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Interaction Between Circulation of the estuary of the James River and Transport of Oyster Larvae

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Estuarine Circulation

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Preface

Estuaries exist along the edge of the oceans and seas, and are characterized by the dilution of sea water by inflowing fresher waters. The motion and interaction of these two types of water (fresh and salt water) determine the salinity distribution within the estuary and that, in turn, affects the organisms residing there. The purpose of this volume is to review the status of our understanding of estuarine circulation and how the circulation patterns affect living and nonliving resources in estuaries.

For many years, the primary paradigm for estuarine circulation was the two-layered net or nontidal gravitational circulation pattern first proposed by Dr. Donald Pritchard in his studies of the James River estuary. During the last decade or so, research has focused on the many variations about this theme and the factors that control the transport processes. Many of these aspects are covered in the initial papers in this volume. Water movement, of course, is of interest because it transports marine organisms, sediments, and pollutants. Estuarine circulation has a significant effect on estuarine food chains, and on the distribution and abundance of organisms, such as the American oyster, that are freely transported by the currents during larval stages. The intent is to bring together many of these topics in a single volume.

This volume is dedicated to Dr. Donald W. Pritchard, our colleague and friend, as was the conference held in Gloucester Point in January of 1985. The conference was organized as one means of recognizing his contributions to our understanding of the physical oceanography of estuaries. It was held in conjunction with the 1985 Charter Day exercises of the The College of William and Mary. At that time, Dr. Pritchard was awarded an honorary degree of Doctor of Science.

The editors would like to thank those who atttended the conference and especially those who made presentations, the authors of the papers included in this volume, the many persons who reviewed these papers, and Mrs. Barbara Cauthorn, who prepared the final versions of the manuscripts.

Bruce J. Neilson
Albert Kuo
John Brubaker

Contents

INTERACTION BETWEEN CIRCULATION OF THE ESTUARY OF THE JAMES RIVER AND TRANSPORT OF OYSTER LARVAE*

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ABSTRACT

Hydraulic model dye test results are examined to provide estimates of nontidal horizontal circulation and movement/retention of oyster larvae in the James River Estuary. Test conditions maintained a constant mean tide and average summer low freshwater discharge. It was assumed that movement of dye in the model would approximate movement of the planktonic (larval) stages of oysters (**Crassostrea virginica**) in the prototype. Test results were used to rank six dye release points (candidate brood stock locations) with respect to relative quantities of dye retained in areas of the model representing commercially important seed oyster beds during the period 20-40 tidal cycles after release (the time, after spawning, when oyster larvae will permanently attach to a suitable substrate). Under the test conditions, nontidal circulation in the model was similar to that found in a weak partially mixed estuary: upstream motion along the bottom and over the right hand shoals (looking upstream) and downstream motion elsewhere. The pattern was modified by cyclonic motion of surface waters in the upstream and downstream reaches which increased residence time of material in the seed oyster bed region. Greatest retention

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* Contribution No. 1410 from the Virginia Institute of Marine Science

during the 20-40 tidal cycle period was from releases over upstream and right hand side shoals and is reflected in release point ranking.

INTRODUCTION

The James River has been, and remains, the most productive seed oyster producing estuary in Virginia's Chesapeake Bay System (Hargis 1966; Haven et al., 1978). Its success is believed due as much to its geomorphological features, salinity regime, and circulation patterns as to its biological characteristics, (Hargis, 1966; Hargis, 1969; Marshall, 1954 ; Pritchard 1952; Wood and Hargis, 1971). A significant portion of that success has been attributed to the possibility that larvae produced downstream are transported to the setting grounds upstream by the inward-moving deeper currents driven by gravitational circulation in the estuary. Thus, downstream beds of mature oysters are believed to have been the basis for a significant portion of the high-levels of spatfall which, in turn sustained the high levels of seed oyster production, prior to 1960 (Haven et al., 1978). Since then production of spat, young recently-set oysters, has been extremely depressed. Consequently, the numbers of 'seed' oysters has also been reduced.

This decline in spatfall and seed oyster production coincided with massive mortalities of older oysters in the higher salinity portions of the Chesapeake Bay and its Virginia tributaries, including the James estuary, caused by an epizootic (epidemic) traced to a protozoan parasite. Commercial removals, made to avoid further losses, also took many. The resulting reduction in breeding-age oysters (or brood-stock) in the lower estuary is believed by some oyster scientists to have been the most likely cause of much of the decline in spatfall and, thus, seed in the upstream seedbeds (Andrews, 1983).

Scientists postulated that the most feasible method for rapid replenishment of market oyster production was to replace the 'missing' larvae with those from specially-bred disease-resistant broodstock. Work was begun on production of such disease-resistant oysters. Anticipating success in this endeavor, we considered the question of where brood stocks should be placed to assure that their larvae would reach the setting areas in appropriate condition and numbers to establish themselves. A scaled hydraulic model of the entire tidal James River was employed to establish the locations in the lower James at which brood oysters should be placed. Accordingly, model experiments were designed to compare the distribution and the quantitative (numbers) and qualitative (time) fate of larvae, as simulated by dye, from selected release points (candidate sites for brood stock planting) in the lower estuary (Hargis, 1969 ; Ruzecki and Moncure, 1969). In this paper we review and further analyze the results acquired during our model studies in 1968.

METHODS

Experimental Design and Procedures

Six experiments using the flourescent dyes Pontacyl Brilliant Pink and Uranine were conducted in three runs of the James River Hydraulic model. The fluorescent characteristics of these dyes permit separable detection of one in the presence of the other when concentrations of each are in the parts per billion (ppb) range. Basic features of the experiments were:

1. Dye release points were sites which could serve as primary larval sources and were likely candidate sites for brood stock planting.
2. Regions of particular sampling interest were the commercially important seed oyster beds shown in Figure 1.
3. Tidal-phase relationships of oyster spawning were unknown, therefore dye was released at a constant rate over one tidal cycle.
4. Mean time between spawning and attachment of resultant oyster larvae is fifteen days (Haven, et al., 1978). Thus sampling started twenty tidal cycles (approximately 10 days) after release and continued at alternating (but not consecutive) local slack water before ebb (SBE) and slack water before flood (SBF) for an additional twenty tidal cycles.
5. River discharge and source salinity matched the multiannual mean for late summer, the primary spawning period in the James.

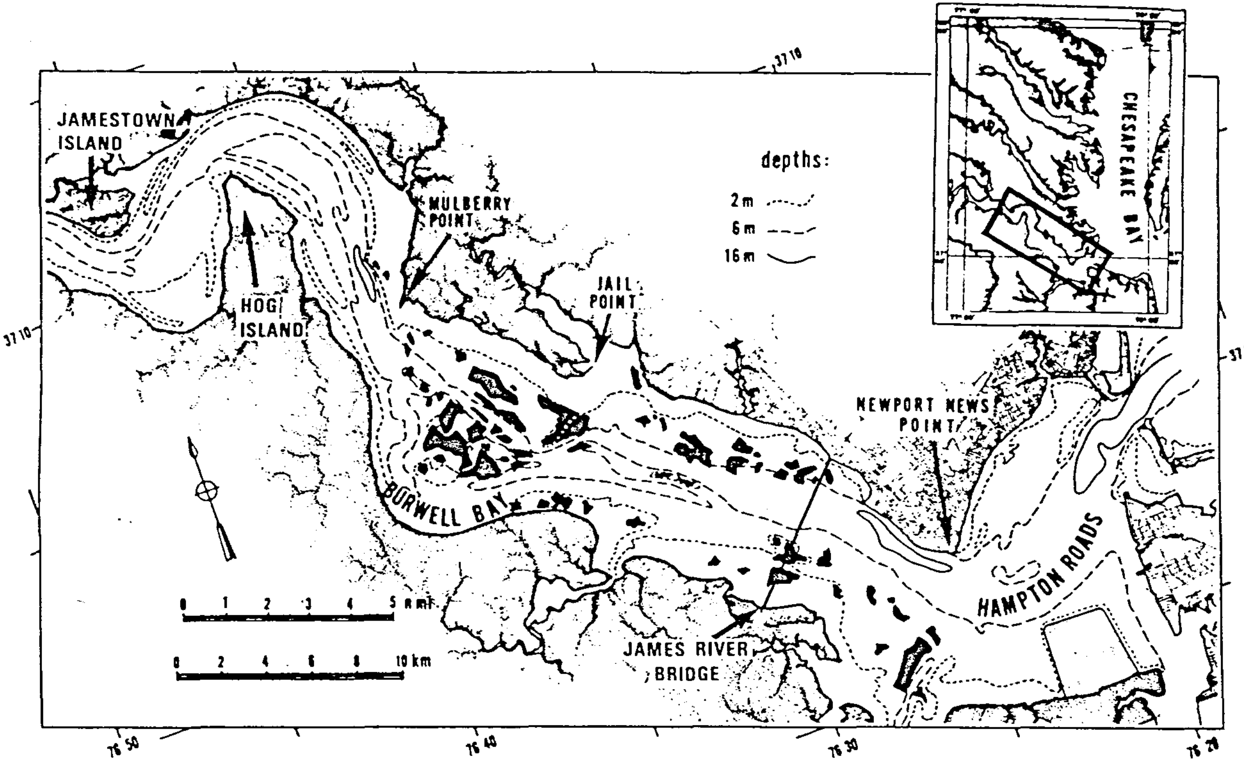

Figure 1. Chart of lower James River showing general bathymetry, location of public seed oyster beds and named features referred to in text. Inset shows location of James relative to Chesapeake Bay.

6. At the conclusion of each model run, the distribution of each dye throughout the model was determined.

The James River Hydraulic Model was a distorted Froude model (USA COE, 1966) with length scaling factors of 1:1000 horizontal and 1:100 vertical and time scaled by 1:100. For each test repetitive mean tides with a prototype (real world) range of 0.76 m. were simulated and freshwater discharge was constant to match prototype flows of 91 $m^3 s^{-1}$ at Richmond and a total of 27 $m^3 s^{-1}$ appropriately distributed among three major tributaries (Appomattox, Chickahominy and Nansemond Rivers). The salt water source salinity was maintained at 26 ppt.

These conditions were maintained for at least 140 tidal cycles prior to dye injection to insure steady state conditions in the model. Steady state was verified by measuring salinity at stations along the model axis every tenth SBE from startup to dye injection.

Dye solutions were prepared by dissolving 5 g of dye in 100 ml of distilled water and increasing the volume to 1200 ml with water removed from the planned injection location in the model. Dye was injected at the model bed by pipetting 50 ml aliquots twenty-five times during a tidal cycle, once every 18 seconds. Injection locations are shown as numbered boxes in Figure 2. Location 6 in the figure represents a brood stock region rendered unproductive by disease and associated commercial harvests.

A detailed description of sampling procedure was given in Ruzecki and Moncure (1969). Briefly, it was as follows: water samples were pipetted from the model at 108 locations approximately 1 m apart in the region between Newport News Point and Jamestown Island (Fig. 1). From one to three samples were taken at each station depending on water depth. Samples were simultaneously siphoned from adjacent stations along paired cross-model transects with transect sampling completed in less than 30 sec (equivalent to 50 min prototype time) at local slack water. Dye concentrations were determined with Turner 110 fluorometers. Each station was sampled fourteen times during a model run.

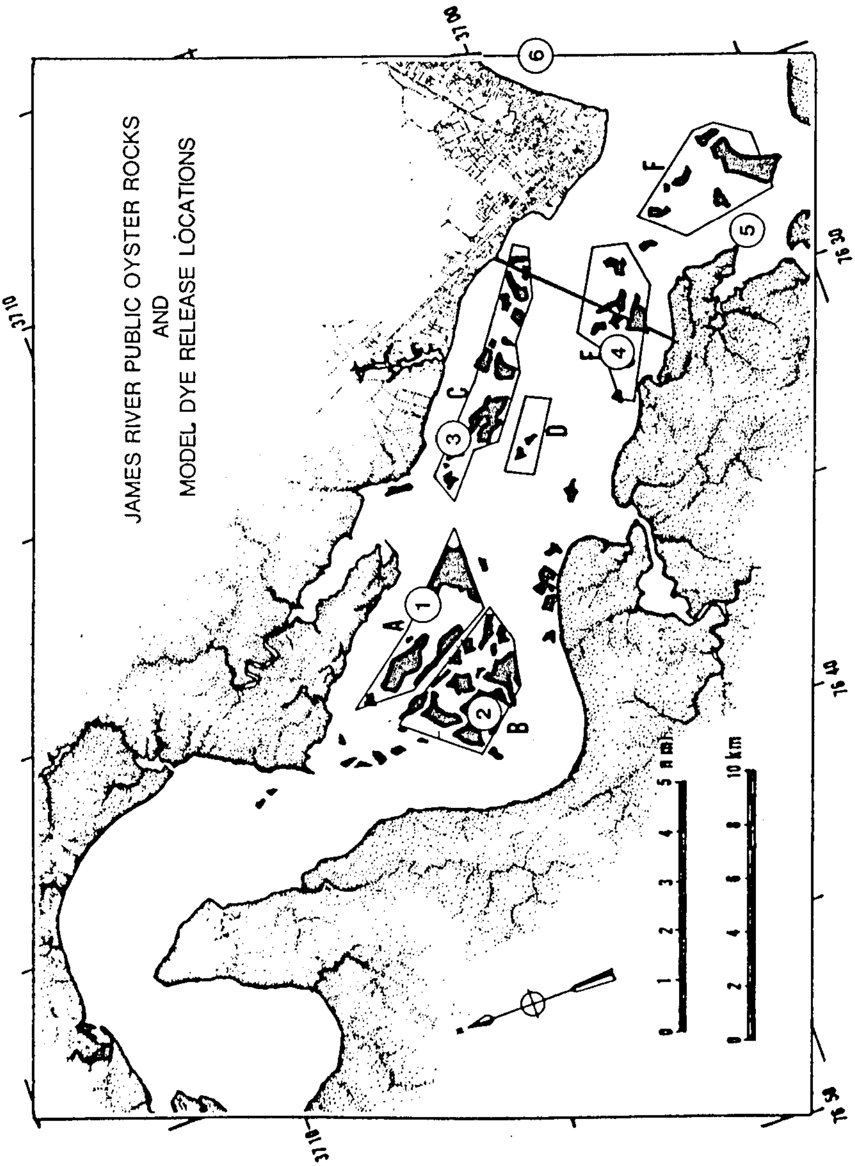

Figure 2. Selected areas representing James River public oyster rocks. Letter designations are: A, Wreck Shoal. B, Point of Shoals. C, Brown Shoal Reach. D, White Shoal. E, Naseway Shoal. F, Nansemond Ridge, boxed numbers indicate dye release locations.

For Test I, dye was injected at Wreck Shoal and Point of Shoals (locations 1 and 2, Fig. 2) and first samples were obtained at SBF twenty cycles after injection. Successive samples were removed every third local slack water with final samples taken at SBE forty cycles after release.

The frequency and duration of sampling were altered for Tests II and III based on dye movement and distributions observed during Test I. During Test II, dye was injected at Brown Shoal and Naseway Shoal (locations 3 and 4, Fig. 2) and first samples were obtained at SBE six cycles after injection. Successive samples were removed every fifth local slack water with final samples taken at SBF thirty-nine cycles after injection. For test III, dye was injected at Nansemond Ridge and Hampton Flats (locations 5 and 6, Fig. 2) and first samples were removed at local SBF six cycles after injection. Successive samples were removed every fifth local slack water with final samples taken at local SBE thirty-nine cycles after injection.

At the end of each test, (SBE after the final sample) the model was segmented by installation of dams at the following locations (see Fig. 1): the mouth of the James and major tributaries; between the bridge and Newport News Point; at either end of Burwell Bay (Jail Point and Mulberry Point); off Hog Island ; and just upstream from Jamestown Island. Water in segments was mechanically mixed and twenty random samples removed from each to establish a final inventory of dye.

Data Treatment

Dye concentrations were treated in two ways:

1) Depth-integrated dye concentrations were determined for each sampling station for each sampling period as:

$$CZ = \Sigma C_i \Delta Z_i$$

where C_i was the measured concentration and ΔZ_i represented depth interval taken from surface to midway between the upper and mid level sample (ΔZ_1), from this level to midway between the mid level and near bottom sample (ΔZ_2) and finally to the bottom (ΔZ_3). The upper limit of ΔZ_1 was taken at near low water for SBF samples and increased upwards by 0.6 cm for SBE samples to approximate tidal variations. Resulting data sets, named LARVAE, were taken to represent a time-dependent measure of oyster larvae per unit bottom area resulting from each release and expressed as mg dye per m^2 of model bottom.

2) Surface SBE concentrations were multiplied by the lesser of: total model water depth below MLW, or 6.0 cm. Associated SBE concentrations had depth adjustments as above. Resulting data sets were named SPAT and taken to represent a time-dependent measure of oyster larvae from each release which, when set would simulate spatfall on commercially worked bottoms (which, in the prototype, are found to water depths of 6 m).

Both data sets were subjected to a SURFACE II interpolation routine (Sampson, 1975). Portions of SBE and SBF LARVAE data sets temporally adjacent to tidal cycle 30 were averaged and plotted as contour maps for each release. SPAT data were summed over designated areas, (Fig. 2) which, in general, represent large aggregates of oyster rocks.

Results and Discussion

The results were used to:

1) Simulate density distribution of oyster larvae available throughout the seed bed areas at the time of maximum spatfall after late summer spawning,
2) rank release points as possible brood-stock sites,
3) rank the seed oyster bed regions as 'spat collectors' during the critical setting time,

4) rank release points with regard to temporal retention of dye within the seed oyster-producing portion of the estuary, and,
5) provide the most probable picture of general circulation of waters in the James estuary under experimental conditions.

Dye Distributions Thirty Tidal Cycles After Release

Average of LARVAE data sets (total dye in the water column) for thirty cycles after release are shown in Figures 3, a through f, as isopleths of mass of dye above unit model area (mg/m^2). At this optimum setting time, the Wreck Shoal release (Fig. 3,a) provided the maximum amount of dye over public oyster rock regions (see Fig. 2). All oyster rocks were covered with more than 10 mg/m^2 and those in the Wreck Shoal and Point of Shoals regions (A and B, Fig. 2) were overlain by more than 25 mg/m^2 of dye. Additionally, this release point provided the greatest quantity of dye retained within the primary seed oyster producing area between Newport News Point and Mulberry Point (see Fig. 1 for locations). The Point of Shoals and Brown Shoal Reach releases (release points 2 and 3) also resulted in relatively large quantities of dye retained in the Newport News-Mulberry Point reach and 6 to 10 mg/m^2 of dye over almost all public oyster rocks (Fig. 3,b and c). When dye was released over southwestern shoal regions downstream from Burwell Bay (release points 4 and 5) and over Hampton Flats in Hampton Roads (release point 6), concentrations were substantially weaker over public rocks and within the Newport News-Mulberry Point reach (Fig. 3,d, e and f). All plots of LARVAE data show higher values over deeper areas (compare Fig. 3,a through f with bathymetry shown in Fig. 1) which, we feel is due to integration over the total water column. This method of data treatment suggests cyclonic motion in the Burwell Bay region (particularly evident in Fig. 3,c) which may be real or an artifact. Nonetheless, a ranking of release points relative to resulting distributions of dye 30 cycles after release would, in general, coincide with the sequencing of Figures 3,a through f.

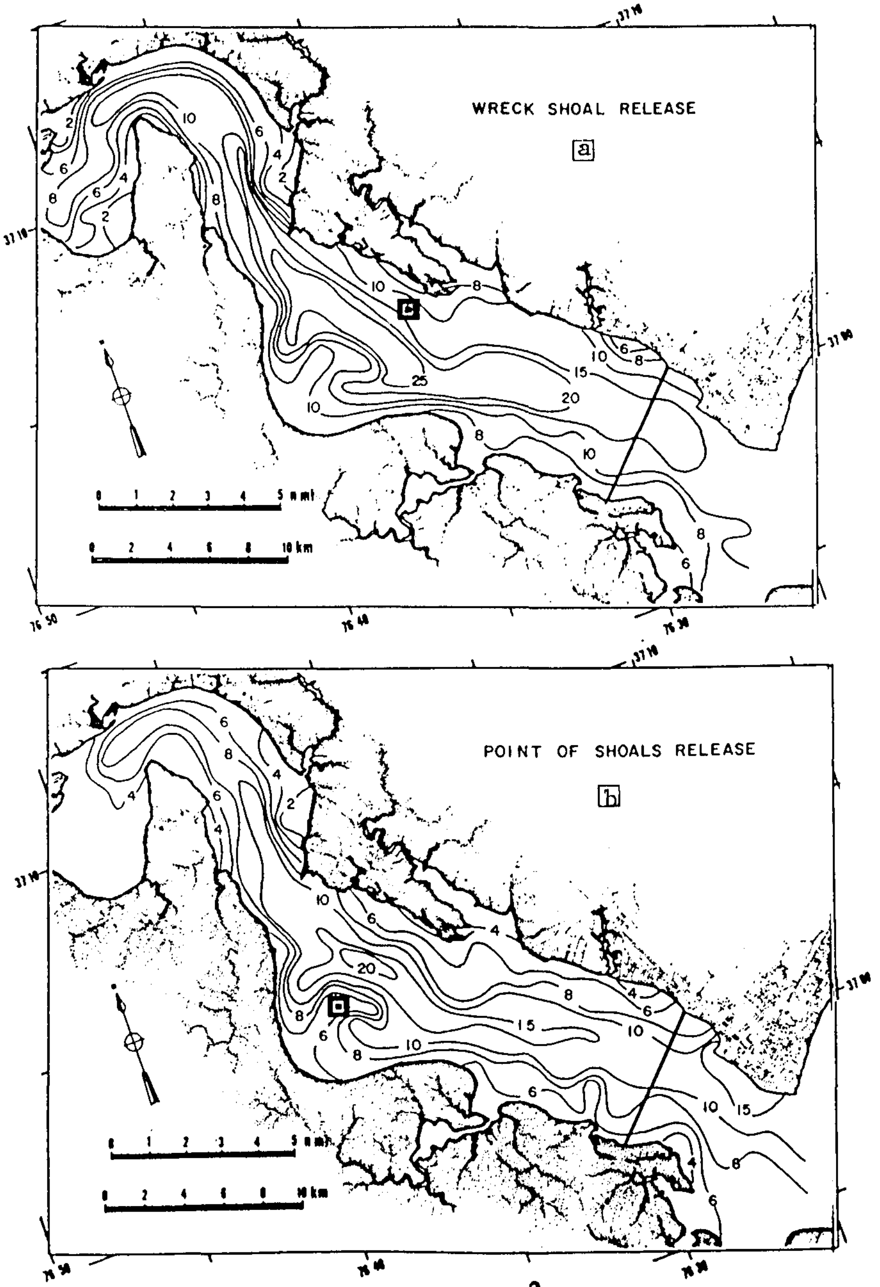

Figure 3. Isopleths of dye, as mg/m^2 in the water column 30 tidal cycles after release. a) upper b) lower

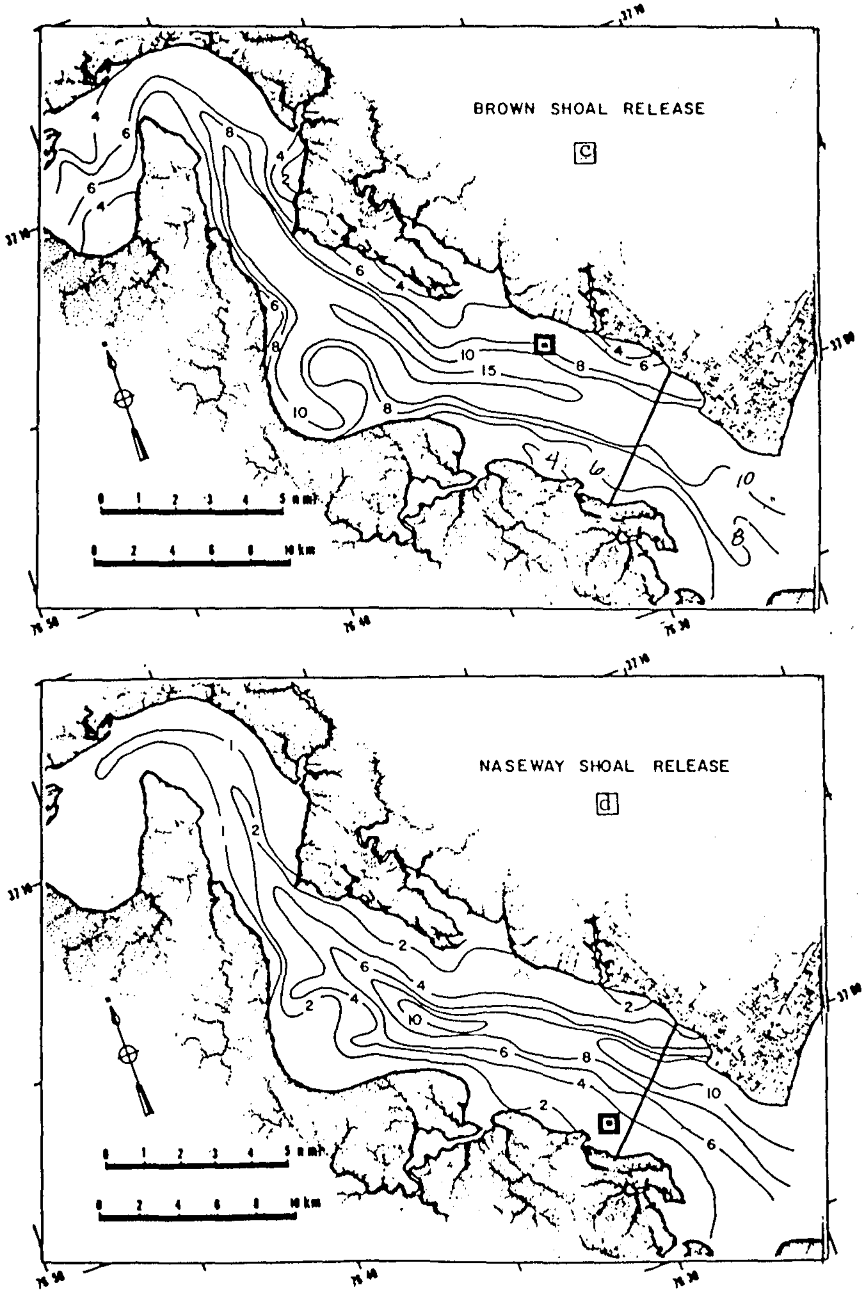

Figure 3 (continued) c) upper d) lower

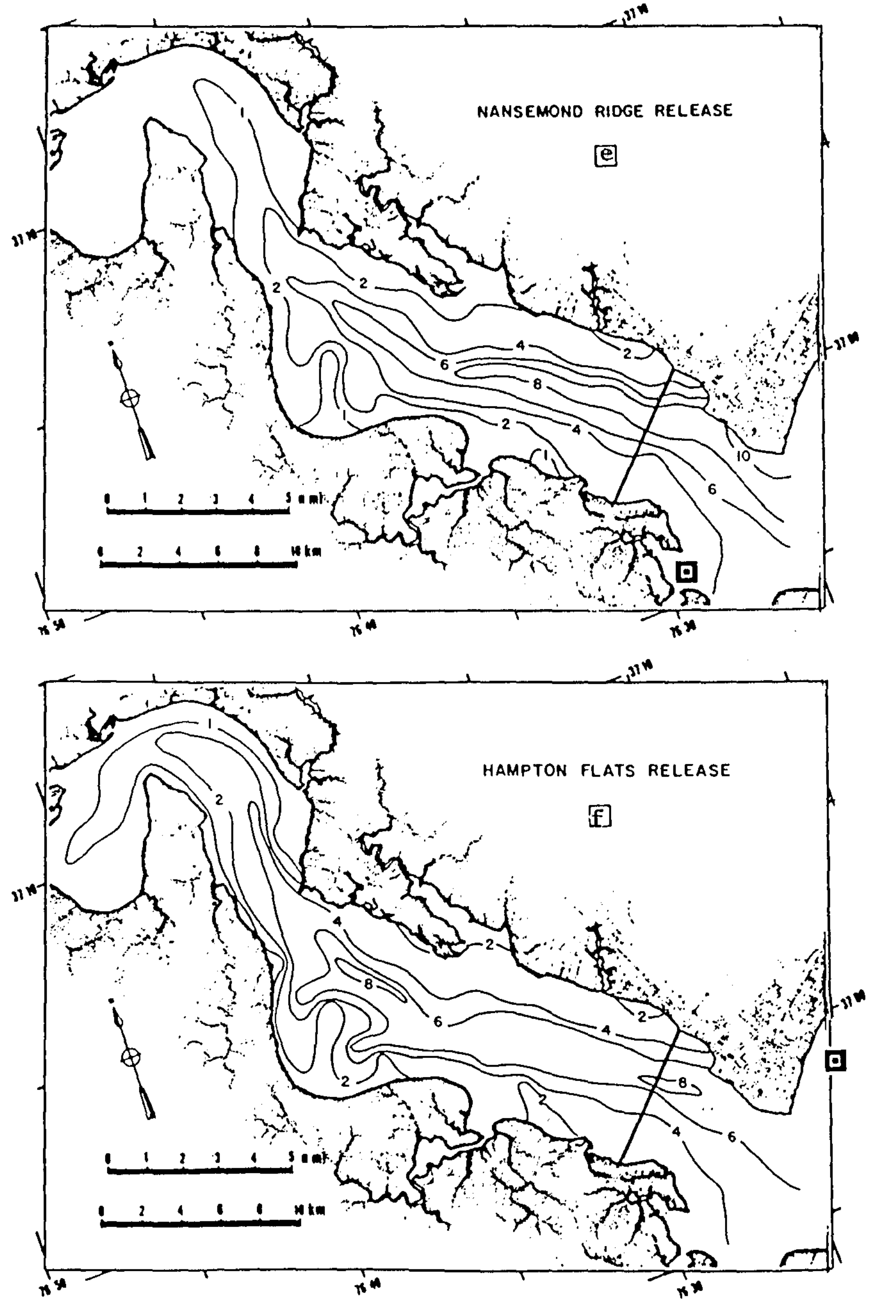

Figure 3 (continued) e) upper f) lower

Temporal Variations of Dye Over Seed Oyster Bed Regions

The SPAT data set was used to examine temporal variations of dye (as mg/m^2) found over each of the six public oyster rock regions shown in Figure 2. Results of this analysis are shown in Figure 4 which consists of six subfigures, each representing a specific oyster rock region, and a copy of Figure 2. Each subfigure has six vertical panels which represent individual dye release points and show SBE (solid line) and SBF (dashed line) variations of dye per unit area from 10 to 20 days (20 to 40 tidal cycles) after release. This analysis eliminates the bias introduced in Figures 3,a through f due to greater water depths in channels and shows agreement with these figures in that the release at Wreck Shoal resulted in greatest quantities of dye over each oyster rock region.

Through linear interpolation, the average quantity of dye over each oyster rock region 30 tidal cycles after release as well as means and standard deviations of dye quantities over the rocks for the period 20 to 40 tidal cycles after release were determined (Table I). Only slight differences existed between the average concentrations and means for the 20-40 tidal cycle period maximum differences were <5% while the average difference was 1.6%. Thus, concentrations on the 30th tidal cycle after release provide a reasonable estimate of mean concentrations during the setting period. Information shown in Table I was used to rank the effectiveness of each release point in providing dye to the seed bed regions and to rank the seed bed regions with regard to receiving dye from the various release points (Table II). The best release points were those in the upstream portion of the model and on the northeastern shoals. All but the Wreck Shoal and White Shoal seed oyster bed regions are excellent to moderately good locations for receiving dye from all release points.

Dye Retention

Results of our final inventory of dye have been arranged according to retention in regions of the model in the following cascading order:

a) Primary seed oyster beds,

Table I

Dye Concentrations (as mg/m^2) Over Selected Seed Oyster Rock Regions From Six Candidate Brood Stock Areas

Test I

Rel.Point 1(Wreck Shoals) Rel.Point 2(Point of Shoals)

	Avg for	Cycles 20–40		Avg for	Cycles 20–40	
Sampling Region	30th cyc.	Mean	Std.Dev.	30th cyc.	Mean	Std.Dev.
Point of Shoals	20.7	20.6	2.9	12.6	12.9	2.0
Wreck Shoals	15.9	16.0	2.3	10.2	10.4	1.4
White Shoals	13.1	13.1	2.5	8.2	8.3	1.2
Brown Shoal Reach	14.4	14.4	3.5	9.1	9.0	1.6
Naseway Shoal	13.4	13.2	2.6	9.2	9.0	1.5
Nansemond Ridge	10.8	10.4	3.0	8.2	8.1	2.1

Test II

Rel.Point 3(Naseway Shoals) Rel.Point 4(Brown Shoal)
Cycles 21–39 Cycles 21–39

Point of Shoals	4.9	4.7	0.8	11.2	11.3	2.0
Wreck Shoals	4.2	4.1	0.7	9.7	9.8	1.4
White Shoal	5.6	5.5	1.1	8.6	8.7	1.4
Brown Shoal Reach	5.8	5.9	1.3	10.0	10.3	1.3
Naseway Shoal	5.9	5.9	1.0	9.1	9.5	1.0
Nansemond Ridge	6.6	6.7	1.3	8.4	8.3	1.2

Test III

Rel.Point 5(Nansemond Ridge) Rel.Point 6(Hampton Flats)
Cycles 21–39 Cycles 21–39

Point of Shoals	4.3	4.2	0.9	5.6	5.6	0.7
Wreck Shoals	3.6	3.5	0.9	4.3	4.3	0.5
White Shoal	4.9	4.7	1.0	4.4	4.4	0.7
Brown Shoal Reach	5.0	4.9	1.1	4.6	4.5	0.6
Naseway Shoal	5.0	5.0	0.8	5.0	4.9	0.7
Nansemond Ridge	5.6	5.5	0.9	5.0	5.0	1.0

Table II

A. Ranking of Release Points with Regard to delivery of Dye to Seed Bed Regions

Ranking	Score*	Release Point
1	30	Wreck Shoal
2	22	Brown Shoal
3	20	Point of Shoals
4	10	Naseway Shoal
5	4	Nansemond Ridge
5	4	Hampton Flats

B. Ranking of Seed Oyster Bed Regions With Regard to Receipt of Dye from all Resease Points

Ranking	Score*	Seed Oyster Bed Regions
1	22	Point of Shoals
2	18	Naseway Shoal
3	17	Brown Shoal Reach
4	15	Nansemond Ridge
5	11	Wreck Shoal
6	7	White Shoal

*Scoring assigned 5 points to highest concentration and 0 points to lowest for each of six dye releases. Consistency in ranking of release points or seed oyster bed regions would have yielded scores of 30, 24, 18, 12, 6 and 0.

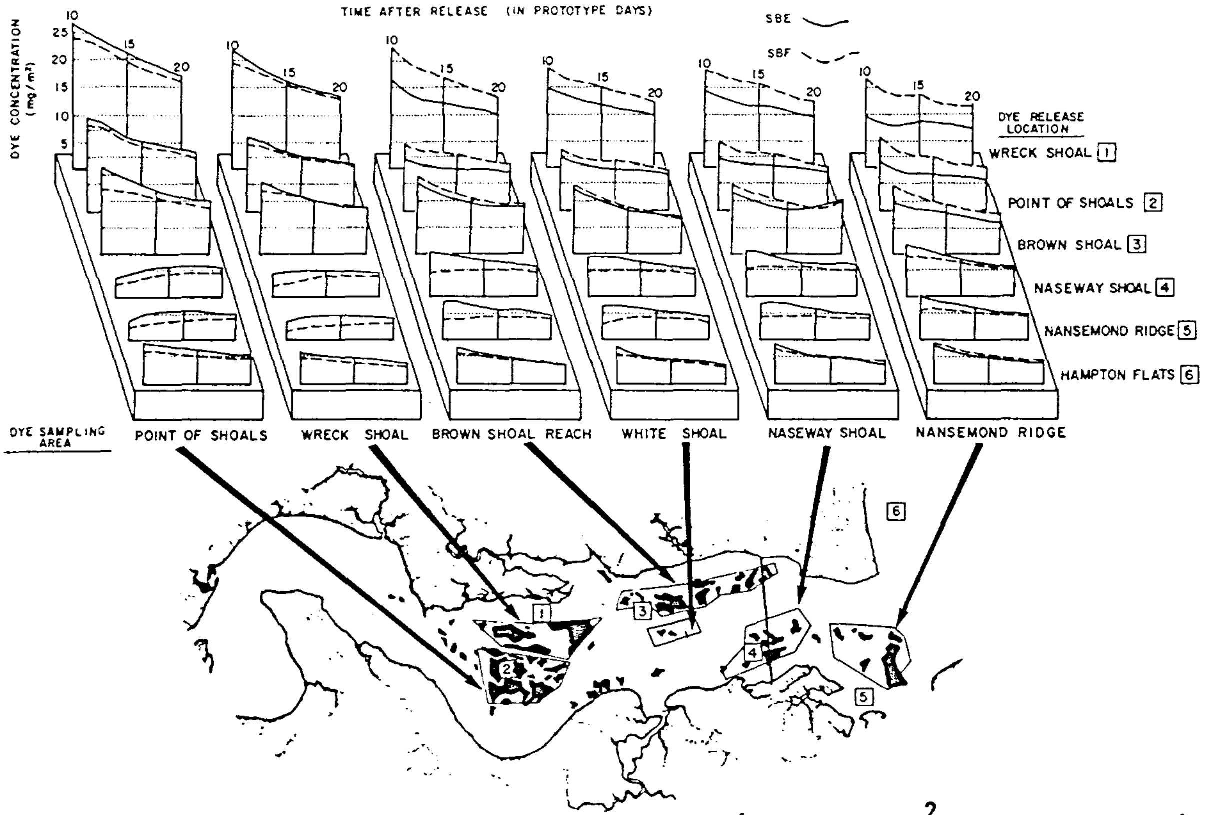

Figure 4. Temporal variations in dye concentrations (as mg/m^2) over each of six seed oyster bed regions resulting from injection at six release points.

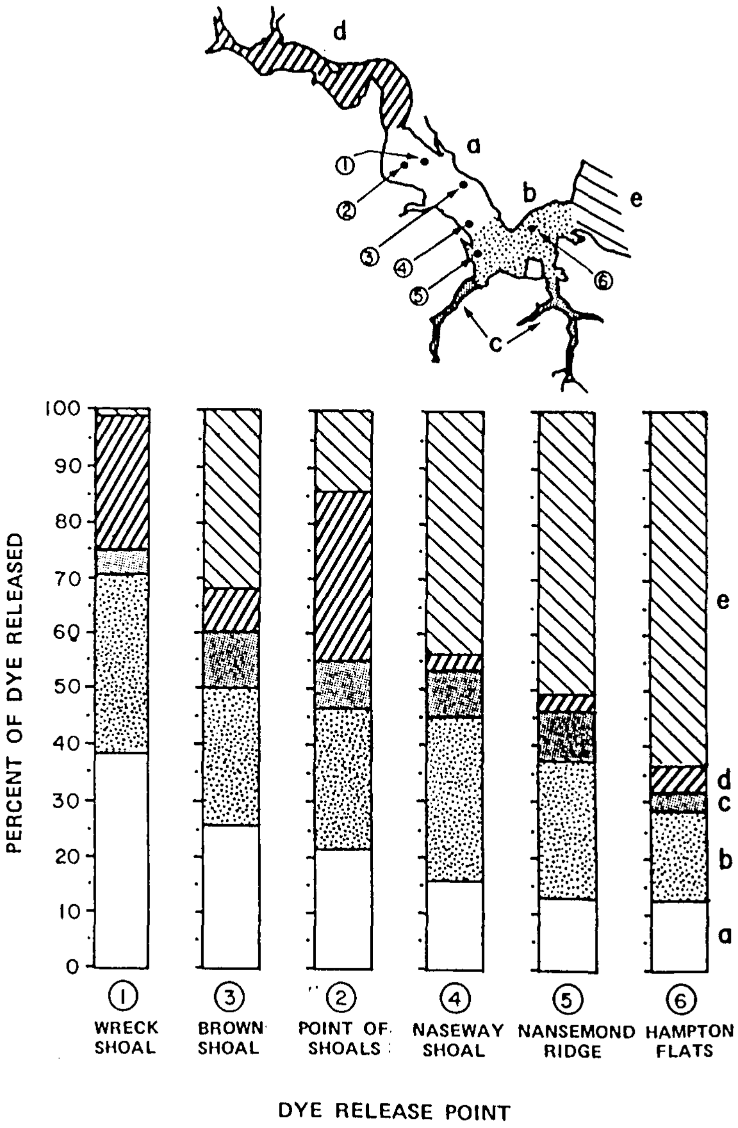

Figure 5. Dye retention (as percent of initial release) in various portions of James River Hydraulic Model after completion of each test (40 tidal cycles) as determined from sampling each model segment. Retention regions are: a) primary seed oyster beds b) Hampton Roads c) the Elizabeth and Nansemond Rivers d) fresher, upstream regions e) portion seaward of mouth of James.

b) the historically important oystering regions of Hampton Roads near the river mouth,
c) large downstream tributaries (the Elizabeth and Nansemond Rivers) where oyster beds exist or could be established if pollution were reduced,
d) the low salinity portions of the system upstream of the seed oyster beds, and,
e) areas outside the mouth of the James River.

These results (Figure 5) show that the Wreck Shoal release point provides best retention of dye within the desirable portion of the system while loss of dye from the James estuary is greatest (over 60%) from the Hampton Flats release point. The Point of Shoals release location has the greatest upstream loss of dye (>30%).

General Circulation in the Model

Temporal variations in dye distributions from the six release points and visual observations of dye movement were used to determine the general circulation in the James River hydraulic model under conditions of these experiments. The pattern is the generally expected movement of water in a 'weak' partially-mixed estuary, as described by Pritchard (1987). Additionally, we find indications of cross-stream transport of dye at either end of the seed oyster regions. Extensive cross-stream movement appears to take place in Burwell Bay. Present information does not indicate whether this motion is direct (i.e. laterally across this region) or results from movement along the northeasternmost channel during a flooding tide and then downstream along the curving southwesterly channel during the ebbing tide thus giving the appearance of cross-stream motion this area. In either case, dye test results show a definite net cross stream transport in the Burwell Bay region.

Similar cross-stream transport of dye in the Hampton Roads region is suggested by releases on the downstream southwest shoals (Naseway Shoals and Nansemond Ridge). Dye released at these locations was measured in the Brown Shoal Reach sampling area within 20 cycles after release. Based on this interpretation of our results, we infer the general cyclonic circulation in the seed oyster area of the James estuary shown in Figure 6.

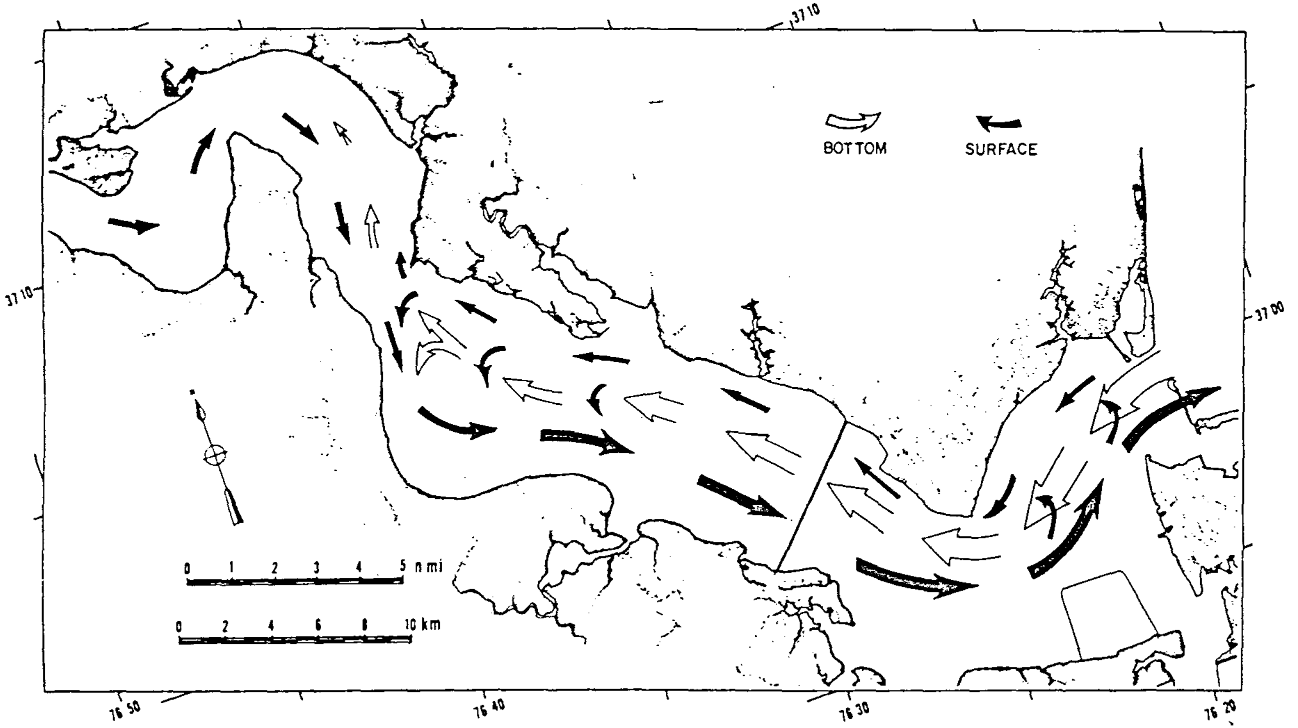

Figure 6. Hypothesized general surface and bottom circulation in the estuarine portion of the James River Hydraulic Model based on observed dye and measured concentrations.

SUMMARY AND CONCLUSION

Assuming that the James River hydraulic model properly mimicked the prototype and that dye particles simulate pelagic oyster larvae reasonably effectively, the following conclusions are possible:

1) The two-layered circulation concept for partially-mixed estuaries developed by Pritchard (1951, 1952 and 1953) appeared in our model dye tests. We note that scaled hydraulic models which do not rotate (such as the James River Hydraulic Model) cannot properly reproduce Coriolis accelerations found in natural physical systems. However, the consequences of these accelerations -- stronger upstream motion on the right side of a northern hemisphere estuary (when looking upstream) and greater downstream motion on the opposite side -- appear to have been properly introduced in the James model.

2) In the historical seed oyster-producing area of the James River Estuary an interesting circulatory pattern is noted. Water moving upstream on the northern side of the estuary crosses over to the southern shore in the Burwell Bay region. Water moving downstream along the southern shore crosses over to the opposite side of the estuary in the Hampton Roads area. Thus, a cyclonic pattern is established within the estuary. Suspended particles within this cyclonic circulation would tend to remain there for a while and generally circulate within the system. Retention is not complete, however, as suspended material leaves the seed-oyster reach both upstream and downstream through advective and diffusive processes. Thirty-percent of the dye released at Wreck Shoal was lost to the upper reaches of the estuary and sixty percent of the dye released on Hampton Flats was lost to lower Chesapeake Bay.

3) Particles suspended in the water column for a significant portion of the time would move with the water masses described above. Oyster larvae, although able to swim relatively strongly in the

> vertical, move as the general horizontal circulation dictates. Thus, larvae originating in the seed-oyster producing region or arriving there from outside would tend to remain and cycle therein for a period. Those attaining their 15th day in viable condition would settle and attach provided suitable substrates were available. Those moving upstream and maturing to setting stage in the lower salinity environment would be lost to the system as would those exiting the James Estuary at the mouth. This cyclonic circulation pattern, with upstream and downstream losses shown by the model, corresponds to a combination of what Andrews (1983) describes as 'trap-type' and 'flushing-type' estuaries.

From the distribution of the dye in our model experiments and the abundance and quantities which reached the different historically productive oyster rocks within the optimal 20-40 tidal cycle period we conclude that larvae originating around Wreck Shoal would remain over the most productive seed beds longer and in greater quantities. Thus spatfall and chance of survival to seed (and market) sizes would be best from this site. The Brown Shoal Reach would be next most productive of spat and seed while Point of Shoals would rank third.

Hampton Flats would rank fourth of all beds in spat and seed production but first of those beds in the lower estuary while larvae originating from brood stocks at Naseway Shoals and Nansemond Ridge would yield the fewest spat to the upriver seed beds.

Andrews (1983) concluded that during the period prior to 1960 (before spatfall and seed oyster production began to fail) the largest portion of viable larvae reaching the upriver-setting areas was produced downstream in the vicinity of Hampton Flats (release point 6) and elsewhere in Hampton Roads, as well as at the mouth of the James and nearby reaches of the lower Chesapeake. However, Haven, et al., (1978), in discussing reduced seed oyster production subsequent to 1960, state 'Other aspects are probably involved in keeping setting down...' and '...it is not possible to absolutely state that any single factor was responsible.' Both concluded that the failure of setting began to occur when disease destroyed many of the mature oysters (brood stocks) on these more saline regions and when commercial oyster planters harvested the remaining plantings to reduce their economic losses.

Our results might seem contradictory but no such contradiction exists. Prior to the onslaught of disease, the down-estuary and lower Bay plantings of commercial oyster farmers were massive, aggregating hundreds of thousands of bushels. They were also older oysters and growth was faster there than on the seed oyster beds. Dye introductions from the several release points were of the same volume and mass simulating equal numbers of larvae. Thus, the experiments did not address the quantitative effects of dye or larvae released from the several sites. An order of magnitude increase in downstream larval production (due to greater density of mature oysters and/or greater fecundity of individual oysters) would significantly alter these results.

If rapid replenishment of these prime seed-oyster producing reaches of the James Estuary by judicious placement of brood stock is the objective of a future management (repletion) effort, plantings should follow the rankings indicated above. If replacement by disease-resistant spat is an objective, specially-bred brood stocks will have to be utilized. If disease-resistance or some other specially-bred feature is judged not particularly desirable or necessary, other techniques such as quarantining of brood-stock in sanctuaries to allow endemic oysters to reach sexual maturity could also be considered. Should survival in downstream areas of Hampton Roads and the lower Chesapeake improve, encouragement of a renewal of downstream plantings by commercial lease-holders would be desirable also. Availability of disease-resistant oysters would encourage renewed planting even if the disease remains endemic.

ACKNOWLEDGEMENTS

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