Production Functions for the Maryland Oyster Fishery

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ABSTRACT

USING seed planting, shell planting, spatfall and fishing effort data, production functions were developed for the Chesapeake Bay oyster fishery. The oyster producing areas of the Maryland portion of the Chesapeake Bay and tributaries were divided into four regions and a production function was developed for each region. Results from these functions were then used to analyze the effectiveness of State operated seed and shell planting programs. The effectiveness of fresh shell versus seed planting in terms of both dollar and harvestable bushels of oysters returned was assessed.

INTRODUCTION

The Chesapeake Bay in Maryland supports a large fishing industry. In 1975 total value of fish and shell fish harvested was $22.5 million. Shellfish accounted for over 90 percent of the total value of fish harvested. The Eastern oyster, (*Crassostrea virginica* Gmelin), accounted for about 64 percent of the total value of shellfish harvested (Current Fisheries Statistics No. 6952, 1976). However, oyster production is only about one fourth of what it was at the turn of the century.

The oyster is a sessile animal usually found attached to old oyster shells, or any other hard surface. They prefer salinity levels between 10 to 28 ppt and water depth between 8 to 25 ft (Loosanoff, 1965). The growth rates of oysters depends on temperature, salinity, water flow rates and other environmental factors. In the Bay, oyster growth rates have been found to vary from 0.4 to 2 in. per year with the average at about 1 in. per year (Beaven, 1952; Krantz and Merrit, 1976; Merrit, 1977).

The oyster bars (collection of oysters in commercially exploitable densities) in Maryland are predominantly a public property resource. Officially, there are, at present, about 1000 oyster bars classified as public bars ranging from 4 to 7500 acres in size. The total acreage is about 310,000 acres of which only about 10,000 acres are held by private lease holders. This study is concerned with production on the public oyster bars only.

EXPLOITATION CONTROLS

The public property nature of the Maryland oyster bars has resulted in a series of regulations aimed at controlling oyster resource exploitation. These regulations take the following forms.

Gear Restrictions

Three types of fishing gear, shaft tong, patent tong and dredge are allowed in Maryland. The shaft tong is the most common type of fishing gear used in Maryland, accounting for about 75 percent of the Maryland harvest. Patent tongs are a mechanized version of the shaft tong. They are larger, heavier and are power operated. There may be either one or two rigs per boat.

A dredge is an efficient harvesting gear. Dredge boat use is restricted (by law) to deeper portions of the Bay mainstem. Dredging is also allowed in the Choptank River and in a few other areas. (For more information see Cabraal, 1978).

Entry Restrictions

Oyster harvesting in Maryland is restricted to State residents. The law requires a license for catching over two bushels of oysters per day. Obtaining a license is a simple, inexpensive matter and does not constitute a valid means of restricting entry.

Setting of Harvest Limits

The State limits oyster harvest to 25 bushels per licensed person, for a tong boat, with a 75 bushel limit per boat. Dredge boats are allowed 150 bushels per day.

Minimum Harvestable Size of Oysters

The law allows only oysters over three inches in length to be harvested.

Controlling Length of Oystering Season

The oystering season in Maryland is from September 15 to March 31 for tongers. The season is shorter for dredge boats and begins on the 1st of November and ends on March 15.

Setting of Culling Laws

Culling is the process of separating live legal sized oysters from all other material brought up. By law all this other material (mostly oyster shells) must be returned to the same oyster bar from which it was removed.

Closing of Depleted Areas

The Department of Natural Resources (DNR) has the authority to close areas, to prevent overfishing, or to protect a bar during a rehabilitation effort.

REPLETION PROGRAM

Until about 1945, controling exploitation was the only method for conserving the oyster population. In the mid

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TABLE 1. MARYLAND OYSTER BAR REPLETION PROGRAM COSTS -- 1976

Material planted	Cost/bushel, cents	Total cost, dollars
Fresh shells	28.79	153,600
Dredge shell	16.59	832,699
Seed oysters, DNR	49.86	289,833
Seed oysters, Potomac River Fish. Comm.	49.86	30,800
Total cost		1,306,932

*These costs do not include overhead costs such as salaries of DNR employees, their transportation expenses, equipment replacement and maintenance, etc.

Source. Commercial Fisheries News (March 1977).

1940's the State began a program of transplanting seed oysters (oyster spat and small oysters) from good seed producing areas to growing areas. By 1950 intensive seed production plans were abandoned. Manning (1968) attributes the decrease in oyster production from 1956 to 1960 to this drastic change in management policy. The planting program was intensified in 1960 and since then about one million dollars have been spent on it annually. The oyster bar repletion program is the responsibility of the Maryland Department of Natural Resources. Currently the program consists of the following: (a) transplanting seed oysters to growing areas, (b) planting fresh oyster shell obtained from processors on public oyster bars, (c) planting oyster shells dredged from barren bottoms on public oyster bars. The latter two methods encourage oyster productivity by providing setting surfaces for the spat.

Each county has a committee of watermen elected by licensed watermen in the county, or appointed by the Department of Natural Resources. This committee advises the Department of Natural Resources on management of oyster beds, and on the repletion program. The committees make recommendations as to seed and shell planting locations, and advise the Department of Natural Resources on closing of areas for rehabilitation. They can also influence the disposition of shell and seed removed from within the county waters. The quantity of seed oysters allocated to each county is based on the relative number of watermen residing in that county (Maryland State Budget, 1966-67). Christy (1964) doubts the possibility of a biologically sound repletion program under the existing, highly political system.

The exact returns of the repletion program are unknown. Bowman (1948) and Suttor and Corrigan (1970) assumed that a bushel of seed oysters planted would yield one bushel of market size oysters three years later. Davis et al. (1974) estimated that in the Potomac River, one bushel of seed oysters produced three bushels of market size oysters (economic breakeven is five bushels of oysters per bushel of seed). The cultch (old shells) planting program requires three bushels of market size oysters for every bushel of cultch planted for it to be self-sustaining. Fresh shell are known to be a more attractive cultch material than dredge shell (Sieling, 1970). Little and Quicke (1976) came to the same conclusion in their Florida shell planting studies. However, greater availability and lower cost make dredged shell an attractive planting material.

No accurate estimates are available as to the success of the repletion program. Manning (1968) attributed the upturn in oyster production in 1967 to the repletion program. Sieling (1970) attributed the 140 percent increase in production since 1963 to this program.

Since the beginning of the repletion program in 1960, the State has spent approximately one million dollars annually on the repletion program. Table 1 shows the cost breakdown for 1976. Until 1967 the program was heavily subsidized by the State. In 1967 and 1968 legislation was enacted to place the program on a self-sustaining basis. However, complete self-sufficiency on the program has not been achieved.

STUDY OBJECTIVES

This paper attempts to model the productivity of the fishery, (a) to obtain a suitable means of predicting future harvests, (b) to estimate the natural productivity of oysters in the Chesapeake Bay, and (c) to determine the effectiveness of the repletion program. The study used harvest and repletion program data from 1963 to 1976 and natural spatfall sampling data from 1955 to 1976 for the analysis.

FUNCTIONAL FORM OF PRODUCTION EQUATIONS

The production function describes the relationship between output from and input into the fishery. The functional relationship in this instance takes the form suggested by Clark (1976):

Output = f (Fishing Effort, Oyster Population)

The fishery output was measured in thousands of bushels harvested (C). Fishing effort was measured in boat-days (BD). Since several types of fishing gear of variable efficiencies are employed, this is not a precise measure of fishing effort. However, due to unavailability of a better indicator, boat-days were used.

Information on oyster population size was not available. Therefore, in its place several lagged* proxy variables were used. These variables influence population size but are not directly proportional to it. The lagged variables used were: (a) natural spatfall estimates (SP); (b) seed plantings (SD); and (c) quantities of fresh (FR) and dredge (DR) shells in thousands of bushels planted permanently on bars; and (d) the catch per boat-day in bushels per boat-day during the previous season.

Natural spatfall samples are commonly employed in predicting success or failure of future harvests. These predictions are qualitative rather than quantitative. An attempt was made to obtain a qualitative relationship between catch and different natural spatfall levels. The number of lags used for spatfall was based on estimates of several researchers (Galstoff, 1964; Christy, 1964; Krantz and Merrit, 1976) for the time oyster spat require to grow to the recruitable size of at least 3 in. After several preliminary studies, spatfall lagged three, four and five years were used to represent recruitment into the fishery.

Fresh and dredge shells affect the oyster harvest by providing attachment surfaces for oyster larvae. The values used in the model were the total quantities planted in an area. These too were lagged three, four and five years.

*Lagged variables refer to those variables whose influences on the dependent variable is felt only after some time has elapsed. For example, if oysters require about three years to reach harvestable size, output in year t would be a function of spatfall in year t-3.

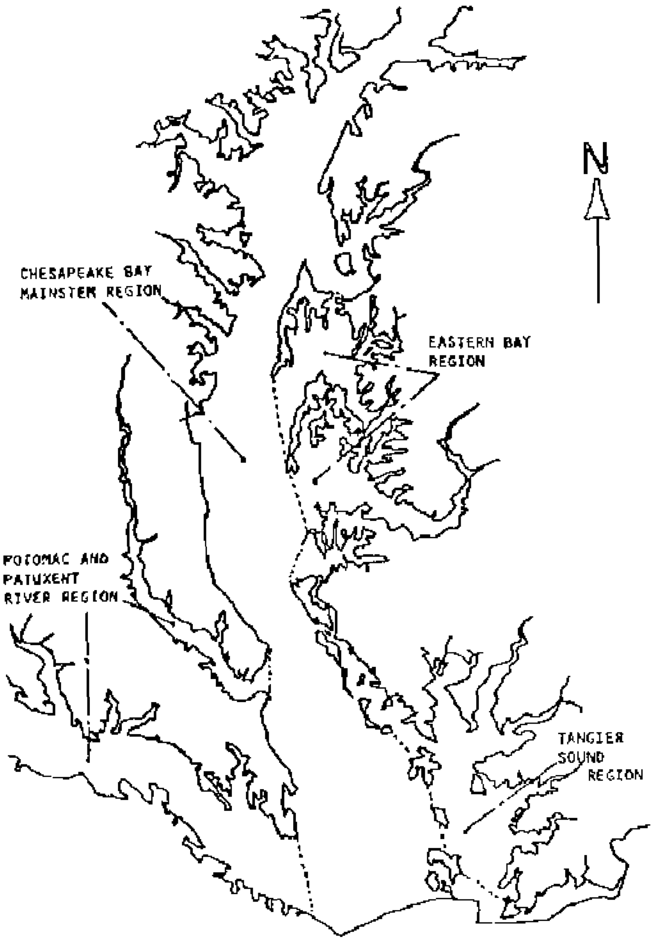

FIG. 1 Regional division of the Chesapeake Bay used in the study.

Planted seed oysters are usually about nine months old at planting time (Christy, 1964). Therefore, total quantity of seed oyster planted, lagged one, two and three years was used to indicate artificial recruitment into an area. Seed plantings also contain substantial quantities of larger oysters (Waterman's Gazette, 1977) which could enter the fishery sooner than the seed. No allowance was made for seed oyster quality since it was unknown.

The production function used catch per unit effort in the previous season as an indicator of standing population size. This assumption is valid as long as the oyster population is not depleted during the previous season. A previous oyster population size estimation study indicated that the rate of exploitation was only about 23 percent (Cabraal, 1978).

As mentioned previously, the Chesapeake Bay has over 1,000 oyster bars. Ideally production functions should be developed for each of the bars since each bar is unique in terms of environmental conditions and harvesting techniques employed. However, data limitations and other practical estimating problems precude such a detailed analysis. For the purposes of this analysis the oyster bars were allocated to river systems or areas of the Bay as shown in Fig. 1. These were the most productive areas of the Bay. The major regions for identification purposes were named, Eastern Bay, Chesapeake Bay Mainstem, Potomac and Patuxent Rivers, and Tangier Sound. The regional division was based on environmental considerations and on the knowledge of gear types operating in each region. The major regions were assumed to have the same marginal productivities.

Dummy variables (DXX) were assigned to areas within each of the major regions. These dummy variables were expected to show constant differences between areas, within a region, if any existed. In particular they should show the effect of the different gear types used in the various areas.

The functional form of the production function is shown below. A separate equation was obtained for each of the major regions.

$$C_t = f(BD_t, CP_{t-1}, SP_{t-3}, SP_{t-4}, SP_{t-5}, SD_{t-1}, SD_{t-2}, SD_{t-3},$$
$$FR_{t-3}, FR_{t-4}, FR_{t-5}, DR_{t-3}, DR_{t-4}, DR_{t-5}, DXX)$$

ESTIMATED PRODUCTION EQUATIONS

Multiple regression equations were developed for each of the regions. Preliminary analysis of the data showed that the variance of the dependent variable, C, was directly proportional to its magnitude. Therefore, a natural logarithmic transformation was used to remove any biases. The functional form of the production function used was:

$$C_t = A\ BD_t\ CP^b \ldots$$

Details of the production function equations are given in Cabraal (1978) for each major region. Since all the variables were log transformed, each regression coefficient is dimensionless and represents the percentage change in output due to a one percent change in the independent variable.

DISCUSSION

Production Function

All four production functions have excellent explanatory power with R squared greater than 98 percent, and all significant coefficients had the expected sign. In every case boat-days explained over 80 percent of the catch variations. The coefficient of the boat-day variable was not significantly different from one. Thus a one percent change in boat-days would result in a one percent change in output, all other variables being held constant. This is in the agreement with the assumption commonly used in the Schaeffer Fisheries Model (Schaeffer, 1954—catch is directly proportional to effort for a given fish population size).

Natural spatfall lagged three and four years was significant in Eastern Bay and Potomac and Patuxent River regions. Only the third year lag was significant in the Chesapeake Bay mainstem. This indicates that time required for spat to reach market size is usually three to four years throughout the Bay. However, percent increase in output due to 100 percent increase in natural spatfall varied from three to eight percent, indicating mortality rate variations across the Bay.

Catch per boat-day during the previous season, the index of standing population, was significant in only Eastern Bay and the Chesapeake Bay mainstem regions. The reasons for the lack of significance in the other two regions is not clear.

Effectiveness of the Repletion Program

The repletion program has significantly increased oyster production although with varying degrees of success. The most successful planting material was fresh shell. Plantings were most successful in the Chesapeake

TABLE 2. OYSTERS HARVESTED DUE TO 100 BUSHELS PLANTED

Region of bay	Planted material: Seed oysters, bu. caught	Fresh shell, bu. caught	Dredge shell, bu. caught
Tangier Sound	N.S.* (115.51)†	7 (153.60)	N.S. (469.10)
Eastern Bay	N.S. (336.55)	25 (182.03)	N.S. (629.93)
Chesapeake Bay Mainstem	12 (317.98)	93 (94.13)	5 (817.36)
Potomac & Patuxent River	19 (357.98)	N.S. (46.25)	N.S. (530.98)

*Corresponding regression coefficient (Cabraal, 1978) is not significant.

†Annual Average bushels planted, 1965 to 1972 are given in thousands of bushels.

The above estimates were obtained from the significant regression coefficients for plantings (Cabraal, 1978). Bushels harvested are mean values for the period 1970 to 1976.

BUSHELS HARVESTED/100 BUSHELS PLANTED.

$= \sum_i 100*(\text{REG. COEFF.})_i *(\text{MEAN CATCH})/(\text{MEAN BUSHELS PLANTED})$

bay mainstem. Increased output due to fresh shell planting occurred about four years after planting. Seed planting affected oyster production one to three years after planting. in the Potomac and Patuxent River regions, seed planting lagged one and three years were significant although the second year lag was not. This could be due to the seed plantings having two distinct year classes. The older year class (the larger oysters) being ready for harvest one year after planting and the younger year class requiring three years to reach recruitable size. Dredge shell was successful in increasing production only in the Chesapeake Bay mainstem.

Using the significant regression coefficients, the effect of the repletion program was estimated. Table 2 shows the number of bushels of oysters harvested due to planting of the different cultch materials. Since planting success is greatly dependent upon environmental conditions these are average values for the period under study. The most successful was fresh shell plantings in the Chesapeake Bay mainstem region where 93 bushels were obtained from every 100 bushel of shells planted. Using the repletion program costs adjusted for inflation, Table 1, and an oyster tax of 25 cents, this amounts to a return of about $1.34 to the repletion program for every dollar spent. The performance of seed oyster plantings in the Potomac and Patuxent River region was 19 bushels per 100 bushels planted. This production level is much lower than the one bushel of oysters per bushel of seed that is normally expected by managing agencies (Suttor and Corrigan, 1970).

TABLE 4. TOTAL COST AND REVENUE, PERMANENT PLANTINGS

	Average planted 1965 to 1972		Average produced 1970 to 1976		Prod. per unit planted	
	Thous. bushels	Thous. 1967 dollars	Thous. bushels	Thous.† 1967 dollars	Bush. per bush.	$ per $
Seed oysters	1128	344	106	424	0.09	1.24
Fresh shell	476	83	144	576	0.32	6.96
Dredge shell	2447	245	41	164	0.02	0.67
Total	4051	672	291	1164	—	1.73

*Calculated using planting costs in Table 1.

†Average price per bushel of oysters = $4.00.

TABLE 3. AVERAGE VALUE OF HARVEST PER DOLLAR SPENT ON PLANTING

Region of bay	Planted Material: Seed oysters, 1967 dollars	Fresh shell, 1967 dollars	Dredge shell, 1967 dollars
Tangier Sound	N.S.*	1.61	N.S.
Eastern Bay	N.S.	5.76	N.S.
Chesapeake Bay Mainstem	1.60	21.40	2.00
Potomac & Patuxent River	2.50	N.S.	N.S.

*Value calculated from estimates in Table 2.

Mean value of harvest due to $1 spent on planting.

$= \frac{(\text{value from Table 2}) * (\text{avg. price of oysters})}{100*(\text{Avg. cost/bushels of planting from Table 1})}$

The repletion program is not a profit making operation. The actual value of oysters harvested as a direct result of the repletion program is of greater interest than the return to the program. Table 3 lists the value generated for every dollar spent on planting. The values were obtained using Table 1 and a price per bushel of oysters of $4 (1967 dollars). The estimates are approximate values calculated as shown at the bottom of the table. Fresh shell although more costly than dredge shell, were the most valuable material planted. Dredge shell plantings in the Chesapeake Bay mainstem produced more value per dollar than seed plantings, although seed plantings generated over twice the amount of bushels of oysters per bushel planted.

Table 4 shows total output in marketable oysters due to seed and shell plantings. The total cost is less than the often quoted one million dollars since it was computed using average value of bushels planted and 1976 costs (Table 1) adjusted for inflation. In addition, cost of planting in seed areas was not included. Fresh shell plantings were by far the most successful planting material. Overall, the repletion program has been able to increase output by about 300,000 bushels annually. At a cost of one million dollars per year (Alford, 1973) this amounts to $3.33 per bushel produced. The varied success rate of the program in the different regions of the Bay indicates that there is room for program improvement.

The desirability of dredge shell plantings is questionable. Fresh shells provide a better surface than dredge shells for spat attachment (Sieling, 1970). This study reinforces this viewpoint. In light of this information, repletion program managers should consider increasing fresh shell plantings at the expense of dredge shell plantings. If fresh shells are in short supply, feasibility of additional treating or cleaning of dredge shells before planting should be investigated. Another matter that requires investigation is the success of plantings in the Chesapeake Bay mainstem region as compared to other regions. If the reasons for this success can be determined, attempts can be made to improve the returns to the planting program in the other regions

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