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Chesapeake Bay research initiatives at the Virginia Institute of Marine Science of the College of William and Mary : accomplishments for the 1986-1988 biennium

Virginia Institute of Marine Science

CHESAPEAKE BAY RESEARCH INITIATIVES

AT

THE VIRGINIA INSTITUTE OF MARINE SCIENCE

OF THE

COLLEGE OF WILLIAM AND MARY

ACCOMPLISHMENTS FOR THE 1986-1988 BIENNIUM

July 1988

PREFACE

This biennium report for 1986-1988 presents the accomplishments achieved through the Commonwealth's Chesapeake Bay Initiative for Research. In addition to those projects, the volume describes our progress on three additional initiatives funded by the General Assembly during the biennium:

--Three-Dimensional Hydrodynamic Model

--Wetlands Management

--Estuarine Research Reserve System

Much of research executed under these programs is highly technical. However, exhaustive technical detail has been avoided in this presentation, and the effort is devoted to communicating the essence of the results and the relevance to resource management. Each project report contains a listing of technical papers derived from the activities which the reader may refer to for additional technical discussion. The first section of the report is a compilation of the individual project executive summaries.

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EXECUTIVE SUMMARIES

PROGRAM I. CHESAPEAKE BAY RESEARCH

James River Seed Oyster Beds: Biological Studies

During the 1986-1988 biennium biological studies of the James River seed oyster beds have focused on several related issues. Settlement of oysters during the summer of 1986 was the lowest in seven years. Settlement was higher in 1987 but still not exceptional. Continued poor to mediocre settlement does not provide hope for rapid recovery of the fishery. Continuing dry summers and associated high salinities have allowed disease organisms to progress upstream to Wreck Shoal, further than ever previously recorded. The associated losses have resulted in the major contribution to spawning being from the abundance of relatively small oysters on the upstream, low salinity rocks at Horsehead. Examination of oyster resources in deep water, essentially beyond the depth normally exploited with a hand tong, show these to be small, probably insufficient to serve as the major broodstock for the river. Recruitment of young oysters to the oyster rocks has been demonstrated to be influenced by a combination of "retentive" circulation in the James and active depth regulation by the microscopic, free swimming larvae in response to gradients of salinity in the river. The river is essentially self contained in that recruitment from parent oysters outside of the river is negligible. Neither low dissolved oxygen conditions in the river nor the presence of a variety of endolithic blue green algae appear to inhibit the settlement of oysters under laboratory conditions -

indeed, the larvae are remarkably hardy! Despite this hardiness post settlement losses in the field are high and to a great extent uncontrollable. Studies of blue crab predation illustrate that a large crab can consume over 30 oysters per day with ease. Only temperatures below 14C and attainment of a shell length of >30mm provide the oyster with a refuge form continued predation.

The James will remain the focus of both the market and the seed oyster fishery in Virginia for at least the coming five years. Disease pressure causes the fishing effort to be concentrated in an ever decreasing area; however, market prices insure that even reduced catches remain profitable. Focus on market oysters has drastically reduced availability of seed for replanting. Both market and seed fisheries are potentially unpredictable and unstable at this time and are cause for continuing concern.

River Circulation Studies for Revitalization of the James River Seed Oyster Industry

It has been proposed that, when examined over several days, a portion of the water in the lower James River tends to flow in a large counterclockwise gyre. This circulation pattern incorporates the results of many field studies and measurements, was observed in the hydraulic model in Vicksburg, and was confirmed by a theoretical model. The gyre, which extends from near Sewell's Point in Hampton Roads to Mulberry Point, is believed to be a primary reason why the seed oyster beds of the James are so productive. Thus, much attention has been given to the details of the circulation, so that managers would have information to use when evaluating options.

Topographic features appear to be extremely important factors that determine the criculation pattern. The existence of the deep natural channels near the Newport News shoreline emphasizes the net upriver movement of the water along the northern (Newport News) shoreline. The sharp wall formed by Wreck Shoal and the river bend at Mulberry Point both steer flooding waters across the channel. These waters then tend to move downriver; net downriver transport at all depths is typical of the shallower flanks of the channel near the southern (Isle of Wight) shoreline. Finally, the convergence of water masses near Newport News Point provides a mechanism for oyster larvae to be transported from the outflowing surface waters to the bottom waters which move upriver towards the seed beds. Managers should be cautious when examining projects which could alter the topography and the circulation. The general circulation pattern also provides a framework for understanding the system and predicting likely responses to natural and man-caused events.

Development of Models Relating Environmental Variations with Strength of Recruitment of Virginia's Populations of Croaker, Summer Flounder and Spot

This research shows that the waters behind the Virginia barrier islands, as well as within the Chesapeake Bay, provide important nursery habitat for newly recruited commercially and recreationally important finfish. The gear we use is appropriate for collecting postlarvae and juveniles, sampling newly recruited croaker 5-10 mm, flounder 15-20 mm and spot 20-25 mm. In both 1986 and 1987, croaker recruited first and at a smaller size in seaside estuaries, indicating transport from nearby shelf areas as hypothesized, however, transport was good in Fall 1986 but poor in Fall 1987. Winter temperatures were marginal both years, forecasting an average year class for Summer 1987 and a poor year class for Summer 1988. Flounder recruited in Fall 1986 to seaside locations, indicating recruitment from northern areas, but they did not recruit at all in Fall 1987, probably due to offshore wind-driven transport of larvae. Flounder recruited in Spring 1987 to locations within the Chesapeake Bay, indicating transport from a southern location. Recruitment for Spring 1988 is almost non-existent and indicates poor year-class strength. Spot showed good recruitment in Spring 1987 and 1988 to bay locations, indicating transport from the south. Qualitative observations show recruitment in the spring following episodes of southerly winds. Initially, croaker predominately recruit to deeper channels and flounder and spot to shallow mud habitats. Depth and substrate preferences appear to change over time.

Striped Bass Early Life History in the Pamunkey River

Striped bass has been an economically and recreationally important species since the seventeenth century. The general trend in abundance has been one of gradual decline punctuated by peaks of abundance. These peaks or "dominant year-class phenomena" have been the result of occasional successful spawning which may or may not have been associated with a large spawning population. The last dominant year-class occurred in 1973.

The precipitous decline in striped bass abundance has resulted in many studies designed to investigate the causes of this decline and prevent further stock depletion. Although there are many interactive factors that may be responsible for striped bass abundance, evidence indicates that survival of early life history stages may be important in determining year-class strength. The striped bass is a broadcast spawner with estimates of fecundity ranging from 65,000 eggs in four year olds to 5,000,000 eggs in 13 to 14 year old fish. These values indicate that egg production can remain high despite a reduction in the number of spawning adults. Hence, variability in survival in eggs, larvae and early juveniles of striped bass can be very important in controlling the magnitude of recruitment.

As a result, the primary objective of this project has been to examine the different factors which may affect survival of striped bass eggs and larvae and try to account for any variability in survival. Three studies are being used to assess these factors. The first two of these studies have been completed while a third was initiated in Spring 1988.

The objectives of the first study were to: (1) determine the kinds and relative abundance of potential fish and invertebrate predators of striped bass larvae through field surveys during striped bass spawning periods; (2) document acceptability of striped bass yolksac larvae as a prey item through laboratory presentations to fish and invertebrates; (3) establish consumption rates of yolksac larvae under laboratory conditions of various prey densities; and (4) examine stomach contents of target fish predators collected on the spawning grounds.

A second study utilized a time-series egg mortality study to test the hypothesis that any declining egg density during the study was the result of natural predation by fishes. This study was designed to determine: (1) egg mortality rates; (2) egg viability; and (3) egg retention mechanisms.

The third, most recent, investigation is a two-year study which will evaluate the separate and interactive effects of starvation, predation and environmental stresses on larval survival by examining the time-space patterns of mortality inferred from the back-calculation of juvenile brthdates. Data sets describing predator and prey fields, food abundance and changing environmental conditions during the spawning season will be compared to patterns of larval survival.

Chemical Poisons in Virginia's Tidal Waters - Fate and Effect of Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAH) are commonly encountered in the environment, in particular in marine sediments. Because of the known mutagenicity and carcinogenicity of some of these PAH, especially after they have been metabolized by biota, their presence is of substantial concern. Although it has been observed that fish living in areas heavily polluted with PAH suffer from a number of diseases such as liver neoplasms, preneoplastic lesions, necrotic lesions, fin rot, cataracts, immune system dysfunction and microscopically identifiable changes in various tissues, it has not been possible to identify a specific link between these problems and the presence of PAH.

In view of the need for answers, the Division of Chemistry and Toxicology of the Virginia Institute of Marine Science with the support of the State of Virginia, Council on the Environment, has started an ambitious, multidisciplinary research program to seek solutions to these problems. Chemists have sought new methodology to identify PAH metabolites by advanced high performance liquid chromatography-mass spectrometry, using several methods to generate ions. In addition, new methods capable of separating many of the PAH metabolites present in bile from feral fish from PAH-contaminated areas were developed. The immunology and pathology group found the cellular immune system of fish from the Elizabeth River to be compromised. It was shown that the chemotactic, phagocytic and chemoluminescent responses of macrophages from some Elizabeth River fish from highly contaminated areas were depressed. Histopathological phenomena observed in fish from the Elizabeth River were duplicated in laboratory experiments by exposing fish to PAH contaminated sediments.

Early Warning System for Chlorinated Hydrocarbons in Seafood

The objective of this research is to provide baseline information on chlorinated hydrocarbon concentrations in seafood harvested in Virginia waters. Chlorinated hydrocarbons are a ubiquitous class of chemicals which can be detrimental to public health and to various life stages of aquatic organisms. The chlorinated hydrocarbons include PCBs, pesticides and industrial compounds. These chemicals may affect the quality of those estuarine organisms which comprise Virginia's seafood resource.

Seafood samples were purchased from wholesale distributors located along the Chesapeake Bay and Eastern Shore of Virginia. Due to the Kepone fishing restrictions, it was difficult to acquire commercial seafood samples from the James River. Samples collected by the State Water Control Board from this river were therefore used.

Fish samples from the James River contained higher levels of PCBs and chlordanes than fish samples from the lower Chesapeake Bay or Eastern Shore of Virginia. Oyster and clam samples were collected from the James River and analyzed. The clam samples generally contained higher PCB and chlordane concentrations than the oyster samples.

A compound of unknown structure and origin has been found in numerous samples from the James River. Efforts are being directed toward the isolation and identification of the unknown compound.

Submerged Aquatic Vegetation

During the past two years, over 30 acres of SAV have been transplanted using whole plant and seed techniques in three estuarine river systems. Investigations have evaluated the effectiveness of several different techniques in an effort to develop the most feasible and economical methods applicable to the Chesapeake Bay system. Other studies have developed water quality thresholds for the dominant SAV species in the region and investigated the single and interactive effects of the most important factors (turbidity and the excess nutrients) thought to have the greatest impact on SAV growth and survival.

Oyster Hatchery and Remote Setting Operations

Research continues on remote setting of hatchery-reared oyster larvae. Post-set oysters are extremely vulnerable to predation until they attain a size of about one inch in length. Experiments on several nursery methods to grow spat to a large enough size to insure good survival are being carried out.

Hatchery production is expected to be about 300 million eyed larvae per year. By mid-July 1988, 68 million eyed larvae have been distributed to participants collaborating with VIMS in field experiments.

PROGRAM II

Three-Dimensional Model

A three-dimensional, time varying estuarine hydrodynamics model has been acquired and is currently being modified and applied to the James River. The anticipated resulting operational model will provide a powerful tool for assessing the environmental impacts of physical and regulatory changes on the James River and, ultimately, other Virginia estuaries.

PROGRAM III

Wetlands Management

The Virginia Institute of Marine Science has been mandated by the General Assembly to provide support for the implementation of the Commonwealth's Wetlands Management Program since the Wetlands Act was passed in 1972. The Institute's role can be effectively defined as a three-part task. First and foremost, wetland scientists at VIMS provide technical advice to both the Virginia Marine Resources Commission and local wetland boards in their review of shoreline modification applications. In addition to a significant amount of field work, this task also requires attendence at numerous public hearings and agency meetings. The second task involves preparation of source materials for resource management groups. This specifically includes, but is not limited to, the preparation, revision and promulgation of wetland inventories. The third task is to develop an enhanced advisory data management program in order to increase the efficiency of permit review, report generation and tracking.

PROGRAM IV

Estuarine Research Reserve System

The Virginia Institute of Marine Science (VIMS) has completed the first phase of the site selection process for a Chesapeake Bay National Estuarine Research Reserve in Virginia with the selection of sites in Mobjack Bay, the

York River, and the upper Rappahannock River for official nomination to the National Oceanic and Atmospheric Administration which administers the national program. When completed, the research reserve system will contain sites in each of the tributaries and along the main stem of the Chesapeake Bay in Virginia. The sites will serve as natural field laboratories for long-term ecological studies and for comparison with areas impacted by development activities and pollution.

PROGRAM I. CHESAPEAKE BAY RESEARCH

PROJECT 1

JAMES RIVER SEED OYSTER BEDS: BIOLOGICAL STUDIES

Roger Mann, Ph.D.

EXECUTIVE SUMMARY

During the 1986-1988 biennium biological studies of the James River seed oyster beds have focused on several related issues. Settlement of oysters during the summer of 1986 was the lowest in seven years. Settlement was higher in 1987 but still not exceptional. Continued poor to mediocre settlement does not provide hope for rapid recovery of the fishery. Continuing dry summers and associated high salinities have allowed disease organisms to progress upstream to Wreck Shoal, further than ever previously recorded. The associated losses have resulted in the major contribution to spawning being from the abundance of relatively small oysters on the upstream, low salinity rocks at Horsehead. Examination of oyster resources in deep water, essentially beyond the depth normally exploited with a hand tong, show these to be small, probably insufficient to serve as the major broodstock for the river. Recruitment of young oysters to the oyster rocks has been demonstrated to be influenced by a combination of "retentive" circulation in the James and active depth regulation by the microscopic, free swimming larvae in response to gradients of salinity in the river. The river is essentially self contained in that recruitment from parent oysters outside of the river is negligible. Neither low dissolved oxygen conditions in the river nor the presence of a variety of endolithic blue green algae appear to inhibit the settlement of oysters under laboratory conditions -

indeed, the larvae are remarkably hardy! Despite this hardiness post settlement losses in the field are high and to a great extent uncontrollable. Studies of blue crab predation illustrate that a large crab can consume over 30 oysters per day with ease. Only temperatures below 14C and attainment of a shell length of >30mm provide the oyster with a refuge from continued predation.

The James will remain the focus of both the market and the seed oyster fishery in Virginia for at least the coming five years. Disease pressure causes the fishing effort to be concentrated in an ever decreasing area; however, market prices insure that even reduced catches remain profitable. Focus on market oysters has drastically reduced availability of seed for replanting. Both market and seed fisheries are potentially unpredictable and unstable at this time and are cause for continuing concern.

PROJECT DESCRIPTION

The James River seed oyster beds are a unique and irreplaceable resource. They are the cornerstone of a significant proportion of the Virginia oyster industry, providing small "seed" oysters for transplant and grow out by private lease holders throughout the Commonwealth. The objective of the seed oyster bed studies is to obtain a greater understanding of factors influencing temporal and spatial (both intra- and interannual) variability in recruitment of oysters into the seed oyster beds and the subsequent growth and survival of those oysters. The management implications of such knowledge are obvious.

The most tractable means of addressing the issue of long-term stability of the seed beds is to examine its component problems. This has been the approach of our research and monitoring effort, and it will be the descriptive approach of this report. During the 1984-86 biennium we focused on mapping temporal and spatial variability of oyster settlement in the James and initiated examination of post settlement losses to predation. During the 1986-1988 period our studies have expanded to focus on (i) continued monitoring of temporal and spatial variability in oyster settlement, (ii) egg production by broodstock oysters, (iii) oyster larval dispersal, (iv) settlement of planktonic oyster larvae to the benthos and (v) post settlement losses to predators. Although not originally planned, our efforts have also involved significant advisory and management activities. For completeness, passing reference will also be made to disease monitoring activities -- results of efforts by a separate research group at VIMS that will be expanded with support of further Commonwealth funding in the 1988-1990 biennium.

RESULTS AND MANAGEMENT IMPLICATION OF 1986-1988 EFFORT

The oyster settlement monitoring program builds on a data base that started over forty years ago. At weekly intervals during the oyster spawning and settlement season (approximately June through late September in the James), "strings" of clean oyster shell are deployed at fixed locations in the James. These are retrieved one week later and replaced with a further "string" of shells. The retrieved shells are examined microscopically for the presence of newly settled oysters. Oyster

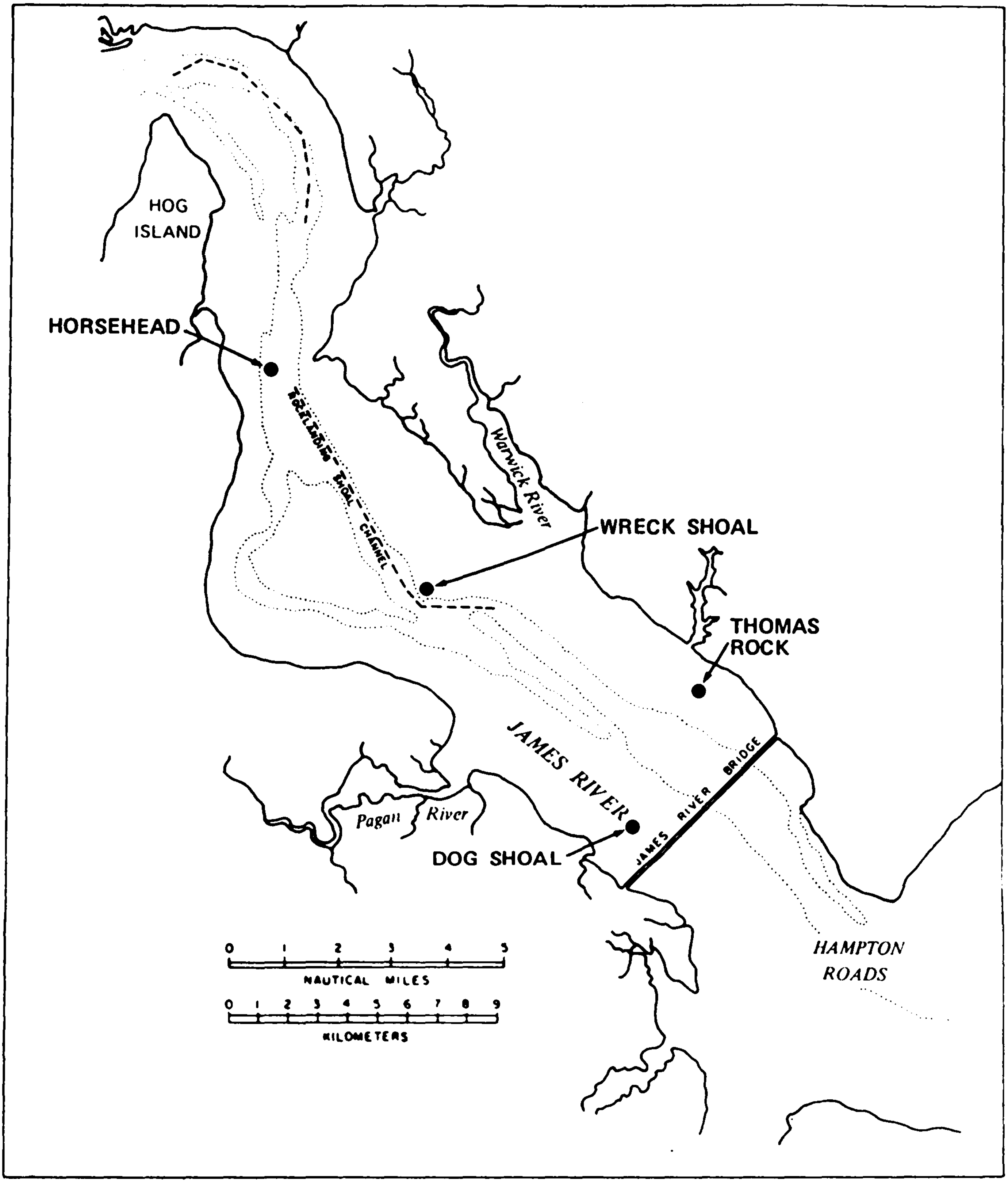

Figure 1: Sites of collection of oysters for broodstock studies in the seed area of the James River during the summer of 1986.

settlement in 1986 was the lowest in seven years. At Horsehead (see Figure 1) the settlement peaks were observed in the third week of July and the third week of August. Further downriver settlement peaked during the second and third weeks of August. Settlement was much higher in 1987, spread throughout the river and occurred from early July through the beginning of October. Clearly a continued good settlement is required for recovery of the fishery. The lack of such settlement is cause for concern.

Our effort focusing on egg production by the larger "broodstock" oysters in the James has taken an increased meaning in the past three years due to the increasing impact of the oyster disease organisms Haplosporidium nelsoni, commonly known as MSX, and Perkinsus marinus, also commonly referred to as "Dermo." Three successive drought summers in 1985, 1986 and 1987 have resulted in more saline waters progressing further upstream in the James and other subestuaries of the Chesapeake. The diseases, which are limited in distribution by salinity, have also moved upstream and now extend to the Wreck Shoal area of the James (see Figure 1). Disease associated losses have clearly reduced the number of adult oysters which contribute to the maintenance of the seed oyster bed through spawning activity. In order to evaluate the relative contributions of the major oyster rocks to spawning activity, we sampled, at biweekly intervals during the summer of 1986, oysters from four rocks along a transect extending downstream from Horsehead, through Wreck Shoal, to Thomas Rock and Dry Shoal. We collected data on number of oysters per square meter of bottom, the size distribution of oysters, their sex ratio and relative fecundity (number of eggs per female oyster) and the state of ripeness of those eggs. In final analysis our results were somewhat surprising -- the most upriver station, that at Horsehead, was calculated to contribute more eggs (and thus larvae) than any of the other stations. The high numbers of oysters (over 450 per sq mt in some samples) at this site more than offset the reduced fecundity associated with smaller mean oyster size.

The decimation of planted oysters in the Hampton Roads region of the lower James in the early 1960's by disease and the separation, by some considerable distance, of the James from the nearest region of abundant oysters relinquish the seed bed area to the state of a self-contained system -- that is oysters recruiting to the seed beds originate from spawning in the seed beds. Clearly, maintenance of adequate broodstock is essential. Even during the 1985-87 period a decline in this broodstock size due to disease alone has been noted. In the aforementioned study oysters from Thomas Rock were, on an individual basis, the most fecund oysters examined but contributed only about 10% of the eggs contributed by Horsehead oysters simply because Thomas Rock is a much smaller rock. Evident in both our time course sampling in 1986 and subsequent work by the disease monitoring group at VIMS is the continued decline of the Thomas Rock and downriver stations due to disease stress.

Management of the James oyster fishery to maintain adequate broodstock is a controversial and frequently volatile issue in that the markedly decreased availability of half shell oysters along the U.S. East Coast (due to local disease related losses, catastrophic weather and red tide related losses or closures on the Gulf Coast) and associated market price increases have refocused the James fishing effort on market rather than seed oysters. In the spring of 1987 a suggestion was proferred by the industry that the oysters on the deeper fringes of the rocks and in the channels form a major broodstock reservoir. This option was examined in two parts. The areas below chosen depth contours on the Baylor Charts (which illustrate the extent of the public oyster bottom) of the James were digitized and computed. The result suggested that only 1% of the productive oyster bottom lay deeper than 18 feet. For perspective, a pair of 22 feet long hand tongs can fish to approximately 18 feet depth so only the resource below that depth is essentially unavailable for harvesting. To further examine the option, a VIMS vessel equipped with a dredge and with representatives of the industry, the Virginia Marine Resources Commission and VIMS spent a day on the James in August of 1987 dredging in some of the deeper "unexploited" regions. Broodstock oysters were indeed present. The deep water oyster stocks undoubtedly form a small but valuable resource; however, they cannot and should not be relied upon to sustain the James seed oyster fishery.

The national market for oysters will insure that a healthy income for the waterman can be maintained from continued fishing in the James during the coming years despite the almost inevitable reduction of catch due to increased fishing effort in an ever decreasing area of the river. Further, the attractive economic nature of fishing for market oysters is in marked contrast to the fishing for seed oysters. Planters who require seed simply are not being adequately supplied. The dilemna of management involves not only the balance between market and seed fisheries but also attempting to stabilize an obviously decreasing broodstock in the face of considerable economic incentive and industry pressure.

Oysters spawn eggs and sperm into the water column. Fertilization occurs and the free swimming, microscopic larval form remains in the water for a period of two to three weeks. Oyster larvae can swim weakly in the vertical plane but have essentially no control over horizontal movement. They drift passively in the water column at the mercy of tide and current. They can only actively contribute to the selection of their ultimate destination by active depth regulation to take advantage of stratified estuarine circulation. (This subject is discussed further in the section of this report dealing with physical circulation in the James.) In order to better relate broodstock spawning data to physical circulation patterns, it is imperative to quantify active larval swimming and identify behavioral stimuli. This work continues in the 1988-1990 biennium; however, our data so far illustrate that larvae can swim at vertical velocities of over 1 mm/sec -- small but sufficient to swim throughout the depth of the James in one tidal excursion. Responses to light attenuation are minimal. Active response to thermoclines and haloclines (salinity boundaries) have been noted. While larvae will swim through (tolerate) haloclines of 2 ppt salinity change over a 3 cm depth (very intense, moreso than occurs in the field), we strongly suspect that the problem is not so much salinity <u>tolerance</u> (oyster larvae are very salinity tolerant -- we can culture larvae from the same parents at all salinities from 5 to 30 ppt!) as salinity <u>preference</u>. Salinity related active depth regulation may clearly aid larval retention in the James. Retention appears to be further enhanced by tidally synchronized frontal formation in the Hampton Roads region of the lower James off Newport News Point. Field collected samples from the fall of 1985, examined and analyzed throughout 1986, clearly illustrate passive vertical movement of entrained larvae with saline waters as they plunge to depth at the aforementioned frontal system and progress upstream toward the seed bed area. The combination of spawning , behavioral and physical data clearly support the suggestion that the James is now a self-contained system with respect to recruitment. Clearly, it should be managed as such.

On completion of larval development, oyster larvae develop a foot for crawling, sink to the bottom and lose their swimming organ. Oyster larvae preferably settle and metamorphose to the attached benthic fauna on other oysters or oyster shells. It is this behavior that is responsible for the building, over geological time, of oyster reefs. Under some circumstances the dissolved oxygen in the water column is dramatically reduced. We have examined the influence of low dissolved oxygen content of the water on larval metamorphosis. Oyster larvae have proven remarkably tolerant of this insult. Prior to metamorphic competency larvae actively swim away from low oxygen regions, even when exposed to less than 0.5 mg/L of oxygen! Competent to metamorphose animals can successfully metamorphose even if such conditions are maintained for several days -- a small percentage even survive after eight days at such stressful levels, a situation probably rarely encountered in the field.

The oyster reefs of the James are abundantly supplied with endolithic blue green algae - microscopic, filamentous algae that bore into the shell layers and, indeed, the shells of live oysters on the oyster rocks. Although studied for over 100 years, these algae are poorly understood. In field studies we found endolithic blue geen algae to be present upstream of Thomas Rock (see Figure 1). Only the presence of boring sponge further down stream appears to prevent occurrence in that location. In laboratory tests we examined the influence of the presence of endolothic blue green alge on oyster larval settlement and metamorphosis and found it to have no deleterious effect.

Clearly, oyster larvae are much more hardy than we had originally considered; however, some demonstrated tolerance of environmental adversity should in no instance be taken as a reason to excuse environmental abuse. The success of larval recruitment and subsequent growth is an end product of continuing maintenance of good environmental conditions, thus any contribution in this arena is valuable.

Post settlement oysters may occur in significant numbers; however, losses to predation can be very significant. In 1986-1987 we focused on predation losses to blue crabs. Under optimal (for the crab) conditions these predators can have devastating effects on oyster survival. A large crab can consume over 30 oysters per day with ease. Various refuges from predation pressure exist. As oyster size increases, the oysters become susceptible only to larger crabs. For example, crabs of 60-80 mm carapace width were unable to prey upon oysters of approximately 35 mm shell length -- unfortunately, crabs grow throughout the summer as do the oysters so the latter cannot easily "outgrow" the former. Male crabs have different cheliped (claw) morphology which allows them to open larger oysters than would a female crab of similar size. Large male crabs are particularly destructive, and it is not until oyster density decreases to such a level as to make further foraging and predation unprofitable, oyster attains a size refuge at >30 mm shell length or temperature decreases below 14^{o}C that blue crab predation becomes minimal (by this time much of the damage is done!).

From a managerial aspect crab predation is essentially uncontrollable in subtidal reef fisheries such as the James. Alternatives exist for intertidal fisheries or for caged culture structures, but these are generally inapplicable to high traffic, multi-user areas such as the James. Crab predation losses are valuable to quantify but offer little option for control.

ANTICIPATED ACTIVITIES IN 1988-1990

Our 1988-1990 continuing studies follow the theme of the 1986-1988 biennium. Strong foci exist in two areas. The first is further quantifying broodstock spawning activity on a temporal basis, examination of larval quality and relating these data to (1) observed circulation and (2) settlement patterns as illustrated by the monitoring efforts. The second focus is on larval biology emphasizing behavior in relation to environmental gradients, methods to collect and identify larvae from the field, assessment of larval quality in field-collected specimens and the influence of environmental stressors on metamorphic success. The eventual goal is to interdigitate spawning and larval data with the three-dimensional circulation model (under development at VIMS) of the James to provide predictive capability on larval settlement, then test the model against long-term observed settlement. The power of such a tool in management of this precious resource is clearly substantial.

LISTING OF PAPERS PUBLISHED/THESES, DISSSERTATIONS

M.A. Theses

1988 Bernardita Campos. Swimming response of larvae of three mactrid bivalves to different salinity gradients.

1988 Carrollyn Cox. Seasonal changes in fecundity of oysters (*Crassostrea virginica* Gmelin) from four oyster rocks in the James River, Virginia.

1988 David Eggleston. Predator prey dynamics between the blue crab *Callinectes sapidus* Rathbun, and juvenile oysters *Crassostrea virginica* (Gmelin).

1988 Ellen Pafford Snyder. Taxonomy and distribution of endolithic algae occurring in *Crassostrea virginica* shell in the lower James River, Virginia.

Manuscripts in Refereed Journals and Symposium Proceedings

1987 Roger Mann, Brian Meehan, Julia S. Rainer, Victor S. Kennedy, Roger I.E. Newell and Wiiliam F Van Heukelem. Influence of low oxygen tensions on larvae and post settlement stages of the oyster *Crassostrea virginica*. pp 139-143 in: Dissolved oxygen in the Chespeake Bay; processes and effects. Gail B. Mackiernan (editor). Maryland Sea Grant Publication UM-SG-TS-87-03, 177 p.

1987 James P. Whitcomb and Dexter S. Haven. The physiography and extent of public oyster grounds in Pocomoke Sound, Virginia. J. Shellfish Res. 6(2):55-66.

1988 Bernardita Campos and Roger Mann. Discocilia and paddle cilia in the larvae of Mulinia lateralis and Spisula solidissima. Biol. Bull. (in review).

1988 Roger Mann. Field studies of bivalve larvae and their recruitment to the benthos: A commentary. J. Shellfish Res. 7(1): 7-10.

1988 Roger Mann. Distribution of bivalve larvae at a frontal system in the James River, Virginia. Marine Ecology Progress Series (in press).

1988 Reinaldo Morales-Alamo and Roger Mann. Anatomical features in frontal histological sections of oysters as an aid in comparative measurements of gonad area. J.Shellfish Res. (in review).

1988 Kevin McCarthy and Carrollyn Cox. The gastropod fauna of a subtidal oyster reef in the James River, Virginia. The Veliger (in press).

1988 Richard D. Rheinhardt and Roger Mann. Development of epibenthic fouling communities on shell deposited on natural oyster bed in the James River, Virginia. Biofouling (in review).

Published Abstracts

1988 Bernardita Campos and Roger Mann. Discocilia and paddle cilia in the larvae of *Mulinia lateralis* and *Spisula solidissima*. J. Shellfish Res. 7(1): 189.

1988 Bernardita Campos and Roger Mann. Swimming behaviour of mactrid larvae in response to salinity gradients. J. Shellfish Res. 7(1): 189.

1988 Roger Mann, Robert J. Byrne and Bernardita Campos. Dispersal of bivalve larvae at a frontal system in the James River, Virgina. J Shellfish Res. 7(1): 124.

1988 Roger Mann and Julia S. Rainer. The response of swimming and metamorphosing oyster larvae to low dissolved oxygen. J. Shellfish Res. 7(1): 168.

1988 Reinaldo Morales Alamo and Roger Mann. Use of gonad area / body area ratio in histological sections of *Crassostrea virginica* to monitor reproductive development: relevence, difficulties and solutions. J. Shellfish Res. 7(1):170.

1988 Richard D. Rheinhardt and Roger Mann. Development of epibenthic fouling communities on shell deposited on natural oyster bed in the James River, Virginia. J. Shellfish Res. 7(1): 130.

PROJECT 2

RIVER CIRCULATION STUDIES FOR REVITALIZATION OF THE JAMES RIVER SEED OYSTER INDUSTRY

Bruce J. Neilson, Ph.D.
Albert Y. Kuo, Ph.D.

EXECUTIVE SUMMARY

It has been proposed that, when examined over several days, a portion of the water in the lower James River tends to flow in a large counterclockwise gyre. This circulation pattern incorporates the results of many field studies and measurements, was observed in the hydraulic model in Vicksburg, and was confirmed by a theoretical model. The gyre, which extends from near Sewell's Point in Hampton Roads to Mulberry Point, is believed to be a primary reason why the seed oyster beds of the James are so productive. Thus, much attention has been given to the details of the circulation, so that managers would have information to use when evaluating options.

Topographic features appear to be extremely important factors that determine the criculation pattern. The existence of the deep natural channels near the Newport News shoreline emphasizes the net upriver movement of the water along the northern (Newport News) shoreline. The sharp wall formed by Wreck Shoal and the river bend at Mulberry Point both steer flooding waters across the channel. These waters then tend to move

downriver; net downriver transport at all depths is typical of the shallower flanks of the channel near the southern (Isle of Wight) shoreline. Finally, the convergence of water masses near Newport News Point provides a mechanism for oyster larvae to be transported from the outflowing surface waters to the bottom waters which move upriver towards the seed beds. Managers should be cautious when examining projects which could alter the topography and the circulation. The general circulation pattern also provides a framework for understanding the system and predicting likely responses to natural and man-caused events.

PROJECT DESCRIPTION

The marine and estuarine waters of the Commonwealth are not equal in their suitability for the culture of oysters. Some areas are especially suited to the production of small oysters. These seed oysters, produced year after year in many locales, occur in prodigious numbers in the middle reaches of the James River estuary. Other areas are especially well suited for the rapid growth of oysters to maturity. Typical of such 'grow out' areas is the Rappahannock River. Young oysters, which either occur naturally or are transplanted there, have found the environment conducive to rapid growth.

Historically the portion of the James River near its mouth, the Hampton Roads area, has been an excellent grow out area and many persons and companies had intensive plantings of seed oysters on privately leased portions of the river bottom. The occurrence of the disease MSX has made this aspect of oyster culture unprofitable. Consequently, little river bottom downriver of the James River Bridge is currently used for grow out purposes. Although present day production is well below the level observed prior to 1960, the area upriver of the James River Bridge continues to be an excellent seed area still producing large quantities of young oysters virtually every year. In recent years (1985-87) oyster mortality has increased due to drought associated incursions of oyster diseases. Several other estuaries in Virginia are good seed oyster areas, but none matches the James in the size of the oyster beds and the magnitude of the production. This suggests that some natural factor, such as river circulation, is responsible for the different rates of production. Hence, the primary objective of this study has been to understand the circulation patterns in the James and to relate them to the life cycle of the oyster, so that potential management options can be addressed and assessed in light of that understanding.

RESULTS

During the 1984-1986 biennium, we identified a large counterclockwise circulation, or gyre, that extended from Sewell's Point in Hampton Roads to Mulberry Point at the upriver end of Rocklanding Shoal Channel. This gyre serves as the primary transport route which not only retains the oyster larvae in the James but also transports them back to the seed bed areas. In the 1986-88 biennium, efforts were directed towards some specific features of the gyre in order to identify the mechanisms responsible for its formation.

Analysis of current meter data suggested that the large scale circulation proposed in the 1984-1986 biennium report required a minor modification. The long-term average currents at a station on the north end of the James River Bridge transect are directed seaward on the surface, contrary to that suggested in the previous biennium report. The two-layer estuarine circulation (seaward flow at the surface and landward flow near the bottom) existed in the shallow waters along the northern shoreline as well as in the deep channel. The net flows were directed seaward throughout the water column on the southern side of the channel. Of the current velocities measured in 1986 and 1987 at six stations in two transects across the river off Mulberry Island, the bottom currents at three stations in the channel all had net flows directed upriver. All surface currents had net flows directed downriver, except one station near Mulberry Point. At this station, the net flow was oriented between upriver and cross-river. If one combines these field measurements with observations made in the hydraulic model in Vicksburg, the general circulation patterns for surface and bottom flows are those presented in Figure 1.

Figure 1 shows that the gyre is not "closed" when surface and bottom water movements are considerd separately. The gyre is completed only when surface and bottom water movements are superimposed and the three-dimensional nature of the circulation is considered. Figure 2 presents the circulation gyre which is composed of the upriver bottom flow in the channel near the northern shore and the downriver flow on the south side of the channel. An estuarine front provides the vertical linkage between the surface and bottom waters. In the vicinity of Newport News Point, water

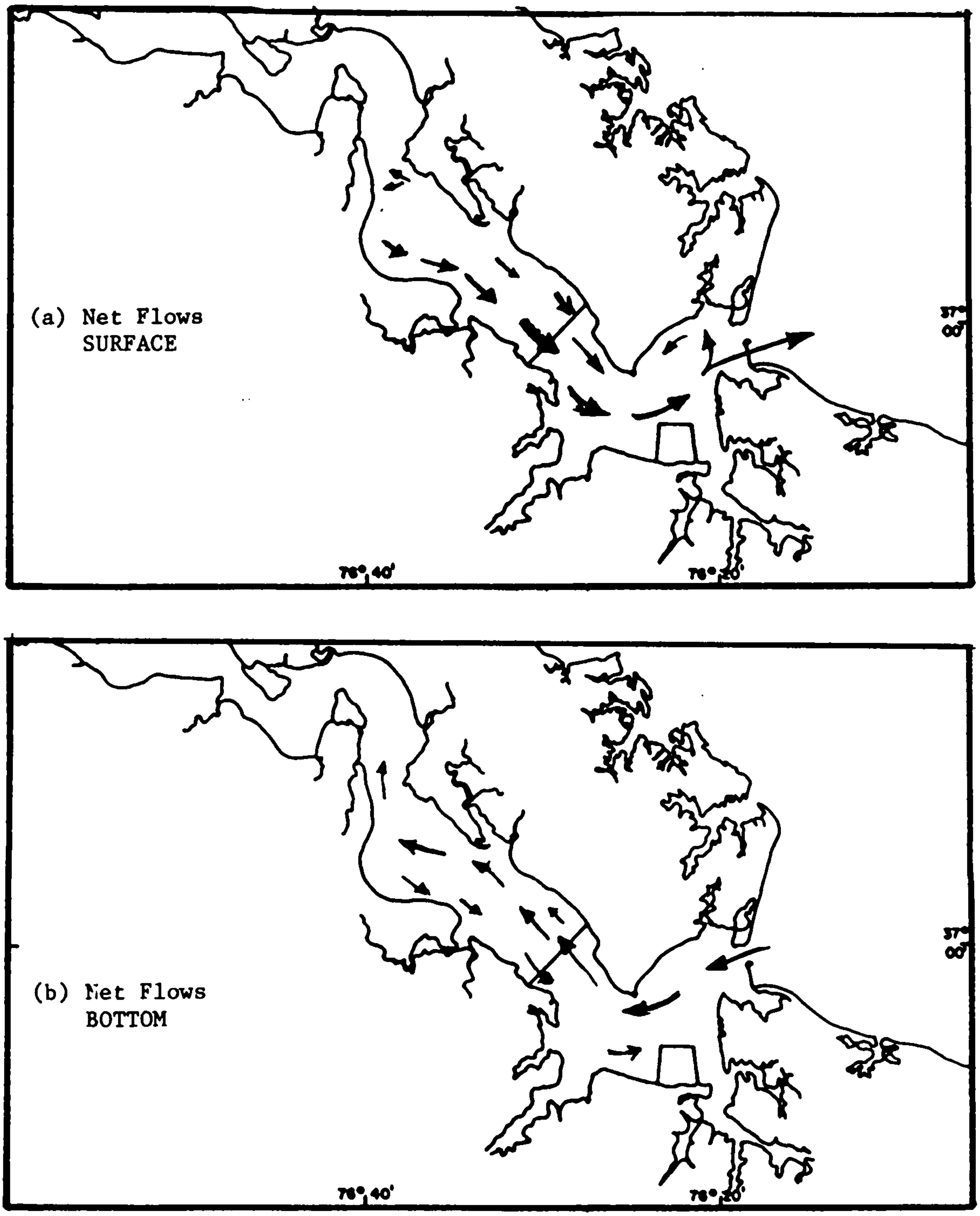

Figure 1. Near surface and bottom flows in the James estuary.

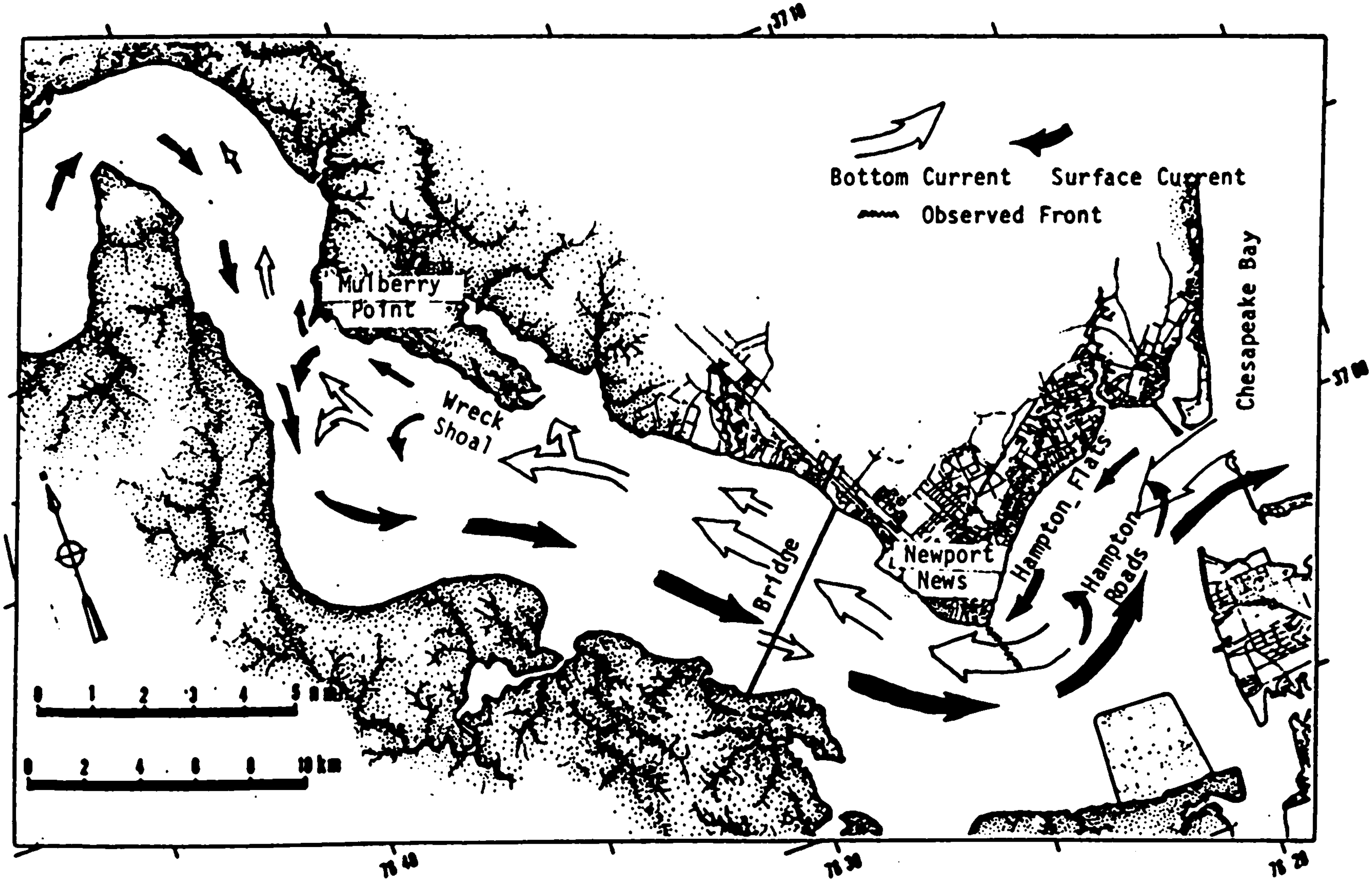

Figure 2. Composite flow patterns resulting in a circulation gyre.

masses converge during early- to mid-stage of flood tide and form a sharp front, or boundary, between water masses. The more saline water from Hampton Roads dives beneath the less saline water of the lower James to depths of 5 meters or more, where the net flow is in the upriver direction. The vertical linkage at the upriver end is believed to be provided by the blocking which Wreck Shoal produces. The breaking of internal waves and the resulting vertical mixing over the steep bottom slope there are subjects of further studies.

In the 1984-1986 biennium report, we stated that the two-layered gravitational circulation, (i.e., a net flow of fresher water out of the estuary at the surface and a net upriver flow of saltier water near the bottom) is persistent in the James, based on the analysis of current data collected over a one-month period. Further analysis of a long-term data set reveals that the circulation pattern is relatively constant throughout the oyster spawning season. Figure 3 is the time series plot of non-tidal current near the bottom of the channel in the James River Bridge transect. It shows that the net current was in an upriver direction from June to September of 1985 except for several brief periods of near zero velocity. The upriver flow was interrupted on three occasions by storm events in October and November.

In November 1987, a field study was carried out in the vicinity of Wreck Shoal. There, flood currents flowing up the main (natural) channel toward the northwest encounter the steep bottom slope at the edge of Wreck Shoal, where some of the water may proceed onto the shoal and some deeper

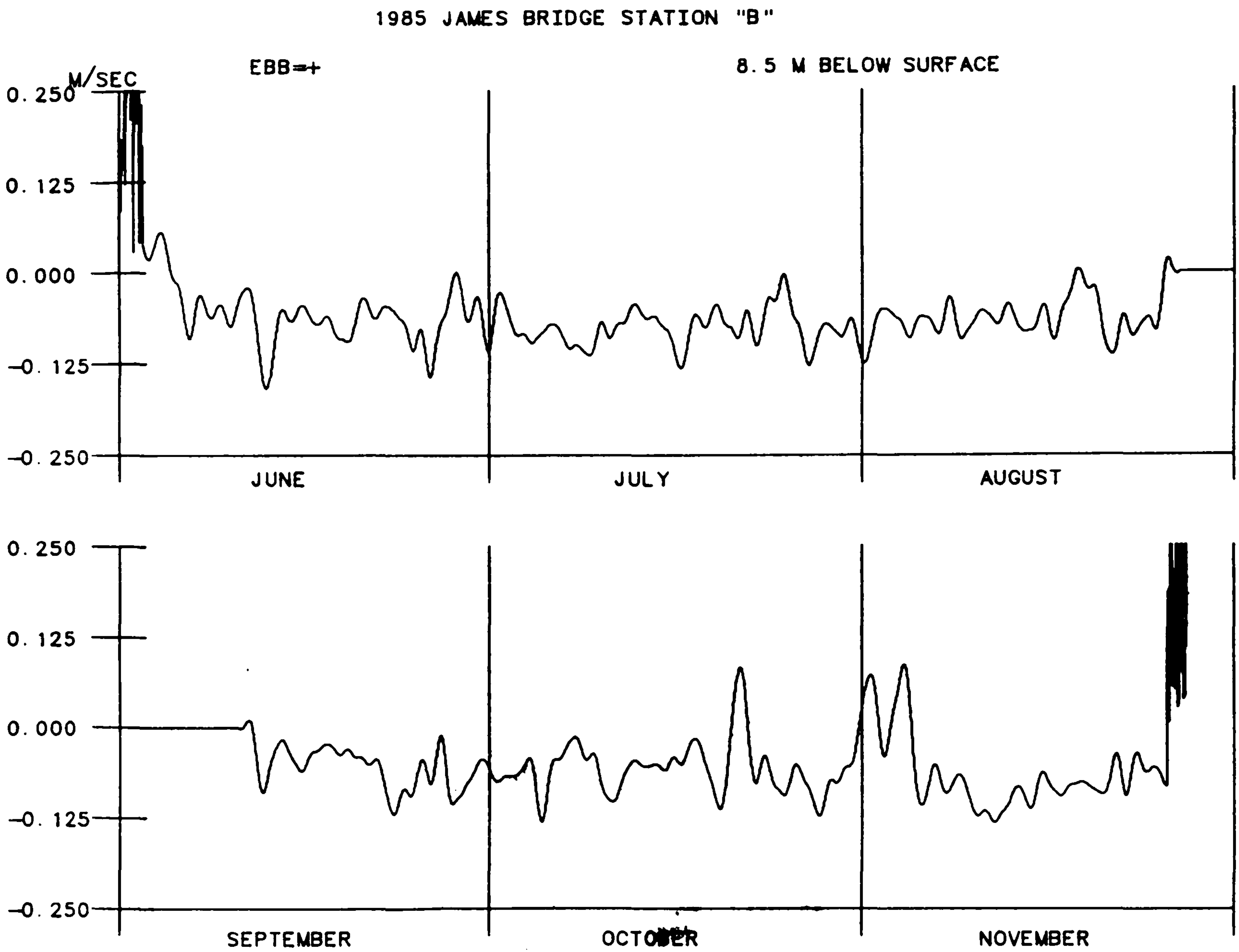

Figure 3 Non-tidal current near the channel bottom at a station just upriver from the James River Bridge.

portion may be turned westward following Rocklanding Shoal Channel. The influence of the bottom topography on "steering" or "blocking" the flow at various depths and under various conditions of stratification and current strength is relevant to the overall transport in the lower James. It is of particular interest since Wreck Shoal is one of the most productive seed oyster beds in the estuary.

There is clear evidence that topographic steering occurred consistently at 4.5 m depth over the 20-day current meter deployment and at 3.0 m depth over the four to five days of available data. With further analysis now underway, we will attempt to quantify the extent of steering and determine whether it varied with stratification and with the magnitude of the flood currents over intra-tidal and fortnightly time scales. However, preliminary processing has revealed data losses, due to various modes of instrument and mooring failure, that will render the study less comprehensive than planned.

To verify the gyre in the horizontal circulation, a theoretical model has been developed. Previous theoretical investigations of the mean horizontal circulation in large coastal plain estuaries have revealed the importance of topographic (water depth) and geostropic (the earth's rotation) influences on the forces which drive the circulation. The primary driving forces are associated with the net freshwater discharge, the longitudinal density or salinity gradient, and nonlinear interactions rectifying the nearly periodic tidal flow in the estuary. The theoretical model which has been developed shows that the topography and the earth's rotation influence the driving forces to the extent of determining the existence of the gyre and its direction of circulation.

The influence of topography has been shown to be of extreme importance in determining the direction of mean circulation over a transect normal to the channel axis. When only the freshwater discharge and longitudinal density gradient forcings are considered, the mean horizontal depth average flow is landward, upriver, at deeper locations and seaward, down river, at shallower locations. Over a large portion of the region where the gyre exists, and particularly near Newport News Point, the river channel is deeper toward the north shore corresponding to net upriver flow consistent with the counterclockwise circulation. Further upriver, the deeper regions of the channel are near the center providing a mechanism for partially closing the gyre. When nonlinear tidal interactions are considered, the influence of topography is less transparent since the time lag between tidal elevation and current is also important. However, using tidal elevation and current data taken near the James River Bridge, the theoretical model predicts again landward flow in the deeper locations and seaward flow in the shallower locations enforcing the river discharge-density gradient driving forces.

The geostrophic influence on the horizontal circulation in the lower James is only significant in relation to the nonlinear tidal interactions. The theoretical model predicts a mean upriver flow on the northern side of the channel, corresponding to the direction to the right of that of the tidal wave propagation, and a downriver flow on the southern side.

In summary, a simple theoretical model developed and applied to the lower James River verifies the previously hypothesized counterclockwise horizontal circulation gyre. For midsummer conditions, the primary mechanisms for the gyre are the freshwater discharge and the longitudinal density gradient, influenced by topography, in particular the deeper channel regions being near the north shore. Secondary, but important, mechanisms are the nonlinear tidal interactions influenced by both topography and the earth's rotation. These secondary mechanisms reinforce the primary mechanisms.

IMPLICATIONS FOR MANAGEMENT

The general circulation pattern elucidated in these studies provides a framework for addressing issues. The general response to a natural or man-induced pollution event can be predicted. For example, if minor flooding in the Richmond area results in a mass of contaminated water moving downstream, the effects will be first observed along the southern shoreline of the lower James and Hampton Roads. If a pollutant is released to the lower James, the non-tidal transport will follow the gyre and eventually both shorelines will be affected.

It is our belief that the gyre is a primary reason why oyster larvae are retained in the James River. Thus, managers must be careful not to modify the system in ways that would alter this and allow the larvae to move more freely into Chesapeake Bay. In particular, channel dredging and plan form modifications should be assessed with regard to the alterations to the mean circulation pattern.

Finally, the details of the circulation, when coupled with the results of studies on oyster larvae behavior, provide information that should be useful to marine resource managers. In particular, activities of reshelling seed beds or to otherwise foster recruitment and the desirability of establishing sanctuaries for brood oysters can be evaluated in light of the circulation patterns.

ANTICIPATED ACTIVITIES IN 1988-90

All field studies were completed by the spring of 1988 and processing of the data was, for the most part, complete as well. During the 1988-90 biennium additional analysis and interpretation of the data will occur, along with preparation of manuscripts for publication. The products of this initiative have already proven to be helpful to the three-dimensional modeling of the James River, and we anticipate further contributions to that project.

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(3) Ruzecki, E. P., P. V. Hyer, K. Kiley and M. S. Jablonsky. Imaging system techniques applied to analysis of hydraulic and finite element model experiment results. Proceedings of the 4th Working Symposium on Oceanographic Data System, IEEE Computer Society Press, Los Angeles, 1986.

(4) Huzzey, L. M. Lateral Variability in a Coastal Plain Estuary. Ph. D. Disertation. College of William & Mary. 1986

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(12) Kuo, A. Y., Hamrick and G. M. Sisson. Presistence of residual currents in the James River estuary and its implication to mass transport. To be presented at the International Conference on Physics of shallow Estuaries and Bays, Pacific Grove, California. 29 November - 2 December, 1988.

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PROJECT 3

DEVELOPMENT OF MODELS RELATING ENVIRONMENTAL VARIATIONS WITH STRENGTH OF RECRUITMENT OF VIRGINIA'S POPULATIONS OF CROAKER, SUMMER FLOUNDER AND SPOT

Brenda L. Norcross, Ph.D.

EXECUTIVE SUMMARY

This research shows that the waters behind the Virginia barrier islands, as well as within the Chesapeake Bay, provide important nursery habitat for newly recruited commercially and recreationally important finfish. The gear we use is appropriate for collecting postlarvae and juveniles, sampling newly recruited croaker 5-10 mm, flounder 15-20 mm and spot 20-25 mm. In both 1986 and 1987, croaker recruited first and at a smaller size in seaside estuaries, indicating transport from nearby shelf areas as hypothesized, however, transport was good in Fall 1986 but poor in Fall 1987. Winter temperatures were marginal both years, forecasting an average year class for Summer 1987 and a poor year class for Summer 1988. Flounder recruited in Fall 1986 to seaside locations, indicating recruitment from northern areas, but they did not recruit at all in Fall 1987, probably due to offshore wind-driven transport of larvae. Flounder recruited in Spring 1987 to locations within the Chesapeake Bay, indicating transport from a southern location. Recruitment for Spring 1988 is almost non-existent and indicates poor year-class strength. Spot showed good recruitment in Spring 1987 and 1988 to bay locations, indicating transport from the south. Qualitative observations show recruitment in the spring following episodes of southerly winds. Initially, croaker predominately

recruit to deeper channels and flounder and spot to shallow mud habitats. Depth and substrate preferences appear to change over time.

PROJECT DESCRIPTION

Rationale

The Chesapeake Bay and Eastern Shore of Virginia are thought to be important nursery areas for croaker (*Micropogonias undulatus*), summer flounder (*Paralichthys dentatus*) and spot (*Leiostomus xanthurus*), but an adequate assessment of juvenile recruitment to the bays or the extent to which the nursery area contributes to successful recruitment is not known. Recruitment success of these species is typically inconsistent on a yearly basis. Examinations of environmental factors affecting the vulnerable periods in the early life history of each species may explain part of the interannual variation of this recruitment. Investigation of the climatic environment, both on the shelf where all three species spawn and in the estuarine nursery, coupled with field collections of these species, should promote an understanding of the vulnerability of these early life stages and lead to a quantification of climatic effects on finfish recruitment. This approach has been successfully employed in earlier research on croaker in which a model based on fall shelf wind patterns and winter water temperatures predicted recruitment. That relationship is continually updated as part of the current project.

1984-86 RESULTS

We constructed a life-history distribution chart of summer flounder in the Mid-Atlantic Bight from literature sources. Based on that information, we formulated the hypotheses that recruitment and subsequent year-class strength of summer flounder will be affected (1) in the fall when larval/postlarval flounder are transported, due to prevailing winds and longshore currents, into Chesapeake Bay nursery area from northern spawning areas; (2) in the spring when larval/postlarval flounder are transported, due to episodal winds, into Chesapeake Bay nursery area from southern spawning areas; (3) the following winter by cold temperatures which adversely affect one-year old flounder through parasite infections.

We further hypothesized that recruitment and subsequent year-class strength of spot will be affected (1) by spawning site, which cannot physically be in Mid-Atlantic Bight in winter because of cold bottom temperatures and, therefore, must be near Cape Hatteras; (2) by episodic transport northward on the shelf to the Chesapeake Bay in the spring; (3) by young-of-the-year mortality in Pamlico Sound due to fishing pressure; (4) relatively little by winter temperature as they recruit after the estuary starts to warm.

Examination of historic VIMS juvenile trawl survey data revealed that young-of-the-year flounder were rarely captured, and, therefore, that data base could not be used to develop a recruitment index. We therefore examined the possibilities that flounder were not caught previously because of site, depth, gear and/or time of collections. Efforts concentrated on designing field collections for flounder, croaker and spot to identify timing, abundance and habitat selection of new recruits.

1986-88 APPROACH

The sampling methods incorporated a variety of locations, depth and substrates previously unsampled by the VIMS trawl survey: three sites on the seaside of the Eastern Shore (Wachapreague, Sand Shoal Inlet and Fisherman's Island), one site on the bayside of the Eastern Shore (Occohannock Creek), and two sites on the west side of Bay at the mouth of the York River (Guinea and Tue Marshes) (Figure 1). At each site, the trawl was towed twice, once with and once against the tide, at shallow mud, deep mud, shallow sand and deep sand stations. The trawl gear chosen for this project has very small mesh (1/4 inch mesh with 1/8 inch mesh liner) specifically designed to sample newly recruited fish. Additionally, a 1/8-inch mesh seine was hauled twice at one very shallow mud station at each site. That was the only station sampled on Fisherman's Island. We sampled twice monthly September 1986 - August 1987 and once monthly September 1987 - August 1988 from an open, 21-ft. privateer outboard vessel. The sampling protocol was changed slightly at the beginning of the second year by dropping the Fisherman's Island site, adding stations at intermediate depth ranges at the other five sites and by also towing an unlined trawl net (5/8-inch mesh) designed to capture the young-of-the-year fish as they grow, in addition to the original net. This will allow for mathematical comparisons of gear efficiencies which have not yet been completed. Two

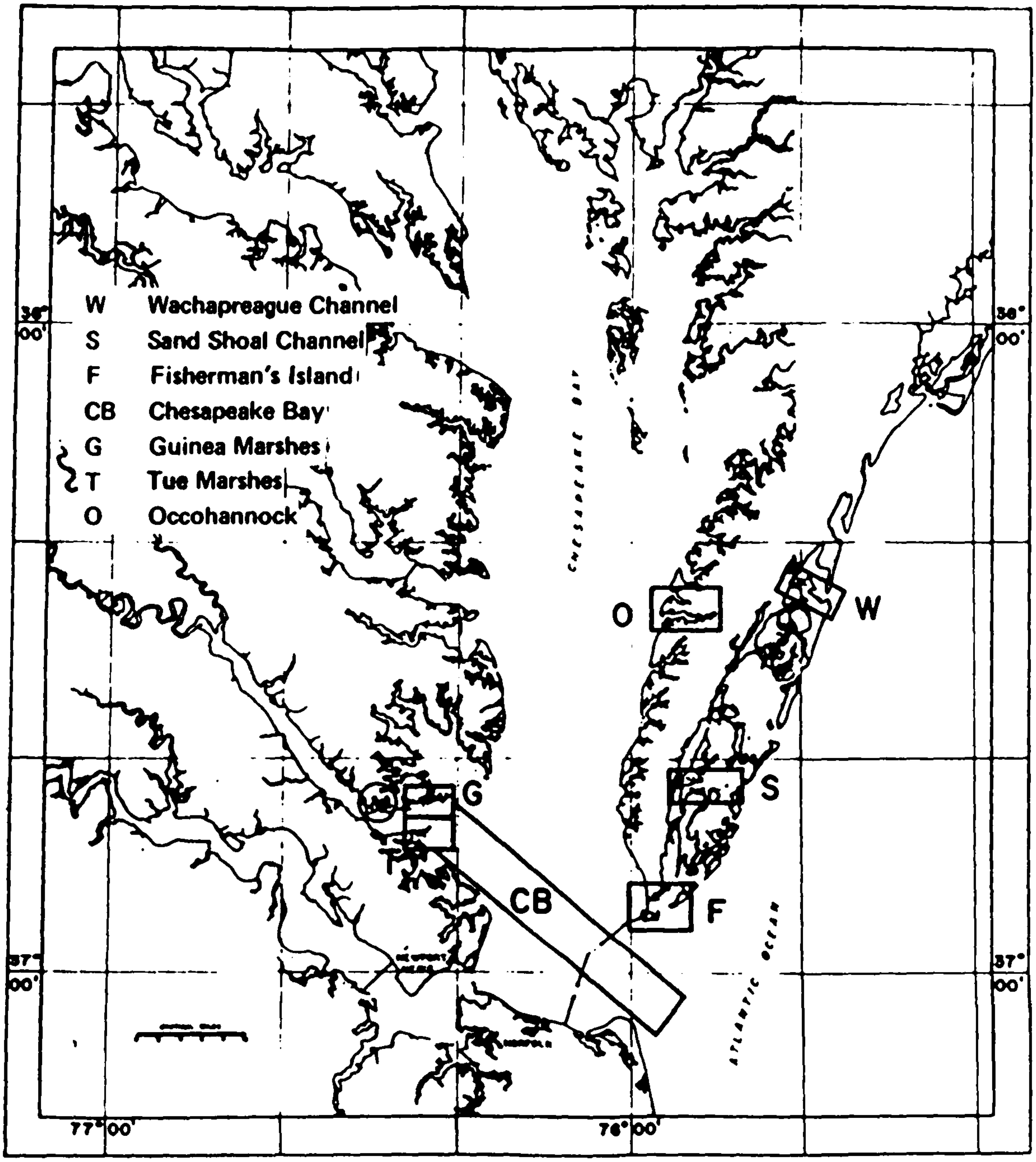

Figure 1. Areas sampled in the Chesapeake Bay and on the Eastern Shore Virginia, 1986-88.

tows, one with each net, were made at each station, both with tide. Additionally, for both years we extended the VIMS river trawl survey, which samples from the R/V Captain John Smith with a 30-ft. lined net, by sampling a transect from the mouth of the York River to the mouth of the Chesapeake Bay and around Fisherman's Island/Cape Charles one day per month. Target species included all sciaenids (drums) and flatfish (flounders) because of their commercial and recreational importance and to prove the gear was adequately sampling for juveniles. All target species were counted and measured to the nearest mm.

RESULTS/DISCUSSION OF 1986-88 RESULTS

Virginia Barrier Islands Waters as Nursery Habitat

Much of what is known about the fish fauna of the Eastern Shore is a compilation of ancillary data from species specific studies, site specific studies, recreational fishing, or information gained from local watermen. Very few studies have ever been directed at the ecology of finfish in this area. In 1965, a 12-month survey covered a broad spectrum of sites, habitats and seasons available (Richards and Castagna, 1970). The 1986-88 study was conducted specifically to assess the importance of the waters behind the barrier islands (Wachapreague, Sand Shoal and Fisherman's Island) for their importance as a juvenile nursery area.

Pooled results of the number of species, at all sizes and life stages, collected by all gear at each site for 1986-87 plotted by month showed a strong seasonal component with the diversity lowest in February and highest in October (Figure 2). While many species were present in low numbers during almost all times of the year, the relative importance of each species varied seasonally. Only two species were present in large numbers during all seasons, Atlantic silverside (Menidia menidia) and bay anchovy (Anchoa mitchilli). The remainder of the top ranking species fluctuated according to season, with several species only being important during one three-month period. The most abundant group of fish was sciaenids (Figure 3) which displayed distinct patterns of juvenile recruitment. These were a result of season-specific influx of new recruits. Croaker ranked number one in abundance in the fall of 1986, but were only present in small numbers in the winter and summer. Spot recruitment in the spring ranked third in abundance and, while not consistent month-to-month, they remained abundant throughout the summer. Newly recruited weakfish (Cynoscion regalis) appeared in very high numbers in late Summer 1987, but were sporadically present the rest of the year. Another sciaenid, silver perch (Bairdiella chrysoura), recruited as young juveniles in late summer and fall but were not as abundant as the other three species. It is apparent from these seasonal patterns, that the waters behind the barrier islands were utilized as a nursery area by at least one species of juvenile sciaenid throughout the year.

The remainder of the most abundant species were flatfish. With the exception of summer flounder, these species were small and not commercially important. In general, the abundance decreased in the winter as the adult flounders migrated offshore (Figure 3). However, some life stage of flounder is present over all seasons. Summer flounder spawn offshore in the

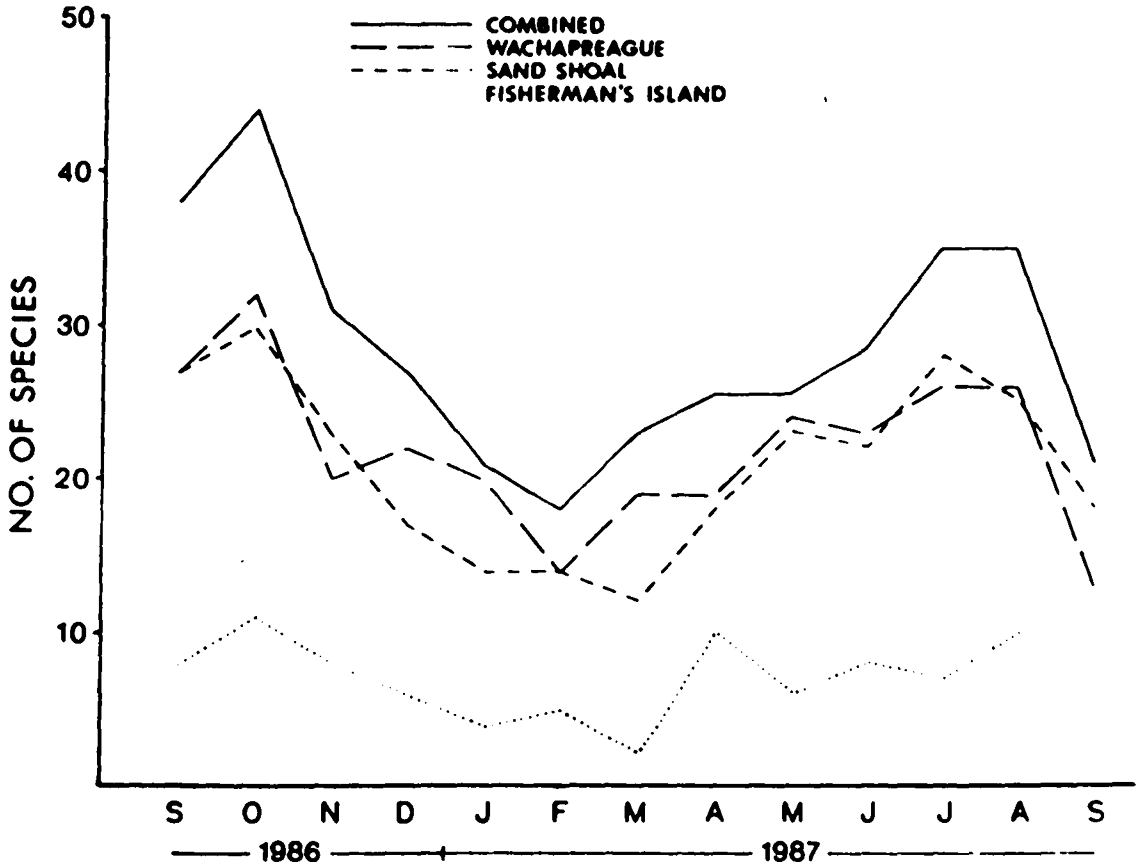

Figure 2. Number of species of all sizes and lifestages collected monthly September 1986 through September 1987 at Wachapreague, Sand Shoal and Fisherman's Island. Combined data show both species overlap and differences between sites.

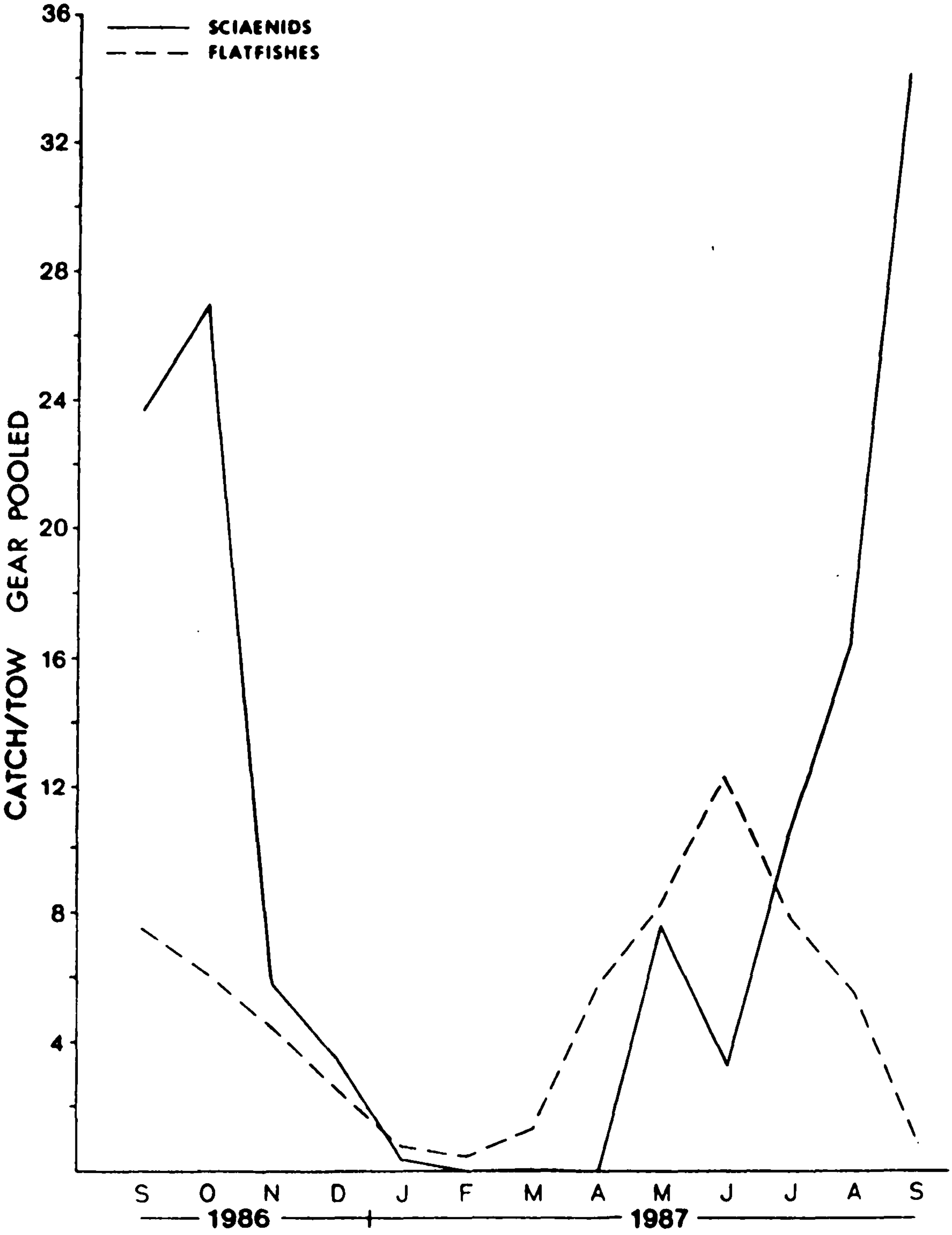

Figure 3. Monthly catch-per-unit-effort for sciaenids and flatfish, September 1986 through September 1987, all lifestages and all sites combined.

fall and winter, and recruitment of juveniles takes place from fall through winter and spring. Spring is also the time of a large influx of adult flounder which supports the recreational fishery. The barrier island area appeared to be a very important habitat for this species, thus the claim by Wachapreague as "the flounder capital of the world".

It was speculated two decades ago that the primary nursery grounds for juvenile summer flounder were the sounds of North Carolina, Chesapeake Bay and bays on the seaside of the Eastern Shore of Virginia (Poole, 1966). Solid evidence to support this hypothesis was lacking prior to this study because few newly recruited summer flounder have been captured in Virginia estuaries (Richards and Castagna, 1970; Weinstein and Brooks, 1983). There is generally very little juvenile summer flounder life history information in the literature, especially for the young-of-the-year (YOY). The few previous studies directed at this species tend to focus on Age I and II juveniles and adults (Powell, 1974; Smith and Daiber, 1977). Estuarine recruitment dynamics, settlement and nursery habitat are a few of the many early life history aspects on which little or no information exists.

Numerous studies show the importance of shallow habitats as nurseries for invertebrates and fish (Heck and Thoman, 1984; Weinstein, 1979); however, the sampling gears and designs were, in many cases, not appropriate for collecting small demersal organisms like young-of-the-year flatfish. This has been the case for summer flounder, particularly in Virginia estuaries. The infrequent capture of YOY summer flounder, particularly recently settled juveniles, in previous studies throughout the species range was probably due to 1) gear design and deployment technique, 2) study site, 3) season of study and 4) interannual recruitment variability.

We addressed the first three factors discussed above by: 1) using a trawl with 1/4 in. (6.4 mm) mesh in the lower body and codend with a 1/8 in. (3.2 mm) liner, 2) fishing all trawls with a tickler chain and deploying the trawls with the current whenever possible and 3) sampling a variety of habitats with three gears during the winter and spring. This resulted in the capture of more recently settled summer flounder than in prior studies conducted in Virginia estuaries.

Study site and season of study are two other important factors. This study included sampling during all months of the year, especially late fall through early spring. The hydrological and geological complexity of the Chesapeake Bay and Eastern Shore estuaries creates high habitat diversity. Many of these habitats, particularly shallow habitats, have not been adequately investigated. This study was designed to sample a variety of habitats, different in terms of depth and geographic location, in order to determine the effect of water depth on the distribution of newly recruited summer flounder in Virginia estuaries. We sampled during the peak recruitment period with gears designed to capture small demersal organisms. Our efforts represent an effort to better define the nursery habitat of YOY summer flounder in this geographic region.

Our preliminary sampling efforts in Spring 1986 resulted in the capture of 174 YOY summer flounder 15-69 mm TL. They were captured exclusively from shallow (< 5 m) mud bottom habitats, which were usually less than 15 m from saltmarsh vegetation. These habitats were located along the edges of large shallow creeks on the eastern side of Chesapeake Bay and along the edges of main channels within extensive saltmarshes on the seaside of the Eastern Shore. Most of the fish were captured near Wachapreague on the seaside of the Eastern Shore. The surface temperature at sites of positive collections ranged from 11.0 to 12.0° C and 14.5 to 17.5° C for Chesapeake Bay and seaside sites, respectively. Surface salinity ranged from 17.3 to 21.2 ppt and 29.5 to 32.0 ppt at these sites.

Interannual variation may overshadow all other factors discussed above. The present investigation indicates that recruitment can vary by orders of magnitude between years. This may partially explain the infrequent capture of young-of-the-year summer flounder in previous studies.

Recruitment of Juvenile Summer Flounder

One method of assessing recruitment success is to compare multiple years of similar measurements. In addition to our trawling and seining at five selected seaside and Chesapeake Bay sites since 1986, we had a week-long intensive Eastern Shore and Bay cruise aboard the NOAA ship FERREL in the summers of 1987 and 1988 to supplement our regular sampling scheme. Our sampling was designed to identify newly recruited summer flounder. Therefore, since flounder are thought to begin spawning in September off of New Jersey (Smith, 1973), with the exception of preliminary sampling in 1986, our sampling year begins in September and runs through the following

August, i.e. 1986-87, 1987-88, 1988-89. We used length/frequency analysis to identify recruits as young-of-the-year flounder. In the fall, we used lengths to separate last year's cohort from newly recruiting flounder. Catch-per-unit-effort (CPUE) is defined as number of flounder captured per seine haul or number of flounder captured per five minute trawl.

Comparison of three types of gear showed a consistent pattern of reduced recruitment of summer flounder juveniles to Virginia waters between 1986 and 1988 (Table 1). Though these numbers are relative only to each other and are not intended to be used as an index of absolute abundance, they clearly demonstrate that young-of-the-year recruitment to Virginia waters has declined over the last three years. Though there was a difference in effort expended each year, the preliminary sampling year, 1986, had the least amount of effort but produced the highest catch-per-unit-effort of newly recruited summer flounder. There were twice as many flounder captured in seven seine hauls that year as were caught in 450 seine hauls over the next two years. The CPUE for seine hauls decreased by two orders of magnitude from an initial level of 14.4 flounder per haul in 1986 to 0.20 flounder per haul in 1986-87 and was 0.00 in 1987-88 when no flounder were captured in seine hauls. An order of magnitude decrease in catch of summer flounder was seen in trawl catches each year. Catches decreased from a CPUE of 3.19 (397 flounder in 614 minutes) in 1986 to 0.89 (868 flounder in 4314 minutes) in 1986-87, to a low of 0.02 in 1987-88 (9 flounder in 2415 minutes) through June 1988.

Table 1. Monthly recruitment of YOY summer flounder 1986-88.

	SEINE			LINED NET				UNLINED NET			
Month	# Seine Hauls	Total # Flounder	CPUE	# Tows	# Minutes	Total # Flounder	CPUE	# Tows	# Minutes	Total # Flounder	CPUE
April 86	5	83	16.6	0	-	-	-	0	-	-	-
May 86	2	18	9.0	0	-	-	-	6	21.0	58	13.81
June 86	0	-	-	0	-	-	-	33	162.8	133	4.08
July 86	0	-	-	0	-	-	-	43	214.1	86	2.01
Aug 86	0	-	-	0	-	-	-	43	215.9	120	2.78
TOTAL	7	101	x=14.4 FL/haul					125	613.8	397	x=3.19 FL/5min.
Sept 86	19	0	0	71	355.0	0	0	0	-	-	-
Oct 86	20	0	0	69	345.0	0	0	0	-	-	-
Nov 86	24	2	0.08	72	360.0	26	0.36	0	-	-	-
Dec 87	25	6	0.24	70	350.0	11	0.16	0	-	-	-
Jan 87	24	3	0.13	69	345.0	10	0.14	0	-	-	-
Feb 87	24	3	0.13	68	339.5	14	0.21	0	-	-	-
March 87	24	7	0.29	64	320.5	32	0.50	0	-	-	-
April 87	24	19	0.79	68	338.0	51	0.75	0	-	-	-
May 87	24	8	0.33	64	320.5	97	1.51	0	-	-	-
June 87	24	1	0.04	68	310.5	247	3.98	45	207.0	43	1.04
July 87	24	4	0.17	75	374.5	193	2.58	0	-	-	-
Aug 87	24	2	0.08	70	348.0	58	0.83	0	-	-	-
TOTAL	280	55	x=0.20 FL/haul	823	4106.5	739	x=0.90 FL/5min.	45	207.0	43	1.04
Sept 87	16	0	0	20	101.5	0	0	23	116.0	0	0
Oct 87	18	0	0	23	113.5	0	0	23	115.0	0	0
late Oct-Nov	18	0	0	23	115.0	0	0	23	115.0	0	0
Dec 87	14	0	0	20	101.0	0	0	23	115.0	0	0
Jan 88	18	0	0	24	117.5	0	0	23	112.5	0	0
Feb 88	14	0	0	22	110.0	0	0	21	102.5	0	0
March 88	16	0	0	22	112.0	0	0	19	95.0	0	0
April 88	16	0	0	21	105.0	1	0.05	21	105.0	0	0
May 88	18	0	0	23	115.0	3	0.13	23	112.5	0	0
June 88	22	0	0	22	176.0	2	0.06	24	260.0	3	0.12
TOTAL	170	0	x=0 FL/haul	243	1166.5	6	x=0.03 FL/5min.	252	1248.5	3	x=0.01 FL/5min.

The data collected in 1987-88 would be more confusing if they occurred during the first year of the study. However, we were fortunate to have one complete and one partial year of prior sampling and are confident of our sampling methods. Thus we do believe there is an actual decrease in recruitment and not an apparent decrease due to sampling technique. Compared to the 1986 samples, the 1988 levels of flounder recruitment are very low, demonstrating the large interannual variability in recruitment that is possible. Two and one-half years of sampling does not provide sufficient data to state what is a "normal" level of recruitment. However, it is reasonable to believe that Virginia waters are presently experiencing very poor recruitment of juvenile summer flounder. According to preliminary analysis and in agreement with our original hypotheses, wind patterns for 1987 and 1988 were not favorable for recruitment from the north in the fall nor from the south in the spring. We cannot speculate what effect this will have on the flounder fishery in two to four years because it is not known what percentage of the fishable population is dependent on Virginia nursery area during their juvenile stage.

Recruitment of Juvenile Atlantic Croaker

Croaker continues to be one of the target species. The objective was to learn more about the distribution and recruitment of this species and to test and update the existing predictive model for croaker recruitment. That model (Norcross, 1983), which is dependent upon fall winds on the continental shelf and winter water temperatures in the rivers, predicts an average year-class for Summer 1987 and a poor year-class for Summer 1988.

The cessation of the southerly wind component occurred in mid-August in 1986 as opposed to the beginning of October in 1987. An earlier occurrence is more favorable for croaker spawning (Norcross and Austin, 1988). According to the model analysis, the wind transport index (W = 13) was better than average in 1986 with onshore winds coincident with time of spawning. However, the wind transport index was worse than average (W = 4) in 1987 with no onshore winds. The high number of recruits captured in October 1987 (Table 2) probably was a result of southerly winds at that time bringing the larvae northward from a spawning location off of North Carolina. The previously defined mathematical relationship between the wind transport index and recruitment of juvenile croaker to the bay in the fall was verified during the fall of 1986 and 1987 (Table 3) by collections comparable to those made by the VIMS river survey, i.e. using the same vessel (R/V Captain John Smith) and gear (30-ft. lined trawl) on which the original model was based.

The average January-February-March temperatures for 1987 and 1988 were 5.05°C and 4.93° respectively. These values are in the range of cold temperatures which do not produce dominant year classes. Though the winter temperatures were similar for both years, the differences in the wind indices had a more negative effect on 1988 croaker recruitment which is therefore expected to be poorer than 1987. The data of summer collections of croaker which are use to verify these predictions are collected by the VIMS trawl surveys. Neither year of data is yet available to test these forecasts. However, data from the current research effort, pooled for all sites by month, reveal comparatively low CPUE values for croaker. While

Table 2. Monthly recruitment of YOY croaker 1986-88.

Month	SEINE #seines	SEINE #CR	SEINE #CR/seine CPUE seine	LINED NET #lined Tow	LINED NET #CR	LINED NET CPUE #CR/Tow	UNLINED NET unlined Tows	UNLINED NET #CR	UNLINED NET CPUE #CR/Tow
Sept. 86	19	0	0	71	708	10.0	0	-	-
Oct. 86	20	44	2.2	69	925	13.4	0	-	-
Nov. 86	24	7	0.3	72	1864	25.9	0	-	-
Dec. 86	25	2	0.1	70	1128	16.1	0	-	-
Jan. 87	24	0	0.0	69	193	2.8	0	-	-
Feb. 87	24	1	0.04	67	235	3.5	0	-	-
March 87	24	0	0.0	64	4	0.1	0	-	-
April 87	24	0	0.0	67	0	0	0	-	-
May 87	24	0	0.0	64	0	0	0	-	-
June 87	24	0	0.0	62	7	0.1	0	-	-
July 87	24	0	0.0	68	12	0.2	0	-	-
Aug. 87	24	0	0.0	69	1	0.01	0	-	-
TOTAL	280	54	AVG CPUE =0.2 CR/SEINE	816	5077	AVG CPUE =6.2 CR/TOW			
Sept. 87	16	0	0	20	4	0.2	23	0	0
Oct. 87	18	1	0.05	23	1345	59.0	23	1	0.04
late/ Oct. 87	18	1	0.05	23	185	8.0	23	5	0.2
Dec. 87	14	0	0	20	125	6.2	23	8	0.3
Jan. 88	18	0	0	23	12	0.5	22	1	0.04
Feb. 88	14	0	0	22	2	0.1	20	0	0
March 88	16	0	0	22	0	0	19	0	0
April 88	16	0	0	21	0	0	21	0	0
May 88	18	0	0	23	0	0	22	0	0
June 88	18	0	0	21	0	0	24	0	0
TOTAL	166	2	0.01= AVG CPUE CR/SEINE	220	1673	AVG CPUE =7.6 CR/ TOW	222	15	AVG CPUE 0.07 CR/TOW

data from the 16-foot trawl used in this present study cannot be directly compared to that collected by the 30-foot trawl used by the VIMS trawl survey, it should be noted that these values (Table 2) are significantly lower than seen in recent (1983-85) years of excellent recruitment. The monthly collections show better recruitment in Fall 1986 than Fall 1987. Spring and winter abundance for both years is poor, in accordance with the predictive results of the model.

Recruitment of Spot

Larval recruits of spot were in great abundance in the Chesapeake Bay beginning in late April 1987 (Table 4). Their initial size range was very narrow, approximately 21-25 mm ±5 mm. Individual cohorts of new recruits were collected throughout April and May. The cohorts could be traced throughout the spring and summer by modal peaks in length frequencies indicating growth. New smaller, cohorts could be detected entering the system. These newly recruited spot post-larvae and juveniles were found at sites on both the western and eastern sides of the Chesapeake Bay. Collections for the same period of time reveal very few spot entering the bays behind the barrier islands on the seaside of the Eastern Shore of Virginia. In this Atlantic Ocean location, spot appeared one month later and in numbers on an order of magnitude less than found within the Chesapeake Bay. The small size of these recruits, 20-25 mm, agrees with a new cohort appearing simultaneously inside the Chesapeake Bay, on the western shore in the York River. Since the barrier island area is north of the mouth of the Chesapeake Bay, this pattern of recruitment indicates that

Table 3. Fall recruitment of YOY croaker in the Chesapeake Bay. R/V Captain John Smith - 30 ft. lined trawl

	Total # of Croaker caught	# of Tows	# Croaker 5 Min. Tow
19 Sept. 1986	0	9	0.00
16 Oct. 1986	49	9	5.44
14 Nov. 1986	23	9	2.56
19 Dec. 1986	662	7	94.57
21 Sept. 1987	166	8	20.75
16 Oct. 1987	49	9	5.44
24 Nov. 1987	189	9	21.00
14 Dec. 1987	10	9	1.11

Table 4. Monthly recruitment of YOY spot 1986-88.

Month	SEINE #seines	#spot	CPUE seine #Spot haul	LINED NET #lined Tow	#spot	CPUE #spot 5min.Tow	UNLINED NET unlined Tows	#spot	CPUE #spot 5min.Tow
Sept. 86	19	0	0	71	0	0	0	-	-
Oct. 86	20	0	0	69	0	0	0	-	-
Nov. 86	24	0	0	72	0	0	0	-	-
Dec. 86	25	0	0	70	0	0	0	-	-
Jan. 87	24	0	0	69	0	0	0	-	-
Feb. 87	24	0	0	68	0	0	0	-	-
March 87	24	0	0	64	0	0	0	-	-
April 87	24	1917	79.9	68	1829	27.1	0	-	-
May 87	24	3544	147.7	64	7317	114.1	0	-	-
June 87	24	239	9.9	62	3534	56.9	0	-	-
July 87	24	91	3.8	69	1856	26.9	0	-	-
Aug. 87	24	13	0.54	70	652	9.4	0	-	-
TOTAL	280	5804	AVG CPUE =20.7 SPOT/TOW	816	15188	AVG CPUE =18.6 SPOT/TOW	0	-	-
Jan-May	120	5461	=45.5	333	9146	=27.47	0	-	-
Sept. 87	16	3	0.19	20	55	2.7	23	215	9.3
Oct. 87	18	0	0	23	11	0.5	23	205	8.9
late/ Oct. 87	18	0	0	23	7	0.3	23	30	1.3
Dec. 87	14	0	0	20	1	0.05	23	10	0.4
Jan. 88	18	0	0	24	0	0	23	0	0
Feb. 88	14	0	0	22	0	0	21	0	0
March 88	16	0	0	22	6	0.3	19	1	0.05
April 88	16	28	1.75	21	1555	74.0	23	3	0.1
May 88	18	2251	125.1	23	3573	155.3	23	311	13.8
TOTAL	148	2282	AVG CPUE 154 SPOT/TOW	194	5208	AVG CPUE =26.8 SPOT/TOW	198	775	AVG CPUE =3.9 SPOT/TOW
Jan-May	82	2279	27.79	112	5128	45.79	170	315	=2.9

the spot were entrained into the Bay after being transported northward from south of the Bay entrance. It appears that the episodes of southerly winds transported waves of new recruits northward from a southern spawning site. This is being investigated in more detail at this time.

Similar length frequency analysis has not yet been completed for spot in spring 1988. However, preliminary analysis of wind transport over that time reveals episodes of southerly winds, similar to those of Spring 1987, occurring approximately one month earlier. Coincident with this was recruitment of spot to the Bay beginning in March and early April 1988 (Table 4). Though trawl survey data, with which to make historic comparisons, have not been analyzed for spot, the catch-per-unit-effort for the two years collected here indicated good recruitment for 1987 and 1988 (Table 4). These values are quite good, especially when compared to the poor CPUE's of croaker. Interesting, but unexplainable, is a comparison between January - May CPUE's each year. The total CPUE for seine and trawl hauls together for both years was equal, while the values for the individual gears were reversed between years. This seems to indicate that in 1987 more spot initially recruited to the very shallow waters sampled by the seine, while more spot were in somewhat deeper areas available to trawl gear in 1988. It is not known if this has any habitat or recruitment implications, but further investigation is needed.

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IMPLICATIONS FOR MANAGEMENT

Estimates of annual recruitment of flounder, croaker and spot to fishable stocks are needed in the development of Fishery Management Plans (FMP's) by the Virginia Marine Resources Commission (VMRC). A goal of this project is to develop models for prediction of juvenile recruitment for those species. The VMRC has expressed an interest in the development of a juvenile flounder index which they hope to use in directing the management of this fishery. Virginia management plans for croaker and spot will be developed following the completion of the flounder plan. VMRC anticipates using the results of this research project to determine Virginia's degree of compliance with the federal management plans. Prior knowledge of precariously low stock sizes will allow for restrictions to be imposed as needed to protect the spawning stock.

Environmental factors, which affect the vulnerable periods in the life history (i.e. egg, larval, juvenile and spawning adult) of each species, may explain this recruitment variation. The simultaneous collection of environmental and biological data, both on the shelf and in the estuary, should promote an understanding of the vulnerability of these life stages and lead to the development of a model quantifying the relationship between environmental factors and the recruitment of juvenile finfish to Virginia estuaries. If the relationship can be quantified, it would permit us to predict the amount of juvenile recruitment by measuring environmental variables. This approach would be less costly than sampling juvenile fish populations in order to obtain a measure of recruitment success.

It is necessary to identify valuable finfish nursery habitat, such as the marsh areas of the Eastern Shore to which the YOY summer flounder recruit. Knowledge of use of these habitats is important to their preservation.

ANTICIPATED ACTIVITIES IN 1988-90

Three objectives will be addressed by continuing the sampling program which began in 1986: 1) identify the patterns and anomalies of recruitment abundance of juvenile croaker, summer flounder and spot; 2) investigate the distribution and habitat of these target finfish species during various stages of their life history which affect recruitment success, such as larvae, juveniles, and spawning adults and 3) identify the trends and cyclic components of environmental variables associated in time and space with effects on juvenile finfish recruitment. That will entail continuing sampling once per month at Wachapreague, Sand Shoal Inlet, Occohannock Creek and the York River mouth using the gear described above. We may expand the sampling to include lower salinity areas or other bottom types to determine spatial and temporal extent of recruitment and of nursery areas. We will continue to take lengths on all flatfish and sciaenids and gonad development information on flounder, croaker and spot. All of this information will be used in assessment of recruitment success and development of indices of recruitment and predictive models.

We will also investigate transport processes affecting recruitment of spot and flounder to the Chesapeake Bay and Eastern Shore of Virginia. The objective is to examine vertical distribution and movement of larvae through discrete depth samples at and around the mouth of the Chesapeake Bay, Wachapreague Inlet (possibly) and the York River to explain effects of wind and currents. This will be accomplished by intensive field sampling at the mouth of the Chesapeake Bay and the York River in Spring 1989. Samples will include a variety of gear (presently undetermined and being tested), possibly including bongo nets, anchored plankton nets, plankton sleds, and Tucker, midwater and bottom trawls. Sampling will be conducted from the Captain John Smith, Langley or possibly Bay Eagle. Note, this is to replace the one day per month of sampling a channel transect from the mouth of the

York River to the mouth of the Chesapeake Bay as has been conducted the last two years. We have learned that scale of sampling is not adequate and therefore are refining the time and space scales.

LISTING OF PAPERS PUBLISHED/THESES, DISSERTATIONS

Manuscripts Submitted

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Multiple regression models: Tools for investigating biological-physical mechanisms in juvenile Atlantic croaker.

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Manuscripts in Preparation

Norcross, B.L.

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Theses and Dissertations in Progress

Wyanski, D.M.

Depth/substrate preferences and other life history aspects of Age 0 summer flounder, *Paralichthys dentatus*.

M. A. Thesis

Bodolus, D.A.

Mechanisms of larval spot transport and recruitment to Chesapeake Bay estuaries.

Ph.D. Dissertation

PROJECT 4

STRIPED BASS EARLY LIFE HISTORY IN THE PAMUNKEY RIVER

John C. McGovern
John E. Olney

PROJECT DESCRIPTION

Striped bass has been an economically and recreationally important species since the seventeenth century. The general trend in abundance has been one of gradual decline punctuated by peaks of abundance. These peaks or "dominant year-class phenomena" have been the result of occasional successful spawning which may or may not have been associated with a large spawning population. The last dominant year-class occurred in 1973.

The precipitous decline in striped bass abundance has resulted in many studies designed to investigate the causes of this decline and prevent further stock depletion. Although there are many interactive factors that may be responsible for striped bass abundance, evidence indicates that survival of early life history stages may be important in determining year-class strength. The striped bass is a broadcast spawner with estimates of fecundity ranging from 65,000 eggs in four year olds to 5,000,000 eggs in 13 to 14 year old fish. These values indicate that egg production can remain high despite a reduction in the number of spawning adults. Hence, variability in survival in eggs, larvae and early juveniles of striped bass can be very important in controlling the magnitude of recruitment.

As a result, the primary objective of this project has been to examine the different factors which may affect survival of striped bass eggs and larvae and try to account for any variability in survival. Three studies are being used to assess these factors. The first two of these studies have been completed while a third was initiated in Spring 1988.

The objectives of the first study were to: (1) determine the kinds and relative abundance of potential fish and invertebrate predators of striped bass larvae through field surveys during striped bass spawning periods; (2) document acceptability of striped bass yolksac larvae as a prey item through laboratory presentations to fish and invertebrates; (3) establish consumption rates of yolksac larvae under laboratory conditions of various prey densities; and (4) examine stomach contents of target fish predators collected on the spawning grounds.

A second study utilized a time-series egg mortality study to test the hypothesis that any declining egg density during the study was the result of natural predation by fishes. This study was designed to determine: (1) egg mortality rates; (2) egg viability; and (3) egg retention mechanisms.

The third, most recent, investigation is a two-year study which will evaluate the separate and interactive effects of starvation, predation and environmental stresses on larval survival by examining the time-space patterns of mortality inferred from the back-calculation of juvenile brthdates. Data sets describing predator and prey fields, food abundance and changing environmental conditions during the spawning season will be compared to patterns of larval survival.

RESULTS/DISCUSSION

Potential Predation by Fish and Invertebrates on Early Life History Stages of Striped Bass

Midwater and bottom trawls and oblique plankton tows were used in surveys of fish, ichthyoplankton and zooplankton along a 38-km section of the Pamunkey River, Virginia. Fourteen taxa of invertebrates were identified in zooplankton collections taken during the spawning season. Density ranges of selected species considered to be potential predators of striped bass eggs and larvae are presented in Table 1. Midwater and bottom trawls captured 18 species comprising 6163 specimens on the spawning grounds. Beach seining contributed six additional species (Table 2). During a two-day period in 1987, striped bass egg densities ranged from 0.54 to 8.37 egg/m^3 (Figure 1). Thus nearshore predators such as pumpkinseed, bluegill and yellow perch may also have the potential to feed on striped bass yolksac larvae.

Sixteen fish species found to have temporal and spatial coincidence with striped bass spawning were presented striped bass yolksac larvae in the laboratory. Juveniles or adults of 11 species readily accepted yolksac larvae implicating them as potential predators of striped bass early life stages (Table 3).

Consumption rate of yolksac larvae by satinfin shiner and spottail shiner increased with increasing prey density to a maximum of 81 larvae per predator per hour and 150 larvae per predator per hour, respectively (Table 4).

Examination of 235 stomachs of 14 species of fishes collected in the Pamunkey River provided no evidence of predation on striped bass eggs or larvae (Table 5). Of these, six species readily accepted striped bass larvae under laboratory conditions. Digestion rate experiments with spottail shiner revealed that yolksac larvae could not be recognized in the gut contents 40 minutes after ingestion. Due to the nature of the soft-bodied yolksac larvae and extremely fragile striped bass eggs, it may be very difficult to document natural predation on striped bass early life stages unless predators were captured immediately after feeding on these prey items. Fish eggs were found in the stomachs of five fish species but most eggs were those of white perch. Eleven invertebrate taxa were identified with amphipods, ostracods, cladocerans and copepods constituting the most important dietary items. Although direct evidence of natural predation on striped bass eggs and larvae was lacking, our data revealed generalized feeding habits or planktivory in species implicated as potential predators (Tables 3 and 5). As a result, the likelihood of predation by these fishes would presumably increase during periods of peak spawning and larval production.

Of the four invertebrate taxa tested, only the cyclopoid copepod, *Acanthocyclops vernalis*, showed any predatory behavior towards striped bass larvae. With the use of a low light video system, we were able to film and repeatedly observe the attack behavior of *A. vernalis* in slow motion. After prey detection the copepod oriented itself to the moving larva, rapidly attacked and then fled. An attacked larva reacted by violent thrashing. Occasionally, the copepod grasped a larva but could not remain in constant contact due to the nature of the prey's reaction. After a larva had been immobilized by one or more attacks, copepods were observed to feed on the dead or dying prey. Scanning electron microscopy revealed large wounds in various regions of the integument. No damage of this nature was observed in any control larvae. Examination of the mouth parts of *A. vernalis* indicated that the distance between maxillae corresponded to the diameter of the striped bass wound. Consumption rate experiments showed that *A. vernalis* was able to kill 0.87 larvae per copepod at prey densities of 20-30 larvae per liter. *Acanthocyclops vernalis* was one of the most abundant taxa taken in zooplankton collections reaching densities greater than $600/m^3$ suggesting that a high probability of predator encounter is likely in patches with high densities of striped bass larvae. Even though predation rates were modest on an individual basis, these small predators could have an important impact on prey populations due to their vast numbers.

A Time-Series Analysis of Striped Bass Egg Mortality

Given the knowledge that a field of potential predators existed on the striped bass spawning grounds, a time-series study was conducted to provide a field estimate of striped bass egg mortality. During peak spawning activity 270 l of a red fluorescent dye was released at the upper limit of a selected sampling area during high slack water. The dye was used as a tag to follow a parcel of water which contained a population of eggs for two consecutive days.

A total of 1,594 eggs were collected during the study. Egg densities at positive stations ranged from 0.54 to 8.37 eggs/m^3 (Figure 1). Over 88% of the eggs collected during the study were viable. These eggs were separated into eight developmental stages after a series from Mansueti (1958). Temperature througout the study ranged from 16.1 to 16.6 C for a mean of 16.4 C indicating that the developmental rate of field caught eggs was probably close to that described by Mansueti (1958) at temperatures of 16.7 to 17.2 C.

Based on Mansueti's series and the known rate of development, five different cohorts were identified during the two-day study. Instantaneous mortality coefficients were calculated for the five cohorts. These corresponded to highly variable egg mortality rates ranging from 17.1 to 92.8 % for a mean of 72.4 % per day. While our mortality estimate of 72.4 % per day agreed with the results of previous investigators, we believe that this estimate may have been biased because of an inability to account for egg gain or loss to the envelope of water defined by the dye. The study site was subjected to extreme turbulence and mixing during ebb and flood tides. This was illustrated by the rapid decrease in dye concentrations during the first few hours of sampling. Since dye spread so rapidly and decreased in concentration so precipitously, we were concerned that the population of eggs sampled might have behaved in the same manner. This was further confounded by the fact that eggs which were initially outside the dye envelope could have also been introduced to the sampling area because of the same mixing processes. Our results have revealed that biases due to physical processes such as advection and diffusion are not easily overcome even when sampling in a small system like the Pamunkey River. Thus our estimates of egg and larval mortality as well as that of previous investigators may not be accurate.

An additional objective of the time-series study was to obtain data on residence time and tidal transport of eggs in regions of the Pamunkey River that represent primary spawning sites. Dye was released during slack-before-ebb at the downstream mouth of a thoroughfare in Sweet Hall Marsh. Preliminary analysis showed that this channel served as a short-cut for water current delivering dye far upriver. The tagged water parcel did not return to the site of dye release on ebb tide when following the main course of the river. This indicates that thoroughfares such as that found in Sweet Hall Marsh may act as a retention mechanism allowing eggs and larvae to remain in a favorable developmental habitat without being swept seaward during critical pelagic stages.

Seasonal Variations in Survival of Larval Striped Bass Estimated from the Age Distribution of Juveniles

A third investigation designed to examine seasonal variation in survival of larval striped bass was initiated during the 1988 spawning season. Bi-weekly ichthyoplankton cruises were conducted from 4 April through 27 May 1988 to determine birthdate distribution and food availability for first-feeding striped bass larvae. Abundances of fish species considered to be potential predators of striped bass early life stages was determined by weekly deployment of a push-net at night. In addition, a continuously recording environmental station located at the lower limit of the striped bass spawning area provided data on pH, water temperature, salinity, dissolved oxygen and rainfall every half hour from 11 March through 17 May 1988. These data are currently being analyzed.

Juveniles are now being collected weekly. Survival will be determined from the age distribution of the juveniles. Patterns of mortality will be compared to data sets describing variations in predator and prey fields during the spawning period as well as those describing changing environmental conditions.

ANTICIPATED ACTIVITIES FOR 1988-1990

Although the cyclopoid copepod, *A. vernalis*, has been implicated as a potential predator of striped bass larvae, it is difficult to provide evidence of natural predation. Cyclopoids were among the most dominant taxa taken in zooplankton collections reaching densities greater than $600/m^3$ on the spawning grounds, suggesting that a high probability of predator encounter is likely in patches with high densities of larvae. We intend to employ the use of an automated plankton camera during the next two years to measure scales of patchiness on the spawning grounds and assess the relative significance of cyclopoid predation to striped bass larval survival. Also, efforts will be continued to test other cyclopoid species as potential predators and measure their predation rates.

Preliminary work has indicated that a study evaluating seasonal variations in survival is feasible. Collection of data will be continued and intensified through the next spawning season. Data analysis for the two-year study should be completed by 1990.

PAPERS PUBLISHED/THESES, DISSERTATIONS

Papers Presented

McGovern, J.C., and J.E. Olney. June 1987. Field and invertebrate predators of early life stages of the striped bass, *Morone saxatilis*, in the Pamunkey River, Virginia. American Society of Ichthyologists and Herpetologists. Albany, New York.

McGovern, J.C., and J.H. Posenau. June 1988. A time-series analysis of striped bass egg mortality in the Pamunkey River, Virginia. Early Life History Section of the American Society of Ichthyologists and Herpetologists. The University of Michigan, Ann Arbor, Michigan.

<u>Published Papers</u>

McGovern, J.C., and J.E. Olney. 1988. Potential predation by fish and invertebrates on ealry life stages of striped bass in the Pamunkey River, Virginia. Transactions of the American Fisheries Society. In Press.

Posenau, J.H., and J.C. McGovern. 1988. A portable data acquisition system for lagrangian investigations of plankton distribution. Institute of Electrical Engineers. In Press.

McGovern, J.C., J.H. Posenau, and J.E. Olney. A time-series analysis of striped bass egg mortality in the Pamunkey River, Virginia. In Prep.

TABLE 1. Density ranges (number m^{-3}) of striped bass eggs and larvae and potential invertebrate predators collected at nine stations on the Pamunkey River, 15 and 19 April 1985. * = values less than 0.1.

Organisms	Station number								
	P-31	P-34	P-37	P-40	P-43	P-46	P-49	P-52	P-55
striped bass eggs			*	* -1.6	0.2-3.6	0-21.2	1.3-6.2	* -0.2	*
striped bass larvae		*		0-3.8	0.2-0.4	2.1-2.2	0.6-0.7	* -0.9	
calanoid copepods	2572.7-6349.4	1421.3-11672.7	1180.5-3110.4	3054.8-4614.4	275.1-742.2	211.2-589.9	32.3-2512.3	22.6-975.9	6.2-61.2
Cyclopoid copepods									
Acanthocyclops vernalis			0-27.0	0-55.0	19.9-21.5	115.5-136.9	58.5-650.7	97.3-224.0	9.4-49.6
Mesocyclops edax			0-18.0		0-5.0	1.9-7.3	5.7-128.4	27.2-28.0	1.6-8
Cladocera		*	0-43.7	* -655.1	11.7-171.3	160.7-685.9	756.9-1691.5	355.1-752.2	67.3-217.2
Leptodora kindti						0-16.5	17.8-58.0	0-30.5	12.9-18.6
Amphipods	2.2-32.1	1.3-1.5	0.1-183.5	4.9-626.6	16.6-108.6	7.2-59.0	10.0-49.7	10.5-125.4	0.5-1.8
Mysids									
Neomysis americana	108.0-130.9	0.6-3.4	23.2-174.7	* -27.8	0-6.5	*			
Water mites	*	* -0.5	*	*	0.4-2.7	* -0.2	0.4-1.1	0.2-0.4	0.2-1.6
Insect larvae	*	*	* -0.4	0-1.0	0.5-2.6	0-0.3	* -1.2	0.3-0.6	* -0.2
Water quality									
Average Temperature (C)	16.2	16.3	16.2	16.2	16.2	16.5	16.6	17.4	18.3
Average Salinity (o/oo)	7.7	5.5	3.8	1.4	0.5	0.1	0.1	0.1	0.1

TABLE 2. Percent composition of fishes captured by all gears on a 23-mile transect of the Pamunkey River, Virginia, April - May 1985. Station designations are mid-points of three mile strata. Asterisks indicate percentage values less than 1.0.

TAXA	STATION NUMBER							
	P-34	P-37	P-40	P-43	P-46	P-49	P-52	P-55
Bay anchovy	96.0	91.0	53.5	60.5	26.6	66.1	17.2	13.8
White catfish	*	*	1.5	1.8	2.6	2.1	4.0	*
Atlantic menhaden	2.6	*	23.5	15.9	52.1	24.4	64.4	79.8
Hogchoker	*	5.7	14.3	4.8	14.9	4.2	8.0	4.6
Channel catfish			*	*	1.9	*	*	
Atlantic croaker	*	*	3.8	4.3	1.1	1.0	*	
Spot	*	*	2.5	11.6	*			
White perch	*	2.0	*	*	*	*	2.3	
Striped bass				*	*	*	*	
Spottail shiner						*	1.1	
Others	*		*	*	*	*	*	*
Number of specimens collected	1196	659	840	775	734	829	1021	109

Table 3. Potential fish predators of early life stages of striped bass

Atlantic menhaden	Channel catfish
Bay anchovy	Bluegill
Satinfin shiner	Pumpkinseed
Spottail shiner	Tessellated darter
White catfish	White perch
	Striped bass

Table 4. Predation rate of satinfin shiner and spottail shiner on striped bass yolk sac larvae at various prey densities.

Satinfin shiner

Prey density (M^3)	Mean number consumed per hour	Range	Mean Percentage of prey items consumed
20	1.0	0-1	60
100	4.4	4-5	88
333	15.0	8-17	88
1650	37.5	2-65	45
3300	40.6	8-81	24

Spottail shiner

Prey density (M^3)	Mean number consumed per hour	Range	Mean Percentage of prey items consumed
20	2.0	2-2	100
100	2.8	2-5	56
333	14.8	14-16	92
1650	82.2	81-83	99
3300	108.7	80-150	65

Table 5. Summary of analysis of stomach contents of fishes collected on the Pamunkey River, Virginia, April and May 1985-1986. Values are percent of total contents (by number) observed for each prey category.

Taxa	Satinfin shiner	Spottail shiner	White catfish	Channel catfish	Atlantic menhaden	Bay Anchovy	Tessellated darter	White perch	Atlantic croaker	Hogchoker
Fish eggs	4		28	38	<1			3		
Amphipods	4		47	30		<1	18	96	98	53
Ostracods	46	68		2	<1	<1	2			
Insects	4	22	1	25		<1	3		1	16
Water mites	1			<1						
Bivalves	8	10	1	<1			1			
Gastropods	<1					<1	2			
Cladocera	30				99	16	35			
Copepods	1		23		<1	84	18			
Polychaetes							22			29
Isopods			<1	5				1		2
Mysids				<1					2	
Number of fish examined	18	12	60	13	11	24	12	4	32	9

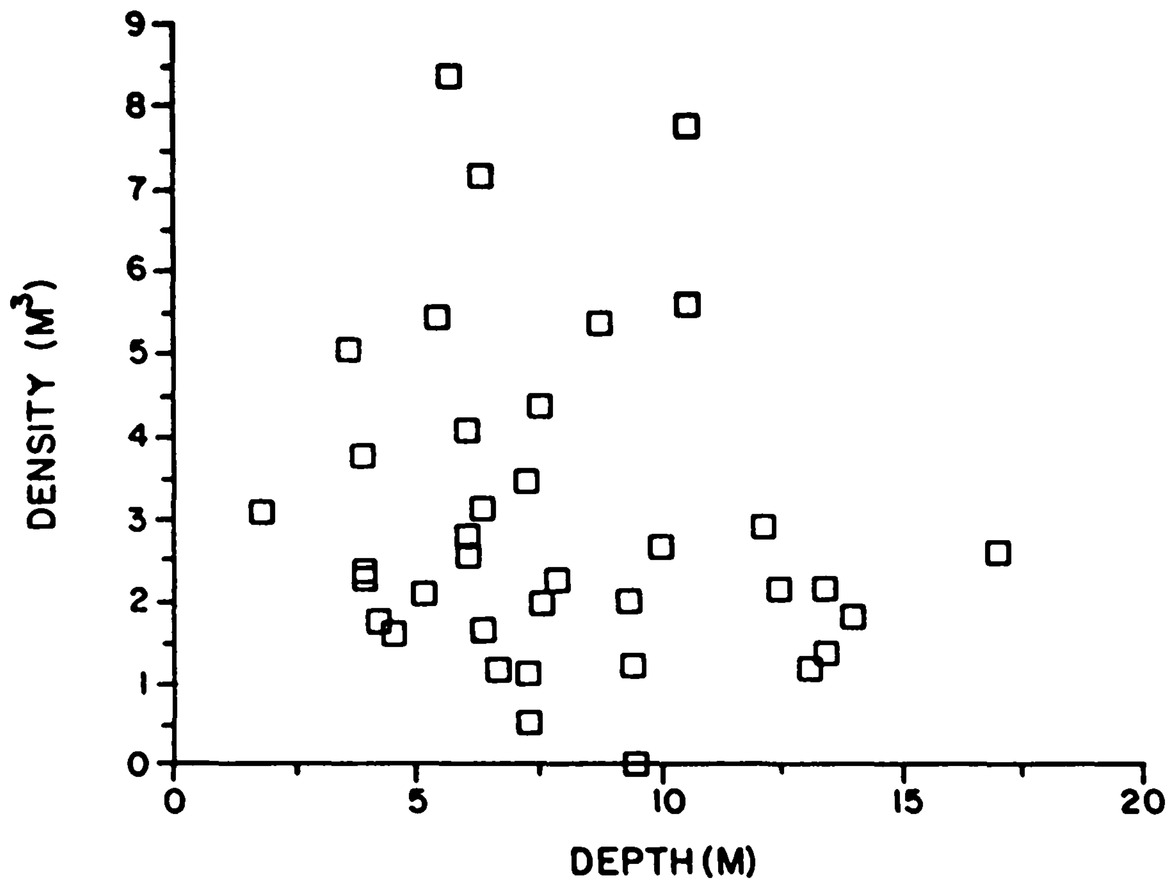

Figure 1. Egg versus depth distribution for samples taken 23-24 April, 1987.

PROJECT 5

CHEMICAL POISONS IN VIRGINIA'S TIDAL WATERS - FATE AND EFFECT OF POLYNUCLEAR AROMATIC HYDROCARBONS

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EXECUTIVE SUMMARY

Polynuclear aromatic hydrocarbons (PAH) are commonly encountered in the environment, in particular in marine sediments. Because of the known mutagenicity and carcinogenicity of some of these PAH, especially after they have been metabolized by biota, their presence is of substantial concern. Although it has been observed that fish living in areas heavily polluted with PAH suffer from a number of diseases such as liver neoplasms, preneoplastic lesions, necrotic lesions, fin rot, cataracts, immune system dysfunction and microscopically identifiable changes in various tissues, it has not been possible to identify a specific link between these problems and the presence of PAH.

In view of the need for answers, the Division of Chemistry and Toxicology of the Virginia Institute of Marine Science with the support of the State of Virginia, Council on the Environment, has started an ambitious, multidisciplinary research program to seek solutions to these problems. Chemists have sought new methodology to identify PAH metabolites by advanced high performance liquid chromatography-mass spectrometry, using several methods to generate ions. In addition, new methods capable of separating

many of the PAH metabolites present in bile from feral fish from PAH-contaminated areas were developed. The immunology and pathology group found the cellular immune system of fish from the Elizabeth River to be compromised. It was shown that the chemotactic, phagocytic and chemoluminescent responses of macrophages from some Elizabeth River fish from highly contaminated areas were depressed. Histopathological phenomena observed in fish from the Elizabeth River were duplicated in laboratory experiments by exposing fish to PAH contaminated sediments.

PROJECT DESCRIPTION

In recent years, much effort has been expended to determine the presence and effects of environmental contaminants in the Chesapeake Bay and its subestuaries. By now, it is well known that while hundreds of chemicals are present - mainly in sediments - their concentrations are seldom high enough to cause acutely toxic effects either in the Bay's biota or in humans ingesting seafood. This, however, does not render such contamination harmless. Instead of exerting acute toxic effects that are easily observed, effects are chronic and, more often than not, difficult to detect. This is particularly true for polynuclear aromatic hydrocarbons (PAH), whose presence in the environment has been found to be ubiquitous and whose effect, in some cases, is suspected to be directly or indirectly linked to cancer in some marine biota. These chemicals are synthesized when organic matter undergoes incomplete combustion. Examples of such processes include burning of fossil fuels, production of coal-tar and the smoking of cigarettes. They enter the aquatic environment after being transported through the atmosphere associated with solid particles or aerosols, or via runoff or spills.

Although it has been established that a high percentage of some flatfish (the English sole) from some heavily contaminated areas in the Puget Sound have liver neoplasms, preneoplastic lesions and necrotic lesions, it has not been possible to determine a specific chemical-disease link. Statistical analyses indicate positive correlations between the concentrations of PAH chemicals in the sediments and the fish diseases, but not enough is known to establish a direct cause-effect relationship. It has been established that fish in portions of the Elizabeth River, highly polluted with PAH from past creosote and coal tar spills, suffer from extensive fin-rot, cataracts, immune system dysfunction and microscopically identifiable changes in various tissues. There is little doubt that PAH are the causative agents but the mechanism of action remains a mystery. With the concentration of PAH in the Bay likely to increase with increasing human population density, the mechanism of action must be determined in order to predict effects and formulate remedial plans as necessary.

RESULTS/DISCUSSION OF 1986-88 PROGRAM

1. Chemistry

A basic knowledge of the biochemical processes to which the pollutants are exposed once they enter an organism is required. Because of the ubiquitous presence of PAH in sediments and the fact that some of these compounds, especially their metabolites, are powerful carcinogens, it was decided to investigate the interaction of PAH with biochemical systems using finfish.

Most PAH metabolites are concentrated in the bile. Attempts to determine their identities and concentrations have been based on high performance liquid chromatography (HPLC). Although this method provides the necessary sensitivity, it is flawed insofar as it is unspecific, requiring the synthesis of every PAH metabolite that is to be identified. The synthesis of such standards is a very expensive and time consuming process. In addition, the methodology lacks chromatographic resolution. We decided to investigate a more sophisticated approach by coupling mass spectrometry and HPLC, and by searching for ways to increase resolution. These efforts will be described in separate sections below.

HPLC-MS As A Tool For Metabolite Identification

In the last biennial report, we described efforts to interface HPLC to a quadrupole mass spectrometer with a direct liquid injection (DLI) probe. It gave reasonable sensitivity, but for many of the metabolites, especially those that join up with a glucuronide or sulfate group (conjugates), a molecular weight could not be determined because the molecule became unstable and fragmented. The results of these efforts have been presented to the scientific community.

We then attempted to determine if the performance of HPLC-MS could be improved by replacing the DLI with a thermospray source (TSP). This source not only held out the promise of higher detection sensitivity, but also of a lesser degree of fragmentation. Another attractive feature of TSP was that it could handle much larger solvent flows, up to 2 ml/min, and thus did not require microbore columns which are difficult to use. The adaptation of the TSP source to our mass spectrometer generated the need for substantial instrument modifications.

Our work with TSP, however, indicated that achievable sensitivities were below those of DLI. Most importantly, fragmentation was still extensive, although somewhat less than for DLI. Molecular ions in general were very low (Fig. 1). The small amounts of molecular ions are shown by the spectral lines labelled $[M]^-$ and $[M+NH_4]^+$ in this figure.

The large solvent volumes entering the mass spectrometer source made frequent shut-downs necessary. Most disappointing was the fact that the systematic variation of available parameters such as temperature, methods of ionization, polarity of monitored ions, mechanical source alignment, etc. did not improve the performance of the source in any substantial way.

From the interpretation of many spectra, it appears that thermal degradation of the conjugated metabolites is a major problem, and since some of the temperatures of the TSP source must be maintained to achieve ionization, this problem appears insurmountable at this time. The performance of TSP sources is extremely compound specific, and the conjugated B(a)P metabolites (and probably other conjugated PAH metabolites as well) will be particularly difficult to analyze by this method.

The HPLC-MS techniques we have developed are still both relevant and important and can be applied to the analysis of PAH metabolites. A combination of mass spectrometric information from the aglycone or desulfated ion with chromatographic retention data should reveal the general identity of the conjugated PAH. The development of methodologies to concentrate the metabolites to levels where they can be detected and analyzed in natural samples are necessary and are at this time being developed. A solid phase extraction is being pursued.

Metabolite Analysis By HPLC

There have been many efforts to maximize the separation of complicated environmental chemical mixtures using a number of microbore columns in tandem. According to one literature report, as many as one million theoretical plates were achieved by using a 22-meter long tandem string of microbore columns. These authors used hydrophobic organic solvents in this study. However, because of the highly polar nature of PAH metabolite conjugates, the present study required the use of water in the mobile phase. This resulted in very high back pressures; the use of microbore columns in the further studies was therefore abandoned.

The fish bile analyses were therefore performed using semi-microbore and analytical columns. It was realized that the column internal diameter

(ID) and the column packing particle size were main determinants of the observed column back pressures. Although an increase in the column resolving capacity was observed with the use of finer particles, the resulting high back pressures suggested the use of wider columns packed with coarser particles would be optimum. After a number of experiments, the following procedure was selected for future HPLC analyses of fish biliary PAH metabolites: a) three 4.6 x 250 mm Perkin-Elmer cartridge columns connected in tandem, b) C-18 bonded-phase silica packing, 10 micron particle size, c) columns eluted with a linear gradient of 100% water to 100% acetonitrile in 240 minutes, d) eluting peaks detected by a Kratos Fluorometer set at 380 and 418 nm (excitation and emission wavelengths), and e) eluting peaks integrated by using a Hewlett-Packard Integrator.

Using this procedure, bile of fish from the polluted Elizabeth River invariably gave the large numbers of intense, reasonably well resolved fluorescent PAH-metabolite-like peaks compared to those from the much cleaner waters of Hampton Roads and the Nansemond, York rivers respectively (Fig. 2). The natural intra- and inter-species variation in PAH-metabolite profile was evident in all fish species studied indicating a variability in the bioavailability and biotransformations of PAH among natural populations of fish. The presence of fluorescing peaks in fish bile indicates the possibility of PAH exposure and may thus be used for the monitoring of aquatic pollution.

2. Pathology and Immunology

Finfish from the Elizabeth River have been observed to exhibit high incidences of hyperemia, fin erosion, ulcerations and lens cataracts. Several other eye lesions, including a tumor of the lens epithelium, retinal deformities, and hypertrophy and hyperplasia of the choroid gland, have also been seen. Internal lesions include hypertrophy, hyperplasia and growth deformities of gill tissues; neoplasms of the buccal, gills, gill cavities and fins; and inflammatory, necrotic, preneoplastic foci, neoplasms, macrophage aggregates in hepatic or pancreatic tissue. Pathological responses have been noted in kidney tissues and those of other internal organs as well. In an early laboratory study, fish exposed to contaminated Elizabeth River sediments began to die within seven to eight days while survivors exhibited cataracts, ulcerations, fin erosion, gill lesions, liver and pancreatic alterations, and lowered hematocrits and body weights. Other acute and chronic effects have been observed in more recent, controlled experiments.

In addition, the cellular immune system was found to be compromised in fish captured in the Elizabeth River and in those exposed to Elizabeth River sediments in the laboratory. Significant changes in the immune activity of kidney macrophages can provide information about recent exposure to environmental stress. Macrophages are an important part of the cellular immune system and function as the first line of defense by degrading foreign material including disease-causing agents. Fish macrophage responses to toxic chemicals, including chemotaxis, phagocytosis, pinocytosis, melanin accumulation and chemiluminescence (CL), have been investigated. The chemotactic, phagocytic and CL responses were depressed in several species of fish from the Elizabeth River which is highly contaminated with PAH, as compared to clean water control fish. Pinocytic activity and the accumulation of melanin, however, were elevated in Elizabeth River fish. Fish exposed to toxic pollutants in the laboratory showed similar changes in immune activity. The macrophage activities of Elizabeth River fish returned to normal after the fish were held in clean water for three weeks. It is anticipated that the gross and histopathological studies and immunological assay techniques currently under investigation will provide reliable bioindicators of the effects of environmental contamination on fish health.

IMPLICATIONS FOR RESOURCE MANAGEMENT

Because PAH are pollutants that are closely related to human activity, environmental concentrations are likely to increase as the population around the Chesapeake Bay grows. It is therefore imperative that the impact of these compounds is understood. The effect of these compounds on the health of the organisms of the Bay and the mechanisms by which they act must be understood in order that an appropriate strategy can be adopted to preserve the biota of the Bay. Furthermore, possible impacts of exposure of humans to contaminated water, sediments and biota must be known. Without knowledge of the effects of these chemicals, decisions made by the resource managers must be largely arbitrary. It is the aim of this research to reduce as much as possible the arbitrary element of this decision making process.

ANTICIPATED ACTIVITIES IN 1988-90

Plans are to concentrate the whole effort not on laboratory studies, but on a comprehensive analysis of the Elizabeth River environment. Fish (croaker, spot, oyster toads) will be sampled from five stations in the Elizabeth River and three control stations in the Nansemond River. We also will include Blue Crabs. All biota will be subjected to an analysis of metabolites in bile as well as the PAH body burden in liver tissue. We also will determine the mixed function oxidase levels and assess DNA damage. Gross pathology changes will be evaluated and comprehensive immunology studies performed. In its details, this program is still in the planning stage.

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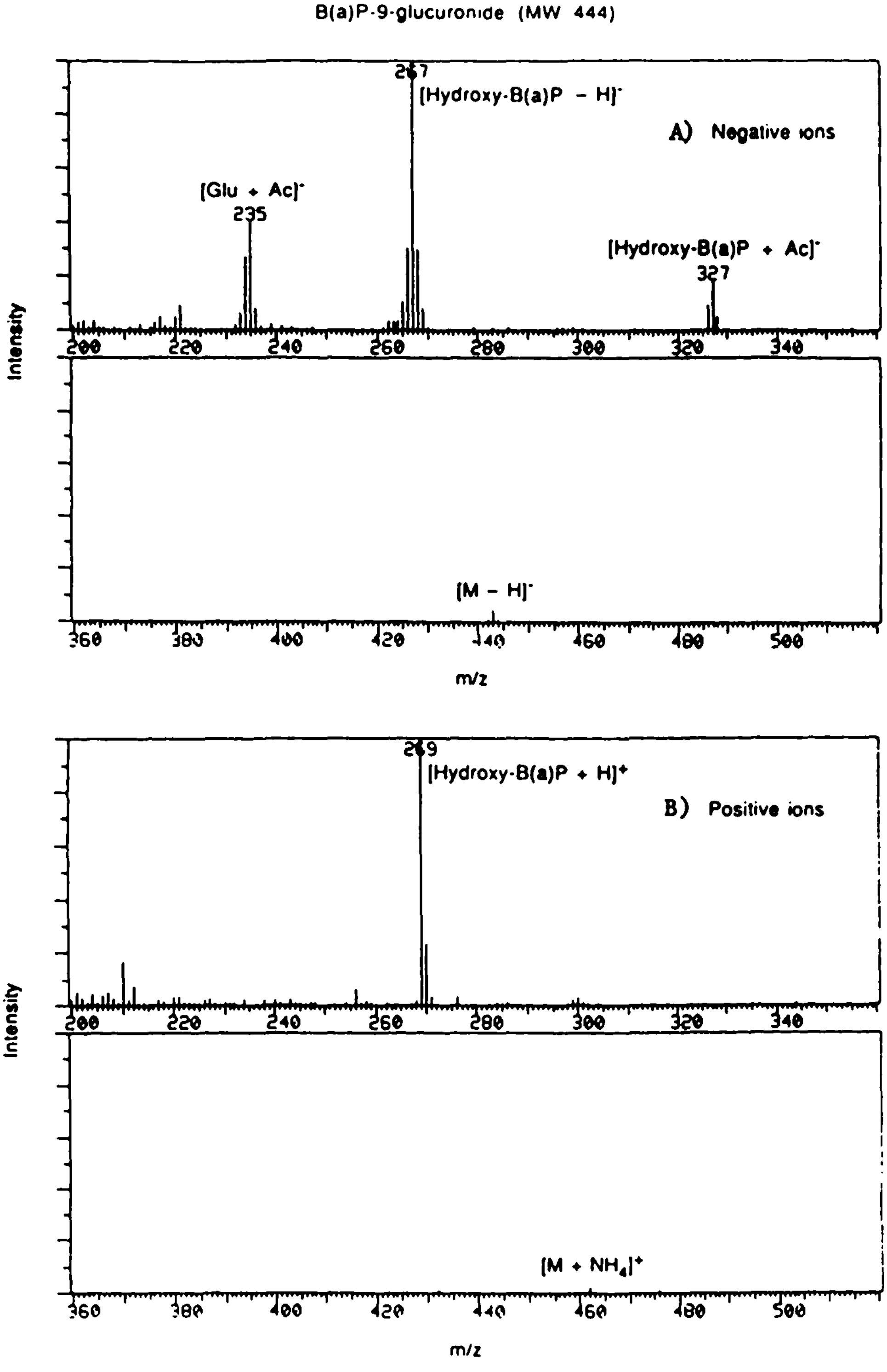


Figure 1. Mass spectrum of B(a)P-9-glucuronide derived from thermospray source (ammonium acetate added as buffer).

A. Negative ions. A molecular ion [M-H] is present, but has an abundance of only 2%. The aglycone fragment at mass 267 is due to the thermal decomposition of the molecule. Two other ions at mass 235 and 327 are adducts of thermal decomposition products with acetate ions from the buffer.

B. Positive ions. No molecular ion is indicated, but there is an adduct ion $[M+NH_4]^+$ with ammonium ions from the buffer. Again, the aglycone ion is the most intense fragment.

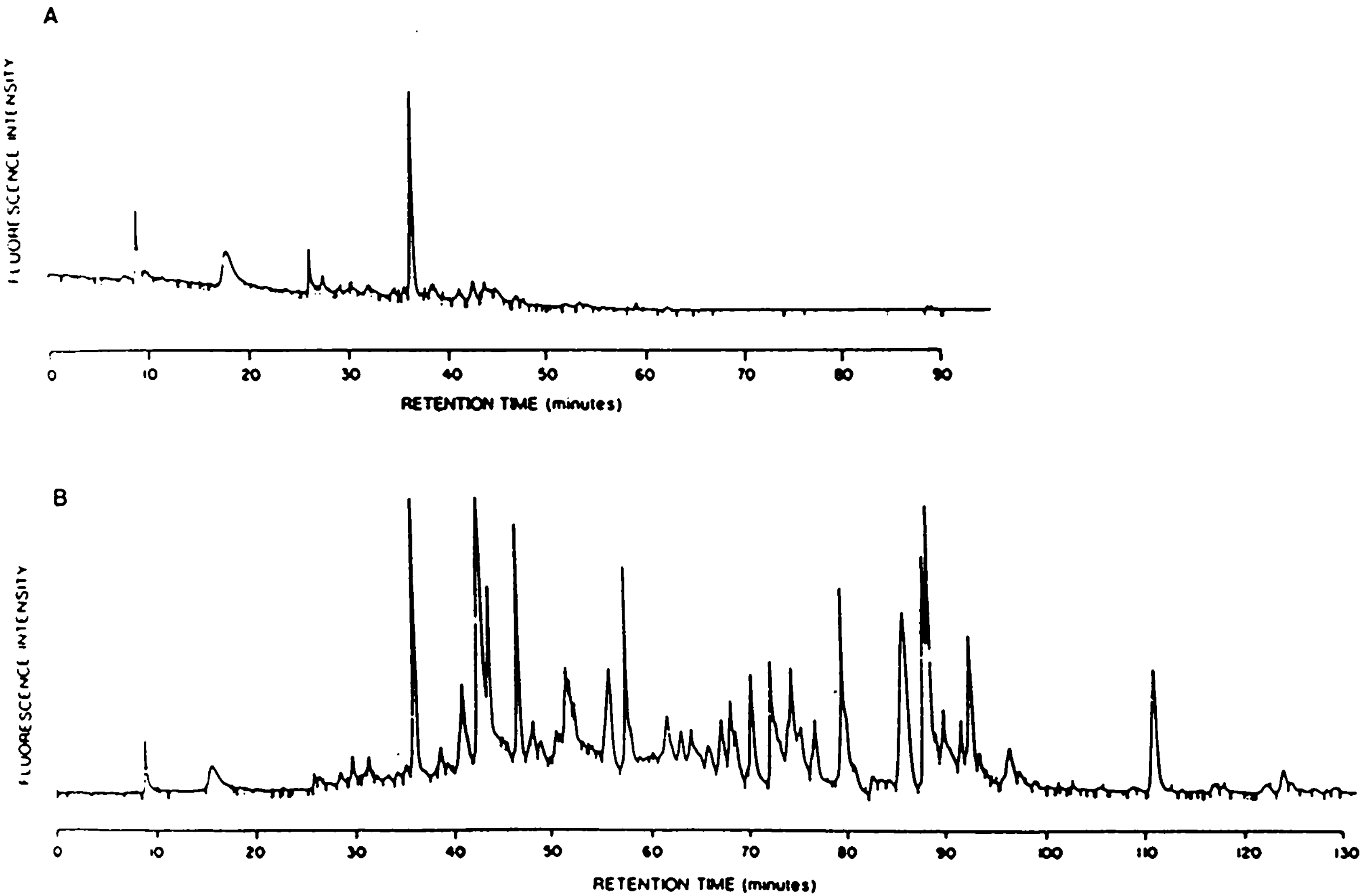


Figure 2. Chromatograms of bile of oyster toadfish (Opsanus tau) from A) Nansemond and B) Elizabeth Rivers, Virginia.

PROJECT 6

EARLY WARNING SYSTEM FOR CHLORINATED HYDROCARBONS IN SEAFOOD

Robert Edstrom
Robert J. Huggett, Ph.D.

EXECUTIVE SUMMARY

The objective of this research is to provide baseline information on chlorinated hydrocarbon concentrations in seafood harvested in Virginia waters. Chlorinated hydrocarbons are a ubiquitous class of chemicals which can be detrimental to public health and to various life stages of aquatic organisms. The chlorinated hydrocarbons include PCBs, pesticides and industrial compounds. These chemicals may affect the quality of those estuarine organisms which comprise Virginia's seafood resource.

Seafood samples were purchased from wholesale distributors located along the Chesapeake Bay and Eastern Shore of Virginia. Due to the Kepone fishing restrictions, it was difficult to acquire commercial seafood samples from the James River. Samples collected by the State Water Control Board from this river were therefore used.

Fish samples from the James River contained higher levels of PCBs and chlordanes than fish samples from the lower Chesapeake Bay or Eastern Shore of Virginia. Oyster and clam samples were collected from the James River and analyzed. The clam samples generally contained higher PCB and chlordane concentrations than the oyster samples.

A compound of unknown structure and origin has been found in numerous samples from the James River. Efforts are being directed toward the isolation and identification of the unknown compound.

PROJECT DESCRIPTION

The objective of this research is to provide baseline information on chlorinated hydrocarbon concentrations in seafood harvested in Virginia waters. This information will be integrated with elements of on-going monitoring and research studies to produce a comprehensive monitoring program. A unique aspect of the Early Warning System design is the capability to track unidentified compounds in seafood samples. This can be followed by efforts to identify these unknown compounds and determine if a potential threat to public health exists.

The analysis of seafood samples during the 1984-1986 Biennium indicated low levels of PCBs, chlordanes and other pesticides in seafood from the Rappahannock River, York River and the middle Chesapeake Bay. Higher concentrations of PCBs ($\geq$ 2.0 ppm) and chlordanes were found in bluefish and grey trout samples from the lower Chesapeake Bay and lower James River during the fall of 1985. The PCB composition patterns of these fish samples suggested a different source of PCBs for the lower James River and lower Chesapeake Bay samples than for the samples from the York River and the middle Chesapeake Bay.

RESULTS/DISCUSSION

The objective of the Early Warning System for the 1986-1988 biennium was to focus on the sampling areas which indicated elevated chlorinated hydrocarbon concentrations in the biota during 1984-1986. The lower Chesapeake Bay and lower James River samples contained the highest concentrations during the first biennium of the project. The James River was of principal concern because of the sites of industrialization associated with the river.

The fish sampled from the lower Chesapeake Bay were the grey trout (*Cynoscion regalis*) and the bluefish (*Pomatomus saltatrix*). The fish sampled from the James River were the grey trout, bluefish, striped bass (*Roccus lineatus*), white perch (*Morone americana*) and eel (*Anguilla rostrata*). Bluefish were collected from the ocean-side of the Eastern Shore during October 1986. Oysters (*Crassostrea virginica*) and clams (*Rangia cuneata*) were collected from the James River during October of 1986. The number of seafood samples analyzed during the 1986-1988 biennium totaled 236.

The fish samples from the Eastern Shore of Virginia contained low levels of PCBs, chlordanes and other pesticides. The mean concentration of PCBs in these fish samples was 0.2 ppm (Table 1).

The concentrations of PCBs and chlordanes in fish samples from the lower Chesapeake Bay for 1986 were lower than the comparable samples from

1985. The mean concentration of PCBs for grey trout and bluefish for the lower bay were <0.5 ppm.

The bluefish and grey trout samples collected during 1986 from the lower James River contained levels of PCBs and chlordanes similar to those found in the same species in 1985. The highest PCB concentrations in bluefish were in the September sampling. The highest PCB concentrations in grey trout were in the October 1986 sampling.

Striped bass samples from the James River contained PCB concentrations less than 2.0 ppm. White perch and eel from the James River were also analyzed and contained PCB concentrations less than 2.0 ppm. The white perch and 1986 eel samples were low in chlordanes, however the chlordane concentrations in 1987 eel samples were higher.

Oysters, Crassostrea virginica, and clams Rangia cuneata, were collected during October of 1986 in the James River. The oyster samples generally increased in PCB and chlordane concentrations with increasing distance upstream. The clam samples generally contained higher PCB and chlordane concentrations than the oyster samples. The clams sampled from the 74 kilometers post contained the highest concentrations of PCBs and chlordanes of all stations sampled in the river.

A compound of unknown structure and origin has been found in numerous samples from the James River. Forty-five percent of all fish samples from the James River which were analyzed during the 1986-1988 biennium appear to contain the unknown compound. Figure 1 shows a comparison of two gas chromatograms. The top chromatogram is a fish sample without the unknown and the bottom chromatogram is a fish sample with the unknown.

Extensive time and effort have been spent developing techniques to isolate the unknown compound from the sample matrix in sufficient quantity for mass spectrometric analysis. Efforts are continuing in this direction, and a timely conclusion to the identity of the unknown compound is expected.

IMPLICATIONS FOR RESOURCE MANAGEMENT

The James River fish analyses have historically demonstrated increasing levels of chlorinated hydrocarbons in fish. It may be, with this information, that the tidal James River area will require a more complete assessment of point and non-point sources of pesticides and industrial compounds.

Highly industrialized sites on the James River are potential sources of contamination which may endanger the viability and quality of the various seafood populations. Early detection and appropriate corrective procedures will help reduce accidental impacts by industry on the James River estuary.

ANTICIPATED ACTIVITES FOR 1988-1990

Activities for the next biennium will include a continuing characterization of fish from the James River. A continuing characterization of the seafood from the James River is important to estimate the impacts of the various types of chlorinated compounds on the James River biota.

Efforts to identify the unknown compound which has frequently appeared in fish samples from the James River will continue. New techniques will be utilized to isolate the compound from the interferences of the sample matrix. The mass spectrometric instrumentation and state-of-the art analytical techniques available in-house will be an invaluable aid in identification of this compound.

Upon the identification of the unknown compound, a sample preparation and analysis methodology will be developed. The scope of the contamination and impact on the James River biota, if any, will be assessed.

The appropriate regulatory agencies will be informed of the results of this investigation.

Table 1

Mean Values of Seafood Data

Month/yr.	Wt. (gm)	ΣPCB (ppm)***	Range***	ΣChlordanes (ppb)***	Range***	Source	Sample (n)
June/'86	850	0.3	0.1-0.4	15.1	6.7-26.1	James River Z-A*	Bluefish (10)
July/'86	177	0.7	0.1-1.5	11.8	N.D.-43.5	James River Z-A*	Spot (10)
August/'86	432	0.1	<0.1-0.2	1.6	N.D.-4.7	Lower Bay	Trout (10)
August/'86	311	<0.1	<0.1-0.2	<1.0	N.D.-3.8	Lower Bay	Bluefish (4)
Sept./'86	576	1.3	0.7-2.1	10.2	N.D.-30.7	James River Z-A*	Bluefish (9)
Sept./'86	598	1.6	0.1-3.3	31.5	2.4-74.4	James River Z-B*	Bluefish (10)
Sept./'86	458	1.3	1.1-1.4	12.9	8.5-18.9	James River Z-A*	Trout (3)
Sept./'86	438	0.5	0.4-0.6	18.2	17.0-19.4	James River Z-C*	Eel (3)
Sept./'86	421	0.2	<0.1-0.6	9.0	N.D.-32.0	Lower Bay	Trout (14)
Sept./'86	335	0.4	<0.1-1.4	30.9	N.D.-81.4	Lower Bay	Bluefish (13)

Table 1

Mean Values of Seafood Data

Month/Yr.	wt. (gm)	ΣPCB (ppm)***	Range***	ΣChlordanes (ppb)***	Range***	Source	Sample (n)
Oct./'86	522	0.8	0.1-2.1	23.7	N.D.-78.7	James River Z-A*	Bluefish (10)
Oct./'86	538	1.6	0.5-3.2	33.2	7.4-88.7	James River Z-B*	Trout (9)
Oct./'86	395	0.2	<0.1-0.5	12.5	2.6-41.2	Lower Bay	Bluefish (10)
Oct./'86	491	0.2	<0.1-0.9	9.2	N.D.-47.8	Lower Bay	Trout (10)
Oct./'86	920	0.2	<0.1-0.5	12.9	N.D.-35.6	Eastern Shore	Bluefish (22)
Dec./'86	1460	0.9	0.5-1.9	26.0	11.1-54.0	James River Z-C*	Striped Bass (9)
Feb./'87	1028	1.0	0.6-1.6	32.5	20.6-66.0	James River Z-C*	Striped Bass (10)
May/'87	885	0.2	0.1-0.4	8.2	3.5-15.7	Rappahannock River	Bluefish (6)

Table 1

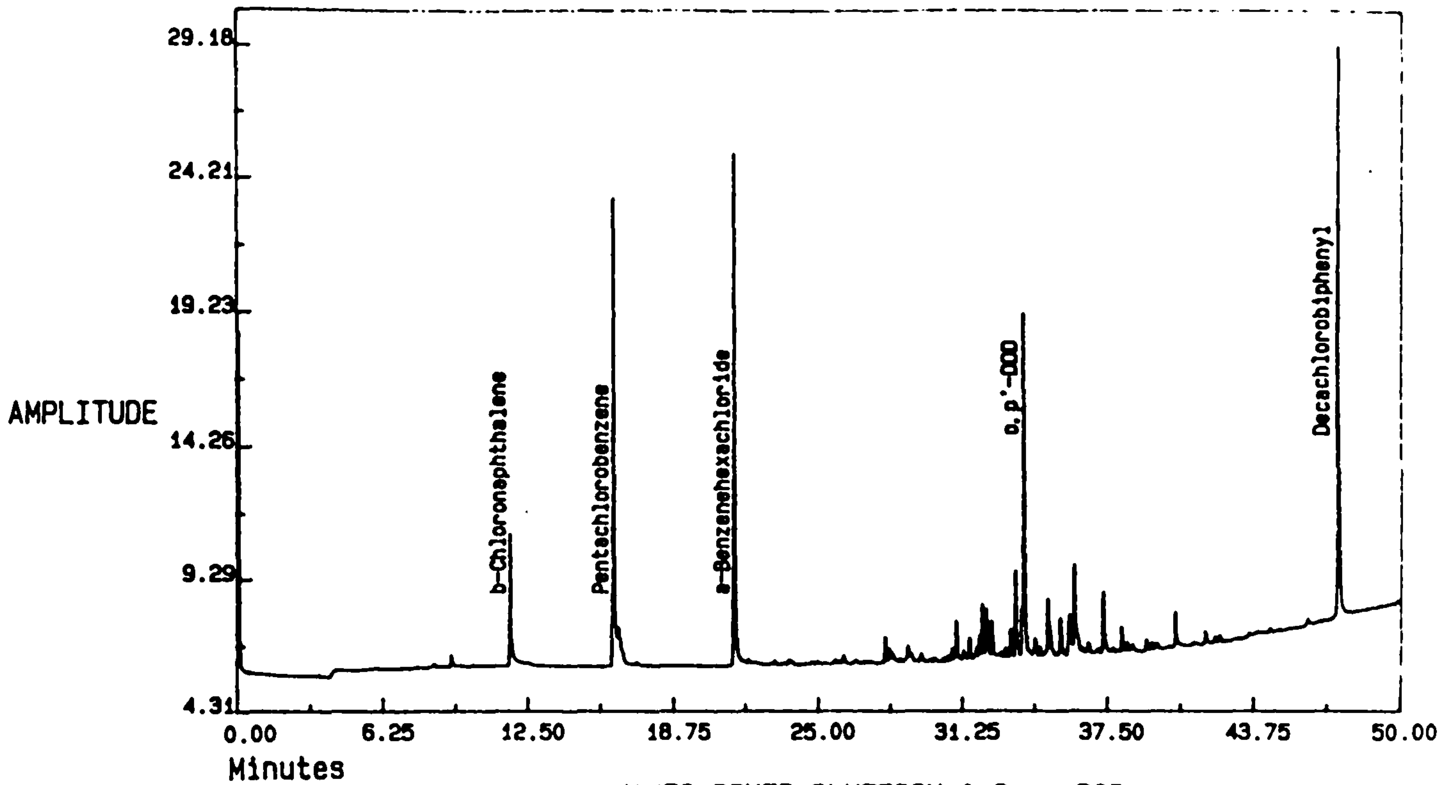
Mean Values of Seafood Data

Month/Yr.	Wt. (gm)	ΣPCB (ppm)***	Range***	ΣChlordanes (ppb)***	Range***	Source	Sample (n)
Aug./'87	129	0.3	0.1-0.6	11.5	5.8-33.1	James River Z-C*	White Perch (10)
Sept./'87	378	0.6	0.2-1.7	59.8	20.2-145.9	James River Z-A*	Eel (10)
Dec./'87	565	0.3	<0.1-0.6	25.6	7.6-51.7	James River Z-C*	Striped Bass (9)
Feb./'88	1520	0.7	0.1-1.3	56.3	20.5-100.3	James River Z-C*	Striped Bass (9)
Feb./'88	538	0.4	0.2-0.8	12.0	N.D.-26.8	James River Z-B*	Striped Bass (10)

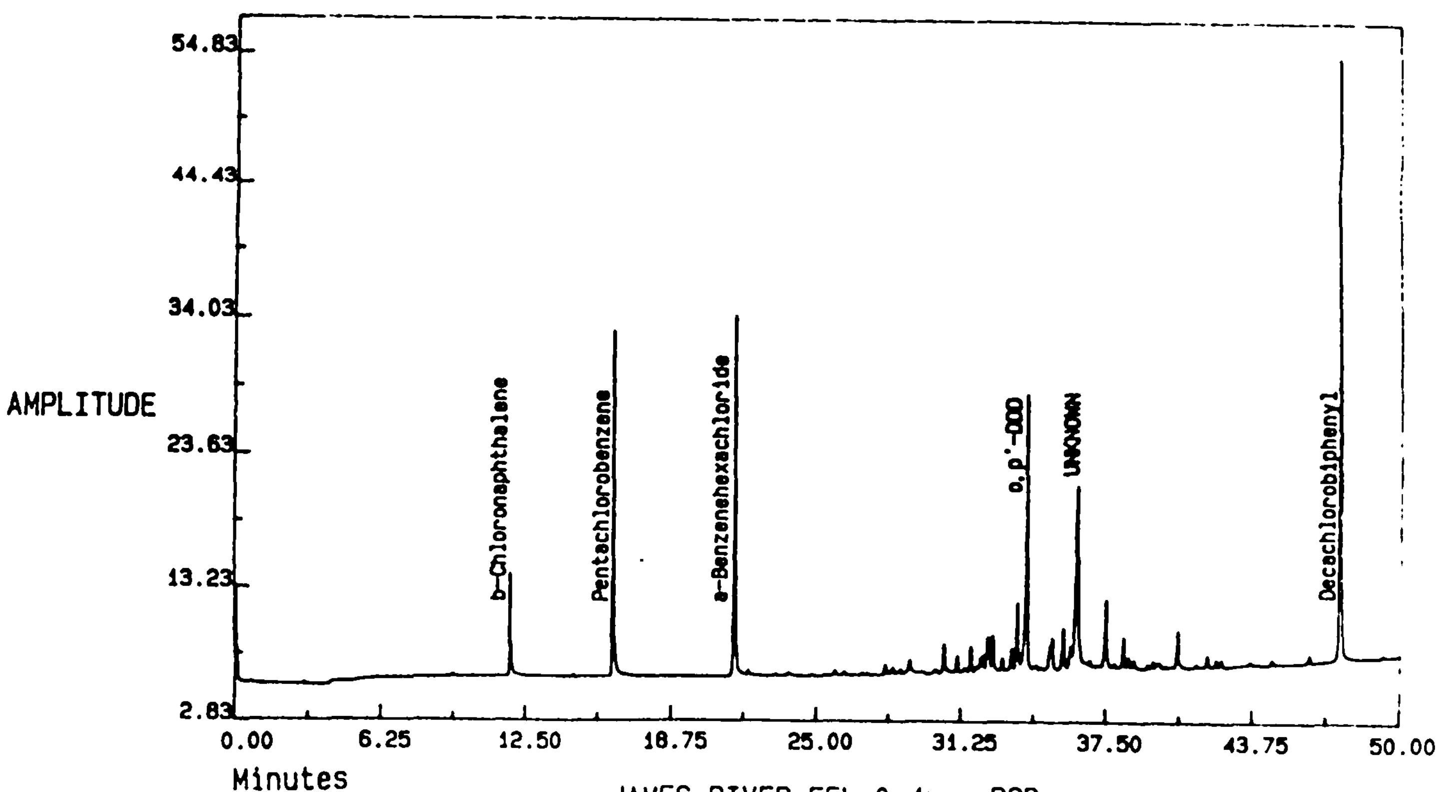
Month/Yr.	ΣPCB (ppb)**	Range**	ΣChlordanes (ppb)**	Range**	Source	Sample
Oct./'86	192.0	79.6-521.2	13.1	3.2-32.0	James River	Oyster
Oct./'86	1104.4	378.1-3848.0	61.9	18.2-242.3	James River	Clam

N.D.= None Detected
Z-A = Zone A
Z-B = Zone B
Z-C = Zone C
* = Refer to Figure 2.
** = Concentrations based on dry weight of composite samples.
*** = Concentrations based on wet weight.

Figure 1.

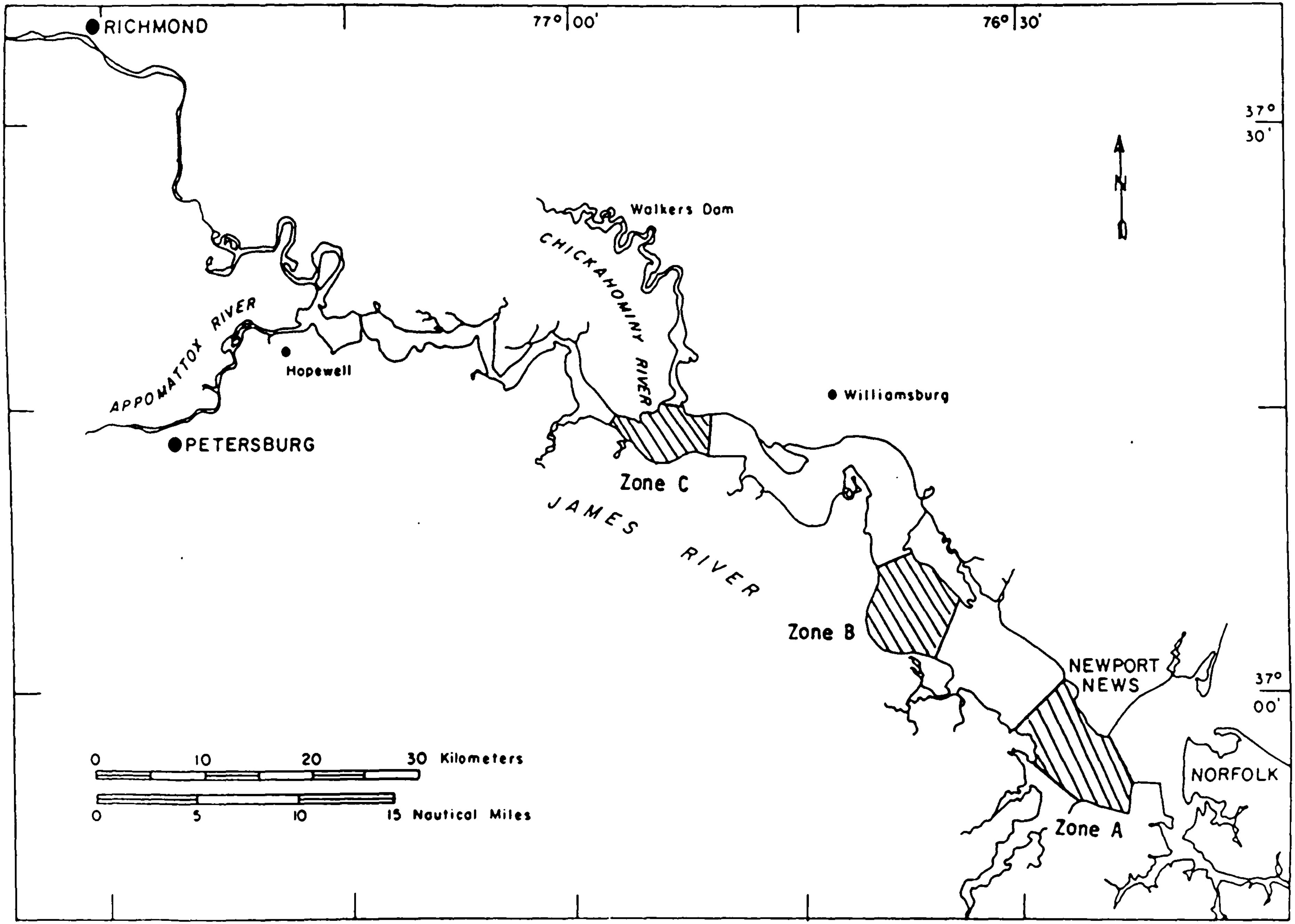


JAMES RIVER BLUEFISH 0.3ppm PCB



JAMES RIVER EEL 0.4ppm PCB

Figure 2.



RICHMOND
77° 00'
76° 30'
37° 30'
N
Walkers Dam
CHICKAHOMINY RIVER
APPOMATTOX RIVER
Hopewell
Williamsburg
PETERSBURG
Zone C
JAMES RIVER
Zone B
NEWPORT NEWS
37° 00'
NORFOLK
Zone A
0 10 20 30 Kilometers
0 5 10 15 Nautical Miles

PROJECT 7

SUBMERGED AQUATIC VEGETATION INITIATIVE

Kenneth A. Moore
Robert J. Orth, Ph.D.

EXECUTIVE SUMMARY

During the past two years, over 30 acres of SAV have been transplanted using whole plant and seed techniques in three estuarine river systems. Investigations have evaluated the effectiveness of several different techniques in an effort to develop the most feasible and economical methods applicable to the Chesapeake Bay system. Other studies have developed water quality thresholds for the dominant SAV species in the region and investigated the single and interactive effects of the most important factors (turbidity and the excess nutrients) thought to have the greatest impact on SAV growth and survival.

PROJECT DESCRIPTION

Submerged aquatic vegetation (SAV) is an important natural resource in the Commonwealth of Virginia's Chesapeake Bay waters. Not only do SAV beds support a diverse assemblage of important organisms, from waterfowl to blue crabs, but they improve water quality by both filtering out suspended particles and absorbing excess nutrients. In addition, they baffle the erosive force of wave action on the upland, thus reducing shoreline erosion. Lush stands of vegetation formerly covered many shallow water areas in the lower reaches of the Potomac, Rappahannock, Piankatank and York rivers, as well as the eastern and western shorelines of the Bay itself. Today, although there has been some recent regrowth in areas, only a fraction of these once extensive meadows remain. The presence of SAV beds has been used to characterize relatively healthy, natural systems; and it has been found that when systems are degraded, it is the SAV habitats that are many times the first to disappear.

Goals of the SAV Program are:

1. To replant submerged aquatic vegetation in areas of Virginia's tidal waters that once supported dense beds of vegetation;

2. To develop the most effective and efficient methodologies for transplanting eelgrass in restoration and mitigation projects;

3. To determine the factors that limit and control the distribution and abundance of SAV; and

4. To provide criteria for the development of water quality standards necessary for SAV conservation and enhancement.

During the 1986-1988 period, over 15 acres of SAV were transplanted at selected sites per year. Transplantings were accomplished by technical personnel assisted by volunteer groups using both whole plants and seeds of eelgrass, the dominant SAV species in the region. Results indicate that SAV can be successfully transplanted into many areas where water quality is marginally suitable for regrowth, but still not in many formerly vegetated sites. Techniques for more efficient transplantings are still being developed, particularly with the use of seeds. Water quality criteria for the characterization of suitable SAV areas have been developed based upon estuarine environmental monitoring and the response of transplanted vegetation. To complete our comprehensive approach to the understanding of SAV recovery, the interactive effects of various potential environmental limiting factors are being investigated in SAV greenhouse experiments.

1986-88 RESULTS

During the fall of 1986 and 1987, over 30 acres of SAV were transplanted into the lower York, Piankatank, and Rappahannock Rivers. Techniques involved the use of whole plants as well as the use of seeds collected from mature reproductive shoots the previous spring.

During the fall of 1986, whole plants were transplanted to nine sites using several techniques. The effect of planting unit density was investigated by transplanting units at 0.5 m, 1.0 m and 2.0 m intervals in replicated plots in the York and Rappahannock rivers. The purpose of this experiment was to determine if transplant survival could be improved while at the same time decreasing the man-hours of effort necessary to revegetate a large area of bottom. Results suggest that initial survival is enhanced by decreasing the spacing between planting units. Transplanting was undertaken by planting a number of sites with patches of planting units separated by unplanted bottom as opposed to covering an entire area planting units at uniform spacing. Such an approach provides rapid cover and, thus, dense, stable patches up to five meters in diameter. Filling in the intervening open areas can then occur by natural seedling production. Of the planting units transplanted in 1986, survival ranged from 25 to 95 percent the following spring. As with most of the transplanting efforts, upriver sites subject to poorer water quality had the poorest success rates.

In the fall of 1987 five sites in the York River were transplanted using whole plants. These transplants, combined with water column monitoring, were used to determine the potential SAV regrowth. At 14 sites in the York, Piankatank, and Rappahannock rivers, nearly 4.5 million seeds were transplanted during October and November, just prior to their natural germination period. A prototype mechanical seed planter was used in many areas. However, at a number of sites replicate experimental plots were set up to compare the effectiveness of several different methods of seed planting, as well as the effectiveness of enhancing areas of widgeon grass with the more dominant and persistent eelgrass species. Additionally, the transplanting of over two acres of eelgrass using whole plants was accomplished with the assistance of personnel from a number of state and federal agencies including the Council of the Environment. The objective of this project was to mitigate the loss of SAV to be destroyed through the shoreline disposal of dredged material generated by the dredging of the Cape Charles entrance channel.

Based on the results of the environmental monitoring program, levels of certain important, water column, environmental variables which charactrize eelgrass habitat in the lower Chesapeake Bay were determined. In this study, a gradient of sites in shoal areas along the York River were sampled biweekly and the results compared to SAV growth in either natural or transplanted beds. Differences in SAV production between sites which do and do not support natural stands of vegetation correleted with differences in water quality most frequently during the spring and fall when the plants are growing at greater than 50 percent of their maximum annual rate. From this information water column thresholds of suitable eelgrass habitat were determined to be: total suspended solids (15 mg/1); PAR light attenuation coefficient (2 m^{-1}); total inorganic nitrogen (20 ug-at/1); orthophosphate (1 ug-at/1); chlorophyll (15 ug/1). Water quality data obtained from the Virginia SWCB tributaries monitoring program were compared to monitoring data from the SAV shoal stations for the York River. Increases in dissolved inorganic nutrient species were observed from midchannel to shoal stations for similar reaches of the river. This preliminary analysis suggests that levels of certain nutrients may be elevated in shoal areas and that mid-channel data may not be representative for evaluation of potential SAV habitat.

Laboratory studies were initiated in 1987 to further determine the role of specific environmental factors in regulating eelgrass distribution and abundance in lower Chesapeake Bay. Presently, average nutrient concentrations at field sites which fail to support vegetation are 2 to 3 times higher than those at sites which support vegetation. Nutrient additions often promote excessive growth of algae on plant surfaces which can reduce the light available for macrophyte photosynthesis, limit the diffusion of carbon to leaf surfaces, and damage epidermal cell walls. Although grazing by invertebrates has been observed repeatedly to control the growth of algae on plant surfaces, the ability of such grazing to effectively limit algal growth during periods of nutrient enrichment is unknown. Therefore, one series of experiments was designed to test the interactive effects of nutrient enrichment and invertebrate grazing activity on eelgrass production. Experiments were done seasonally (spring, summer, and fall) in replicated aquaria equipped with flow-through seawater and internal water circulation systems. Nutrient additions simulated enrichment levels observed in the lower bay, and grazing invertebrates were applied at field densities. Results will suggest whether the level of cultural euthrophication found in lower Chesapeake Bay can inhibit or preclude eelgrass growth and survival.

A second series of experiments addressed the relationship between water column turbidity and eelgrass production. Flow through aquaria containing eelgrass were shaded with different densities of screening to simulate light levels observed in the field. Of particular interest was the effect of light reductions on plant carbohydrate storage, since sufficient accumulation of energy reserves during favorable growth conditions may enable the plants survive otherwise limiting periods during the summer.

IMPLICATIONS FOR RESOURCE MANAGEMENT

Transplanting SAV provides for direct revegetation of denuded bottom and provides for a source of propagules in areas where revegetation is limited by natural disperal mechanisms. It also assists in developing expertise necessary for the Commonwealth to evaluate mitigation and compensation proposals. Replacing or enhancing seagrass meadows is a difficult task. With increasing development pressures on the tidewater shorelines, difficult decisions will have to be made concerning a wide variety of projects that will affect SAV, ranging from nourishing beaches to dredging navagation channels.

The use of transplants allows us to evaluate the factors limiting SAV regrowth in many of Virginia's tributaries. Transplants can be used to test the relationships between water quality and SAV survival and to assist the federal and state regulatory agencies in developing water quality criteria based on habitat requirements, an important and sound approach.

ANTICIPATED ACTIVITIES IN 1988-1990

During this biennium the use of seeds as a tool for efficient transplantation of SAV in the lower Bay will be investigated and SAV will be transplanted into previously vegetated estuarine areas using this method. To further these objectives the seed germination process will be investigated in the laboratory and the field. The enhancement of widgeon grass beds with the more dominant and persistent eelgrass species will be undertaken and studied. The specific factors limiting SAV regrowth will be further evaluated and the SAV water quality threshold criteria recently developed will be tested in several different river systems.

Listing of Papers, Theses, Dissertation

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Ryer, C. H., J. van Montfrans and R. J. Orth. In Prep. Spatial and temporal partitioning of molting activity by blue crabs in seagrass and marsh creek habitats.

Orth, R. J. and J. van Montfrans. In Prep. Latitudinal gradients in the utilization of shallow water habitats by blue crabs.

Sadler, P. W., J. van Montfrans and R. J. Orth. In Prep. The spatial and temporal distribution of Callinectes sapidus megalopal settlement in the York River.

Olmi, III., E. J., J. van Montfrans, R. N. Lipcius and R. J. Orth. In Prep. Patterns of post larval availability and settlement in the blue crab: Effect of time, space and habitat.

van Montfrans, J., C. Peery, and R. J. Orth. In prep. Variation in postlarval bluecrab settlement on artificial substrates in the York River, Virginia.

Moore, K. A., H. A. Neckles, and R. J. Orth. In prep. Relationships between *Zostera marina* L. and habitat in the Chesapeake Bay region. I. Plant growth and production.

Moore, K. A., H. A. Neckles, R. L. Wetzel and R. J. Orth. In prep. Relationships between *Zostera marina* L. and habitat in the Chesapeake Bay region. II. Environmental factors.

PROJECT 8

OYSTER HATCHERY AND REMOTE SETTING OPERATIONS

Michael Castagna

Executive Summary

Research continues on remote setting of hatchery-reared oyster larvae. Post-set oysters are extremely vulnerable to predation until they attain a size of about one inch in length. Experiments on several nursery methods to grow spat to a large enough size to insure good survival are being carried out.

Hatchery production is expected to be about 300 million eyed larvae per year. By mid-July 1988, 68 million eyed larvae have been distributed to participants collaborating with VIMS in field experiments.

Project Description

The oyster industry in Virginia has suffered a drastic decline in production over the last 35 years despite annual state-supported repletion and transplanting programs. This decline in production has been blamed on a number of factors; perhaps the most commonly agreed upon factor has been the outbreak of oyster diseases such as *Minchinia nelsoni* and *Perkinsus marinus*. Other factors contributing to the decline may be the deterioration of overall water quality within the Bay and influx of man-made toxic chemicals.

Under these adverse conditions, the few remaining stocks are often overfished.

At the present time there are over 7,000 man-made organic chemicals found in nature, and many of these find their way to the Bay. Despite the fact that juveniles and adults survive in some chemically-tainted water, the sub-lethal loads of chemicals often prevent gametogenesis or embryogenesis of species which have external (in the water column) fertilization and development.

To further compound industry's problem, Virginia oyster packers are now importing oysters from other states, including the Japanese oyster from the Pacific coast, for resale to their customers. Estimates run to about 300,000 gallons of imports for resale last year. It may be only a matter of time before these out-of-state suppliers bypass the Virginia packers and ship directly to their customers.

It is apparent that it is time for innovation if the Virginia oyster industry is to continue.

A production oyster hatchery was established to produce eyed larvae to test remote setting of oysters. The west coast oyster industry has been using this technology for a number of years with the Japanese oyster *Crassostrea gigas*. The technique had not been proven with the Virginia oyster *Crasssostrea virginica*. The goals of the hatchery effort are four-fold: 1) to test the feasibility of supplementing natural oyster production with a production hatchery; 2) to evaluate the cost of remote setting oyster spat and compare to the costs of traditional shell planting and seed harvesting; 3) to test the feasibility of improving oyster stocks by spawning stock selection; and 4) to test new methods of protecting, hardening and growing spat to a size adequate for transplanting to growing areas.

RESULTS AND DISCUSSION

Facilities Construction and Production

An existing building on the Gloucester Point campus was converted into a production-type hatchery. A pump house and pipe chase were constructed, and a dual seaater system with replicate pumps, plumbing and drains was established throughout the hatchery. Tanks, troughs and water treatment equipment were installed, and by September 1985 the system was operational and seven groups of oysters were spawned, producing eight million oyster larvae.

In 1986 oysters were collected and placed in our own conditioning system where they were ripened before the normal season and spawned at leat four months early. Production in 1986 was over 400 million eyed larvae.

Extension Service

VIMS marine extension agents have met with industry representatives to explain the remote setting process. Arrangements have been made for cooperative tests or demonstrations of this method.

For on-site setting we have constructed two trailer-mounted, portable tanks that are completely self contained. We pull these to the user's dock, fill the tank with Bay water at his property, fill the shell bags with his shells and set a batch of eyed larvae at the site. The user needs only to furnish an invitation, an electrical outlet for an aerator and cultch shells.

Post Set Hardening and Nursery

Only a limited amount of information is in the literature concerning the survival of post set oysters. From the time oysters set until they are big enough to transplant, they grow from the size of a period (.) until they are about one and one-half inches in length. During this time they are preyed upon by natural predators, smothered, poisoned and suffer through many of the difficult environmental factors found in an estuary. A program to develop nursery techniques to improve survival has been underway.

Preliminary experiments have shown that the majority of oyster mortalities take place when the oysters are smaller than one inch in length. Oysters set on crushed oyster shell (chicken grit) are being grown in a pumped upwelling system. This technique seems to have many advantages. Using crushed shell (mini cultch) reduces the amount of shell necessary for a commercial set from tons of shell to only about 100 lbs. of shell grit. This also reduces handling and trucking of large amounts of cultch. Some types of artifical cultch are also being tested. Other types of less intensive nurseries are also being examined, such as a trestle and tray system and intertidal trays.

Laboratory and field tests of predation rates for various predators are also underway.

In addition to the remote setting and nursery experiments, stock selection experiments are underway. If successful, this may help develop a faster growing or more disease-resistant strain of oyster.

RELEVANCE TO MANAGEMENT OF RESORUCES

This program will evaluate using remoting setting of hatchery-reared oysters to supplement the harvest of natural oyster seed. It will evaluate the benefits of using selected broodstock to develop selected lines of oysters. It will also develop and evaluate new methods of growing oyster spat to seed size large enough for planting.

ANTICIPATED ACTIVITIES IN 1988-90

The production of eyed larvae and set spat will continue with a target of 300,000,000 eyed larvae for calendar year 1988.

Further demonstrations of remote setting are planned for this summer and fall, and all current inquiries from the oyster industry will be answered.

A continual upgrading of techniques and equipment in the hatchery will improve the eyed larval production to a scale that could have a significant impact on the industry.

PUBLICATIONS RESULTING FROM PROJECT

A paper entitled "Penetration of Cultch Mass by Eyed Larvae of *Crassostrea virginica*" was presented at the 80th Annual Meeting of the National Shellfisheries Association, Inc., in New Orleans, Louisiana.

PROGRAM II. THREE-DIMENSIONAL MODEL

PROGRAM II

THREE-DIMENSIONAL MODEL

John Hamrick, Ph.D.
Albert Y. Kuo, Ph.D.

EXECUTIVE SUMMARY

A three-dimensional, time varying estuarine hydrodynamics model has been acquired and is currently being modified and applied to the James River. The anticipated resulting operational model will provide a powerful tool for assessing the environmental impacts of physical and regulatory changes on the James River and, ultimately, other Virginia estuaries.

PROJECT DESCRIPTION

Research in estuarine hydrodynamics over the last two decades has established the consensus that estuarine circulation and the associated transport of dissolved and suspended materials is strongly three dimensional in space and highly variable in time. Likewise, studies of the movement of water borne contaminants and of living resources, such as oyster larvae, have revealed the significant and complex role played by estuarine circulation processes. The continuing management of water quality and living resources in the estuarine environment requires that the impact of proposed physical and regulatory changes be predicted and assessed as a key role in planning and decision making processes.

Mathematical modeling of circulation and transport provides a powerful tool for assessing the impact of changes in the estuarine environment. However, for a mathematical model to be useful for a number of applications it must be capable of fully resolving the three-dimensional spatial structure of circulation and transport over a sufficiently long-time interval to Distinguish significant trends in the system's behavior. Fortunately, over the last decade, major advances in computational estuarine hydrodynamics software and computer hardware have brought three-dimensional, time varying modeling to a state of practical reality, with a number of models available for general applications.

The objectives of this project, which began in the 1986-88 biennium, are: to acquire a general three-dimensional estuarine hydrodynamics model for use by the Virginia Institute of Marine Science in its applied research and advisory activities, and to apply the model to the James River Estuary with particular attention directed toward the study of three-dimensional transport of oyster larvae and of dissolved and suspended contaminants.
It is anticipated that the three-dimensional model will be fully operational during the 1988-90 biennium for the James River and of immediate usefulness in assessing proposed physical and regulatory changes. It is also anticipated that the model will be readily adaptable to other major estuaries including the York and Rappahannock Rivers.

RESULTS AND DISCUSSION

To meet the objectives of the project, a number of major activities began in 1986-87. A contractural agreement was made with Dr. Y. P. Sheng of the University of Florida to apply the CH3D three-dimensional hydrodynamic model to the James river, to install intermediate and final operating versions of the model on VIMS computers, and to train VIMS staff in the use of the model. The CH3D model is the latest boundary fitted grid version of the CELC3D model developed by Dr. Sheng for the U.S. Army Corps of Engineers. The CH3D model has also been selected by the Corps of Engineers and the US Environmental Protection Agency for use in their current model study of the Chesapeake Bay. Two additional staff members, a faculty level scientist and a staff level scientist joined the VIMS Physical Oceanography Division with primary responsibilities being the participation in this project, as collaborators with Dr. Sheng and the ultimate ongoing application of the model to the James River and other Virginia estuaries. Finally, a Digital Equipment Corporation MicroVAX II computer and a CSPI Mini Map Array Processor were purchased for dedicated use in running the CH3D model.

Dr. Sheng and his associates at the University of Florida began work on the project in late 1986, and by mid-1987 the two new staff members had joined VIMS and the above described computer hardware had been installed. By the mid-1988 end of biennium, considerable progress toward meeting the project objectives have been made. The CH3D model has been extensively modified by Dr. Sheng and his associates to enhance model performance and correct a number of unanticipated difficulties encountered in the application to the complex geometry of the James River. The currently operating version of CH3D has demonstrated the model's three-dimensional capabilities in predicting tidal elevations and circulation on a large scale in a time varying fashion. The current version of the model and associated grid generation and preprocessing programs have been installed at VIMS on the Micro VAX II computer. The two VIMS staff members are currently working with this version of the model and collaborating with Dr. Sheng in further modifications to the model which should result in completing the large scale calibration demonstrating the model's ability to predict the three-dimensional salinity distribution and mean circulation.

RELEVANCE TO RESOURCE MANAGEMENT

In its first two years, this project has demonstrated the reality of applying a three-dimensional, time varying hydrodynamic model to the study of estuarine circulation and mass transport. The application of the 3D model to the James River and the encouraging preliminary results is of particular relevance to estuarine resource management. Of the Virginia tributaries to the Chesapeake Bay, the James River is likely the most hydrodynamically complex, the most developed and utilized and the most productive in terms of seed oysters, an important natural resource. It is anticipated that when the 3D model is fully operational for the James River by 1990, it will be a powerful tool for gaining insight into the complex movement of contaminants and oyster larvae and assessing the impact of physical and regulatory changes on such movement and the distribution of contaminants and living resources.

ANTICIPATED ACTIVITIES AND RESULTS - 1988-90

During the coming biennium this project will be completed and it is anticipated that the overall objective of an operational general three-dimensional estuarine hydrodynamic model which has been specifically applied to the James River will be achieved. The major remaining activities include: additional modifications to the model to improve performance using boundary fitted grids; the completion of the large scale calibration and verification, demonstrating the model's ability to predict three-dimensional tidal and mean circulation and the distribution of salinity on a large scale; the mesoscale scale or intermediate scale calibration and verification demonstrating the model's ability to predict certain localized processes; and a series of long-term model simulations to track particle trajectories or pathways through the James River system. All of these activities will be conducted as a collaboration between VIMS staff and Dr. Sheng and his associates at the University of Florida.

PROGRAM III. WETLANDS MANAGEMENT

PROGRAM III

WETLANDS MANAGEMENT

Gene Silberhorn, Ph.D.

EXECUTIVE SUMMARY

The Virginia Institute of Marine Science has been mandated by the General Assembly to provide support for the implementation of the Commonwealth's Wetlands Management Program since the Wetlands Act was passed in 1972. The Institute's role can be effectively defined as a three-part task. First and foremost, wetland scientists at VIMS provide technical advice to both the Virginia Marine Resources Commission and local wetland boards in their review of shoreline modification applications. In addition to a significant amount of field work, this task also requires attendence at numerous public hearings and agency meetings. The second task involves preparation of source materials for resource management groups. This specifically includes, but is not limited to, the preparation, revision and promulgation of wetland inventories. The third task is to develop an enhanced advisory data management program in order to increase the efficiency of permit review, report generation and tracking.

PROJECT DESCRIPTION

Management of Wetlands: Permit Applications, Marsh Inventories and Advisory Data Management 1987-1988.

Task I: Expanded Permit Review

From 1972 to 1980, wetland staff members at VIMS responded to an average of 473 shoreline applications per year. Starting the decade in 1980, the yearly average (1980-1985) increased to 669. The average permits reviewed per year in the last two years is now 1572. As of June 1988, the staff has processed 1083 permit applications, up more than 25 per cent for the same period last year.

In general, 1980 was a year of major transition for the staff and the regulatory system. Passage of the Coastal Primary Sand Dune Protection Act increased the permit application load significantly but of equal importance is the complexity of most dune applications in general compared to the typical wetland application. Because of the substantial costs and complexity associated with most dune projects, time invested in each action is many times that of the average permit. In most cases, dune applications involve multiple site vists and meetings which are very time consuming for our scientists. Passage of the Dune Act in 1980 came soon after our major reduction in personnel (1979) from which we did not recover until 1987 when the General Assembly provided funds for two new wetland scientists.

The enactment of the Non-vegetated Wetlands Act (sand and mud flats) in 1982, although not significantly increasing our application numbers, had a serious impact on our workload. A number of localities formed new boards in response to this law and the previously enacted Dune Act. These developments had the effect of increasing our travel time, training sessions and general application response requirements. Advising local wetland boards requires more of an investment of time than working with the Virginia Marine Resouces Commission. The VIMS staff is now advising 32 wetland boards vs. 15 in the 1970's.

In addition to wetland boards' involvement, the period from 1980 to the present has seen the demands for our expertise increase on the state and federal regulatory level. Staff members must now attend regular joint processing meetings each month with all involved agencies, as well as the Corps of Engineer's Dredge Management Coordination Meeting. We are also constantly consulted by the federal agencies, as well as by increasingly active environmental groups and consulting firms, for advice. Both the Environmental Defense Fund and the Chesapeake Bay Foundation have established offices in Virginia and are relying on us for expertise. In addition, the State Water Control Board has increased considerably the amount of NPDES permit applications which we are asked to evaluate. Many of the applications are highly complex and require personnel to coordinate with other scientists in the Institute and prepare detailed assessments. Since 1980, the Virginia Department of Highways and Transportation has established a monthly coordination meeting which staff members are required to attend as part of the General Permit Agreement with VMRC. Although we are responding to MRC's needs in this area, we were not able to attend the meetings in Richmond until recently when we obtained two new personnel. One of are staff members now attends these meeting on a regular basis.

Objectives and Scope of Work for Task I (1987-1988)

- Orientation and training of two Marine Scientist A's in permit review and advisory activities.

- Improve VIMS ability to provide environmental advisory services to resource managers and property owners.

- Increase the number of shoreline permits which can receive thorough environmental review.

- Increase the number of applications scrutinized in a timely fashion.

- Expand our educational and advisory activities through the Wetlands Board Bulletin and various other contacts with resource managers.

- Reinstitute review and advisory role in dealing with the Virginia Department of Highways and Transportation subaqueous permit requests.

Task II: Enhanced Wetland Inventory Program

The Institute is mandated by the Wetlands Act to evaluate, classify, and inventory tidal wetlands. A classification system was worked out based on 12 different vegetation types occurring within the salt, brackish and tidal freshwater ecosystems in the tidewater region of Virginia. The 12 types were grouped into four basic ecological value categories. The ecological value and classification system was published in a report titled Coastal Wetlands of Virginia: Wetland Guidelines Interim Report No.3. The publication also contains chapters on the consequences of altering wetlands as well as general and specific guidelines involving shoreline defense structures, dredging and filling, sediment control and channeling into marshes and uplands. The publication was later promulgated by VMRC as Wetland Guidelines and was primarily targeted for wetland boards and other interested groups in order to improve wetlands management decisions. This report has undergone several revisions since it was first published in 1974, and more than 10,000 copies have been distributed. Guidelines has been favorably received by wetland managers and has been referenced in a number of wetland resource publications.

Plans were formulated in 1972 to establish a tidal marsh inventory program. The development of the evaluation and classification system provided baseline information for the inventory. Unfortunately, operating funds were not provided to initiate an iventory program, although monitoring and inventoring were mandated in the Act. Despite a limited budget, the program began in late summer of 1972. Funds were eventually obtained from other sources such as Research Applied for National Needs (RANN) and, later, from the Office of Coastal Zone Management (OCZM).

Requests for the inventory reports have been substantial over the years. From 1974 to 1981, 26 reports were published and distributed, totalling over 13,000 copies. Funding from OCZM ended in 1979, resulting in the loss of three staff members. As a result, the inventory and advisory services (shoreline application processing) suffered dramatic setbacks.

The task of finishing the inventories is especially difficult because the principal investigators of the inventory program also process shoreline applications and perform other advisory work. Thirteen of the 26 inventory reports are ten years old or older and should be revised. A monitoring program of current wetland status did not progress until 1987 because of budget restraints.

The marsh inventory reports are an integral part of the wetland resource management program in the Commonwealth. They are utilized by local wetland boards, state and federal agencies, developers, utility companies, marine contractors, consulting firms, planning commissions and environmental organizations.

<u>Objectives and Scope of Work for Task II (1987-1988)</u>

- Completion of the remaining eight unfinished inventories at a rate of at least two per year.

- Revise the inventory program to utilize new, higher resolution imagery and techniques.

- To better address current resource management needs.

- Initiate a program of routine revision and analysis of inventories.

Task III: Enhanced Advisory Data Management

It had become increasingly evident, in our efforts to become more efficient in our advisory efforts, that no mechanism existed for evaluation of the Commonwealth's wetlands management program. Our advisory work involves intense scrutiny of a vast array of information concerning development and management of resources in the coastal zone; however, scientists performing the work are unable to access the information in a manner which permits anything beyond site specific analysis. In order to improve the efficiency of the advisory program and to simultaneously create the opportunity for scientific analysis of coastal management, it became necessary to incorporate the data management capabilities of computers. By itself the volume of reviews and reports which must be tracked, prepared, disseminated and stored is sufficient rationale for computerization. An even more compelling reason, however, is the incredible amount of data which resides in files, essentially inaccessible for summarization and/or analysis. Utilizing appropriate hardware and software, the current procedures for preparation of shoreline perrmit application advisories could be both streamlined and vastly improved. We need to enable ourselves to perform periodic analysis of all advisory activities in an effort to: 1) document development trends, 2) analyze management efforts, 3) address questions of cumulative impacts, 4) help direct research activities, 5) document resources losses, and 6) produce resource management publications.

Objectives and Scope of Work for Task III (1987-1988)

- Increase the efficiency of permit review, report generation and tracking.

- Provide a link between advisory and research efforts by facilitating access to advisory program data bases.

- Acquire and install software and hardware for data management program.

- Create data entry formats, report formats, and data analysis protocols.

- Train personnel in computer use.

1987-1988 RESULTS

Task I: Expanded Permit Review

Shoreline construction applications for 1987 (reviewed permits) totalled 1712, up approximately 20 percent from the 1986 total of 1432. As of June 30, 1988, applications for 1988 total 1083, up more than 25 percent from June of last year. This advisory activity consumes many man-hours and remains one of the most important tasks in the wetlands program at VIMS. The role of the two new marine scientists (hired in July of 1987) has eased the burden of this specific task significantly. The scientists are now fully involved in their duties after a six month training period. Geographic areas of application responsibility have been reorganized to include the newer members of the staff. The more senior staff members spend less time on application processing and can concentrate on interagency policies, training in nontidal wetland delineation, computer training, symposium and workshop participation, applied research and long term resource management problems.

Funds supporting the operating budget for this task and the expanded personnel have enhanced our responses to a more in-depth review of each application, reinstated our advisory role in interacting with the Department of Highways and Transportation regarding subaqueous permit requests, enabled us to become involved in nontidal wetland legislation and strengthened our advisory education activities.

Task II: Enhanced Marsh Inventory Program

Three marsh inventory reports were published in 1987: City of Norfolk, King William County and King and Queen County. Aerial imagery for Isle of Wight County was completed and delivered to the county government. The photographs were taken on a scale of 1" to 600' a definite improvement of the earlier inventory which was done on a scale of 1" to 2,400' ten years ago. The photographs were categorized according to the original inventory report and cross-referenced according to flightlines and waterways. Also produced were over 350 35mm slides of the entire shoreline for presentation purposes. The scope of work was done through a local CRM/COE grant. This project is our first revised tidal marsh inventory in our quest to revise all inventories that are ten years old or older. Data reduction, digitizing, ground-truthing and aerial imagery analysis continue on a daily basis. At the present time, ground-truthing for the cities of Portsmouth and Chesapeake and Prince George County is an ongoing project.

Task III: Enhanced Advisory Data Management

The long term objectives of this task are to increase the efficiency of permit review, report generation and tracking and to provide a link between advisory and research efforts by facilitating access to advisory program data bases. The software package, Info/Text has been loaded on the mainframe at VIMS. Efforts are now being made by computer personnel to render Info/Text compatible with Wordmarc Compose so that its report generation capabilities can be utilized. All members of the wetlands advisory staff are now provided with IBM compatible personal computers which are also in communication with the mainframe. Several personnel are training to use both the pc's and Info/Text. All personnel should be fully trained by October 1988.

Implications for Research Management

All aspects of the objectives and scope of work of these three tasks will greatly enhance our capabilities as technical and scientific advisors to the Wetlands Act and marine/estuarine resources in general. Scientists who were working on routine case studies and processing numerous applications can now concentrate on more long term issues such as mitigation and compensation policies, nontidal wetlands in the coastal zone and various other applied research projects that are crucial to resource management.

Anticipated Activities in 1988-1990

It is anticipated that the pace of submitted permit applications will continue to increase at a rate exceeding 20 percent per year. This task will always be a priority effort within the wetlands program at VIMS. The staff will likely be involved in the formulation of nontidal legislation. At the present time, the staff is undergoing training in nontidal wetland delineation and identification.

At least four wetland inventory reports should be ready for publication during this biennium. Specifically, the reports will include City of Virginia Beach Vol.3 (Back Bay), the cities of Portsmouth and Chesapeake and Prince George County. We will also continue to revise older reports with new imagery. Inventory personnel will also be trained in using computer software (Arch/Info) in order to facilitate inventory report preparation.

The data management program will be fully utilized by all staff members during this period. It is anticipated that this tool will greatly improve our role in wetland resource management.

LISTING OF RELEVANT PUBLICATIONS

Silberhorn, G.M. and W.I. Priest, III. 1987. City of Norfolk Tidal Marsh Inventory. SRAMSOE# 281. Virginia Institute of Marine Science. Gloucester Point, VA 23062.

Silberhorn, G.M. and A.W. Zacherle. 1987. King William County and Town of West Point Tidal Marsh Inventory. SRAMSOE# 289. Virginia Institute of Marine Science. Gloucester Point, VA 23062

Silberhorn, G.M. and A.W. Zacherle. 1987. King and Queen County Tidal Marsh Inventory. SRAMSOE# 291. Virginia Institute of Marine Science. Gloucester Point, VA 23062.

PROGRAM IV. ESTUARINE RESEARCH RESERVE SYSTEM

PROGRAM IV

ESTUARINE RESEARCH RESERVE SYSTEM

Carroll N. Curtis

EXECUTIVE SUMMARY

The Virginia Institute of Marine Science (VIMS) has completed the first phase of the site selection process for a Chesapeake Bay National Estuarine Research Reserve in Virginia with the selection of sites in Mobjack Bay, the York River, and the upper Rappahannock River for official nomination to the National Oceanic and Atmospheric Administration which administers the national program. When completed, the research reserve system will contain sites in each of the tributaries and along the main stem of the Chesapeake Bay in Virginia. The sites will serve as natural field laboratories for long-term ecological studies and for comparison with areas impacted by development activities and pollution.

PROJECT DESCRIPTION

VIMS has been studying the feasibility of establishing a Chesapeake Bay National Estuarine Research Reserve System in Virginia pursuant to Section 315 of the Coastal Zone Management Act of 1972, as amended, since mid-1985. Section 315 provides to coastal states grants of up to 50 percent of the costs of acquiring, developing and managing research reserves and conducting research and education projects at designated sites. Research reserves serve as natural laboratories in which to study and gather data on natural and human processes occurring within estuaries.

The research reserve program offers a unique opportunity to confront Chesapeake Bay environmental programs in Virginia. Relatively pristine areas along the tributaries and the main stem of the Chesapeake Bay, which represent a cross-section of coastal environments in Virginia, will be protected and used for benchmark studies and as controls against which to measure ecological changes in other areas. Research and monitoring programs will be designed to enhance basic scientific understanding of estuarine systems and aid in coastal resource management decision making. The information derived from sponsored studies will provide a basis for measuring progress in Chesapeake Bay clean-up efforts, developing future coastal policy and management initiatives, and increasing public awareness of coastal issues. The goal is to establish and manage a multiple site research network representing the major ecological zones found in Tidewater Virginia.

VIMS conducted a feasibility study during 1985 and 1986 under a small grant from the National Oceanic and Atmospheric Adminstration. During this period, VIMS devised a classification scheme which was used to identify ecological zones and environmental features that should be represented by sites selected for the research reserve system, developed site evaluation criteria based on federal guidelines, and identified and evaluated 113 natural areas as possible research reserves. The evaluation consisted of site visits, review of existing and acquired site information, discussions with knowledgeable individuals, and technical workshops to rate the sites using the evaluation criteria and a numerical ranking procedure. Through this process, VIMS narrowed the list of eligible sites to 50.

DISCUSSION OF 1986-1988 RESULTS

In 1987, VIMS received an appropriation from the Virginia General Assembly under the Chesapeake Bay Initiatives to complete the site evaluation process. To accomplish this, an indepth assessment of the 50 eligible sites was needed to obtain additional information on the ecological characterisitics of each site, research and education value, onsite and adjacent land use practices, property ownership and management opportunities. The York River basin (including Mobjack Bay and the Pamunkey and Mattaponi Rivers) and the upper Rappahannock River basin were chosen for initial consideration and pilot effort.

Ecological surveys were conducted at the top ranking sites in the York and upper Rappahannock River basins in the fall of 1987 and spring and summer of 1988. Aerial photography was obtained and interpreted to study vegetative community patterns and land use characteristics. Species lists were compiled and biotic communities were described on the basis of preliminary quantitative data collected during 1987-1988. Site descriptions were produced, as required by federal guidelines, which discuss research, education and resource protection proposals. An official nomination package is being prepared.

To meet federal requirements for designation, research reserve sites must be protected from development and other activities which disturb natural ecological processes and disrupt scientific studies. Traditional activities such as fishing, hunting and boating generally do not conflict with the research objectives, although these activities are evaluated on a case-by case basis in determining appropriate protection strategies. During 1987-1988, VIMS met with and discussed various protection mechanisms with landowners in the York and Rappahannock River basins whose property has been identified as possible research reserve sites. These mechanisms include conservation easement, long-term lease or contract, management agreement, donation of the property to the Commonwealth and fee-simple acquisition. Landowner response has been favorable.

Also within the 1986-1988 biennium, VIMS initiated discussions on the research reserve program with county and state officials, local and regional environmental organizations and representatives from federal programs. The focus of these discussions has been on what the research reserve program proposes to accomplish, the ways in which the research programs may serve the needs of resource managers and decision makers, the mechanisms available to transmit technical information in a useful form to administrators, educators, and concerned citizens, and the interests of government, industry, academia, and environmental groups in representation on advisory committees. The outcome of these discussions has been constructive and encouraging.

IMPLICATIONS FOR RESOURCE MANAGEMENT

The research, monitoring and education opportunities afforded by the proposed Chesapeake Bay Estuarine Research System in Virginia will be invaluable in furthering scientific understanding of coastal ecosystems in Tidewater Virginia and the impacts of natural and human-induced stresses on these environments. The technical information from directed programs can provide a rational basis for intelligent management of coastal resources. Ecological data from research reserves can be used to monitor vital changes occurring within the estuaries and watersheds and to predict the consequences of anticipated activities in the coastal zone of Virginia, such as effects of population growth, land use practices and conservation measures. The research reserve program will also enhance local resource protection programs through the development and implementation of management plans to direct research, education, resource protection and administrative activities at each site.

ANTICIPATED ACTIVITIES IN 1988-1990

During the 1988-1990 biennium, five (5) sites will be nominated to the federal government for approval as research reserves. Approval of nominated sites will move the Commonwealth into the next stage in the federal designation process and will make VIMS eligible for federal funds to complete management plans and environmental impact assessments for approved sites. Official site designation will take place during the biennium and work will begin on sites in the James River (including Chickahominy River basin) and Potomac River.

LISTING OF PAPERS PUBLISHED/THESES, DISSERTATIONS

Curtis, C.N. & M.P. Lynch. 1987. The site selection process for a Chesapeake Bay National Estuarine Research Reserve System, pp. 621-630. IN: Lynch, M.P. & K.L. McDonald (eds.). Proceedings of Tenth National Conference of the Coastal Society: Estuarine and Coastal Management Tools of the Trade. New Orleans, LA (12-15 October 1986). Volume 1.