cultch off the bottom (suspension) increases spatfall and survival, but it is costly and impractical in Virginia because of rapid fouling by sea squirts, hydroids, barnacles, sponges, and moss animals (Bryozoa).

The size at which spat enter their first winter varies widely. Oysters set in July on shellbags in the Rappahannock River may reach two inches in length by December whereas many spat set in September in the James River overwinter at pinhead size. It was always a surprise to find small spat growing on James River oysters in April after they had been cleaned with a brush weekly throughout the winter for weighing. Smothering is the chief winter threat to small spat.

Hydrography and Larval Transport

Simple tidal movements in estuaries caused by positions of the moon and the sun would tend to retain bivalve larvae in the systems. This would also limit the distribution of larvae which is a major objective of species with planktonic stages. There could be a problem with nutrients if there were no freshwater inflow and if the ocean were the chief source of replenishment.

In estuaries such as Chesapeake Bay there are fluctuating amounts of seasonal freshwater runoff from the land. To maintain a gradient of salt balance in estuaries, there must be a net counterflow of saltwater upstream to compensate for the fresh water discharged into bay or ocean. This salt water is heavier than fresh water; therefore, it enters along the bottom, primarily in the channel and deep bordering areas.

Wind and tide constantly mix fresher upper layers of water with saltier deeper layers. The interface between the two layers in the James River is at a depth of about 3 m in summer (Pritchard 1952, 1955). It is called the layer of no-net-motion, meaning that ebb and flood tides balance each other and there is no net displacement of water up or down stream during tidal cycles.

Planktonic animals and plants that are genetically coded to seek the saltier, deeper layers of water can be transported upstream, seemingly against the tides and currents. Those organisms in surface waters tend to be carried out of the river or bay during several tidal cycles. Numerous larval or juvenile stages of marine animals utilize this "salt-wedge" transport mechanism to move upstream from the ocean and the bay far into rivers. The list of proven upstream migrators includes many fish larvae and juveniles (e.g. spot and croakers Weinstein, 1979), and invertebrate decapods such as crab larvae (Sandifer, 1975), and barnacle larvae (Bousfield, 1955).

It is agreed that mollusk larvae, including those of oysters, also utilize this transport system (Korringa, 1951). The method of use is in dispute (Carriker, 1951; Andrews, 1979). Do mollusk larvae rest on the bottom during ebb tides and arise with increasing salinities (Haskin, 1964) to ride on flood tides? Or do they swim continuously and utilize channel currents and the salt-wedge transport system to move upstream? I believe that a variety of observations support the latter process. This salt-wedge of bottom waters penetrates upstream beneath a layer of lighter fresh water on the surface. Freshwater flow is the prime motive force for the salt-wedge layer and steepness of vertical and horizontal salinity gradients depend upon it; therefore, the strength of the salt-wedge transport system also depends on flow of river runoff by seasons. In the James River, most bottoms on the oyster flats bordering the channel are less than 3 m in depth, therefore, if larvae continue swimming in these shallow waters they tend to be carried by tides downstream and out of the system in the 10 to 14 days that larvae are planktonic.

In spring, when an abundance of freshwater runoff occurs, there is strong vertical stratification of estuarine waters with salinities below 3-5 m depth often being double the values for surface waters. This freshwater flow induces a strong compensatory saltwater flow in the deeper layers. To a lesser degree, this also occurs in fall and winter depending on the amount of rainfall. It is in these latter seasons that blue crab larvae and fall-spawned fish larvae ascend the estuaries in the salt-wedge layers.

Summer and early fall conditions are quite different with little freshwater flow in the rivers and a weak salt wedge. In fact, during much of summer in Hampton Roads, tidal and wind-mixing forces produce essentially uniform salinities and temperatures from surface to bottom even in the channel. Nevertheless, there is a transport system in the channel where flood tides at all depths run longer than on adjacent flats. After dispersing larvae over the oyster beds, the tide ebbs again to pick up another cargo of larvae in the deep waters of Hampton Roads. My sampling indicates that larvae are also carried downriver by ebb currents in the channel in about equal numbers to those found in flood tides (Fig. 2) (Andrews, 1979). It is only when larvae get dispersed over shallow oyster beds or other flats that they escape the rapid transport in the channel. Lateral dispersion of larvae from the channel to the flats is the least studied and most difficult aspect of larval-transport studies. Wind-mixing is probably a major factor in this process.

Behavior of Larvae

What is the physical role of mollusk larvae in this upstream transport? Is it passive or active? Can they be compared to coal particles which were abundant in net samples of plankton near the James River Bridge in strong currents, both flood and ebb (Wood and Hargis, 1971)?

There are many observations to suggest that bivalve larvae swim continuously during their 10-day larval life in the warm (25°-30°C) waters of Chesapeake Bay. Oysters cultured in hatcheries using containers as small as 2 liters swim continuously night and day, and only collect on the bottom when sick or when responding to sudden changes in salinity or temperature. In an 8-foot-long plastic tube about 1 foot in diameter, set up at VIMS by Langley Wood (Wood and Hargis, 1971), oyster larvae swam up in loose spirals for a foot or two, then rested as they sank a similar distance, thus they alternated resting and swimming. A strong light over a tank of larvae causes them to arrange in dense drifts or swarms where, still swimming, shade or relief from light is obtained. If too abundant, oyster larvae may bump each other causing momentary cessation of swimming, but even densities of 50 larvae per ml in cultures do not prevent feeding and growth. Oyster larvae must swim to feed.

It does not seem probable that bivalve larvae would be genetically programmed to rest on the river bottom half the time (ebb tides) considering the urgency of reaching setting size and escaping predation by a multitude of fishes, invertebrate larvae and filter-feeding sedentary animals. Descending to the bottom on an oyster bed is a very risky thing for bivalve larvae because adult oysters are the most efficient collectors of larvae from the plankton by virtue of the large quantities of water they pump. Furthermore, when strong tides are running, there is a "storm" of sand grains, fecal pellets, and silt running up to 1 m deep above the bottom of the channel which entraps them by constant pelting. If not already in the channel on the bottom before tides run fast, how do "resting" larvae negotiate the transfer from shallow flats to channel currents against a flood tide spreading water over the flats? Larvae were consistently most abundant in the channel.

Oyster larvae do not require a current to swim off the bottom. They are strong vertical swimmers and become stronger with age, as witness the discarding of stunted larvae in hatcheries because they cannot compete for food. Even in the relatively still, non-tidal waters of Bras d'Or Lake in Nova Scotia, (Medcof, 1955) larvae swim easily and position themselves selectively in the very clear natural waters. In many fjord-like sites, cold waters confine bivalve larvae to the upper few feet of warmer surface waters (Quayle, 1969) where continuous swimming is a necessity until setting occurs.

My theory of larval transport up the James River assumes that larvae swim continuously until setting size is reached when it may become necessary to descend to the bottom to find suitable cultch. I visualize bivalve larvae being swept down river in surface waters after eggs are spawned on the flats. The D-shaped, straight-hinge larvae of 60 to 80 μm (micron = 1/1000 mm) are most photo-positive of all stages of larvae, but in the muddy James River, even in calm, plankton-filled water in late summer, light is probably rather insignificant as a factor affecting most bivalve larvae. After reaching the deeper waters of Hampton Roads where near homogenicity of density exists, mixing of larvae into deeper water layers by winds is easily achieved.

The tidal currents then sweep the larvae upriver past Hampton Bar, which usually has the greatest spatfall in James River, into the channel and up onto the oyster beds of the James River seed area. In 10 days the larvae may be recycled up and down river several times. One must not think of the flood tidal current as being totally confined to the channel area. In fact, sampling in the channel just above James River Bridge revealed many fewer larvae at the 10 m depth (bottom) than at the surface. Larvae were most abundant at the 4 and 7 m levels. Larvae are quite capable of moving vertically in a 10 m water column in a rather short time (minutes not hours).

The flood tides are stronger on the right side looking up river and the ebb tides stronger on the left side. This results in larvae moving up on the flats on the right side in greater abundance. Channel currents tend to cross Wreck Shoal because of a turn to the left in the channel which is probably a cause of the huge area of deep shell beds built up over thousands of years by flood currents carrying oyster larvae. Most natural oyster "shoals" are on the right side of the river. Setting is nearly always higher on the right (east) side of the river. In 1964, one brood of larvae was followed up the right side and back down the left side by spatfall counts at a series of 22 shellstring stations arranged in a network.

Although flood tides are continously carrying larvae upstream, there is a steady decline in abundance of any one brood as the net flow of water in any cross-section of the river must be downstream.

This is required to discharge into the Bay a quantity of water equal to the freshwater input at the head of the river. This spreading and thinning of larval broods accounts for the gradient of decreasing setting rates on beds with distance upriver. The brood of larvae from one mass spawning becomes a swarm in an increasingly larger area in three dimensions, with the density of larvae greatest down river and near the channel and least upriver and inshore. This is the pattern shown repeatedly by newly set spat on weekly spat collectors after approximately 20 tidal cycles, or ten days of planktonic larval life (Table 2).

Many other factors affect the pattern of setting which becomes very complex when detailed studies are made. The morphometry of the river basin as seen in depths, tributary streams, swamps, marshes and other flow-retarding situations, all affect transport of larvae. Even the contour of the bottom, and any interruptions of flow such as a reef or a shellbag rising a few inches above the bottom contour may result in fewer or many more spat settling.

Most important to the larvae are pheromones released by adult oysters signalling the location of a populated oyster bed. Larvae have no capacity to seek out a particular oyster reef, but if they pass over one while ready to "strike" as oystermen call setting, they will descend and explore for living oysters and a hard surface. The larvae are gregarious in setting and prefer to attach on or near another oyster (Bayne, 1969; Hidu, 1969; Hidu and Haskin, 1971).

Larvae crawl over the shell or cultch surface leaving a mucous trail that enhances settlement by later larvae. However, they must be terribly opportunistic because they cannot choose the site except by dropping out of the swimming mode as frequently as necessary to find a clean surface. Most setting occurs at slack tidal periods when currents are low or some refuge from currents is found. Currents are always slower near the bottom due to frictional drag, which facilitates setting. This does not mean that larvae prefer the bottom to some reef or piling extending above it, but often it is the only choice.

The choice of substratum is not critical for setting of larvae as they will use wood, stone, glass, gravel, sand, iron, rubber tires and anything else hard and non-toxic. Nevertheless, oyster shells impregnated with residues of oyster tissues are preferred if a choice is available. If the external organic coat (periostracum) of shells is removed with Chlorox®, larvae no longer show preference for the shells (Crisp, 1967). However, fossil shells seem to serve almost as well as recent shells for cultch. A bacterial film is considered helpful in preparing shells for setting of larvae but this occurs rapidly and where abundant larvae are ready to set, daily exposures of shells are made successfully for monitoring setting rates.

I do not believe that swarms of larvae produced in major rivers have any significant effect on setting in other estuarine systems. Each major estuary (i.e., James, York, Rappahannock, and Potomac rivers) is a unit dependent upon the oyster brood stocks within it's boundaries. There are places where larvae carried outside their river of origin drift downstream along a shore and provide significant setting in adjacent bays or smaller streams. Instances of this were observed in the creeks below the Great Wicomico River and above the Rappahannock River in the mid-1960's when setting was so intensive in the former system. This also occurs in Chesapeake Bay below the Piankatank River, and below the St. Mary's River and Smiths Creek which spill larvae onto the lower Maryland shore of the Potomac River, and probably spillage from other systems occurs. However, some few mollusc larvae do get carried long distances up bay of which _Mytilus edulis_ setting at Gloucester Point in the York River is an example some springs.

The edible mussel is a northern species that breeds in relatively cold waters below 20°C. Its range barely extends to Virginia waters and mature individuals are found only occasionally in the deeper waters near the Bay mouth. Despite the scarcity of broodstock, which may possibly be as far away as Ocean City, Maryland, young mussels appear on our trays at Gloucester Point fairly regularly, e.g. 1980 and 1981. Young mussels are nearly always scarce in Virginia waters and do not survive the hot summers in even moderate salinties (20-25^{o}/oo at Gloucester Point in 1980). They survive quite well in the Baltic Sea in rather low salinities (about 10^{o}/oo) where temperatures remain low. However, the point to be made about _M. edulis_ is that it sets in Virginia in the cool spring months before fish and planktonic predators have become abundant in the Bay. Also, the salt-wedge transport system is near it's maximum strength. Survival is evidently good considering the relative scarcity of larvae that is presumed to occur due to distance and lack of adults.

Another northern species of shellfish that escapes predation by breeding at low temperatures (15-20°C) is Mya arenaria the soft-shell clam. It rarely fails to reproduce successfully in Chesapeake Bay each fall in October and November and often does so in spring (May). Mya seems to have no problem keeping some larvae in a river system despite an apparent low population of adult clams, situated mostly intertidally in Virginia because of predation. The young clams are essentially eliminated subtidally by early summer (June) by predators, chief of which is the blue crab. Soft-shell clams gain several advantages by breeding in the fall or spring despite the slower growth of larvae that accompanies cold waters. Most fish, including fry of the species, have left the Bay by fall or graduated to prey of larger size than 0.2 mm larvae. The larvae may also prolong their setting period in cold weather without severe losses, and may use the attachment byssus or thread to stay above the bottom on grass or bushy colonial animals (hydroids, bryozoa) until a more suitable size and place for bottom living are reached. The result of this mix of advantages and handicaps, is that Mya larvae are common and easily found in Virginia waters and setting is extraordinarily successful and regular.

The flood by tropical storm Agnes in June 1972 (Andrews, 1973) seemed to enhance or concentrate Mya reproduction in the fall of that year. Huge wave-rows of living Mya were washed ashore in the winter and spring of 1973 in Mobjack Bay because there was not room enough for all to dig into the substrates. Setting of clams in oyster beds that year probably attracted the cow-nosed rays that have now become habitual predators of oyster beds in the Rappahannock River, long after the clams were dug out. This was a new experience of oyster predation on the Western Shore of Chesapeake Bay for me after 25 years of freedom from such destruction. It has always been a problem with hard clams and oysters on Seaside of Eastern Shore.

I don't think cownose rays appeared because clams did.

I agree! They have always been here but in 1972-3 Mya set on everything including oyster beds + eel grass beds. They were attracted to the beds by presence of Myas & the oysters too.

It is not understood why certain other invertebrate larvae of summer breeders are so much more successful than oysters in withstanding predation and flushing from river systems, particularly the James River. Barnacles and hooked mussels routinely set in the upper reaches of James River with facility and relatively lower losses from predators. Considering their relatively low fecundity compared to oysters, it is not clear how the larvae escape predators and dispersal by tidal currents. The hooked-mussel larvae presumably have essentially the same patterns of planktonic activity as those of oysters. Does a byssal attachment, even permitting occasional movement, provide better survival than a cement attachment? Most discouraging is the persistent fouling of oysters by mussels in such places as the upper Rappahannock River where oyster spatfall is a regular failure. This happened in the wet year of 1979, accompanied by record rainfall, and some freshwater mortality of oysters. These mussels belong to a southern species that does not extend north of Chesapeake Bay, therefore, they are summer breeders that face the same larval transport problems as oysters.

Mention should be made of other bivalve species that avoid prolonged planktonic life by producing large eggs and thereby reduce exposure to predation and limit wastage by losses to tides and currents. Oysters of the genus *Ostrea* are adapted to high-salinities in open bays adjoining the seas and to colder climates than *Crassostrea* by producing eggs from 2 to 5 times as large as *C. virginica*, and brooding the larvae in the mantle cavity for 10 days or more (Andrews, 1979). Those species with the largest eggs (0.5 mm) have a very short larval life (hours) to avoid cold waters, strong currents, and losses to the sea. Some mollusks such as bay scallops, (*Crepidula fornicata*) and oyster drills produce young that are similar in appearance to adults without any planktonic phase. For the advantages of brooding their young, they lose greatly in number of young produced and in wide distribution achieved rapidly by oysters and invertebrates with planktonic larvae (Sastry, 1979).

Spatfall - Setting of Oysters (Strike)

The Virginia oyster is an estuarine species adapted to difficult environments and ready to exploit vacant niches created by erratic weather by virtue of its very high reproduction rate and rapid distribution by planktonic larvae. An adult oyster may easily be induced to release 10 to 20 million eggs by application of sperm or eggs to stimulate spawning, if temperature increases alone do not cause it. In one spawning season, a large oyster of C. virginica may easily produce 100 million eggs which is about 50 times as many as the European flat oyster produces in one season (Andrews, 1979). As Loosanoff (1966) found in Long Island Sound, when conditions for larvae were right, a small broodstock produced an intensive spatfall and replenished a whole river or bay.

There are many instances of unexpected spatfalls in Chesapeake Bay (Beaven, 1954). The most dramatic was the 1963 river-wide spatfall in the Potomac River (Table 5) (Beaven and Andrews, 1964). Beginning in 1965, huge quantities of oysters were extracted from the Potomac River for several years and some up to the time of the freshwater kill by tropical storm Agnes in 1972. Only very minor setting occurred during the years when oyster populations were so large in the Potomac River, and very little has occurred through the years to 1980. During many of these years two Maryland tributaries of the Potomac River, St. Mary's River and Smiths Creek, were producing seed oysters in abundance (Manning and Whaley, 1954). Nearly 100 years ago, when millions of bushels of Potomac River oysters were dredged and shipped to New England for marketing (Ingersoll, 1881), this river apparently had adequate spatfalls to sustain intensive harvesting. It is astonishing however, how quite moderate spatfalls (as 1 or 2 spat/shell) can maintain an oyster fishery in predator-free, low-salinity waters such as occur in the Potomac River and the James

River. These areas are essentially free of predators and oyster diseases which results in very high survival ratios of spat and adult oysters, respectively. There is a mountain of buried shell in the Potomac River to provide cultch for oyster setting, and hard, barren bottoms are very extensive in area. The potential is great but the status as public beds without adequate capital for repletion, and lack of local sources of seed oysters are inhibiting development (Beaven and Andrews, 1964).

The size of breeding populations of oysters needed to insure adequate spatfall for any production area has always been a disputed subject. Even irregular setting every few years would be adequate if these occurred at intensities of 1 or 2 spat per shell. The problem seems to be the rate of flushing of larvae which is excessive in open rivers like the Potomac and Rappahannock rivers. Counting the private beds of oysters in the Rappahannock River, this breeding population is quite large and oysters have adequate food to produce large quantities of spawn. The answer seems to be that building up large breeding populations in these rivers is not feasible under public management and if spatfalls were successful they might disrupt the excellent growth patterns now prevailing. It would be far easier to plant seed oysters on these public beds from proven low-salinity seed areas and permit private leasing to finance the operation.

Leasing even some areas of the Potomac River for planting would increase brood stocks and enhance chances of getting some natural strike on the remaining public grounds, but even this option may be insufficient for producing spatfalls to restock the river. It has not worked in the Rappahannock River except at low levels of spatfall and slow repletion of natural beds. The effects of low oyxgen levels on larvae in summer in deeper channel waters of these rivers will be discussed later.

How to Attract Setting Larvae

Unless larvae are very abundant and setting pressure very heavy as observed on Seaside of Eastern Shore, Virginia (Mackin, 1946), intertidally in South Carolina (Lunz, 1955), and along the Cape May Shore of Delaware Bay (Hidu and Haskin, 1971), special effort is needed to insure adequate sets. It is not enough to plant shells. Unless there are oysters mixed with the shells, the larvae will usually keep moving until they find an oyster bed. This is a protective mechanism, for where there are live oysters there is some insurance that the substrate is favorably located for survival of oysters. Shell beds in James River catch far fewer spat than adjacent oyster beds although the same swarms of larvae pass over both. A better approach is to sprinkle productive oyster rocks with shells at frequent intervals but avoiding amounts that would smother oysters. Prior to the decline in setting after MSX appeared in 1959, there were regular spatfalls each year in the James River, and shells with spat would have been ready for harvest after one year of closure of the shelled bed. Oyster tongers object to sorting blank shells, naturally, and this failure of setting thereby leaving blank shells is apt to happen in James River seed beds now.

Another method of increasing spatfall in marginal setting areas is to introduce artificial cultch or baffling that interrupts and slows currents allowing larvae to drop out over a longer period of time. Common devices that utilize this effect include shellbags, limed tiles in Europe, shellstrings in Japan and the U.S. west coast, slatted wooden racks in Australia, mangrove and other brushy wood in tropical countries, and recently in France bundles of plastic straps dipped in lime and sand mixes (Korringa, 1976). The arrangement of all these assemblages is intended to expose maximum surface areas ~~arranged~~ to allow slow water currents to trickle through narrow spaces. All extend up above the bottom in stacks to intercept larvae carried by currents in a wider band of water than do shells on the bottom. Many are placed in vertical position or piles to limit the surface exposed to silting on the upper faces which deters oyster setting.

The character of the surfaces is also important to induce setting. Shells of almost any mollusk are probably the ideal cultch in surface characteristics. However, cavities do fill with silt or sand if facing cupped-side up. Quayle (1970) invented synthetic "cultchettes" the size of shells, designed to be handled on wire strings similar to oyster shells. They are shaped to avoid silting, and they disintegrate in six months, to provide single oysters.

Oyster larvae often set in small scratches or pits on shells. They prefer minute rugosities and tend to set heavier on the external surfaces of shells than on the smooth interior ones - provided fouling organisms do not interfere. The sand and lime coatings, developed long ago by French oyster farmers, satisfy the need for rugosity and calcium content and also make detachment of spat easier.

The most attractive collectors for Virginia oyster farmers are shellbags filled with oyster shells. Chicken-wire and plastic netting (1-1/2 or 2 inch mesh) are equally satisfactory containers. One-half to two-thirds bushel bags are easy to handle and provide about the maximum thickness that larvae will penetrate to insure setting on most shells. In 1958, Quayle and Andrews planted several thousand 1/2 bushel wire bags in several areas of Virginia including James River in groups of 3 bags tied together at the top. The year 1958 was a wet one with freshwater kill of oysters in spring at the upper end of the James River seed area, but it was also the year of greatest spatfall in the James River since I began monitoring it in 1946. Therefore, the 1958 test of shellbags was not satisfactory for demonstrating increased catch of spat under low setting intensity. Also, setting was satisfactory throughout the river because of the high intensity of the 1958 spatfall, therefore areas of testing (inshore private beds) were not important that year.

Commercial use of shellbags has occurred in the low setting areas of the Great Wicomico River and small tributaries on the Virginia side of the Potomac River for many years. The bags are made and filled during slack-work periods by employees at shucking houses. I would like to see short-term leases or permits allowing oyster farmers to plant shellbags on barren areas of public grounds in the best setting areas such as James River. With three-dimensional cultch a great many bushels of shells could be exposed to setting on an acre or two of bottom. If barren areas, such as occur in large acreages inshore of Wreck Shoal, were made available from 1 August to 1 April for shellbag collectors, enterprising entrepreneurs could produce significant quanitites of seed oysters. It would be difficult however to compete with $2 a bushel natural-bottom seed oysters containing 500 to 800 two-inch, and two- or three-year-old oysters now available. But the time may soon arrive when mechanized shellbag-type operations will be feasible and necessary to enhance low spatfalls.

Suspension of cultch off the bottom to produce seed oysters and traying of oysters for growth and marketing are far too costly and attended by serious fouling problems that make cleaning too labor-intensive to be economical in Virginia. It will take a dramatic turnaround in management of waterways and in the cost of labor for American oystermen to imitate the Japanese and French in these off-bottom cultural practices.

The Virginia oyster is essentially a reef oyster that prefers to attach above the bottom. Most species of the genus Crassostrea set and survive well in the intertidal zone where as spat they escape many predators and competitors. They will strike on surfaces at any angle in the water but prefer under and upper (0° and 180°) surfaces probably because of the problems created by currents impinging on vertical surfaces (Andrews, 1979).

The James River - A Seed Oyster Area

The James River is a shallow river with nearly all the flats less than 3 meters deep. The channel is also shallow compared to other Chesapeake Bay large tributaries. Only in Hampton Roads below Newport News Point are there channel depths much greater than 10 meters. Upriver, the natural channel that follows the curve of Burwell Bay has been virtually filled in with silt, and a narrow 8-meter-deep, dug, navigation channel (Rocklanding Shoal Channel) cuts through a vast expanse of oyster beds and deep shell beds. About a hundred years ago, scores of oyster "rocks" ebbed dry at low spring tides (Marshall, 1954), but today only one spot above White Shoal Light ebbs out. As usual, there is about a 10-meter-depth sill at the mouth of the James River in the Bay. But the river is close to the Bay mouth and has access to high-salinity waters from the ocean. No problems with low oxygen or black bottoms have occurred. Excellent hydrographical and biological studies of the James River seed area were made by Loosanoff (1932).

The dominant feature of the James River is its rather steep, horizontal, salinity gradient from Old Point Comfort to Deep Water Shoal Light, the range of oyster beds (Andrews, 1979). In a 25 mile stretch, salinities rarely get much below 20^{o}/oo at Old Point Comfort, whereas, Deep Water Shoal Light is usually fresh in winter and spring and averages about 10^{o}/oo in summer. The tributaries are small and shallow, and therefore have little effect on the wide river with its large drainage basin and tremendous freshwater flow. The effect of this freshwater flow and the responding salt-wedge flow on invertebrate larvae has been discussed. Above James River Bridge, the river has salinities too low, and spring freshets too regular, to allow predators and diseases to penetrate the oyster seed beds very far for very long. *Minchinia nelsoni* (MSX) penetrates as far upriver as Wreck Shoal in dry years such as 1964 and 1980. However, oysters discard the disease in May when salinities get below 10^{o}/oo. Transplanting infected oysters to low-salinity areas in fall and winter involves little risk of losses, but transplanting to high-salinity areas can result in deaths the following summer.

To reconstitute the setting level that prevailed before MSX arrived in 1960 is a difficult program. Assuming that loss of broodstock in the Hampton Roads areas was the cause of reduced spatfalls, there must be developed commercial stocks of MSX-resistant oysters to replant the area. Unless plantings are rotated and harvested regularly, oyster drills will build up populations on what are essentially bare bottoms now. Spatfall on Hampton Bar is highest of any place in the James River but drills prevent survival of spat. Pollution from overflows of domestic sewage systems at times of heavy rainfalls only complicates repletion efforts by preventing direct marketing of oysters.

The York River - a Salty River with MSX-Resistant Oysters

The York River is a short, wide estuary with very limited freshwater runoff via the Pamunkey River and the Mattaponi River. Salinities average 15 to 25^{o}/oo in summer and fall permitting oyster diseases and predators to range nearly the full distance upstream where oysters are grown. Natural oyster rocks are rather scarce in this river and relatively unproductive. Most oysters are grown on muddy or sandy bottoms by private planting. Setting is quite light in the river but is fairly regular in Mobjack Bay, particularly the tributaries on the eastern shore of the Bay.

One factor of considerable importance in the York River alone is the development of resistance to MSX by native oysters (Andrews and Frierman, 1974). All broodstocks in the river have been subjected to MSX selection for 20 years which made this possible. <u>Dermocystidium marinum</u> is also a serious problem in the York River which can only be controlled by isolation of plantings from public beds and others that retain a few old infected oysters (Andrews, 1979). Clean-up and fallowing of beds is helpful in controlling the disease but piers or pilings with attached oysters are always sources of infection. Only trial oyster plantings have been made in the lower York River below the bridge and on the extensive beds at the mouth of Mobjack Bay since MSX became established in 1960.

In the search for new seed-producing areas in the early 1960's following the decline of the James River, all the tributary creeks of the York River were monitored for setting for several years. These creeks appear to be totally dependent upon the York River for setting larvae, therefore, above the bridge there is little prospect of useful spatfalls in the creeks.

Mobjack Bay and its four tributary rivers are areas of widely fluctuating commercial oyster harvests. The salinities in these waters are typically above the $15^{o}/oo$ salinity required by MSX, Dermo, and oyster drills. There is little freshwater inflow in the Mobjack Bay system. Oysters may be killed by these pests at any size, with drills most serious for spat and yearlings whereas diseases kill older oysters. Fairly regular spatfalls replenish the stocks and resistance to MSX will be increasingly helpful in this area of constantly changing population levels.

The Rappahannock River - A Major Growing Area

The Rappahannock River has a moderate-size drainage area confined to the Coastal Plains and Piedmont regions of Virginia. Oysters on natural public beds in this river are rarely subjected to freshwater kill. However, its position on Chesapeake Bay provides salt water of only moderate salinity, therefore, salinities exceeding $20^{o}/oo$ are seldom experienced at the river mouth even in late summer and fall. The salinity gradient going up river is quite gradual with only $2^{o}/oo$ lower values midway at Towles Point and an autumn salinity average of

12°/oo at Bowlers Rock, the uppermost commercial public bed (Andrews, 1973).

Towles Point at the entrance of the Corrotoman River is a convenient point at which to divide the river into two rather distinctive oyster-growing areas. Below Towles Point the river tends to be deeper both in the channel and on the public beds situated on the borders of the channel. For many years the patent tong line at Towles Point divided the river into hand tonging above and patent tonging (> 7 meters) below the Point. Recently (1980) the patent tong line has been moved upriver several miles. In the lower river the channel is 20-23 meters deep except at the mouth where it barely reaches 10 meters and establishes a sill that greatly affects the supply of salty water from the Bay. This sill has important effects on oyster survival and reproduction that will be discussed later.

Above Towles Point are extensive, shelly-bottom, public beds that border the channel on both sides and produce a large portion of the oysters harvested from public grounds in Virginia. Inshore are quite shallow, private, rented grounds that often carry 2 million bushels of growing oysters transplanted from the James River seed-oyster area. Because it is essentially disease-free and predator-free, this upper Rappahannock River area is the most important market oyster area in Virginia. Even though the rented private beds are not hard, natural, oyster grounds, yields from James River seed oysters are relatively high, often 2 or more bushels harvested for each bushel planted.

Despite large populations of mature oysters full of spawn, setting in the Rappahannock River has been inadequate over 35 years to replenish public beds and is not wanted on private beds where oysters are being grown for market. Spatfall is heavier below Towles Point and quite light and intermittent in the upper oyster-growing sector (Tables 3, 4). The last intensive sets upriver were in 1954 and 1964. However, public beds have continued to produce some oysters throughout the 35 years of monitoring spatfall because survival of low-intensity spatfalls is excellent in the upper river. In the lower river before 1972, drills killed a large proportion of annual spatfalls which averaged about the 100 to 200 spat per bushel level. Hurricane Agnes eradicated drills from the Rappahannock River in June 1972 with a record deluge of freshwater. It also killed many oysters.

Failure of setting must be attributed to failure in survival of larvae. It may be that larvae are swept out of the estuary because the salt-wedge, upstream-transport system is weak in the Rappahannock River compared to that in the James River. During the warm season there is little freshwater flow and therefore very weak vertical stratification. It may be significant that major spatfalls in the river have been late-season ones in August and September when storms and cooling of waters occurs. A probable major factor is the occurrence of oxygen deficiency in channel waters nearly every summer that may rise to within 4-6 meters of the surface. There is no sharp demarcation level to warn larvae, but oxygen levels decrease gradually with depth. The existence of a 10 m sill at the mouth of the river tends to trap low-oxygen pools in the deeper channels upstream. Low-oxygen layers also develop in deep waters of Chesapeake Bay and the mouth of the Potomac River which may contribute to the problem. It is believed that physical factors cause the low spatfalls in the Rappahannock River and not the size of broodstock-oyster populations.

Another set of primarily physical factors develops in early May of wet years that endangers survival of oysters in depths below 5 m of water. At the peak of freshwater river flow in spring, in early May usually, there is strong vertical salinity stratification of Rappahannock River waters that results in anaerobic conditions on the bottom. Iron and heavy metal sulfides develop from the sulfur released by decaying organic matter and they turn everything on the bottom black. "Black bottoms" have appeared on oyster beds at 5-6 m in 1949, 1953, 1974, and 1980, and killed oysters in 1953. This condition occurs only in years of heavy runoff which sets up strong vertical stratification of fresh and salt water. A period of rapidly increasing temperatures in early May causes high O_2 demand on the bottom that cannot be resupplied by tidal mixing because of density stratification. High nutrient levels lead to phytoplankton blooms concurrently with high O_2 demand by organic matter carried in with freshwater flow (Andrews, 1955).

At least twice in 35 years, hurricanes have killed oysters in the Rappahannock River, both storms were considered unusual and record-breaking in amounts of riverflow. The August 1955 catastrophe occurred when two hurricanes (Connie and Dianne) passed inland of Tidewater Virginia within a week of each other. Up to 90% of oysters were killed on some public beds, particularly in shallow waters. Kills caused by freshwater alone are greatest in shallow waters and least in deep oyster beds adjacent to the channel. If O_2 deficiency is the cause, mortalities occur on deep beds and not on shallow, inshore grounds. The second big mortality was caused by Hurricane Agnes in June-July 1972 with its record-breaking runoff over the Chesapeake Bay watershed. It was strictly a freshwater kill of oysters. The whole of Chesapeake Bay was already low in salinities from a wet year (1971) preceding the storm. With low salinities in the Bay at the mouth of the river and a sill preventing access of deep salty waters, the Rappahannock River could not recoup its salinity levels in time to save oysters in the upper bed sector of the river (Andrews, 1973; Haven, et al., 1978).

The location and morphometrics of the Rappahannock River make it susceptible to damage of oyster beds by extraordinary weather conditions and there is not much oystermen can do to anticipate or avoid unusual situations. Most years it is a superb oyster growing river with freedom from diseases, predators, and salinity problems.

Repletion efforts on public beds in the Rappahannock River should consist mostly of shell plantings in the lower river where setting is more favorable than above Towles Point. The Corrotoman River is dependent upon the Rappahannock River for larvae and its setting patterns. However, the huge public oyster bed called Drummond Ground at its mouth often obtains higher spatfalls than other areas in the lower Rappahannock River, probably because the river makes a turn here and flood currents from the channel run over the bed into the Corrotoman River. An added benefit from this turn is that some years the Corrotoman River obtains spatfalls of seed-oyster density. These slow-growing oysters are best used by transplanting to the upper Rappahannock River. The Corrotoman River was once considered for use as a seed-oyster area following good spatfalls in the late 1940's and early 1950's.

The other source of seed oysters for the large acreage of growing grounds in the Rappahannock River is the Piankatank River. Spatfalls are irregular but often intensive. Good spatfalls in 1949, 1950, and 1951 were followed by years of relative failures until the mid-1960's when very large sets occurred (1963-65). Because growth tends to be slow in the Piankatank River, when counts reach 500 to 1000 oysters per bushel oysters should be moved out, preferably to private grounds, by public tonging or hand dredging.

The Potomac River - Great Unused Oyster-Growing Potential

The Potomac River has the greatest potential for oyster farming, and now the smallest production, of any system in Chesapeake Bay. The problems are two-fold. The river is operated solely as a public fishery administered jointly by Virginia and Maryland. Spatfall is inadequate to maintain the river at even a low level of production

(Table 5). Also, sources of seed oysters are limited as are funds to pay for them. The 1972 Agnes flood further destroyed broodstocks in the upper river thereby reducing the already low probability of spatfalls. Some seed oysters have been purchased from Virginia but huge areas of barren bottoms exist.

The oyster-growing area of the Potomac River extends from the mouth upriver to Mathias Point above the bridge. For many years oysters persisted at Beacon Bar and Popes Creeks with some losses to freshwater, but the record runoff of 1972 destroyed a low-salinity adapted population. Over this 50-mile stretch of river there is only a low, horizontal, salinity gradient ranging from 20°/oo at the mouth to 13°/oo at the bridge in late summer. However, only two major freshwater mortalities are reported for the Potomac River one in 1936 (Frey, 1946) and the other in 1972.

There is a gradient of setting with decreasing intensities of spatfall with distance up river (Table 5). This is best shown by the 1963 riverwide set. Most years there is appreciable setting only on the Maryland shore just above Point Lookout on beds known as Cornfield Harbor and Jones Shore. I suspect that most of this spatfall is derived from larvae carried down the shore from St. Mary's River and Smith Creek where seed oysters have been produced many years.

Although spatfalls in most areas of the river fail regularly, survival is so high that even a trickle of spat gradually builds up a small population of old oysters over the years. Before the 1972 deluge, old oysters of 15 to 20 years age were encountered sporadically on otherwise barren grounds. The supply of shells for setting of oysters is typically very low.

Beginning about 1966, seed oysters from the Great Wicomico and Piankatank rivers were planted on the best growing beds in the middle sector of the river between Swan Point and Piney Point, including Virginia shore areas such as Nomini Bay. Setting failed in these seed rivers after 1966 and seed oysters were only available for planting in the Potomac River in 1966 and 1967. Some James River seed oysters were planted in subsequent years up to 1974 and a lot of fossil shells were planted. Private oystermen in the Great Wicomico River area sold several thousands of bushels of shellbag-caught seed oysters to the Potomac River Commission in the mid-1960's.

There was a boom in Potomac River oystering for about 5 years beginning in 1965-66 when the first oysters from the big 1963 set were harvested. This yearclass of oysters, unprecedented in recent times, was augumented by seed oysters from Virginia planted on the best growing bars in the middle sector of the river. Salinities were above normal during the mid-1960's which induced good growth of oysters, too.

Following the 1972 storm, most years of the 1970's were wet and the Potomac River had its lowest oyster populations ever. The upper half of the oyster-growing area was almost denuded of oysters and setting has failed consistently.

The Potomac River oyster is a fast-growing race with physiological traits that separate it from other Chesapeake Bay oysters, particularly James River stocks. With the loss of so many native oysters and introduction of Virginia oysters, the status of this superior race is questionable. However, there is no probability of building back the native population for reproductive purposes, therefore, use of outside seed oysters is necessary.

The tributaries of the Potomac River and adjacent Virginia rivers such as the Great Wicomico and Piankatank rivers should be used when seed oysters are available to stock the Potomac River. The St. Mary's River was for many years an important seed area for Maryland and other small tributaries along northern shore of the Potomac sometimes achieved good sets. Since all these small tributaries fall in the trap-type setting systems they seem most likely to get good spatfalls in dry years and drought periods such as occurred in the mid-1960's and 1980 (above Pt. Lookout).

I do not believe it is possible to build up broodstock populations large enough to produce spatfalls with any regularity in the Potomac River. It is an open-type river with a weak salinity gradient that tends to flush larvae into the Bay. If such an objective is to be achieved, it will certainly require leasing oyster grounds to private oyster farmers, with the capital to stock their beds with seed oysters. The acreage of good bottoms is far too great to replenish the river with public funds.

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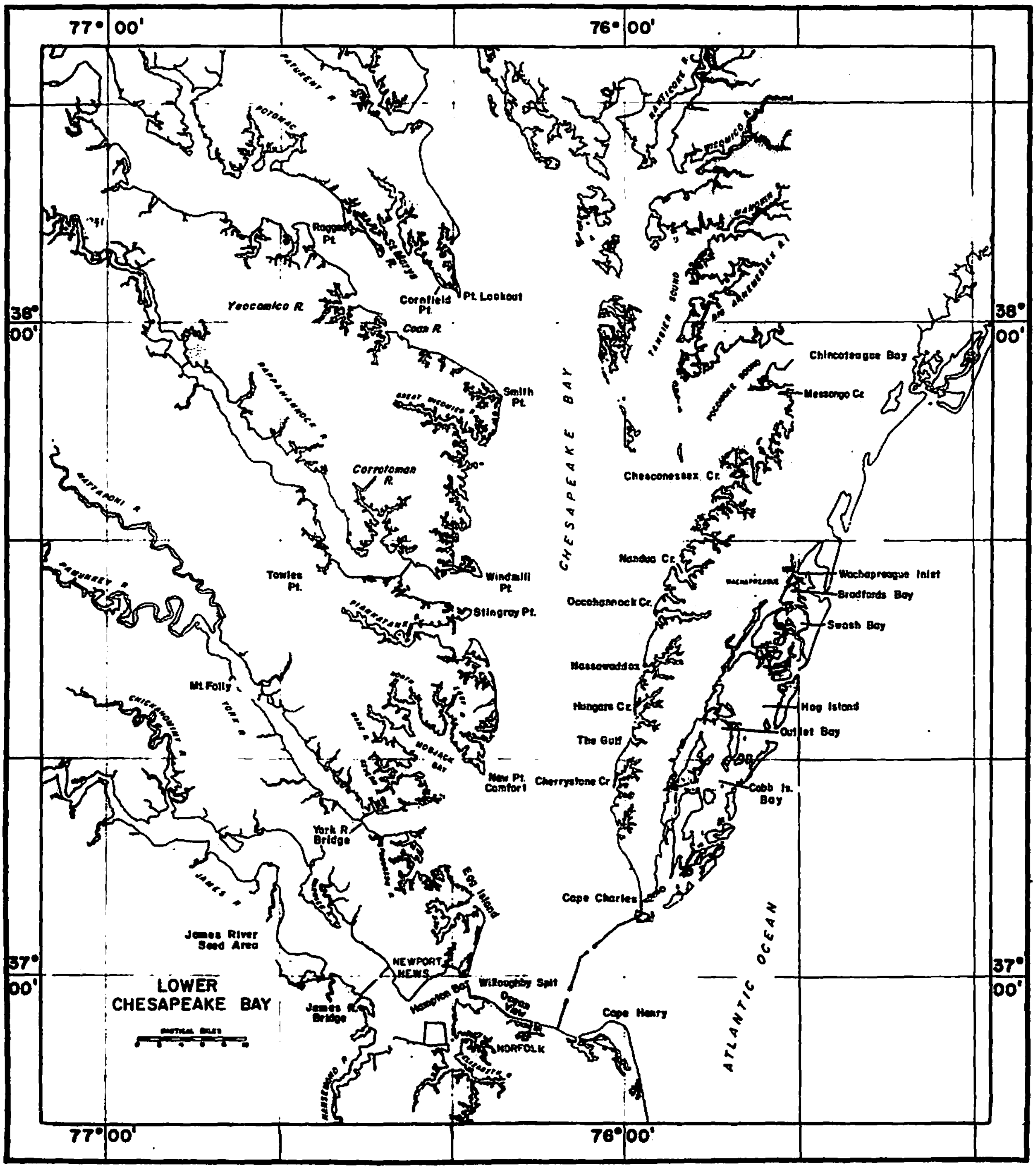
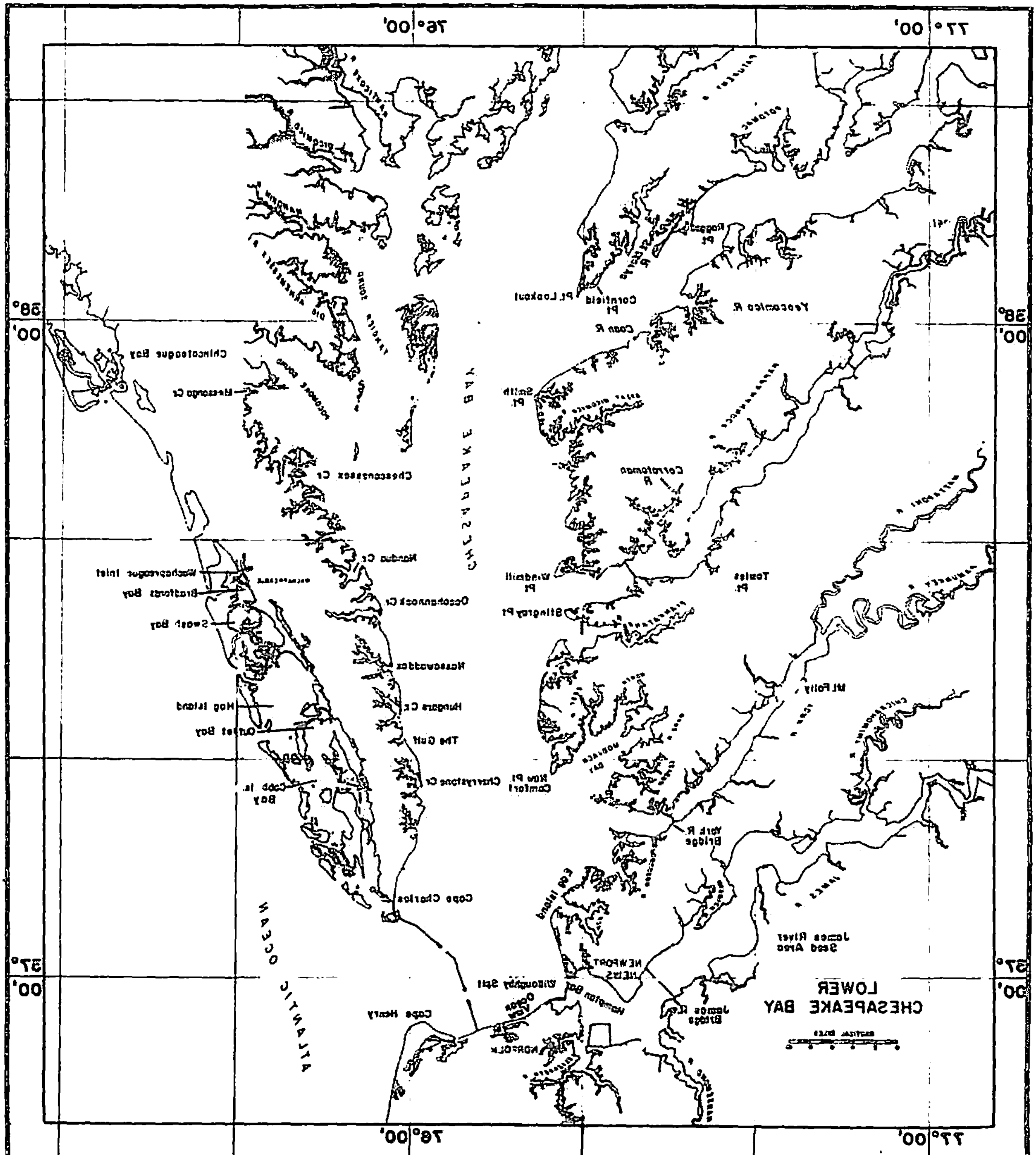
Figure 1. Map of lower Chesapeake Bay showing major rivers and their tributaries. Major geographic features such as bays, sounds, land points marking entrances to rivers are shown.

Figure 2. Bivalve larvae in river-wide swarms move up and down the river with tides but they are most abundant in the channel. Early-stage larvae, from spawn released in the seed area, are carried downriver over shallow flats into deep, wide channels in Hampton Roads. On flood tides, larvae are carried upriver primarily in the channel at all depths. As flood tides spread over the flats, some larvae are left over oyster beds, but most return to Hampton Roads on ebb tides for constant recycling. Survey ships anchored near James River Bridge revealed high bivalve-larvae counts from mid-flood to mid-ebb. Over a 12 day sampling period only early-stage oyster larvae were found, therefore, recruitment every two or three days occurred through new spawnings. Larval transport was a failure in 1965 and almost no setting occurred above James River Bridge. Drought and low freshwater runoff resulted in a weak upriver, net non-tidal transport system. Hampton Roads waters were essentially homogenous with depth for salinities and temperatures and the salt-wedge system was weak.



77° 00'
76° 00'
38° 00'
37° 00'
LOWER
CHESAPEAKE BAY
Ragged Pt
Cornfield Pt
Pt. Lookout
Yeocomico R.
Coan R.
Smith Pt.
Corrotoman R.
Towles Pt.
Windmill Pt.
Stingray Pt.
Mt Folly
New Pt. Comfort
York R. Bridge
Egg Island
James River Seed Area
NEWPORT NEWS
James R. Bridge
Hampton Bar
Willoughby Spit
NORFOLK
Cape Henry
Cape Charles
CHESAPEAKE BAY
ATLANTIC OCEAN
Chincoteague Bay
Messongo Cr.
Chesconessex Cr.
Nandua Cr.
Occohannock Cr.
Nassawaddox
Hungars Cr.
The Gulf
Cherrystone Cr.
Wachapreague Inlet
Bradfords Bay
Swash Bay
Hog Island
Outlet Bay
Cobb Is. Bay


LOWER CHESAPEAKE BAY
77° 00'
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CHESAPEAKE BAY
ATLANTIC OCEAN
Chincoteague Bay
Messongo Cr
Chesconessex Cr
Nandua Cr
Occohannock Cr
Nassawadox
Hungars Cr
The Gulf
Cherrystone Cr
Cape Charles
Wachapreague Inlet
Bradfords Bay
Swash Bay
Hog Island
Outlet Bay
Cobb Is. Bay
Pt. Lookout
Cornfield Pt
Coan R
Ragged Pt
Yeocomico R.
Smith Pt.
Corrotoman R
Windmill Pt
Towles Pt.
Stingray Pt
Mt Folly
New Pt. Comfort
York R. Bridge
Egg Island
Newport News
James River Seed Area
Willoughby Spit
Hampton
Ocean View
Cape Henry
Norfolk
James R. Bridge

Fig.2. TRANSPORT OF BIVALVE LARVAE

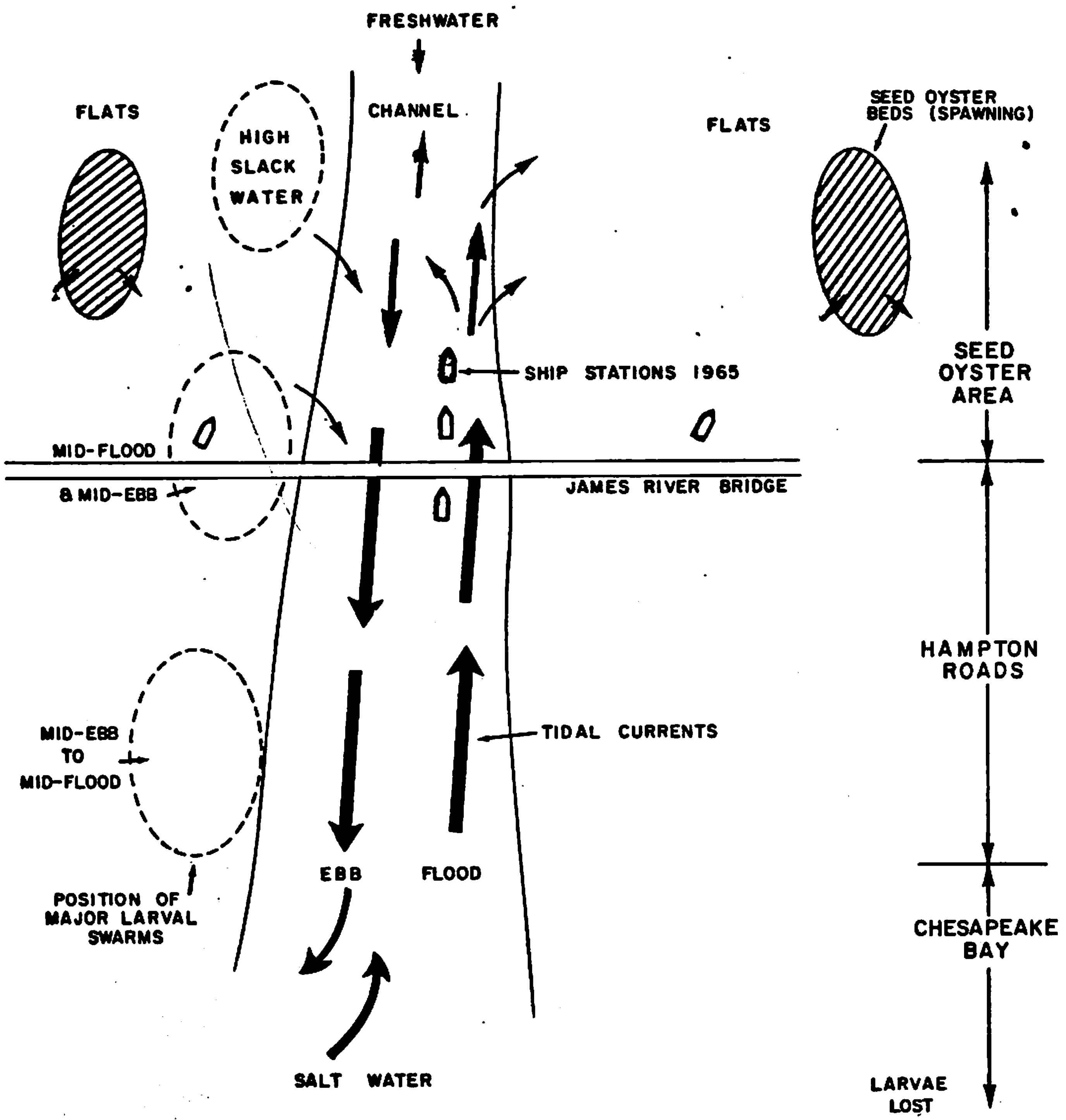

Table 1. Weekly spatfall of oysters in bags of oyster shells at Wreck Shoal bed in the James River Seed Area*

Period by weeks	No. of Spat per 100 shellfaces per week 1947	1948	1949	1950	1951
June 4th	0	0	10	0	0
July 1st	0	40	150	0	170
2nd	195	120	220	10	150
3rd	120	360	80	90	360
4th	495	288	590	210	1270
Aug 1st	752	160	1780	195	330
2nd	1422	432	1650	335	300
3rd	2833	718	1845	145	200
4th	3135	1053	1830	340	230
Sept 1st	3025	1790	695	3900	340
2nd	2180	670	725	3175	310
3rd	900	1000	740	1360	106
4th	425	1480	425	630	85
Oct 1st	380	205	20	265	193
2nd	5	30	30	130	0
3rd	5	--	--	--	--
4th	0	--	--	--	--

*100 flat right valves = 1/6 Virginia oyster bushel. Usually, averages of two shellbags with 20 shellfaces counted from each. Double to get counts per shell.

Table 2. Gradient of weekly spatfalls in James River with distance[1] above mouth of river during peak setting.

	Av. spatfall per shellface per week					
	1949 shellbags[2]			1950 shellbags[3]		
Period of exposure by weeks	Brown Shoal (J11E)	Wreck Shoal (J17E)	Deep Water Shoal (J24E)	Brown Shoal	Wreck Shoal	Deep Water Shoal
July 1st	2.9	1.5	0.	-	0	0
2nd	5.8	2.2	0.	-	0.1	0
3rd	0.3	0.8	0.1	0.8	0.9	0
4th	7.4	5.9	0	6.7	2.2	0
Aug 1st	15.6	17.8	0.2	3.4	1.9	0.4
2nd	32.6	16.4	2.6	3.1	3.3	0.1
3rd	29.3	18.4	0.7	1.0	1.5	0.2
4th	29.0	18.3	0.3	4.2	3.4	0.2
Sept 1st	19.1	7.0	0.1	43.1	39.0	1.0
2nd	12.3	7.2	0.5	45.1	31.7	1.0
3rd	4.6	7.4	0	23.4	13.5	0
4th	1.1	4.3	0.1	4.3	6.3	0
Totals	160.0	107.2	4.6	135.1	103.8	2.9

[1]Distance in nautical miles of these public oyster beds above mouth of river, and position east or west of main channel.
[2]Actual counts of spat on 20 shellfaces from each of two shellbags usually.
[3]Spat on 10 shellfaces counted on shellstrings suspended just off bottom with flat right valves facing down.

Table 3. Spatfall on Natural Cultch in Rappahannock River, Virginia (1947-1952 and 1954).

	Counts of Spat per Virginia Oyster Bushel							
Below Towles Pt.	1947	1948	1949	1950	1951	1952	Av.	1954*
Butlers Hole	976	376	656	1152	----	110	654	36
Broad Creek	560	320	438	272	264	95	325	24
Parrots Rock	----	280	612	64	96	48	220	30
Drummond Gr.	664	432	1102	736	195	134	540	284
Above Towles Pt.								
Hoghouse Bar	560	32	48	----	7	17	133	92
Rogues Hole								
Bluff Rock	72	32	12	----	16	3	27	623
Smokey Pt.	----	0	64	96	2	1	33	216
Punchbowl	0	16	0	----	8	----	6	143
Piney Is.	----	8	196	48	0	----	63	383
Morattico Bar	8	0	28	24	4	3	11	49
Bowlers Rock	64	32	24	16	0	5	24	0
Ross Rock	64	80	0	8	16	5	29	12

*Best set above Towles Pt. where most public oyster beds are located in a decade--previous one in 1944.

Table 4. Spatfall on Natural Cultch in Rappahannock River, Virginia (1961-1967).

	Counts of Spat per Virginia Oyster Bushel							
Below Towles Pt.*	1961	1962	1963	1965	1966	1967	(Av.)	1964**
Butlers Hole	11	----	----	----	----	----	-----	----
Broad Cr.	37	98	127	----	----	----	87	269
Parrotts Rock	9	33	81	----	----	----	41	189
Drummond Gr.	13	169	90	227	68	5	95	142
Above Towles Pt.								
Hoghouse Barr	0	35	89	60	21	0	34	82
Rogues Hole	0	31	108	351	161	0	108	223
Bluff Rock	0	2	7	134	74	0	36	65
Smokey Pt.	0	28	29	112	42	0	35	254
Punchbowl	0	----	1	62	2	2	13	34
Piney Is.	0	2	4	17	19	0	7	48
Morattico Bar	4	2	5	52	29	0	15	53
Bowlers Rock	0	----	----	----	----	----	-----	25
Ross Rock	0	----	----	----	----	----	-----	28

*Samples difficult to obtain in 1960's and drills killed most spat early.

**Best set above Towles Pt. in a decade.

Table 5. Summary of Spatfall in Potomac River, 1942-1963[1]

Year	Upper River (5 bars) (Above Swan Pt.)	Middle River (7 bars) (Above Ragged Pt.)	Lower River (4 bars) (Above Pt. Lookout)
	Average No. spat per Md. bushel on natural cultch		
1942	1	13	---
1943	14	79	387
1944	0	3	32
1945	4	9	---
1946	0	0	---
1947	1	1	33
1948	0	11	12
1949	1	5	19
1950	2	3	137
1951	24	18	95
1952	21	11	56
1953	0	2	12
1954	1	2	29
1955	0	1	72
1956	0	2	50
1957	1	0	17
1958	0	2	26
1959	22	7	63
1960	2	0	17
1961	20	5	9
1962	11	10	104
Average	6	9	65
1963	53	128	140

[1]Data extracted from Beaven and Andrews, 1964. No change of setting patterns occurred from 1964 to 1980 with low spatfalls except on bars near Pt. Lookout.