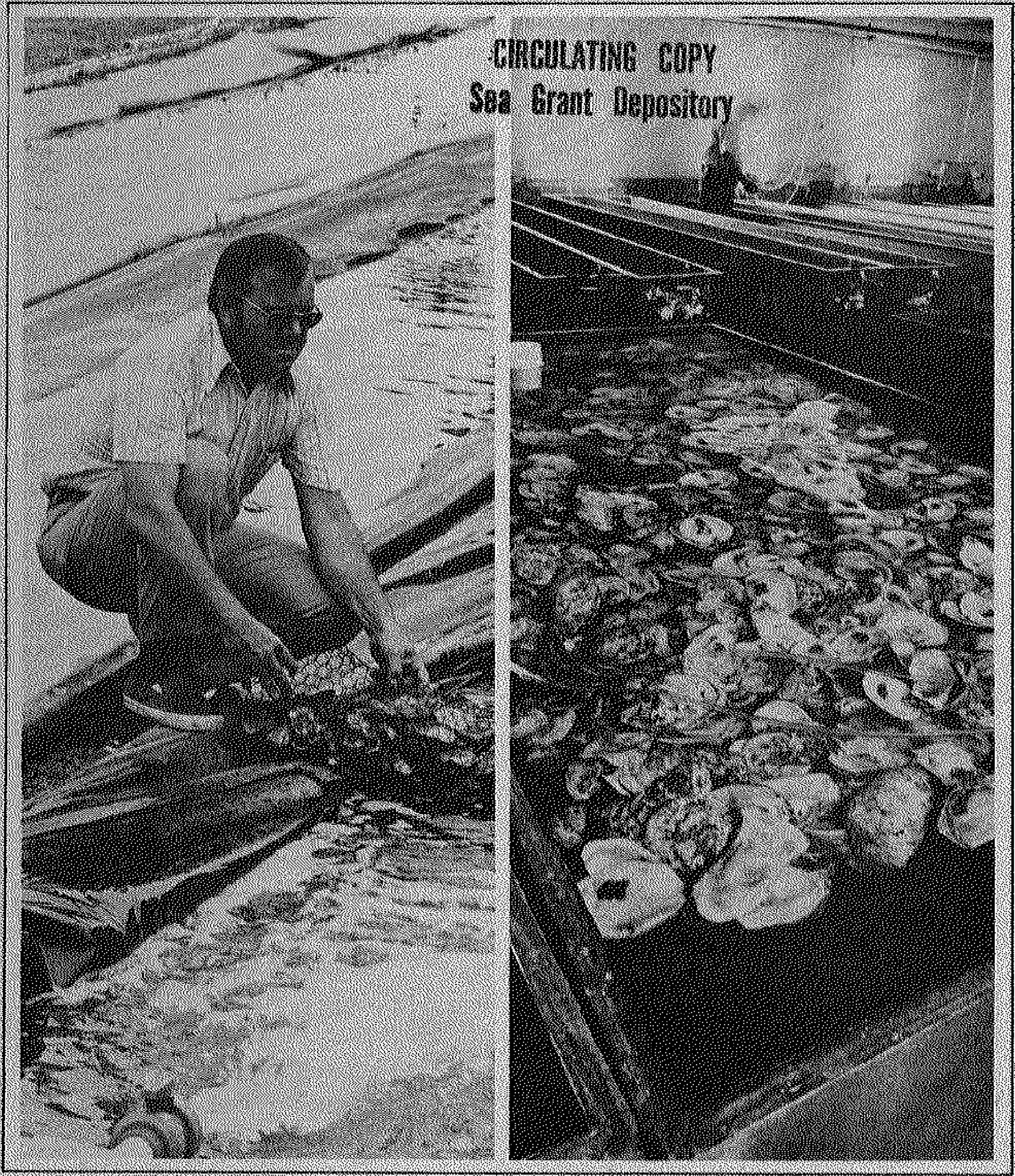
Oyster Hatchery Technology Series



Oyster Hatchery Technology Series

George E. Krantz

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It is obvious to any reader of this document that the principal investigator could not have conducted this work without the assistance of many technicians and other scientists. This project was conceived and initiated by the collective efforts of Dr. L. Eugene Cronin, Dr. Herbert Hidu, Dr. Curt Rose, Elgin Dunnington, Klaus Drobeck, and Hayes Pfitzenmeyer. These individuals contributed many innovative ideas and assistance throughout the project. Once the project began operation of the Maryland pilot aquaculture plant and shellfish hatchery, day-to-day activities were conducted by an energetic team effort that originally began with Klaus Drobeck, Donald Meritt, William Rosenberg, and Dan Terlizzi. As the project grew, additional individuals, Garry Baptist, Morgan Bennett, Max Chambers, and James Perdue, participated in the day-to-day operation and carried the project to completion.

Throughout the tenure of the project Donald Meritt provided daily oversight of all hatchery operations, assisted in the planning and modification of various activities, and was responsible for most of the data collection. Many innovative algaeculture techniques were developed by Garry Baptist and Dan Terlizzi that made the project a success.

I wish to sincerely thank these individuals for their input; without it the project would not have produced the data used in this report.

George E. Krantz, Ph.D.

Preface

The Chesapeake Bay still bears the title of the nation's major oyster-producing estuary, though recent harvests weigh in at one seventh of what they were at the close of the nineteenth century. To tap the resources of the Bay and to bring back something akin to those great harvests, the University of Maryland's Center for Environmental and Estuarine Studies has staged investigations into the American oyster and its potential for profitable aquaculture.

At the Center's Horn Point Laboratories near Cambridge, Maryland, researchers have focused on ways to spawn, feed and grow oysters, as well as on ways to attract and encourage the setting of oyster spat. In this OYSTER HATCHERY TECHNOLOGY SERIES, Dr. George Krantz reviews his investigations into oyster aquaculture at Horn Point, focusing on the efficiency, the feasibility and--importantly--the cost of producing oysters in a controlled environment. This series of technical publications includes an overview of the Maryland oyster industry, as well as a description of specific hatchery experiments and results.

Research described in these pages helped provide in 1982 for the founding of the Cooperative Shellfish Research Unit, a combined effort of the University of Maryland and the Maryland Department of Natural Resources. The Research Unit oversees a small-scale oyster hatchery on Deale Island, Maryland, which has already produced seed oysters and planted them in the Bay.

Requests for publications in this hatchery technology series should go to the Maryland Marine Advisory Program, H. J. Patterson Hall, University of Maryland, College Park, MD 20742. The Marine Advisory Program is a joint effort of the Maryland Sea Grant Program and the University of Maryland Cooperative Extension Serivce.

Part I

Summary and Hatchery History

Part I

OYSTER HATCHERY TECHNOLOGY SERIES
SUMMARY AND HATCHERY HISTORY

PART I

GENERAL SUMMARY

Background

The Chesapeake Bay has led the nation in commerical production of the American oyster (Crassostrea virginica) for many decades (Figure 1). Between 40 and 50% of the Bay's production or about 27% of the United States' oyster harvest came from Maryland's portion of the Chesapeake and its tributaries until 1965-1969. Since that time Maryland has made an ever-increasing contribution to the total landings of the Bay, and during the 1974-1975 season Maryland's waters produced 75% of the Bay's harvest (Haven et al. 1977). The Maryland oyster fishery had an annual dockside value exceeding $20 million in 1981 and it provides livelihood for about 4,000 watermen and approximately 5,000 Bayside residents engaged in the shucking, processing, transportation, and marketing activities related to the fishery. Estimates of the economic multipliers that come from the oyster industry range from 3.0 to as high as 9.0 (Pate 1978). The reason for these relatively high estimates of the value of the oyster industry to Maryland is that many dockside communities rely on oyster harvesting and processing, supplemented by the summer crab fishery, as their principle means of livelihood. The unique social structure of Maryland fishing communities is sustained by the natural resources of the Chesapeake Bay. These resources are part of Maryland's public domain; hence it is mandated that modern resource management strategies be employed to preserve this unique relationship and the Chesapeake's natural resources.

Harvest statistics for the Bay (Figure 1) document both historical and recent declines in the oyster harvest which have periodically created numerous legislative inquiries and resultant scientific investigations since around 1900. All of these studies reported serious shortages in oyster recruitment in the Maryland portion of Chesapeake Bay (Yates 1913, Nichol 1937, Beaven 1945, Engle 1946, Beaven 1954, Engle 1955, Manning 1968, Davis 1976, Krantz and Meritt 1976, and Ulanowicz 1979). Several studies have addressed the political, social, and managerial problems of the Maryland oyster industry and have asserted that over-expoitation resulting from a predominately public fishery is the second most important negative impact on the biological stability of this natural resource (Beaven 1945, Glude 1966, Agnello and Donnelly 1975, Alford 1975). Analyses of all aspects of the fishery suggest the major problem with the Maryland fishery is the inability of natural recruitment (spat set) to sustain the heavy level of harvesting placed on the natural bars by the public fishery. Therefore this valuable resource has highly variable annual yields of raw product which deter modern business ventures from entering the processing, marketing, or aquaculture components of the fishery. This same problem suppresses the desire of existing industry participants to invest in plant modernization or in commercial aquaculture.

The relationship between depresssed oyster spat set (recruitment) on the natural bars and subsequent oyster harvest of Chesapeake Bay is illustrated in Figure 2 (Meritt 1977, Krantz and Meritt 1976). A major decline in annual recruitment of oysters in the Maryland portion of the Bay began in 1967 and has persisted to the present time (Krantz, in press). The extremely high spat fall of 1980 did not occur in all portions of the Bay. Waters of the Western Shore, the upper Bay, upper Chester River, upper Patuxent, and upper Potomac River received no detectable spat set (Davis, Webster and Krantz 1981). Recent reductions in the amount of spat set during the past decade ranged from 50 to 97% on some of Maryland's most productive oyster beds. The period of poor natural recruitment in Maryland waters was intensified by the impact of Hurricane Agnes in June 1972. Cumulative effects of the prolonged failure in spat set and the dramatic change in water quality due to Hurricane Agnes greatly reduced stocks of harvestable oysters throughout Chesapeake Bay (U.S. Corps of Eng., 1975). Immediately following assessment of damage by Hurricane Agnes, University of Maryland personnel requested financial assistance from the United States Department of Commerce, Economic Development Administration (Project No. 01-6-09-509-70), to plan and direct a program designed to establish a Maryland pilot-plant shellfish hatchery along with the supportive restoring, rehabilitating, and expanding of shellfish production in areas damaged by Hurricane Agnes. The contact provided funds to develop a shellfish hatchery and equip it with state-of-the-art hatchery equipment. Several research programs (oyster and soft clam rehabilitation, algal selection and culture, and extension and advisory services) were part of the 1972 U.S. Economic Development Administration Contract work plan. The grant was to establish the technical capability and the human and mechanical resources that could seek solutions to enhance the quality of the shellfish industry in Maryland. From this basic grant a pragmatic research program evolved in which shellfish hatchery technology has been carefully evaluated for biological, economic, and operational feasibility. Some basic research on soft clam culture techniques was also conducted, but it was found that hatchery culture of clams was unnecessary to help replenish natural stocks. Emphasis has therefore been placed on algal culture and oyster rehabilitation.

The intensity and geographic distribution of natural oyster recruitment in Chesapeake Bay has undergone dramatic changes since 1972, and the Maryland oyster fishery has shifted its efforts to those waters which now yield economicly acceptable levels of harvest. A composite of studies that document spatfall over the past five years shows the major areas where the Maryland oyster fishery is now located (Figure 3), and where it probably will be located in the coming years. Most of the oyster beds in the upper Potomac River, along the Western Shore, and above Eastern Bay on the Eastern Shore were severely impacted by Hurricane Agnes and will have difficulty recovering due to the present harvest pressure and low level of recruitment. The primary moderating influence that prevented total economic collapse of the oyster industry was the extremely high spat set in 1964 and 1965 (Figure 2). The attitudes of watermen and natural resource managers remained relatively complacent about levels of poor recruitment until recent catches per man/boat/day declined dramatically (Cabraal 1979). Now all groups involved in the oyster industry are keenly aware of the precarious status of the resource.

The seafood processing industries and state agencies interested in the viability of all aspects of Maryland's economy perceived the present problem before the recent decline in harvest. The Department of Economic and Community Development received encouragement from state legislators to develop a seafood marketing evalution report in March 1975. This report noted that the oyster industry was lagging behind all other Maryland seafood industries in productivity and profitability. An analysis of causes for the depressed growth of the oyster industry was the subject of an extensive investigation by the Department of Economic Development (Anastasi 1976). This study suggested several remedial programs to increase the growth of the oyster industry in Maryland. Based on the contents of the Anastasi report, available scientific information, and growth potential of Maryland's oyster industry, the joint legislative chairmen established the Maryland Oyster Resource Expansion (MORE) Task Force in 1977. The mission of this interagency task force was to recommend mechanisms for implementing programs to: (1) improve the supply of oysters in Maryland waters, (2) increase oyster processing capability in Maryland, and (3) improve the marketability of Maryland oyster products. While addressing mechanisms to increase and stabilize the oyster supply, the MORE Task Force recommended that a pilot production-scale research hatchery be developed and that data be collected to demonstrate whether or not existing oyster hatchery technology and aquaculture techniques could be biologically and economically feasible for approaches for increasing the supply of seed oysters to Maryland's oyster industry.

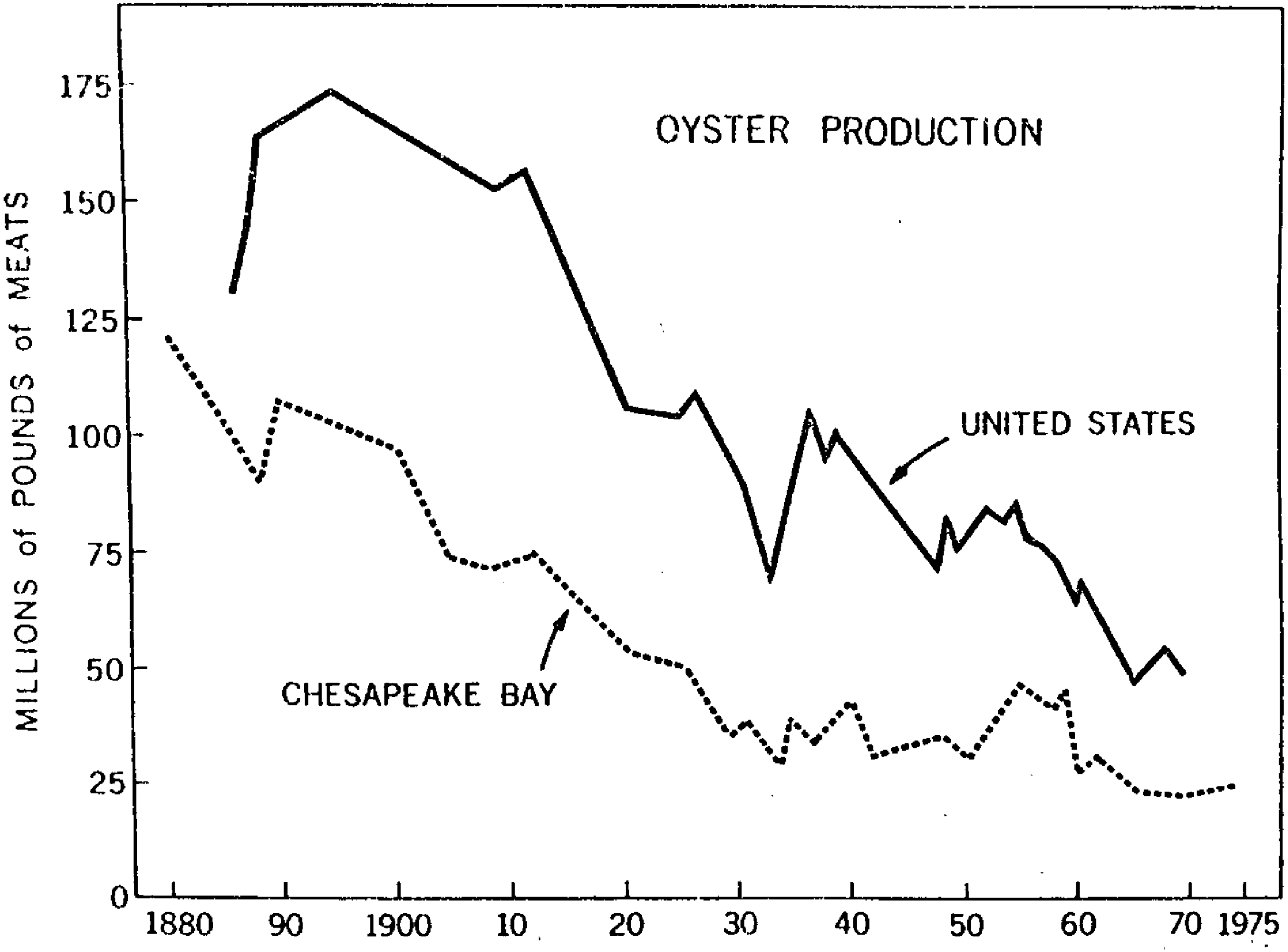


Figure 1. Chesapeake harvest data for the American oyster (Crassostrea virginica), 1880-1980. (Adapted from Meritt, p. 4.)

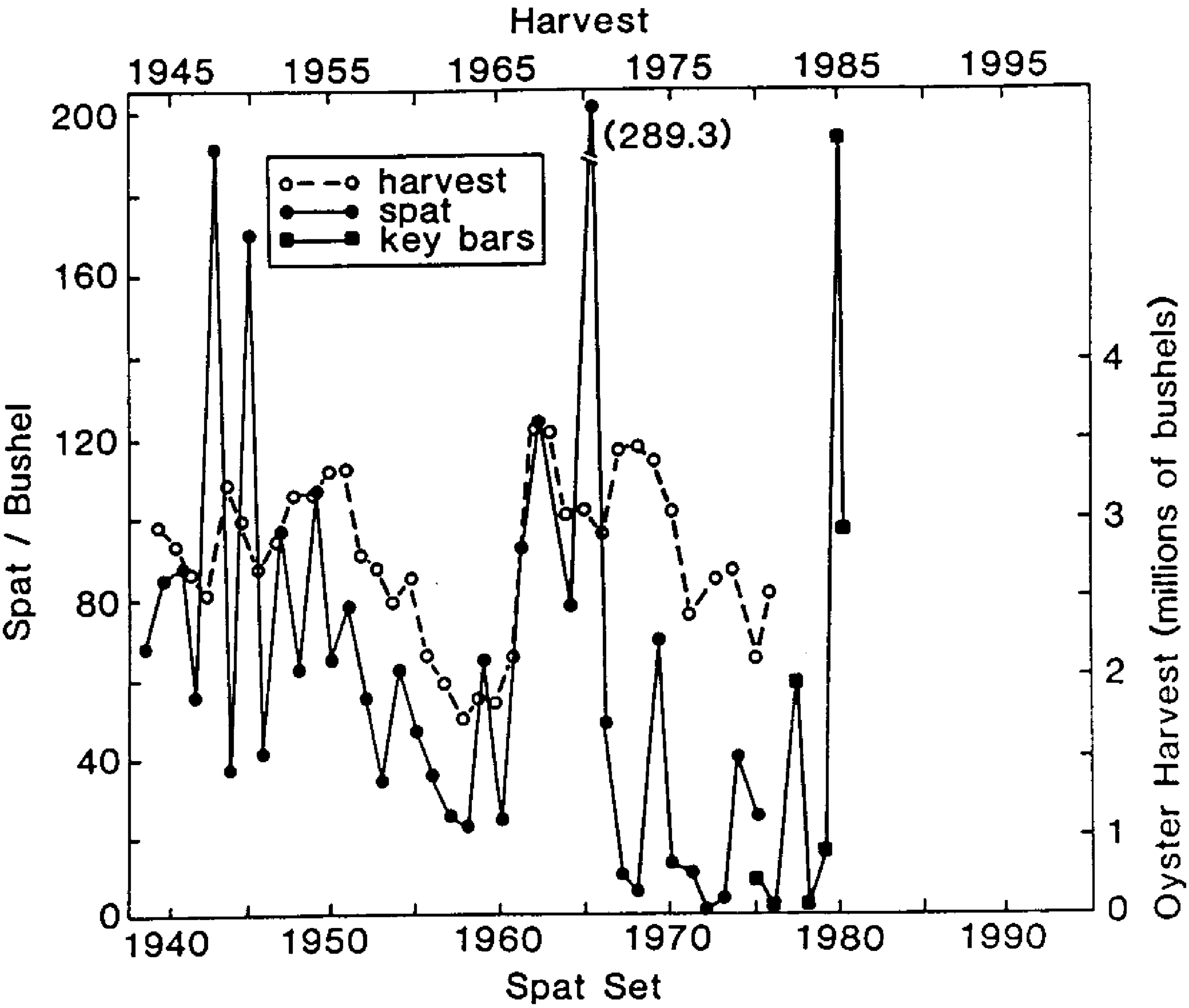


Figure 2. Comparison of oyster spat set on natural cultch with commercial harvest statistics adjusted for a five-year lag. Harvests actually occurred five years later than shown here, after oyster spat grew to market size. Squares indicate data from "key bars," 1975-1981.

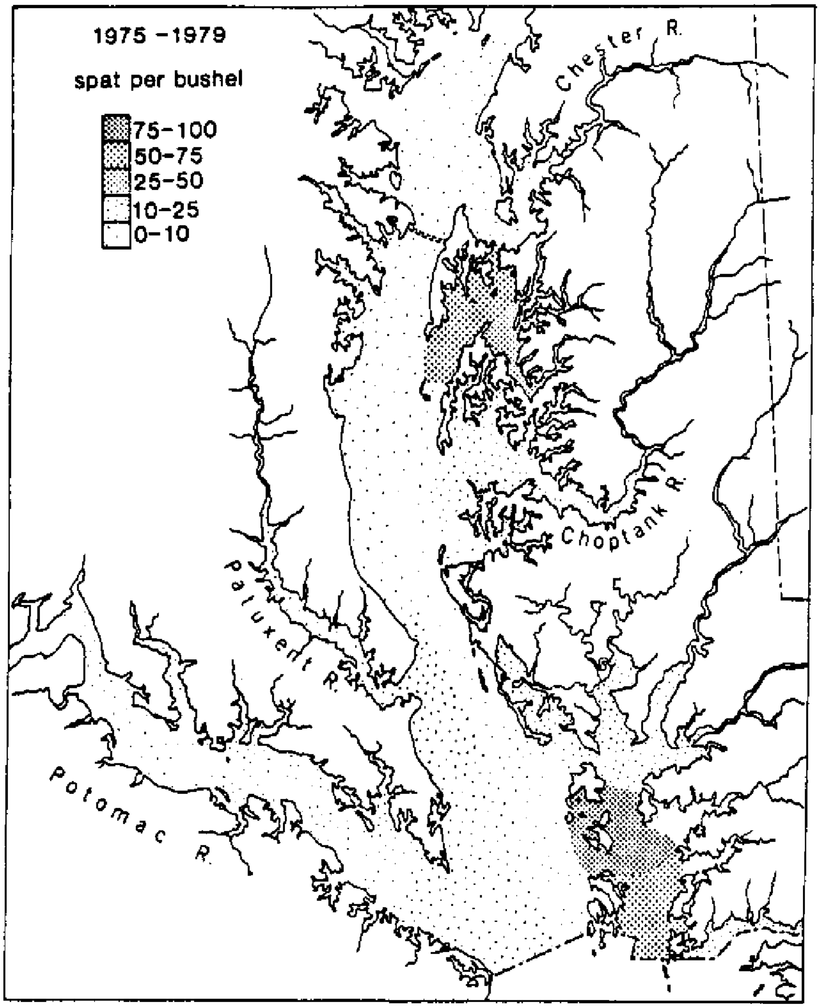


Figure 3. Spatfall on Natural Oyster Bars in the Maryland Portion of Chesapeake Bay, 1975-1979.

The Maryland Department of Natural Resources has been aware of declining spat set and potential threats to future production and industrial growth of Maryland's oyster fishery, and several management strategies have been employed by this agency to stabilize the oyster harvest. Among current management activities are the transport of oysters from water polluted by domestic wastes to clean waters where natural depuration occurs and the planting of dredged oyster shell as culch in seed areas (areas of traditionally high spat set), followed by transportation of the attached spat to growing areas. These techniques have been very effective in sustaining harvests, especially during periods of high spat set (1964-1965). However, during the recent period of low spat set these management techniques have failed to sustain an economically acceptable level of recruitment to Maryland's oyster populations (Pate 1978). Variation in the quantity and location of spat set throughout the Bay has resulted in an unreliable supply of seed oysters, and therefore an unpredictable and low level of raw material for the Maryland oyster industry. Maryland oyster packers, processors, and shippers are reluctant to invest in the modernization of their plants or to make long-term commitments to the Maryland processing labor force. This has caused a loss of income to the State of Maryland, since a majority of Maryland oysters is processed in Virginia. Therefore, Virginia, rather than Maryland, receives the benefit of the resource's economic multipliers (Pate 1978).

In light of the reduced effectiveness of the shell planting program which was supplying seed oysters to sustain the public industry, the Maryland Department of Natural Resources planned to build a large-scale oyster seed hatchery at Deal Island. It was hoped that large quantities of spat could be produced at this facility and planted on natural beds at a lower cost per bushel of harvestable oysters than that of existing shell-planting management techniques. Most importantly, the management agency would have a predictable and consistent level of input of seed oysters into the fishery. If hatchery production of seed resulted in a more predictable supply of oysters, packers and seafood brokers could then plan to expand their markets for Maryland oysters.

During the planning and development of the Deal Island hatchery, many legislators, administrators, and shellfish biologists expressed concern about the lack of valid data on the production costs and operational characteristics of oyster hatcheries. Even though numerous research hatcheries exist and volumes of research studies on oyster culture have been published, virtually no information is available on the performance of commercial oyster culture ventures or production-scale oyster hatcheries. The academic orientation of research biologists and the reluctance of private industry to disclose their financial posture has created a void in the information needed to design an economically viable oyster production hatchery for the State of Maryland.

The lack of production information is well illustrated by an actual planning problem: should a production hatchery raise oyster spat on cultch (oyster shell, clam chip or stone, etc.) or produce oyster spat in a cultchless form as is being advocated by several research scientists (Dupuy 1976, Hidu 1977)? Hatchery design, operating characteristics, and survival of spat vary so much between cultched and cultchless oysters that a facility design and management program based on one methodology would not be applicable to the other. For example, some of the equipment in the hatchery for handling cultchless oysters cannot be used in any manner to grow oysters on cultch. Material handling of cultch necessitates that numerous trays and/or containers be used to hold the newly set spat. When oysters of the two types are planted on natural bottom, cultchless oysters must be planted on bottom covered with shell or on natural oyster bars, whereas oysters on whole shell cultch may be placed on a varity of bottoms, including firm mud. Unfortunately, data necessary to make a choice between these fundamental design differences did not exist in the scientific literature or in files of private consultants prior to the HPEL study.

Because of the lack of information on oyster hatchery design, operational efficiencies, production costs, and economic return of such a program, the Maryland Department of Natural Resources delayed plans for construction of an oyster spat production facility at Deal Island. The remedial oyster spat planting programs envisioned in the Economic Development Administration (EDA) contract have also been delayed until small-scale plantings of spat, raised by the Horn Point Environmental Laboratories (HPEL) hatchery, have been evaluated to determine the optimum spat size to be planted for good survival, spat planting density, and best type of cultch to use to ensure survival of hatchery-raised oysters. The HPEL oyster research hatchery program is now under contract with the Maryland Department of Natural Resources to generate data necessary to develop a management advisory to the Department of Natural Resources on the use of oyster hatchery technology in Maryland. The advisory document (Part II of this series) includes one or more management strategies for the production and use of hatchery-reared spat, the probable cost of each strategy, the potential benefit to the Maryland oyster industry, and the optimum use of the Deal Island site as an oyster production hatchery.

Development of Oyster Hatchery at HPEL

The University of Maryland Center for Environmental and Estuarine Studies has a shellfish research program with a strong historical orientation toward monitoring Maryland's natural oyster populations (Beaven 1954, Meritt 1977). Approximately a decade ago, research investigators became convinced that oyster hatchery technology could be refined and used in Maryland to alleviate the problem of declining and irregular spat set. Contributions of Hidu (1969), Dupuy (1973), Drobeck (1976), and Dupuy et al. (1977) indicate that many technical and biological problems are encountered when the traditional Milford (Loosanoff and Davis 1963; Figure 4) or the Wells-Glancy (Wells 1920; Figure 5) procedures for oyster culture are used in Chesapeake Bay. To overcome these site-specific problems, Hidu (1969) suggested a "CBL-Wilde" method which was a combination of the Milford-Long Island method, and in addition drew upon oyster culture experience in Chesapeake Bay over a ten-year period (Figure 6). Both Hidu and Wilde found that cultured algae was not necessary at their specific locations in Maryland during the period 1965 to 1970. A simplified conditioning and feeding scheme was utilized to obtain viable eggs. They devized a culture system that would function well in a modest, low-cost oyster hatchery; however, the reliability of their techniques has not been very high. Blooms of natural algae now occur randomly and frequently disappear for long periods as oyster larvae are growing. At the HPEL hatchery location, our initial studies during 1974 and 1975 found a complete lack of algae of the proper size and species needed to propagate oyster larvae in the hatchery. A similar situation was encountered by Frank Wilde in three of the last five years (1974-1979). However, during this period low levels of larger algae and large quantities of detrital material were present in the ambient bay water and could be used to feed oyster spat. As a result, the HPEL hatchery strategy (Figure 7) utilized cultured algae and an operational strategy somewhat like the "CBL-Wilde" and Wells-Glancy technique. The HPEL hatchery uses the algal culture techniques developed by the Virginia Institute of Marine Science (Dupuy et al. 1977) as supplemental food to insure that hatchery culture of larvae will succeed. Dupuy points to the superiority of his method in that each brood or batch of larvae and spat receives a complete diet with proper nutritional characteristics for predictable growth. The labor and cost of culturing algae in the HPEL hatchery is very similar to the amount of labor and effort needed to concentrate and grow algae by the Wells-Glancy technique, or by the requirement of changing the larvae oyster cones on a daily basis according to Hidu's "CBL-Wilde" technique.

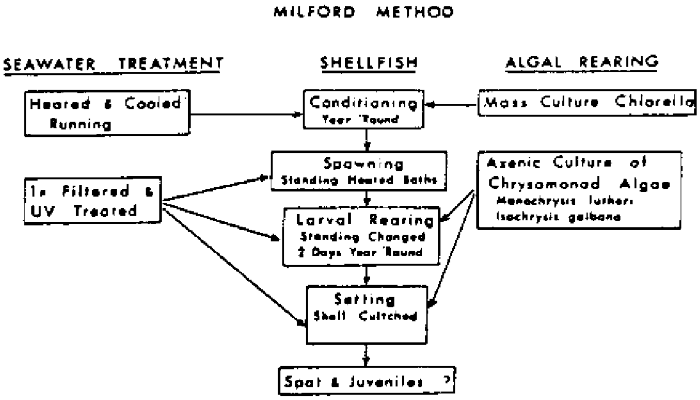


Figure 4. Simplified outline of essential systems in the USBCF-Milford hatchery system.

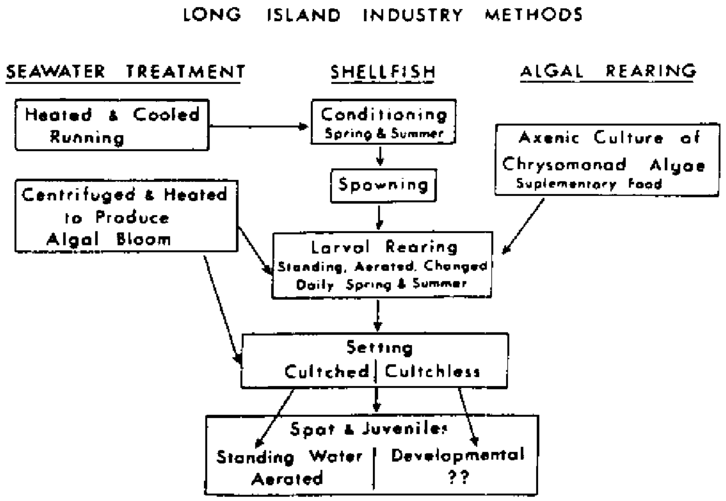


Figure 5. Simplified outline of essential systems in Long Island commercial oyster hatcheries. In most Long Island hatcheries, backup algal rearing systems have been added to the basic Wells-Glancy natural algal methods.

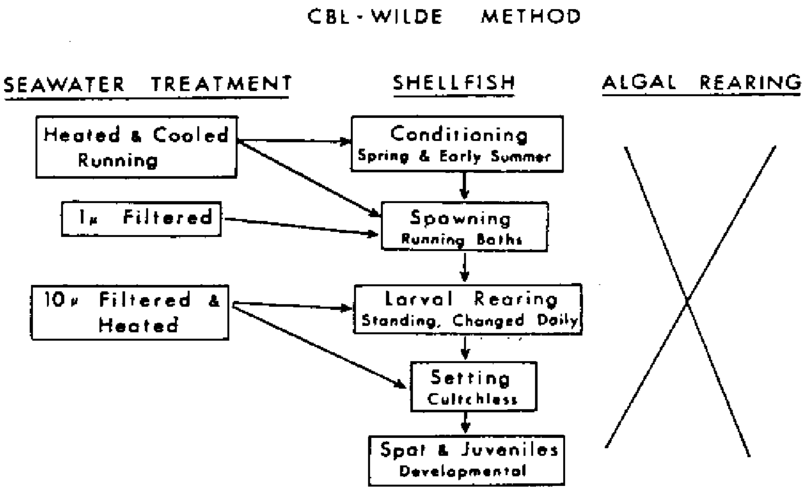


Figure 6. Outline of essential systems in the CBL-Wilder pilot oyster hatchery. The system incorporates 88-309 hatchery experience in simplifying existing Milford and Long Island techniques.

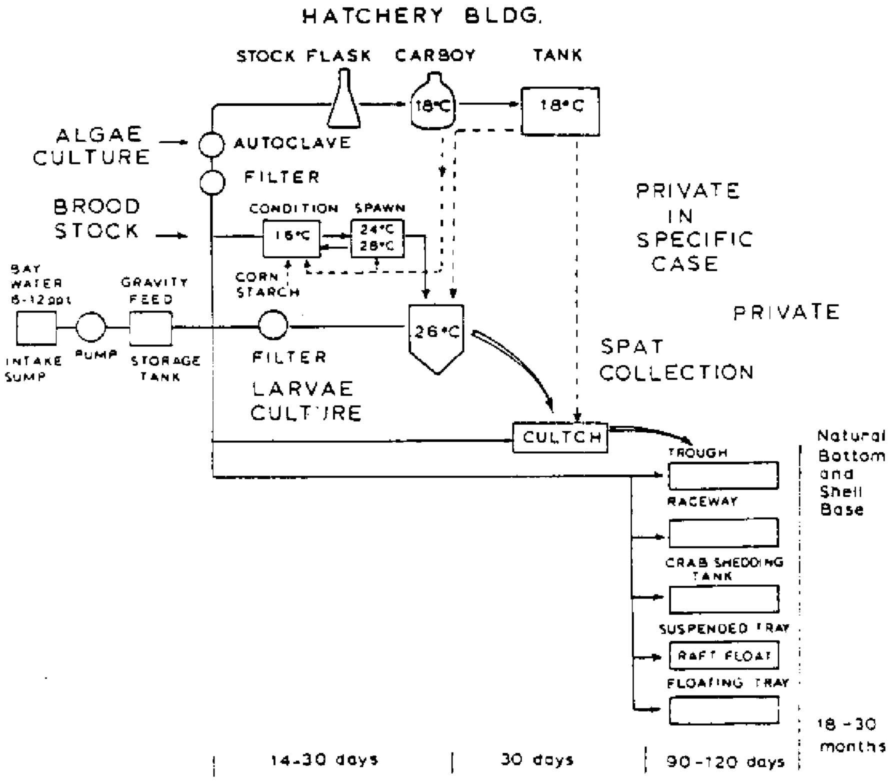


Figure 7. Schematic outline of the primary systems in the HPEL Shellfish Pilot Production Hatchery.

Knowing that the HPEL hatchery would use the algal culture systems recommended by Dupuy, the other hatchery systems (setting, spat growth, etc.) were designed to be compatible with the algae culture effort. Dupuy and his co-workers (1977) state that his technique will yield the setting of larvae in 9-11 days with a relatively high "12% survival from the fertilized egg to set oyster larvae on a year-round basis...." Dupuy's technique was reputed to yield a 3/4-inch oyster spat in 110-120 days and to produce a cultch-free spat of uniform size and shape with a minimum of labor and cost. However, it must be pointed out that Dupuy et al. (1977) also recommended stringent site selection criteria based on water quality, salinity, amount of sediment in the water, and the relationship of the site to domestic and industrial pollution sources. Each of these variables is known to have an extremely important impact on the production efficiencies of seed from an oyster hatchery.

The hatchery design and procedures recommended by Dupuy et al. (1977) were never tested in a production mode. Therefore, it was anticipated that many additional engineering and economic problems would be encountered as these methods were applied in a production-scale operation in Maryland. Unfortunately, it has been discovered that some of these problems could become major deterrents to the successful development of oyster hatcheries in the Chesapeake Bay.

Results of the Research Program at the HPEL Facility 1977-1979

At present, the research thrust of the University of Maryland program is to test hatchery culture concepts in a production mode and to determine the impact of various unpredictable natural and man-induced perturbations on the biological systems and the resultant costs of producing spat. The primary need for this oyster hatchery pilot production and research program was a well-designed physical plant. The impetus and funding for this plant was provided by the U.S. Department of Commerce Economic Development Administration (EDA Grant #01-6-09-509-70). The University of Maryland--with the EDA construction grant, four years of research support from the Maryland Department of Natural Resources, research contracts from the University of Maryland Sea Grant Program (RF/4 and RF/5), and labor from the Dorchester County Community Development Corporation--has operated a highly successful oyster larvae production-scale hatchery at Horn Point. Table 1 summarizes the financial investment in this project to date.

The 5600 sq. ft. oyster hatchery building became fully operational in May 1977. The facility is supplied with dual pumps and distribution lines capable of delivering 1000 gpm ambient water from the Choptank River. An additional 1000 gpm standby capacity can be used for short-term experiments. The building has an equipment room (500 sq. ft.) capable of heating or cooling about 200 gpm of river water to any desired temperature, while maintaining a variety of air temperatures in the hatchery rooms. Heated, cooled, and ambient river water and fresh water from a well are available at all locations throughout the building. Details of the construction of this facility (Figure 8) are available from the plans and specifications cited in Appendix 1. A temperature-controlled algae culture room (600 sq. ft.) and two support laboratories (725 sq. ft.) are available for growing mass cultures of algae, media preparation, algal stock culture maintenance, counting and measuring algae and oyster larvae, chemical tests, microbiological assays, and detailed microscopic examinations. Major items of equipment in this area include:

- ten 1000-liter flat mass culture tanks,
- eight carboy racks that hold eight 15-liter carboys,
- four temperature-controlled stock culture boxes,

- three autocalves,
- three microscopes,
- a particle data counter and computer terminal,
- a continuous-flow centrifuge,
- UV water purifier,
- balances, and
- miscellaneous laboratory equipment.

In the 3000 sq. ft. area where oysters are conditioned, spawned, and the resulting larvae reared are located:

- eleven different brood stock conditioning tables (292 sq. ft.) with automatic temperature control systems,
- nineteen larval culture cones with a conditioned capacity of 14,500 liters of water that could hold approximately 200 million larvae,
- spawning table with automatically controlled flowing water and separate chambers for spawning up to three broods (150 oysters) simultaneously,
- observation table with two microscopes and equipment for counting larvae.

In the 1000 sq. ft. spat-growing area there are 40 DupMO Mark II flumes (2'x12'x6") each furnished with heated, cooled, and ambient water. Nestier culture trays hold the growing spat at densities of 2500 spat per sq. ft. Walkways and drains occupy some space permitting the room to hold approximately 1.2 million cultchless spat in a controlled culture environment. An additional oyster spat growing area (3600 sq. ft.) was developed through Sea Grant Research Project RF/4 in 1977 and 1978. These structures were designed as low-cost, outdoor growout facilities ("raceways") to increase the spat production capacity at HPEL. Low cost construction was emphasized so that private individuals could participate in the raceway culture of oyster spat with a minimal capital investment. The development and research conducted in these structures is described in a recent publication by Lomax and Krantz (1979) (Appendix 2). The HPEL raceway structures can accommodate approximately 10 million spat to a size suitable for planting in a three- to four-month summer growing season.

The potential for production of spat from the HPEL facility could place it in the top five oyster-production facilities on the North American continent. Many Maryland citizens, watermen, legislators, and oyster resource managers speculated that this facility would now be yielding large quantities of seed oysters to boost the declining industry. However, one of their primary considerations was the cost of seed oysters. Probably the most exemplary summary of the cost of oyster hatchery technology in Maryland can be prepared by simply summarizing the HPEL hatchery operating expenditures during three biological production seasons (1977-1979) (Table 2). Included for comparison are the expenditures in a laboratory-scale hatchery operated by Maryland Department of Natural Resources personnel at Deal Island in 1979. The 1976 laboratory-scale hatchery was used to determine some of the site-specific requirements and environmental constraints for the large-scale hatchery before it became operational. Studies were conducted to determine the types and concentrations of algae present in Choptank River water, survival of oyster eggs and larvae, and problems in growing spat in the HPEL water source. During that year a modest quantity (4.5 million) of plantable spat was produced in a small tray growout facility at HPEL and at the Deal Island facility. The cost of these spat ($4/1000) was considered to be acceptable in comparison to the production cost of spat in other hatcheries in the middle Atlantic region and on the West Coast of the United States.

During the three years of pilot production activity at HPEL, operational expenditures were similar and major budget differences came in the amount of seasonal labor used in the hatchery procedure. Table 2 shows a very wide range of production costs for spat. The primary reasons for this variation were the survival and growth rate of larvae, pediveligers, and newly attached spat due to the differences in salinity of Choptank River water during 1977 (10 to 14 ppt) and 1978-1979 (5-10 ppt.). The periodicity of these variations in salinity are illustrated in Figure 9 which shows the weekly range of salinity throughout three production years. The cost of raising spat in the HEPL facility was strongly influenced by salinity and water quality which altered the biological characteristics of algal growth, larval survival, spat-settling ability, survival and growth of the spat, and ease of handling the living animals in all of the hatchery operations. Since the HPEL system uses ambient Bay water (Figure 7), there is little opportunity to modify the salinity of the large volume of water that the growing larvae and spat require. To illustrate the impact of salinity on hatchery efficiency, compare the production costs and relative success of the biological phenomena between Deal Island and the pilot production HEPL hatchery during 1979. The small-scale Deal Island hatchery with a low operating budget and seasonal labor has the capability of producing low-cost spat without incurring the risk and cost of capital investment in highly refined technology or a large annual operating budget which supports technically trained biologists to operate a commercial-scale hatchery. When the efficiency of the commercial-scale hatchery is decreased by an uncontrolled factor, then the economy gained by large volume production is destroyed.

To understand more clearly the realtive costs of operating a pilot production hatchery, the annual operating budgets for the HPEL facility were separated into labor, energy, supplies, maintenance, and repairs (Table 3). This table shows the seasonal operating costs of the facility only for operation of the facility during the biological production season (8 months). Labor accounted for approximately 53% of the total operating cost. Energy for heating the building and water, as well as electricity for lighting the building and cooling and pumping water, composes approximately 30% of the seasonal operating costs. Supplies and chemicals to grow the algae, expendable items such as water filters, and cultch for setting the spat comprise approximately 10% of the operating budget. Maintenance and repair costs have risen annually as the facility has been in operation and now exceed 10% of the seasonal operating cost.

Total expenditures for a production hatchery program are slightly underestimated in Table 3 because the facility only operated eight months of the year. The staff of professional biologists and maintenance personnel must be retained on an annual basis to preserve the future integrity of the operation. During the remaining four winter months, these persons are taking compensatory leave and performing alternate tasks which do not produce oyster spat. However, the building must be maintained with heat and some level of electrical expenditure. Therefore, Table 4 summarizes the annual operating cost for an oyster hatchery operation as would be required by the state management agency or by a private corporation. This operation plan includes management costs and the year-round cost of maintaining the technically trained labor pool. Some additional expenditure of energy occurs for maintenance and repairs when the facility is operated on a 12-month basis rather than seasonally. The total annual operating cost exceeds the seasonal (production period) costs by 65%. This additional cost renders economically unfeasible the use of large-scale hatchery technology to produce seed oysters for Maryland's public fishery.

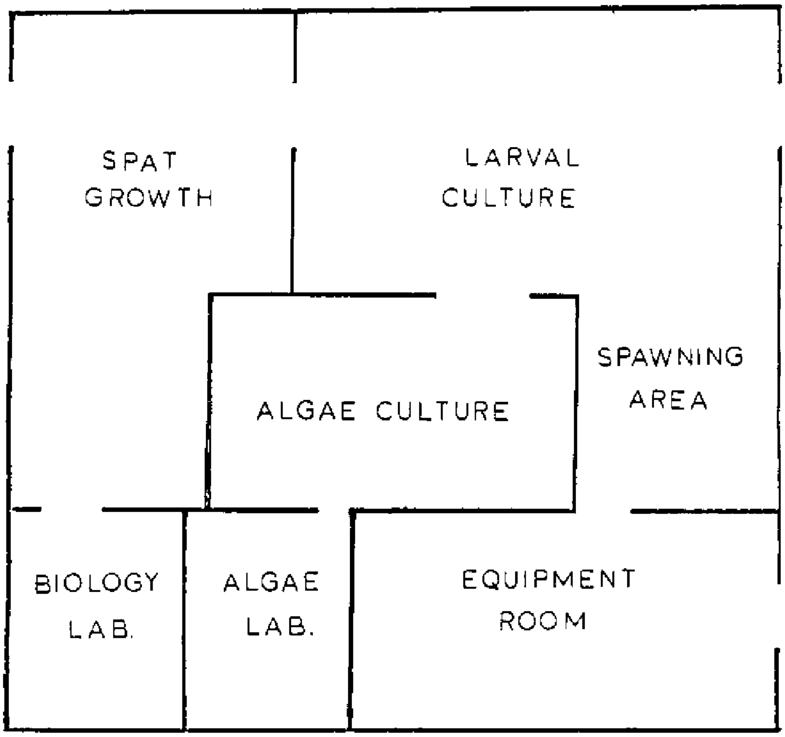


Figure 8. Floor plan of HPEL pilot production oyster hatchery.

Table 1. Funding sources for HPEL Hatchery Program

Source	Construction Cost	Capital Equipment	Operating Expenses	Labor & Overhead	Total
University of Maryland 78-79	$110,000	$181,000	$130,000	$204,000	$ 625,000
EDA Grant 72-75	313,000	29,000	20,000	20,000	382,000
Maryland Sea Grant 77-78	10,000	1,000	17,266	50,364	78,630
Maryland DNR 76-79	-	-	32,100	42,900	75,000
Total	$433,000	$211,000	$199,366	$317,264	$1,160,630

Table 2. Hatchery production costs for HPEL and Deal Island

	1976 Lab-Scale	1977 HPEL Pilot	1978 HPEL Pilot	1979 HPEL Pilot	1979 Deal Island
Season cost (x $1,000)	18.00	83.90	88.90	71.50	9.86
Production (x 10^6)					
Eggs	120.00	1000.00	2000.00	1230.00	136.00
Eyed pediveligers	10.00	220.00	130.00	49.00	24.10
Plantable spat	4.50	51.90	10.10	1.40	3.00
Cost per planted spat	$0.004	$0.0016	$0.0088	$0.051	$0.0033
Ambient salinity (ppt)	8-12	8-14	5-10	5-10	9-15

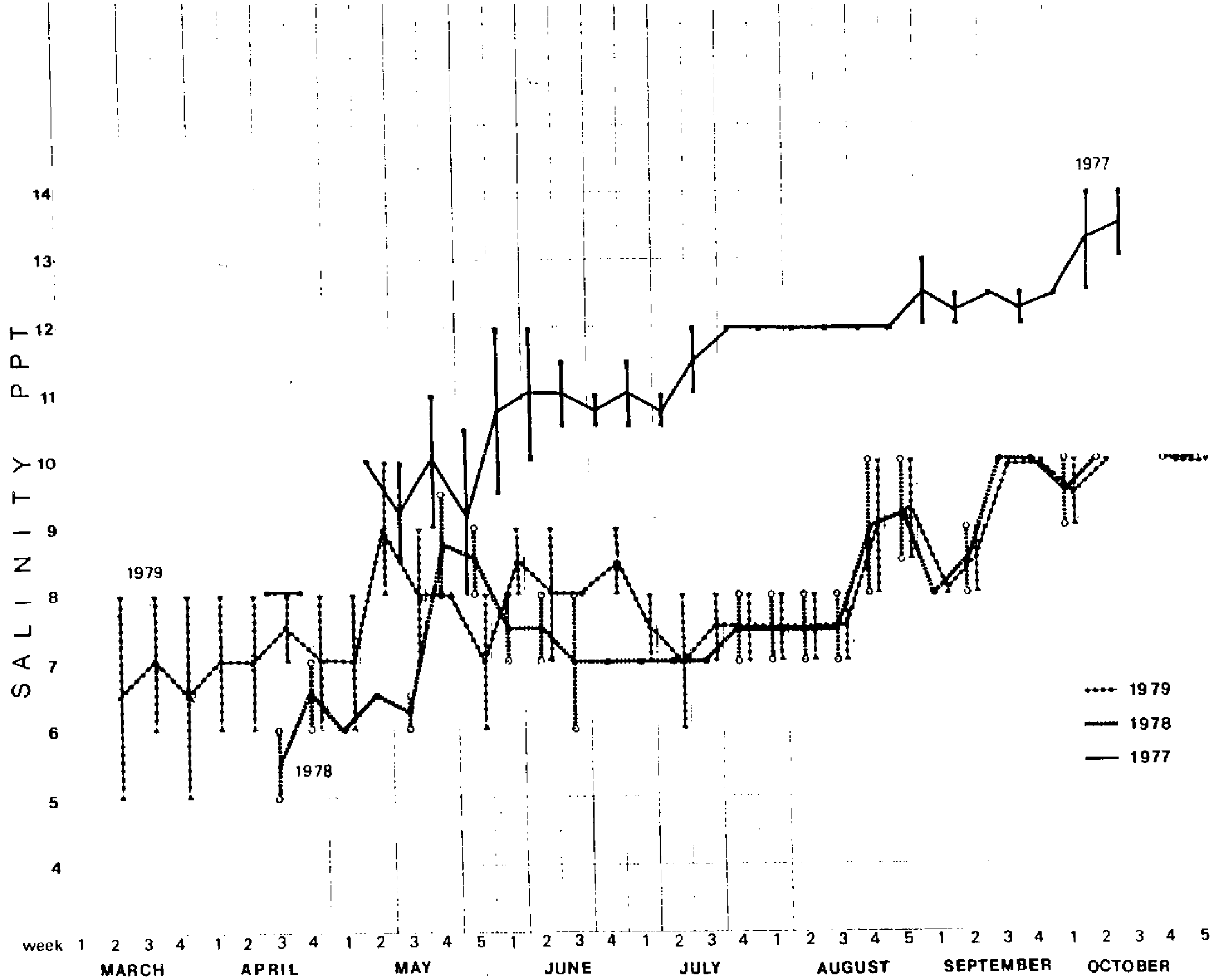


Figure 9. Weekly means and ranges of salinity of Choptank River water in the HPEL hatchery during operation in 1977 through 1979.

Hatchery production cost for seed oysters shown in Table 2 is therefore based on seasonal cost with the assumption that a state-owned or state-operated facility would probably use the facility and/or staff to conduct other research or to produce an alternate species (striped bass, shad, etc.). The annual operating costs, however, do give a better concept of the total investment for a commerial venture using hatchery technology of the size of the Horn Point hatchery. Data in Table 2 illustrate the variation in biological efficiency of producing oyster eggs, eyed pediveliger larvae, and plantable spat through variation in production costs that were encountered in the HPEL hatchey production process. The annual variation in biological production is more clearly illustrated by comparing Figures 10, 10A, and 10B. These figures summarize the weekly production of eyed pediveligers (clear bars) and accumulate the seasonal production (shaded bars) for 1977, 1978, and 1979. The production of pediveligers was used to illustrate a biological response to HPEL hatchey technology because the existing hatchery can produce any quantity of eggs it desires. However, the ultimate output of these eggs are pediveliger larvae, which result from the larval culture (two to four weeks) and algae production (four to twelve weeks) of labor and utilization of resources. These two hatchery functions are by far the most technical and expensive in terms of trained labor and energy resources. Plantable spat, then, are the product of the survival of the pediveligers when they are placed in the setting tray and during the subsequent three- to four-month growing procedure in the hatchery trays, raceways, crab floats, or in suspended culture systems. Figure 7 is a diagrammatic representation of the three major biological production features shown in Table 2 and in Figure 10.

The most striking variation in the three years of production from the Horn Point hatchery occurred in the total cumulative output. Trend analysis of the production data shows statistically significant differences among the three years. More importantly, the periodicity of a given year's output (Figure 10) provides some clues to some of the reasons for the highly variable production of pediveligers on an annual and on a weekly basis. During 1977 ambient salinity remained relatively low through the early part of May and June (Figure 9). Some difficulty was encountered with the spawning procedure, and larvae grew very slowly with high mortality during this period. Resultant production of pediveligers was very low. When an increase in salinity from 8 ppt to 10 ppt occurred during the early part of July, 1977, weekly production of pediveliger larvae exhibited a definite increase. This point is marked "a" in Figure 10. The depression in pediveliger production during the third week of July occurred because a production run (brood) had completed the setting stage, whereas the next growing brood had not yet begun to produce eyed pediveligers. Through the month of August and into September, production was very consistent with the exception of a complete absence of production during the third week of September ("b" in Figure 10). This was caused by a mechanical failure in the air conditioning system which killed many of the larvae and destroyed algal cultures required to maintain the growing pediveligers. As a result of a five-day failure in the air conditioning system, three weeks of pediveliger production were lost. After the equipment was repaired, two additional broods of oysters were spawned and hatchery production returned to the same level of output that had been experienced in July and August.

During 1978 early spring production was again delayed by the inability to spawn oysters at salinities below 8 ppt. By mid-May a rapid change in salinity (Figure 9) permitted successful spawning, high survival in larval culture procedures, and a high survival of eyed pediveligers to the setting stage. This event is marked "c" in Figure 10A. The ambient salinity then fell with a resultant decline in the production of pediveligers. A second peak in activity ("d" in Figure 10A) occurred during the natural spawning period for oysters in this geographical location. This spawning peak was followed by a decline in production due to decreasing salinity in ambient water. A rise in salinity during late

August and September increased the survival of the continuous runs of oysters spawned in the hatchery ("e" in Figure 10A).

During 1979 hatchery staff was completely unable to spawn oysters in the early part of the biological season because of low salinity conditions. Those eggs which were obtained were infertile and unusable for production-scale output. Finally, a few pediveliger larvae were produced in mid-June. The only significant production of eyed pediveliger larvae occurred in late July when ambient salinity finally rose to about 8 ppt ("f" in Figure 10B). Unfortunately this production of spat was subsequently destroyed by a human error that caused anaerobic water to be discharged from one of the dual water lines onto the growing spat. Production of pediveligers during late August was enhanced by a rise in salinity during the early part of that month (Figure 9). It is significant to note that even though there were dramatic differences in production during the three years, the numbers of eggs (1 to 2 x 10^7) placed in the production system each year were very similar, as were the operating budgets for labor, energy, etc. The efficiency of pediveliger production which will subsequently produce oyster spat was strongly influenced by environmental conditions of the hatchery location. Variation such as that encountered at HPEL during its three years of pilot production testing inhibits the capability of a hatchery production manager to predict facility output. Production costs of the resultant spat are variable at a given production budget, and during a year of low salinity in ambient waters, the cost of spat may climb to 20 times the production cost experienced in a "good year" like 1977.

Another source of variation was the biological performance of individual broods or spawning groups of oysters. During 1977 eleven groups of oysters were spawned and placed in the hatchery production process (Table 5). The eggs from these groups resulted from different combinations of males and females, and the yield of eggs per female was variable depending upon the time of year they were spawned, as well as on the source of the brood stock. As these eggs were reared in the HPEL larval culture process, various percentages of the eggs reached the eyed pediveliger larval stage (6-23%). During 1977 we observed that when eyed pediveligers were taken from the larval culture cone (Figure 7) and placed into spat-settling trays, there was a tremendous amount of difference in the percentage of eyed pediveligers that would attach and develop into spat. At that time hatchery personnel were concentrating on techniques to improve survival of spat that had attached and did not take accurate records of spat retention. By the end of the season we had determined that the spat settlement phenomenon was highly variable even with larvae produced by the same female oyster. However, we were only able to estimate the total percentage of the eyed larvae that probably had set. These estimates were developed from the total number of spat and boxes (dead spat) that were recovered from each of the groups of pediveligers handled in 1977. Therefore, we were only able to develop weak estimates of mortality from setting to the end of the procedure. During 1978 and 1979, our hatchery production work schedule included the additional task of recording the retention of eyed larvae in the spat-settling trays, the percentage of larvae that set, and the mortality of the newly attached spat during the growout procedure in the hatchery building or in the raceways. These observations permitted us to develop more accurate estimates of efficiency of the various production steps in the hatchery procedure (Tables 6 and 7).

During three years of conducting a given sequence of hatchery operations in the HPEL facility, all biological phenomena--production of eyed larvae, mortality of set spat, or survival of the spat through the hatchery procedures (Tables 5, 6, 7)--exhibited a greater variation and lower efficiencies than reported in the scientific literature. The complete lack of prediction of spat output from a given brood of eggs was probably the most frustrating yet technically important phenomenon encountered in the study. Three years of hatchery experience also demonstrated that mortality rates during pediveliger production and during growth of attached spat were much greater than suggested by Dupuy in his technical manual (1977) or by Hidu in the efficiencies listed in his presentation at a Delaware Symposium on the Feasibility of Oyster Hatcheries (1970; Figure 11). Figure 12 compares the HPEL hatchery mortality rates shown in Tables 5, 6, and 7 to those of Hidu in Figure 11. It is quite obvious that Hidu anticipated a greater survival of eyed pediveligers during setting and had assumed that once the spat had settled there would be no additional mortality. This was not our experience during pilot production testing. In certain instances, 75-95% of the newly attached spat were killed during the first three to seven days of attachment when suspended sediment in the Choptank River was very high (greater than 40 ppm) due to wind and wave action. The hatchery labor force was insufficient to keep the spat clean enough to assure survival during these periods of high suspended sediment.

The operation of the HPEL oyster hatchery did not follow a predictable production process. Because of tremendous impact of periods of low salinity, high suspended sediment, and variation in algal blooms, the contribution of specific broods could not be predicted when eggs were taken from the brood stock. Therefore, throughout a production season there must be changes in procedure to compensate for poor larval survival, low spat set, or high spat mortality if a facility is to meet a planned level of production. These decisions require the presence of a trained biologist and/or production manager on the staff. Biological data must be retrieved and analyzed rapidly so that decisions to correct the production process can be made. The labor involved in quantifying many of the biological parameters adds an excessive cost to the production of spat not considered by Dupuy, Hidu, Wilde, or others who are proponents of the high state of development of hatchery technology.

Once the oyster seed production year had ended (in October or November), the growing spat were transferrred from the raceways or hatchery trays to the natural Chesapeake Bay environment. Their survival under these conditions was the ultimate test of the efficiency and feasibility of hatchery technology as a management tool in Maryland waters. Hatchery-reared spat must be able to survive, grow, and reach market size during a reasonable period of time. Prior to the initiation of the HPEL hatchery program, there were no data in the scientific literature on the expected survival of large quantities of hatchery-reared spat on various types of bottom in the natural environment.

Portions of Bay bottom at various locations on the Eastern Shore of Maryland were carefully marked with concrete blocks and buoys. Then hatchery-reared spat of various sizes were placed on the plots during October and November. Spat of a given size group and on a similar type of cultch material were placed in one location. Additional locations in the immediate vicinity were used to plant larger spat or spat set on another type of cultch material. A variety of bottom types was selected so that spat were placed on a layer of oyster shell, on natural gravel bottom, on muddy oyster bars (which are typical of 90% of the oyster bars in Maryland), on a clay bottom (which usually has a low density of natural oysters) and on the mud bottom characteristic of any middle Atlantic estuary. The "mud bottom" is relatively soft, but comprises the remainder of the Chesapeake Bay bottom which is not occupied by oyster bars or by hard clay or sand. These mud bottoms are considered to be marginal for the culture of oysters unless shell or some sort of solid aggregate is placed on the bottom to make it more firm. However, one of the objectives of the Maryland management agency was to use hatchery technology to rehabilitate and repopulate these marginal bottoms which are presently devoid of oysters. Table 8 summarizes the ranges of survival that we observed in groups of hatchery-produced oyster spat after placing them in Maryland waters. Data are organized by the

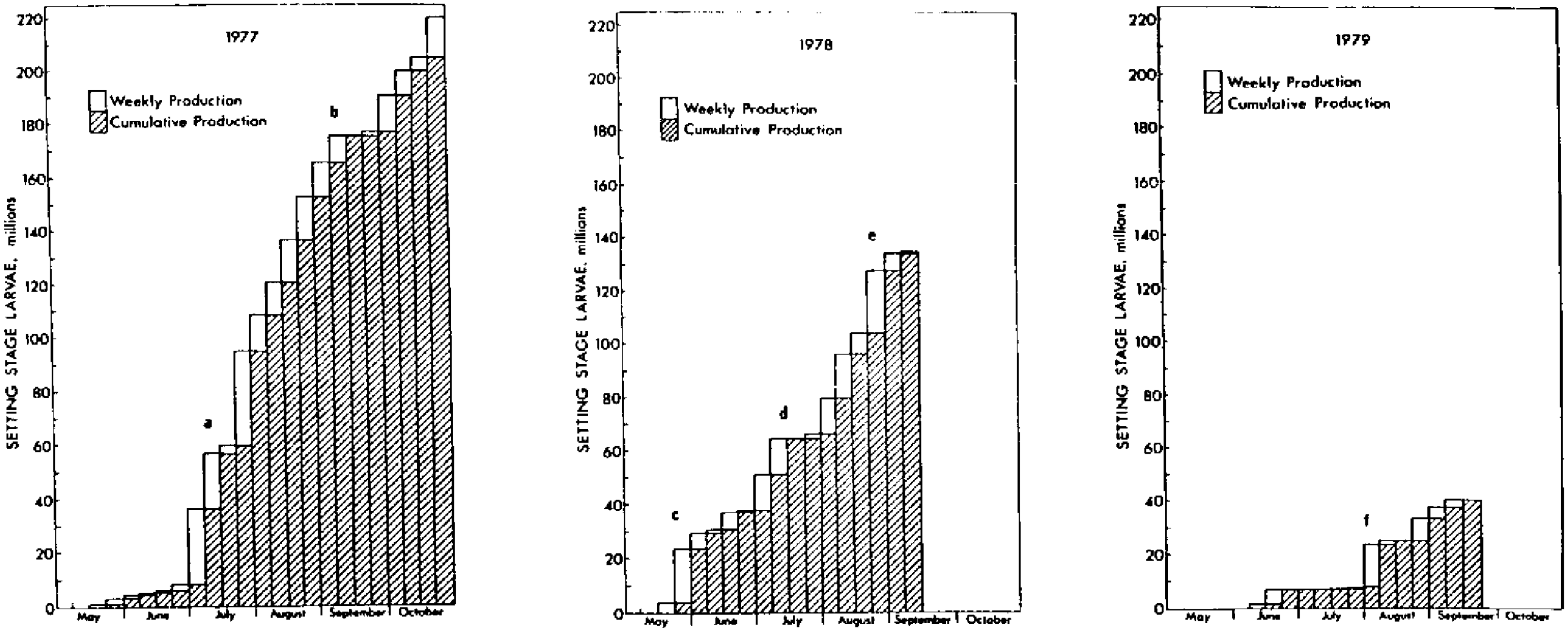
Table 3. Summary of seasonal hatchery costs for HPEL facility (Amounts x $1,000)

Item	1977		1978		1979		3-Year Mean	
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
Labor (7 mos.)	45.8	54.6	50.4	56.7	33.4*	46.7	43.2	53.1
Energy:								
Fuel	9.0	10.7	9.5	10.7	10.2	14.3	9.6	11.8
Electricity for building	8.4	10.0	8.5	7.6	8.1	11.3	8.3	10.2
Electricity for pumps	5.2	6.2	5.5	6.2	5.7	7.9	5.5	6.8
Supplies	8.5	10.1	7.0	7.9	7.1	9.9	7.5	9.1
Maintenance and repairs	7.0	8.3	8.0	8.9	7.0	9.9	7.3	9.0
Total	83.9		88.9		71.5		81.4	

*Understaffed in spat growout function

Table 4. Summary of annual HPEL hatchery operating costs with management and temporary seasonal labor (Amounts x $1,000)

Item	1977		1978		1979		3-Year Mean	
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
Labor (12-month temporary and management	93.1	69.3	101.1	70.5	79.9	64.0	91.4	68.0
Energy:								
Fuel	11.5	8.6	12.1	8.5	15.0	12.0	12.9	9.5
Electricity for building	9.0	6.7	9.2	6.4	10.0	8.0	9.4	7.0
Electricity for pumps	5.2	3.9	5.5	3.8	5.7	4.6	5.5	4.1
Supplies	8.5	6.3	7.0	4.9	7.1	5.7	7.6	5.7
Maintenance and repairs	7.1	5.2	8.5	5.9	7.1	5.7	7.6	5.7
Total	134.4		143.4		124.8		134.4	



10A

10C

10B

Figure 10. Hatchery production of eyed pediveliger larvae.

1977 HORN POINT HATCHERY PRODUCTION

	Brood Number											Total/ Average
	1	2	3	4	4A	5	6	7	8	9	10	
Source	Fox	Fox	Marumsco	Marumsco	Fox	Howell Pt.	Shell Hill	Royston	Howell Pt.	Shell Hill	Howell Pt.	
Date spawned	11 May	12 May	6 June	14 June	14 June	-	11 July	13 July	20 July	1 Aug.	10 Sept.	
No. Male	1	8	2	2	8	7	5	27	10	9	3	82
No. Female	1	1	3	1	2	7	4	6	47	16	8	96
Average No. eggs per female	50.0	63.0	30.0	60.0	16.5	32.6	31.9	43.5	8.5	30.5	29.4	21.19
Total no. eggs (x 10^6)	50.0	63.0	90.0	60.0	33.0	228.0	127.5	260.7	400.0	488.0	235.0	2034.5
Total no. eggs kept (x 10^6)	50.0	63.0	90.0	60.0	33.0	228.0	127.5	260.0	7.0	438.0	235.0	1591.5
No. eyed larvae (x 10^6)	0	3.927	5.91	10.92	5.75	31.445	29.64	43.776	1.375	48.06	39.702	220.51
Percent eyed larvae	-	6.0	7.0	18.0	17.0	14.0	23.0	17.0	19.0	10.9	16.9	10.84
Percent eyed larvae remaining in set trays	DATA NOT TAKEN DURING 1977											
Total percent set	-	30	50	50	80	80	75	50	75	80	75	69.3
Maximum no. set (x 10^6)	-	1.178	2.96	5.46	4.6	5.16	22.23	21.89	1.03	38.45	29.78	152.73
Estimated mortality	-	50	50	50	80	75	60	50	75	70	70	34.0
Estimated no. spat produced at end of season (x 10^6)	-	0.59	1.48	2.045	0.92	6.29	8.89	10.94	0.26	11.54	8.93	51.88

Table 5. 1977 Horn Point Hatchery Production Summary.

Table 6.

1978 HORN POINT HATCHERY PRODUCTION SUMMARY

	Brood Number												Total/
	1	2	3	4	5	6	7	8*	9	10	11	12	Average(1)
Source	Alabama	Alabama	Beacon Bar	Deep Neck	Del. Bay	Popes Cr.	Howells Pt.	Del. Bay	Va. (P175)	Del. Bay	Va. (P163, P181,P183)	Dixon	
Date spawned	1 May	8 May	2 June	9 June	16 June	19 June	23 June	5 July	6 July	14 July	7 Aug.	25 Aug.	
Total no. stimulated	-	±30	22	23	-	30	25	30	19	26	59	18	282
No. males spawned	1	4	2	7	2	2	4	2	5	2	27	5	58(2)
No. females spawned	2	4	5	12	1	13	4	4	3	9	27	2	79(2)
Percent spawned	Stripped	27	32	83	Stripped	43	32	Stripped	42	42	75+	39	54
Total no. eggs produced (x 10^6)	18.0	181.9	135.4	220.0	4.2	231.0	171.0	270.0	143.0	241.0	400.0	18.0	2,033.5 1,741.3(2)
Average no. eggs per female (x 10^6)	9.0	45.5	22.6	18.3	4.2	17.7	42.7	57.5	49.5	26.7	28.9	9.0	2,204(2)
No. eyed larvae produced (10^6)	0.0	32.8	7.64	0.1	0.03	11.11	16.4	0	2.5	31.2	24.7	0.0	126.5
Percent larvae reaching eyed stage	0	18.0	5.6	0.05	0.7	4.8	9.6	-	1.7	12.9	6.2	0	6.2
Percent eyed larvae remaining in setting trays	-	75	80	-	-	70	86	-	69	74	78	-	77
Percent total set total set	-	12	4	-	-	3.4	8.3	-	1.2	9.5	4.8	-	6.2
Maximum no. set (x 10^6)	-	22.7	6.1	0.01	0.1	7.8	14.1	-	1.7	23.1	19.3	-	94.9
Percent estimated spat mortality	-	75	80	-	-	80	95	-	95	98	98	-	88.0
Estimated no. spat produced at end of season (x 10^6)	-	5.7	1.2	0.005	0.05	1.5	0.7	-	0.09	0.46	0.39	-	10.1
Percent survival	-	3.0	0.9	-	-	0.6	0.4	-	0.06	0.2	0.09	-	0.5

*Poor quality, eggs discarded at 6 days.

(1) Does not include broods that failed to produce eyed larvae.

(2) Does not include broods that were stripped.

TABLE 7

1979 HPEL HATCHERY PRODUCTION SUMMARY

	Brood Number									Total/ Average
	1	2	3	4A	4B	4C	5	6	7	
Source	Shell Hill Dixon	Howells Pt. Dixon	Shell Hill	Flat Rock	Beacon	Hatchery F_1	Va. (P183) Sandy Hill	Va. (MSX) Sandy Hill	Mt. Vernon Wharf	
Date spawned	8 May	21 May	3 July	30 July	30 July	30 July	10 Sept.	1 Oct.	6 Oct.	
No. Male	6	15	5	2	2	2	4	3	4	43
No. Female	1	21	9	5	2	7	1	1	9	56
Average No. eggs per female	10.8	27.3	71.1	12.0	18.5	35.4	18.0	1.0	11.1	30.1
Total no. eggs (x 10^6)	10.8	573	640	60	37	248	18.0	1.0	100.0	1,687.8
Total no. eggs kept (x 10^6)	10.8	524.8	478.3	60	37	120	-0-	-0-	-0-	1,230.9
No. eyed larvae (x 10^6)	0.3	7.295	18.160	5.259	9.893	8.018	-	-	-	48.925
Percent eyed larvae	2.8%	1.4%	3.7%	8.9%	26.7%	6.7%	-	-	-	4.0%
Percent eyed larvae remaining in set trays	-	95%	85%	-	83%	82%	-	-	-	86%
Total percent set	-	1.3%	3.2%	-	22.2%	5.5%	-	-	-	3.0%
Maximum no. set (x 10^6)	0.3	6.930	15.436	-	8.211	6.575	-	-	-	37.152
Estimated mortality	80%	95%	99.9%	95%	95%	95%	-	-	-	93%
Estimated no. spat produced at end of season (10)^3	60	347	15	263	411	329	-	-	-	1,425.
Percent survival (eggs to spat)	0.5	0.07	0.003	0.4	1.0	0.2	-	-	-	0.1

type of bottom on which the spat were planted and by the size of spat at time of planting. The ranges in percent survival observed at one, two, and three years after the spat had been planted are shown. Survival was several orders of magnitude lower than we had anticipated. Occasionally our field samples failed to yield spat, whereas subsequent samples detected their presence. This variance in sampling is expected with variable survival of low numbers of animals under natural conditions. None of the hatchery spat reached harvestable size during the first two years on the Bay bottom. Approximately 30-50% of the surviving oysters had reached marketable size during the third year on the bottom. Our studies of spat survival should extend into a fourth year when a more valuable and more acceptable market-size oyster is produced from the hatchery-reared spat.

The unexpected low survival we found changed our original perspective on the usefulness of hatchery-reared spat in a state oyster management program. A total of 25.98 million oysters produced by the HPEL pilot production hatchery, the lab-scale hatchery at HPEL, the Deal Island facility, and cultchless oysters from the Ridge, Maryland, hatchery were involved in developing the data base. The 54 planting sites are separated into the type of bottom on which cultchless oysters or oysters on cultch were planted. Table 8 shows that seed oysters planted on a firm substrate, such as on a layer of oyster shell or a rock-gravel substrate, had the greatest survival. When hatchery-reared seed were placed on marginal bottom (that which would be available for private leaseholders), survival was very poor. Sand, mud, muddy oyster bars, and a clay bottom substrate were also poor locations for the survival of hatchery-reared oysters.

In table 9 the same field observations are organized to compare the survival of seed oysters set on oyster shell (dredged or fresh) to the survival of the Mylar cultchless oysters or semi-cultchless oysters that were set on chips of oyster shell or chips of clam shell. Presentation of the data in this form does not consider bottom substrate but focuses on the mode of hatchery operation and the survival of spat produced by three distinct hatchery procedures. The cultchless and semi-cultchless oysters were grouped together because the primary sources of mortality appeared to be (1) spat settling into the soft mud substrate and between the spaces of a shell base or (2) spat washing away by movement of tide, wind-driven currents, and other actions. Spat on shell did not seem to suffer losses due to these physical factors.

It is obvious that seed oysters less than 10 mm (1/2 inch) have virtually no value when planted in the estuarine environment. Yet this size oyster has been provided a growing environment in the hatchery for approximately two to three months. Since survival of small seed oysters is so low, a production hatchery would have to maintain spat in a protected growing environment for over 13 weeks. The size-specific survival of larger hatchery-reared spat dictates that any commercial oyster culture operation or state management effort that is going to produce harvestable oysters must plant oyster spat that are greater than 20 mm in size.

These field data were utilized in mathematical models by Lipschultz and Krantz (1978, 1980) which clearly showed the superior survival and economic advantages of producing spat on cultch as opposed to the cultchless production mode. In addition, estimates of production costs for cultchless oysters were found to be 45% greater than the production costs of semi-cultchless oysters or spat on shell.

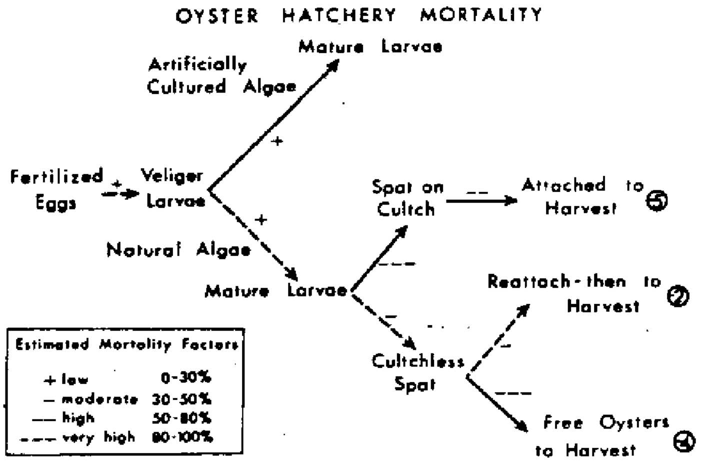


Figure 11. Estimated mortality factors at several oyster life stages using the available hatchery techniques. Estimates are based only on opinion of shellfish workers in the field. The dashed line indicates the sequence of techniques that probably will produce the least overall mortality from fertilized egg to harvest in the hatchery (After Hidu 1970).

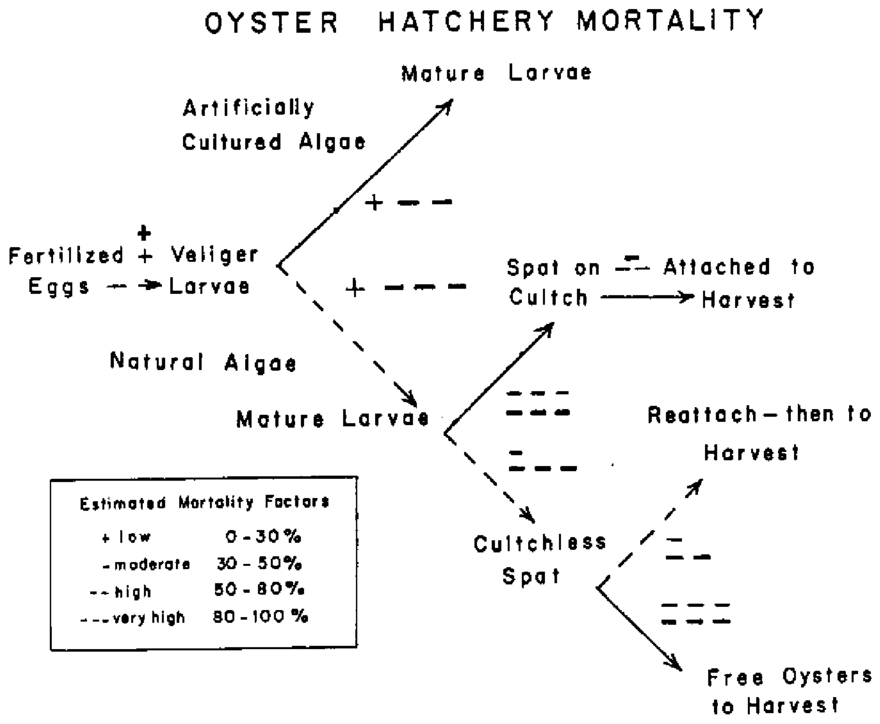


Figure 12. Hidu's estimated mortality factors at several oyster life stages modified to reflect HPEL hatchery experience.

Table 8. Estimates of the survival of hatchery-produced oyster spat planted in low salinity waters.

Bottom Type	Mean Spat Size (mm) at Planting	Number of Planting Sites	Total Spat Planted x10^6	Percent Survival at		
				One Year	Two Years	Three Years
Oyster shell	10	5	6.91	0-10	0-10	-
	25	10	3.01	20-94	20-30	-
Rock/Gravel	10	7	3.3	30-90	5-30	0-30
	25	6	2.85	75-90	25-50	-
Clay	15	2	1.7	0-5	0	0
	20	3	2.25	50	30	5-10
	40	2	0.75	30	10	5
Mud	10	1	0.001	20	0	-
	15	3	0.245	0-5	0-30	0
	25	1	.25	10	0	0
	35	2	.45	0-30	0-40	0-30
Hard sand	6	1	0.5	0	0	-
	10	1	0.75	10	0	-
	20	2	0.752	10	0	-
	30	3	0.752	30	0-10	0
TOTAL		54	25.98			

Even though survival of hatchery-produced spat on cultch is higher, growing spat on shell in the oyster hatchery occupies a large amount of physical space and retains a large quantity of sediment which must be carefully removed. The amount of labor required to handle spat on shell in the oyster hatchery destroys the cost-effectiveness of this technique.

Field survival data, as well as some of the practical difficulties encountered in handling spat on shell, cultchless oysters, or semi-cultchless oysters, all point to the need for the development of a spat-growing device which will improve the survival of spat in the hatchery and the survival of spat once they are placed in the natural environment. Developments of innovative technology could solve this major constraint, but some new technique for protecting and growing small spat is needed before hatchery-reared spat can become a cost-effective management tool.

There are few comparable data on the survival of hatchery-reared oysters when planted in the natural environment. Proponents of hatchery technology frequently point to the high survival of hatchery-reared spat when raised in suspended culture or in protected trays or cages (Hidu 1981). However, the impetus of the HPEL program is to utilize hatchery technology to rehabilitate the public fishery in the natural Chesapeake Bay system; therefore, the product of the hatchery (oyster spat) must be able to survive the rigors of the natural environment. Similar plantings of spat reared in the HPEL hatchery were made in Delaware, Alabama, and Virginia. Their survival was similar to that which we observed in Maryland. Mr. Frank Wilde, who has a long history of hatchery production in Maryland waters, reports that his cultchless spat seldom reach market size when planted on natural bottom (Wilde 1980). The primary reason for these losses is now thought to be predation by cownose rays and blue crabs. Some of Wilde's spat (approximately 500,000) were also planted in Virginia waters during 1979 and failed to survive more than two months during the summer months when crabs and fish were active. A complete loss of hatchery-reared oysters in Alabama was attributed to the influx of fresh water which dropped Mobile Bay salinity below 1 ppt for a three-month period. In Delaware, a soft mud bottom and high levels of turbidity at selected planting sites appeared to be responsible for high losses (76-85%) of hatchery-reared spat over a three-year growth cycle.

The ultimate cost-accounting procedure, and one which interests Maryland management agencies, is the cost of producing a bushel of harvestable oysters using hatchery technology. Table 10 is a comparison of producing 1000 spat in the University of Maryland's hatchery during 1977 and 1978 and the resultant seed cost per harvested Maryland bushel of these seed if they follow the same pattern of survival documented in Tables 8 and 9. The cost of spat production in 1978 and 1979 (Table 2) and low, variable survival shown in Table 8 forces one to place a value of $1.60 to $8.80 for the hatchery seed which produced a bushel of harvested oysters. The Maryland management agency would generate between 25¢ and 40¢ in direct tax revenues from these oysters. Therefore, hatchery-produced seed, if placed into the public fishery, would have to be highly subsidized through state revenues and sources other than revenues from the oyster fishery. If the spat were placed on private grounds an oyster farmer could obtain a significant profit from the $1.60 per thousand seed. Mean dockside price for oysters reared on private Maryland leases in 1979 was $8.97 per bushel.

In comparison to naturally produced seed either from the James River of Virginia or from the Maryland Shell Planting Program in 1976, hatchery-produced seed is more expensive. Determination of costs for seed produced by the Maryland shell planting program used prices that the Maryland Department of Natural Resources paid for dredge shell and for moving a bushel of seed on shell. Counts of spat moved in 1976 ranged from

Table 9. Comparison of Survival Between Cultchless Spat and Spat on Shell when Planted in the Chesapeake Bay.

	Spat Size at Planting (mm)	Number of Spat x10^6	Number of Planting Sites	Number of Sites with Survival	Range in Percent Survival at One Year
Cultchless or Semi-Cultchless Spat	5-10	2.45	5	1	-5
	11-20	4.84	11	6	5-90
	21-30	6.80	18	5	1-20
	31-40	2.6	6	5	1-30
Spat on Shell	5-10	4.0	2	1	5
	11-20	2.8	4	2	10-75
	21-30	2.36	7	5	5-46
	31-40	0.13	1	1	94

300 to 1200 spat per bushel of material. An estimated 33 percent survival of seed (bushel of seed yields a bushel of marketable oysters) was used to determine seed cost per harvested bushel. Our original hypothesis was that the higher seed costs would be offset by having a predictable quantity of hatchery-produced seed each year. This supply of hatchery seed would supplement the oyster industry in years when natural spatfall did not occur. Three years of production experience at HPEL demonstrated that hatchery procedures are highly variable and subject to the same types of fluctuation that probably influence the level of the natural spat set in the Maryland portion of Chesapeake Bay. Large quantities of seed were not produced at this location during periods of poor natural spatfall.

The production cost for 1000 seed oysters--or ultimately a bushel of harvestable oysters—by the University of Maryland hatchery is competitive with the seed costs from a private hatchery that was located in Ridge, Maryland, in 1975 and 1976. Oyster seed costs from this private hatchery are very high in comparison to production costs of seed by the HPEL operation in 1977 but more closely resembled HPEL production costs during 1978. A California hatchery quoted a market price for a comparable size (15-20 mm) of seed oysters at $14 per 1000 spat in 1978. In Table 9 the survival of the hatchery-produced seed from other sources is assumed to be the same as the University of Maryland hatchery-produced seed. Therefore, production costs per bushel of harvested oysters reflect the seed oyster cost, but not labor to plant and harvest the oysters.

In order to comprehend more thoroughly the intricate interrelationships of biological hatchery processes, various levels of survival in spat, and the costs of purchasing land and constructing a hatchery in terms of the variation in annual hatchery operating efficiencies, a linear computer model of the hatchery procedure was prepared and refined during the last two years of the project to reflect hatchery operation efficiencies encountered in 1977. This linear optimization model incorporates the variation in the various biological phenomena as shown in Table 5 for 1977 and was written to describe as accurately as possible the biological efficiencies of the hatchery process. The model was prepared to be integrated with other linear programs describing the economics of various investment schemes and a program to optimize plant design and operating efficiencies while minimizing the production cost of seed oysters. The program was extended to simulate a commercial business venture that would have used a hatchery similar to the one at HPEL to determine if this type of technology would be economically viable in the private sector. The logic was to assume that if the technology could be transferred to a private business venture, and it was highly probable, then it would be a cost-effective technique for use in the partially subsidized state management system. The performances of many private business ventures in terms of investment plans, management overhead schemes, and costs for capital construction and for labor are well known. These same types of data are not known for the Maryland state management agency. The assumptions needed to create a model for the existing Department of Natural Resources management scheme would probably be erroneous and very misleading.

The linear program model in its final form (Appendix 3) has withstood peer review and detailed scrutiny of other mathematic modelers as well as that of other oyster hatchery operators in the United States. The model predicts that 1977 operating efficiencies at the HPEL hatchery could be used by a vertically integrated oyster hatchery and wholesale marketing company to produce a gross profit (revenue which would be left after eliminating all capital debts, interest, and operating expenses) that would begin to accumulate about the ninth year of operation. However, if during the decade of operating, any change in the production output of the hatchery, such as that which occurred at HPEL in 1978 and again in 1979, would cause economic failure. Failure of any one brood of oysters to set and survive within the range of efficiencies observed in 1977 would likewise destroy the economic vitality of the operation. It is obvious from the HPEL production records presented in Tables 6 and 7 that the efficiencies of the 1977 operation were not duplicated each year; therefore, the model predicts that the HPEL hatchery could never be a viable business venture.

The computer model clearly demonstrated that sale of seed oysters to be planted by someone else was likewise not an economically viable industry. Most of the revenue was generated by sale of the commodity to the public consumer. The range of spat survival found by the HPEL study suggests that customers would probably switch to another source of seed oysters (natural set) after a few years of poor return.

A preliminary linear model of the HPEL hatchery developed in 1978 addressed the relative efficiency of using cultched vs. cultchless seed oysters in hatchery procedure (Lipschultz and Krantz 1978, Appendix 3). This model clearly showed the superior cost effectiveness of using oysters that were set on finely ground oyster shell or whole oyster shell as cultch. In addition to the economic predictions of the mathematic model, the evaluation of survival of several million cultchless oysters that were planted on the natural Bay bottom showed complete mortality in most of the plantings. Cultchless hatchery oysters cannot survive heavy levels of predation of blue crabs (Krantz and Chamberlin 1979, Appendix 4), softness of the Bay bottom, and heavy amounts of deposited sediment that are characteristic of the Chesapeake Bay. A shellfish hatchery to be operated to help sustain the public fishery in Maryland must use seed oysters set on cultch that will maximize survival on natural Bay bottom and the operation must be heavily subsidized by the state funds.

Table 10. Comparison of oyster seed costs for spat produced by oyster hatcheries and by exploitation of natural spatfall. Survival of seed from all sources is assumed to be the same as observed in Table 8.

Source	Year	Spat Cost $/1000	Seed Cost per Harvested Maryland Bushel (Dollars)
Hatchery:			
University of Maryland	1977-78	1.60 - 8.80	1.50-8.75
Maryland	1976	7.50	6.75
California	1978	14.00	12.60
Deal Island	1979-80	2.27 - 3.30	0.75* - 3.10
Natural:			
James River, Virginia	1977	3.00	2.36
Maryland Shell-Plants	1976	0.98 - 3.24	0.98 - 3.24

*Survival on concrete-coated wire not yet known for years 2 and 3. Calculation is based on survival at one year.

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Part II

A Management Advisory

Part II

MANAGEMENT ADVISORY ON OYSTER HATCHERY TECHNOLOGY FOR THE MARYLAND DEPARTMENT OF NATURAL RESOURCES

PART II

MANAGEMENT ADVISORY ON OYSTER HATCHERY TECHNOLOGY FOR THE MARYLAND DEPARTMENT OF NATURAL RESOURCES

Project Background

The reproduction of oysters in Maryland waters has shown a dramatic decline due to the impact of Tropical Storm Agnes and to other subtle factors in the Chesapeake Bay environment. Several of the more productive rivers where state seed areas are located exhibited some of the greatest declines: St. Mary's River, 81%; Broad Creek, 68%; Harris Creek, 82%; Little Choptank, 69%; Tar Bay, 97% (Figure 2) (Meritt 1977). Environmental conditions in the Maryland portion of the Bay changed so severely that reproduction or spat settlement did not occur in significant quantities between 1968 and 1980 (Figure 2). Even when a very high spatfall occurred in 1980, there were still vast expanses of once-productive oyster bars in the Potomac River, Chester River, upper Bay and along the Western Shore that received virtually no spatfall (Figure 13). These areas still require the planting of large quantities of low-cost oyster spat. Since 1968, depressed levels of oyster reproduction reduced harvests in specific portions of the Chesapeake Bay, and Maryland's oyster industry in these locations is experiencing economic hardships. Supplies of oysters are unpredictable, and high prices for local oysters have created narrow profit margins. The processors have lost their work force to other occupations. They are reluctant to modernize or expand their plants, and they are very conservative in their marketing efforts. Members of the Department of Natural Resources (DNR), the Maryland seafood industry, Maryland Watermen's Association of the Department of Economic and Community Development (DECD) and numerous federal agencies are aware of this decline in the viability of the Maryland oyster industry and are attempting to initiate remedial actions to stablize and enhance future oyster harvests. All of these groups have suggested the utilization of oyster hatchery technology to provide seed oysters to generate more raw materials for Maryland public and private oyster fisheries.

A recent review of oyster culture technology by members of a legislatively appointed task force, Maryland Oyster Resource Expansion Task Force (MORE), found that the feasibility of oyster hatchery methodology and the cost-effectiveness of the suggested techniques on a large production scale were virtually unknown. This same conclusion had been reached several years earlier by members of the Department of Natural Resources who had contemplated construction and operation of a production-scale oyster hatchery at Deal Island. They envisioned a facility large enough to sustain the Maryland oyster industry during periods of decreased spat settlement such as Maryland waters have experienced recently. During the planning process, administrators and biologists became acutely aware of the lack of valid data on production efficiencies and economic costs for producing oysters in the middle Atlantic states. The same group found no data on the survival and growth of hatchery-reared oysters on various types of Bay bottom characteristic of those found in the Maryland portion of the Chesapeake Bay.

All of the recommendations from various agencies for use of oyster hatchery technology as a management strategy for Maryland's oyster resource were accompanied by the very natural question concerning the cost-effectiveness and the potential biological and economic benefits from the use of oyster hatchery technology in Maryland. These individuals were sincerely interested in wise expenditures of public tax revenues to conserve the valuable oyster resources of the Bay.

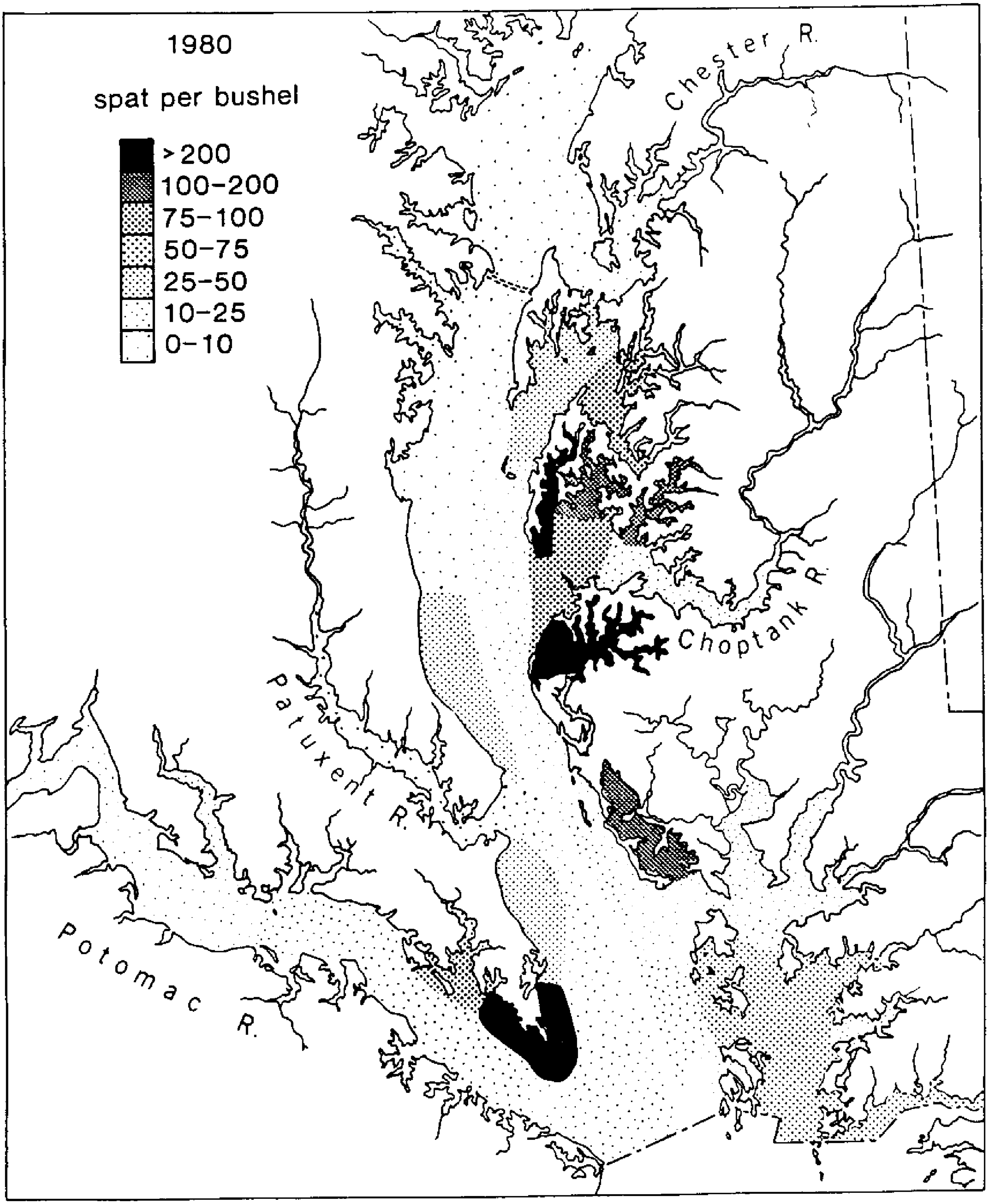

Figure 13. Geographical distribution of the 1980 spat set on natural cultch in the Maryland portion of the Chesapeake Bay.

During this search for information, the University of Maryland Center for Environmental and Estuarine Studies constructed a Shellfish Hatchery Research Laboratory and pilot oyster production facility near Cambridge. This facility was primarily financed by a grant from the U.S. Department of Commerce Economic and Development Administration and was built to participate in the rehabilitation of Maryland oyster stocks destroyed by Tropical Storm Agnes. Because of concurrent interest in hatchery technology, DNR provided funds for a research program at the HPEL facility to develop data on the biological and economic feasibility of operating a production-sized oyster hatchery in Maryland's unique estuarine environment. The research results and recommendations reported herein are an attempt to answer basic questions posed by resource managers in the development of a management strategy based on the use of hatchery-reared oyster spat.

The research objectives of the DNR contract included hatchery studies at Deal Island, a potential site for a large production hatchery. In 1977 an abandoned oyster shucking plant at Deal Island was used to grow spat in trays with flowing ambient Deal Island water. Growth, survival and meat quality of oysters grown at the Deal Island site were superior to the oysters grown at the HPEL site that year. In 1979 and again in 1980, the Deal Island facility was operated as a low-cost, low-capital oyster hatchery. Therefore, the management advisory on oyster hatchery technology will include comments and observations made on two different types of oyster hatchery technology: (1) capital-, labor- and technology-intensive, such as the HPEL facility; and (2) low-cost systems with appropriate or essential technology, such as is found at Deal Island.

Capital- and Technology-Intensive Systems and Low-Cost, Essential Technology Systems

The Horn Point facility is characteristic of a modern facility wih a high-capital investment, using the latest in engineering technology. This facility has complex temperature control systems, water quality control systems, air-handling components, and expensive fiberglass, glass and nontoxic plastic equipment.

The design concept for the HPEL facility was that it be operated on a year-round basis with a one- to two-month closure for maintenance. This production concept maximized the output of oyster spat from the facility and from a highly trained labor force. In Part I of this report, many of the details of biological efficiencies, production problems and facility costs encountered with year-round operation of this facility have already been addressed.

In contrast to the HPEL facility, the Deal Island oyster hatchery is characteristic of a low-cost, "Mom-and-Pop" operation. The Deal Island facility utilizes a minimal-cost building. All of the components of the facility were purchased from local hardware stores; therefore, repair parts are easily obtained from local inventories. Maintenance does not require factory-trained mechanics or skilled technicians such as are required at HPEL. Plant operation and maintenance of the Deal Island facility is an alternative work task for existing DNR field superintendents and staff biologists. The labor force at the Deal Island facility received no formal college training in biological processes or oyster culture. Their skills were learned through on-the-job training and instruction given by University staff. The Deal Island facility is a seasonal operation which maximizes the availability of natural food in the Deal Island water since phytoplankton productivity peaks during the summer months (June through September) the facility lies dormant during the rest of the year. This seasonal operational concept was the optimal solution for all oyster hatcheries predicted by the early computer model by Lipschultz and Krantz (1978).

Low-cost hatchery technology is highly amenable to the initial development of private oyster hatcheries in Maryland. Few individuals have the capital needed to construct facilities such as those at Horn Point. The Deal Island facility has an equipment cost of approximately $20,000 and can be housed in a 1000 sq. ft. building that would cost as little as $15 per sq. ft. The seasonal output of spat from Deal Island could equal that of the Horn Point facility if the proper cultch-handling devices and operational strategies are followed. Such a private venture could be operated by local watermen as an alternate to their participation in the public oyster and crab fisheries that sustain their livelihood (Krantz 1981).

Many of the biological studies described in this document occurred at both the Horn Point and Deal Island facilities. This provided a demonstration of the profound effect geographical location may have on the efficiency of the operation of a hatchery. Apparently, there are important yet very subtle characteristics of the water at any given site in the Bay that either enhance or deter growth of oyster larvae and spat. The temporal stability of the biological and physical systems at various locations in the Bay is very different. At Horn Point, changes in the natural phenomena were intense and there were long periods when the phytoplankton blooms and other components of water quality (sediment, dissolved organic compounds, phytoplankton, bacteria, BOD) were not suitable for the maintenance of larvae or survival of newly attached spat. At Deal Island, changes in these types of phenomena were virtually unnoticed, with the exception of a two-week period in 1980. Water quality at Deal Island was very stable with an ever-present, moderate level of sediment and an abundance of natural phytoplankton.

Both locations are influenced by the surrounding land mass and by local water uses. Even at the relatively isolated location of Horn Point, water quality is influenced by activities in the Cambridge area as well as short-term activities from other research groups at the HPEL facility. The Deal Island site receives water from a channel with a high tidal exchange rate and is not presently affected by local water use by seafood harvesters or pleasure boaters; however, obscure and difficult-to-define phenomena are often generated by other water uses, and many are known to play a major role in the efficiency of oyster hatchery operation. Therefore, the location of any future oyster hatchery must consider conflicting water uses as well as biological and physical characteristics of water supply for hatchery operation. Any management advisory must be site-specific and must include biological and chemical testing of water quality to describe algae concentrations, dissolved oxygen, BOD of sediment, sediment load and salinity regime as well as a small-scale growout study of oyster larvae and oyster spat at the candidate location. Once these data are obtained, a meaningful management advisory on a specific site can be offered.

Analysis of Pilot-Production Operations at HPEL

In the preceding technical summary of the HPEL project (Part I), the cost of oyster hatchery construction, hatchery operation efficiencies and production costs for seed oysters from the HPEL hatchery were presented in summary form. The physical plant and equipment for production of seed oysters as installed at Horn Point are typical of present state-of-the-art hatchery technology. This type of facility would be the probable work product of any current engineering attempt to design an oyster hatchery for capital construction consideration in the state of Maryland. The building alone has a high capital investment ($360,000, or $65/sq. ft. of floor space in 1974). When the various hatchery components of the capital investment are separated into their operational uses (Table 11), it is evident that the maintenance and replacement costs will increase this capital investment annual through repairs and equipment.

The HPEL oyster hatchery utilizes sophisticated equipment typically found in light industries of the U.S. These industries routinely use complex electrical control devices, large air-conditioning equipment, temperature control rooms and fiberglass containers for production of a marketable product. A facility of this nature would characteristically produce a product which earns from 300-1000% gross income above manufacturing costs. Unfortunately, the product of an oyster hatchery is an agricultural food item which in the United States traditionally produces a lower margin of profit than products from light industry. In fact, the present gross profit of U.S. agriculture ranges between 10-25% of product production cost. This level of return on investment is lower than the current interest rate charged by major capital lending firms or gained through state bond issues. Investment of expensive manufacturing technology in food products with a low margin of profit is presently considered an unsound business practice and poor management of public funds. In addition to this problem, oyster production from the HPEL high-cost technology yielded a profit so low that minor decreases in the annual production process would cause a commercial venture to lose money, or the management program to waste public funds.

Oyster hatchery technology of the type installed at Horn Point must use professionally trained staff and technicians with a minimum of a bachelor's degree. Therefore, this work force demands a slightly higher salary than most Maryland State classified employees in natural resource management. The continuous operation of the capital-intensive hatchery necessitates numerous instantaneous decisions of a biological, chemical or technical nature that cannot be handled by minimum-wage technicians. The complex temperature-controlled equipment and mechanical devices necessitate full-time employment of trained mechanics. Repairs must be made instantly to protect the investment in equipment and living animals and to maintain the sustained production capacity of the facility. This maintenance operation must be on a seven-day-a-week basis for at least ten calendar months a year.

The operation of a capital-intensive hatchery is conceived to be year-round to gain the greatest production output per capital dollar invested in the facility and per man-year of employment. This concept would create severe problems if staffed by personnel conforming to the Maryland State Classified Employee guidelines. Continuous operation necessitates seven-day staffing by trained technicians. Even the flexible nature of university research staff and employment regulations on daily workload, overtime and shift differential placed unbearable demands on the research staff and their administrators.

With the hatchery operations restricted to a seven- to eight-month period, the HPEL staff was expected to work seven days a week during the period of optimum biological conditions and to incur a tremendous quantity of overtime or compensatory time to be recovered during the other four months of the year. These personnel arrangements for staffing the facility with technically trained personnel on a seasonal basis are virtually impossible under the existing State of Maryland classified system. The problem of management of technically trained personnel in a production hatchery would be one of the major constraints encountered if the State of Maryland operated a capital-intensive hatchery.

Table 11. Component Costs for U. of Maryland Pilot Production Hatchery Building

Item	Cost/Dollars	Estimated Life
Building, 5600 sq. ft.	84,400	25
Electrical	42,500	25
Heating & Ventilation	52,00	5 - 15
Plumbing	4,000	15
Sea Water Plumbing	150,000	8
Hatchery Equipment	176,000	2 - 08
Installation Labor	±120,000	-
	628,900	

Assuming that a future hatchery would hire trained staff in permanent line positions and only operate for seven to eight months, the annual operating cost is virtually double the seasonal operating costs.* It is very important to note that all seed production costs in this paper are based only on seasonal labor and maintenance costs. Therefore, all seed costs should be doubled in vlaue to realistically stimulate the cost effectiveness of seed produced by a state-financed hatchery operation.

In our attempts to reduce oyster hatchery production costs, we observed that technical labor accounted for approximately 50% of the HPEL operating budget. Therefore, any major change in production costs would most likely occur by reducing the amount of labor or by eliminating the labor from culture methods. All hatchery refinements developed at HPEL and utilization of cheaper chemicals in the algae culture effort only changed the total operating budget by a few percent. Refinements needed are several orders of magnitude greater than those that have been accomplished after four years of pilot-production study. One of the most promising developments was the recent use of a new type of spat collector instead of oyster shell as cultch. This collector has been incorporated into an inexpensive cultch-handling technique which can be automated. The collector also provides a protected spat culture system that has been found to be badly needed by all oyster culturists. Attempts to operate the Horn Point facility during winter months demonstrated the need to switch to the seasonal operating mode because of the high cost of energy to maintain temperatures adequate for oyster growth. During these winter months, it was also found that the food supply in the ambient water of the Choptank River was not adequate to maintain growth of spat and adult oysters. This biological phenomenon placed an increased burden on the algal production unit, which could not produce enough load to raise a significant quantity of spat during the winter months. Since we were unable to use the facility continually, return capital investment per unit of production output was greatly diminished. The capital-intensive HPEL hatchery contained a large quantity of expensive heating equipment and was grossly over-designed for use in Maryland waters.

The most distressing finding in the evaluation of hatchery production cost was the great amount of variation in the production of seed oysters from the HPEL facility. In three years of experience, the range of spat production at HPEL went from 52 million spat at a cost of $0.0016 each in 1977 to a spat production of 1.4 million at $0.051 each in 1979. This variation occurred with use of the same facility, the same work staff and similar operating budgets. The observed variation virtually destroys the economic feasibility of utilizing hatchery technology to produce seed oysters for state management use or for sale to private industry.

Annual production of seed oysters was primarily determined by the biological efficiency of oysters grown in the HPEL facility (Tables 6, 7 and 8). The spat production capability of the hatchery could be strongly influenced by daily, weekly or annual variation in these biological efficiencies. Minor, and often undetectable, changes in ambient water quality had a dramatic effect on survival of spat. Even in the most efficient case of hatchery production (1977), the cost for seed oysters produced by the HPEL capital-intensive facility was not less than the cost of seed produced by the present state shell-planting program. Pilot-production studies at HPEL did <u>not</u> sustain the hopes of advocates of hatchery technology and hatchery biologists who had predicted that capital-in-

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*See tables 3 and 4, Part I.

tensive hatchery technology would produce a predictable and consistent supply of seed oysters for Maryland management needs. In the three years of HPEL production, data suggest that the same factors that controlled natural production of spat may also be influencing survival of spat in the hatchery environment. It is highly possible that these factors are also involved in spatfall variations in the upper, middle and lower sections of the Potomac, Patuxent and Choptank Rivers (Figure 14). The HPEL facility is located close to the junction of the upstream and middle portions of the Choptank River. This particular site receives only intermittent spat set of a very low density. The HPEL hatchery site cannot be used as a cost-effective supplemental supply of seed oysters during periods of poor natural spat set.

If we compare the cost of producing a bushel of harvestable oysters in the Maryland fishery by using hatchery technology to the costs of obtaining seed from other sources, we find the Maryland state shell-planting program the most cost-effective source of seed oysters. Table 10 (see Part I) shows the relative cost per bushel of seed produced by the University of Maryland HPEL hatchery compared to other commercial hatcheries in the U.S., as well as the cost of producing seed in the natural environment. James River seed oysters, often thought to be cost-prohibitive for use in Maryland waters, are the least expensive seed available in Chesapeake Bay. However, transportation costs from Virginia to Maryland destroy the economy gained from purchase of these seeds oysters.

It should be noted that the Maryland shell-planting program produces seed oysters at a lower price than James River seed during years when natural spatfall is relatively high. However, during these years when the cost-effectiveness of the Maryland shell planting program is greatest, natural oyster bars in the Maryland portion of the Bay probably receive more spat from natural set than they do from seed subsequently placed on them by the state management program. Capital-intensive hatchery techniques for the production of seed are definitely more costly in terms of producing harvestable oysters for the Maryland fishery than is the shell planting program. The HPEL hatchery compares favorably to two commercial sources that advertise seed oysters in this region. One reason for the great disparity of prices among the two commercial hatcheries and the HPEL hatchery is that the cost of Horn Point seed does not include any profit or payment of capital investment for the culture facility.

At present, revenues gained from landing a bushel of oysters in Maryland waters (35 cents severance tax) are not adequate to pay for the seed produced by either the state shell-planting program or the hatchery program. By this measure, neither program is "cost-effective." Both of these management practices can help sustain Maryland oyster harvests if the state legislature is willing to contribute general funding from other state revenues to subsidize the oyster fishery. If hatchery technology is used as a management tool to produce seed oysters, the great amount of annual variation in output will constantly change the level of subsidy per bushel of Maryland oysters, depending on the production efficiency of the hatchery operation. There can be no reliable prediction of the number of spat that a Maryland hatchery will produce in the coming year; therefore, it would be virtually impossible to meet a production quota to justify a given legislative appropriation. If management is cost-conscious of output from the hatchery, unrealistic quotas or production data based on good production years could cause an unfavorable image for hatchery technology during years of poor levels of output. In any case, it would be extremely difficult to justify the real amount of biological variance and cost-effectiveness to legislative auditors or to the general public.

Comparison of the HPEL Hatchery to Other High-Technology Hatchery Operations

While the HPEL research program was underway, there was a surge of awareness within the scientific community and public aquaculture interests in the U.S. for the need for pilot-production testing of the oyster hatchery concept. Several federal agencies, including Sea Grant, NMFS and the National Academy of Science alleged that oyster hatchery technology was highly perfected and ready for full commercial development by public interests. Some of the organizations that were involved in oyster aquaculture during this period are now releasing reports to the contrary (Hidu 1977; Henderson 1978). Proponents of the use of hatchery technology were encouraged by purely mathematical exercises on potential economic returns from hatchery operations. Liango and Imo (1978) presented a very favorable picture for the West Coast seed oyster industry. Their study, however, was based on biological efficiencies observed in a laboratory-scale hatchery operation. They expanded these production efficiencies and biological performances to an industrial-size hatchery for an investment program. Lipovsky (1980) reviewed several West Coast oyster hatchery operations that were attempting to meet the economic projections found in the scientific literature. He observed that all of the capital-intensive West Coast oyster hatcheries were experiencing economic difficulty. The general reasons for these difficulties were: (1) over-optiministic expectations of production and biological efficiencies; (2) periodic and unexplained mass mortalities of larvae, newly attached spat and algae in intensive culture systems; (3) amount of variance in size and growth rate of hatchery-reared spat; and (4) consumer resistance to purchasing a mixture of spat sizes. Essentially, Lipovsky's observations paralleled many of the phenomena that were identified during the HPEL pilot-production experience. It was the primary intent of the HPEL research program to avoid any such errors of scaling of laboratory studies and to base economic predictions and this management advisory on actual biological data and real production efficiencies.

Hidu (1970) emphasized the readiness of hatchery technology for the cultivation of oysters in Maryland. However, this observation were based on laboratory-scale studies of low-cost hatchery technology with an unusually large amount of skilled labor. Many of his projections shown in Figure 11 were based on a sparse number of replicates. His projections were not confirmed by the Horn Point experience with capital-intensive technology (Figure 12).

While the Horn Point facility was in the initial year of operation, Dr. John Dupuy of VIMS constructed and operated a privately financed hatchery in Ridge, Maryland. This hatchery was based on the design criteria set forth by Dupuy in 1973 and closely followed procedures from a comprehensive operational manual prepared by Dupuy and his co-workers in 1977. In fact, many of the recommendations and design criteria used by Dupuy are those upon which the Horn Point hatchery was designed and initially operated. Because of the poor biological performance observed at the HPEL hatchery, modifications were made so that biological efficiencies achieved in 1977 could be realized from the Dupuy-design hatchery.

In the technical description of a "capital-intensive" oyster hatchery by Dupuy and his co-workers, there is a prediction of the economic efficiency of oyster hatchery technology in Maryland.[1] Since the predictions of production and spat growth made by Dupuy

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[1] J.L. Dupuy, N.T. Windsor and C.E. Sutton, Manual for Design and Operation of an Oyster Seed Hatchery for the American Oyster Crassostrea Virginica. Special Report No. 142, Virginia Institute of Marine Science, June 1977, pp. 100-103.

et al. were not fulfilled at the HPEL facility--and since the Ridge, Maryland, facility went bankrupt--several comments are offered to explain factors that contributed to the discrepancy between Dupuy's predictions and observed hatchery performances.

One of the first assumptions that influenced Dupuy's economic analysis was that an oyster hatchery in Maryland could operate on a year-round basis. In the 1977 manual prepared by Dupuy and his co-workers, they stated that for at least two months of the year oyster larvae and spat did not grow, even though water temperatures were maintained at a level higher than ambient in their laboratory-scale hatchery. The cost of maintaining growth temperatures of large volumes of flowing water was underestimated in their production unit, and the fuel used was virtually wasted since no growth resulted from heating the water. The failure of the spat to grow was probably due to a lack of food in the winter Bay water and the limited capability of the Dupuy hatchery system to produce enough alage to feed the oysters. These same problems in year-round hatchery operation were encountered in the HPEL hatchery. The annual operating mode is definitely not recommended for hatcheries located in Maryland waters.

The second assumption made by Dupuy was that the hatchery would use a cultchless technique of producing spat that would yield 3/8" to 1" length seed oysters in a very short period (100-130 days). At HPEL the seasonal and annual growth of cultchless oysters was approximately 50% less than that alleged by Dupuy. Field studies that describe growth and survival of cultchless hatchery seed oysters planted in the natural environment at Horn Point, in Virginia and on the West Coast all found cultchless oysters to have very poor survival. These studies found that cultchless seed oysters less than 1" in size suffer mortalities from 80 to 90 percent within a few months. The economic feasibility exercise in Dupuy's manual is based on seed oysters that are too small to be of any economic value when planted in Maryland waters. The impact of such biological inefficiencies on the economics of a commercial hatchery cannot be ignored.

Two other areas where biological efficiencies of the Dupuy hatchery are inconsistent with observations made at Horn Point resulted from the mortality of eyed pediveligers when placed on cultch and from mortality during the spat-growth period in the tanks and growout flumes. Dupuy states that "conservative estimates of 50% of the set oysters successfully metamorphosed" and that "mortality during the growth period in the spat tanks and the growout flumes rarely exceeds 10%." The data presented in Tables 6, 7 and 8 indicate much greater levels of mortality in the HPEL operation.

Professional staff requirements listed by Dupuy[2] are highly questionable, especially since they do not include personnel to conduct administrative functions that are an essential component in any private, state or university facility. Secretarial and accounting personnel are required, especially when one is dealing with a staff of six people, to handle purchases, travel vouchers and payroll entries at the local level. In addition, Dupuy listed no plant maintenance requirements. Any facility with a financial investment of the magnitude of the Dupuy venture should be protected by routine maintenance and plant repair.

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[2] Ibid., p. 100.

In Dupuy's development of operating costs and income projections one finds several errors and underestimates that probably besieged the private venture during its first year of operation.[3]

Plant construction costs are valid only for the amount paid for the waterfront acreage ($3500/acre) on which the building was constructed, and construction estimates for the the building are erroneous. Present building costs for a similar oyster culture building that meets state and federal requirements for employee safety, health and well-being range from $28 to $32/sq. ft. These costs cover the basic building <u>without</u> any hatchery equipment. The cost of the HPEL hatchery as designed by the State Department of General Services and erected under a state-executed contract was $32.66/sq. ft. In Dupuy's economic projection, the cost of plumbing was not assessed, since it was stated that hatchery personnel could install all the piping. Installation of the HPEL hatchery plumbing was performed by Horn Point personnel, but we carefully accounted for the amount of labor that was required. For the Horn Point facility, we spent over $120,000 for installation labor to place over $300,000 of PVC sea water piping and specially designed hatchery equipment. The completed HPEL hatchery cost $628,900 or $112.30/sq. ft.

Dupuy's example of seed oyster hatchery cost and income flow (page 102) included no payment of the principal or interest for the construction of the hatchery building. This is unrealistic for a commercial venture and, of course, does not address the method by which a state agency would incur a capital operating cost. A state agency constructing the hatchery would have incurred an initial capital cost without principal and interest, but this cost would be charged to the total project. In a private venture, borrowed capital and interest would be charged in some manner against production of oyster spat and therefore affect the economic viability of the project. Most importantly the linear computer program model of the oyster hatchery prepared by Lipschultz and Krantz (1980) found that payment of the principal and interest on the hatchery venture was the major element in the annual operating expense for a commercial oyster hatchery. Income to meet these payments was strongly influenced by production efficiencies and by the number of seed oysters that would be produced for sale on a monthly basis. Any reduction in biological efficiency or production schedule below the 1977 HPEL hatchery performance would have prevented payment of principal and interest to a lending agency. Dupuy predicted that a net profit could be gained by August of the first year of the project. Our linear model found that net income could be made by the end of the ninth year, primarily because of the indebtedness of principal and interest to a lending agency. Dupuy probably addressed this indebtedness with an item in his cash flow listed as "rent." This implies that the property and special building was leased to the operating individuals and someone else held the mortgage on capital construction. It is in conceivable that any astute investor or state agency would consider building a capital-intensive building on someone else's property and then lease the building from them. Apparently, this capital cost and the resultant indebtedness from the construction of the oyster hatchery was not fully understood by Dupuy in his business operation of the Maryland seed oyster hatchery.

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[3] <u>Ibid.</u>, p. 101.

Linear Computer Models of Hatchery Technology

Pilot-production studies in the HPEL hatchery and the survival of 25 million spat that were planted in the Bay generated an enormous amount of data on the biological efficiencies of the hatchery process as well as production problems, technical constraints and expenditures of manpower and supplies to produce oysters. Complex interactions of all of these variables are very difficult to analyze. Simplistic approaches such as were used to estimate the cost of seed oysters in Table 2 (see Part I) can be prepared by simply dividing the number of spat produced in a given year by the total expenditures of resources. However, this approach does little to illuminate interactions of phenomena in the process. Within the scientific community during the past two decades, computer programming of production schedules and economic investment schemes has become a very skilled art and has been applied to almost all facets of American business. The University of Maryland has several linear programs that conduct economic analyses while optimizing production schedules, manpower utilization and blends of process equipment. These programs need the input of specific details of a given process and a format describing periodicity of uses of resources. Investment schemes for private development, amortization of capital equipment and even some assessment of the advantage of future price trends in a current commodity cost are included in the analysis package. The HPEL pilot-production hatchery program was a definite attempt to demonstrate the extremes and distribution of values for various biological efficiencies and hatchery processes. The variance in these data among years, among various broods, among various cones within the same brood, and on a day-to-day basis was recorded for phenomena, such as setting efficiency and setting cohort mortality. All hatchery production tests from 1976 through 1980 were used to create a linear program matrix of equations that defined the operational sequence within the HPEL oyster hatchery. Manpower and operational requirements for the production of oysters on various types of cultch in a cultchless mode were incorporated into production schedules. Linear equations described each of the biological phenomena and incorporated them in an optimization program. The optimization program then minimized a cost objective function within the constraints that had been described for the HPEL hatchery. The program also had the capability of changing the design of the HPEL hatchery and developed a theoretical optimum situation, making the best of all the described requirements so as to minimize the cost of producing seed oysters.

Our first model was intended to compare the production costs of raising cultched and cultchless oysters and to test the validity of mathematical descriptions of various hatchery functions (Lipschultz and Krantz 1978). Data for the calculation of the matrix coefficient in this model was taken from records of the HPEL small-scale hatchery that was operated in 1976, from the detailed description of a hatchery by Dupuy, 1973 and by Dupuy and his co-workers in 1977. These data on oyster hatchery performance in the Chesapeake Bay environment provided estimates of the range of manpower requirements for each hatchery activity, for oyster growth rate, oyster mortality rate and hatchery equipment costs. Dupuy's papers were used to provide the space and density requirements for growing oyster larvae, newly attached spat and "hardened" spat. The temporal sequence of oyster development was based on a review of the scientific literature, specific observations made in the HPEL small-scale hatchery and observations made by Hidu at the CBL hatchery.

The primary requirement of our first hatchery model was to determine optimum production schedules and equipment mix for a "theoretical" oyster hatchery that would operate in the Chesapeake Bay environment. We were then able to compare the HPEL hatchery and the Dupuy-design hatchery with the optimum blend of equipment selected by the computer model. In this initial activity, the computer model presented us a very surprising solution to hatchery operation. The analysis of all types of hatchery operations showed that skilled labor was the major cost component in all hatchery schedules. The optimum solution for hatchery operation in the Maryland environment involved the purchase of large amounts of equipment which remained idle most of the year, used in only two production pulses during the natural biologically active season for oyster growth. This finding deviated so dramatically from the existing philosophy that hatcheries should operate on a year-round basis that we asked the model to examine other operational modes. The computer model gave us time and sequence in activity levels for the production of 50 million oysters in the HPEL hatchery.[4]

As one example of the loss of efficiency incurred by using something other than an optimal hatchery operation we compared the number of carboys used in algae culture in the unconstrained, optimum solution to the number used in a solution constrained by our HPEL work schedule. (Figure 2 of the NSA paper shows the number of carboys that would be in operation during both hatchery production cycles.) In the HPEL operation plan the number of carboys was consistent in each time period, as was the labor and electrical energy needed to sustain the operation of these carboys. In the unconstrained mode, on the other hand, labor could be used to set up the carboys, after which the labor pool could switch to doing other activities, thereby reducing the number of trained individuals needed to operate the oyster hatchery. The constant, maximum use of capital equipment and capital facilities required less equipment and less space but far more labor, which increased total production costs.

The HPEL hatchery was initially designed to utilize cultchless seed oysters produced by the Dupuy technique. At the time of design (1972-1974) state-of-the-art hatchery technology and research trends suggested that the use of cultchless spat technology would increase the output of seed oysters from a given physical facility by many orders of magnitude. Tests of this theory in the HPEL pilot hatchery in 1975 and 1976 provided basic data for a computer analysis of the relative costs and efficiencies of the production of oysters set on cultch and cultchless oysters in the hatchery operation. In addition, the computer model contained data from two years of field observations on the survival of cultchless oysters when planted in the natural environment of Chesapeake Bay. The model showed that production cost of spat on cultch was 44% less than the cost for production of cultchless oysters by the Dupuy technique. Primary reasons for the difference in production costs lay in the space needed for growing cultchless oysters and in the greater survival of spat setting on oyster cultch as compared to survival on the Mylar substrate. There were also some cost advantages in labor requirements for handling spat on cultch versus removing the growing spat from Mylar and caring for them in Nestier-design trays.

When the cultched and cultchless hatchery modes were compared using the actual equipment and space available at Horn Point, it was demonstrated that more oysters placed on cultch could be produced from the HPEL hatchery than oysters in the cultchless mode. The constraint for producing cultched oysters in the HPEL hatchery was in the number of troughs needed to grow the attached spat. This was one of the primary reasons that the development of low-cost, outdoor spat-growing facilities (oyster race-

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[4] F.G. Krantz and F. Lipschultz, An Analysis of Oyster Hatchery Production of Cultched and Cultchless Oysters Utilizing Linear Programming Techniques, Proceedings of the National Shellfish Association, Volume 68 (June 1978), Figure 1.

ways) was initiated. By developing a large amount of oyster-growing space with a minimal capital investment, we were able to utilize more fully other capital resources and technical labor in the HPEL hatchery program. This change in production concept resulted in a significant increase in the production of spat during the 1977 operation of the HPEL hatchery.

As we gained more actual information on the changes in efficiency that were predicted by the model, we were able to develop more valid equations describing the general characteristics of oyster hatcheries, especially those larger than the pilot-scale HPEL facility. The model assisted us in changing some of the initial plans for hatchery operation and gave guidance for the collection and organization of biological data and plant efficiency data. The model also indicated where new research and technical improvements in the hatchery process could be of the greatest economic benefit. Our final use of the initial model was to define areas which needed more data from the actual operation of a production-level shellfish hatchery. The question of gains in economy that could be obtained from a larger hatchery had to be addressed; therefore, in 1978 and 1979 we attempted to increase the total production in the HPEL facility. As these data became available we began reformulating the model to make it a better predictive tool and a tool by which we could determine the total economic viability of hatchery technology for the Chesapeake Bay. As a result of these efforts, a publication on the "second generation model" was presented in 1980.

The final model was used to evaluate changes in design and in use of equipment and human resources. In all cases, output of the model was found to be consistent with observed changes once the model solution was introduced in the HPEL hatchery program. For example, the model recommended an increase in larval density as a mechanism to gain more cost-effective production. The model showed that larval density in culture cones could be increased concurrently with similar increases in supply of food, labor and more frequent cleaning of the cones. The differential mortality resulting from the higher density was less than the economic gain from more fully exploiting skilled labor and expensive equipment.

The next constraint encountered by the model was that if we fully used all cones to capacity, we would not have enough hot water to condition the growing broodstock to produce enough eggs to make full use of the HPEL hatchery. We addressed this constraint by changing the design and operation of the HPEL heat exchangers to increase the heated water available. The net effect of using the increased larval density was to increase the cost effectiveness by 26% and the output of market oysters from a theoretical vertically integrated oyster farm by 18%. Note that this increase was gained merely by changing the use and efficiency of existing equipment. Many other minor examples that contributed to changes of efficiency of 2-10% were found by the model. Because some of these changes could not be instituted in the HPEL hatchery we permitted the second generation model to develop a totally theoretical hatchery and compared it to the operation of the Horn Point facility.

The economic feasibility of the HPEL oyster hatchery and of the theoretical computer-design hatchery as a commercial venture were estimated using actual HPEL (1974) building costs at 12% interest, straight-line depreciation and optimized production schedules based on the biological and physical efficiencies of the 1977 oyster hatchery operation. Computer analyses showed that when both hatcheries were coupled to a harvesting operation, they were capable of a sustained gross profit after initial start-up. The theoretical hatchery demonstrated marked production increases by further refinement in the arrangement and temporal use of hatchery equipment. However, this profit relied on the maximum observed growth and survival of larvae and spat and the growth conditions that were encountered only in 1977. Salinity fluctuations, equipment failures and frequent changes in the growth and survival of larvae, newly attached spat and growing spat as we observed in 1978 and 1979 totally destroyed any opportunity for a commercial venture to survive economic constraints. The most important lesson learned from the pilot-production studies was that in two out of three years of pilot-production operation, a commercial venture with HPEL production records would have undergone bankruptcy before creating a positive cash flow.

The most important finding: the small difference between economic success and failure in commercial oyster hatcheries. Both the real and the projected hatchery were only marginally successful in recovering from failure of one production run or from any reduction in revenue. Both hatcheries indicated a very high risk of capital investment as commercial operations.

The model also examined different investment schemes, different interest rates, and many other variables that could affect a commercial hatchery operation. Some of these findings and data may be found in the six tables of our 1980 paper.

The modeling effort was enlightened in many respects. Initially it provided a focus for collection and organization of important production and biological information from the hatchery. The model permitted an analysis of those features which had the greatest economic impact on the total hatchery operation and commercial viability. By optimizing hatchery production schedules, the model suggested methods for alleviating constraints and allowed investigators to correct some production problems. The use of a theoretical hatchery design by the model assured the researchers that the HPEL hatchery was typical of the expected results from a commercial venture located in the same environmental conditions anywhere else in the Maryland portion of the Chesapeake Bay.

The modeling effort was supported primarily by the Maryland Sea Grant Program and the University of Maryland Center for Environmental and Estuarine Studies. However, the output and the intent of the model addressed all of the requirements of a DNR Management Advisory. Both publications on the models alluded to in this series provide information about the viability of oyster hatchery technology. The actual model and data bank are stored and can be reactivated upon negotiation to cover the appropriate manpower and computer expenses. The model can analyze any oyster hatchery in the temperature North American continent.

Evaluation of Alternate Strategies for Use of Oyster Hatchery Technology in Maryland

Many scientists and watermen have raised questions about the feasibility of using the hatchery to raise large numbers of eyed larvae or newly attached spat and immediately planting them in the Bay instead of enduring the costs of spat hardening and spat growth procedures which occupy hatchery space and require manpower and enough energy to pump large quantities of water. The use of a tremendous quantity of HPEL floor space for the growth of oyster spat make these questions very logical. If the same amount of time, manpower, floor space and plant facilities were applied to the production of large quantities of newly attached spat or eyed larvae, the increased numbers of spat could potentially compensate for the anticipated high mortality in nature. The computer model (Tables 1 and 2 of the 1980 Lipschultz and Krantz model paper) as well as hatchery data presented in Tables 6, 7 and 8 of Part I of this series contain information on biological efficiency and survival rates of various-sized oysters as well as some of the production data required to address this question. These data were used to reconstruct various production costs, labor costs and biological efficiencies of oyster larvae and spat at various stages in the hatchery production procedure shown in Table 12.

Selected for consideration were production of: (1) eyed pediveligers that would be grown in the hatchery and then planted in the natural environment to set on natural cultch on Maryland oyster bars; (2) spat two days after attachment; (3) "hardended" spat that are 4 weeks old; (4) spat grown in the hatchery for 13 weks; (5) spat grown for 20 weeks and (6) spat grown for 26 weeks.

Costs for producing larvae and spat were an accumulation of the activities and costs described in Table 1 as well as the resource requirements described in Table 2 of our 1980 paper. Survival and duration of growth of spat were the median values for the 1977 HPEL hatchery experience.

The HPEL hatchery cost for eyed larvae is very similar to a 1981 price list from a commercial hatchery in California. Note that the cost of producing eyed larvae is 35.7% of the cost of producing 26-week-old spat. A 26-week-old spat is considered the most desirable product of a hatchery in Maryland waters because it has a greater survival when planted in the estuarine environment (Tables 8 and 9). But some have questioned the value of retaining spat for such a long time when the field survival found mortality rates as high as 75-95% for spat planted on marginal Bay bottom. Many persons believe that these losses destroy the cost-effectiveness of keeping the spat for a 26-week period in the hatchery. The analysis in Table 12 tests this hypothesis by considering the number of oyster spat that would remain after one year in the natural environment. When the unit hatchery production costs for spat is adjusted for the observed field survival, 26-week-old spat are clearly the most cost-effective source of oysters for a state management effort, or for a commercial venture.

The second category of oysters in Table 12 is "spat at set" or spat that have just undergone metamorphosis. These spat are only two-to-four days older than eyed larvae and their cost is an accumulation of the activities and resource requirements (through X5) on Table 2 of our 1980 paper (Lipschultz and Kranz 1980). Production cost of spat at setting is 59.6% of the cost of the most desirable 26-week-old spat. The difference in cost between eyed larvae and spat at setting is primarily the labor needed to place cultch in the setting tanks, carefully monitor the sediment load on the newly attached spat and transfer the larvae to the spat settlement tanks.

The next category considered in the comparison is spat that are four weeks old, and in hatchery jargon are considered to be "hardened spat." These spat have developed enough shell structure to withstand movement and impact of other shell fragments. This is the stage at which the spat are usually transferred from the settlement tanks in the hatchery to growing tanks, raceways, crab floats, etc. (Figure 7). At some locations in the U.S., spat of this size are planted directly on the natural bottom or on oyster shell beds.

The difference in numbers of four-week-old spat from a given production run of eyed pediveligers is totally dependent upon biological phenomena and sediment-induced mortality. Data in Tables 6, 7 and 8 indicate that in certain years mortality between eyed larval stage and spat four weeks old was as high as 99%. In 1977, however, the values were approximately 45%. Even if the 1977 mortality values are used, the number of hardened spat would be about 1-5% of the number of eyed larvae that were placed in the setting containers. There is no reason to hypothesize that survival in a natural sys-

Table 12. Cost of Hatchery Oysters if Planted at Various Production Stages.

Oyster Stage	Eyed Larave	Spat at Set	Spat at 4 Weeks	Spat at 13 Weeks	Spat at 20 Weeks	Spat at 26 Weeks
Size (mm)	0.2	0.3	5	20	30	40
Unit Cost/1000	$ 0.07	$ 0.54	$ 0.97	$ 1.39	$ 1.61	$ 1.83
Percent of Desirable Size Cost	35.7%	59.6%	63.5%	68.2%	97.9%	100.0%
Survival at 1 year	± 0.2%	2.0%	5.0%	10.0%	25%	50%
Unit Cost at 1 year/1000	$32.58	$27.24	$19.35	$13.86	$ 6.43	$ 3.66

tem with a large variety and number of predators would be any greater than in the HPEL hatchery.

Production costs for spat at 13, 20 and 26 weeks were extracted directly from an activities code. This variable growing time was considered in the economic efficiencies of the HPEL hatchery and a theoretical hatchery. Mortality among the spat between 13 and 26 weeks is relatively low (less than 10 percent). The only production costs are for pumping water and the labor to clean sediment from the spat.

The computer model treated spat-growing costs as fixed costs rather than variable costs because of the constant demand for water and labor. However in Table 12 actual HPEL costs for labor and the water in which to grow spat are used. The water costs are based on 2 cents per KWH for the pumping efficiency of the HPEL pumps. There are no capital amortization or repair costs considered in the cost of water to grow the spat. Labor was calculated at $5 per hour and the amount of labor assigned to each of the spat categories depended upon the number of days needed to clean the spat. There was more cleaning activity assigned to the 13- and 20-week spat than to the 26-week spat because the smaller sized spat have a lower survival rate if covered with sediment and must be cleaned more often to obtain the survival shown in Table 12.

In the hatchery, eyed larvae are definitely the cheapest product, with 26-week-old spat being several orders of magnitude greater in cost. The important feature that influences the ultimate impact of the hatchery product in a resource management strategy is the mortality of the hatchery product in nature. Biological efficiency is rarely considered by individuals who have suggested placing early-stage oyster larvae and spat into the environment. Survival at one year was selected as criteria for comparison, since survival rate of 4-, 13-, 20- and 26-week spat have been demonstrated in the HPEL hatchery. Survival of these spat ranged from less than 0.1% to 4%; therefore, 2% was arbitrarily chosen as a mean figure. Eyed larvae have never been placed into the natural environment, primarily because the mortality rate within the hatchery under controlled conditions is so high (50-95%). In laboratory studies of the effect of sediment and water quality on the attachment of eyed larvae, students have demonstrated less than 1% survival of spat which attach to surfaces covered by ambient levels of turbidity found in Choptank River water. Attachment to surfaces is prevented by benthic organisms, especially barnacles and tube worms that compete for biological space. A recent publication by Steinberg and Kennedy (1979) describes predation of eyed oyster larvae by filter-feeding components of the benthic community. For these reasons, a generous figure of 0.2% survival for one year was assigned to the eyed larvae.

Eyed larvae are by far the most expensive source of harvestable oysters at $32.58/1000 (over $10/bushel of harvestable oysters), whereas 26-week-old spat produce oysters that may provide a "cost-effective" bushel of oysters on private bottom or in the public fishery. The cost of using eyed larvae and newly attached spat in a management program is ten times more expensive than the use of 26-week-old spat.

In review of the exercise shown in the above table, it is clear that proponents of releasing eyed larvae and newly attached spat failed to consider the impact of mortality imposed by the natural environment. In the management of trout, salmon, large-mouth bass, muskellunge and white shad fisheries throughout the United States, the same theory that the release of high numbers of small and delicate life stages was a cost-effective management tool has been disproven. The salmon hatchery experience on the West Coast exemplifies the experience of many hundreds of man-years of hatchery effort aimed at resource management. Initially the salmon were captured, the eggs fertilized and released into the river systems. Techniques progressed where the eggs were hatched in containers using natural flowing water, and newly emerged sac fry were then released. However, very few salmon appeared in lakes, streams and other areas where there were no natural spawning areas. Attempts were then made to release a fingerling fish that had initiated feeding. Though approximately two inches in length, these fingerlings-- it was soon learned - - that served only as forage for endemic predators. Years of search, of marking and releasing various sizes of salmon, were needed to show that pre-smolt and post-smolt fish provided the best return to the natural fishery. These stages required several months of feeding and intensive labor and occupied a large amount of hatchery space. However, the ultimate cost-effectiveness of the hatchery's contribution to the fishery determined the decision to use life stages with a higher survival value, though they prove more expensive in the short term.

A similar biological situation exists in the survival rates of hatchery-reared oyster spat and larvae in the Chesapeake Bay. Data in Table 1 should lay to rest the question of releasing eyed larvae and newly attached spat into the natural environment. The contribution from these life stages is certainly not cost-effective.

Collection of Spat from the Natural Environment

Many critics of hatchery technology point to the high cost of equipment and trained personnel required to produce a relatively limited quantity of spat. They suggest developing techniques to collect spat from the natural environment, especially by using suspended cultch contained in various devices. In 1979 the University of Maryland Sea Grant provided funds to evaluate the biological efficiency and production costs of collecting spat from the natural environment at four locations in Chesapeake Bay and at one site in Chincoteague Bay. Spat collection devices were placed on the bottom or suspended in the water column. The details of this study are contained in a Sea Grant technical report[5]

The project found that any spat collection device is dependent upon the natural environment and will produce an unpredictable suppy of spat during a given year. The same mechanisms that enable successful spat set to occur on natural oyster bars also control the deposition of spat on collection devices. Additionally, the study found that collection devices attached large quantities of fouling organisms. These organisms (tube worms, bryozoans, barnacles) completely occluded the surfaces of the devices and deterred efficient spat collection. Sediment from the natural water column rapidly accumulated and collected on the devices. The levels of sediment observed on the collectors had been shown to deter spat settlement in HPEL hatchery experiments. During the study another deterrent to cost-effective use of suspended collection devices surfaced. Several small thunderstorms and one tropical storm ("David") destroyed between 60% and 70% of all collectors involved in this study. These losses could have created severe economic difficulty for a private business venture relying on natural spat set.

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[5] George E. Krantz and Harold A. Davis, Biological Efficiency of Spat Collection Devices Placed on Oyster Seed Areas in Maryland, Maryland Sea Grant Research Note, UM-SG-TS-80-07.

Detailed evaluations of labor and materials cost for collection of spat from the natural environment found that collection of spat from the natural system was not as cost-effective as the state shell-planting program or as seed oysters produced by a capital-intensive hatchery such as the Horn Point facility. The collection efficiency of cultch material placed on the bottom and the efficiency of the same materials in the water column were approximately the same, whereas the cost of the suspended collection material was several times greater than the cost of the material placed on the bottom.

A laboratory study examined the relative efficiency of various types of spat collection surfaces. Fresh and dredged oyster shell were among the best collectors, and differences were few found between types of shell. One of the most cost-effective collection devices was a concrete-coated wire frame developed to stimulate a device recently produced in France.

Low-Cost or Appropriate Technology for Maryland Oyster Hatcheries

Studies at the Chesapeake Biological Laboratory (CBL) by Hidu and his co-workers, at the Horn Point Environmental Laboratories, in private Maryland oyster hatcheries operated by Wilde, Chambers and Dupuy, and at the DNR Deal Island facility have all focused on the same types of biological information oyster hatchery technology to be implemented in the immediate future in Maryland. Attempts to use the same biological information and procedure in a large corporate venture that is capital-intensive, with modern engineering technology, have all met with economic and biological failure. On the other hand, successful hatchery operations and those which have remained economically viable during the past decade have all employed low-cost technology (Mathiessen 1979; Mann 1979). Successful hatcheries in North America use low-cost building structures and have a minimum investment in capital equipment and electronic control devices. Hidu and his co-workers in Maine have perfected several small-scale hatcheries for that area. A description of the planned development of this technology can be found in "A Development Plan for Maine's Aquaculture Industry" (anon. 1980). A similar plan could be developed and implemented within Maryland Coastal Zone Management, Department of Economic Development or by special legislative appropriation. Such a plan should also take advantage of oyster hatchery development experiences in California, Washington, Oregon, Hawaii, Louisiana and Massachusetts.

The Deal Island facility—an abandoned oyster-shucking house converted into an oyster hatchery—provides an excellent example of low-cost technology. There has been a minimal amount of capital investment in real estate and building construction. By using an existing commercial operation located immediately adjacent to the water, many legal and social problems are circumvented. The need for acquiring commercial zoning on waterfront property was eliminated. Most permits for water use and water discharge exist from the previous fisheries operation. The problem of right-of-way to the property and access to the water are solved by the deed to the property. The Deal Island facility utilizes a building which is actually larger than its immediate needs. The operation could be housed in a structure between 800 and 1500 sq. ft. if the spat-growing operation were placed outdoors. Items to conduct hatchery operations have been furnished from the inventories at the HPEL laboratory and the state shellfish propagation organization. These items appear in Table 13 and have a total purchase cost of around $19,820. Cost for capital equipment and installation can be compared to the HPEL capital-intensive technology listed in Table 12. The probable production of spat from the Deal Island facility at this level of investment is 20 million viable spat per month of operation. Since the facility operates only during June, July and August, only 30 million plantable spat (20-30

Table 13

Hatchery equipment for a Small Oyster Hatchery at Deal Island
40×10^6 Setting Stage Larvae/Month $\pm$ 20×10^6 Spat/Month

Item	# of Items	Unit Cost ($)	Total Cost x $1,000
250-gal. larval tank	8	240	1.92
Trays, 4' x 8'	24	75	1.80
Wet tables, 3' x 6'	2	200	.60
Algae tanks, 4' x 8'	2	200	.40
Tables	2	150	.30
Carboy rack	1	40	.40
Carboys	8	25	.20
Lights	24	8	.20
Air pump	1	1,500	1.50
Water heater	1	1,200	1.20
Heat exchanger	1	1,600	1.60
Filter units	4	150	.60
Microscope	1	1,200	1.20
Pumps	2	600	1.20
Piping			4.00
Selves			1.00
Steam cleaner			.50
Buckets & chemicals			.50
Cultch			1.50
Miscellaneous lab supplies and filters			3.20
			19.82

mm) per season can be reared. With modification to the existing hatchery equipment and installation of additional raceways or finger piers, the Deal Island facility could produce as many as 50 million plantable spat each summer. Utilization of the concrete-coated wire spat collector may double this estimated capacity.

The low-cost hatchery design at Deal Island is best contrasted to the Horn Point design by a recent article entitled "Appropriate Technology" by Reilly in September 1979. Reilly categorizes all U.S. technology as moving along one or two pathways:

> The first, characterized by ever-more complicated, capital-intensive, and automated processes, includes such items as mini-computers, agribusiness combines, SST's, automated automobile assembly factories, hugh chemical complexs, and nuclear power plants plants . . . .
>
> The second pathway calls for no less creativity than the first, but seeks to develop similar, smaller, more flexible technologies which require less capital and generally place less of a burden on an area's natural environment and societal framework. Products of this technological track . . . have been called small-scale, light-capital, intermediate, or socially-relevant technologies . . .

The low-cost hatchery described in the above paragraphs and in this report is highly recommended for use in the production of seed oysters for Maryland's industry. Deal Island has already produced two very cost-effective production runs of spat (Table 10). The operational concept of a low-cost facility is to use it only on a seasonal basis when ambient water temperatures are ideal for oyster growth and survival. This eliminates the need for supplemental feeding, electrical energy and complex controls to condition oysters out of season or to grow large quantities of algae to feed larvae and spat. Seasonal farming has always characterized agriculture. For each crop there is an appropriate season to plant, grow and harvest crops to obtain optimum return from production costs and investment in farm equipment. One can grow crops outside these proper seasons only with a great expenditure of capital equipment for things such as greenhouses, special heating systems, continuous labor and expensive control systems. Oyster culture is simply another form of farming, farming done in water. The same seasonal concept that applies to agriculture applies to the operation of an oyster hatchery and oyster growing systems.

Low-cost, appropriate technology eliminates the need for a culture facility with a complex algae culture facility and skilled labor to produce food for the oysters. By eliminating the algae culture facility, savings of about 25-40% are realized in labor. The capital investment in the facility is reduced by about 25%. A small-scale algae culture operation can be used as a backup system. Perhaps the most cost-effective approach for immediate implementation of oyster culture technology in Maryland would be to use the existing HPEL algae culture capability to prepare large quantities of algae and concentrate this aglae in paste form. This reserve of algal food can be kept in a refrigerator and used to supplement the diet of growing larvae and spat in case the natural food supply at a given site undergoes a natural suppression. A severe decrease in food concentration occurred during the late summer of 1980 at Deal Island for the first time in three years of operation. Two other supplemental food sources are dried algae, which is commercially available from several mariculture firms, and dried yeast which is a marginally acceptable food for the continued growth of larvae, but an excellent food supplement for low levels of natural algae such as occur in Chesapeake Bay.

Any low-cost oyster hatchery facility must be located in an area proven to have good water quality and adequate food supply. These attributes greatly influence larval growth, larval survival, spat set, spat survival and spat growth. All poor biological efficiencies and low survival of larvae and spat encountered at Horn Point would have been greatly improved by proper site selection. A general rule for the location of an oyster hatchery facility is to be close to an area where there is good natural spat set, growth and survival. Historical data on the location of natural spat set are available in the Annual Fall Survey of Spat Set in Chesapeake Bay* and in Oyster Spat on Natural Cultch in the Maryland Portion of the Chesapeake Bay[6] (Meritt, 1977).

The results of two bioassays conducted in 1980 (Ref. 80-151 HPEL) and in 1979 (Ref. 79-50 HPEL) show the advantages of growing oyster larvae and spat at a candidate hatchery location and comparing the performance to a known culture process. In these bioassays, adult oysters were spawned at Horn Point, and equal quantities of eggs were transferred to Deal Island and Crisfield, two possible sites for oyster hatcheries. An equal quantity of eggs were kept at Horn Point. At Deal Island and at Crisfield, the culture process used only the natural food supply in the ambient water. At Deal Island larval development was more rapid with a shorter larval culture time, and therefore at a lower production cost. Spat settlement at Deal Island was also higher and occurred in a shorter time period. In fact, the test broods of larvae had completely set and a new group could have been initiated before larvae from the same group of eggs set at Horn Point. The growth of larvae and newly attached spat at Crisfield was very poor, even inferior to that observed at Horn Point. The 1980 bioassay report results of these comparative larval growth studies and illustrates the need for a biological assessment to determine suitable locations for oyster hatcheries in Maryland. It is strongly recommended that any candidate site for a public or private oyster hatchery have a similar type of evaluation conducted for a full year prior to the investment of any capital for building, land or equipment.

As part of the development of appropriate technology for the growth of oysters in Maryland, additional research is needed to develop a suitable low-cost spat setting substrate which will permit subsequent growth of seed oysters in a protected environment so as to maximize the cost-effectiveness of investment in the oyster hatchery. The preceding description of the concrete-coated wire collector is an example of one type of technology which should meet these needs. Plans for development of the Deal Island facility include the placement of finger piers in the channel immediately adjacent to the hatchery building. This channel receives an excellent tidal flush in both landward and bayward directions. Finger piers can become the hatchery spat-growing system simply by suspending trays of oyster shell containing spat or concrete-coated spat collectors from the finger piers. This reduces demand for space in the oyster hatchery and completely eliminates costs of pumping water and labor to clean sediment from the spat once they have attached. It is estimated that the overall savings in labor to produce spat at Deal Island would be 65-75% over that of the HPEL hatchery. The implementation of the concrete-coated wire collector at Deal Island can maximize the output of spat from the existing larval culture facility. The wire frames can have 2,000 spat attached to the 18 sq. in.

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*Published annually by the Maryland Sea Grant Program.

[6] University of Maryland Center for Environmental and Estuarine Studies Special Report No. 7, February 1977.

wire surface. These frames can be placed on finger piers at Deal Island which may be 8 feet long and will have at least 4 feet of water depth under them. One finger pier can hold as many as 325,000 spat, and with ten finger piers, the facility has the capacity of growing 3.2 million spat. If the growth of the spat at Deal Island is as good as that observed in 1978 and 1980, two crops of 3 million spat can easily be produced from the finger piers. Also, 2-5 million spat can be grown in the existing troughs inside the facility.

The wire frame spat collector is also ideal for utilization in the raceway system such as that found at HPEL. Raceways, 3 feet wide and 100 feet long, can hold 390 frames or approximately 800,000 spat. If the hatchery production mode is such that spat are being produced as seed oysters that will be removed from the frame when they reach approximately one inch and distributed on the natural bottom, each raceway would be capable of handling 1.2 million spat and the finger pier facility at Deal Island would be capable of holding a total of 5 million spat of this production type at a given time. The numbers of hatchery-reared spat that could be produced from the HPEL raceways (15 million), on the Deal Island finger piers (10 million) and inside the Deal Island facility (5 million) are somewhere in the range of viable hatchery effort. This program can be implemented in 1981 with a minimum investment in operating funds for wire frames and expendible supplies and no expenditure for capital equipment.

A distinct advantage of the Deal Island low-cost technology is that the existing DNR work force could operate the hatchery. This present work assignment covers technical assistance to the shell-planting program and seed oyster planting efforts. This activity occupies the time commitment of DNR field staff during early spring (March-June) and in the fall and winter months (October-December). At other times their services are minimal. These personnel can be trained in a matter of months to rear larvae. The Deal Island facility has already been operated by DNR personnel with a minimum of instruction during 1980 and 1981. The facility has a very low maintenance requirement. There is no need for highly skilled maintenance personnel capable of handling steam boilers or complex electrical equipment, since all of the hatchery components are of simple PVC construction, easy to maintain and move.

Development of a Concrete-Coated Wire Spat Collection Device for Use in Oyster Hatcheries

The concrete-coated wire collector has already been shown to be a valuable device for collection of spat in the natural environment (Krantz et al. 1980). The wire collector proved to be a very light and easily handled collector (about 10 lbs.) as opposed to shell bag collectors which became fouled and heavily laden with sediment and reached a weight of 80 lbs. by the end of the three-month field collection period. One attribute of the wire collector is a large surface area which exposes attached spat to at least two dimensions of flowing water. The relatively narrows columns of coated wire prevent sediment accumulation since slight movement of the collector washes sediment from the surfaces. Because the wire collector attract a large quantity of spat, it is the most cost-effective technique for collecting spat from the natural environment.

While field studies on the concrete coated collector were being conducted, concurrent laboratory studies of the settling efficiency on various types of cultch proved the wire collector superior to other types of cultch for collection and subsequent survival of spat in the HPEL hatchery system. The wire collector was light, easily handled, contributed no debris to the spat settlement tanks and was extreme attractive to setting larvae. The collectors were easily cleaned and sediment which usually causes high mortality in the hatchery system was easily removed from the wire frames.

It now appears that the most important use of the wire spat collector may be in its application to the collection and handling of spat in oyster hatcheries. Preliminary laboratory-scale studies found that concrete-coated wire collectors devices increased survival of newly attached spat in the oyster hatchery and showed that the amount of hatchery space needed for collection of spat was decreased 50%, the amount of hatchery labor for growing spat down 65%. Several different densities of spat were placed on the collector, but the optimum number to produce rapidly growing, uniformly shaped seed oysters is not known at this time. Nor have we demonstrated the capabilities of this technique to grow market-size oysters.

One of the major research needs identified in the 1979 National Aquaculture Plan (Shaw 1979) is a cost-effective system for growing hatchery-produced oyster spat into a marketable product. Present hatchery culture systems are primitive, labor-intensive and very costly. The Aquaculture Plan suggests that "research should result in the design of low-cost off-bottom growing devices which can be handled with a minimum amount of labor. Such devices might be suspended near the bottom in a way that does not interfere with navigational or recreational uses of the water. A major effort should be devoted to developing low-cost systems for growing these oysters to market size." Essentially, the concrete-coated wire spat collector satisfies these requirements if its use is extended into a spat-growing system. At the present time the design of the collector is totally aritrary and based on the availability of some previously constructive vinyl-coated wire trays. These trays were constructed of 14-gauge steel wire. In the cost analysis of various types of spat collector, the cost of the concrete-coated wire collector was approximately $2.73. This cost can be halved merely by changing the wire size for the construction of the collector. Further reductions of the same magnitude could be gained if woven wire (chicken wire) were used instead of welded steel wire with a heavy vinyl coat. At present we are not sure that the vinyl coating is needed to grow oysters.

It is strongly recommended that additional studies of the concrete-coated wire oyster spat collector and culture system be instituted to optimize the design and use of the wire collector for producing spat at the Deal Island and HPEL hatchery systems. Additionally there should be a demonstration of the use of the spat collector as an intensive culture technique for production of high-quality seed and marketable oysters in the Chesapeake Bay environment. A demonstration plot to describe the production density and the marketability of oysters that are grown on the concrete collector should be placed in the Bay in the immediate future. This demonstration plot could help motivate private ventures to use this technology. Additionally the demonstration plot should serve as a pilot test for the durability and stability of various types of wire and concrete that may be used in fabricating collectors. This type of technology development could reduce the hatchery production cost of spat by 75-90% and thereby make the hatchery a cost-effective source of seed oysters in Maryland. Demonstration and pilot production-scale implementation of the technology is necessary to prove this hypothesis.

Implementation of a Program of Appropriate Hatchery Technology in Maryland

In addition to the Deal Island facility which can become immediately operational, a similar DNR work center exists at Piney Point in St. Mary's County at the confluence of the St. Mary's River and the Potomac River. This work center has a small storage shed located close to the water that could serve as a hatchery. The field staff at the center could be trained to operate a facility similar to the one at Deal Island. All the tanks and equipment necessary to set up a small hatchery are presently available at HPEL. Following one year's evaluation of the water quality and biological characteristics--such as has been conducted at Deal Island and Cristfield--a carefully designed facility could be developed at the Piney Point work center. The DNR field staff at Piney Point would essentially double production anticipated at the Deal Island site with a capital investment of approximately $100,000.

Recently there has been considerable interest in using the Marine Products Laboratory (MPL) at Crisfield as a site for the development of oyster hatchery technology. If used for the development of low-capital technology this site could contribute to the total hatchery management effort in Maryland. The site has a salinity regime slightly higher than Deal Island, but bioassay studies conducted during 1980 suggest that there may be some unusual environmental conditions that deter larval development and survival in the ambient water at the MPL site.

The building at Crisfield is primarily designed for offices and does not have adequate floor drains, plumbing or electrical service needed for a low-cost oyster hatchery. The concrete floor and concrete block walls would have to be modified for hatchery use. The cost of this modification most likely would exceed the cost of construction of a small strand-steel building or "pole barn"-type building adjacent to the existing office building. The small steel building would have a concrete pad with appropriate drain channels in the pad. Spat growth could be in low-cost outdoor raceways located to the west of the MPL building.

The MPL building has an annual maintenance cost for temperature-control equipment designed for office comfort levels which is quite high in comparison to the maintenance of the low-cost hatchery at Deal Island, the proposed hatchery at the St. Mary's work site or the above proposed hatchery building at Crisfield.

At the present time, the major constraint at the Crisfield site is water quality and poor growth of oyster larvae at that location. Even after the bioassay study in 1980, we know very little of annual fluctuations in water quality and other biological phenomena in the water immediately adjacent to the Crisfield site. There should be a more intensive year-round study of water quality at Crisfield before making a commitment to develop an oyster hatchery at that location. The development of hatcheries at Deal Island and at St. Mary's could produce significant quantities of oysters to meet present state management needs.

While considering water quality and oyster hatchery locations, it is pertinent to review criteria for oyster hatchery site selection set forth by Dupuy et al. in 1979. His explanation is as straight-forward and succinct as one can find in the scientific literature.[7] Selected from the document is the following quotation:

> Of the multiple factors which must be considered to achieve a viable hatchery system, selection of a site for the hatchery becomes one of the most important, one which will control the technological success or failure of such a system. Failure to adhere strictly to adequate quality criteria will ... result in additional biological problems that will negate the technology that has been laboriously and successfully developed and tested for this hatchery system.

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[7] Dupuy et al., pp. 5-8.

The 1980 oyster larvae bioassay studies (Appendix 7) showed higher levels of mortality in oyster larvae and spat at Crisfield than were encountered at Deal Island or Horn Point. These problems may have originated from using the water immediately adjacent to the MPL facility. The waterway originates from a dead-end harbor and intersects with a shallow dredged channel that extends from the Big Annemessex River to the Little Annemessex River through a typical salt marsh environment. The flushing rate of this system is extremely low and very few oysters are found to occur naturally within the system. In the dead-end harbor boat basin, there are several crab shedding operations, evidence of illegal disposal of vessel bilge wastes and a large amount of debris from human activity in the area. Sediment and accumulated organic material on the bottom is resuspended by the daily movement of boats in and out of the harbor. There is also potential for pollution from the industrial and domestic activities in the Crisfield harbor area. Discharge from the Crisfield sewage treatment plant does not occur immediately into this waterway, but its discharge into adjacent waters may eventually be transferred into the waterway that would provide water for the oyster hatchery. Dupuy et al. (1977) emphasizes that the point-sources of pollution within the immediate area of the hatchery should be completely avoided, such as marinas, boatyards, refineries, sewage disposal plants and other light and heavy industry.

Transfer of Oyster Hatchery Technology to the Public Sector in Maryland

A major question is raised by the results of the HPEL pilot-production study: "If the cost of producing seed oysters from the capital-intensive hatchery such as the one at Horn Point exceeds the revenues gained from their sale in Maryland why should the State consider investing any funds in the further development of oyster hatchery technology?" Throughout this report there has been an obvious effort to separate capital-intensive technology and low-cost appropriate hatchery technology. It is highly recommended that all future hatchery programs be oriented toward the use of low-cost technology not only because it is more cost-effective but because it is amenable for transfer into the hands of individuals who are presently participating in Maryland's public oyster fishery. A project to demonstrate technology and spat production mechanisms for a low-cost hatchery technology can be completed within the next calendar year with existing State of Maryland facilities and within existing personnel and budget structures of the Department of Natural Resources and the University of Maryland. It is suggested that both the Horn Point hatchery and the Deal Island facility be operated as small-scale, low-cost hatcheries to provide a source of seed to individuals who are interested in growing oysters and utilizing oyster hatchery technology in the future. Seed produced from these hatcheries may also find use in existing State management programs. State oyster management biologists may wish to use seed oysters in rehabilitation of specific oyster bars (upper Potomac River, Chester River, Upper Bay, Western Shore) that have not received significant quantities of spat set in recent years. There may be specific research projects such as bioassays or water quality surveillance studies in which hatchery-produced spat may be appropriate study organisms. Hatchery seed from the program may also supplement the number of oysters on public oyster bars. However, the greatest potential use of the seed produced by the small-scale hatcheries is in demonstration plots and hatchery demonstration workshops so that members of the public Maryland fishery and private oyster industry can understand and be trained in hatchery technology and produce their own seed oysters in the future.

Staff at the Deal Island facility and at the Horn Point facility have been operating both locations for a minimal level of production of oyster spat over the past two years (1979-1980) without any significant expenditure of operating funds. This mode of operation, with a shift of emphasis to the development of concrete-coated wire of different dimensions and different materials, should continue for approximately one to two years until the growing oysters are large enough to prove their marketability and survival on the system.

While these two facilities are operating with the low-cost technology concept, technical advisory specialists from the University of Maryland's Sea Grant Program and DNR Extension Program can devote a percentage of their time to the transfer of information about hatchery technology to Maryland citizens, especially to watermen in the public fishery. The annual workshop on oyster culture in Maryland has attracted a surprisingly large number of persons interested in oyster culture. This workshop concept can be expanded with numerous small demonstrations and on-site workshops to provide "hands-on" experience for interested individuals at both oyster hatcheries.

Manpower to handle the planned workload can be satisfied by utilizing field supervisors in the oyster management program, summer students employed by DBR, student trainees from the Maryland Sea Grant Program, and perhaps one or two additional people at Horn Point would be to have the oyster management field supervisors in the Cambridge region participate in the operation of the Horn Point hatchery.

The total budget requirement for this suggested effort is relatively low and has been handled in the oyster propagation budget for the past two years. If the HPEL and Deal Island facilities are operated at full capacity from mid-July to mid-October 1981, a budget of 10,000 ($8,000 for HPEL, $2,000 for Deal Island) would cover expendible supplies. The transfer of low-cost oyster hatchery technology to the public sector is the most cost-effective use of oyster propagation funds that has evolved from this study. Once the cost of producing seed oysters is transferred from the public responsibility into the private sector, revenues from additional oysters severance taxes and from economic multipliers gained by having more oysters processed in the Maryland oyster industry will create a source of new income. Since low-cost oyster hatchery technology is within the investment capabilities of most people who presently earn a livelihood from the water, it is anticipated that many of the existing 7,000 acres of leased oyster bottom will be put into full production using hatchery-reared oysters. The Maryland industry could obtain an annual production of over 4 million bushels of oysters, or approximately two times the present harvest from public beds.

At present there are several watermen and at least five private hatchery operators in the State of Maryland who are interested in further refinement of oyster hatchery technology. All these individuals will be using information produced by this program within the next five years. All these individuals have expressed an interest in seeing a demonstration hatchery and a demonstration planting made so that a more pragmatic expression of output from the hatchery can be understood.

Cost Benefits of Hatchery Technology to the State of Maryland

One important aspect of the pilot-production studies and field research supported by the Maryland DNR contract was to determine the cost and probable benefits of using hatchery-reared spat in the management of Maryland's oyster industry. This advisory has discussed several alternate strategies for employing of oyster hatchery technology in the management of Maryland oyster resources. Collectively, detailed analysis of the HPEL hatchery operation, economic analyses made by the computer models, and operation of low-cost hatchery technology at Deal Island provide an indication of the relative costs of each of the specific types of technology. Hatchery activity would parallel or supplement the present shell planting program mobilized by the state menagement agency to place seed oysters on bars depleted by harvest activity. Analyses of both systems have been discussed in previous portions of this document. Seed oysters from neither the state shell planting program nor from hatchery sources are cost-effective in terms of their yield of revenues to the State of Maryland.

Perhaps the most easily understood cost-benefit exercise would be to list a range of annual fundings for the production of seed oysters and show a corresponding cost to the State per thousand of marketable oysters upon harvest, two to four years later. This approach will give some idea of the total impact seed oyster programs may have on Maryland management strategy. Table 14 shows two levels of seed costs, seed from a hatchery and from the state shell-planting progrma. See oyster costs can then be equated to annual funds ranging from $100,000 to $1 million per year for a seed program. Two levels of projected yield of harvestable oysters, 200 bu/acre and 100 bu/acre, are shown for each of the two seed costs. A level of 100 bushels per acre would be equivalent to the yield from some of the best natural oyster bars in Maryland; a level of 200 bushels per acre could be equivalent to the yields expected from a well-managed oyster lease in Maryland. In considering seed oyster costs from the state shell-planting program, $1/1000 would represent moving a bushel of high-quality seed (1000-1500 count per bushel) from one of the seed areas and placing it on an oyster bar. Likewise, the $3/1000 would represent seed generated by moving a bushel of 300-400 count seed from the state seed area to the planting bottom. At various levels of funding we can then predict the number of acres managed by this expenditure. Note that even the most cost-effective situation of $1/1000 oysters with annual funding of $1 million would be capable of managing approximately 10,000 acres of oyster bottom. It is quite interesting to note that even using these funds to manage oyster bottom to produce 200/bu/acre/year, an output of only approximately 250,000 bushels may be realized. By logical extension, the state seed program is contributing only 10-15% of the present annual harvest from the natural oyster bars in Maryland. The rest of the harvest is due to natural spatfall or the transfer of marketable oysters from othr environments.

The two levels of seed cost could also represent the cost of hatchery seed. In 1977 HPEL hatchery seed cost approximately $3/1000, whereas in 1979 Deal Island hatchery seed cost less then $1.33/1000. Some of the projected savings gained by utilizing the concrete-coated wire spat collection technique and growout system may place the cost of hatchery-reared seed at $1/1000 or less. The present cost of hatchery-reared seed on the concrete-coated wire collector is under $3/1000 but greater than $1/1000. Future improvements in technology will definitely price seed produced on concrete-coated wire collectors at $1/1000 or less. Table 14 graphically illustrates the relatively small number of acres of Bay bottom than can be managed with present levels of funding from the DNR oyster management program. The table points to the need for transferring a large portion of financial and operational responsibility for production of oysters from the state program into the hands of private industry to realize a truly cost-effective oyster management program.

One of the recommendations of this management advisory is to enhance the development of the private oyster industry to defray most production costs for oysters within the State of Maryland. This removes the burden of fiscal responsibility from the Maryland taxpayer and Maryland management agency. If we use the same criteria to judge the cost-effectiveness of existing management programs--and especially the seed produced by the shell planting program used to analyze hatchery technology--the only cost-effective management program is to transfer all of these costs of seed production to the public fishery or private sector. As the Bay bottom survey is completed and more leased ground may be made available, low-cost technology can be expanded by getting more individuals involved in the technology. The transfer of hatchery technology from the scientific community into the hands of the public may take 5-10 years. During this time period, demonstration hatcheries must be operated to provide examples of that technology. Operation of these hatcheries can meanwhile provide modest numbers of seed oysters at costs shown in Table 14 for use in selected management activities. Once there is adequate product being developed by the private sector, the need for seed oysters planted in the public system should diminish.

Table 15 was prepared to give an estimate of the cost of a development program for low-cost technology in the next five years. A technology transfer operation can begin immediately within Maryland by utilizing DNR, the University of Maryland Sea Grant Marine Advisory Service, Tidal Fisheries personnel at Dael Island, and UMCEES personnel at the HPEL oyster hatchery. Only a small amount of funds are needed to cover the operating expense for expendible supplies, travel, workshops and the increased cost of office correspondence. In 1981 these costs may be about $10,000. In 1982 through 1984, the technology transter program is envisioned to have an increasingly active function as new hatchery facilities are developed and operated at Deal Island, Crisfield and St. Mary's.

Under Research and Development on Table 15 there is a temporary effort that will produce seed oysters for the private sector and for management needs at HPEL and at the existing Deal Island facility. Approximately $10,000 a year for two years should provide enough seed for interested individuals and for demonstrations of technology transfer by extension personnel.

Included in Table 15 is a budget to cover research and development of the concrete-coated wire collector and other refinements in low-cost oyster hatchery technology. These refinements will be developed at HPEL and at the existing Deal Island facility. This research and development program will have an ultimate result of reducing overall seed cost of growing hatchery-reared oysters. Details of the research program have been outlined briefly in the above text.

Deal Island hatchery development should include equipment (carts, davits, pulleys, and proper cultch-holding trays) to enhance the handling of large quantities of spat. After these improvements, there is design and construction of a new hatchery building ($150,000 in 1983) and installation of raceways ($30,000) to maximize use of this site for production. It is estimated that the new Deal Island building will be approximately 10,000 sq. ft. Because of the use of existing hatchery equipment and the low-cost hatchery concept, the total installation cost should be around $15/sq. ft. Raceways could be installed by 1984 and will follow the same construction cost criteria as outlined elsewhere by Lomax and Krantz.*

The proposed use of the MPL building at Crisfield for an oyster hatchery should be more completely evaluated by bioassay studies conducted during 1981. A building should be designed and constructed to be similar in nature to the proposed building at Deal Island. Both of these buildings could be constructed in calendar year 1983. Again,

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*Paper presented to a joint meeting of the American Society of Agricultural Engineers and the Canadian Society of Agricultural Engineering, June, 1979.

Table 14 Impact of hatchery-produced seed at two levels of projected yield in the management of oyster bottom. Data are in managed acres at each of two seed costs: 1000 bushels per acre yield is comparable to leased bottom output; 200 bushels per acre is similar to production from a good natural bar. Data are number of managed acres.

	Seed Cost			
	$1/1000 Projected Yield Bu/acre		$3/1000 Projected Yield Bu/acre	
Annual Funding for Seed Production	1000	200	1000	200
$100,000	200	1000	67	333
$200,000	400	2000	134	666
$500,000	1000	5000	333	1667
$700,000	1400	7000	467	2333
$1,000,000	2000	10,000	666	3330

Table 15 Proposed Development of Appropriate Hatchery Technology in Maryland by DNR, UMCEES and University of Maryland

Item	1981	1982	1983	1984	1985
Technology Transfer (Operation Budget)	$10,000*	$30,000*	$30,000*	$25,000	$10,000
Research and Development					
Seed Production at HPEL & Deal Island	18,000	10,000*	-	-	-
Wire Collector Development HPEL	40,000	15,000	5,000	-	-
Deal Island Hatchery Development					
Improvements	5,000				
Finger Piers					
Building			150,000		
Raceways				30,000	
Operating Budget	2,000	5,000	10,000*	35,000*	35,000
Crisfield Hatchery Development					
Bioassay	5,000				
Building		10,000	150,000		
Raceways				40,000	
Operating Budget				100,000*	100.000
St. Mary's Hatchery Development					
Bioassay	5,000	5,000			
Building Improvements		20,000			
Raceways				30,000	
Operating Budget			20,000*	25,000*	25,000
Seed Oyster Production (Millions)	12	16	30	85	100
BUDGET SUMMARY					
Research and Development	68,000	30,000	5,000	-	-
Operating Budget	12,000	35,000	60,000	185,000	170,000
Capital Improvement	5,000	30,000	300,000	100,000	-
TOTAL	$85,000	$95,000	$410,000	$285,000	$170,000

*funds for seed oyster production

raceways would be needed to utilize more fully production from the Crisfield building an annual operating budget of approximately $100,000 to being in 1984.

If a low-cost hatchery is desired at the St. Mary's work center, bioassay studies should be initiated in 1981. These studies should cost no more than abour $5,000 in manpower and equipment. Additional biological studies could be conducted during 1982 as the existing facility is altered to be an oyster hatchery. Seed oyster production from the Deal Island facility could be doubled by St. Mary's seed production.

The last line in Table 15 shows a rough estimate of the number of seed oysters that could be produced from the above facilities. These estimates of seed oyster production are based on the output from the Deal Island hatchery in 1980 and the production of plantable seed oysters from the HPEL hatchery from 1978 and 1979, which were probably representative of average environmental conditions for the HPEL facility. It should be noted that once the low-cost hatcheries are developed at Deal Island, Crisfield and St. Mary's, there would be no need for seed production activity at HPEL. At that point, the HPEL facility would revert to the research contract mode of operation on other areas of hatchery technology such as the development of genetically superior strains of oysters, synthetic diets for oyster larvae and possibly new mechanisms for depuration of oysters that are raised on polluted oyster bottom. Funds followed by an asterick for a given year are those which contribute to the production of seed oysters from the facilities. The use of the seed oysters would be at the discretion of the state management agency.

The five-year plan shown in Table 15 exemplifies the level of budget commitment and the types of activities that would be necessary to develop a viable oyster management program based on low-cost hatchery technology within Maryland. Two of the most important components of this program are the demonstration and transfer of technology to the public and the research effort to refine low-cost hatchery techniques to make this technology more cost-efficient.

Summuary of Specific Recommendations in the DNR Management Advisory

The HPEL pilot production evaluation of oyster hatchery technology was one of the first public-funded studies to determine the biological and engineering efficiencies and costs of hatchery-produced seed oysters. The product of the capital-intensive oyster hatchery—plantable seed oysters—does not appear to be part of a cost-effective management strategy for the public fishery, when the cost of producing seed oysters is compared to revenues gained from taxes on resultant marketable oysters at harvest. This disparity exists not only in hatchery-reared seed oysters, but in seed oysters produced by the present state shell planting program. After careful evaluation of all factors, the HPEL experience indicates that low-cost hatchery technology has a potential for producing cost-effective seed oysters for the private grower. More importantly, low-cost hatchery technology can be easily developed, demonstrated and transferred to the public sector so the required volume of raw product for the Maryland oyster industry becomes a result of the risk of private capital rather than state subsidy. Parts I and II of the report of the HPEL studies contain several specific suggestions and recommendations that should be noted:

1. Capital-intensive oyster hatchery technology is not a cost-effective source of seed oysters for use in the estuarine environment typical of Maryland's oyste fishery.

2. All oyster hatchery technology had a variable and unpredictable level of production. This variance is apparently controlled by environmental factor which also influence the annual level of spatfall in the natural environment.

3. Variable biological factors in the oyster hatchery cause the hatchery operator to have limited prediction as to the annual production of seed oysters; therefore legislative appropriation for operation of a state oyster hatchery may result in outputs of seed oysters that vary as much as tenfold annually.

4. Capital-intensive, high-cost hatchery technology has been demonstrated to be an unsound investment for private venture capital.

5. The concept of year-round operation of a capital-intensive oyster hatchery to gain maximum utilization of capital investment equipment and skilled labor is prohibitive in cost.

6. All oyster hatcheries in Maryland should be operated on a seasonal mode to decrease the amount of energy utilized; however, in this mode of operation the skilled hatchery labor force will remain idle during most of the year.

7. Existing employment restrictions by the Maryland State Civil Service are incompatible with the 7-day-a-week, seasonal mode of operation of a capital-intensive oyster hatchery.

8. Low-cost oyster technology produces seed oysters at a cost that is highly competitive with seed oysters from the natural environment and at a much lower cost than seed oysters produced by a capital-intensive hatchery.

9. Low-cost oyster hatchery technology is now developed to an extent that it could be transferred into private operator's hands.

10. A low-cost hatchery and a grow-out lease are ideally suited for operation by Maryland watermen as an alternate to their seasonal participation in the public oyster fishery.

11. Primary attributes of the low-cost or appropriate technology oyster hatchery are that the facility is seasonal in operation and maximizes the natural growing conditions in the Chesapeake Bay environment. The low-cost hatchery consumes a minimum of electrical energy, has few complicated control devices, does not rely on the continuous production of algae to feed the growing oyster larvae and spat and uses labor that has an alternate occupation.

12. A state-supported demonstration hatchery could serve as a center for extension personnel who would solve unforseen problems in privately owned hatcheries and "oyster farms."

13. The low-cost technology hatchery concept that may best suit present state management needs would promote numerous small facilities located in different regions of the Bay which would remain idle for at least half of the year. These facilities would be staffed by oyster propagation personnel during the summer months.

14. Seed oysters produced form the low-cost demonstration hatcheries could help satisfy present requests from Maryland watermen for seed oysters and could satisfy specific management needs of the Maryland state oyster propagation program.

15. A research and development effort should be initiated to make specific improvements in low-cost hatchery technology. This should include development of concrete-coated wire cultch, spat growout systems and new sources of large quantities of low-cost cultch.

16. Evaluation of cultchless oysters produced by the Dupuy Mylar technique found them to be of no value when planted in the natural environment. The primary reason for the failure of the seed to survive was predation by blue crabs and the loss of the small-sized oysters into natural Bay sediment.

17. Survival of hatchery-reared seed oysters less than one inch in length is very low in the Chesapeake Bay. Data from this project suggest that hatchery-reared seed must be kept in a projected environment or hatchery system one growing season before being planted in the natural environment.

18. The survival of seed oysters produced by the state shell planting program should be evaluated. Studies should be conducted to document survival of seed oysters produced by low-cost hatchery technology and by wire frame culture devices.

19. Production of seed oysters by collecting them from the natural environment has been shown to be more expensive than the present state seed oyster program and more expensive than hatchery-reared seed. There was little difference in the amount of spat collected by suspended cultch materials as compared to those cultch materials placed on the bottom, whereas the cost of suspended collection devices is approximately twice that of those on the bottom.

20. Research evaluation of various types of cultch material and collection devices for production of seed oysters in Maryland found that green oyster shell is the most attractive substrate. Oyster shell provides the greatest survival of seed oysters when planted in the natural environment.

21. The HPEL pilot-production oyster hatchery is not properly located nor designed correctly to be used as a seed production facility to supplement the public fishery of Maryland. The HPEL facility would best be utilized in a cooperative program with DNR to develop low-cost oyster technology. The HPEL facility can be rearranged to contain the components of a low-cost hatchery and be used to train hatchery operators. The primary advantage of the HPEL facility is the proximity of University extension and advisory service personnel and UMCEES faculty members with training in specialized disciplines that can help solve biological problems of private hatcheries and who can supplement the education experience of hatchery trainees.

22. The existing facility at Deal Island is an excellent example of low-cost oyster hatchery technology. Growth of larvae, spat and juvenile oysters at this facility is superior to most locations in the Chesapeake Bay.

23. Development of bulkhead and finger piers at Deal Island will greatly enhance the use of this facility for the production of seed oysters. With the development of concrete-coated wire technology and the use of outdoor raceways that can be installed at a minimal cost, the Deal Island facility could equal the 1977 production from the HPEL hatchery (50 million seed oysters).

24. HPEL and Deal Island hatcheires can be utilized in the immediate future (1-3 years) to provide a source of seed oysters to satisfy requests for seed from watermen and from state management personnel. Thereafter the HPEL facility should be directed toward training and educational activities related to technology transfer and to specific research programs.

25. Two other sites for low-cost oyster hatchery technology could be the work center at Piney Point on St. Mary's River and the Marine Products Laboratory site at Crisfield. Both sites should have one or more years of biological testing to document the survival and growth rate of oyster larvae and newly attached spat before additional plans for use of these facilities are made.

26. Distribution of three DNR-operated low-cost facilities on the Bay should satisfy short-term local and regional needs. A minimum of capital equipment needs to be purchased and the facilities can be operated within the

existing personnel structure of the DNR oyster propagation program.

27. A cooperative DNR-UMCEES oyster management program has been initiated and should become a major component of the state's strategy to manage Maryland's oyster fishery. This program should include development and demonstration of low-cost oyster hatchery technology, extension programs to transfer low-cost hatchery technology to the public, research and development of innovative and appropriate culture techniques, evaluation and development of new oyster management strategies, refinement of oyster population survey techniques and assistance to the Maryland oyster industry to develop new oyster products.

28. Financial support for the above-listed programs is presently available only through Maryland DNR. Additional funding for the suggested programs should be sought from the Maryland Coastal Zone Management Program, the Maryland State Legislaure and other state and federal agencies interested in enhancement of the economic base and natural resources of Maryland's estuarine waters.

PART III

PROJECT REPORT

OF

TECHNICAL ACTIVITY AND FACILITY DEVELOPMENT UNDER THE U.S. DEPARTMENT OF COMMERCE ECONOMIC DEVELOPMENT ADMINISTRATION OFFICE OF TECHNICAL ASSISTANCE

Grant No. 01-6-09599-70
Maryland Pilot Plant and Shellfish Hatchery
Technical Assistance Program

Introduction

All of the technical and biological objectives set forth in the University of Maryland proposal to U.S. Department of Commerce Economic Development Administration and the specific tasks delineated in technical assistance grant No. 01-6-09599-70 have been fulfilled by this project, but within a slightly different time frame than originally planned. Administrators and biologists in the University of Maryland CEES have concentrated on achieving the primary objective in the Scope of Work of the grant: to "plan and direct a program designed to establish the Maryland pilot Plant and Shellfish Hatchery with supportive research and services to assist the shellfish industry in restoring, rehabilitating and expanding shellfish production areas damaged by Hurricane Agnes."

As this project evolved, the emphasis of activity shifted from mere production of oyster spat and planting them in the environment to obtaining a comprehensive understanding of hatchery technology and cost-effectiveness of technology needed to rehabilitate and expand the Maryland shellfish industry. The staff members involved in the preparation of the original project plan were very optimistic about the speed at which the University of Maryland could respond to the objectives of the technical assistance grant. They were not fully informed of the state requirements for the expenditure of capital construction funds and knew very little of the operational costs of the hatchery or the potential impact that hatchery-reared oysters could have on the natural populations of oysters in Chesapeake Bay. Instead of a one-year period to develop a hatchery and research program as envisioned in the 1973 proposal, more time was needed to properly plan for hatchery construction and numerous technical research activities. Many of the details in the early development of the EDA funded portion of this project are delineated in a brief chronology found in Appendix 9.

The initial site for the oyster hatchery and several relevant research programs were located at the Chesapeake Biological Laboratory (CBL) in Solomons, Maryland. As the planning process evolved, the site for the hatchery facility was shifted to the Horn Point Environmental Laboratories (HPEL) on the Eastern Shore of Maryland. Therefore the construction of the pilot-production research hatchery was delayed for several years. The HPEL facility became operational in the summer of 1977. In the meantime, temporary oyster hatchery facilities were utilized to conduct specific research tasks delineated in the EDA research proposal. As more experience was gained in the growth and mass production of shellfish under estuarine conditions peculiar to the Maryland portion of Chesapeake Bay, all persons concerned with the project became keenly aware of the need for a more complete evaluation of the cost-effectiveness of hatchery technology before large amounts of funding were requested to sustain proposed rehabilitation attempts. This technology evaluation is being completed in 1981 with a specific management advisory to the Maryland Department of Natural Resources (DNR) Tidal Fisheries Administration, which is responsible for the management and manipulation of Maryland's shellfish resources. This management advisory (Part II of this report) and the general project summary (Part I) state major research accomplishments and operational details of the hatchery program initially envisioned in the technical assistance grant from EDA. Collectively the first three portions of a comprehansive technical review of five years' research on oyster hatchery technology are offered as a final project report to the U.S. Department of Commerce Economic Development Administration.

Specifically, Part III addresses the report requirements set forth in the EDA contract document. The format of Part III follows the outline of the special terms and conditions that accompanied the scope of work statement for the EDA project.

TECHNICAL ASSISTANCE PROGRAM

Hatchery Facilities

One of the primary needs of an oyster hatchery program--a well-designed physical plant--was made possible by the EDA contract, state capital budget appropriations and the University of Maryland operating budget. (Details of facility construction can be found in Appendix 1.) The shellfish research hatchery at Horn Point consists of 5600 sq. ft. of floor space totally devoted to production-scale culture of estuarine animals and the propagation of algae to feed them. The facility is supplied with dual pumps and distribution lines capable of delivering 1,000 gpm of ambient water from the Choptank River. An additional 1,000 gpm of standby capacity can be used for short-term experiments. The hatchery building has an equipment room capable of heating and cooling about 200 gpm of river water to any desired temperature. Heated and cooled river water and fresh well water are available at all locations in the building. The floor plan and details of the interior components of the HPEL hatchery building have been discussed in Part I of this series (Pages I-13-I-19).

One of the work products of the EDA contract was the development of the design and construction drawings of a modern production-scale oyster hatchery. This structure and its components represent state-of-the-art technology as of 1973 and 1974. The design is unique among the aquaculture engineering efforts in North America and is specifically adapted to some of the estuarine conditions found in the Maryland portion of Chesapeake Bay. All of the components in the hatchery can be utilized if there is a future need to construct new facilities once economic and biological feasibility of hatchery technology is clearly demonstrated.

In addition to the hatchery building, an additional oyster spat growing area of 3600 sq. ft. was developed through a University of Maryland Sea Grant research project in 1977. These structures are designed as low-cost outdoor growout facilities so that private investors can have a mechanism in which to culture oysters with a minimum of capital investment. The development and ongoing research conducted in the "oyster raceways" is described in Appendix 2.

EDA Grant Supported Studies

The periodicty of laboratory studies charged against the operating funds provided by EDA contract 01-6-09599-70 extended from 22 November 1972 through 30 June 1974. This time period included an extension to the expenditure of research funds granted on 22 May 1973. Research accomplished during the period when EDA funds were expended was reported in quarterly progress reports submitted to the Director, Economic Development Administration.

In the early months of this contract, the primary effort was directed towards developing design criteria and selecting equipment for the construction of a functional oyster hatchery. Many modifications to the original design occurred and the physical location of the hatchery changed. Project personnel responded to numerous requests from the University of Maryland and State of Maryland design teams for information on hatchery technology (November 1972 through June 1973). Project personnel were actively involved in the evaluation of several potential sites where the hatchery was to be placed. Two documents, prepared for in-house use, reflect the scope of some of these studies: (1) CBL Ref. No. 73-102 by Rose et al. (Appendix 10) was a statistical correlation of data on water quality at the potential hatchery site on the Choptank River to the extensive data base on water quality in existence for the Chesapeake Biological

Laboratory site on the Patuxent River; (2) a study by Rose and Meritt, CBL Ref. No. 74-120 (Appendix 10) was a laboratory bioassay study to describe water quality at potential hatchery sites at Deal Island and at Solomons.

During the period of support by the EDA contract, two technicians were hired and trained in hatchery culture and algal culture procedures by the staff at CBL. Project personnel concentrated on refining the techniques of spawning oysters in the low-salinity environment and the culture of selected species of algae that could sustain rapid growth and high survival of oyster larvae. These laboratory efforts were most intensive during the summer of 1973 and spring of 1974. Both technicians developed outstanding capabilities in the culture of oysters and algae.

Part of the proposed hatchery program was to save oyster brood stock from an upstream bar in the Potomac that had survived the effects of Hurricane Agnes. These animals were used as brood stock to develop progeny which are still being maintained in the present hatchery program. Details of this study were documented by Drobeck and Meritt (CBL Reference No. 77-22, Appendix 11).

At the termination of the research period covered by EDA funds (June 1974) the oyster hatchery at HPEL was still not operational. Research studies supported by EDA funds were terminated at the time so that the University of Maryland would not be financially liable for overexpenditure of grant funds. In the fall of 1974, laboratory-scale studies a CBL were terminated. Personnel and laboratory equipment were shifted to a temporary hatchery located at HPEL in anticipation of moving into the new hatchery building.

Due to the constraints of the process required to develop a production-scale hatchery imposed by the Maryland State planning process, many of the terms of the EDA contract could not be fulfilled during the time period when the expenditure of technical research funds were authorized. However, the planned studies have been conducted and all of the terms and expectations of the initial contract have been met. Details of the studies are summarized in Parts I and II of this document. Upon completion of three years of operation of the HPEL pilot-production facility in 1979, administration and biologists of UMCEES felt that enough data existed to satisfy the scope of work promised for final report to U.S. Department of Commerce Economic Development Administration.

PROGRAM OPERATIONS FUNDED BY EDA CONTRACT

Oyster Rehabiliation

General Hatchery Procedures

Rehabilitation of natural oyster populations by planting hatchery-reared oyster spat is still in the field trial stage, whereas the physical facilities and techniques used to produce hatchery-reared spat have reached a highly perfected status. Program personnel and several investigators at other institutions have prepared comprehensive reports on hatchery methodology and equipment. The hatchery program that was developed at HPEL uses the most technically advanced culture procedures described by these workers. These reports and manuals are a source of specific details of procedures used in this project. As part of the EDA contract, Klaus Drobeck prepared a draft of an operating manual for an oyster hatchery in Maryland. This document can be made available upon request. Culture procedures found in Drobeck's document, the comprehensive manual by John Dupuy et al. (1977), and published reports by Hidu et al. (1968, 1969) are used extensively in the daily operation of the HEPL hatchery. However, these carefully prepared instructions serve only as general guidelines to the experienced oyster culturist. Personnel in this project found that there is no substitute for years of experience and training in the basic biological sciences.

All of the details of the HPEL physical facility may be found in Appendix 1. Culture procedures may be found in recent scientific contributions by Dupuy (1973), Dupuy et al. (1977), Breese and Malouf (1975), and Hidu (1982).

Daily operating procedures in any oyster hatchery require continuous modifications of techniques to adjust to changes in water quality, mechanical problems and unexpected biological phenomena. Changes in procedure are based on the experience, intuition and training of the hatchery operator who relies on his understanding of all of the state-of-the-art information rather than a strict list of procedures. Many of these specific details will be discussed in Parts IV and V of the Oyster Hatchery Technology Series.

Genetic Improvement of Brood Stock

The development of genetically selected oyster stocks can be accomplished only through propagation of several generations of animals. Each generation of oysters requires at least two years of growth. During this project several stocks of oysters were collected from isolated, unmanaged oyster bars and used to produce oyster larvae and spat in the hatchery. These animals and their progeny are being maintained in special trays at CBL, on the Horn Point pier and at the DNR facility at Deal Island, Maryland. For instance, we still have oysters from the laboratory studies conducted at CBL during 1973 and 1974 and Potomac River brood stock that survived many weeks of exposure to freshwater during the Hurricane Agnes event. Samples of the cultchless oysters used in the 1975 and 1976 plantings are being kept at three locations in the Bay. During HPEL hatchery operations in 1976 through 1980, samples of each separate brood (spat produced by spawning of a given sub-population of oysters) were retained on the Horn Point pier. These stocks and further genetic research—such as is being supported by University of Maryland Sea Grant in 1980 and 1981—will form the basis for the next major research thrust at the HPEl hatchery.

It is the long-term objective of the HPEL hatchery program to concentrate on genetic selection of oysters for their tolerence to low-salinity environmens, resistance to specific oyster diseases, fast larval development, rapid growth under hatchery conditions, and production of a marketable shell shape when placed in the natural environment. Each of these characteristics is probably controlled by a complex gene pool, and a great amount of basic research is still needed before selected strains of oysters are developed. A perspective of some of the current research on oyster genetics may be gained from the 1980 Sea Grant project proposal.

Conditioning of Adult Oysters for Spawning

Conditioning oysters for spawning is more difficult in the Maryland portion of Chesapeake Bay than in other areas of the Atlantic coast. Hidu et al. (1969) developed the basic techniques currently in use at HPEL. Essentially Hidu found that oysters require 6-8 weeks of intensive feeding in water temperatures between 16°C and 18°C. The greater the flow of water and volume of supplemental food (algae and cornstarch) within the conditioning tanks, the more rapid and more complete is the gonadal development of the brood stock. The major constraint we have encountered with the Hidu technique is the lack of reliable temperature conditioning equipment and occasional failure of automatic operating valves. With some modifications to hatchery equipment, we were able to maintain production capability even at salinities below 7 ppt with techniques that will be more fully described in Parts IV and V of the completed version of the hatchery report.

Spawning of Adult Oysters

The EDA contract and subsequent grants from Sea Grant and the Maryland Department of Natural Resources have permitted development of a large capacity, continuous-flow oyster spawning table. This unit can accommodate 100-150 oysters and yet permit separation of individuals from the group as they spawn. Spawning is induced by raising the temperature of the flowing river water from about 18°C to 30-32°C over a period of several hours. Chemical stimulation of the brood stock is frequently used and consists of injecting mascerted gonadal material into the in-current flow of water entering the oysters on the spawning table.

Culture of Oyster Larvae

The procedures and equipment used for the culture of oyster larvae are essentially those developed by Dupuy (1973) and Dupuy et al. (1977). Our experience with these techniques is comparable to Dupuy's reported results with two major exceptions, at HPEL the larval period is longer and mortality is greater because (1) ambient salinity is at the lower tolerance level for development of oyster larvae; (2) the food value of phytoplankton cultured in low-salinity water is reduced; and (3) undefined local water quality factors.

The depressed larval growth rate encountered at HPEL increased the number of days the larvae were housed in filtered water and fed cultured algae. The amount of technical labor involved in producing an attached spat was much greater than estimates found in the scientific literature. Repeatedly we have attempted to optimize the variables of the culture technique in order to increase larval growth. Our most successful procedures will be found in Parts IV and V of the Oyster Hatchery Technology Series.

Metamorphosis (Setting) of Larvae

The HPEL program has successfully used the cultchless setting procedures described by Dupuy et al. (1979) as well as a variety of mollusk shells and concrete-coated wire substrates. Oyster larvae produced in the hatchery attached to all substrates but during specific times of the year--especially under conditions of high suspended sediment in ambient water--mortality of newly attached spat was found to be very high (90-99%). To date we have found that ground oyster shell chips used in the poultry industry is one of the most easily handled substrates for use in the Dupuy-design hatchery. Due to the small partical size, this cultch material produces a high percentage of single (semi-cultchless) oysters. Crushed soft clam shell, hard clam shell and dredged oyster shell have likewise been used successfully for setting larvae. Whole oyster shell encourages aggregation of the oyster larvae on a few shells. These crowded spat have a lower growth rate, thin, irregular shell, and they form an inferior market product; however, their survival when planted in natural environment is greater than semi-cultchless oysters. Most of the techniques for settling oyster spat on shell are described in hatchery manuals by Dupuy et al. 1977 and Breese and Melcenf 1975.

One of the recent advances in settlement of hatchery-reared spat is the use of the concrete-coated wire spat collectors and culture devices.

Grow-out Phase for Oysters

During EDA-supported laboratory studies in 1973 and 1974, only small quantities (+ 10,000) of spat were produced. At the HPEL facility, production quantities of spat were grown in 1976 and set on Mylar as described by Dupuy et al. (1979) and on mollusk shell substrates. Unfortunately, when flows of ambient Choptank River water that Dupuy recommended were delivered to the HPEL spat growing tanks, the spat failed to grow. Studies to optimize spat density and flow rate on a seasonal basis are still in progress. At present our studies suggest that we need 4 to 5 times the volume of flowing water to achieve the same spat growth that Dupuy observed in Virginia waters. Unfortunately the HPEL hatchery design for tank space, water flow and operating schedules were based on the projections of Dupuy et al. (1979). These discrepancies adversely affected the planned production of spat from the HPEL facility.

To accomodate the quantities of spat produced by the Horn Point hatchery in 1977 and 1978, 16 low-cost outdoor culture tanks (raceways) were constructed with Sea Grant funds. A description of this culture system may be found in Appendix 2.

The Maryland Department of Natural Resources (DNR) operates a facility to grow spat at Deal Island, Maryland. This facility is housed in an abandoned oyster processing plant and can grow 3 to 7 million spat to a size suitable for planting in one growing season. Similar facilities have been developed by the Delaware State Management Agency to grow spat produced by the HPEL facility in 1978.

Soft-Shell Clam Rehabilitation Program

Concurrent with the EDA contract-supported oyster research program, other investigators at CBL were directing their research efforts toward spawning and rearing the soft-shell clam (*Mya arenaria*). In 1974 soft-shell clams were spawned successfully and large quantities of healthy larvae were reared from the eggs of some females. Many technical difficulties still exist in spawning and larval culture procedures for rearing large quantities of clams in the hatchery environment.

The soft clam industry in Maryland began showing a decline in landings during the late 1960's due to widespread mortality in the upper Bay and Potomac River regions. Hurricane Agnes had a severe impact on clam landings in 1972 and many hundreds of acres of commercially productive clam beds were destroyed. As a result, the Maryland clam fishery experienced low levels of harvest during the early 1970's but in 1974 and 1975 vast unharvested beds of clams were found in the lower Eastern Shore tributaries of Maryland. As a result of this discovery and the depleted beds in the northern portion of the Bay, the Maryland clam industry is now limited to Tangier Sound in the southern portion of Chesapeake Bay and a small area near the mouth of the Choptank River. In 1977 the Maryland clam industry was reputed to be very strong, with over 260 clam boats catching their limit before noon. Because of the natural resiliency of the soft clam population and the extreme difficulty encountered in the mass culture of clams in the hatchery, laboratory studies on the culture of soft clams have been discontinued. The techniques and procedures for the culture of clams described in a report by H. T. Pfitzenmeyer (Appendix 14) still need many refinements before they will yield predictable quantities of small clams of a size suitable for planting.

Algal Selection and Culture

At the time of the submittal of the proposal for the USDA grant, Chesapeake Biological Laboratory oyster hatchery technology was seasonal and used natural algae in Bay water to feed oyster larvae and spat. To satisfy the objectives of the proposed work and to operate on a year-round basis, investigators were required to develop the capability of growing large quantities of a variety of species of algae. Technicians and faculty visited the Virginia Institute of Marine Science (VIMS) laboratory-scale oyster hatchery, where mass cultures of algae were being propagated. They received instruction in techniques for growing the species of algae described in the manual by Dupuy et al. (1979). These techniques were used at both the CBL temporary oyster hatchery in 1973 to 1975 and at HPEL's temporary hatchery in 1976.

During the initial years of the project an intense research effort adapted the high-salinity strains of algae obtained from Virginia to the lower salinity regime in Maryland waters. This was accomplished after three years of laboratory work and all of the algae used by VIMS are now in cultivation at the HPEL pilot-production hatchery. Some of the details of the preliminary algae culture efforts and attempts to modify the VIMS techniques for the CBL hatchery may be found in the manual by Drobeck. In addition to the Virginia algae strains, over 14 new strains of algae that are accepted as food by oyster larvae are in culture at the HPEL facility. Two of these strains, a small marine Chlorella, and a naked chrysophyte called "Tahitian Isochrysis", they are easily grown in low-salinity waters and do not require as narrow a range of culture temperature as do the VIMS strains of algae, have become very important food sources in the HPEL facility.

Several modifications to VIMS techniques were made to reduce labor and cost of raw materials while increasing production and reliability of growing mass cultures of algae. Details of these procedures are described in Parts IV and V of this report. One of the most significant accomplishments during the HPEL pilot-production studies was the implementation of a continuous flow centrifuge which concentrates growing algae into a thick paste that can be stored for 2-6 months in the refrigerator. The stored algae paste provides an immediate supply of food for growing larvae and spat in case there is a mechanical breakdown or a biological failure in the algae culture system. A tremendous quantity of space and labor is saved by use of the concentrated algae. Algae from 1000 liters of culture medium which would occupy approximately 65 cu. ft. of tank space can be compacted to a container of 250 ml. After most of the algae is removed from the concentrated culture, the remaining nutrient growth medium still contains 10^3 algal cells per ml. A second, and sometimes third, fourth and fifth dense population of algae can be grown from the same investment in raw materials for growth medium.

Algae culture techniques presently used at HPEL may produce more oyster food per unit of floor space and man-hours of labor than any other shellfish hatchery.

EXTENSION AND ADVISORY SERVICES

Advisory services to the public and private oyster industries have been well ntegrated into the HPEL hatchery program. Within the organizational structure of UMCEES, and specifically at CBL and HPEL, advisory functions are handled by special "advisory" or "field extension agents." These personnel provide information over a broad variety of fishery topics and on all of the research activities conducted in UMCEES. Among these extension efforts have been numerous advisories on the status of the HPEL shellfish hatchery program. In 1978 the University of Maryland Sea Grant Program became very active in providing advisory information to the oyster industry. Several Sea Grant-funded marine extension agents or specialists are located at Horn Point. They have displayed an outstanding comprehension of the hatchery program and have been responsible for numerous information exchanges with the Maryland hatchery program personnel. An outstanding example of the advisory efforts was the formation of an annual, one-day conference on oyster culture for Maryland residents in 1979. The 1979, 1980 and 1981 conferences were attended by over 250 Maryland oystermen, packers, seafood distributors and interested persons who exchanged their views and posed questions to an array of scientists, resource managers, enforcement agents, bankers, lawyers and seafood brokers. The proceedings of those conferences were very meticulously recorded, published, and made available to conference attendees and the general public by the University of Maryland Sea Grant extension agents and technical staff. Over 500 copies of the 1979 proceedings have been distributed and requests for this valuable information base are now just beginning to be received from residents of oyster growing areas of the West Coast, Gulf Coast and New England.

During the period when EDA grant funds were being expended, several newspaper articles were prepared to advise the Maryland public of the plans for the hatchery program. An article giving a comprehensive description of the EDA project was placed in the commercial fisheries newsletter. Copies of these public information releases were included in the monthly progress reports forwarded to EDA.

Since 1975 personnel at Horn Point have had contractural arrangements with the Maryland Department of Natural Resources to provide technical assistance on the development of a state hatchery program in Maryland. The three-year contract was negotiated in 1975 to assist the state in planning the production hatchery technology in the management of Maryland's oyster industry (Part II of this report) and many of the HPEL hatchery production studies were the work product of this contract.

The development of the oyster hatchery program in Maryland has attracted intense interest from the news media and the general public in the tidewater portions of the State. In 1976 when the HPEL hatchery was near completion and the temporary hatchery at HPEL was operational, over 200 news articles on the hatchery program were collected from Maryland newspapers. In 1977, 83 articles were found, and to date the staff at HPEL has collected over 500 articles written to keep the general public advised of the status of the hatchery program. In 1977 a seven-minute special TV program was prepared by a Baltimore station. Since that time five other television programs that explained hatchery technology have been shown by Maryland television stations. The general public has been aware of the hatchery program through annual articles in the Maryland Commercial Fisheries News, University of Maryland campus newspaper, University of Maryland faculty newsletter, a feature story in the first issue of University of Maryland Sea Grant newsletter and a recent review of the Maryland Sea Grant Program.

Since 1974 the principal investigator of the project has published eight scientific papers on specific aspects of the hatchery program, presented 10 oral presentations at national scientific society meetings, and given seven siminars at various universities on the oyster hatchery program at Horn Point. Two of the most comprehensive reviews of the program were given to the National Academy of Science Aquaculture Advisory Task Force and the North American Oyster Culture Workshop. Some of the preliminary data developed at the HPEL hatchery was included in the National Academy of Science report to the U.S. Congress relative to the recently enacted National Aquaculture Bill.

An extremely large number of requests are received to visit the HPEL hatchery. We have intentionally minimized the number of groups or individuals what we show through the hatchery so that the research staff can pursue their work. However, during 1976 over 300 visitors and 5 organizations toured the facility. During 1977 alone over 1000 individuals, 20 organizations and 7 international visitors visited the facility and were given a brief description of the hatchery procedure and programs. Visitor tours during 1980 rose to three times the 1977 level. During the five years of pilot-production hatchery activities at Horn Point, 21 students have participated in work-study or training programs involving hatchery technology. Included in this diverse group were two 4H projects--one of which received first place in the 4H project competition in the State of Maryland--and four graduate students from foreign countries.

In our efforts to retain direct communication with members of the Maryland oyster industry, HPEL staff has supplied technical advice and conducted minor research projects for six oyster hatchery operators in Maryland, Virginia and Delaware. One private hatchery owner from Maryland was employed in 1978 to conduct research on causes of spat mortality, which is a severe problem in his hatchery and in the HPEL facility. On three occasions, members of the Maryland Watermen's Association have visited the hatchery and have been given a very comprehensive outline of the technology. At these opportune moments, efforts were made to organize cooperative work agreements with individuals of the oyster industry. A newly formed aquaculture company in Virginia has benefited greatly from the research and development of the oyster raceway. This company was able to realize a substantial reduction in their capital investment in a clam farming operation by using the HPEL raceway design.

A portable pictorial display and technical explanation of the oyster hatchery program was prepared in Fall 1976. The display and samples of oyster spat produced at the HPEL hatchery have been exhibited at ten "waterside fairs" where large numbers of Maryland's public visit Bayside communities to become acquainted with the unique aspects of the fishing industry and watermen's life style. One of the most notable display activities has been the annual Chesapeake Appreciation Days, where as many as 8,000 visitors were counted at the display during a one-day period. The general response of the public, oyster fishermen, members of the seafood processing industry and state resource managers to the formation of the HPEL hatchery program has been extremely enthusiastic. The concept of developing a new management strategy for the Maryland oyster industry has been very widely accepted. However, all of the various components of the Maryland fishery are critically awaiting the results of a long-term demonstration period and the detailed data on the economic feasibility of using hatchery technology in Maryland waters.

The project has also developed job skills in several (18) Eastern Shore residents. These individuals have been trained in the spawning and culture of oyster larvae, care of spat and maintenance of hatchery equipment. However this work-experience program is seasonal and supported by limited temporary grant funds.

ENVIRONMENTAL CONSIDERATIONS

Impact of Hatchery Operation

The hatchery program at HPEL is believed to have a minimal adverse impact on quality of ambient river water that passes through the facility. Hatchery operation procedures use no soaps, detergents, oils or chemicals in any of the larvae culture, algae culture or spat growing rooms. Chemicals are used only in the laboratory area. All drains from the laboratory areas enter a septic tank and the effluent then drains into a tile field. All hatchery personnel are particularly careful not to introduce any foreign material or chemicals into the ambient water flowing through the hatchery.

The University is required by Maryland State and Federal (EPA) water use and discharge permits to maintain water flow records and measurements of turbidity on a daily basis. Hatchery flow rates are rather constant (+5%), and we have obsered a range of 8-180 ppt suspended sediment as determined by gravimetric technique in the incoming ambient water. Effluent from the hatchery contains practically the same level of suspended sediment. Variation between levels entering and leaving the hatchery to date is about 3% which may be within the error of the measurement technique.

During the operation of the hatchery, temperature and salinity measurements are made daily at several locations in the building. The temperature and salinity of flowing ambient water has not been observed to change as it passes through the facility. However there is a modification of water temperature in the larval culture cones, which are kept between 26°C and 30°C. Water used as medium for the growth of algae is changed from ambient, since the algae culture containers are maintained at 16°C.

Contribution to Natural Stocks of Oysters

The HPEL hatchery project has planted 25.9 million oyster spat into waters of Chesapeake Bay. A summary of these plantings was presented in Tables 9 and 10 in Part I of the Oyster Hatchery Technology Series where the data were analyzed and discussed. From the field observations made on these plantings, we have found that the survival of planted oyster spat is greatly dependent upon their size at the time of planting and on the physical characteristics of the bottom upon which the spat are placed. Hatchery-reared oyster spat must be over one inch in length when planted to insure a reasonable level of survival. Placement of the spat on hard Bay bottom, a natural oyster bar, or on a bed of newly planted shells appears to be the best planting strategy. All of our attempts to plant oysters on bottom not inhabited by natural stocks have failed because of the rapid rate of sediment deposition from Bay water and the unstable Bay bottom. Oyster spat attached to small pieces of oyster shell or clam shell are more easily handled in the hatchery process but may have a lower survival than spat attached to large oyster shell. Apparently oyster shell offers protection from natural predators in the Bay such as the blue crab and the Atlantic croaker.

Cultchless oysters were found to have virtually no survival regardless of their size at planting or the type of bottom upon which they were placed. In 1975 and 1976 over 2.5 million cultchless oysters were consumed by blue crabs. Laboratory studies confirmed the field observations that crabs easily cracked the softer shells of cultchless spat, and were unable to damage spat of the same size that were attached to cultch. Details of this study may be found in Appendix 4.

From estimates of hatchery-reared spat that have survived to the present time, the hatchery research program has made a contribution that could result in 15,000 bushels of oysters once the spat reach market size. Most importantly, many of the hatchery-reared spat were placed on barren bottom and now constitute foci of potential breeding oysters that could repopulate the adjacent unproductive bottom. The planting sites included upstream areas of the Potomac and Chester Rivers where Hurricane Agnes destroyed native oyster stocks. The hatchery-reared stocks have survived and are growing at these locations. Growth is very slow in the Potomac River; however, some oyster spat that were placed in the Chester River reached marketable size (3 inches) in two years.

To date our limited field observations have not detected any reproduction that could be ascribed to the planted oyster spat. However, if these animals do spawn and produce offspring that repopulate these areas, their contribution to the future economic health of the oyster industry may be many times the investment to date.

Part IV

Oyster Hatcheries on the Chesapeake: A Prospectus

Part IV

A PROSPECTUS FOR THE IMPLEMENTATION OF MODERN OYSTER CULTURE TECHNIQUES IN MARYLAND

PART IV

A PROSPECTUS FOR THE IMPLEMENTATION OF MODERN OYSTER CULTURE TECHNIQUES IN MARYLAND

Introduction

> "The Chesapeake! The name was familiar to all children, for on this great water, strange things occurred. This was the magical place where the waters became even wider than those of the Susquehanna, where storms of enormous magntiude churned up waves of frightening power. This was the river of rivers, where the fish wore precious shells."
>
> --James A. Michener, Chesapeake

In the Indians' language, Chesapeake meant "the great river in which fish with hard-shell coverings abound." Each village along the Susquehanna possessed precious lengths of roanoke (or wampum) made from shells gathered from Bay waters. Indian wealth and food was derived from the American oyster, *Crassostrea virginica*. Today's residents of tidewater Maryland and Virginia still derive much of their subsistence and wealth from the Bay. James Michener captured much of the evolution of the extremely complex social and cultural heritage of the Bay, the Indians, settlers, and watermen in his recent book *Chesapeake*. That book illuminates the cultural sources of conflict between the present oyster fishery and modern oyster aquaculture concepts in the Chesapeake Bay.

For over 350 years various components of a truly unique society in Maryland and Virginia have fished a common property resource originally granted to the early colonists by the King of England. As in all hunt-and-capture fisheries, conflicts occurred between the "have" and the "have-nots." Equal opportunity for exploitation of the natural resource--rather than conservation--was and still is the driving force in these human interrelations. In an attempt to make order out of chaos, legal systems at all levels of government have enacted laws to satisfy, or temporarily pacify, the public. Unfortunately, new legislation rarely removed earlier restrictions; therefore, today's mandate for the management of the oyster fishery of the Chesapeake Bay is extremely conservative and based on maintaining the status quo of existing legal, commercial, public, and private fishery institutions.

Most of the scientific community truly believes in the future potential of aquaculture. However, we have failed to appreciate the realism of the democratic process, especially in established subpopulations of humans. The rule "by the people and for the people" has developed many legal constraints to implementation of modern aquaculture practices or even the mere expansion of existing oyster farming practices. Any position paper calling for the enhancement of oyster culture in the Chesapeake Bay has to take into account existing legal requirements and unwritten social attitudes of Bay watermen--or become another empty academic exercise.

Historically, the Chesapeake Bay has dominated oyster production in the United States, with Maryland and Virginia sharing this production equally in the past. At the beginning of the data base shown in Figure 1 (U.S. Bureau of Commercial Fisheries Statistics), Maryland production was approximately 15 million bushels per year. By 1900,

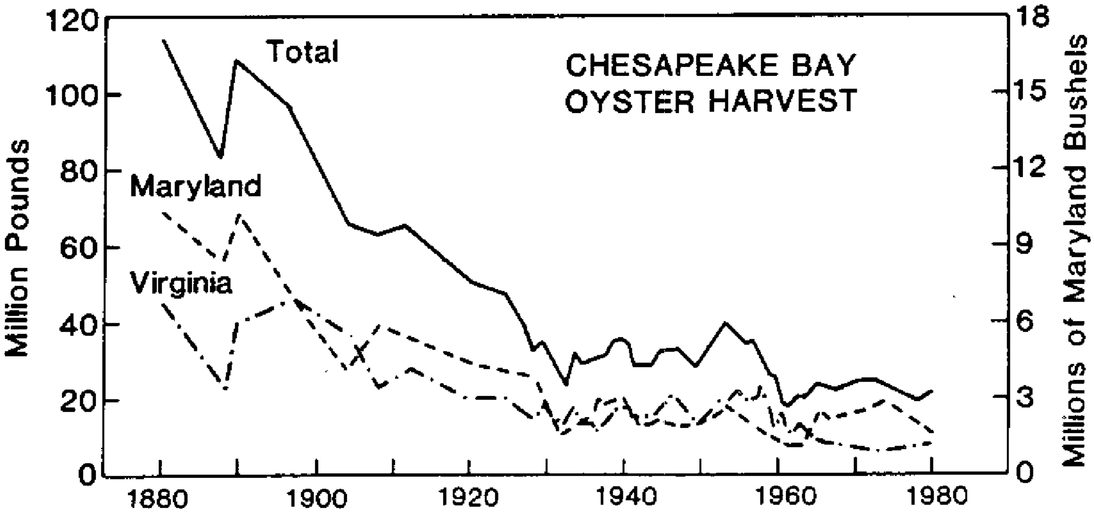

Figure 1. Chesapeake Bay Oyster Production

production had dropped to 9 million bushels per year, but oyster culture was well underway at that time. In 1830 a one-acre lease law was passed. In 1865 the size of allowable leases was increased to 5 acres. By 1900 laws on shell planting, an oyster cull law and seasons for oyster harvests were implemented to preserve national oyster populations for future generations (Yates, 1913). These laws were enacted primarily because of the shortage of the product in the Maryland processing market and a very high demand for Maryland oysters by the American consumer.

In 1908 an Oyster Culture Act (Grave, 1912) was passed which encouraged the leasing procedure within the state of Maryland. This law was stimulated by the need for more product in the oyster industry and the serious decline in the natural fishery. The Act made barren bottom that was not a natural oyster bar available for lease. A Baywide survey was conducted to delineate this barren bottom, and by 1913 over 36,000 acres of bottom were under an application for lease status. Scientific projections at that time were that over 300,000 acres (Yates, 1913) would be utilized by leaseholders, and a projected 20 million bushels could be added to a natural fishery which was yielding 5 to 6 million bushels.

About this time, numerous legal battles between public and private interests and the state management agency created an atmosphere of chaos. By the end of World War I, only 4,000 acres of leased bottom had been given to private growers. The primary reason for the collapse of the projected private industry was in the legal definition of natural oyster bars. A lease application was disallowed on the mere testimony of a waterman who would claim that he caught oysters from that location sometime during a five-year period prior to the lease application. Numerous other legal, social and political activities influenced the decision to turn public opinion against a planned large-scale oyster leasing program in Maryland. One major constraint to modern aquaculture emerged from this furor: Maryland leases <u>cannot</u> be held by corporations, only by private individuals.

Figure 1 shows that since the early 1920's, Maryland and Virginia production has fallen. Maryland presently is harvesting between 1.5 and 3.0 million bushels per year. Maryland and Virginia continued to share equally in the harvest until about 1955, when "MSX Disease" and "Dermo Disease" devastated many oyster bars in Virginia. Since that time Maryland has been contributing between 60 to 70 percent of the Chesapeake Bay harvest.

Figure 2 is an example of the magnitude of some of the recent changes in the Maryland and Virginia oyster fisheries. This figure shows the relative relationships of total landings from the two states before and after the impact of oyster diseases on Virginia oyster stocks. In 1955, Maryland and Virginia shared equally in the harvest. By 1970, the fishery was dominated by the Maryland public oyster bar fishery. The attitude of the Maryland industry at this time was that their business was better than ever, and both watermen and packers could not perceive the serious decline in the amount of oyster produced from the Chesapeake Bay. Maryland processors had gained customers and sales that were previously held by Virginia private leaseholders, and their marketing problems disappeared. In 1955, Maryland and Virginia were virtually mirror images of one another in the ratio of public to private oyster grounds. The change in that ratio in recent years in Virginia has enabled many Maryland watermen to point to the Virginia situation as evidence for how unproductive and unwise private ownership of oyster leases in Maryland could become. They use this evidence to maintain the dominance of the public fishery and to encourage Maryland management agencies and legislators to echo their desire to suppress business competition.

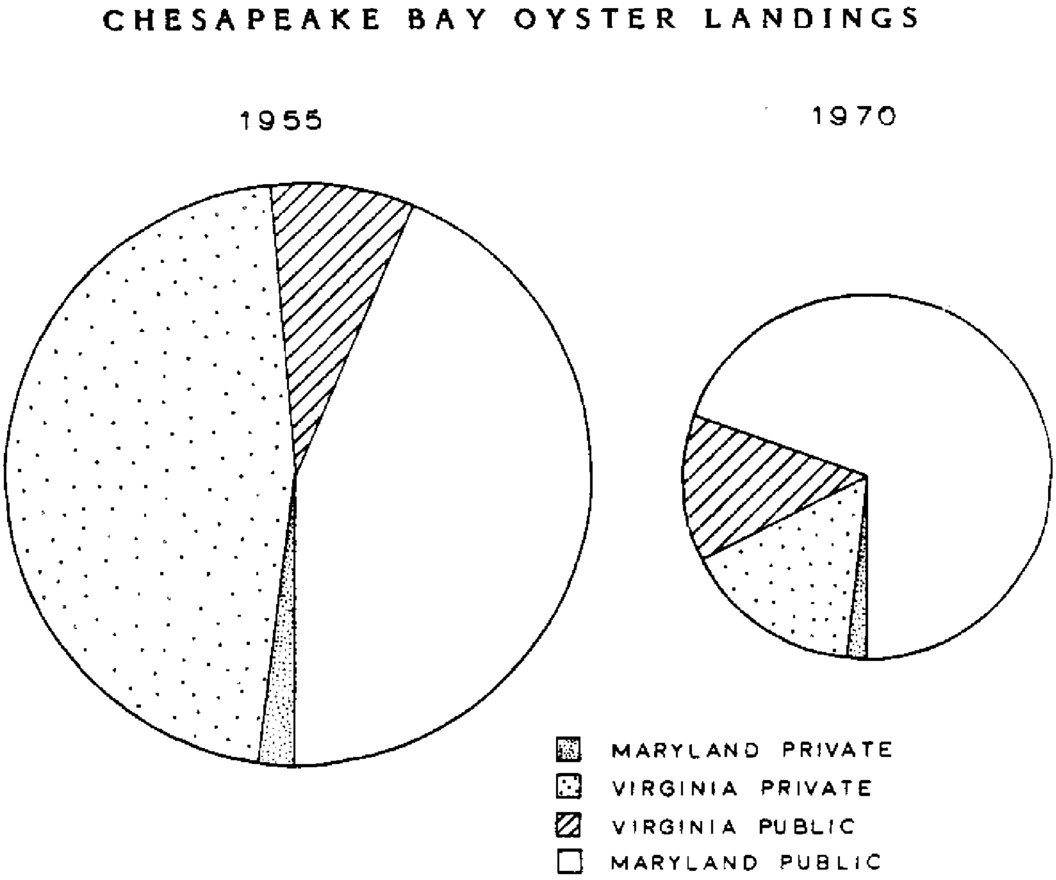

Figure 2. Relative size of oyster harvest in 1955 and 1970 with relationship of Maryland and Virginia public and private catches.

The Present Status of Oyster Lease Operation in Maryland

Approximately 4,000 licensed Maryland watermen use the public fisheries and supply about 76 oyster processing plants. The public fishery covers approximately 215,000 acres of Bay bottom. The private oyster culture component in Maryland is comprised of 625 to 650 individuals who farm approximately 9,000 acres of bottom legally defined by about 1,000 separate leases. Maryland private leases contribute from 2 to 8 percent of the annual Maryland harvest, but in some years their contribution has been as high as 16 percent. This increase occurred during 1957 through 1960 when there was a decline in production from natural oyster beds to less than 1.5 million bushels. Oysters from Maryland leases command a slightly higher resale price than oysters from the public fishery; therefore the private grower contributes from 3 to 10 percent of the dollar value of the Maryland fishery.

Maryland oyster leases are distributed throughout the geographical range of natural oyster populations in the Bay (Figure 3). This distribution is influenced by county and subdivision regulations, even though the Bay oyster industry is managed on a statewide basis. Prior to 1968, the Maryland fishery was regionalized on a county basis and the public fisherman could operate only within his county. Now Maryland watermen have free access to all waters under state jurisdiction. While management regulations were under county subdivisions, several groups of watermen strongly opposed private oyster leases, and their counties passed restrictions against leases. There are, for example, no leases permitted in Kent County, located on the northern Eastern Shore. In the past forty to fifty years several other counties on the Eastern Shore have passed restrictions to deter new oyster leases. In general, Maryland leases are more numerous in the southern portion of the Chesapeake Bay, primarily because the waters are slightly higher in salinity, which imparts a better flavor to the oysters. This area contains residents who have participated in the Virginia private lease industry. The southern portions of the Bay also have less turbidity than the upstream portions of the Bay, which are strongly influenced by runoff from the Susquehanna River and rivers along the Western Shore near Annapolis and Baltimore.

Maryland oyster leases are relatively small with a medium size of 3 to 5 acres. Over 75 percent of the leases are under 10 acres with only 12 percent of the leases over 20 acres (Figure 4). There are very few leases in the open Bay, even though leases up to 500 acres are permitted under existing law. In the open portion of waters of Tangier Sound in the southern portion of the Bay leases can range from 1 to 100 acres. Within the boundaries of other counties in Maryland, the maximum size of the lease is 30 acres.

The present distribution of leases on a county-by-county basis is fairly uniform. However, the income for leases within the counties is not equal, and certain counties seem to have aggregations of active lease farmers (Table 1). In other counties--probably because of past conflicts with the local public fishery--leases are totally inactive.

The distribution of harvest and earned income from Maryland oyster leases (Figures 5 and 6) suggests a strong economic constraint against the present oyster culture system being able to generate enough venture capital internally to expand. Data shown in Figures 5 and 6 and Table 1 were collected from the compulsory oyster sales receipts

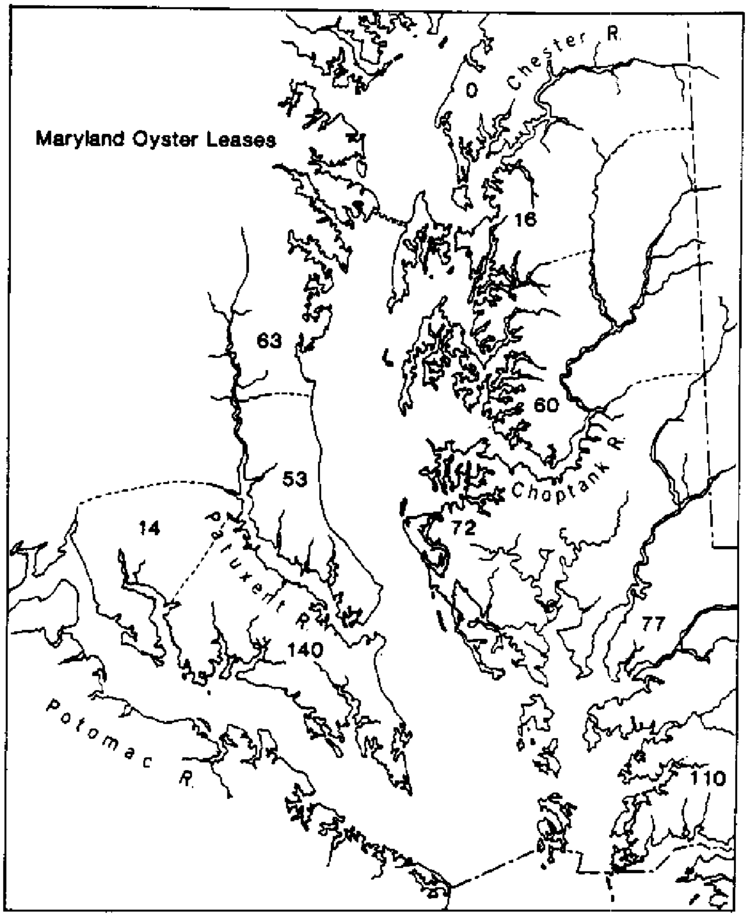

Figure 3. Distribution of Maryland Oyster Leases by County

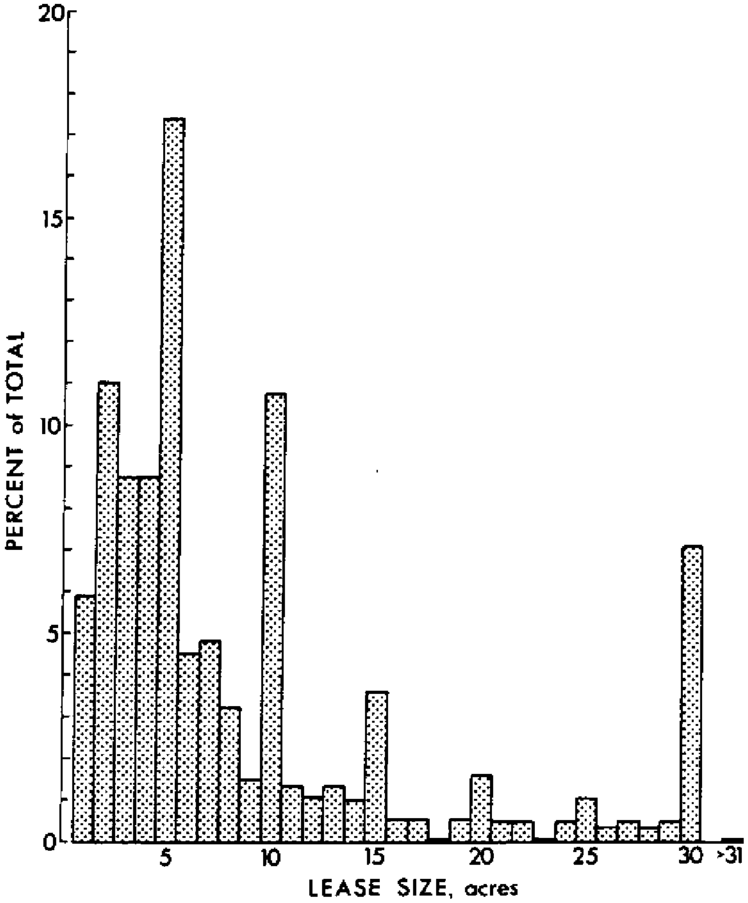

Figure 4. Frequency distribution of Maryland oyster leases by size, 1980

TABLE 1. MARYLAND OYSTER LEASE ANALYSES BY COUNTY

LOCATION	NUMBER OF LEASES	PERCENTAGE OF TOTAL LEASES	NUMBER BUSHELS	1979 DOLLAR VALUE
CHESAPEAKE BAY				
Western Shore		(43.6)		
Ann Arundel	63	10.1	4,945	$ 50,143
Calvert	53	8.6	4,748	50,578
St. Mary's	140	22.6	7,360	76,192
Charles	14	2.3	224	2,912
Eastern Shore		(54.1)		
Cecil	1	0.2		
Kent	0	0		
Queen Annes	16	2.5		
Talbot	60	9.6		
Dorchester	72	11.6	5,562	53,370
Wicomico	77	12.4	19,762	146,157
Somerset	110	17.8	3,402	33,906
OCEAN SIDE		(2.1)		
Worcester	13	2.1		

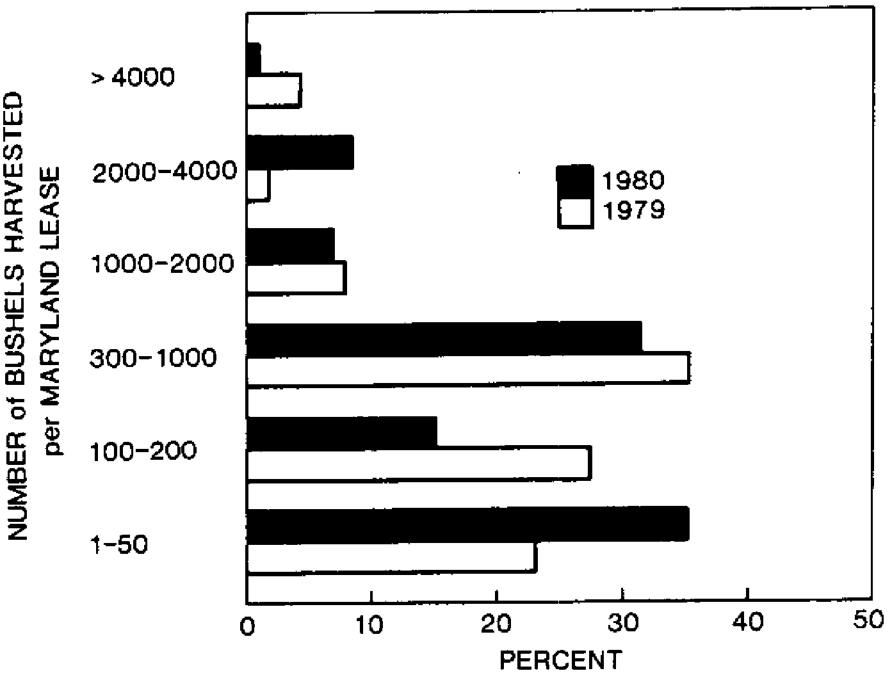

Figure 5. Frequency distribution of oyster harvest from Maryland oyster leases, 1979-1980

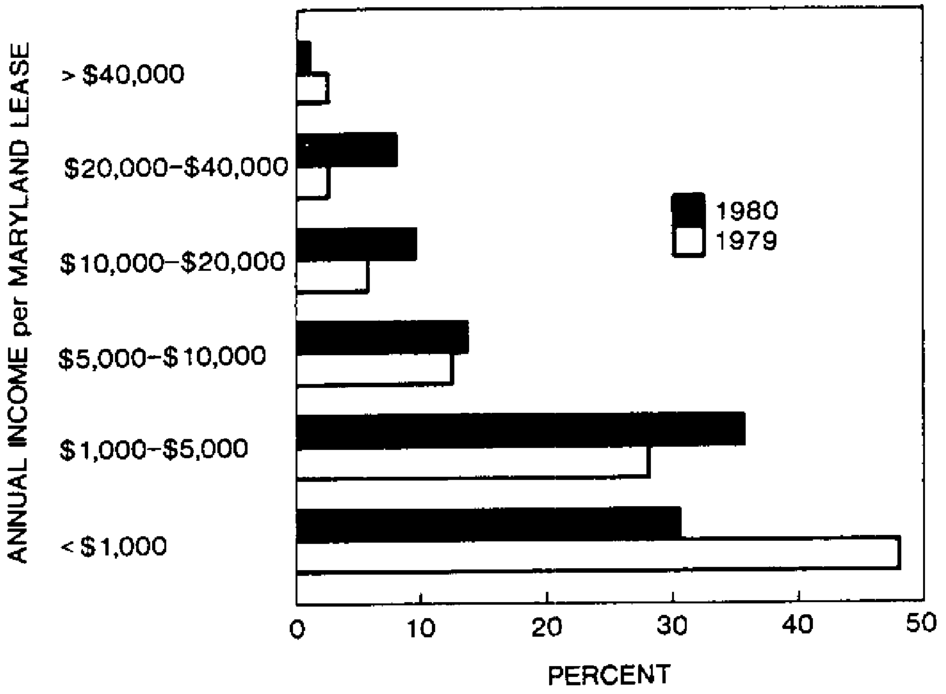

Figure 6. Frequency Distribution of Gross Earned Income from Maryland Oyster Leases

that are sent into the Maryland Department of Natural Resources by the oyster growers.*

About 12 percent of the Maryland lease holders reported harvests from their leases in 1980, while 17 percent reported landings in 1979. Approximately 80 percent of the Maryland leases are not reporting any harvest. Of those leases reporting harvests, 15 percent had yields over 2,000 bushels; in other words, less than 2 percent of the leases in Maryland are creating enough product to sustain a reasonably sized private business.

Maryland management personnel, state legislators, economists, and, of course, university oyster biologists, have always been curious about how many Marylanders are actually farming their leases and how they conduct their farming operations. In 1979 the University of Maryland, Maryland Sea Grant, and state Department of Natural Resources extension personnel held a state-wide oyster culture conference (Webster, 1979). Approximately 90 oyster lease operators attended the conference, and part of their activity was to complete a questionnaire designed to determine how oyster growers actually farmed their leases. Seventy percent of those growers who attended the meeting reported productions ranging from 50 to 500 bushels per acre (Table 2). The results of the survey may be skewed by the composition of the 90 leaseholders. Our questionnaire sampled some of the most active leaseholders in Maryland: 34 percent of the leaseholders held between 50 and 100 acres of lease and 85 percent held over 10 acres. However, the size frequency distribution of legal leases in Maryland has a medium lease size of 5 acres (Figure 4). Most of the people who attended the conference were farming their oyster leases, and those individuals just holding leases did not attend. Some of the people in attendance held several leases, as well as shared leases with other household members and relatives. These complex titles to ownership reflect intelligent responses to county and state laws restricting the mode in which leases may be farmed and the number of acres a person may legally lease. These complex ownership problems and lease titles would have to be resolved before these persons could participate in a modern investment scheme for commercial development, or apply for loans from a federal agency such as the Farmers Home Administration. As a group, Maryland leaseholders do not have sufficient income to launch a business expansion effort.

The survey found that the number of years that the lease operators have been in the oyster farming business showed a bimodal frequency distribution with 42 percent being in the business for over ten years and approximately 40 percent new leaseholders (Table 3). There appears to be a significant turnover in lease operators within the Maryland system. These new ventures could provide an opportunity to introduce new oyster culture technology into the traditional oyster culture system.

Maryland law restricts oyster leases to "barren bottom," areas where commercial quantities of oysters are not found. This bottom is usually composed of soft mud and must be over 150 feet from a natural or legally defined oyster bar. Over 85 percent of Maryland leaseholders are required to plant oyster shell as a growing substrate for seed oysters. At our meeting and in recent interviews, oyster growers reported using between

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*Maryland oyster harvest data use the Maryland bushel-approximately 350 oysters--which equals 1.6 cubic feet or 0.046 cubic meters. A Maryland bushel contains approximately 6.7 pounds of meat (3 kilograms) and yields a meat volume of about 8/10th of a U.S. Gallon (six pints), approximately 3 liters.

TABLE 2. SURVEY OF MARYLAND OYSTER LEASE OPERATORS WHO ATTENDED THE 1979 MARYLAND OYSTER CULTURE CONFERENCE TO DETERMINE THE NUMBER OF ACRES OF BOTTOM THEY LEASE OR CONTROL BY CONTACT:

NUMBER OF ACRES	PERCENT
1 - 5	15.6
10 - 25	28.1
25 - 50	15.6
50 - 100	34.4
100 -	6.3

TABLE 3. SURVEY OF MARYLAND OYSTER LEASE OPERATORS TO DETERMINE THE NUMBER OF YEARS THEY FARMED THEIR LEASES:

YEARS	PERCENT
1 - 5	39.4
6 - 10	18.2
11 - 15	6.1
15 -	36.4

TABLE 4. SURVEY OF MARYLAND OYSTER LEASE OPERATORS TO DETERMINE THE AMOUNT OF SEED (IN BUSHELS) THEY PLANT PER ACRE (ASSUME 1,000 SPAT/BUSHEL)

NUMBER OF BUSHELS	PERCENT
100	4.8
100 - 250	19.0
250 - 500	23.8
500 - 750	14.3
750 - 1,000	23.8
1,000 - 1,500	9.5
1,500 -	4.8

TABLE 5. SURVEY OF MARYLAND OYSTER LEASE OPERATORS AT THE 1979 OYSTER CULTURE CONFERENCE TO DETERMINE THEIR PRODUCTION (BUSHELS) FROM AN ACRE AT HARVEST:

NUMBER OF BUSHELS	PERCENT
50	16.7
50 - 100	33.3
100 - 500	37.5
500 - 1,000	4.2
1,000 - 1,500	4.2
1,500 -	4.2

4,000 to 15,00 bushels of shell per acre to sterilize the bottom. In 1979, the cost for shell was approximately 40 cents per bushel delivered on site. Therefore, the Maryland leaseholders spend approximately $1600 to $6000 an acre just for a shell substrate on which to grow oysters. Our questionnaire found that only 1.8 percent of the Maryland oyster growers considered their bottom to be characteristic of an oyster rock or oyster bar.

Maryland oyster growers reported that they plant between 250 and 1,000 bushels of 1,000-count spat per acre of prepared bottom (Table 4). This amounts to 250,000 to 1,000,000 seed oysters per acre, a density of 5.7 to 30 per square foot (60 to 300 per square meter). Questionnaire data in Table 5 indicate that 125 bushels per acre was the medium harvest from Maryland leases. This is a harvest of approximately one oyster per square foot. A harvest of 500 bushels per acre would mean four oysters per square foot, and a yield of 1,000 bushels per acre would equal eight oysters per square foot. These data suggest a relatively high mortality or loss of oysters to harvest of somewhere between 60 and 75 percent of the seed oysters planted on prepared lease bottom. These data compare favorably to a Bay-wide rule of thumb used by oyster management biologists and oyster growers. Most growers feel that one bushel of 600- to 1,000-count seed, one to two inches in size, will yield one bushel of marketable oysters, or about 300 to 350 individuals. This mortality of 65 percent compares favorably to the data obtained from oyster growers at the conference. A recent analysis of the Maryland State Seed Program (Swartz & Strand, 1981) and the Potomac River Fisheries Commission management strategy (Krantz, 1981) confirm this ratio of planted seed oysters to yields of harvestable oysters.

Over 70 percent of the Maryland oyster growers at the 1979 Oyster Culture Conference reported they needed to buy seed, since natural spatfall occurred very frequently or not at all on their leases. All leaseholders felt that natural spat set in the Chesapeake Bay was too light for them to farm properly and that seed oysters should be planted for proper management. In response to a question about how many years the grower left the seed oysters on the bottom before harvest, 66 percent of the Maryland oyster growers responded that they left their seed on the bottom for two to three years--only 10 percent left the seed on the bed for five years. This was due to use of cultured oysters as half-shell trade. Also, after five years the mortality rate of oysters seems to increase, due either to disease or to the weight of the oysters causing them to sink into the soft bottom.

With this background of lease farming activity, the distribution of income among Maryland leaseholders can be more critically analyzed. The present income distribution indicates that only 20 percent of the leaseholders earn enough money for an occupation (Figure 6). Through interviews, I have found that most Maryland oyster leaseholders have an alternate income. Many of the small leaseholders work in the public fishery and use their cultured oysters to extend their oyster catching effort one or two months in the early spring until the crab fishery begins. Another use of Maryland leases is to store oysters when there is no market for oysters harvested from the public oyster grounds. These can then be harvested at a later date. Some persons speculate by catching oysters and then placing them on private ground to wait for a rise in oyster prices during the late spring and summer months, when the public fishery is not operating.

Approximately 20 individual leaseholders in Maryland also own an oyster processing plant, and they use their oysters to sustain the processing plant when oysters from the public fishery are not available. This type of oyster culture has been pursued by Mr. Howard Kennerly (Kennerly, 1981).

In general, there are several farming strategies within the Maryland oyster culture activity. Each individual lease operator has a strategy that seems to be more suited to his lifestyle and needs for income. Free enterprise seems to be the motivation for Maryland leaseholders.

Production Potential for Maryland Leases

The Maryland portion of the Chesapeake Bay contains over 1.5 million surface acres of high quality estuarine water that chemically can sustain shellfish growth. Public oyster bars occupy 270,000 acres, crab bottom 40,000 acres, clam bottom 6,000 acres, and military uses 43,000 acres (Jensen, 1980). There are 479,000 acres of marginal bottom in counties that permit no oyster leases; additionally there are 300,000 acres of bottom in waters over 40 feet deep and 85,000 acres that are too close to water classified for other uses (or under reparian ownership) to be used for on-bottom oyster culture. About 65,000 acres are considered polluted and of little value for leasing. Existing laws could make only about 175,000 additional acres available for oyster culture after a current study to reclassify the Bay bottom in Maryland (Jensen, 1980).

All 9,000 acres now leased and the potentially available 175,000 acres occupy barren bottom where no oysters occur naturally. These bottoms are now freely used by the public clam, crab and finfish fisheries, as well as by a recreational fishery and a huge boating public.

Since only a small percentage of the Maryland leases are farmed, the present industry gains only an average of 7 to 22 bushels of oysters per leased acre per year. However, if all the leases currently held in Maryland were farmed properly, with seed oysters planted on a shell base to stabilize the bottom, Maryland growers could produce over 4,000,000 bushels of oysters per year (Table 6).

By comparison, the present Maryland public fishery is harvesting 11 bushels of oysters per acre per year, with some of the best natural bars producing 750 bushels per acre per year. The public fishery may increase its harvest to as high as 3,000,000 to 3,500,000 bushels per year within the next five years as a result of a very good spat set in 1980.

The projected yield from making the present 175,000 acres of barren bottom available for oyster leasing instead of dedicating it to a public clam fishery could result in production of 20 million to over 40 million bushels of oysters per year for Maryland. However, a conflict exits over the 175,000 acres of land, since the Maryland clamming industry feels the bottom should be devoted solely to their use, instead of having it used for private oyster culture or used as new bottom for the public oyster fishery. This dispute precipated the reclassification of the Bay bottom and two polarized potential "user groups" have already emerged in competition. It will be very difficult for the state legislature to assign this bottom to an oyster culture group which does not now exist. An even more difficult legal maneuver would be to change present county attitudes and release the 479,000 acres in counties which now permit no leasing. If this were done, the State of Maryland would have a future potential of 650,000 acres of bottom from which an uncomprehensible volume of oysters could be produced. As one views this very attractive theoretical projection, which would increase yields from Maryland oyster leases by about twenty times, one naturally asks the question, "What would be the key to developing the existing 9,000 acres of leased bottom now held by Maryland leaseholders?" This was one of the questions that the 1979 Maryland Oyster Culture Conference

TABLE 6.

PRODUCTION POTENTIAL OF MARYLAND LEASES

ACRES	PRODUCTION (MILLIONS OF BUSHELS)
EXISTING LEASES: 9,000	1.8 - 9.0
PRESENT POTENTIAL: 175,000	20 - 40+
FUTURE POTENTIAL: 650,000	?

addressed. We found that 81 percent of the people in attendance could conduct a financially viable culture operation by paying $0.60 a bushel for oyster shell to stabilize the bottom and $3.50 for 1,000-count seed currently available from the James River and from other areas in Virginia. The costs of producing seed in the University of Maryland Horn Point Environmental Laboratories pilot production hatchery and in the Department of Natural Resources low-cost technology hatchery at Deal Island range from $1.00 to $3.50 a 1,000 for one-to-one and-a-half-inch seed oysters. It is obvious that the current cost for the essential materials for oyster farming i.e., shell and seed, are not prohibitive to most Maryland oyster farmers.

In order to identify constraints, I asked the attendants of the 1979 Oyster Culture Conference and several other active leaseholders to discuss with us their needs, to be discussed at the North American Oyster Workshop (Seattle, Washington, March 1981). One of the things in the forefront of their response was the recent moratorium on the acquisition of new leases in Maryland and the social-political discussions that resulted in a resurvey of the Chesapeake Bay bottom. They also suggested that the recent increase in amount of information on aquaculture as a result of legislation and enactment of the National Aquaculture Bill has caused some suspicion among the conservative elements in the Maryland oyster industry. Essentially, knowledge of and fear of legal constraints to free enterprise of the public fishery were involved in all of their responses.

In contrast to a Maryland leaseholder who risks his investment, the Maryland public fishery is a classical hunt-and-capture fishery that replies on natural recruitment to sustain its harvest. Participants in the public fishery do not have any financial risk. The state regulations and resource management activities focus on the maximal utilization of the resource in an attempt to sustain an annual production of 2 to 2.5 million bushels. Past legislative activities and county ordinances have generated a very complex set of oyster fishery regulations that (1) maintain the use of inefficient gear, such as hand tongs and sail dredges in the fishery; (2) restrict daily harvest, and (3) adjust the oyster season to insure ascendancy of the public fishery during the traditional peak of consumer demand in the fall. State management efforts focus on enforcing regulations, monitoring water quality in shellfish waters, placing cultch on natural oyster bars, and transporting seed oysters. Management agencies do not have any legislative or administrative mandate to provide services to the private oyster grower. Only recently have individual interpretations of legal restrictions by the State's Attorney's Office and by the Maryland Management Agency provided any support for the private oyster grower.

At present, there is a total moratorium on acquisition of new leases until a survey of Bay bottom is complete. Estimates of the completion dates for this reclassification range from 1982 to 1986. Even then, there are existing State laws that permit new leases to be obtained only in four counties (Figure 7). These counties contain very limited amounts of usable bottom and are in serious conflict with urbanization and recreational use.

The inefficiency of oyster harvest methods mandated for the public fishery is also promulgated on the private grower's harvest techniques. There are laws that require the harvest of oysters by hand tongs or by patent tongs in areas where most of the productive oyster leases in Maryland are located. Because of this legal constraint, 51 percent of the oyster growers in Maryland use hand tongs to harvest their oysters. There is no way they can personally harvest enough acreage to sustain a modern oyster culture business using this method. Leaseholders must hire watermen to harvest the oysters and pay them $1.50 to $2.00 a bushel for their labor. (In certain geographical regions of the Bay, the public oyster fishermen will only work for 50 percent of the dockside value of the oysters

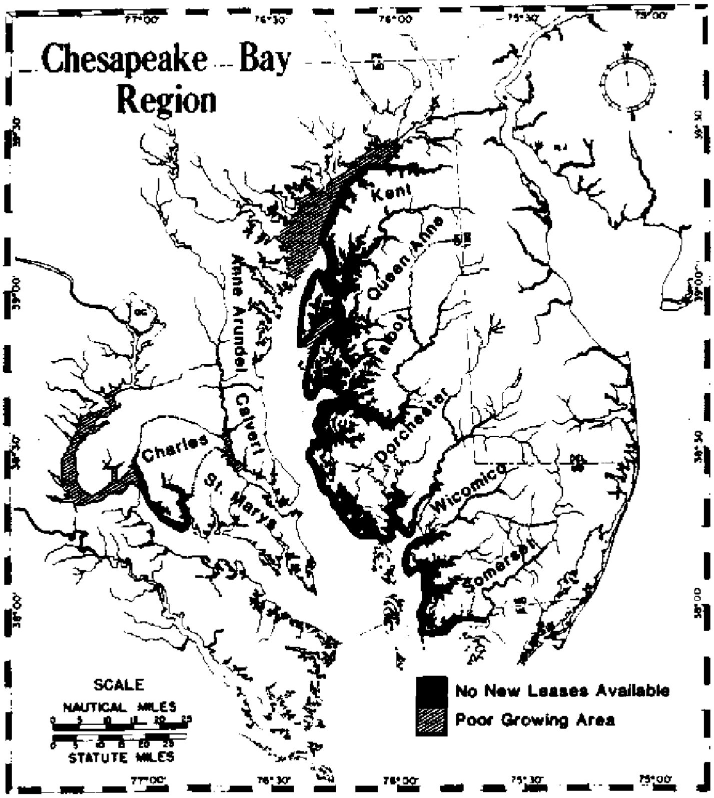

Figure 7. Status of Maryland Bay Bottom that could be used for oyster culture

grown on private leases.) Only 5 percent of the Maryland leaseholders use modern hydraulic oyster dredges, and only 40 percent use power dredges to harvest their leases.

Even though the private culture industry cannot expand at this time, availability of new land for leasing does not seem to be a major constraint on the present members of the Maryland private culture industry. Most of the progressive growers in Maryland seem to be satisfied with the size of the acreage that they have. At the conference, we found that the responses to the question "How many acres of new bottom would they lease if it were available?" ranged from 0 to 600 acres. The mean of the distribution was 64 acres. Therefore the alleged constraint of the existing moratorium on new leases or the unavailability of the 175,000 acres of barren bottom is not a major deterrent to the present or short-term development of oyster culture in Maryland.

Participants at the 1979 Maryland Oyster Culture Conference identified the availability of seed, poaching, and operating capital as major deterrents to the present oyster lease operations (Table 7). Biologically, the major problem with the Maryland oyster industry has been a predictable and cost effective source of seed oysters. Natural spatfall in Maryland has always been low. Spatfall has been cited as a constraint to both public and private oyster culture about every decade from 1900 to the present time by biologists who were studying reasons for decline in productivity in the Maryland oyster industry (Yates, 1913; Nichol, 1937; Beaven, 1945; Engle, 1946; Beaven, 1954; Engle, 1955; Manning, 1968; Davis, 1976). Many areas where private leases and public bars are located have had no significant recruitment since 1968 (Figure 9). The period from 1975 to 1979, which would sustain current oyster harvest, showed the same pattern of low spat recruitment (Figure 10). Therefore, shell planted on leased bottoms in most areas of the Bay has failed to produce marketable crops of oysters for over a decade. This drought of spatfall also changed the cost effectiveness and the volume of seed produced by the Maryland State Shell Planting Program for the public fishery. A shortage of product for the processing components of the Maryland oyster industry evolved from these natural biological phenomenon.

The development of oyster hatchery technology and the application of intensive seed culture techniques as an alternative source of seed in Maryland has been relatively slow. Several small privately owned hatchery operations have been unsuccessful in producing profitable quantities of seed oysters or enough harvestable oysters to sustain their private business ventures. Abstracts of papers presented at the North American Oyster Culture Workshop by Messers Frank Wilde and Max Chambers exemplify the problems of the small hatchery operator in Maryland.

The University of Maryland Center for Environmental and Estuarine Studies has been relatively active in evaluating the cost effectiveness of both low-cost technology and capital-intensive technology. Analyses of the Horn Point Environmental Laboratory pilot production hatchery and several small-low cost hatchery operations detected great variation in the biological production efficiency from Maryland hatcheries on an annual--and even on a monthly--basis. This biological variation leads to unpredictable levels of production and creates severe financial constraints for the operator to repay venture capital. Unpredictable production caused by fluxes in natural environmental conditions appear to be the major factor for economic failure in private oyster hatcheries in Maryland.

To study the economic viability of the HPEL pilot production hatchery we utilized linear computer models to analyze hatchery operations and to detect operational constraints and financial constraints in oyster hatcheries (Lipschultz and Krantz, 1978,

TABLE 7. THE MAJOR CONSTRAINTS ENCOUNTERED BY MARYLAND OYSTER GROWERS IN THE OPERATION OF THEIR LEASE.

	Percent
Seed Source	27.1
Poaching	17.6
Capital	16.5
Pollution	12.9
Mortality	10.6
Bottom type	9.4
Poor growth	3.5
Market price	2.4
Market availability	0.0

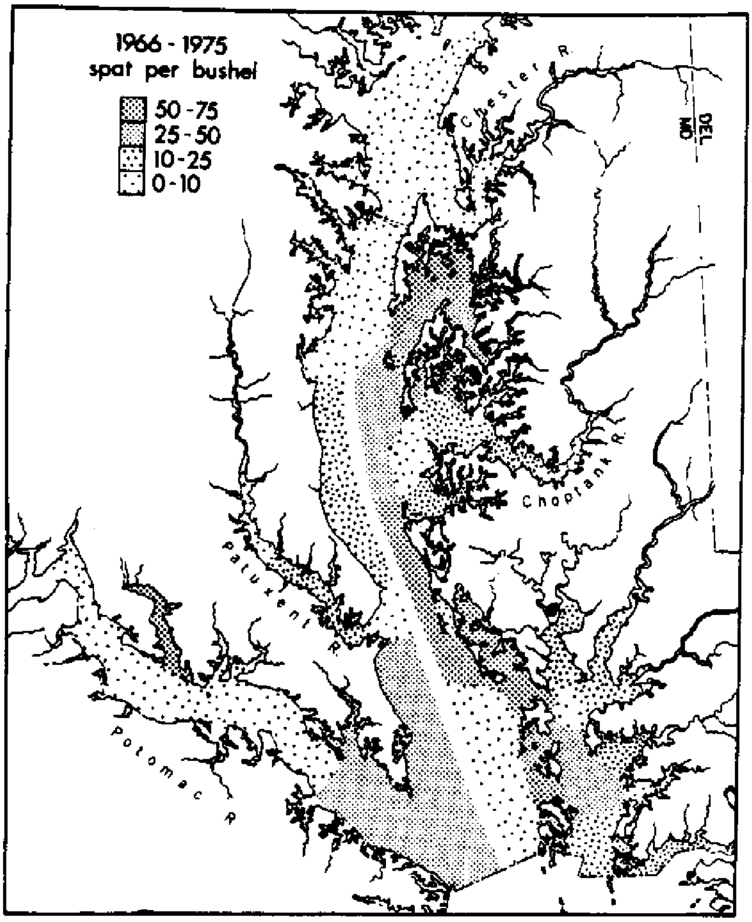

Figure 9. Distribution of spatfall on natural oyster bars between 1966 and 1975. Spatfall on private oyser leases in these areas exhibited a very similar pattern. (Adapted from Meritt, p. 25).

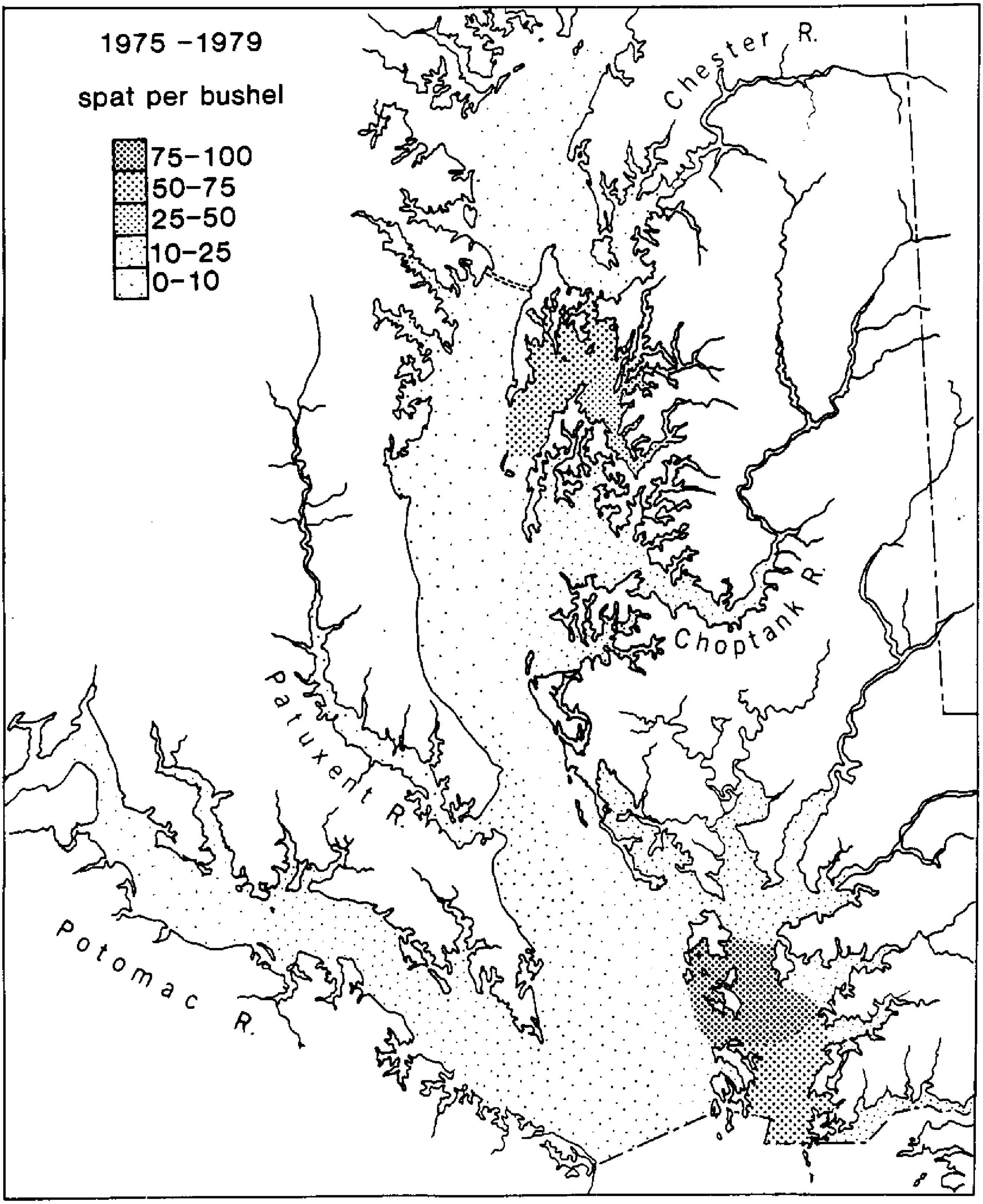

Figure 10. Distribution of spatfall on natural oyster bars between 1975 and 1979. This level of recruitment is presently sustaining Maryland's oyster harvest.

1980). After all the elements of hatchery operations and biological production efficiencies were optimized, we found that any changes in the level of hatchery production from that which we observed in what we could call a good year (1977), would cause economic collapse of a commercial venture. It appears that one can only expect a good production year that would sustain a commercial seed hatchery in one out of every five years in the low salinity environment found in the Maryland portion of the Chesapeake Bay.

High mortality of hatchery-reared seed oysters when planted in the Chesapeake Bay environment also reduced the profit potential of even the best farming operation (Table 6). To date, our pilot production efforts at the Horn Point and Deal Island hatcheries have produced over 25 million seed oysters, which we planted on various types of Bay bottom. Field studies to document survival from these plantings indicate that the marginal or barren bottoms--those that are presently used by oyster farmers--contribute to the loss of 75 percent to 90 percent of the hatchery-reared seed oysters placed on them. Seed oysters have the best survival (40 percent to 80 percent) when planted on very firm substrate or on an oyster shell base. The size of seed oysters at planting is very important, and any oysters less than one inch (25 mm) are of virtually no commercial value when planted in the Chesapeake Bay. Our studies have also found that cultchless seed oysters have virtually no survival when planted in the natural environment and exposed to the large predator populations found in estuaries (Krantz and Chamberland, 1978). Cultchless oysters may be farmed only in protected growing devices, which at the present time have not been developed or proven to be an economical culture technique (Hidu, 1981). However, the survival rate of hatchery-reared oysters is very similar to the survival rate of seed oysters that Maryland oyster growers have obtained from the James River, and similar to the survival rate of seed oysters produced by the Maryland State Shell Planting Program. Our hypothesis suggests that 65 percent to 75 percent of these oysters die when planted in the natural environment of the Chesapeake Bay.

The second greatest constraint to oyster culture in Maryland--and perhaps the greatest constraint in Virginia--is the lack of adequate legal protection for oysters growing on private grounds. Enforcement of existing laws is at present minimal, and recent public advisories to the Maryland oyster culturists suggested that the development of legal evidence and the initiation of arrest procedures were the responsibility of the oyster grower (Cook, 1979). There is no legislative mandate to provide for protection of private leases as a priority for the Virginia or Maryland marine police. At the present time, these agencies have undergone serious fuel allocation cuts and have been forced to assume many of the responsibilities previously covered by the United States Coast Guard. The United States Coast Guard in the Maryland portion of the Bay will no longer respond to requests for assistance from the huge pleasure boating public. This assistance must be provided by the state agencies. Additionally, there has been an increased amount of activity related to drug surveillance. The enforcement agency is also involved with numerous conflicts between the very large sport fishing and boating populations and the oyster grower. These conflicts have resulted in the establishment of very strict regulations by the U.S. Coast Guard and the marine police, as well as county zoning and city ordinances on "navigation hazards," especially for oyster lease markers and suspended or "off bottom" oyster culture devices. Regulations even exist that define dockage areas where oysters may be unloaded. County zoning requirements are now beginning to address the utilization of waterfront property for oyster culture as a commercial venture. In the past there were no zoning restrictions, nor did there seem to be any resistance to using waterfront land for oyster industry activities in Maryland. This attitude has completely reversed in the past decade. Now there is a great demand for the use of waterfront land for recreation, marinas, and especially for residential development.

The third major constraint cited by the Maryland oyster culture industry is financial. Financial resources to buy seed oysters or shell, to construct an oyster hatchery, or to provide working capital for many private Maryland oyster growers are virtually nonexistent. Financial constraint is possibly one area where a change in national and state policy could greatly assist the oyster grower. It seems entirely feasible to make low-cost loans to the traditional agricultural farmer, and oyster aquaculture is simply an extension of farming practices to the aquatic environment. However, all Maryland lending institutions consider oyster culture to be a high-risk venture and require loan collateral far beyond the means of most individual leaseholders. Also, all Maryland lending institutions demand interest payment long before the oyster grower can begin generating a saleable crop. The image of poor risk is reinforced by the strong, openly expressed resentment against oyster leases among participants of the public fishery and the common knowledge that adequate protection is not provided to protect the oysters growing on Maryland leases. The absence of any legislative action to enhance or even to encourage oyster culture for over one hundred years also reinforces this poor image of modern oyster farming in Maryland. The few private investors who have recently entered oyster culture in Maryland have greatly underestimated labor costs for the preparation of oyster beds and for harvest, as well as the time at which they could receive a cash flow and profitable return from the oysters they grew.

When we surveyed the participants of the 1979 Maryland Oyster Culture Conference, we found that their concept of expanded oyster lease farming would require between \$20,000 and \$50,000 in additional funds. Most of the individuals seemed to require a relatively modest amount of working capital. However, just to satisfy the financial needs of the oyster growers at that conference (which is less than 15 percent of the total oyster culturists in Maryland) there would have been demand for 175 million seed oysters in the first year of their theoretical expanded operation. In each of the following years, the operators would require an additional 135 million seed oysters. If all of the 9,000 acres of Maryland leases were expanded with the same amount of capital and interest in growing oysters, over 1 billion seed oysters a year would be required to plant the leases. Therefore, even if financial resources are made available through lending institutions, the constraint of the availability of seed oysters would remain. At this point, hatchery technology seems to be the only legally available source of low cost oysters for Maryland growers.

Chesapeake Bay Environment

The Chesapeake Bay Environment has a profound influence on oyster culture techniques. The Bay is naturally eutrophic from the high input of waters from the Susquehanna drainage, which flows over limestone-rich soils. The Bay is shallow, with large expanses of open waters that are frequently very rough. The bottom topography is dominated by a very long, shallow flood plain with a deep central channel from an old Pleistocene river system. The Bay is highly turbid with numerous subsurface deltas in the mouths of each of the river systems. Since the bottom of the Chesapeake Bay is composed of very soft, recently deposited sediment, any storm event or major change in wind condition immediately increases turbidity. A zone of maximum turbidity (25-150 mg/liter) occurs at the salt wedge between the fresh water and salt water interfaces. This is also the upstream range for oysters.

The shallow nature of the Chesapeake Bay and the wide expanses of very rough water make off-bottom culture of oysters totally impractical (Andrews, 1971). During recent studies to evaluate the effectiveness of different types of oyster spat collection devices suspended on rafts, between 30 percent and 90 percent of the devices were lost during one summer thunderstorm (Krantz and Dais, 1980).

In the winter, the Chesapeake is covered with heavy ice in nine out of ten years. As the ice leaves the Bay, strong winds and tides usually drive large flows of ice and remove virtually every oyster culture structure in the water column. Heavy ice cover may frequently also have an adverse affect on the survival of seed oysters and adult oysters planted on private leases (Krantz, 1977). Certain river systems in Maryland are very eutrophic and during heavy ice conditions oxygen depletion occurs, resulting in the total loss of benthic communities.

The Chesapeake Bay occasionally experiences periods of high fresh water flow. In 1945, between 4 million to 8 million bushels of oysters were reported killed in an area above the Chesapeake Bay Bridge near the approaches to the Chesapeake and Delaware canal (Engle, 1946). In 1972, Hurricane Agnes devasted oyster populations in this same area, as well as in the Potomac, Chester, and other rivers. Conservative estimates place these losses at over 10 million bushels (U.S. Corps of Engineers, 1975).

The Western Shore of the Chesapeake Bay is becoming urbanized at a very high rate. At the present time, Maryland has approximately 7 million residents and growth to 18 million is projected by the year 2020 (Young, 1981). The Eastern Shore of Maryland, where many of the productive oyster leases occur, has not yet been impacted by many point source discharges from municipal sewage treatment plants. However, most of the Western Shore rivers have been affected, especially oyster leases in the upstream portion of these rivers. Changes in water quality on these leases have caused at least one-third of the leaseholders in these areas to cease farming. Concurrent with water quality changes in the upstream portions of the river, natural spatfall showed a precipitous decline (1981, Hydroqual, Inc.). The pattern of spatfall in the Patuxent River illustrates this phenomena (Figure 11). As urbanization of Maryland and Virginia occurs, there is an increasing need for long-range planning and the establishment of aquaculture or oyster farming zones within the Chesapeake Bay. These plans could be enacted through Coastal Zone Management, even long-term planning at the county level. However, few Maryland county planners have an expertise in estuarine biology and virtually no appreciation for oyster farming. Therefore a state or federal plan should be developed. Even such an innocuous maneuver as the establishment of oyster culture zones would be interpreted as a positive sign that the oyster culture industry has received some mandate or encouragement from the state legislative processes.

A shortage of seed oysters has been identified as one of the primary constraints to the Maryland oyster industry, both public and private. Dramatic changes in the pattern of natural spat set in Maryland waters that have occurred recently have aggrevated this chronic problem (Figures 9 and 10). Prior to 1965, spatfall was consistent on a yearly basis throughout much of Eastern Bay, in the Eastern Shore tributaries, and in Tangier Sound. During the mid-1960's, Maryland's Tangier Sound and most of Virginia's waters experienced an epizootic of "MSX Disease" (Minchinia nelsoni), and large expanses of public oyster bars and private beds were destroyed. However, the disease epizootic does not seem to be the primary reason for the recent decline in Maryland spatfall. Between 1965 and 1975 (Figure 10), there was a Bay-wide reduction in spatfall, especially in areas where there was no disease. The highest loss of spat set occurred in the lower tributaries of the Maryland estuary. This is the location of the largest concentration of Maryland oyster leases (Figure 3). In 1975 through 1979, the trend for reduced spatfall continued, with two concentrations of spatfall in Tangier Sound and Eastern Bay. These areas are now where the public oyster fishery is concentrated, and watermen from other geographical regions are migrating to these sites to participate in the exploitation.

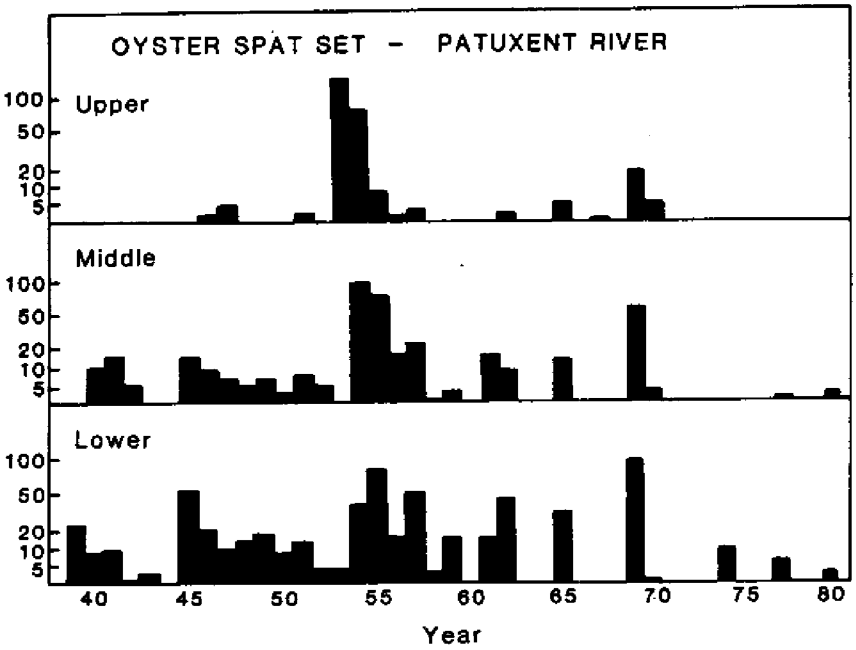

Figure 11. Oyster spatfall on natural cultch in the Patuxent River, 1939 to 1980. Upper portion of river has experienced water quality changes since 1968.

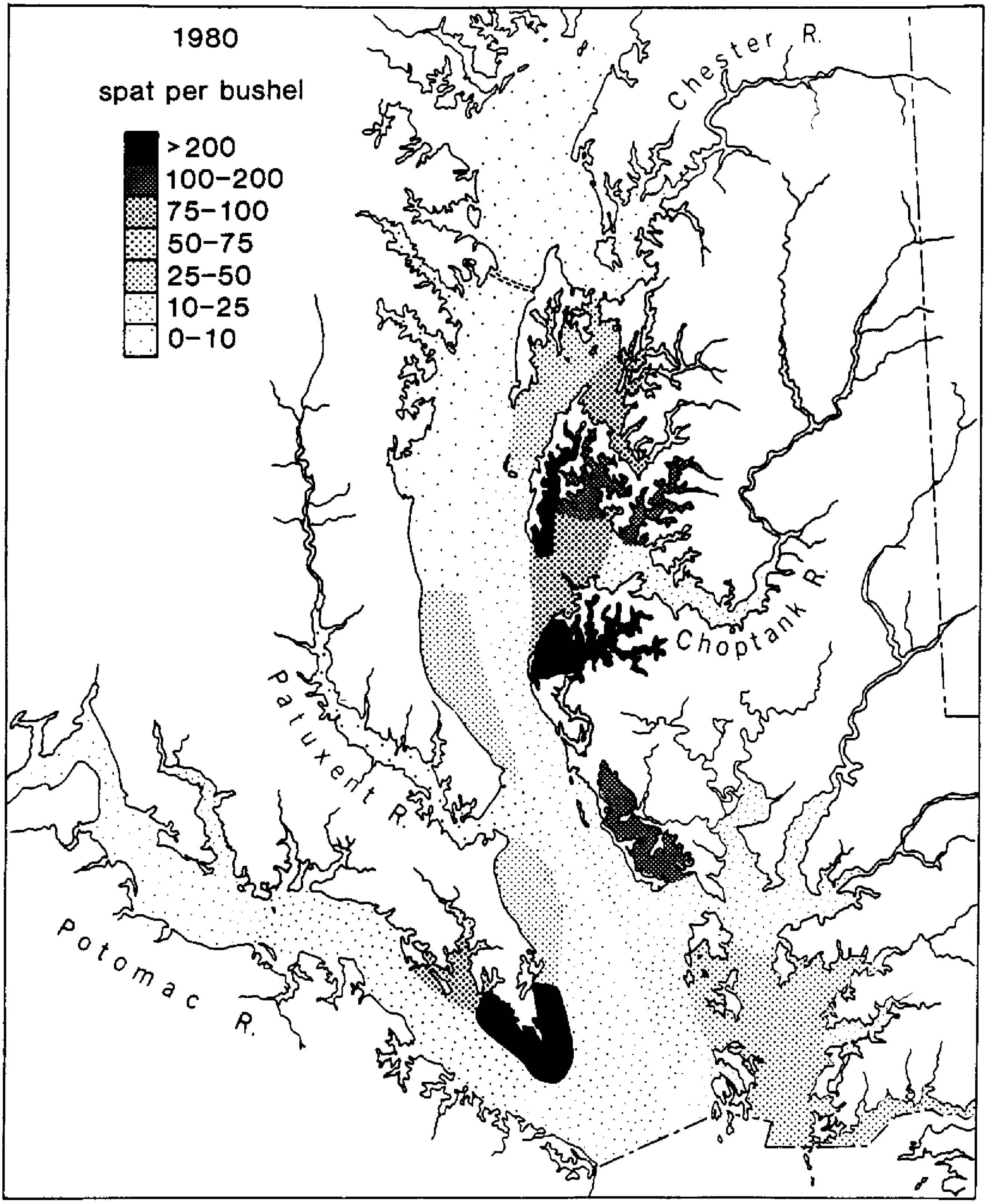

Figure 12. Geographical distribution of spat set on natural oyster bars in the Maryland portion of the Chesapeake Bay in the Fall of 1980.

The summer of 1980 marked a resurgence of spatfall to Bay-wide levels (Figure 12) similar to those in 1939 to 1965. However, there still was little spat settlement in many areas that are presently under lease or available to be leased. Spatfall was virtually non-existent along the Western Shore, in the upper Bay, and in the upstream portion of several rivers.

The Chesapeake Bay, particularly the Maryland portion, has a large blue crab (Callinectes sapidus) population and a very active crab fishery. Laboratory feeding studies (Krantz and Chamberland, 1978) have demonstrated the blue crab to be an excellent predator of hatchery-reared—as well as naturally produced—oyster spat. Blue crabs can easily eat three-inch cultchless oysters, primarily because of the thinness and fragility of the shell at the site of spat attachment. Our field studies repeatedly found 100 percent mortality in planted cultchless oysters. Cow Nose rays (Rhinoptera quadriloba) and other benthic fishes, such as the drum (pogonias cromis) and Atlantic croaker (Micropogon undulatus) are reported by some leaseholders to be serious predators. Seed oysters should be set on relatively large or heavy cultch and the size of spat at planting should exceed an inch to an inch and a half in shell length to protect them from predators. Maryland oyster leaseholders have repeatedly observed that the larger the seed oysters the better their survival.

Commercially available seed oysters of two to five millimetes in length produced by West Coast hatcheries are of no commercial value when planted in the Chesapeake Bay. Several private oyster planters and personnel in state management agencies in Maryland, Delaware, and Virginia have found very high mortality, including the total loss of small cultchless seed oysters.

Oyster diseases have had a very serious impact on the Middle Atlantic oyster industry (Andrews, 1968; Andrews and Wood, 1967). "MSX Disease" (Minchinia nelsoni) destroyed much of the Delaware and Virginia fisheries in the late fifties. This disease entered the Maryland portion of the Bay in the early sixties and affected mainly the oyster bars in Tangier Sound (Farley, 1975). The disease subsided by 1968, and it is now virtually absent from the Maryland portion of the Chesapeake Bay. However, a high salinity regime during 1980 and 1981 may change this disease pattern (Andrews, 1981). This disease and a close relative, "SSO Disease" (Minchinia constatis), still remain a deterrent to oyster culture in Virginia, Delaware, New Jersey, and the oceanside bays of Maryland.

About the same time that "MSX Disease" entered the Chesapeake Bay, "Dermo Disease" (Perkinsus marnuim) seemed to spread northward along the south Atlantic coast, entering the Bay in the late fifties. The disease was never incriminated in major mortalities of Maryland oysters. However, in 1975, "Dermo Disease" was found in epizootic portions in certain regions in Tangier Sound (Krantz and Otto, 1980). Cumulative annual mortality reached 60 percent on the most severely affected bars. Since that time, we have followed the distribution and intensity of the disease in several oyster populations in Maryland. The present distribution of "Dermo Disease" has a foci of infection in Tangier Sound and in St. Mary's River (Figure 13). Unfortunately, "Dermo Disease" is present in two of the five areas where dense sets of oysters occurred in 1980 (Figure 12) and may be spread during movement of seed from these areas.

"Dermo Disease" has caused some problems for oyster growers in Tangier Sound. Recently several growers have noted unusual mortality in oysters left on the bottom for four years or longer. Research (Andrews and Hewitt, 1957) has demonstrated that infection intensity and mortality increases with the number of years oysters are exposed to natural infection.

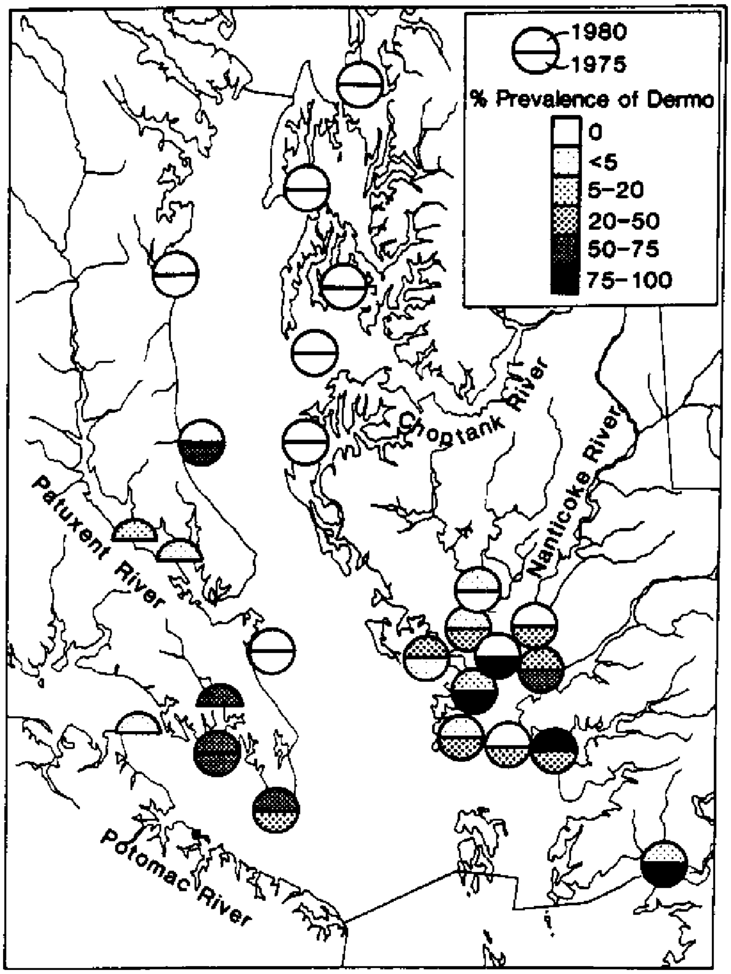

Figure 13. Present distribution of "Dermo Disease" in the Maryland portion of the Chesapeake Bay.

Future Research Needs in Maryland

Many members of the Maryland oyster industry, field management biologists, and marine extension agents feel that future oyster aquaculture research should focus on site-specific problems encountered on existing oyster leases and in existing private hatcheries. The academic orientation of most of the present laboratory studies is not addressing any of the primary constraints to modern oyster farming. Many of these constraints can be encountered only on an active oyster lease or through the operation of a pilot-scale oyster farm intended to demonstrate new culture concepts or to solve problems encountered by the oyster industry. Several such subsidized oyster farms may be required in various regions of the Chesapeake Bay, since our studies have shown that local water conditions greatly influence biological performance of oyster larvae in hatcheries and the subsequent growth of oyster spat in the natural environment. Individual Maryland leaseholders cannot afford investment in the proposed experimental or pilot production systems. Chesapeake Bay oyster growers, however, appear willing to use modern oyster culture concepts if there is an adequate demonstration of the techniques and if extension or technical advisory personnel are supplied to help them learn to use the technology.

Studies of oyster genetics appear to be necessary to develop environmentally adapted strains of oysters that will grow and survive in the low salinity environments peculiar to the Chesapeake Bay. Specific areas of the Bay can benefit from the development of disease-resistant strains of oysters. Existing disease-resistant oyster strains from Virginia and New Jersey appear to be environmentally fixed to high salinity and will not grow well in Maryland waters. There is an obvious need for a protected spat-growing system for hatchery-reared oysters that can be utilized by the individual leaseholder. If the small seed are transferred from seed production hatcheries to the leaseholder, he must protect the animals from high populations of predators, as well as prevent them from being smothered by sediment from the highly turbid waters of the Chesapeake Bay. This spat culture system must be cost effective and be compatible with the legal, social, and natural constraints of the Chesapeake area.

The Maryland Department of Natural Resources, Maryland Sea Grant Program, and University of Maryland Center for Environmental and Estuarine Studies have formed a Cooperative Oyster Research Unit to further develop low-cost oyster hatchery technology, to assist the private oyster grower in solving his problems, and to solve specific management questions. Part of the planned efforts will include site-specific services for oyster growers patterned after the Agricultural Extension Service. At present, this unit is not funded by any federal agency or national effort.

University and state extension personnel have held three consecutive annual conferences for the Maryland oyster grower and have assisted at least five growers in obtaining financial support from private backers and lending institutions. This group was instrumental in bringing the Small Business Administration, Farmers Home Administration, Land Bank, and local bankers into the arena of Maryland oyster culture and helped them understand some of the economic risks and business manipulations required by the Chesapeake Bay oyster grower. This extension-oriented group has also provided technical assistance to the commercial development of the salted half shell oyster industry that is now marketing Maryland oysters on a year-round basis.

Basic research in Maryland has not been neglected. The University of Maryland Sea Grant has directed over $564,000 of its funding to academic research on oysters in the Chesapeake Bay. Future oyster research and extension activities in Maryland will be limited only by funding, not by lack of qualified University scientists, enthusiastic extension agents, or the absence of a number of private oyster culturists who are intensely interested in becoming more profitable businessmen.

In view of recent technical advances in oyster farming and the present Maryland natural resource "status quo" management strategy, waters of the Maryland portion of the Chesapeake Bay are totally underutilized. Biological characteristics of these waters are optimum for the culture of the American oyster. Maryland is the center of the natural geographical distribution of the species on the Atlantic coast. Most importantly the business infra-structure already exists for harvesting, processing, and distribution of the product from the public fishery, as well as from the oyster leases. Reflecting upon historical harvest statistics (Figure 1), Maryland processors are capable of handling three to five times as much product as they are currently producing. Many economic analysts (Anatasia, 1975; DeAngeleo and Donnelly, 1970; Alford, 1968) feel that the Maryland processing industries and the expansion of the Maryland public fishery is being curtailed by the lack of the continuous, year-round supply of quality raw product. Because there is no predictable year-round source of raw product, the Maryland oyster processing industry is presently reluctant to engage in expansion, modernization of the plants, or aggressive product promotion campaigns (Pate, 1969). The industry is responding to "status quo" management.

The most logical management strategy for the enhancement and development of oyster culture in Maryland is to learn to use efficiently the resources that already exist before a new massive oyster culture program is initiated. Many aquaculturists and federal planners think of enhanced oyster culture only in terms of a mega-buck aqua-business employing numerous scientists and business managers who use techniques described in aquaculture texts and research papers. This is not possible in Maryland, since large corporate ventures cannot own oyster leases and their operational concept is socially unacceptable to Maryland oystermen.

Modern United States agriculture developed from the same situation that now exists in the Maryland oyster industry. In the 1920's and 1930's, there were large numbers of small individually owned farms. Extension techniques, especially 4-H educational programs, enhanced production of these farms and trained the owners in new farming techniques. Agriculture demonstration farms were established to prove that new agricultural concepts could be utilized in a given location before they were placed in the hands of the practicing American farmer. The same developmental sequence for oyster culture should be followed in Maryland. However, as the introduction warned, one needs to review carefully the history of the local fishery and the basis for the region's social and cultural heritage, especially as they relate to the development and enactment of new aquaculture concepts.

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